



# SUSTAINABILITY IN DEBATE

SUSTENTABILIDADE EM DEBATE



## EDITORIAL

A Call to Responsibility

## DOSSIER

Environmental System Modeling  
and Landscape Management

## ARTICLES VARIA

Linking migration, climate and social protection  
in Brazilian semiarid: case studies of Submédio  
São Francisco and Seridó Potiguar

Short-term effect of adding nitrogen in forest soil  
of an urban rainforest

Emergency funding public policy for disaster  
response in Brazil from 2013 to 2017

Climate change and the unsustainable urbanism  
in the municipality of João Pessoa, Paraíba, Brazil

VOL. 11 - N. 2  
MAY - AUG  
2020  
ISSN-e 2179-9067

Copyright © 2020 by Centro de Desenvolvimento Sustentável da Universidade de Brasília.  
Total or partial reproduction of the articles is allowed provided that the source is properly cited.

**UNIVERSITY OF BRASILIA**

Rector: Márcia Abrahão

**CENTER FOR SUSTAINABLE DEVELOPMENT**

Director: Maurício de Carvalho Amazonas

**ENERGY AND ENVIRONMENT LABORATORY – INSTITUTE OF TECHNOLOGY**

Director: Antonio Cesar Pinho Brasil Junior

**LABORATORY OF CONSTRUCTED ENVIRONMENT, INCLUSION AND SUSTAINABILITY**

Coordinator: Raquel Naves Blumenschein

**SUSTAINABILITY IN DEBATE JOURNAL**

Editors-in-chief: Carlos Hiroo Saito e Marcel Bursztyn

Executive Editors: Gabriela Litre e Melissa Curi

Cover Designer : Paula Simas de Andrade

Indexation and Communication Editor: Melissa Curi

Reviews Editor: Gabriela Litre

Website Administration: Melissa Curi e BCE / UnB

Editing: Flávio Ramos / Editora IABS / [www.editoraiabs.com.br](http://www.editoraiabs.com.br)

Text Formatting: Livia Brito / IABS

Proofreading: Stela Máris Zica

English translation: Cristiana Dobre

Graphic Designer: Stefania Montiel

Cover Picture: Marcel Bursztyn

Frequency: Quarterly

Peer-review process: *double blind peer-review*

Support: Brazilian Institute for Development and Sustainability - IABS and Research Support Foundation of the DF

Federal Project: *Internationzalication and increase in the Scientific Impacto of the Sustainabilityh in Debate Journal*

Format: eletrônica

Submissions Website: [www.revista.sustentabilidade.unb.br](http://www.revista.sustentabilidade.unb.br)

Publisher Address: Campus Universitário Darcy Ribeiro - Gleba A, Bloco C - Av. L3 Norte, Asa Norte - Brasília-DF, CEP: 70.904-970

Phones: 55(61) 3107-6000, 3107-6001, 3107-6002, Fax: 3107-5972

*E-mail*: [sustentabilidade.debate@gmail.com](mailto:sustentabilidade.debate@gmail.com) | Site: [www.cds.unb.br](http://www.cds.unb.br)

Author Guidelines: <http://periodicos.unb.br/index.php/sust/about/submissions#authorGuidelines>

Publication Ethics and Malpractice Statement:

<http://periodicos.unb.br/index.php/sust/about/editorialPolicies#custom-4>

---

Sustentabilidade em Debate – Centro de Desenvolvimento Sustentável da Universidade de Brasília, v. 11, n.2 (2010 - 2020), Brasília, DF, Brasil.

Quarterly - ISSN Eletrônico 2179-9067

Desenvolvimento Sustentável. Universidade de Brasília. Centro de Desenvolvimento Sustentável.

**CDU 304:577**

---



## Editorial Board / *Conselho Editorial*

### President / *Presidente*

Carlos Hiroo Saito - Universidade de Brasília

### Members / *Membros*

|                                  |   |
|----------------------------------|---|
| Alan Cavalcanti Cunha            | Universidade Federal do Amapá   |
| Arun Agrawal                     | University of Michigan  |
| Anthony Hall                     | London School of Economics  |
| Asher Kiperstok                  | Universidade Federal da Bahia   |
| Bertha Becker (falecida)         | Universidade Federal do Rio de Janeiro                                  |
| Boaventura de Sousa Santos       | Universidade de Coimbra   |
| Carolina Joana da Silva          | Universidade do Estado do Mato Grosso                                   |
| Francisco Ferreira Cardoso       | Universidade do Estado de São Paulo                                     |
| Gabriele Bammer                  | The Australian National University                                      |
| Hassan Zaoual (falecido)         | Université du Littoral, Côte d'Opale                                    |
| Hervé Thery                      | Universidade de São Paulo   |
| Ignacy Sachs                     | L'École des Hautes Études en Sciences Sociales                          |
| Jalcione Almeida                 | Universidade Federal do Rio Grande do Sul                               |
| Jean-François Tourrand           | La Recherche Agronomique pour le Développement                          |
| Joan Martinez-Allier             | Universitat Autònoma de Barcelona                                       |
| Laura Maria Goulart Duarte       | Universidade de Brasília  |
| Leila da Costa Ferreira          | Universidade Estadual de Campinas                                       |
| Lúcia da Costa Ferreira          | Universidade Estadual de Campinas                                       |
| Marilene Corrêa da Silva Freitas | Universidade Federal da Amazonas  |
| Mário Monzoni                    | Fundação Getúlio Vargas   |
| Martin Coy                       | Universität Innsbruck   |
| Merilee Grindle                  | Harvard University  |
| Michael Burns                    | Harvard University  |
| Michele Betsill                  | Colorado State University   |
| Neli Aparecida de Mello Théry    | Universidade de São Paulo   |
| Othon Henry Leonardos            | Universidade de Brasília  |
| Roberto Bartholo Jr.             | Universidade Federal do Rio de Janeiro                                  |
| Suely Salgueiro Chacon           | Universidade Federal do Ceará   |
| Umberto Maturana                 | Universidade do Chile   |
| Vandana Shiva                    | Research Foundation for Science, Technology and Natural Resource Policy |

## Table of Contents / Sumário

### Editorial / Editorial

A Call to Responsibility / *Um chamamento à Responsabilidade*  
Marcel Bursztyn, Melissa Curi, Carlos Hiroo Saito

doi:10.18472/SustDeb.v11n2.2020.33457..... 7

### Dossier / Dossiê

Environmental System Modeling and Landscape / *Modelagem de Sistemas Ambientais e Gestão da Paisagem*

Rodrigo Affonso de Albuquerque Nóbrega, Fernanda Zimmermann Teixeira, Doris Aleida Villamizar Sayago

doi:10.18472/SustDeb.v11n2.2020.33466..... 11

Agriculture and sustainable landscapes: agricultural diversification in the state of Minas Gerais, Brazil / *Agricultura e paisagens sustentáveis: a diversidade produtiva do setor agrícola de Minas Gerais, Brasil*  
Marina Lorena Campos Teixeira, Sônia Maria Carvalho Ribeiro

doi:10.18472/SustDeb.v11n2.2020.28147..... 17

Non-timber forest products (NTFP) in the Brazilian Amazon and Cerrado biomes: multi scale governance for implementing enhanced socio-biodiversity chains / *Produtos florestais não madeireiros (PFNM) nos biomas da Amazônia brasileira e do Cerrado: governança multiescala para implementação de cadeias da sociobiodiversidade*

Sônia Maria Carvalho Ribeiro, Helder Lages Jardim, Úrsula Ruchkys de Azevedo, Vagner Coelho, Laura Salles Bachi, Britaldo Soares-Filho

doi:10.18472/SustDeb.v11n2.2020.28393..... 43

The handwriting of society on the landscape: modeling of the Environmental Changes on the Borders of Protected Areas located in the Espinhaço Mountain Range, state of Minas Gerais, Brazil / *A caligrafia da sociedade na paisagem: modelagem ambiental das transformações ambientais no entorno de Unidades de Conservação da Serra do Espinhaço, Minas Gerais, Brasil*

Ana Pimenta Ribeiro, José Augusto Drummond, Eduardo Magalhães Ribeiro

doi:10.18472/SustDeb.v11n2.2020.28378..... 64

Simulated deforestation versus satellite data in Roraima, Northern Amazonia, Brazil / *Desmatamento simulado versus dados de satélite em Roraima, extremo norte da Amazônia, Brasil*

Paulo Eduardo Barni, Reinaldo Imbrozio Barbosa, Antônio Ocimar Manzi, Philip Martin Fearnside

doi:10.18472/SustDeb.v11n2.2020.27493..... 81

Use of multicriteria analysis to define priority areas for reforestation in the Piranga River Basin, MG, Brazil / *Uso da análise multicritério para definição de áreas prioritárias para reflorestamento na Bacia do Rio Piranga, MG, Brasil*

Caroline de Souza Cruz Salomão, Luiz Gustavo de Souza Paula, Marcos Antônio Timbó Elmiro

doi:10.18472/SustDeb.v11n2.2020.30468..... 95

Geotechnologies as an environmental licensing support tool in the state of Piauí, Brazil / *Utilização de programas abertos de geotecnologia para o emprego no licenciamento ambiental no estado do Piauí, Brasil*

Bruna de Freitas Iwata, Danielly dos Santos Ferreira, Adriano D'Carlos Batista Oliveira

doi:10.18472/SustDeb.v11n2.2020.29253..... 121

The use of remote sensing techniques by MODIS (MCD45A1) images using to identify and evaluate burned areas in the metropolitan region of Belo Horizonte-MG, Brazil / *Uso de técnicas de sensoriamento remoto utilizando imagens MODIS (MCD45A1) para identificação e avaliação de áreas queimadas na Região Metropolitana de Belo Horizonte - MG, Brasil*

Luiza Cintra Fernandes, Marcelo Antonio Nero, Plínio da Costa Temba, Marcos Antônio Timbó Elmiro

doi:10.18472/SustDeb.v11n2.2020.28145..... 143

Case study of a model of local solar radiation potential and discussion on the associated sustainable applications and potentials / *Construção de um modelo de potencial de radiação solar local e discussão das aplicações sustentáveis e potenciais associados*

Marcelo Antonio Nero, Daniel Henrique Carneiro Salim, Caio César de Sousa Mello, Rafael Tarantino Amarante, Bráulio Magalhães Fonseca, Plínio da Costa Temba

doi:10.18472/SustDeb.v11n2.2020.27773..... 173

Dry port location optimization to foster sustainable regional development / *Otimização locacional de portos secos para fomentar o desenvolvimento regional sustentável*

Marlon Fernandes de Souza, Paulo H. Góes Pinto, Raphael B. Alves Teixeira, Carla de O. Leite Nascimento, Rodrigo A. de Albuquerque Nóbrega

doi:10.18472/SustDeb.v11n2.2020.27073..... 208

## Articles Varia / Artigos Varia

Linking migration, climate and social protection in Brazilian semi-arid: case studies of Submédio São Francisco and Seridó Potiguar / *Conectando migração, clima e proteção social no semiárido brasileiro: estudos de caso do Submédio São Francisco e Seridó Potiguar*

Ana Claudia de Almeida, Alisson Flávio Barbieri, Saulo Rodrigues Filho

doi:10.18472/SustDeb.v11n2.2020.31293..... 238

Short-term effect of adding nitrogen in forest soil of an urban rainforest / *Efeito a curto prazo da adição de nitrogênio no solo de uma floresta urbana*

Bruno Moraes Nascimento, Fernando Vieira Cesário, Fabiano de Carvalho Balieiro, Renato de Aragão Rodrigues, Henderson Silva Wanderley

doi:10.18472/SustDeb.v11n2.2020.30339..... 252



Emergency funding public policy for disaster response in Brazil from 2013 to 2017 / *CPolítica pública de auxílio financeiro para resposta a desastres no Brasil no período 2013-2017*  
Victor Marchezini, Adriano Mota Ferreira, Glauston Roberto Teixeira de Lima, Demerval Aparecido Gonçalves

doi:10.18472/SustDeb.v11n2.2020.31268..... 266

Climate change and the unsustainable urbanism in the municipality of João Pessoa, Paraíba, Brazil / *Mudanças climáticas e o urbanismo insustentável no município de João Pessoa, Paraíba, Brasil*  
Letícia Palazzi Perez, Andréa Leandra Porto Sales e José Augusto Ribeiro da Silveira

doi:10.18472/SustDeb.v11n2.2020.32330..... 304

## Editorial

# A Call to Responsibility

Marcel Bursztyn, Melissa Curi, Carlos Hiroo Saito

*doi:10.18472/SustDeb.v11n2.2020.33457*

The literature is lavish with publications on the double characteristic of times of crisis. A recurrent image (and controversial) in texts is that of the Chinese ideogram, which combines expressions of risk and opportunity. It is controversial because Mandarin scholars consider this transliteration is not genuine. Nevertheless, the allegory is convenient.

Crises are times when dangers are most latent and also opportune moments for bolder decisions that can lead to solutions. In other words, they are drivers of change and can lead to progress in different spheres. But, they can also engender tragedies.

The pandemic of Covid-19 which has befallen the world this year, 2020, is not over and is already showing us lessons, good and bad. Among the good ones, it is worth mentioning the remarkable mobilization of science and the realization that this is the best way to anticipate and face threats to life on our planet, and also the evidence that we must act with a broader vision than just the short term one.

Never has the notion of sustainability, in its most exhaustive, durable and radical sense, been so crystal-clear! Among the bad lessons, there is an ordeal of examples: the denialism of science; the short-term selfishness of those who do not give up the immediate profitability of their investments (even if this implies risks of future losses); the dismantling of the Welfare State; racism and other forms of social exclusion and the emergence of discourses (political and pseudoscientific) of charlatans, who launch and propagate miraculous formulas of solutions without any scientific basis.

All this happens at a very particular moment in history. Covid-19 arrived quickly and soon spread, due to the massive movement of people and goods around the world. A world, marked by the rise of rulers that are eager to put into practice ideas that go in the opposite direction of ideals of well-being, solidarity, peace and responsibility, which seemed to be legacies of the 20th century.

The great environmental crisis of industrial society has led to a mobilization of the growing sectors of society, to make the State, worldwide, a key player in ensuring ecological balance, quality of life and the environment in general. Since the United Nations Conference on the Human Environment, held in 1972 in Stockholm, the theme has gained a planetary dimension. Gradually, each country was creating its institutional structures to deal with the environment, and several international protocols and laws have been established. But, the 21st century has brought negative surprises, especially in recent years. Two examples are eloquent.

First, the election of tycoon Donald Trump in the United States represents a milestone in the inflexion of ideals that seemed to be legacies of the previous century. Early on, Trump appointed to head the EPA (the country's Environmental Protection Agency), a prominent climate change sceptic (Scott Pruitt), who tried to minimize the regulatory role of that agency. Due to allegations of scandals, Pruitt had to resign in 2018, being replaced by Andrew R. Wheeler, a well-known coal industry lobbyist.

The second example comes from Brazil. The election of right-wing extremist Jair Bolsonaro, who assumed the Presidency of the Republic in 2019, represented a negative shift in the relevance of controlling deforestation, protecting indigenous peoples, enforcing legislation on environmental

crimes, control over the use of pesticides, among other setbacks in addressing the environmental issue. Bolsonaro, who had already fined for violation of environmental standards, chose to dismiss the head of the National Institute of Space Research - INPE, an internationally recognized body for its competence when it showed the alarming data on deforestation in the Amazon. In the tellings of the one chosen for the role of Minister of the Environment, the government should take advantage of the opportunity opened by the Pandemic of Covid-19, with the press focusing on the theme of health, to literally “open the gate” and “let the buoy pass”, alluding to the deconstruction of regulatory instruments and environmental protection practices.

These are two worrying examples, which, unfortunately, cannot be seen as isolated cases. The attitude of some political leaders in the face of the pandemic also reveals the lack of empathy and responsibility with exposing people to a disease that can be lethal. Populist temptation seduces tyrants, adventurers and opportunists. Boris Johnson, in the UK, was only convinced of the seriousness of the problem when affected by the disease. Trump strives every day to deny reality and tries to shift the responsibility for the effects of caution to governors who oppose him. In Belarus, the tyrant Lukashenko, in power since 1994, mocks the severity of the pandemic by suggesting that the best prevention is the combination of sauna and vodka. In Brazil, Bolsonaro insists that the use of chloroquine, which science has proven to be ineffective and to bring real side effects, solves what he considers a “little flu”.

The discourse around the fact that measures to combat COVID-19 would undermine the economy, which would be allegedly exaggerated and unnecessary, shows a version of necropolitics outside the contexts of militarized warfare. A genocide is underway which by the way, is selective.

Never have the principles of responsibility, precaution, and prevention, so dear to sustainable development, been so current and imperative! Never has the concept of inclusion and respect for the life of humankind, been so necessary.

In this difficult moment of serious risks and necessary responsible action, Sustainability in Debate launches, in its second edition of 2020, nine articles in the thematic *Dossier* “Environmental Systems Modeling and Landscape Management” and four articles in the *Varia* section, presented below.

The first article of the section *Varia* is titled “Linking migration, climate and social protection in Brazilian semiarid: case studies of Submédio São Francisco and Seridó Potiguar ” and proposed by the authors: Ana Claudia de Almeida, Alisson Flávio Barbieri and Saulo Rodrigues Filho. They analyze the link between droughts, migrations, and social protection in the Semiarid region, based on the conceptual discussion around two case studies: The São Francisco Submédio and the Seridó Potiguar.

In the article “ Short-term effect of adding N in the urban rainforest “, the authors Bruno Moraes Nascimento et al. present the results of an experiment carried out to investigate the effects of nitrogen addition on soil respiration during five days in the Tijuca Forest.

Authors Victor Marchezini et al., in the article “ Emergency funding public policy for disaster response in Brazil from 2013 to 2017”, based on data from the Decrees of Emergency Situation and State of Public Calamity and the costs of disaster relief and response in the country, assess the use and expenditure of these public policies.

Finally, the article “Climate change and the unsustainable urbanism in the municipality of João Pessoa, Paraíba, Brazil”, by the authors Letícia Palazzi Perez, Andrea Leal Porto Sales and José Augusto Ribeiro da Silveira, based on spatial data from the recent deforestation of João Pessoa, analyzes the legal and socio-environmental characteristics of the city’s urban sprawl and how municipal urban and environmental policy have catalyzed processes of socio-environmental injustice.

The Editors



## Um chamamento à Responsabilidade

Marcel Bursztyn, Melissa Curi, Carlos Hiroo Saito

doi:10.18472/SustDeb.v11n2.2020.33457

A literatura é pródiga em referências sobre a dupla característica dos tempos de crise. Uma imagem frequente (e controversa) nos textos é a do ideograma chinês, que no caso combina as expressões risco e oportunidade. Controversa por que os estudiosos do mandarim consideram que a transliteração não é exatamente esta. Em todo caso, a alegoria é conveniente.

Crises são momentos em que perigos são mais latentes; e são também momentos que oportunizam decisões mais ousadas, que podem conduzir a soluções. Ou seja, crises são portadoras de mudanças e estas podem levar a progressos em diferentes esferas. Mas podem, também, levar a tragédias.

A crise da pandemia do Covid 19, que se abateu sobre o mundo neste ano de 2020, ainda não está debelada e já nos mostra lições (boas e ruins). Dentre as boas, vale mencionar a notável mobilização da ciência e a constatação de que esta é a melhor forma de antever e enfrentar ameaças à vida no nosso planeta, e também a evidência de que temos de agir com visão mais ampla do que apenas o curto prazo.

Nunca a noção de sustentabilidade, em sua acepção mais abrangente, durável e radical, foi tão clara! Dentre as lições ruins, há um verdadeiro calvário de exemplos: o negacionismo da ciência; o egoísmo *curtoprazista* dos que não abrem mão da rentabilidade imediata dos seus investimentos (mesmo que isso implique riscos de perdas futuras); o desmonte do Estado de Bem-Estar Social; o racismo e outras formas de exclusão social e a emergência de discursos (políticos e pseudocientíficos) de charlatões, que lançam e propagam fórmulas miraculosas de solução sem qualquer fundamento científico.

Tudo isso acontece em um momento muito particular da história. A Covid-19 chegou rapidamente e logo se propagou, graças à enorme circulação de pessoas e mercadorias pelo mundo. Um mundo marcado pela ascensão de governantes ávidos por colocar em prática ideias que vão no sentido oposto aos ideais de bem-estar, solidariedade, paz e responsabilidade, que pareciam ser legados do século XX.

A grande crise ambiental da sociedade industrial provocou uma mobilização de crescentes setores da sociedade, no sentido de tornar o Estado, em todo o mundo, um ator-chave na garantia do equilíbrio ecológico e da qualidade de vida e do meio ambiente em geral. Desde a Conferência das Nações Unidas sobre Meio Ambiente Humano, realizada em 1972, em Estocolmo, o tema ganhou dimensão planetária. Aos poucos, cada país foi criando suas estruturas institucionais para tratar do meio ambiente. Vários protocolos internacionais foram estabelecidos e legislações criadas. Mas o século XXI trouxe surpresas negativas, principalmente nos anos recentes. Dois exemplos são eloquentes.

Primeiramente, eleição do magnata Donald Trump, nos Estados Unidos, representa um marco na inflexão dos ideais que pareciam ser legados do século anterior. Logo de início, Trump nomeou para dirigir a EPA (a Agência de Proteção Ambiental do país) um proeminente cético das mudanças climáticas (Scott Pruitt), que tratou de minimizar o papel regulatório daquele organismo. Em razão de denúncias sobre escândalos, Pruitt teve de renunciar em 2018, sendo substituído por Andrew R. Wheeler, conhecido lobista da indústria do carvão.

O segundo exemplo vem do Brasil. A eleição do extremista de direita Jair Bolsonaro, que assumiu a Presidência da República em 2019, representou uma forte guinada negacionista da relevância do controle do desmatamento, da proteção aos povos originários, da aplicação da legislação sobre

crimes ambientais, do controle sobre o uso de agrotóxicos, dentre outros recuos do enfrentamento da questão ambiental. Bolsonaro, que já havia sido autuado por violação de normas ambientais, optou por demitir o dirigente do Instituto Nacional de Pesquisas Espaciais – INPE, organismo reconhecido internacionalmente pela sua competência, quando este mostrou os alarmantes dados sobre desmatamento na Amazônia. Nos dizeres daquele que foi escolhido para a função de Ministro do Meio Ambiente, o governo deveria aproveitar a oportunidade aberta pela pandemia do Covid-19, quando a imprensa está focada no tema da saúde, para literalmente “abrir a porteira” e “deixar a boiada passar”, em alusão à desconstrução dos instrumentos regulamentares e das práticas de proteção ambiental.

São dois exemplos preocupantes, que infelizmente não podem ser vistos como casos isolados. A atitude de alguns dirigentes políticos, diante da pandemia, também revela a falta de empatia e de responsabilidade frente aos riscos da exposição das pessoas a uma enfermidade que pode ser letal. A tentação populista seduz tiranos, aventureiros e oportunistas. Boris Johnson, no Reino Unido, só se convenceu da gravidade do problema quando ele próprio foi acometido pela doença. Trump se esforça, a cada dia, em negar a realidade e em tentar transferir a responsabilidade sobre os efeitos da precaução aos governadores que lhe fazem oposição. Na Belarus, o tirano Lukascenko, no poder desde 1994, ironiza a gravidade da pandemia, ao sugerir que a melhor prevenção é a combinação de sauna e vodka. No Brasil, Bolsonaro insiste que o uso da cloroquina, que a ciência comprovou ser ineficaz e trazer efeitos colaterais graves, resolve o que ele considera uma “gripezinha”.

O discurso de que a economia está sendo prejudicada pelas medidas de combate ao covid-19, que seriam alegadamente exageradas e desnecessárias, mostra uma versão da necropolítica fora dos contextos de guerra militarizada. Um genocídio se encontra em curso, que por sinal é seletivo.

Nunca os princípios da responsabilidade, da precaução e da prevenção, tão caros ao desenvolvimento sustentável, foram tão atuais e imperativos! Nunca, o conceito de inclusão e respeito à vida de toda a humanidade se fez tão necessário.

Neste difícil momento de graves riscos e de necessária ação responsável, *Sustentabilidade em Debate* lança, nesta sua segunda edição de 2020, nove artigos no Dossiê temático “Modelagem de Sistemas Ambientais e Gestão da Paisagem” e quatro artigos na seção *Varia*, que serão apresentados a seguir.

O primeiro artigo da seção *Varia* “Conectando migração, clima e proteção social no Semiárido brasileiro: estudos de caso do Submédio São Francisco e Seridó Potiguar”, dos autores Ana Claudia de Almeida, Alisson Flávio Barbieri e Saulo Rodrigues Filho, faz uma análise sobre o nexos entre secas, migrações e proteção social na região do Semiárido, com base na discussão conceitual em torno de dois estudos de caso: o Submédio São Francisco e o Seridó Potiguar.

No artigo “Efeito a curto prazo da adição de nitrogênio no solo de uma floresta urbana”, os autores Bruno Moraes Nascimento *et al.* apresentam os resultados de um experimento realizado para investigar os efeitos da adição de nitrogênio na respiração do solo, durante cinco dias, na Floresta da Tijuca.

Os autores Victor Marchezini *et al.*, no artigo “Política pública de auxílio financeiro para resposta a desastres no Brasil, no período 2013-2017”, com base nos dados dos decretos de Situação de Emergência e Estado de Calamidade Pública e dos custos de socorro e resposta a desastres no país, realizam um levantamento sobre o uso e os gastos destas políticas públicas.

Por fim, o artigo “Mudanças climáticas e o urbanismo insustentável no município de João Pessoa, Paraíba, Brasil”, dos autores Letícia Palazzi Perez, Andrea Leal Porto Sales e José Augusto Ribeiro da Silveira, a partir de dados espaciais do desflorestamento recente de João Pessoa, analisam as características jurídicas e socioambientais da expansão urbana da cidade e como a política urbana e ambiental municipal têm catalisado processos de injustiça socioambiental.

Os Editores

## Dossier

# Environmental System Modeling and Landscape Management

Rodrigo Affonso de Albuquerque Nóbrega<sup>a</sup>

Fernanda Zimmermann Teixeira<sup>b</sup>

Doris Aleida Villamizar Sayago<sup>c</sup>

<sup>a</sup>Assistant Professor, Graduate Program on Analysis and Modeling of Environmental Systems, Federal University of Minas Gerais, Belo Horizonte, MG, Brazil.  
E-mail: raanobrega@ufmg.br

<sup>b</sup>Associate Research, Group of Road and Railroad Ecology, Graduate Program on Ecology Federal University of Rio Grande do Sul, Porto Alegre, RS, Brazil.  
E-mail: fernandazteixeira@gmail.com

<sup>c</sup>Full Professor, Center for Sustainable Development, University of Brasília, Brasília, DF, Brazil  
E-mail: doris.sayago@gmail.com

doi:10.18472/SustDeb.v11n2.2020.33466

The rising pressure over the environment, associated with the increase in the demand for natural resources, resulted in an increased attention to social and environmental issues. However, the 21st century reveals many key challenges to reach a sustainable landscape management. The understanding that environmental systems are a result of complex interactions among multiple variables resulted in the need to develop and apply more robust analyses to generate knowledge about the environment. Moreover, the increased attention to environmental issues also created an important demand for predicting future scenarios to support current decision making related to landscape management.

The use of specialized tools and methods for modeling environmental systems strengthens the human capacity to intervene on behalf of landscape management for a sustainable environment. Environmental modeling, due to its interdisciplinary nature, has been widely applied in understanding the causal mechanisms between environmental systems and their interactions with different socioeconomic contexts in Brazil and worldwide. The current technological stage allows not only the use of sophisticated geospatial tools but also to develop and explore transdisciplinary models to help the understanding of the complex interactions between humans and nature.

The GIS have reached relative maturity in terms of analytical capacity and functionality. Their current emphasis shifted towards the construction of sophisticated models for representation of environmental systems and time-space computational simulations. Environmental geographic modeling seeks to understand the dynamics of spatial phenomena (which have a geographic expression), whether natural or anthropic as well as their role in the organization and evolution of Earth's systems.

It consists of a theoretical-instrumental procedure that involves a set of quantitative and spatial techniques, aiming to operationalize a systemic approach. As a result, the integrated development of Earth sciences (Geology, Geography, Ecology, Climatology, among others) opens up a wide field for investigating environmental processes, which currently is considered as a cutting-edge research topic and a thematic priority.

In the seek for sustainable development, the modeling of environmental systems is gaining an outstanding role to create integrated knowledge of the environment, the society, and their interactions. It provides methodologies, technologies, and products capable of subsidizing and driving public policies for the prevention and mitigation of human impacts, especially concerning global changes. Thus, the environmental sciences have been trying to insert the environmental modeling into the designing processes of public policies and the evaluation of their performance. This has been the premise of the Graduate Program in Analysis and Modeling of Environmental Systems (AMSA) at UFMG, and it has propelled the program's research areas of Environmental Analysis, Systems Modeling, and Landscape Management.

The research approach traditionally practiced by AMSA is quantitative, which somewhat restricts the scope and impact in society, including the scientific peers in the CAPES' environmental sciences group. Early in 2018, through a wise and opportune approach, the Center for Sustainable Development (CDS) at UnB invited AMSA to start an academic partnership between the two programs. The CDS envisioned that quantitative geographic modeling could enhance the high quality of the research practiced in the house, traditionally in the qualitative domain. For AMSA, the opportunity of partnership with a mature graduate program, recognized for its excellence, was great to reinforce its growing and strengthening process.

The partnership was implemented by the end of 2018 with the III Symposium on Systems Modeling and Landscape Analysis of the Graduate Program in Analysis and Modeling of Environmental Systems, which is a biannual event of AMSA that, in this edition counted with the co-participation of the coordination CDS and associated researchers. This event aimed to present and debate the challenges and perspectives of environmental systems modeling, to discuss the methods and applications of geographic modeling and landscape management, and to address the role of environmental modeling in the formulation of policies for landscape planning and management.

The Symposium has become a platform for the convergence of scientific articles and the basis for the preparation of this Dossier. In addition to selected manuscripts from the event, the Dossier "Modeling Environmental Systems and Landscape Management" of the Sustainability on Debate journal also gathers scientific manuscripts that address topics related to innovative methodologies in quantitative modeling and GIS capable of promoting ways to improve management and territorial governance in for socio-environmental sustainability.

The Dossier includes 9 articles. The first one, entitled "*Agriculture and sustainable landscapes: agricultural diversification in the state of Minas Gerais*", analyzes the dynamics of agriculture production and the diversity of its products from the environmental sustainability standpoint. The findings show that the agricultural diversity in the municipalities are associated with family farming context.

The second article, "*Non-Timber Forest Products in the Brazilian Amazon and Cerrado biomes: Multi-Scale Governance for Implementing Enhanced Socio-biodiversity Chains*" contextualizes non-timber forest products as a channel to drive policies for social and biodiversity governance in their production chains in the two most extensive biomes Brazilians.

The article "*The Handwriting of society on the landscape: modeling of the environmental changes on the borders of protected areas located in the Espinhaço Mountain Range (state of Minas Gerais, Brazil)*" investigates the patterns of natural resources use by the local population and the respective dynamics of land use over time in the context of the creation of two protected areas in a sensitive region.

In the article "*Simulated deforestation versus satellite data in Roraima, northern Amazonia*", the authors analyze the pattern of land cover and land-use change, with special regards to the deforestation phenomena. They simulated scenarios for the period 2011-2017 and compared the results of their computational approach to the PRODES official data. The study investigated areas of silvopastoral use and excluded indigenous lands and conservation units, which together concentrate most of the state's territory.

Next, in the work *“Use of multicriteria analysis to define priority areas for reforestation in the Piranga River Basin/MG”*, the authors analyze and identify areas that could be designated for reforestation. The investigation took the perspective of the areas of permanent preservation consolidated in the new Forest Code and multicriteria geographic analysis techniques to support decision-making. The study focused on an environmentally sensitive and water-recharge region located within the geographic context of the environmental tragedy driven by the dam break in Mariana/MG.

The sixth article in the Dossier, *“Geotechnologies as an environmental licensing support tool in the state of Piauí”*, presents and discusses the use of tools and open access geographic data in the environmental licensing process. Also in this theme of open access data, the article *“The application of remote sensing techniques using MODIS (MCD45A1) images to burned areas identification and assessment in the metropolitan region of Belo Horizonte – Minas Gerais, Brazil”* analyzes the use of open access orbital images and traditional techniques for recognizing and extracting features in the images, especially for burned areas susceptible to environmental damage in the peri-urban context.

In the eighth article, *“Case study of a model of local solar radiation potential and discussion on the associated sustainable applications and potentials”*, the authors present a detailed investigation focused on mapping and quantifying the potential for solar energy generation in densely-built areas. The study used technologies such as drone imaging to capture both the level of detail and the geometry aspects of the complex roof surfaces in urbanized areas.

Finally, the article *“Dry port location optimization to foster sustainable regional development”* presents a geographically explicit model for mapping and identifying regions with the greatest feasibility for implementing dry ports in the state of Minas Gerais. Other than the traditional location-allocation optimizing approach practiced by engineering, the model adds multicriteria analysis of the continuous surface variables including socioeconomic characteristics such as the generation of jobs and local revenue, together with environmental elements.

Although the III Symposium on Environmental Modeling and Landscape Management occurred in the end of 2018, a month before the inauguration of Bolsonaro’s administration, and the present Dossier is being published in August 2020 (*Annus Horribilis*, in reference to the Editorial of volume 11 of the Sustainability on Debate), the material presented in this Dossier exposes a critical vision of the academy, so massacred in this same period, about environmental issues of common interest and benefit to society. The environment, literally inflamed in 2019 and in the present *Annus Horribilis*, calls for better days. Thus, the academy is trying to make a difference.

We appreciate the colleagues who attended the event, the authors who sent the manuscripts, and the reviewers who collaborated with this edition of the Dossier. Good reading.

Editors of the Dossier

## Dossiê

# Modelagem de Sistemas Ambientais e Gestão da Paisagem

Rodrigo Affonso de Albuquerque Nóbrega<sup>a</sup>

Fernanda Zimmermann Teixeira<sup>b</sup>

Doris Aleida Villamizar Sayago<sup>c</sup>

<sup>a</sup>Professor Adjunto do Programa de Pós-Graduação em Análise e Modelagem de Sistemas Ambientais, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
End. Eletrônico: raanobrega@ufmg.br

<sup>b</sup>Pesquisadora do Núcleo de Ecologia de Rodovias e Ferrovias, Programa de Pós-Graduação em Ecologia da Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil.  
End. Eletrônico: fernandazteixeira@gmail.com

<sup>c</sup>Professora Titular do Centro de Desenvolvimento Sustentável, Universidade de Brasília. Brasília, DF, Brasil  
End. Eletrônico: doris.sayago@gmail.com

doi:10.18472/SustDeb.v11n2.2020.33466

A crescente pressão sobre o meio ambiente, associada ao aumento da demanda por recursos naturais, priorizou a atenção para as questões socioambientais. Entretanto, são muitos os desafios que se levantam à gestão sustentável das paisagens no século XXI. O entendimento de que os sistemas ambientais são o resultado de interações complexas de múltiplas variáveis trouxe a necessidade de desenvolver e aplicar análises mais robustas para gerar conhecimento sobre o meio ambiente. Ademais, a crescente atenção para as questões ambientais também criou uma importante demanda de predição de cenários futuros que possam embasar a tomada de decisão sobre a gestão das paisagens no momento atual.

O uso de métodos e técnicas de modelagem de sistemas ambientais fortalece a capacidade para intervir na busca de soluções para o manejo e gestão de paisagens. A modelagem ambiental, pela sua natureza interdisciplinar, vem sendo amplamente aplicada no entendimento dos mecanismos causais entre sistemas ambientais e suas interações com diferentes contextos socioeconômicos no Brasil e no mundo. O estágio tecnológico atual permite não apenas o emprego de ferramentas geoespaciais sofisticadas, mas também o desenvolvimento e exploração, em caráter transdisciplinar, de modelos para auxiliar a compreensão da complexa interação entre humanos e a natureza.

O Geoprocessamento atingiu relativa maturidade quanto à funcionalidade e capacidade de análise. A ênfase atual passou então a centrar na construção de sofisticados modelos de representação de sistemas ambientais e cálculos de simulação. A modelagem geográfica ambiental busca a compreensão da dinâmica de fenômenos espaciais (que possuem expressão geográfica), quer sejam naturais ou antrópicos, e o seu papel na organização e evolução dos sistemas da Terra, consistindo-se em um procedimento teórico-instrumental que envolve um conjunto de técnicas quantitativas e espaciais, visando à operacionalização de uma abordagem sistêmica. Como resultado, o desenvolvimento integrado das ciências da Terra (Geologia, Geografia, Ecologia, Climatologia, dentre outras) abre um amplo campo à modelagem de processos ambientais, sendo hoje já considerada como área de pesquisa de ponta e de temática prioritária.

Em busca de um desenvolvimento sustentável, a modelagem de sistemas ambientais vem ganhando um papel de destaque na geração de conhecimento integrado sobre o meio ambiente e a sociedade e suas interações, provendo metodologias, tecnologias e produtos capazes de subsidiar e direcionar políticas para a prevenção e mitigação dos impactos antrópicos, sobretudo em relação às mudanças globais. Para tanto, as ciências ambientais vêm tentando se inserir no desenho de políticas públicas e na avaliação de seu desempenho. Essa tem sido a premissa do Programa de Pós-Graduação em Análise e Modelagem de Sistemas Ambientais (AMSA) da UFMG, e que tem alimentado as linhas de pesquisa em Análise Ambiental, Modelagem de Sistemas e Gestão da Paisagem.

A abordagem tradicionalmente praticada nas pesquisas do AMSA é de natureza quantitativa, o que de certa forma restringe a completude de seu alcance na sociedade, incluindo os pares na área de ciências ambientais da CAPES. Foi neste sentido que, no início de 2018, o Centro de Desenvolvimento Sustentável (CDS) da UnB estendeu, de forma sábia, o convite ao AMSA para iniciar uma parceria acadêmica entre os dois programas. O CDS enxergou que a modelagem geográfica quantitativa poderia potencializar a alta qualidade das pesquisas, em geral de domínio qualitativo, praticadas na casa. Para o AMSA, a parceria com um programa de pós-graduação maduro e reconhecido por sua excelência foi uma oportunidade singular para reforçar o seu processo de amadurecimento.

A parceria foi concretizada no final de 2018 com o desenvolvimento do III Simpósio de Modelagem de Sistemas e Análise da Paisagem do Programa de Pós-Graduação em Análise e Modelagem de Sistemas Ambientais, evento bianual do AMSA que nesta edição contou com a coparticipação da coordenação do CDS e pesquisadores associados. O evento, que teve como objetivo apresentar e debater os desafios e perspectivas da modelagem de sistemas ambientais, discutir as metodologias e aplicações de modelos geográficos e gestão da paisagem, e de abordar o papel da modelagem na formulação de políticas públicas e privadas para o planejamento e gestão de paisagens, tornou-se uma plataforma de convergência de artigos científicos, e a base para a elaboração do presente Dossiê. Além de trabalhos selecionados do III Simpósio, o Dossiê Modelagem de Sistemas Ambientais e Gestão da Paisagem da revista Sustentabilidade em Debate reúne manuscritos que abordam temas relacionados a metodologias inovadoras em modelagem quantitativa e geoprocessamento capazes de promover meios de aprimorar a gestão e a governança territorial em prol da sustentabilidade socioambiental.

O Dossiê apresenta nove artigos, sendo que o primeiro artigo, *“Agricultura e paisagens sustentáveis: a diversidade produtiva do setor agrícola de Minas Gerais”*, analisa a dinâmica da agricultura mineira quanto à produção e diversidade de seus produtos sob a perspectiva da sustentabilidade ambiental, e mostra que a grande diversidade da agricultura produzida nos municípios está associada ao contexto da agricultura familiar.

O segundo artigo, *“Produtos florestais não madeireiros nos biomas Amazônia e Cerrado: Governança em escala para implementar cadeias aprimoradas de sociobiodiversidade”*, contextualiza os produtos florestais não madeireiros para a implementação de políticas para governança social e de biodiversidade em suas cadeias produtivas nos dois mais extensos biomas brasileiros.

O artigo *“A caligrafia da sociedade na paisagem: transformações ambientais no entorno de unidades de conservação da Serra do Espinhaço”* analisa o contexto da criação de duas áreas protegidas a partir do entendimento de padrões de uso dos recursos naturais pela população local e a respectiva dinâmica de uso do solo ao longo do tempo.

No artigo *“Desmatamento simulado versus dados de satélite em Roraima”*, os autores analisam as mudanças no padrão de cobertura e uso do solo em Roraima, sobretudo quanto ao desmatamento, comparando os resultados de cenários simulados computacionalmente para o período 2011-2017 e os dados oficiais do PRODES. O estudo investigou áreas de uso silvo-pastoris e excluiu terras indígenas e unidades de conservação, que juntas concentram grande parte do território do estado.

Na sequência, o artigo *“Uso da análise multicritério para definição de áreas prioritárias para reflorestamento na bacia do rio Piranga/MG”*, os autores analisam e identificam, sob a ótica das áreas de preservação permanente consolidadas no novo Código Florestal e técnicas de análise geográfica multicritério para apoio à tomada de decisão, as áreas que poderiam estar sendo destinadas a reflorestamento em uma região de recarga de água, ambientalmente sensível, e no contexto geográfico da tragédia ambiental de Mariana/MG.

O sexto artigo do Dossiê, *“Utilização de programas abertos de geotecnologia para o emprego no licenciamento ambiental no estado do Piauí”*, apresenta e discute o emprego de ferramentas e dados geográficos livres no processo de licenciamento ambiental. Também nessa linha, o artigo *“Uso de técnicas de sensoriamento remoto para identificação e avaliação de áreas queimadas na região metropolitana de Belo Horizonte”* analisa o emprego de imagens orbitais gratuitas e de técnicas tradicionais de reconhecimento e extração de feições nas imagens, para identificação de áreas queimadas susceptíveis a danos ambientais no contexto periurbano.

No penúltimo artigo, *“Construção de um modelo de potencial de radiação solar local e discussão das aplicações sustentáveis e potenciais associados”*, os autores mapeiam de forma minuciosa telhados urbanos para quantificar o potencial para geração de energia solar em áreas densamente construídas. O estudo recorreu a tecnologias como imageamento por drone para poder ser sensível às nuances e aos aspectos de geometria das complexas superfícies dos telhados e coberturas das áreas urbanizadas.

Por fim, o artigo *“Otimização locacional de portos secos para fomentar desenvolvimento regional sustentável”* apresenta um modelo geograficamente explícito para mapear e identificar as regiões com maior viabilidade para implantação de portos secos em todo o estado de Minas Gerais. O modelo adiciona características socioeconômicas como a geração de empregos e receita local, e elementos ambientais à tradicional perspectiva logística da engenharia.

Embora o III Simpósio de Modelagem Ambiental e Gestão da Paisagem tenha sido realizado no final de 2018, antevéspera da troca do Governo, e o presente Dossiê publicado em Agosto de 2020 (*Annus Horribilis*, em alusão ao Editorial do volume 11 da Revista Sustentabilidade em Debate), o material aqui apresentado traz à tona o olhar da academia, tão massacrada neste mesmo período, a temas ambientais de interesse e benefício comum para a sociedade. O meio ambiente, literalmente inflamado em 2019 e neste *Annus Horribilis*, clama por dias melhores. A academia faz aqui o seu papel.

Agradecemos aos colegas que prestigiaram o evento, aos autores que enviaram seus trabalhos e aos avaliadores que colaboraram com esta edição do Dossiê. Boa leitura.

Editores do Dossiê



# Agriculture and sustainable landscapes: agricultural diversification in the state of Minas Gerais, Brazil

*Agricultura e paisagens sustentáveis: a diversidade  
produtiva do setor agrícola de Minas Gerais, Brasil*

Marina Lorena Campos Teixeira<sup>a</sup>

Sónia Maria Carvalho Ribeiro<sup>b</sup>

<sup>a</sup>Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
E-mail: marina-lorena@hotmail.com

<sup>b</sup>Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
E-mail: sonia.carvalhoribeiro@googlemail.com

doi:10.18472/SustDeb.v11n2.2020.28147

Received: 29/11/2019  
Accepted: 02/04/2020

ARTICLE - DOSSIER

## ABSTRACT

The intensification of agricultural production and its impact has been widely discussed around the world. Agricultural diversification is a possible path to promote sustainability in agriculture, considering ecological and socioeconomic aspects. Thus, this paper aims to develop an indicator that could assess the agricultural diversification of the municipalities of Minas Gerais, to understand the dynamics of agriculture in the state. Our results show that most of the municipalities (76%) presented a “high” or “very high” diversification, and it can be explained by the strong presence of family farming. However, the share of the gross domestic product (GDP) of these municipalities relative to agriculture activity is relatively low, highlighting that economic sustainability has not been fully achieved yet. In addition to the producer’s interest in increasing agricultural diversification, it is important to ensure a rural development public policy fostering diverse agricultural production systems aligned with environmental sustainability standards.

**Keywords:** Agriculture Diversification. Simpson Diversity Index. Sustainable landscapes. Governance.

## RESUMO

A produção de alimentos é importante para garantir a segurança alimentar, e os diferentes modos de produção podem gerar diferentes impactos ambientais. A diversificação agrícola é considerada uma das formas de promover a sustentabilidade, tanto em termos ecológicos quanto socioeconômicos. Para compreender a dinâmica da agricultura em Minas Gerais, este trabalho utiliza um indicador para caracterizar os sistemas de produção agrícola e avaliar a diversidade produtiva dos 853 municípios do estado. A maior parte dos municípios (76%) apresentou uma diversidade alta ou muito alta, sendo esta associada principalmente ao contexto da agricultura familiar. No entanto, a contribuição desses sistemas agrícolas diversificados para a economia dos municípios é relativamente baixa, mostrando que a sustentabilidade econômica de sistemas diversificados ainda é um desafio. É importante que, além do interesse do produtor, exista uma política pública de desenvolvimento rural capaz de viabilizar sistemas de produção agrícola alinhados com padrões de sustentabilidade ambiental.

*Palavras-chave: Diversificação Agrícola. Índice de Diversidade de Simpson. Paisagens Sustentáveis. Governança.*

## 1 INTRODUCTION

Food demand increases as the world population grows, and the scenario foreseen for the coming years is not encouraging: United Nations (UN) estimates that 11.2 billion people will be living on the planet in 2100 (UN, 2017). This perspective calls for agricultural systems able to supply food and economic needs of an increasing population.

In this context, the process of agriculture intensification stands out, which aims to increase the amount of food produced per unit area (productivity), especially with the use of technologies that allow large-scale production, generally using monoculture as a way of production. In addition to food, monocultures are also intended for biofuel production, which production is increasing year after year (IEA, 2019). Considering only the Brazilian sugarcane production destined for the sugar-energy sector, 8.6 million hectares were harvested during 2018/2019 (BRASIL, 2019), this corresponding to 85% of the total sugarcane planted area in the country (IBGE, 2019a). This reinforces the prominent position that agribusiness holds in the Brazilian economy.

The expansion to new agricultural areas and the intensification of existing areas would contribute to the increase in production fulfilling this rising demand (TILMAN et al., 2011). However, it is known that many environmental impacts are associated with agricultural activity, especially monocultures such as soil degradation and eutrophication (KASTNER, KASTNER and NONHEBEL, 2011), biodiversity loss (PERFECTO and VANDERMEER, 2010), greenhouse gas (GHG) emissions due to changes in land use and the use of fertilizers (BURNEY, DAVIS and LOBELL, 2010), among others.

Currently, several regions in the world are dominated by monocultures, which replace ecosystems that were previously marked by a high richness of species. In this way, agriculture was largely responsible for simplifying and homogenizing diverse ecosystems around the world (TILMAN, 1999).

One of the technical proposals to reduce landscape simplification and homogenization is the promotion of agricultural diversification (KASSAM and FRIEDRICH, 2012), which can be done through the integration of two or more agricultural activities (plant species) in the same rural property (SANTANA, FERREIRA E ALENCAR, 2009). It can reduce the risks of monoculture as the main source of income for the producer and increase both economic and landscape sustainability. Regarding family farming, there is a number of advantages associated with agricultural diversification: increase in marketing possibilities throughout the year, rescue of traditional product crops, increase in incomes and the improvement in living conditions of the family as a whole (BARBOSA ET AL. 2016; HAAS, 2008).

Michler and Josephson (2017), for example, assessed the impact of agricultural crop diversification on families from the most disadvantaged regions in Ethiopia. By analyzing official statistical data in the country, they were able to quantify that families with diversification of crops in their properties have, on average, lower poverty rates. In addition, it has been found that the diversification of agricultural production reduces the probability that an economically weak family will fall into poverty. In a similar context, Waha et al. (2018) state that, at the family level, agricultural diversification is more successful in ensuring food security.

The concept of sustainability has been widely discussed and adopted for environmental issues in recent decades. However, it has been overlooked in the context of the landscape. Sustainable landscapes, according to the International Institute for Sustainability, are those that take on the challenge of reconciling social, economic and ecological interests, by integrating them into territorial planning processes at different scales from urban areas to rural areas and from pristine to degraded areas

(IIS, 2015). Specifically dealing with the rural environment, the sustainability of landscapes aims to establish conditions for biodiversity conservation and development of productive activities to be combined in common areas.

Considering the context of sustainable agriculture and the importance of using indicators that are able to assess landscape sustainability, it is necessary to formulate metrics that quantify landscape aspects related to socioeconomic and environmental dimensions. As diversification of agricultural production is one of the possibilities to increase sustainability of rural landscapes, it is important to propose indicators that are able to assess diversification of agricultural production at the municipality level.

## 2 DIVERSIFICATION OF AGRICULTURE IN MINAS GERAIS

Agriculture has great relevance in the historical and economic context of Minas Gerais. Agricultural practices are closely related to the development of mining in the state, from the 18th century onwards, but initially as a subsistence activity. The activity only gained a prominent position with mining decline, when new markets for agricultural products emerged, in the course of the 18th century (MINAS GERAIS, 1978).

Minas Gerais' agriculture once again gained great importance at the beginning of the Brazilian republican period, when coffee production became one of the main pillars of the country's economy. Later, the state aimed to diversify production, in order to consolidate a strong agricultural sector, capable of sustaining a vigorous industrialization process (GARCIA AND ANDRADE, 2007).

In the current scenario, agriculture still has great importance in the socioeconomic context of Minas Gerais. According to data from MapBiomas, agriculture areas increased over a short period of time: from approximately 635,000 ha in 1985 to 3,575,000 ha in 2018 (PROJETO MAPBIOMAS, 2020). In addition, agribusiness GDP accounted for 33.5% of the state's total GDP (EMATER, 2018).

According to 2017 Agricultural Census, Minas Gerais has 607,557 rural establishments, and they occupy approximately 65% of the state's territory (IBGE, 2019b). Family farming has also a great importance in Minas Gerais: data from the same census indicate the existence approximately 440,000 family establishments in the state, which corresponds to 73% of the total rural establishments in Minas Gerais (IBGE, 2019b).

Considering the relevance of family farming in Minas Gerais scenario, the state also gains prominence when diversification of agricultural production is analyzed. According to the 2018 Municipal Agricultural Production Survey, Minas Gerais is the state with the largest variety of crops (temporary and permanent) in Brazil: out of 71 crops analyzed in the survey, 52 were found in the state (IBGE, 2019a). However, the specific effects of diversification are not yet widely understood, so the incentive for this practice has not yet reached its full potential.

Thus, this work aims to quantify the agricultural diversity of each one of the municipalities of Minas Gerais through a consistent indicator. We also aim at assessing how agricultural diversity is associated to other socioeconomic and environmental indicators.

## 3 METHODS

### 3.1 DATA COLLECTION

Data used in this study was collected in Municipal Agricultural Production Survey (IBGE, 2019). We first estimated the planted area for each agricultural crop. We used only those cases whose quantity produced was at least one ton and distributed over at least one hectare. For this purpose, it was used

average values (2014 to 2018), in order to reduce the exceptionalities that may have occurred in some years of the historical series. With these data, it was possible to calculate the agricultural diversity index for each municipality using the Simpson index, as described in section 3.2.

Then, this data was compared to other variables that allow to outline the productivist and conservationist profile of the municipalities of Minas Gerais. The following variables were selected:

- Percentage of anthropized area by municipality;

The percentage of anthropized area measures the degree of human intervention in landscapes. As agricultural production requires an available area for its development, it is assumed that the increase in the anthropized area is related to the productive aspect of the municipalities. To this purpose, it was used database (shapefile) containing land uses, from Brazilian Foundation for Sustainable Development (FBDS)(FBDS, 2018).

- Contribution of agriculture to the municipal Gross Domestic Product (GDP);

The share that agricultural activity adds to the municipal GDP is an important indicator of the size of this sector in the local economy. The higher the value, the greater is the predominance of the activity, which shows a strong productive aspect of the municipalities. This same indicator was used by Pinto Correia et al. (2016) to assess the productive dimension of human occupation in rural spaces. To calculate this indicator, it was considered the percentage of added value of agriculture at municipal GDP over the total GDP (IBGE, 2016).

- Euclidean nearest-neighbor distance (forest fragments)

Euclidean nearest-neighbor distance is one of the landscape metrics used to assess landscape fragmentation - in this case, forest fragmentation. It can cause several negative consequences, such as habitats and biodiversity loss, changes in ecological interactions, among others (SOUZA et al., 2014). The greater the distance between fragments, the greater the degree of isolation verified, which is detrimental to biodiversity conservation. In this study, the analysis of the Euclidean nearest-neighbor distance of fragments used available data from FBDS database (FBDS, 2018), and performed on FRAGSTATS 4.2.1 software.

- Average size of forest fragments;

The average size of forest fragments is another landscape metric used to assess fragmentation - larger fragments are usually better for promoting connectivity and biodiversity conservation (VALENTE E VETORAZZI, 2005). It is important to note, however, that the total area of the fragment was considered, including border area. As the scale of this study involves all municipalities in Minas Gerais, encompassing different biomes and ecosystems, it was considered inappropriate to assume a single border value for all areas. Thus, only the structural element of the landscape was considered, without considering its functional aspect. Once again, average size of the fragments of forest areas was calculated using FBDS database and was performed in FRAGSTATS 4.2.1 software.

- Percentage of permanent protection areas by municipality;

Permanent protection areas (PPAs) are instituted through specific legal regulations, (BRASIL, 2012). PPAs were adopted as a surrogate for the conservationist profile of the municipalities as it is a common factor to all of them. Shapefiles containing these areas are available in FBDS database. It is important to note, however, that these areas are related only to riparian areas.

### 3.2 CALCULATION OF THE AGRICULTURAL DIVERSITY INDEX OF THE MUNICIPALITIES

With variables previously calculated, the productive diversity of each municipality was calculated using the Simpson Diversity Index (SID) (SIMPSON, 1949), using the following equation:

$$SID = 1 - \sum_{i=1}^N \left( \frac{X_i}{\sum_{i=1}^N X_i} \right)^2$$

Where:  $X_i$  = occupied area by each product and  $N$  = number of agricultural products in the municipality that occupy more than one hectare and whose quantity exceeds one ton.

This index ranges from 0 to 1, with 0 being the municipality that presents only one type of agricultural production, and increases to the value of 1 as diversity increases.

The values obtained for each municipality were associated with a geographic database (shapefile of municipalities in Minas Gerais), in order to generate a map of agricultural diversity.

The municipalities were grouped into five distinct classes:

- Very low diversification:  $SID \leq 0.20$ ;
- Low diversification:  $SID > 0.20$  e  $\leq 0.40$ ;
- Medium diversification:  $SID > 0.40$  e  $\leq 0.60$ ;
- High diversification:  $SID > 0.60$  e  $\leq 0.80$ ;
- Very high diversification:  $SID > 0.80$ .

### 3.3 STATISTICAL ANALYSIS

First, the normality of data was verified, using Kolmogorov-Smirnov test. After this verification, descriptive statistics of data and the correlation between the agricultural diversity and the other analyzed variables were calculated. All analyzes were performed on SPSS 19 statistical software.

## 4 RESULTS AND DISCUSSION

Table 1 shows values of descriptive statistics, while Figure 1 shows the distribution of the calculated values for the agricultural diversity index.

**Table1 |** Descriptive statistics of the analyzed variables

| <i>Variable</i>   | <i>Number of occurrences</i> | <i>Minimum value</i> | <i>Maximum value</i> | <i>Average</i> | <i>Standard deviation</i> |
|---|------------------------------|----------------------|----------------------|----------------|---------------------------|
| SID   | 853                          | 0.00                 | 0.88                 | 0.66           | 0.13                      |
| CONTRIBUTION OF AGRICULTURE TO THE MUNICIPAL GROSS DOMESTIC PRODUCT (GDP) | 853                          | 0.00                 | 0.72                 | 0.17           | 0.12                      |
| PERCENTAGE OF ANTHROPIZED AREA  | 853                          | 0.09                 | 0.94                 | 0.67           | 0.16                      |

| Variable   | Number of occurrences | Minimum value | Maximum value | Average | Standard deviation |
|--|-----------------------|---------------|---------------|---------|--------------------|
| AVERAGE SIZE OF FOREST FRAGMENTS; (HA)                     | 853                   | 1.02          | 70.30         | 6.32    | 5.53               |
| EUCLIDEAN NEAREST-NEIGHBOR DISTANCE (FOREST FRAGMENTS) (M) | 853                   | 25.40         | 246.64        | 62.76   | 22.85              |
| PERCENTAGE OF PERMANENT PROTECTION AREAS BY MUNICIPALITY;  | 853                   | 0.01          | 0.61          | 0.11    | 0.05               |

Source: Elaborated by the author.

According to results of socioeconomic variables presented in Table 1, contribution of agricultural activity to the municipal GDP of the 853 municipalities in Minas Gerais ranges from 0 to 72%, while the anthropized area varies from 0.9 to 94%. Regarding the results of landscape metrics, Table 1 shows that the average area of forest patches varies from 1 to 70.3 hectares, with mean and standard deviation being 6.32 and 5.53, respectively. For Euclidean nearest-neighbor distance between forest fragments, average values per municipality range between 25 and 246 meters. Finally, Table 1 shows that, on average, Minas Gerais municipalities have 11% of their territory in riparian permanent protection areas.

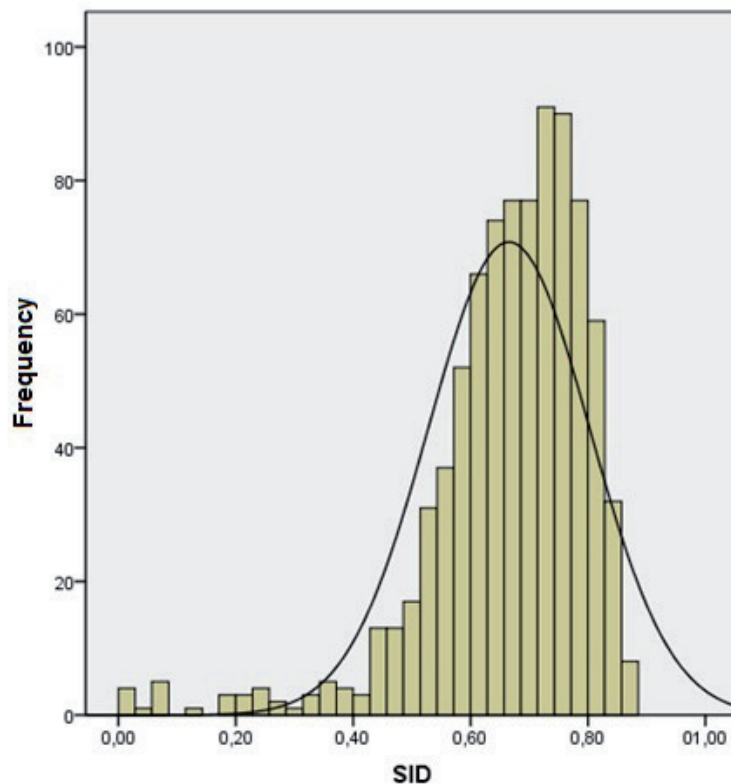


Figure 1 | Distribution of calculated values for agricultural diversity

Source: Elaborated by the author.

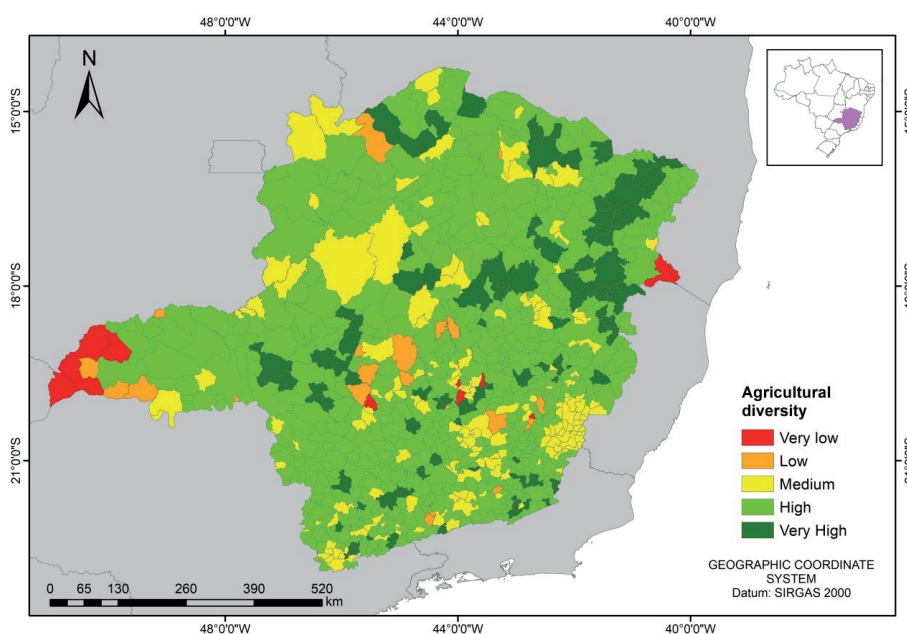
Also according to Table 1, the average and standard deviation of the agricultural diversity index of the 853 municipalities in Minas Gerais is of  $0.66 \pm 0.13$ . After calculating the index for each one of the municipalities, it was found that 1.6% of Minas Gerais municipalities are classified as having a very low agricultural diversity, 2.6% as low diversification, 19.5% as medium diversification, 64.7% as high diversification and 11.6% have very high diversification.

Figure 2 shows the map with the classification of agricultural diversity in the municipalities of Minas Gerais. In the group with the lowest values for agricultural diversification, there is a strong concentration in Triângulo Mineiro region. This can be explained by the exploitation of agribusiness that takes place in the region, developed by medium and large-sized rural entrepreneurs who make intensive use of technology, making this agricultural region the most dynamic and developed in the state (BASTOS E GOMES, 2011).

Other municipalities are dispersed in several regions of the state, and a possible explanation for the low diversification may be related to the fact that agriculture is not one of the main economic activities developed in these areas (IBGE, 2016b). In this group, Belo Horizonte (capital of the state) stands out, as no information on agricultural production was verified. So, the calculated index assumed zero value.

Geographic factors may also be an explanation for the different levels of diversification observed in Minas Gerais. There is, for example, in the intermediate region of Juiz de Fora, a strong concentration of municipalities classified with a medium diversification. This can be explained by topography of the rugged relief and land forms with steep slopes present in the region, which can be considered an obstacle to agricultural production, with the most fertile areas being limited to the region's valleys (BASTOS E GOMES, 2011).

The two categories of municipalities with the highest values for the diversity index cover 651 municipalities (76.3% of the total municipalities in Minas Gerais), which are homogeneously distributed in the state. These results reinforce the importance of Minas Gerais in the Brazilian agricultural scenario, and also indicate the relevance of family farming in the state, since diversification is a practice intrinsically associated with this type of production.



**Figura 2 |** Agricultural diversity in the state of Minas Gerais

*Source: Elaborated by the author*

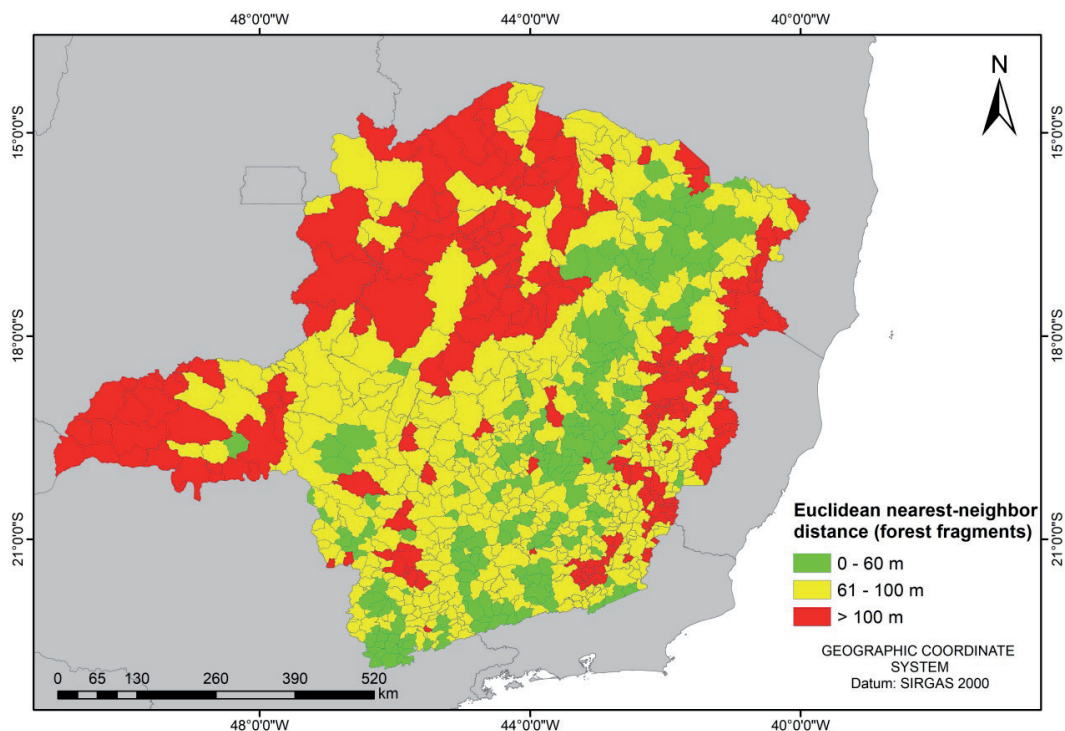
It is important to understand, however, how agricultural diversity is reflected in production and conservation aspects in the state. For this purpose, a statistical analysis was performed, and it was verified that data do not follow normal distribution, which implies the choice of Spearman's correlation coefficient to verify which is the relationship between the variables. The detailed results of correlation amongst variables are found in Annex 1.

Our results show that there is no significant correlation ( $\alpha = 0.05$ ) between the index of agricultural diversity and the variables: average size of forest fragments, percentage of permanent protection areas by municipality; contribution of agriculture to the municipal Gross Domestic Product (GDP) and percentage of anthropized areas by municipality.

The only significant correlation obtained among the variables analyzed was related to the variable "Euclidean nearest-neighbor distance (forest fragments)". It was found that the increase in the

diversification index is related to the decrease in the Euclidean nearest-neighbor distance (forest fragments), as shown by the negative value for the correlation (-0.073). Although the value obtained is not high, this result can be considered an indication that agricultural diversification may be positively associated with increased connectivity between forest fragments (without considering specific focus groups), which favors biodiversity conservation. Annex 2 shows the difference between the averages of the variables analyzed for each one of the five groups of agricultural diversification.

The map in Figure 3 shows how the municipalities classify in relation to the variable “Euclidean nearest-neighbor distance (forest fragments)”. The shorter the Euclidean nearest-neighbor distance, the greater the likelihood of biodiversity conservation taking place, as the isolation of fragments has a negative effect on species richness, decreasing the (potential) rate of immigration or recolonization (ALMEIDA, 2008). As a result, from an ecological point of view, there is an increase in the landscape sustainability.



**Figure 3 |** Spatial distribution of the variable “Euclidean nearest-neighbor distance (forest fragments)”.

*Source: Elaborated by the author.*

In general, it seems that the increase in agricultural diversity positively impacts landscape in terms of conservation; however, when assessing social aspect of landscapes, related to agricultural production and the income generated from it, agricultural diversity does not yet have a significant influence in terms of improving economic indicators, which directly raise the issues of reconciling ecological and economic sustainability.

It is important to highlight that, in this work, it was discussed exclusively the concept of agricultural diversity, while another concept is important to explain the productive dynamics of rural environments: rural diversification, which consists of combining, in addition to agricultural activities, other non-agricultural activities, in order to explore all the potential that the property / region has. Some authors (SILVA, 2001 apud SANTANA, FERREIRA AND ALENCAR, 2009) point out that the diversification of agriculture itself is not able to promote an increase in income sufficient to reduce the dependence of producers in relation to local labor markets, which it may justify the low correlation between the agricultural diversity index and economic variables.



Even though agricultural diversification has the producer as one of the main social actors, it is highlighted that the success of this action does not depend exclusively on producers themselves. It is necessary to have an associated rural development policy, so it will be possible to generate a complex chain of reciprocal interactions between all axes (credit, agricultural research, technical assistance and rural extension), thus guaranteeing access to land and technologies for production and sustainable management of establishments (BITTENCOURT, 2002 apud SANTANA, FERREIRA E ALENCAR, 2009). Therefore, it is evident that the achievement of sustainable landscapes through agricultural diversification must be the result of actions of several sectors of society, with the public sphere (municipal and state governments) playing a fundamental role in the fostering of agricultural diversity.

## 5 FINAL CONSIDERATIONS

The development of sustainability strategies in rural areas has proved to be a great challenge, since the concept of landscape sustainability has had difficulties in assuming a relevant role, given the inherent complexity of its management process. One of several challenges is the development of metrics to track progress and enable landscape management. Throughout this paper, the agricultural diversity index was calculated, in order to classify municipalities of Minas Gerais. It was found that most municipalities in the state (76.3%) were classified as having a “high” or “very high” agricultural diversity, which confirms the state’s position as the most diversified in the country. However, this diversification is not yet fully reflected in economic and environmental indicators, which shows that there is still a need to implement a series of actions that, in fact, target to guarantee landscape sustainability, both in environmental and economic aspects. Considering that each municipality presents a particular reality (with problems and strengths), it is desirable that different portfolios of public policies are developed, targeting different local identities that guarantee the involvement of all actors in order to generate long lasting results.

## ACKNOWLEDGMENT

The first author thanks FAPEMIG for the grant of master’s scholarship. Second author thanks CNPq for its PQ scholarship.

## REFERENCES

- ALMEIDA, C. G. **Análise espacial dos fragmentos florestais na área do Parque Nacional dos Campos Gerais, Paraná**. 2008. Dissertação (Mestrado em Gestão do Território) – Universidade Estadual de Ponta Grossa, Paraná. Ponta Grossa, PR.
- BARBOSA, P. J. F. et al. A importância da diversificação agrícola como complemento na renda familiar na região de Manhuaçu – MG. **Revista do CCEI**, v. 20, n. 35, 2016.
- BASTOS, S. Q. DE A.; GOMES, J. E. Dinâmica da agricultura no estado de Minas Gerais. **Ruris**, v. 5, n. 2, p. 45-76, 2011.
- BRASIL. **Lei 12.651/2012**. Dispõe sobre a proteção da vegetação nativa. Brasília, DF. Brasil. Constituição da República Federativa do Brasil de 1988. Brasília, DF.
- BRASIL. Ministério de Minas e Energia. **Análise de conjuntura dos biocombustíveis – ano 2018**. Empresa de Pesquisa Energética – EPE. Rio de Janeiro, 2019.
- BURNEY, J. A.; DAVIS, S. J.; LOBELL, D. B. Greenhouse gas mitigation by agricultural intensification. **Proc. Natl. Acad. Sci. USA**, v. 107, p. 12052–12057, 2010.

- EMPRESA DE ASSISTÊNCIA TÉCNICA E EXTENSÃO RURAL DO ESTADO DE MINAS GERAIS. **Balço do Governo de Minas apresenta o crescimento e a diversidade da agricultura do estado**. 2018. Disponível em: <[http://www.emater.mg.gov.br/portal.cgi?flagweb=novosite\\_pagina\\_interna&id=22669](http://www.emater.mg.gov.br/portal.cgi?flagweb=novosite_pagina_interna&id=22669)>. Acesso em: 04 out. 2018.
- FUNDAÇÃO BRASILEIRA PARA O DESENVOLVIMENTO SUSTENTÁVEL. **Mapeamento em Alta Resolução dos Biomas Brasileiros – Metodologia**. 2018. Disponível em: <<http://geo.fbds.org.br/Metodologia.pdf>>. Acesso em: 24 set. 2018.
- GARCIA, J. R.; ANDRADE, D. C. Panorama geral da industrialização de Minas Gerais (1970-2000). **Leituras de Economia Política**, Campinas, n. 12, 2007.
- HAAS, J. M. Diversificação de Produção no Meio Rural como Estratégia de Sobrevivência: um estudo de caso da região noroeste do Rio Grande do Sul. In: **Encontro Nacional da Anppas**, 4, 2008, Brasília.
- INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Produto Interno Bruto dos Municípios**. 2016. Disponível em: <<https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9088-produto-interno-bruto-dos-municipios.html?=&t=downloads>>. Acesso em: 26 jun. 2019.
- INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Censo Agro 2017**. 2019a. Disponível em: <<https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2017>>. Acesso em: set. 2019.
- INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Produção Agrícola Municipal (PAM): culturas temporárias e permanentes**. 2019b. Disponível em: <<https://sidra.ibge.gov.br/pesquisa/pam/tabelas>>. Acesso em: nov. 2019.
- INSTITUTO INTERNACIONAL PARA A SUSTENTABILIDADE. **Paisagens Sustentáveis: integrando desenvolvimento rural e conservação ambiental**. 2015. Disponível em: <[http://www.iis-rio.org/media/archives/Relatorio\\_Workshop\\_Paisagens\\_Sustentaveis\\_IIS\\_2015.pdf](http://www.iis-rio.org/media/archives/Relatorio_Workshop_Paisagens_Sustentaveis_IIS_2015.pdf)>. Acesso em: 20 abr. 2019.
- INTERNATIONAL ENERGY AGENCY. **Biofuels for transport**. 2019. Disponível em: <<https://www.iea.org/tcep/transport/biofuels/>>. Acesso em: 02 abr. 2019.
- KASSAM, A.; FRIEDRICH, T. An ecologically sustainable approach to agricultural production intensification: global perspectives and developments. **Field Actions Science Report**, special issue 6, 2012.
- KASTNER, T.; KASTNER, M.; NONHEBEL, S. Tracing distant environmental impacts of agricultural products from a consumer perspective. **Ecological Economics**, v. 70, p. 1032-1040, 2011.
- MICHLER, J. D.; JOSEPHSON, A. L. To Specialize or Diversify: agricultural diversity and poverty dynamics in Ethiopia. **World Development**, v. 89, p. 214-226, 2017.
- MINAS GERAIS. **A agropecuária mineira: sua história, sua evolução**. 1978, 146 p.
- ORGANIZAÇÃO DAS NAÇÕES UNIDAS. **World Population Prospects 2017**. 2017. Disponível em: <<https://population.un.org/wpp/DataQuery/>>. Acesso em: 30 mar. 2019.
- PERFECTO, I.; VANDERMEER, J. The agroecological matrix as alternative to the land-sparing/agriculture intensification model. *Proc. Natl. Acad. Sci. USA*, v. 107, p. 5786–5791, 2010.
- PROJETO MAPBIOMAS. **Coleção 4.1 da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil**. 2020. Disponível em: <<http://mapbiomas.org/map#coverage>>. Acesso em: 06 jun. 2020.
- SANTANA, A. C.; FERREIRA, P. A.; ALENCAR, E. Diversificação da Agricultura Familiar no Sul de Minas Gerais: uma análise da percepção de professores e pesquisadores. **Sociedade Brasileira de Economia, Administração e Sociologia Rural**, p. 2-4, 2009.
- SIMPSON, E. H. Measurement of diversity. **Nature**, v. 163, p. 688, 1949.
- SOUZA, C. G. et al. Análise da fragmentação florestal da área de proteção ambiental Coqueiral, Coqueiral – MG. **Ciência Florestal**, v. 24, n. 3, p. 631-644, 2014.
- TILMAN, D. et al. Global food demand and the sustainable intensification of agriculture. *Proc. Natl. Acad. Sci. USA*, v. 108, p. 20260–20264, 2011.

TILMAN, D. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. *Proc. Natl. Acad. Sci. USA*, v. 96, p. 5995–6000, 1999.

VALENTE, R. O. A.; VETTORAZZI, C. A. Comparação entre métodos de avaliação multicriterial, em ambiente SIG, para a conservação e a preservação florestal. *Scientia Forestalis*, n. 69, p. 51-61, 2005.

WAHA, K. et al. Agricultural diversification as an important strategy for achieving food security in Africa. *Global Change Biology*, v. 24, n. 8, 2018.

## ANNEX 1 – CORRELATION ANALYSIS BETWEEN VARIABLES

| Correlations   |   |                         |        |                                       |  |   |   |                                       |
|----------------|---|-------------------------|--------|---------------------------------------|--|---|---|---------------------------------------|
|                |   |                         | SID    | Average size of forest fragments (ha) | Euclidean nearest-neighbor distance (forest fragments) (m) | % of permanent protection areas by municipality | Contribution of agriculture to the municipal Gross Domestic Product (GDP) | % of anthropized area by municipality |
| SPEARMAN'S RHO | SID   | Correlation Coefficient | 1,000  | ,003                                  | -,073*   | -,063   | -,055   | -,056                                 |
|                |   | Sig. (2-tailed)         | .      | ,928                                  | ,034   | ,068  | ,107  | ,101                                  |
|                |   | N                       | 853    | 853                                   | 845  | 853   | 853   | 853                                   |
|                | AVERAGE SIZE OF FOREST FRAGMENTS (HA)                                     | Correlation Coefficient | ,003   | 1,000                                 | -,168**  | -,107**   | -,189**   | -,558**                               |
|                |   | Sig. (2-tailed)         | ,928   | .                                     | ,000   | ,002  | ,000  | ,000                                  |
|                |   | N                       | 853    | 853                                   | 845  | 853   | 853   | 853                                   |
|                | EUCLIDEAN NEAREST-NEIGHBOR DISTANCE (FOREST FRAGMENTS) (M)                | Correlation Coefficient | -,073* | -,168**                               | 1,000  | -,092**   | ,111**  | ,533**                                |
|                |   | Sig. (2-tailed)         | ,034   | ,000                                  | .  | ,007  | ,001  | ,000                                  |
|                |   | N                       | 845    | 845                                   | 845  | 845   | 845   | 845                                   |
|                | % OF PERMANENT PROTECTION AREAS BY MUNICIPALITY                           | Correlation Coefficient | -,063  | -,107**                               | -,092**  | 1,000   | -,134**   | ,040                                  |
|                |   | Sig. (2-tailed)         | ,068   | ,002                                  | ,007   | .   | ,000  | ,242                                  |
|                |   | N                       | 853    | 853                                   | 845  | 853   | 853   | 853                                   |
|                | CONTRIBUTION OF AGRICULTURE TO THE MUNICIPAL GROSS DOMESTIC PRODUCT (GDP) | Correlation Coefficient | -,055  | -,189**                               | ,111**   | -,134**   | 1,000   | ,165**                                |
|                |   | Sig. (2-tailed)         | ,107   | ,000                                  | ,001   | ,000  | .   | ,000                                  |
|                |   | N                       | 853    | 853                                   | 845  | 853   | 853   | 853                                   |
|                | % OF ANTHROPIZED AREA BY MUNICIPALITY;                                    | Correlation Coefficient | -,056  | -,558**                               | ,533**   | ,040  | ,165**  | 1,000                                 |
|                |   | Sig. (2-tailed)         | ,101   | ,000                                  | ,000   | ,242  | ,000  | .                                     |
|                |   | N                       | 853    | 853                                   | 845  | 853   | 853   | 853                                   |

\*. Correlation is significant at the 0.05 level (2-tailed).

\*\*.. Correlation is significant at the 0.01 level (2-tailed).

Source: Elaborated by the author.

## ANNEX 2 – DESCRIPTIVE STATISTICS OF ANALYZED VARIABLES BY DIVERSIFICATION GROUP

| <i>SID Group</i> |                    | <i>Average size of forest fragments (ha)</i> | <i>Euclidean nearest-neighbor distance (forest fragments) (m)</i> | <i>% of permanent protection areas by municipality</i> | <i>Contribution of agriculture to municipal GDP (%)</i> | <i>% of anthropized area by municipality</i> | <i>Number of cultures (units)</i> |
|------------------|--------------------|--|---|--|---|--|-----------------------------------|
| VERY LOW         | AVERAGE            | 5.43   | 100.11  | 8.41   | 13.69   | 69.36  | 7.64                              |
|                  | MEDIAN             | 5.84   | 117.84  | 7.17   | 9.24  | 81.96  | 8.00                              |
| LOW              | STANDARD DEVIATION | 2.12   | 47.01   | 3.94   | 13.79   | 23.99  | 5.06                              |
|                  | AVERAGE            | 5.28   | 72.03   | 10.89  | 20.61   | 73.17  | 11.27                             |
|                  | MEDIAN             | 4.38   | 63.51   | 11.32  | 18.79   | 78.96  | 11.00                             |
| MEDIUM           | STANDARD DEVIATION | 3.22   | 24.84   | 5.66   | 12.87   | 15.20  | 5.62                              |
|                  | AVERAGE            | 5.80   | 64.33   | 12.68  | 17.50   | 69.02  | 11.21                             |
|                  | MEDIAN             | 4.76   | 59.02   | 13.16  | 17.18   | 71.98  | 11.00                             |
| HIGH             | STANDARD DEVIATION | 3.36   | 23.93   | 4.07   | 11.31   | 13.56  | 4.64                              |
|                  | AVERAGE            | 6.29   | 61.43   | 11.47  | 17.24   | 67.23  | 13.86                             |
|                  | MEDIAN             | 4.79   | 57.06   | 11.23  | 15.15   | 71.62  | 13.00                             |
| VERY HIGH        | STANDARD DEVIATION | 5.61   | 21.00   | 4.87   | 11.73   | 16.27  | 4.95                              |
|                  | AVERAGE            | 7.72   | 60.13   | 11.86  | 16.11   | 62.85  | 15.36                             |
|                  | MEDIAN             | 5.53   | 53.64   | 11.02  | 12.26   | 68.95  | 15.00                             |
| VERY HIGH        | STANDARD DEVIATION | 8.00   | 20.65   | 7.07   | 13.32   | 20.13  | 4.52                              |

Source: Elaborated by the author.

# Agricultura e paisagens sustentáveis: a diversidade produtiva do setor agrícola de Minas Gerais, Brasil

*Agriculture and sustainable landscapes: agricultural  
diversification in the state of Minas Gerais, Brazil*

Marina Lorena Campos Teixeira<sup>a</sup>

Sônia Maria Carvalho Ribeiro<sup>b</sup>

<sup>a</sup>Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
End. Eletrônico: marina-lorena@hotmail.com

<sup>b</sup>Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
End. Eletrônico: sonia.carvalhoribeiro@googlemail.com

doi:10.18472/SustDeb.v11n2.2020.28147

Received: 29/11/2019  
Accepted: 02/04/2020

ARTICLE- DOSSIER

## RESUMO

A produção de alimentos é importante para garantir a segurança alimentar, e os diferentes modos de produção podem gerar diferentes impactos ambientais. A diversificação agrícola é considerada uma das formas de promover a sustentabilidade, tanto em termos ecológicos quanto socioeconômicos. Para compreender a dinâmica da agricultura em Minas Gerais, este trabalho utiliza um indicador para caracterizar os sistemas de produção agrícola e avaliar a diversidade produtiva dos 853 municípios do estado. A maior parte dos municípios (76%) apresentou uma diversidade alta ou muito alta, sendo esta associada principalmente ao contexto da agricultura familiar. No entanto, a contribuição desses sistemas agrícolas diversificados para a economia dos municípios é relativamente baixa, mostrando que a sustentabilidade econômica de sistemas diversificados ainda é um desafio. É importante que, além do interesse do produtor, exista uma política pública de desenvolvimento rural capaz de viabilizar sistemas de produção agrícola alinhados com padrões de sustentabilidade ambiental.

**Palavras-chave:** Diversificação Agrícola. Índice de Diversidade de Simpson. Paisagens Sustentáveis. Governança.

## ABSTRACT

*The intensification of agricultural production and its impacts has been widely discussed around the world. Agricultural diversification is a possible path to promote sustainability in agriculture, considering ecological and socioeconomic aspects. Thus, this paper aims to develop an indicator that could assess the agricultural diversification of the municipalities of Minas Gerais, in order to understand the dynamics of agriculture in the state. Our results show that most of the municipalities (76%) presented a "high" or "very high" diversification, and it can be explained by the strong presence of family farming. However, the share of the gross domestic product (GDP) of these municipalities relative to agriculture activity is relatively low, highlighting that economic sustainability has not been fully achieved yet. In addition to the producer's interest in increasing agricultural diversification, it is important to ensure a rural development public policy fostering diverse agricultural production systems aligned with environmental sustainability standards.*

*Keywords: Agriculture diversification. Simpson Diversity Index. Sustainable landscapes. Governance.*

## 1 INTRODUÇÃO

A demanda por alimentos aumenta à medida que a população mundial vai crescendo, e o cenário previsto para os próximos anos não se mostra animador: a Organização das Nações Unidas (ONU) estima que em 2100 seja alcançada a marca de 11,2 bilhões de pessoas no planeta (ONU, 2017). Essa perspectiva requer que a agricultura assuma uma forma de organização que seja capaz de suprir as necessidades alimentares e econômicas da população.

Nesse contexto, destaca-se o processo de intensificação da agricultura, que visa aumentar a quantidade de alimentos produzida por unidade de área (produtividade), especialmente com o emprego de tecnologias que permitam a produção em larga escala, geralmente utilizando a monocultura como forma de produção. Além da alimentação, as monoculturas destinam-se também à produção de biocombustíveis, cuja produção apresenta aumento ano após ano (IEA, 2019). Considerando apenas a produção brasileira de cana-de-açúcar destinada ao setor sucroenergético, foram colhidos 8,6 milhões de hectares na safra 2018/2019 (BRASIL, 2019), o que corresponde a 85% da área total plantada de cana no País (IBGE, 2019a) e reforça a posição de destaque do agronegócio na economia brasileira.

A expansão para novas áreas agrícolas e a intensificação das áreas já existentes contribuiriam para o aumento da produção que a nova demanda mundial requer (TILMAN et al., 2011). Sabe-se, no entanto, que muitos impactos ambientais estão associados à atividade agrícola, especialmente às monoculturas, como, por exemplo, a degradação dos solos e a eutrofização (KASTNER, M.; KASTNER, T.; NONHEBEL, 2011), perda de biodiversidade (PERFECTO VANDERMEER, 2010), emissão de gases de efeito estufa (GEE) devido às mudanças ocasionadas no uso da terra e à utilização de fertilizantes (BURNEY; DAVIS; LOBELL, 2010), entre outros.

Atualmente, diversas regiões no mundo encontram-se dominadas por monoculturas, sendo que estas substituem ecossistemas que anteriormente eram marcados por uma elevada riqueza de espécies. Dessa forma, a agricultura foi uma das grandes responsáveis por simplificar e homogeneizar diversos ecossistemas em todo o mundo (TILMAN, 1999).

Uma das propostas técnicas para reduzir a simplificação da paisagem é a promoção da diversificação de culturas agrícolas (KASSAM; FRIEDRICH, 2012), que pode ser feita por meio da implantação de duas ou mais atividades agrícolas em uma mesma propriedade rural (SANTANA; FERREIRA; ALENCAR, 2009). A diversificação pode diminuir os riscos da monocultura como principal fonte de renda do produtor e aumentar a sustentabilidade, tanto do ponto de vista econômico quanto do ponto de vista das paisagens naturais. No âmbito da agricultura familiar, existe uma série de vantagens associadas à diversificação da agricultura: o aumento de possibilidades de comercialização ao longo do ano, o resgate de cultivos de produtos tradicionais, o abastecimento da própria família, a ampliação de renda e a melhoria nas condições de vida da família como um todo (BARBOSA et al., 2016; HAAS, 2008).

Michler e Josephson (2017), por exemplo, avaliaram o impacto da diversificação de culturas agrícolas em famílias de regiões mais desfavorecidas na Etiópia, e conseguiram quantificar, pela análise de dados estatísticos oficiais do país, que as que apresentam uma diversificação de culturas em suas propriedades, possuem, em média, menores índices de pobreza. Além disso, verificou-se que a diversificação da produção agrícola reduz a probabilidade de uma família economicamente frágil entrar em situação de pobreza. Em um contexto semelhante, Waha et al. (2018) afirmam que, em âmbito familiar, a diversificação da agricultura é mais bem-sucedida em garantir a segurança alimentar.

O conceito de sustentabilidade tem sido muito discutido e adotado nas questões ambientais nas últimas décadas. No entanto, tem sido pouco utilizado no contexto da paisagem. Paisagens sustentáveis, segundo o Instituto Internacional para Sustentabilidade, são aquelas que assumem o desafio de

“conciliar interesses sociais, econômicos e ecológicos, integrando-os aos processos de planejamento territorial nas diferentes escalas de atuação, seja no meio urbano ou não, nas áreas degradadas ou não” (IIS, 2015, p. 7). Tratando especificamente do meio rural, a sustentabilidade das paisagens visa então estabelecer condições para que a conservação da biodiversidade e o desenvolvimento de atividades produtivas sejam combinados em áreas comuns.

Considerando o contexto da agricultura sustentável e a importância da utilização de indicadores que sejam capazes de avaliar a sustentabilidade no âmbito da paisagem, é necessária a formulação de métricas que sejam capazes de quantificar os aspectos da paisagem relativos às dimensões socioeconômica e ambiental. Como a diversidade da produção agrícola é uma das possibilidades para aumentar a sustentabilidade da paisagem rural, é importante a proposição de indicadores que sejam capazes de avaliar a diversificação da produção agrícola em âmbito municipal.

## 2 AGRICULTURA E DIVERSIFICAÇÃO EM MINAS GERAIS

A agricultura apresenta uma grande relevância no contexto histórico e econômico de Minas Gerais. A sua prática está intimamente relacionada ao desenvolvimento da mineração no estado, a partir do século XVIII, mas inicialmente como atividade de subsistência. A atividade só ganhou uma posição de destaque com o declínio da mineração, quando houve o surgimento de novos mercados para os produtos durante o século XVIII (MINAS GERAIS, 1978).

A agricultura mineira ganhou novamente grande importância no início do período republicano brasileiro, quando a cafeicultura se mostrou como um dos grandes pilares da economia do País. Em um momento posterior, visou-se a diversificação produtiva para consolidar uma agropecuária forte, capaz de sustentar um processo de industrialização vigoroso (GARCIA; ANDRADE, 2007).

No cenário atual, a agricultura ainda apresenta uma grande importância no contexto socioeconômico de Minas Gerais. De acordo com dados do MapBiomas, as áreas destinadas à agricultura apresentaram um aumento significativo em um curto espaço de tempo: passaram de aproximadamente 635.000 ha no ano de 1985 para 3.575.000 ha em 2018 (PROJETO MAPBIOMAS, 2020). Além disso, o PIB do agronegócio foi responsável por 33,5% do PIB total do estado (EMATER, 2018).

Segundo dados do Censo Agropecuário de 2017, o estado possui 607.557 estabelecimentos rurais, perdendo em quantidade apenas para o estado da Bahia. Além disso, esses estabelecimentos ocupam aproximadamente 65% do território mineiro (IBGE, 2019b). A agricultura familiar também exerce grande importância em Minas Gerais: dados do mesmo censo indicam a existência de mais de 440 mil estabelecimentos familiares no estado, o que corresponde a 73% do total de estabelecimentos rurais de Minas Gerais (IBGE, 2019b).

Considerando a relevância da agricultura familiar no cenário mineiro, o estado ganha destaque também quando é analisada a diversificação da produção agrícola. Segundo a pesquisa de Produção Agrícola Municipal (PAM) de 2018, Minas Gerais é o estado que apresenta a maior variedade de culturas (temporárias e permanentes) no País: das 71 analisadas na pesquisa, 52 são encontradas no estado (IBGE, 2019a). No entanto, os efeitos concretos da diversificação ainda não são amplamente compreendidos, de forma que o incentivo para essa prática ainda não alcançou o seu completo potencial.

Dessa forma, este trabalho tem como objetivo quantificar a diversidade produtiva agrícola de cada um dos municípios de Minas Gerais, por meio de um indicador consistente, e avaliar de que forma essa diversidade produtiva agrícola se encontra refletida nos demais indicadores socioeconômicos e ambientais do estado.

## 3 MATERIAIS E MÉTODOS

### 3.1 COLETA DE DADOS

A coleta de dados foi realizada tendo como fonte a pesquisa de Produção Agrícola Municipal (IBGE, 2019a). A primeira etapa consistiu na tabulação da área plantada para cada uma das culturas agrícolas cuja quantidade produzida fosse, no mínimo, uma tonelada e distribuídas em, no mínimo, um hectare. Para tanto, decidiu-se utilizar os valores referentes à média dos anos de 2014 a 2018, com o objetivo de diminuir excepcionais eventualmente verificadas em alguns anos da série histórica. Com esses dados, foi possível calcular o índice de diversidade da produção agrícola para cada município usando o Índice de Simpson, conforme descrito na seção 3.2.

Em seguida, esse dado foi comparado a outras variáveis que permitem delinear o perfil produtivista e conservacionista dos municípios de Minas Gerais. Foram selecionadas as seguintes variáveis:

- Porcentagem de área antropizada por município

A porcentagem de área antropizada mede o grau da intervenção humana nas paisagens. Como a produção agropecuária requer área disponível para seu desenvolvimento, assume-se que o aumento da área antropizada está relacionado ao favorecimento do aspecto produtivista dos municípios. Para tanto, utilizou-se a base de dados da Fundação Brasileira para o Desenvolvimento Sustentável – FBDS (FBDS, 2018).

- Contribuição da agropecuária no Produto Interno Bruto (PIB) municipal

A parcela que a atividade agropecuária adiciona ao PIB municipal é um importante indicador da dimensão desse setor na economia local. Quanto maior o valor, maior é a predominância da atividade, o que mostra um forte caráter produtivista dos municípios. Esse mesmo indicador foi utilizado por Pinto Correia et al. (2016) para avaliar a dimensão produtiva da ocupação humana nos espaços rurais. Para o cálculo desse indicador, foi avaliada a porcentagem do valor adicionado bruto da agropecuária (VAB) sobre o valor total do PIB municipal, relativo ao ano de 2016 (IBGE, 2016).

- Distância média ao vizinho mais próximo (fragmentos florestais)

A distância média do vizinho mais próximo é uma das métricas da paisagem utilizadas para avaliar a fragmentação da paisagem – nesse caso, da classe de florestas. A fragmentação florestal provoca diversas consequências negativas, como a perda de habitats, de biodiversidade, alteração nas interações ecológicas, entre outras (SOUZA et al., 2014). Quanto maior a distância entre os fragmentos, maior o grau de isolamento verificado, o que se mostra prejudicial à conservação da biodiversidade. Neste estudo, a análise da distância média do vizinho mais próximo de fragmentos de áreas florestais foi feita utilizando a base de dados da FBDS (FBDS, 2018). Foi selecionada a classe “formação florestal” para a análise no *software* FRAGSTATS 4.2.1.

- Tamanho médio dos fragmentos florestais

O tamanho médio dos fragmentos florestais é outra métrica da paisagem utilizada para avaliar a fragmentação da paisagem – fragmentos maiores são usualmente melhores para promover a conectividade e a conservação da biodiversidade (VALENTE; VETORAZZI, 2005). É importante destacar, no entanto, que foi considerada a área total do fragmento, incluindo a chamada área de borda. Como a escala de trabalho envolve todos os municípios de Minas Gerais, abrangendo biomas e ecossistemas distintos, julgou-se inadequado assumir um valor único de borda para todas as áreas. Dessa forma, considerou-se apenas o elemento



estrutural da paisagem, sem considerar o aspecto funcional. A análise do tamanho médio dos fragmentos de áreas florestais foi feita utilizando, novamente, a base de dados da FBDS. Foi selecionada a classe “formação florestal” para a análise no *software* FRAGSTATS 4.2.1.

- Porcentagem de APPs ripárias por município

As Áreas de Proteção Permanente são instituídas por meio de dispositivos legais, segundo critérios previamente estabelecidos (BRASIL, 2012). Dessa forma, as APPs foram adotadas como um critério na avaliação do perfil conservacionista dos municípios por ser um fator comum a todos eles. As APPs dos municípios mineiros foram obtidas na base de dados da FBDS. Essas áreas abrangem apenas as APPs ripárias, tendo sido calculada a porcentagem de APPs dentro da área do município.

### 3.2 CÁLCULO DO ÍNDICE DE DIVERSIDADE PRODUTIVA DOS MUNICÍPIOS

A partir dos valores encontrados, calculou-se a diversidade produtiva de cada um dos municípios por meio do Índice de Diversidade de Simpson (*Simpson Index of Diversity – SID*) (SIMPSON, 1949), utilizando a seguinte relação:

$$SID = 1 - \sum_{i=1}^N \left( \frac{X_i}{\sum_{i=1}^N X_i} \right)^2$$

Onde:  $X_i$  = área ocupada por cada produto e N = número de produtos agrícolas produzidos no município que ocupam mais de um hectare e cuja quantidade excede uma tonelada.

Esse índice varia de 0 a 1, sendo 0 o município que apresenta apenas um tipo de produção agrícola, e aumenta até o valor de 1 conforme aumenta a diversidade.

Os valores obtidos para cada município foram associados a uma base de dados geográfica (*shapefile* de municípios de Minas Gerais elaborado pelo IBGE), de forma a gerar um mapa de diversidade agrícola.

Os municípios foram agrupados em cinco classes distintas previamente determinadas:

- Diversificação muito baixa:  $SID \leq 0,20$ ;
- Diversificação baixa:  $SID > 0,20$  e  $\leq 0,40$ ;
- Diversificação média:  $SID > 0,40$  e  $\leq 0,60$ ;
- Diversificação alta:  $SID > 0,60$  e  $\leq 0,80$ ;
- Diversificação muito alta:  $SID > 0,80$ .

### 3.3 ANÁLISE ESTATÍSTICA

Primeiramente, verificou-se a normalidade dos dados trabalhados, por meio da aplicação do teste de *Kolmogorov-Smirnov*. Após essa verificação, foram calculadas as estatísticas descritivas dos dados e também a correlação entre a diversidade produtiva agrícola e as demais variáveis analisadas. Todas as análises foram desenvolvidas no *software* estatístico SPSS 19.

## 4 RESULTADOS E DISCUSSÃO

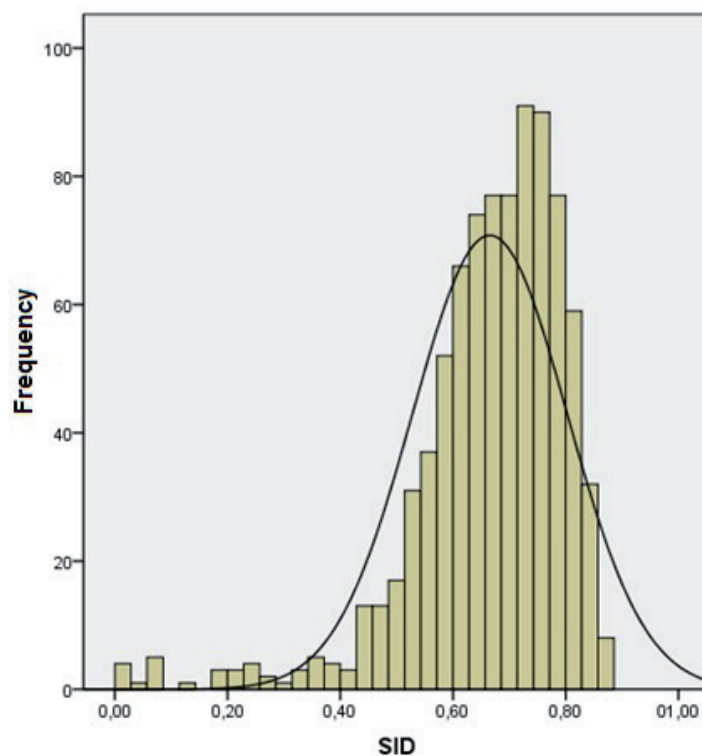
A Tabela 1 mostra os valores obtidos na análise de estatística descritiva realizada no *software* SPSS, enquanto a Figura 1 mostra a distribuição dos valores calculados para o índice de diversidade produtiva agrícola.

**Tabela 1** | Estatística descritiva das variáveis analisadas

| Variável                                      | Número de ocorrências | Valor mínimo | Valor máximo | Média | Desvio Padrão |
|---|-----------------------|--------------|--------------|-------|---------------|
| SID   | 853                   | 0,00         | 0,88         | 0,66  | 0,13          |
| CONTRIBUIÇÃO DA AGROPECUÁRIA NO PIB MUNICIPAL | 853                   | 0,00         | 0,72         | 0,17  | 0,12          |
| PORCENTAGEM DE ÁREA ANTROPIZADA               | 853                   | 0,09         | 0,94         | 0,67  | 0,16          |
| ÁREA MÉDIA DAS MANCHAS (HA)                   | 853                   | 1,02         | 70,30        | 6,32  | 5,53          |
| DISTÂNCIA DO VIZINHO MAIS PRÓXIMO (M)         | 853                   | 25,40        | 246,64       | 62,76 | 22,85         |
| PORCENTAGEM DE APPS RIPÁRIAS                  | 853                   | 0,01         | 0,61         | 0,11  | 0,05          |

Fonte: Elaborada pelas autoras.

Conforme os resultados das variáveis socioeconômicas apresentadas na Tabela 1, a contribuição da atividade agropecuária no PIB municipal dos 853 municípios mineiros varia de 0 a 72%, enquanto a área antropizada varia de 0,9 a 94%. Em relação aos resultados de métricas da paisagem, a Tabela 1 mostra que a área média das manchas de floresta varia de 1 a 70,3 hectares, sendo a média e o desvio padrão 6,32 e 5,53, respectivamente. Já em relação à distância média do vizinho mais próximo entre fragmentos florestais, os valores médios por município variam entre 25 e 246 metros. Por fim, a Tabela 1 mostra que, em média, municípios mineiros têm 11% do seu território em área de APP ripária.



**Figura 1** | Distribuição dos valores calculados para a diversidade produtiva agrícola.

Fonte: Elaborada pelas autoras

Ainda de acordo com a Tabela 1, a média e o desvio padrão do índice de diversidade produtiva agrícola dos 853 municípios de Minas Gerais é de  $0,66 \pm 0,13$ . Após o cálculo do índice para cada um dos municípios, verificou-se que 1,6% dos municípios mineiros são classificados com uma diversidade produtiva muito baixa, 2,6% como diversificação baixa, 19,5% como diversificação média, 64,7% como diversificação alta e 11,6% apresentam diversificação muito alta.

A Figura 2 mostra o mapa com a classificação da diversidade produtiva dos municípios de Minas Gerais. Entre os municípios classificados como muito pouco diversificados, verifica-se uma forte concentração na região do Triângulo Mineiro. Isso pode ser explicado pela exploração do agronegócio que acontece na região, desenvolvida por empresários rurais de médio e grande porte e que fazem uso intensivo de tecnologia, o que permitiu tornar essa região agrícola como a mais dinâmica e desenvolvida do estado (BASTOS; GOMES, 2011). Os demais municípios encontram-se dispersos em diversas regiões do estado, sendo que uma possível explicação para a baixa diversificação pode estar relacionada ao fato de a agropecuária não ser uma das principais atividades econômicas desenvolvidas nessas áreas, de acordo com dados sobre o Produto Interno Bruto (PIB) municipal (IBGE, 2016). Nesse grupo destaca-se o município de Belo Horizonte, capital do estado, onde não foi verificada nenhuma informação de produção agrícola, de forma que o índice calculado assumiu o valor zero.

Fatores geográficos podem ser também uma explicação para os diferentes níveis de diversificação verificados no estado. Observa-se, por exemplo, na região intermediária de Juiz de Fora (que abrange parte da antiga Zona da Mata) uma forte concentração de municípios classificados com uma diversificação mediana. Isso pode ser explicado pelo relevo acidentado com encostas íngremes presentes na região, o que pode ser considerado um obstáculo à produção agrícola, sendo as zonas mais férteis limitadas aos vales da região (BASTOS; GOMES, 2011).

As duas categorias de municípios com maiores valores para o índice de diversidade abrangem 651 municípios (76,3% do total de municípios de Minas Gerais), que se encontram homogênea e distribuídos no estado. Esses resultados reforçam a importância de Minas Gerais no cenário agrícola brasileiro, e indicam também a relevância da agricultura familiar no estado, visto que a diversificação é uma prática intrinsecamente associada a essa modalidade de produção.

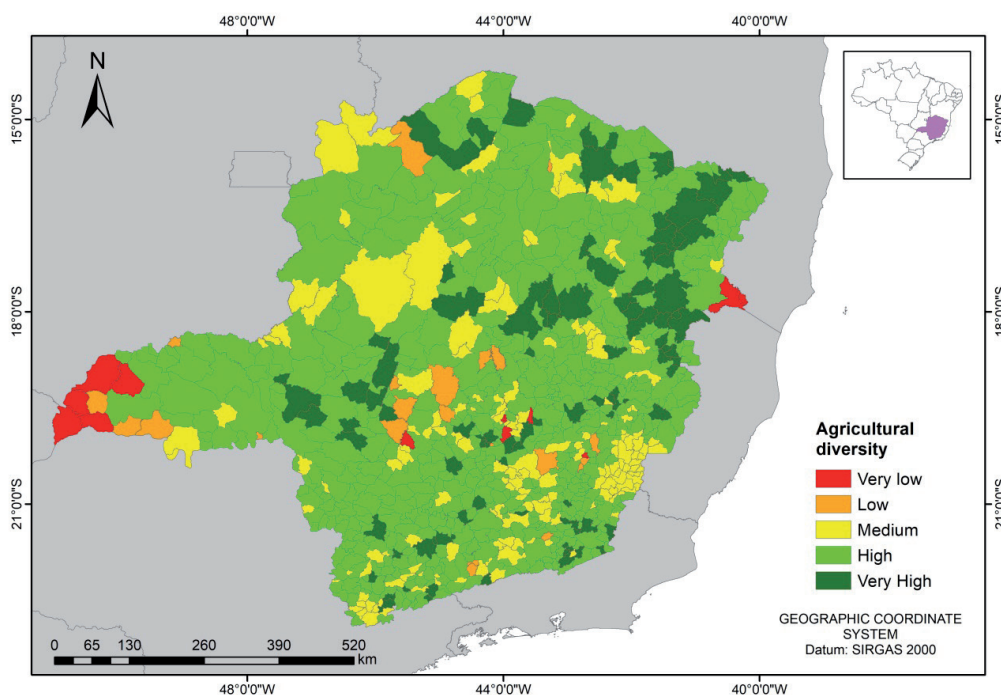


Figura 2 | Diversidade produtiva no estado de Minas Gerais.

Fonte: Elaborada pelas autoras

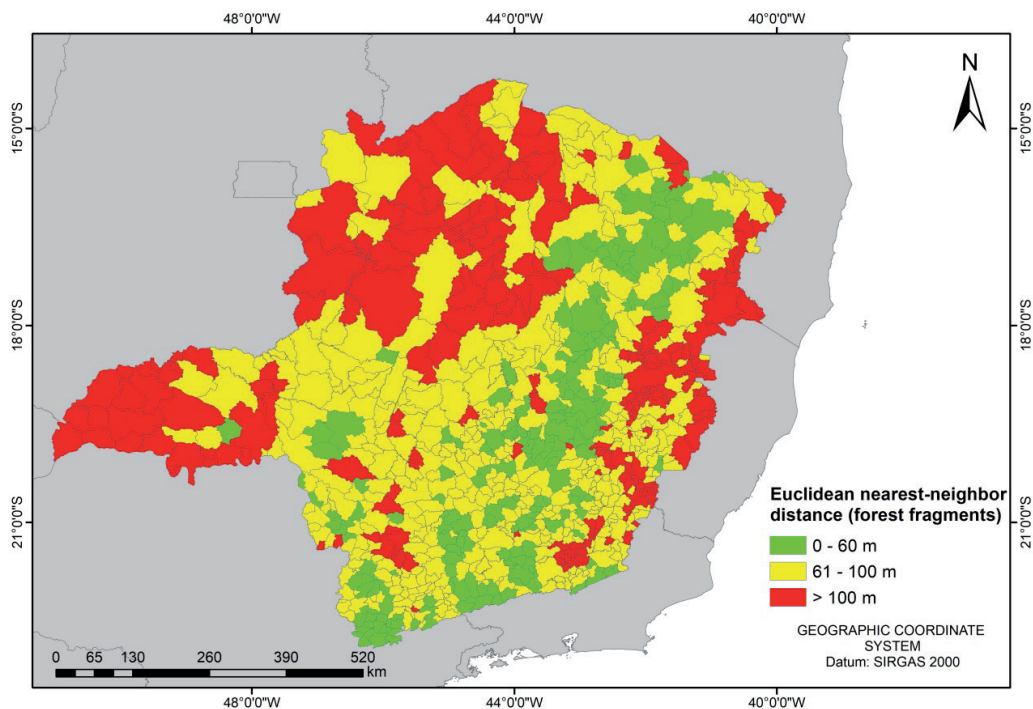
É importante compreender, todavia, de que forma a diversidade produtiva encontra-se refletida em aspectos produtivistas e de conservação no estado. Para tanto, procedeu-se à análise estatística, onde foi verificado que os dados não seguem a distribuição normal, o que implica na escolha do coeficiente de correlação de *Spearman* para verificar qual a relação entre as variáveis. O resultado da análise de correlação encontra-se no Anexo 1.

No caso dos dados trabalhados, não foi verificada uma correlação significativa ( $\alpha = 0,05$ ) entre o índice de diversidade produtiva e as variáveis: área média das manchas florestais, porcentagem de APPs ripárias, contribuição da agropecuária no PIB municipal e porcentagem de áreas antropizadas no município.

A única correlação significativa obtida, entre as variáveis analisadas, foi em relação à variável “distância média do vizinho mais próximo (para fragmentos florestais)”. Verificou-se que o aumento do índice de diversificação está relacionado à diminuição da distância média do vizinho mais próximo entre os fragmentos florestais, como mostra o valor negativo para a correlação (-0,073).

Ainda que o valor obtido não seja muito elevado, esse resultado pode ser considerado um indicativo de que a diversificação produtiva pode estar positivamente associada ao aumento da conectividade entre fragmentos florestais (sem considerar grupos focais específicos), o que, por sua vez, favorece a conservação da biodiversidade. O Anexo 2 mostra a diferença entre as médias das variáveis analisadas para cada um dos cinco grupos de diversificação agrícola, e é possível verificar a redução da distância média conforme o grau de diversificação aumenta.

O mapa apresentado na Figura 3 mostra como os municípios se comportam em relação à variável “distância média do vizinho mais próximo entre fragmentos florestais”. Quanto menor for a distância média do vizinho mais próximo entre os fragmentos florestais remanescentes, maior a probabilidade de acontecer a conservação da biodiversidade, visto que o isolamento dos fragmentos tem um efeito negativo sobre a riqueza de espécies, diminuindo a taxa (potencial) de imigração ou recolonização (ALMEIDA, 2008). Com isso, verifica-se um aumento da sustentabilidade da paisagem, porém, apenas do ponto de vista ecológico.



**Figura 3 |** Distribuição espacial da variável “distância média do vizinho mais próximo entre fragmentos florestais”.

Fonte: Elaborada pelas autoras

De uma maneira geral, verifica-se que o aumento da diversidade produtiva impacta positivamente a paisagem em termos de conservação; no entanto, quando avaliado o aspecto social da paisagem, relacionado à produção agrícola e à renda dela gerada, a diversidade produtiva ainda não exerce uma influência significativa no sentido de melhorar os índices econômicos, que refletem diretamente na questão da sustentabilidade econômica.

É importante destacar que, neste trabalho, tratou-se exclusivamente da aplicação do conceito de diversidade agrícola, ao passo que outro conceito é importante para explicar a dinâmica produtiva do meio rural: trata-se da diversificação rural, que consiste em aliar, além das atividades agrícolas, outras atividades não agrícolas, de forma a explorar todas as potencialidades que a propriedade/região possui. Alguns autores (SILVA, 2001 apud SANTANA; FERREIRA; ALENCAR, 2009) pontuam que a diversificação da agricultura por si só não é capaz de promover o incremento de renda suficiente para reduzir a dependência dos produtores em relação aos mercados locais de trabalho, o que pode justificar a baixa correlação entre o índice de diversidade agrícola e as variáveis de natureza econômica.

Ainda que a diversificação agrícola tenha o produtor como um dos principais atores sociais, destaca-se que o sucesso dessa ação não depende exclusivamente dele. É necessário que haja uma política de desenvolvimento rural associada, de forma que seja possível gerar uma cadeia complexa de interações recíprocas entre todos os eixos (crédito, pesquisa agrícola, assistência técnica e extensão rural), garantindo assim o acesso à terra e a tecnologias para a produção e o manejo sustentável de seus estabelecimentos (BITTENCOURT, 2002 apud SANTANA; FERREIRA; ALENCAR, 2009). Assim, fica evidente que o alcance da sustentabilidade das paisagens por meio da diversificação agrícola deve ser fruto das ações de diversos setores da sociedade, tendo a esfera pública (governos municipais e estadual) um papel fundamental para a consolidação da diversidade produtiva agrícola.

## 5 CONCLUSÃO

O desenvolvimento de estratégias de sustentabilidade em áreas rurais tem se mostrado um grande desafio, pois o conceito de sustentabilidade da paisagem tem tido dificuldades em assumir um papel relevante, dada a complexidade inerente ao processo de gestão da paisagem. Um dos diversos desafios é o desenvolvimento de métricas para acompanhar o progresso e permitir o gerenciamento das paisagens.

Ao longo deste trabalho foi desenvolvido o índice de diversidade produtiva agrícola, que pretendeu ranquear os municípios de Minas Gerais em relação à sua diversidade produtiva agrícola. Verificou-se que a maior parte dos municípios mineiros (76,3%) foi classificada com uma diversidade produtiva agrícola alta ou muito alta, o que confirma a posição do estado como o mais diversificado do País.

No entanto, essa diversificação ainda não se encontra plenamente refletida em indicadores econômicos e ambientais, o que mostra que ainda há uma necessidade de implementar uma série de ações que sejam, de fato, voltadas para garantir a sustentabilidade das paisagens, tanto no aspecto ambiental quanto econômico. Considerando que cada município apresenta uma realidade particular, com problemas e pontos fortes que não são necessariamente verificados em todos os casos, é desejável que sejam elaborados diferentes portfólios de políticas públicas, que sejam direcionados à realidade local e que garantam o envolvimento de todos os atores sociais, a fim de gerar resultados duradouros.

## AGRADECIMENTOS

A primeira autora agradece à Fundação de Amparo à Pesquisa de Minas Gerais (Fapemig) pela concessão da bolsa de mestrado. A segunda autora agradece ao Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) pela bolsa de produtividade em pesquisa.

## REFERÊNCIAS

- ALMEIDA, C. G. **Análise espacial dos fragmentos florestais na área do Parque Nacional dos Campos Gerais, Paraná**. 2008. Dissertação (Mestrado em Gestão do Território) – Universidade Estadual de Ponta Grossa, Paraná. Ponta Grossa, PR.
- BARBOSA, P. J. F. et al. A importância da diversificação agrícola como complemento na renda familiar na região de Manhuaçu – MG. **Revista do CCEI**, v. 20, n. 35, 2016.
- BASTOS, S. Q. DE A.; GOMES, J. E. Dinâmica da agricultura no estado de Minas Gerais. **Ruris**, v. 5, n. 2, p. 45-76, 2011.
- BRASIL. **Lei 12.651/2012**. Dispõe sobre a proteção da vegetação nativa. Brasília, DF. Brasil. Constituição da República Federativa do Brasil de 1988. Brasília, DF.
- BRASIL. Ministério de Minas e Energia. **Análise de conjuntura dos biocombustíveis – ano 2018**. Empresa de Pesquisa Energética – EPE. Rio de Janeiro, 2019.
- BURNEY, J. A.; DAVIS, S. J.; LOBELL, D. B. Greenhouse gas mitigation by agricultural intensification. **Proc. Natl. Acad. Sci. USA**, v. 107, p. 12052–12057, 2010.
- EMPRESA DE ASSISTÊNCIA TÉCNICA E EXTENSÃO RURAL DO ESTADO DE MINAS GERAIS. **Balanco do Governo de Minas apresenta o crescimento e a diversidade da agricultura do estado**. 2018. Disponível em: <[http://www.emater.mg.gov.br/portal.cgi?flagweb=novosite\\_pagina\\_interna&id=22669](http://www.emater.mg.gov.br/portal.cgi?flagweb=novosite_pagina_interna&id=22669)>. Acesso em: 04 out. 2018.
- FUNDAÇÃO BRASILEIRA PARA O DESENVOLVIMENTO SUSTENTÁVEL. **Mapeamento em Alta Resolução dos Biomas Brasileiros – Metodologia**. 2018. Disponível em: <<http://geo.fbd.org.br/Metodologia.pdf>>. Acesso em: 24 set. 2018.
- GARCIA, J. R.; ANDRADE, D. C. Panorama geral da industrialização de Minas Gerais (1970-2000). **Leituras de Economia Política**, Campinas, n. 12, 2007.
- HAAS, J. M. Diversificação de Produção no Meio Rural como Estratégia de Sobrevivência: um estudo de caso da região noroeste do Rio Grande do Sul. In: **Encontro Nacional da Anppas**, 4, 2008, Brasília.
- INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Produto Interno Bruto dos Municípios**. 2016. Disponível em: <<https://www.ibge.gov.br/estatisticas/economicas/contas-nacionais/9088-produto-interno-bruto-dos-municipios.html?=&t=downloads>>. Acesso em: 26 jun. 2019.
- INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Censo Agro 2017**. 2019a. Disponível em: <<https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2017>>. Acesso em: set. 2019.
- INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Produção Agrícola Municipal (PAM): culturas temporárias e permanentes**. 2019b. Disponível em: <<https://sidra.ibge.gov.br/pesquisa/pam/tabelas>>. Acesso em: nov. 2019.
- INSTITUTO INTERNACIONAL PARA A SUSTENTABILIDADE. **Paisagens Sustentáveis: integrando desenvolvimento rural e conservação ambiental**. 2015. Disponível em: <[http://www.iis-rio.org/media/archives/Relatorio\\_Workshop\\_Paisagens\\_Sustentaveis\\_IIS\\_2015.pdf](http://www.iis-rio.org/media/archives/Relatorio_Workshop_Paisagens_Sustentaveis_IIS_2015.pdf)>. Acesso em: 20 abr. 2019.
- INTERNATIONAL ENERGY AGENCY. **Biofuels for transport**. 2019. Disponível em: <<https://www.iea.org/tcep/transport/biofuels/>>. Acesso em: 02 abr. 2019.
- KASSAM, A.; FRIEDRICH, T. An ecologically sustainable approach to agricultural production intensification: global perspectives and developments. **Field Actions Science Report**, special issue 6, 2012.
- KASTNER, T.; KASTNER, M.; NONHEBEL, S. Tracing distant environmental impacts of agricultural products from a consumer perspective. **Ecological Economics**, v. 70, p. 1032-1040, 2011.
- MICHLER, J. D.; JOSEPHSON, A. L. To Specialize or Diversify: agricultural diversity and poverty dynamics in Ethiopia. **World Development**, v. 89, p. 214-226, 2017.

MINAS GERAIS. **A agropecuária mineira: sua história, sua evolução.** 1978, 146 p.

ORGANIZAÇÃO DAS NAÇÕES UNIDAS. **World Population Prospects 2017.** 2017. Disponível em: <<https://population.un.org/wpp/DataQuery/>>. Acesso em: 30 mar. 2019.

PERFECTO, I.; VANDERMEER, J. The agroecological matrix as alternative to the land-sparing/agriculture intensification model. **Proc. Natl. Acad. Sci. USA**, v. 107, p. 5786–5791, 2010.

PROJETO MAPBIOMAS. **Coleção 4.1 da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil.** 2020. Disponível em: <<http://mapbiomas.org/map#coverage>>. Acesso em: 06 jun. 2020.

SANTANA, A. C.; FERREIRA, P. A.; ALENCAR, E. Diversificação da Agricultura Familiar no Sul de Minas Gerais: uma análise da percepção de professores e pesquisadores. **Sociedade Brasileira de Economia, Administração e Sociologia Rural**, p. 2-4, 2009.

SIMPSON, E. H. Measurement of diversity. **Nature**, v. 163, p. 688, 1949.

SOUZA, C. G. et al. Análise da fragmentação florestal da área de proteção ambiental Coqueiral, Coqueiral – MG. **Ciência Florestal**, v. 24, n. 3, p. 631-644, 2014.

TILMAN, D. et al. Global food demand and the sustainable intensification of agriculture. **Proc. Natl. Acad. Sci. USA**, v. 108, p. 20260–20264, 2011.

TILMAN, D. Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. **Proc. Natl. Acad. Sci. USA**, v. 96, p. 5995–6000, 1999.

VALENTE, R. O. A.; VETTORAZZI, C. A. Comparação entre métodos de avaliação multicriterial, em ambiente SIG, para a conservação e a preservação florestal. **Scientia Forestalis**, n. 69, p. 51-61, 2005.

WAHA, K. et al. Agricultural diversification as an important strategy for achieving food security in Africa. **Global Change Biology**, v. 24, n. 8, 2018.

## ANEXO 1 – ANÁLISE DE CORRELAÇÃO ENTRE VARIÁVEIS

|                |   | Correlations            |                             |   |                 |                           |                    |         |
|----------------|---|-------------------------|-----------------------------|---|-----------------|---------------------------|--------------------|---------|
|                |   | SID                     | Área Média das Manchas (ha) | Distância Média Fragmentos Florestais (m) | % APPs hídricas | Contrib. Agropecuária PIB | % Área Antropizada |         |
| SPEARMAN'S RHO | SID                                       | Correlation Coefficient | 1,000                       | ,003                                      | -,073*          | -,063                     | -,055              | -,056   |
|                |   | Sig. (2-tailed)         | .                           | ,928                                      | ,034            | ,068                      | ,107               | ,101    |
|                |   | N                       | 853                         | 853                                       | 845             | 853                       | 853                | 853     |
|                | ÁREA MÉDIA DAS MANCHAS (HA)               | Correlation Coefficient | ,003                        | 1,000                                     | -,168**         | -,107**                   | -,189**            | -,558** |
|                |   | Sig. (2-tailed)         | ,928                        | .   | ,000            | ,002                      | ,000               | ,000    |
|                |   | N                       | 853                         | 853                                       | 845             | 853                       | 853                | 853     |
|                | DISTÂNCIA MÉDIA FRAGMENTOS FLORESTAIS (M) | Correlation Coefficient | -,073*                      | -,168**                                   | 1,000           | -,092**                   | ,111**             | ,533**  |
|                |   | Sig. (2-tailed)         | ,034                        | ,000                                      | .               | ,007                      | ,001               | ,000    |
|                |   | N                       | 845                         | 845                                       | 845             | 845                       | 845                | 845     |
|                | % APPS HÍDRICAS                           | Correlation Coefficient | -,063                       | -,107**                                   | -,092**         | 1,000                     | -,134**            | ,040    |
|                |   | Sig. (2-tailed)         | ,068                        | ,002                                      | ,007            | .                         | ,000               | ,242    |
|                |   | N                       | 853                         | 853                                       | 845             | 853                       | 853                | 853     |
|                | CONTRIB. AGROPECUÁRIA PIB                 | Correlation Coefficient | -,055                       | -,189**                                   | ,111**          | -,134**                   | 1,000              | ,165**  |
|                |   | Sig. (2-tailed)         | ,107                        | ,000                                      | ,001            | ,000                      | .                  | ,000    |
|                |   | N                       | 853                         | 853                                       | 845             | 853                       | 853                | 853     |
|                | % ÁREA ANTROPIZADA                        | Correlation Coefficient | -,056                       | -,558**                                   | ,533**          | ,040                      | ,165**             | 1,000   |
|                | Sig. (2-tailed)                           | ,101                    | ,000                        | ,000                                      | ,242            | ,000                      | .                  |         |
|                | N   | 853                     | 853                         | 845                                       | 853             | 853                       | 853                |         |

\*. Correlation is significant at the 0.05 level (2-tailed).

\*\* . Correlation is significant at the 0.01 level (2-tailed).

Fonte: Elaborado pelas autoras.



## ANEXO 2 – ESTATÍSTICA DESCRITIVA DAS VARIÁVEIS ANALISADAS POR GRUPO DE DIVERSIFICAÇÃO

| <i>Diversidade Produtiva</i> |               | <i>Área média dos fragmentos florestais (ha)</i> | <i>Distância média do vizinho mais próximo (fragmentos florestais) (m)</i> | <i>% APPs hídricas por município</i> | <i>Contribuição da agropecuária no PIB municipal (%)</i> | <i>% área antropizada por município</i> | <i>Número de culturas (unid.)</i> |
|------------------------------|---------------|--|--|--------------------------------------|--|---|-----------------------------------|
| MUITO BAIXA                  | MÉDIA         | 5.43   | 100.11   | 8.41                                 | 13.69  | 69.36                                   | 7.64                              |
|                              | MEDIANA       | 5.84   | 117.84   | 7.17                                 | 9.24   | 81.96                                   | 8.00                              |
|                              | DESVIO PADRÃO | 2.12   | 47.01  | 3.94                                 | 13.79  | 23.99                                   | 5.06                              |
| BAIXA                        | MÉDIA         | 5.28   | 72.03  | 10.89                                | 20.61  | 73.17                                   | 11.27                             |
|                              | MEDIANA       | 4.38   | 63.51  | 11.32                                | 18.79  | 78.96                                   | 11.00                             |
|                              | DESVIO PADRÃO | 3.22   | 24.84  | 5.66                                 | 12.87  | 15.20                                   | 5.62                              |
| MÉDIA                        | MÉDIA         | 5.80   | 64.33  | 12.68                                | 17.50  | 69.02                                   | 11.21                             |
|                              | MEDIANA       | 4.76   | 59.02  | 13.16                                | 17.18  | 71.98                                   | 11.00                             |
|                              | DESVIO PADRÃO | 3.36   | 23.93  | 4.07                                 | 11.31  | 13.56                                   | 4.64                              |
| ALTA                         | MÉDIA         | 6.29   | 61.43  | 11.47                                | 17.24  | 67.23                                   | 13.86                             |
|                              | MEDIANA       | 4.79   | 57.06  | 11.23                                | 15.15  | 71.62                                   | 13.00                             |
|                              | DESVIO PADRÃO | 5.61   | 21.00  | 4.87                                 | 11.73  | 16.27                                   | 4.95                              |
| MUITO ALTA                   | MÉDIA         | 7.72   | 60.13  | 11.86                                | 16.11  | 62.85                                   | 15.36                             |
|                              | MEDIANA       | 5.53   | 53.64  | 11.02                                | 12.26  | 68.95                                   | 15.00                             |
|                              | DESVIO PADRÃO | 8.00   | 20.65  | 7.07                                 | 13.32  | 20.13                                   | 4.52                              |

Fonte: Elaborado pelas autoras.

# Non-Timber Forest Products (NTFP) in the Brazilian Amazon and Cerrado biomes: multi scale governance for Implementing enhanced socio-biodiversity chains

*Produtos florestais não madeireiros (PFNM) nos biomas  
da Amazônia brasileira e do Cerrado: governança  
multiescala para implementação de cadeias da  
sociobiodiversidade*

Sónia Maria Carvalho Ribeiro<sup>a</sup>

Helder Lages Jardim<sup>b</sup>

Úrsula Ruchkys de Azevedo<sup>c</sup>

Vagner Coelho<sup>d</sup>

Laura Salles Bachi<sup>e</sup>

Britaldo Soares-Filho<sup>f</sup>

<sup>a</sup>Doutora em Ciências do Ambiente, University of East Anglia, Inglaterra, Professora do Departamento de Cartografia, Universidade Federal de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil.  
E-mail: sonia.carvalhoribeiro@gmail.com

<sup>b</sup>Doutor em Geografia Física, Universidade Federal do Rio de Janeiro, UFRJ, Professor Associado do Instituto de Geociências, Universidade Federal de Minas Gerais – UFMG, Belo Horizonte, MG, Brasil.  
E-mail: hljardim@gmail.com

<sup>c</sup>Doutora em Geologia, Universidade Federal de Minas Gerais – UFMG, Professora Associada do Programa de Pós-graduação em Geografia e em Análise e Modelagem de Sistemas Ambientais, UFMG, Belo Horizonte, MG, Brasil.  
E-mail: tularuchkys@yahoo.com.br

<sup>d</sup>Doutor em Engenharia de Sistemas e Computação, Universidade Federal do Rio de Janeiro - UFRJ, Professor do Departamento de Cartografia, Universidade Federal de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil.  
E-mail: vagnercoelho@hotmail.com

<sup>e</sup>Doutoranda do Programa de Pós-graduação em Análise e Modelagem de Sistemas Ambientais, UFMG, Belo Horizonte, MG, Brasil.  
E-mail: bachilaura@gmail.com

<sup>f</sup>Doutor em Engenharia de Transportes, Universidade de São Paulo – USP, Professor do Departamento de Cartografia, Universidade Federal de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil.  
E-mail: britaldosf@gmail.com

doi:10.18472/SustDeb.v11n2.2020.28393

Received: 29/11/2019  
Accepted: 02/04/2020

ARTICLE- DOSSIER

## ABSTRACT

Non-Timber Forest Products (NTFP), contribute to the livelihoods of over 6 million people in Amazon and over 4 million people in the Cerrado biomes. Here we explored data on the socio-ecology of extractivist landscapes at the biome scale in Amazonia and Cerrado in Brazil. We found that there are market chains for 45 and 58 NTFPs in Brazilian Amazon and Cerrado, respectively. Although there is a vast repertoire of empirical data for characterizing sociobiodiversity in Brazil this body of literature is mostly case-study driven, focusing on a very limited number of products and using different methodological approaches. Therefore, although there is a robust research legacy meaningful comparisons are very challenging. So far we have a fragmented view of vegetal extractivist dynamics at the biome scale. Our work contributes to upscale from the socioecology of individual NTFP to the biome scale encompassing a variety of products and its associated livelihoods.

**Keywords:** Extractivist landscapes. Socio-Ecological Systems. Sustainable use. Sociobiodiversity.

## RESUMO

*Os produtos florestais não madeireiros (PFNM) contribuem para a subsistência de mais de 6 milhões de pessoas nos biomas da Amazônia e mais de 4 milhões de pessoas do Cerrado. Aqui exploramos dados sobre a socioecologia de paisagens extrativistas nos biomas da Amazônia e Cerrado no Brasil. Descobrimos que existem cadeias de mercado para 45 e 58 PFNM na Amazônia brasileira e no Cerrado, respectivamente. Embora exista um vasto repertório de dados empíricos para caracterizar a sociobiodiversidade no Brasil, a literatura sobre este tema é principalmente orientada por estudos de caso, concentrando-se em um número muito limitado de produtos e utilizando diferentes abordagens metodológicas. Portanto, embora exista um legado de pesquisa robusto, as comparações significativas são muito desafiadoras. Até agora, temos uma visão fragmentada da dinâmica extrativista vegetal na escala do bioma. Nosso trabalho contribui para melhorar a escala individual da socioecologia de PFNM para a escala do bioma, abrangendo uma variedade de produtos e seus meios de subsistência associados.*

**Palavras-chave:** Paisagens extrativistas. Sistemas Socioecológicos. Uso Sustentável. Sociobiodiversidade.

## 1 INTRODUCTION

Cerrado and Amazon biodiversity in Brazil live together with a variety of sociocultural groups: over 644,000 families of ribeirinhos<sup>1</sup> agro-extractivists, 204 indigenous tribes of over 605,000 families and over 4,500 families of Quilombolas<sup>2</sup>, creating a rich cultural heritage, singular Traditional Ecological Knowledge (TEK), and skilled traditional abilities. In Brazil, these traditional communities' use and trade raw materials of surrounding Amazon forests and Cerrado biomes as part of their livelihoods. These raw materials thereafter referred to as Non Timber Forest Products (NTFP), have been for centuries contributing to traditional livelihoods both for family consumption and trade. Despite decades of a prolonged debate on the role of the Non Timber Forest Products (NTFP) in contributing to traditional livelihoods as well as to reduce deforestation (PETERS, GENTRY et al. 1989, HUMPHRIES, HOLMES et al. 2012) a number of paradoxes remain. Historically, the appeal of these products (e.g. rubber) as an development option has faded with failure as was the utopian case of Fordlandia (Grandin 2010). The linkages between extractivist activities and conservation of biodiversity is fragile (Homma 2008), and a number of threats remain for example to the sustainability of Brazil nut collection (Peres, Baider et al. 2003).

Although acknowledging the challenges involved on the use and trade of NTFP, still nowadays, those products contribute to the livelihoods of over 6 million people in Amazon and over 4 million people<sup>3</sup> in the Cerrado biomes. These traditional livelihoods in addition to collection of NTFP also include small

scale farming and agro husbandry. One of the problems is that those products that are part of traditional livelihoods are associated to a lower capacity to generate household income. Often, as extractivist products enter the world market as “commodities”, the market value of these raw-materials collected in native Amazonian forests or cerrado savannas is low, when compared from estimates based in local markets (Peters, Gentry et al. 1989). Moreover rents from extractivist activities of NTFP are eclipsed either by products originating in intensive cultivation processes in other parts of the world (e.g. rubber monocultures in China) or by other higher income activities such as cattle ranching associated to deforestation (e.g. cattle grazing) and “cowboy” imagery (Carvalho Ribeiro, Soares Filho et al. 2018).

Aware of the limitations on keeping native vegetation standing while contributing to socio ecological developments, Government policies and civil society alike, often in collaboration to International players (such as World Bank, FAO, European Union) have been encouraging management plans for those products to both conserve native vegetation and ensuring traditional livelihoods. In most of the cases, the development of management plans (for example of sustainable use reserves), is based on bottom up participatory processes involving traditional communities often associating to programs of Payment for Ecosystem Services (PES) (Wunder, Angelsen et al. 2014). In parallel, for overcoming this “NTFP market failure”, raw materials and low-processed products collected and traded by extractivists have been nurtured by governments’ worldwide and civil society alike. These products were awarded in 2009 as formal recognition of Brazilian Socio-biodiversity (MMA 2009). Despite decades of public investment and very rich body of “local” case studies and participatory management plans, little is yet known as how to frame governance arrangements for extractivist landscapes in biomes such as Amazonia and Cerrado.

This work aims at exploring and draws a reflection on possible ways for framing governance for traditional extractivist livelihoods in biomes such as Amazonia and Cerrado. This paper explores possible multiscale governance strategies that may contribute to overcome the dilemmas of extractivist activities in Brazil. This work advances the state of the art by including non-material goods associated with these products, for example, landscape identity and traditional local knowledge (TEK Traditional Ecological Knowledge) through its association with cultural ecosystem (Carvalho Ribeiro, Soares Filho et al. 2018).

The results present the characterization and mapping of the sociobiodiversity associated to vegetal extractivism in the Brazilian Amazon and Cerrado using a unique conceptual model of the Multilevel Perspective [6]. According to the typology of Sociotechnical Transitions (Geels & Schot, 2007), we consider the diversity of products in each biome as a socio technical regime (Figure 1). Following this framework, each biome is considered as a socio technical regime with its diversity of products, however to analyze its diversity of production systems we will explore only two products in each biome. We particularly focus on four NTFP, two in Cerrado and two in Amazon biomes. One product is of wide and another narrow scope in terms of geographical distribution. Our major goal is to specify which governance mechanisms (bottom up and top down) can improve the transition to sustainability in extractivist landscapes in two of the most emblematic biomes in Brazil.

The questions we address are as follows:

- I. Which sources of literature refer to the diversity of NTFPs in Cerrado and Amazon?
- II. Which are major characteristics of the Amazon and Cerrado socio technical regimes concerning: Productive cycles species/productivity (tons per ha), seasonality, Markets, Technology used Norms & Politics, Traditional Ecological Knowledge (TEK) associated and Science, research & development
- III. Which multiscale governance mechanism can lead extractivist landscapes in Amazon and Cerrado biomes towards sustainability?

## 2 METHODS

### 2.1 CONCEPTUAL FRAMEWORK

We use a unique conceptual model of the Multilevel Perspective for analyzing Amazon and Cerrado Biomes. According to the typology of Socio-Technical Transitions (Geels 2011, Geels & Schot, 2007), we consider the diversity of products in each biome as a socio technical regime (Figure 1). At the bottom of the socio technical regime, and in order to transform the socio technical regime to a more sustainable state, there might be niche innovations that may lead the regime to a sustainable transition. Those niche innovations can increase momentum through the learning process as well as bottom up performance improvements.

These bottom-up innovations can eventually pressure “socio-technical regimes”. When pressure is placed on Socio-Technical Regimes, it creates “windows of opportunity” for niche innovations. However, not all niche innovations and innovative technologies will be able to become part of the new regime without the influence of the external player (often top down processes). In many cases the transition to sustainability occurs when bottom up niche innovations are reinforced by top-down external factors such as finance, legislation or education.

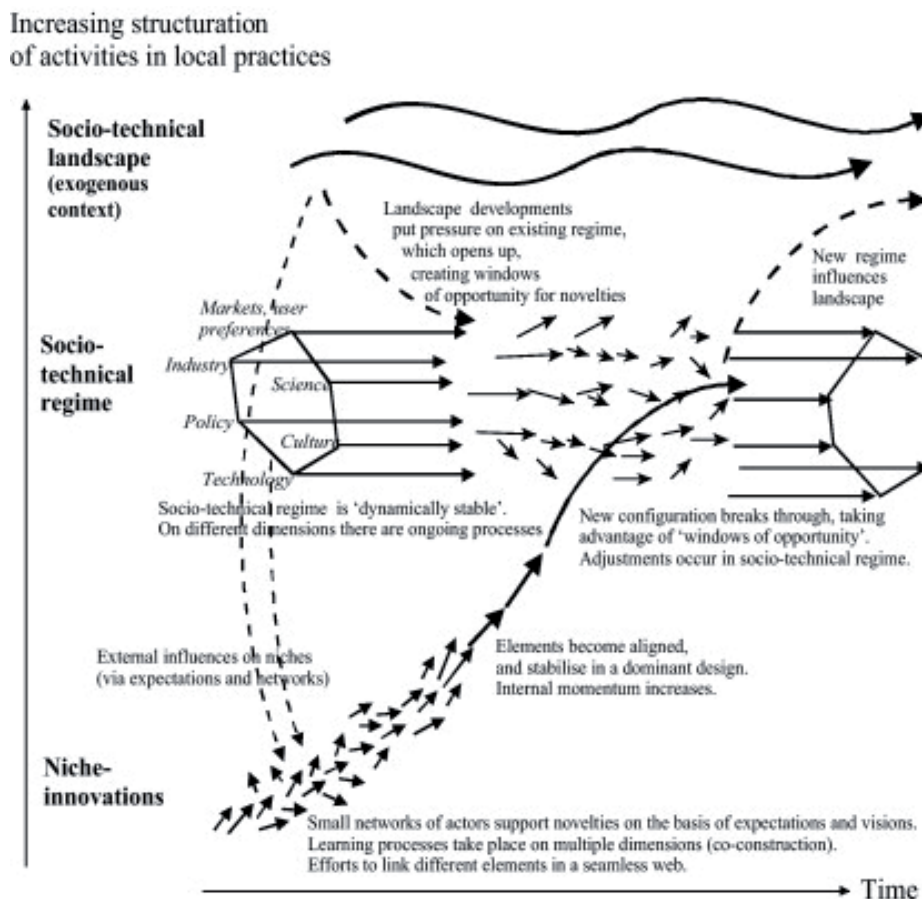


Figure 1 | Multi Level Perspective.

Source: Geels (2011).

We analyze each biome (Amazon and Cerrado) as a Socio-Technical regime and we explore Productive cycles of NTFP, Markets, Technologies, Policies Culture and Traditional Ecological Knowledge (TEK) and finally Science, research & development.

## 2.2 DATA COLLECTION AND LITERATURE REVIEW

After defining the conceptual framework, we collected data from Governmental and Non-Governmental organizations able to describe the dynamics of extractivist products in Brazil. We started by downloading data from IBGE and from the Ministry of Environment concerning the Sociobiodiversity chains (MMA, 2009). Based on the names of the municipalities and its NTFPs we assess the geographical distribution of the sociobiodiversity chains in Brazil (Figure 2). We also reviewed literature able to systematize the 6 characteristics of the sociotechnical regime described in 2.1 above but also for exploring both “Niche Innovations” and the “Socio Technical Landscape”, as shown in Figure 1. Niche innovations concern small scale initiatives that are likely able to transform the regime. As niche innovations we describe local initiatives developing in the last 20 years. We aim at capturing number of initiatives and its driving forces as well as the type of actors developing these initiatives. The major goal is to assess evidence of whether or not niche innovations in place can lead the Socio-Technical Regime towards a sustainable transition. We will also look for evidences for characterizing the Socio-Technical Landscape and explore whether or not there are top down initiatives likely to lead extractivist Socio-Technical Regimes into a sustainable transition. Our review includes both scientific papers and grey literature. We review work published from 2008 to 2018 (supplementary material 1 lists all the documents reviewed)

## 3 RESULTS

### 3.1 DATA SOURCES AND LITERATURE REFERRING TO THE DIVERSITY OF NTFPS IN CERRADO AND AMAZON

The Brazilian statistics office IBGE (Instituto Brasileiro de Geografia e Estatística) reports data on production (in tons) and values of production (in thousand reais) of 33 Non Timber Forest Products - NTFP, which are organized into 6 different categories: Rubber, Waxes, Fiber, Tenants, Oils, Food, Aromatic and Medicinal (Table 1). Shaded in Table 1 are the products awarded as Sociobiodiversity chain<sup>4</sup>. The IBGE data set is based on municipal reports and does not explicitly refer to the products of vegetal extractivist activities by biome.

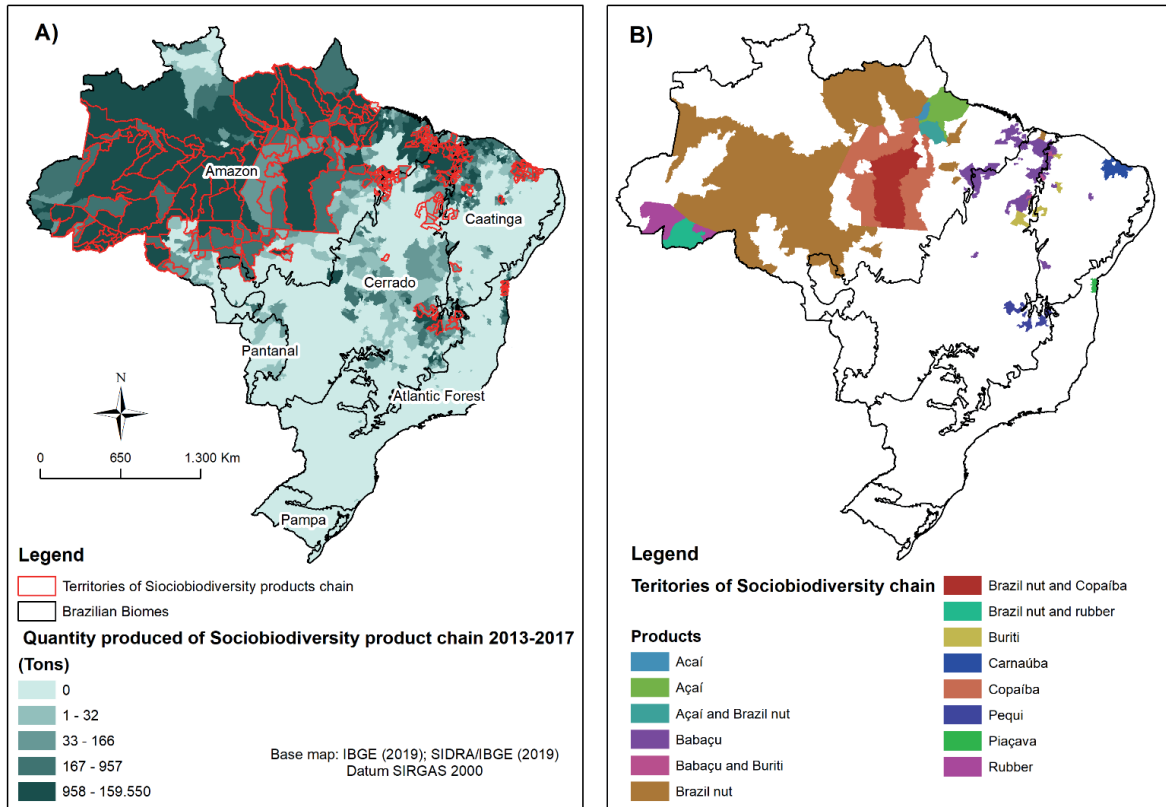
**Table 1 | NTFP organized into six IBGE categories.**

| <i>Rubber</i>            | <i>Waxes</i>      | <i>Fiber</i> | <i>Tanantes</i>    | <i>Oils</i>      | <i>Food</i>      | <i>Aromatic/ medic.</i> |
|--------------------------|-------------------|--------------|--------------------|------------------|------------------|-------------------------|
| Hévea (coagulated latex) | Carnaúba (wax)    | Buriti       | Angico (shell)     | Babaçu (almond)  | Açaí (fruit)     | Jaborandi (leaf)        |
| Hévea (liquid latex)     | Carnaúba (powder) | Carnaúba     | Barbatimão (shell) | Copaíba (oil)    | Castanha de caju | Urucu (seed)            |
| Maçaranduba              | Others            | Piaçava      | Others             | Cumuru (almond)  | Castanha-do-Pará | Others                  |
| Sorva                    |                   | Other        |                    | Licuri (coconut) | Erva-mate        |                         |
|                          |                   |              |                    | Oiticica (seed)  | Mangaba (fruit)  |                         |
|                          |                   |              |                    | Pequi (almond)   | Palmito          |                         |
|                          |                   |              |                    | Tucum (almond)   | Pinhão           |                         |
|                          |                   |              |                    | Others           | Umbu (fruit)     |                         |

NTFP shaded are included into the Socio Biodiversity plan by (MMA 2009).

*Source: IBGE (2015).*

In addition to IBGE data, the National Plan for promoting the sociobiodiversity chains developed by the Ministry of environment in 2009, lists the names of the municipalities that were awarded by the sociobiodiversity program and the product that was selected in each municipality (called in portuguese “*territórios da cidadania*”). Based on this data we were able to analyze the spatial distribution of the sociobiodiversity chains in Brazil (Figure 2). As can be seen in Figure 2 infographic the majority of the municipalities comprising the sociobiodiversity plan are located in the Northwest of the country notably in Amazonia.



**Figure 2 |** National Plan of Sociobiodiversity plan, A) quantity produced of sociobiodiversity products chain (e.g. Açaí, Brazil nut, Rubber, Pequi, Babaçu, Andiroba, Carnaúba, Buriti, Copaíba and Piaçava) between the year of 2013 – 2017 and B) spatial distributions of the products chains.

Source: survey data (2019).

### 3.2 NON-TIMBER FOREST PRODUCTS IN THE CERRADO BIOME

The second largest biome in Brazil, the Cerrado covers an area of 2 million km<sup>2</sup>, corresponding to 204 million hectares. This represents almost a quarter of the country’s total land area. Notwithstanding being home of about 46 million inhabitants Cerrado is considered a biodiversity hotspot holding about 12,000 species of plants (trees, shrubs, herbs and vines), 251 species of mammals, 856 species of birds, 262 species of reptiles, 209 species of amphibians, 800 species of fish , which partially shows the richness of this biome. However, only 8.3% of the cerrado is protected. Deforestation has been steadily occurring and as a consequence of this deforestation, several species of fauna (266) and flora (637) are already threatened by extinction (Embrapa, 2019). Cerrado, has several subtypes and fitophisnomies (campo sujo, campo limpo, cerradão), which are dependent on soil types, relief, groundwater, etc., results in a great variety of products, the collection of which sustains many inhabitants of this biome (Table 2).

**Table 2 | Fruits from Cerrado biome and scientific names.**

| <i>ID</i> | <i>Fruit</i>              | <i>Scientific name</i>            |
|-----------|---------------------------|-----------------------------------|
| 1         | Amora-Preta               | <i>Bubus cf brasilliensis</i>     |
| 2         | Ananás                    | <i>Annas ananassoides</i>         |
| 3         | Araçá                     | <i>Psidium firmum</i>             |
| 4         | Araticum                  | <i>Annona crassiflora</i>         |
| 5         | Araticum-de-Casca-Lisa    | <i>Annona coriacea</i>            |
| 6         | Araticum-Rasteiro         | <i>Annona pygmaea</i>             |
| 7         | Araticum-Tomentoso        | <i>Annona cf. tomentosa</i>       |
| 8         | Babaçu                    | <i>Orbygnia cf. phalerata</i>     |
| 9         | Bacupari                  | <i>Salacia campestris</i>         |
| 10        | Banha-de-Galinha          | <i>Swartzia langsdorfii</i>       |
| 11        | Baru                      | <i>Dypterix alata</i>             |
| 12        | Buriti                    | <i>Mauritia vinifera</i>          |
| 13        | Cagaita                   | <i>Eugenia dysenterica</i>        |
| 14        | Cajuzinho-do-Cerrado      | <i>Spondia cf. lutea L.</i>       |
| 15        | Caju-de-Árvore-do-Cerrado | <i>Anacardium othonianum</i>      |
| 16        | Caju-Rasteiro             | <i>Anacardium pumilum</i>         |
| 17        | Cajuzinho-do-Cerrado      | <i>Anacardium humile</i>          |
| 18        | Chichá                    | <i>Sterculia striata</i>          |
| 19        | Coquinho-do-Cerrado       | <i>Syagrus flexuosa</i>           |
| 20        | Croadinha                 | <i>Mouriri elliptica</i>          |
| 21        | Curriola                  | <i>Pouteria ramiflora</i>         |
| 22        | Fruto-do-Tatu             | <i>Crhysophyllum soboliferum</i>  |
| 23        | Gabiroba                  | <i>Campomanesia cambessedeano</i> |
| 24        | Gravatá                   | <i>Bromelia balansae</i>          |
| 25        | Guapeva                   | <i>Pouteria cf. gardineriana</i>  |
| 26        | Guariroba                 | <i>Syagrus oleraceae</i>          |
| 27        | Ingá-do-Cerrado           | <i>Inga laurina Willd..</i>       |
| 28        | Jaracatiá                 | <i>Jacaratia hiptaphylla</i>      |
| 29        | Jatobá-do-Cerrado         | <i>Hymenaea stigonocarpa</i>      |
| 30        | Jatobá-da-Mata            | <i>Hymenaea stilbocarpa</i>       |
| 31        | Jenipapo                  | <i>Genipa americana</i>           |
| 32        | Jerivá                    | <i>Syagrus romanzoffiana</i>      |
| 33        | Lobeira                   | <i>Solanum lycocarpum</i>         |
| 34        | Macaúba                   | <i>Acrocomia aculeata</i>         |
| 35        | Mama-Cadela               | <i>Brosimum gaudichaudii</i>      |
| 36        | Mangaba                   | <i>Hancornia spp.</i>             |
| 37        | Maracujá-de-Cobra         | <i>Passiflora coccinea</i>        |
| 38        | Maracujá-do-Cerrado       | <i>Passiflora cincinnata</i>      |
| 39        | Maracujá-Doce             | <i>Passiflora alata</i>           |
| 40        | Maracujá-Nativo           | <i>Passiflora eichleriana</i>     |
| 41        | Maracujá-Roxo             | <i>Passiflora edulis</i>          |
| 42        | Marmelada-de-Bezerro      | <i>Alibertia edulis</i>           |
| 43        | Marmelada-de-Cachorro     | <i>Alibertia sessillis</i>        |
| 44        | Marmelada-de-Pinto        | <i>Alibertia elliptica</i>        |
| 45        | Melancia-do-Cerrado       | <i>Melancium campestre</i>        |
| 46        | Murici                    | <i>Byrsonima verbascifolia</i>    |
| 47        | Palmito-da-Mata           | <i>Euterpe adulis</i>             |



| <i>ID</i> | <i>Fruit</i>          | <i>Scientific name</i>                           |
|-----------|-----------------------|--|
| 48        | Pequi                 | <i>Caryocar brasiliense</i>                      |
| 49        | Pequi-Anão            | <i>Caryocar brasiliense (subsp. Intermedium)</i> |
| 50        | Pêra-do-Cerrado       | <i>Eugenia klotzchiana</i>                       |
| 51        | Perinha               | <i>Eugenia lutescens</i>                         |
| 52        | Pimenta-de-Macaco     | <i>Xilopia aromatica</i>                         |
| 53        | Pitanga-Vermelha      | <i>Eugenia calycina</i>                          |
| 54        | Pitomba-do-Cerrado    | <i>Talisia esculenta</i>                         |
| 55        | Puçá                  | <i>Mouriri pusa</i>                              |
| 56        | Saputá                | <i>Salacia elliptica</i>                         |
| 57        | Tucum-do-Cerrado      | <i>Bactris spp.</i>                              |
| 58        | Uva-Nativa-do-Cerrado | <i>Vitis spp.</i>                                |

Source: <http://www.centraldocerrado.org.br/categoria/frutos/>

In general, some of the products are endemic to the type of Cerrado in which they are found and others are spread throughout the territory occupied by this biome. Below we list Cerrado main products.

### 3.2.1 THE PRODUCTS OF THE CERRADO

The cerrado in all its forest formations provides an enormous amount of fruit and extractive products and many local communities rely on the raw materials “in natura” collection of fruits such as pequi, cagaita, ata, baru, bacuri, mangaba, buriti, among many other products. These products are usually traded in local markets of the regions where they are collected either raw or slightly processed by agroindustries, such as the production of frozen pulps, ice creams, jellies, jellies, dehydrated fruits, biscuits, cakes, pies, cosmetics and medicines (SEBRAE, 2013). Due to the huge diversity of Cerrado products, we focus in only two: Pequi and sempre vivas, one product of wider scope and other geographically restricted, respectively.

#### PEQUI

Pequi (*Cariocar rasilense* camb) is a native fruit of the Brazilian cerrado. There are diverse types of using pequi. Pequi can be simply boiled and used in the preparation in several dishes, jelly, sweets, liqueurs, and oils. The oils are also used in cosmetic and pharmacy industry (Oliveira, 1988, apud Oliveira et al (2008)). From its core can also be extracted an oil used in biodiesel (Peres 2019). However, in order to make up for this, there is a need for time and investment for the development of the technology. Nevertheless, the oil has been already tested in the composition of biofuels and the National Petroleum Agency has already authorized the mixture of biofuel extracted from pequi in official cars of some Brazilian Universities (USP, 2005). Pequi wood is also considered to be of good quality and highly resistant. However, since there are no programs to manage and use the specie on a sustainable basis, when cutting off the trees, it can cause irreparable damages to the ecosystems. Pequi bark can produce tannin and a kind of dark brown tincture used in artisan dyeing (Ribeiro et al, 1982). It also has many fibers, and can be used in human and bovine (has a quantity of protein, among other characteristics, much higher than that of wheat flour). Other uses and properties of Pequi have been investigated (Passos et al, 2002), such as the antimycotic effects found in leaves and seeds.

#### SEMPRE VIVAS

Sempre vivas are different species of plants that preserve its natural and dry appearance for long periods of time. Giuletta et al. (1996) highlight the following species of five monocotyledon families: Eriocaulaceae, Poaceae (Gramineae), Xyridaceae, Cyperaceae and Rapateaceae. Sempre vivas, refer to species whose external morphology resembles a “daisy” (all of the family *Eriocaulaceae*) and “buds”, (Moreira, 2010).

Sempre vivas occur in the Cerrado Biome distributed in the Southeast and Center-West regions of Brazil. The greatest diversity is in the tops of mountainous regions, at altitudes above 900 meters where rocky fields associated with rocky outcrops of quartzite, sandstone or iron formations occur – in the latter case under the name of ferruginous fields. Sempre vivas are occurring in the rupestrian fields of the highlands of the Espinhaço Range (MG and BA) and in the mountains of Goiás (Giulietti et al., 1996) and Tocantins.

One of the most important production and commercialization center is the municipality of Diamantina (MG) (Giulietti et al., 1988) and Jalapão (TO) where the species *Syngonanthus nitens* known as “golden grass” is marketed (Shmidt, 2005). They grow in different edaphic conditions, inhabiting dry, moist and even flooded soils, but always exposed to the sun (Scatena et al., 1999).

The harvest of sempre vivas is carried out during various periods of the year depending on the species. It is made by traditional communities, and it is common to find entire families in the field doing this activity during the flowering season. In Minas Gerais and Bahia, the most difficult areas to reach involve the displacement of groups of collectors who camp up to three months in the highlands during the entire flowering period. In the Jalapão region of Tocantins, the golden grass is collected by women, men and children in wet fields, adjacent to the trails, between July and October. The harvest is done by pulling the extremity of the flower (Shmidt, 2005). As in Minas Gerais and Bahia, harvesting sites may be close to houses or more distant. In all cases the collected material does not undergo any specific treatment, being gathered in small bundles, tied, and arranged in places to dry.

The extractive management is centered on the collection and burning of the humid fields in order to maximize production by manipulating the productive effort of the target plants (Shmidt, 2005; Bedê, 2006). Production is believed to be larger one year after the burning of the moist field. The management of this extractivist product can affect the demography of native populations in different ways, according to the part of the plant collected, quantities and time of collection, among other factors that may contribute to the decline of the productivity of the species (Ticktin 2004). In fact, uncontrolled exploitation impairs the recovery of natural populations, putting species with a more restricted geographical distribution at risk of extinction (Giulietti et al., 1988).

There are records of the commercialization of sempre vivas from the Serra do Espinhaço region in Minas Gerais since the 1930s. There is also records of shipping them to Vienna in Austria in 1935 (Instituto Terra Brasilis, 1999). In the Jalapão region, commerce began in the mid-1990s, when it became known for the scenic beauty that attracted tourists, leading to the dissemination of handicrafts made with golden grass, until then produced on a small scale for use by the black community of Mucamba (Shmidt, 2005).

The five most frequently traded species of Minas Gerais, Bahia and Goiás are used for ornamental use, due to their beauty and durability, in interior decoration (Giulietti et al., 1996). Due to its malleability the golden grass is used to make baskets hats, bags, earrings by means of a technique of sewing small saucers with buriti silk in concentric bundles (Shmidt, 2005).

### 3.2.2 NON-TIMBER FOREST PRODUCTS IN THE BRAZILIAN AMAZON

Amazonia legal covers an area of 5, 2 million km<sup>2</sup>, this representing 61% of Brazil land area. Amazon biome only covers 4,2 million Km<sup>2</sup> about 49% of Brazilian land of which 2,2 million Km<sup>2</sup> are protected lands. According to the last IBGE census Legal Amazon is home to about 23 million inhabitants.

It is scarce the literature referring to the total number of NTFPs in the Brazilian Amazon (Table 3). INPA reports that there are 45 native NTFPs in the Amazon, 38 of which are traded in Manaus local markets (IMPA, 2012). According to IBGE (IBGE 2015), 30 out of 33 NTFPs found in Brazil occur in the Amazon region. From the 33 NTFPs reported by IBGE we could not find any record for Umbú, Pinhão and Erva Mate.

**Table 3** | Fruits from Amazon biome and scientific names.

| <i>ID</i> | <i>Fruit</i>        | <i>Scientific name</i>        |
|-----------|---------------------|-------------------------------|
| 1         | Abiu                | <i>Pouteria caimito</i> )     |
| 2         | Açaí-solteiro       | <i>Euterpe precatoria</i>     |
| 3         | Açaí-do-Pará        | <i>Euterpe oleracea</i>       |
| 4         | Araçá-boi           | <i>Eugenia stipitata</i>      |
| 5         | Bacaba              | <i>Oenocarpus bacaba</i>      |
| 6         | Bacabí              | <i>Oenocarpus mapora</i>      |
| 7         | Bacuri              | <i>Garcinia</i>               |
| 8         | Biribá              | <i>Rollinia mucosa</i>        |
| 9         | Buriti              | <i>Mauritia flexuosa</i>      |
| 10        | Cacau               | <i>Theobroma cacao</i>        |
| 11        | Cacau-da-mata       | <i>Theobroma sylvestre</i>    |
| 12        | Caiaué              | <i>Elaeis oleifera</i>        |
| 13        | Caju                | <i>Anacardium occidentale</i> |
| 14        | Cajuaçu             | <i>Anacardium spruceanum</i>  |
| 15        | Castanha-de-cutia   | <i>Acioa edulis</i>           |
| 16        | Castanha-do-Brasil  | <i>Bertholletia excelsa</i>   |
| 17        | Castanha-sapucaia   | <i>Lecythis pisonis</i>       |
| 18        | Cupuaçu             | <i>Theobroma grandiflorum</i> |
| 19        | Cumaru              | <i>Dipteryx odorata</i>       |
| 20        | Guaraná             | <i>Paullinia cupana</i>       |
| 21        | Inajá               | <i>Maximiliana maripa</i>     |
| 22        | Ingá-chichica       | <i>Inga alba</i>              |
| 23        | Ingá-cipó           | <i>Inga edulis</i>            |
| 24        | Ingá-peluda         | <i>Inga macrophylla</i>       |
| 25        | Ingáí               | <i>Inga laurina</i>           |
| 26        | Jenipapo            | <i>Genipa americana</i>       |
| 27        | Mapati              | <i>Pourouma cecropiifolia</i> |
| 28        | Mari-da-terra firme | <i>Cassia grandis</i>         |
| 29        | Moela-de-mutum      | <i>Lacunaria jenmanii</i>     |
| 30        | Murici              | <i>Byrsonima chrysophylla</i> |
| 31        | Pajurá              | <i>Couepia bracteosa</i>      |
| 32        | Patauá              | <i>Oenocarpus bataua</i>      |
| 33        | Pitomba             | <i>Talisia esculenta</i>      |
| 34        | Pupunha             | <i>Bactris gasipaes</i>       |
| 35        | Pupunha-de-porco    | <i>Syagrus inajai</i>         |
| 36        | Puruí               | <i>Borjoa sorbilis</i>        |
| 37        | Sapota-do-Solimões  | <i>Quararibea cordata</i>     |
| 38        | Sorvinha            | <i>Couma utilis</i>           |
| 39        | Taperebá            | <i>Spondias mombin</i>        |
| 40        | Tucumã              | <i>Astrocaryum aculeatum</i>  |
| 41        | Tucumã-i            | <i>Astrocaryum acaule</i>     |
| 42        | Ubaia               | <i>Eugenia patrisii</i>       |
| 43        | Umari               | <i>Poraqueiba sericea</i>     |
| 44        | Urucum              | <i>Bixa orellana</i>          |
| 45        | Uxi                 | <i>Endopleura uchi</i>        |

Source: [http://frutasnativasdaamazonia.blogspot.com/2013/01/fruteiras-dobosque-da-ciencia-do-inpa\\_31.html](http://frutasnativasdaamazonia.blogspot.com/2013/01/fruteiras-dobosque-da-ciencia-do-inpa_31.html)

Among the 30 NTFP reported by IBGE for the Amazon, Brazil nut collection and rubber extraction are the two most important<sup>5</sup> as they together provide incomes to a large number of forest communities (Ferreira 2008). Generally, during summer, from November to March, there is collection of Brazil nut in the forest, while during winter, from April to October there is extraction of rubber. Table 4 shows the annual work calendar for ten families in Acre.

Table 4 | Annual work calendar

| FAM | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1   | ■   | ■   | ■▲  | ■◆● | ◆◆  | ▲◆◆ | ◆◆◆ | ◆◆◆ | ◆   | ■◆● |     | ■   |
| 2   | ■■  | ■   | ■   | ■◆  | ◆◆● | ▲◆◆ | ◆◆◆ | ◆◆◆ | ■▲◆ | ●   | ◆   | ■   |
| 3   | ■   | ■   | ▲●  | ◆   | ■◆◆ | ▲◆◆ | ▲◆◆ | ◆◆◆ | ◆   | ■◆● | ◆   | ◆   |
| 4   | ■   | ■   | ■▲  | ■◆  | ◆   | ▲◆◆ | ◆◆◆ | ◆◆◆ | ◆   | ■◆● | ◆   | ◆   |
| 5   | ■■  | ■   | ■▲● | ◆   | ◆◆◆ | ▲◆◆ | ◆◆◆ | ◆◆◆ | ■◆● | ◆●  | ◆   | ◆   |
| 6   | ■   | ■   | ■●  | ■◆  | ◆◆● | ▲◆◆ | ◆◆◆ | ▲◆  | ●   | ■◆  | ◆   | ■◆  |
| 7   | ■   | ■   | ■●  | ▲◆  | ◆◆◆ | ◆◆◆ | ◆◆◆ | ▲◆  | ■●  | ◆●  | ◆   | ■◆  |
| 8   | ■   | ■   | ■▲● | ◆◆  | ▲◆◆ | ◆◆◆ | ◆◆◆ | ◆◆◆ | ◆●  | ■◆  | ■◆  | ■   |
| 9   | ■   | ■■  | ■▲● | ◆   | ◆◆◆ | ▲◆◆ | ◆◆◆ | ◆◆◆ | ■◆  | ◆●  | ■◆● | ■■  |
| 10  | ■   | ■   | ■●  | ◆◆  | ◆◆◆ | ◆◆● | ◆◆◆ | ◆◆◆ | ◆   | ◆●  | ◆   | ■   |

(■) Brazil Nut; (■) Maize; (▲) Beans; (◆) Açaí; (◆) Rubber; (●) Rice; (●) Cacava

Source: adapted from Rocha (2002)

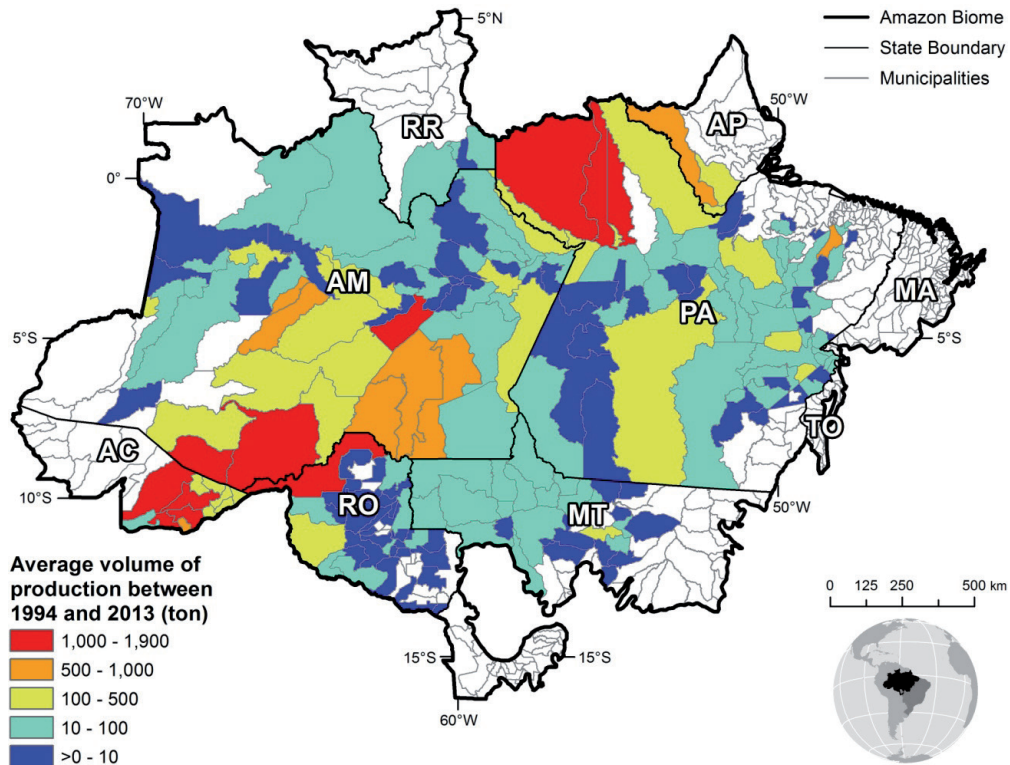
There is noted lack of information concerning the productivity and yield distribution across Amazonia. The only comprehensive work that models productivity and yield distribution across the biome was done through the project “Amazon Ecoservices”.<sup>6</sup> Throughout this project using interviews and focus groups with extractivists from Acre and Pará altogether with spatially explicit modelling it was estimated productivity of two NTFPs namely rubber and Brazil nut. In this work we report the estimates of the project referring to its project Report (Soares Filho, Carvalho Ribeiro et al 2015).

### BRAZIL NUT

The Brazil nut tree (*Bertholletia excelsa*) produces one of the main seeds (Brazil nut) commercially harvested in rainforest ecosystems (Peres, Baider et al. 2003, Nunes, Soares-Filho et al. 2012, SEAPROF 2014). The next set of figures show the IBGE data on production (in ton) and value of production (in US\$ converted from real at 2,36 using the 2015 average rate). These values are not weighted by the forest area of the municipality, as it is likely that there is a market of NTFP across the municipalities, in which nuts produced in one municipality might enter the market in other municipality.

The mean annual production per municipality over the last 20 years (from 1994 to 2013) ranged from 0 (municipalities depicted in white) to 1,900 tons. Figure 3 shows the higher mean values in the municipalities (shaded in red) within Pará, Acre, Amazonas and Rondônia states, which produced, on average, from 1,000 to 1,900 tons of Brazil nut per year. There are municipalities producing, on average, 100 to 1,000 tons (shaded from orange to yellow). Lower production occurs, in general, in the municipalities at the biome’s fringe (municipalities shaded in white producing less than a ton) and in the municipalities shaded from dark to light blue (average production between 1 and 100 tons).

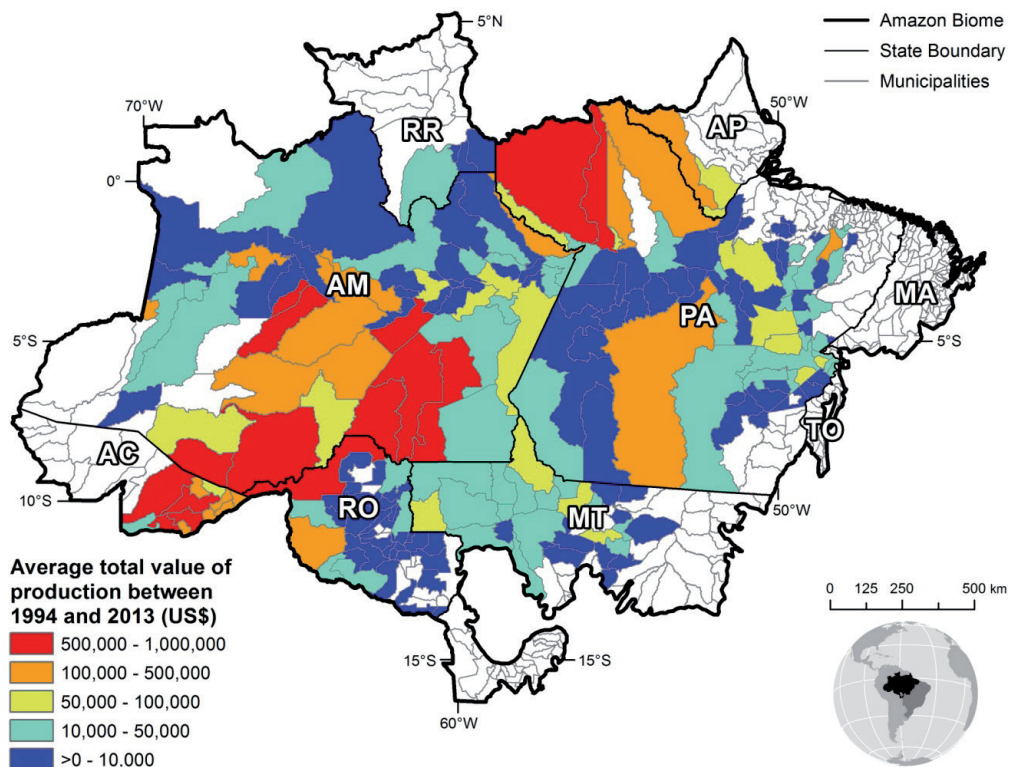




**Figure 3 |** Average volume of production between 1990 and 2013 (ton).

Source: Soares Filho; Carvalho Ribeiro et al. (2015).

The total value of production of Brazil nut, per municipality, ranges from US\$ 1 to US\$ 1 million. Notice that the municipalities with higher mean production (shaded in red) are also the ones with higher mean production values (Figure 4) (Soares Filho, Carvalho Ribeiro et al. 2015).



**Figure 4 |** Average total value of production between 1994 -2013 by municipality.

Source: Soares Filho, Carvalho Ribeiro et al. (2015).

The mean annual values hide a huge variability. For example, in 2013 the production of Brazil nut in the Amazon municipalities ranged from 0 to a maximum of 3,700 ton. The value paid to producer also varies in different Amazonian states (Table 4).

**Table 4 |** Brazil nut maximum price (US\$) per kg of unshelled nuts between 2013 and 2015 used as price paid to producer in different states.

| <i>Estate</i> | <i>Market (US\$) price per kg Cooperative</i> |
|---------------|---|
| Acre          | 1.42  |
| Amapá         | 1.42  |
| Amazonas      | 1.77  |
| Pará          | 1.85  |
| Maranhão      | 0.85  |
| Mato Grosso   | 0.85  |
| Tocantins     | 0.85  |
| Rondônia      | 0.85  |

Source: Soares Filho, Carvalho Ribeiro et al. (2015).

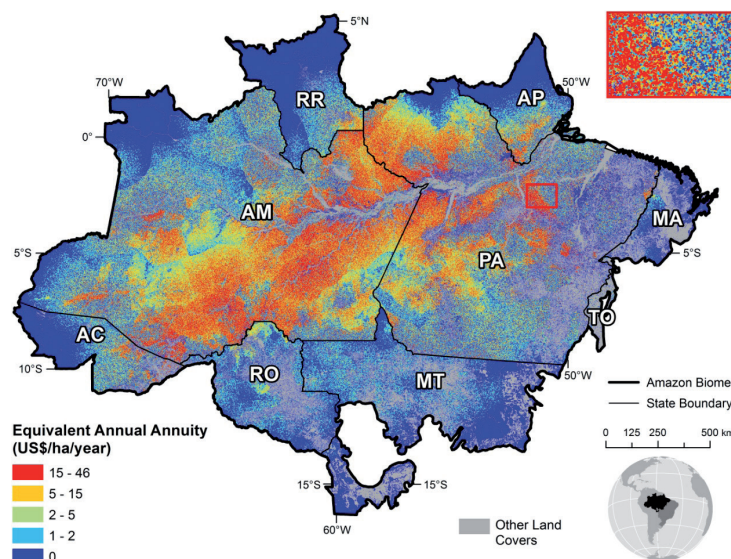
Brazil nut yields in the vast majority of areas (99%) of the Brazilian Amazon situate between 0 to 30 kg per ha-1year-1, although there are locations where yields can reach 152 kg per ha (1% of the biome) (Table 5).

**Table 5 |** Brazil nut yields.

| <i>Brazil nut yield (kg/ha)</i> | <i>Brazilian Amazon</i> |
|---------------------------------|-------------------------|
| Minimum                         | 0.00                    |
| Maximum                         | 30.00                   |
| Mean                            | 8.19                    |
| Variance                        | 57.92                   |
| Standard deviation              | 7.41                    |

Source: Soares Filho, Carvalho Ribeiro et al. (2015)

The annual rents of Brazil nut, presented as the Equivalent Annual Annuity (EAA), range from US\$ 0 to 46ha-1year-1 (Figure 5), with average rents of US\$ 5.05 ha-1year-1 (Table 6).



**Figure 5 |** Equivalent Annual Annuity<sup>7</sup> for Brazil nut.

Source: Soares Filho, Carvalho Ribeiro et al. (2015).

**Table 6 | Brazil nut EAA.**

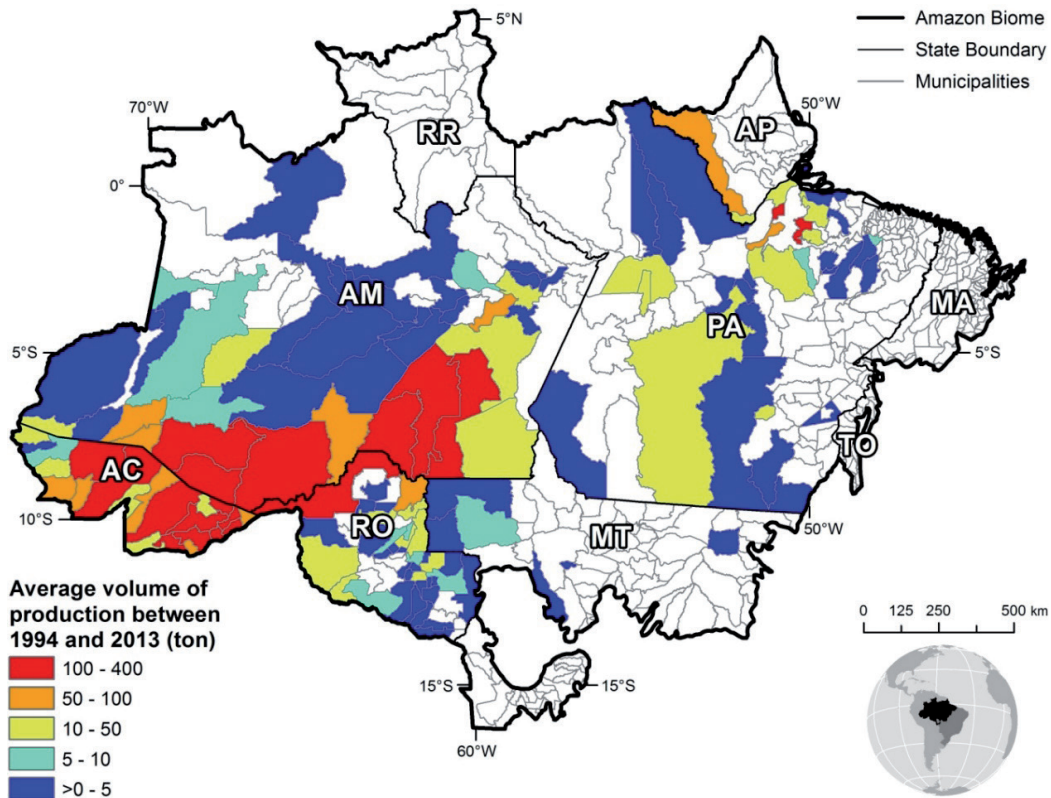
| <i>Rent Brazil nut</i> | <i>Brazilian Amazon</i> |
|------------------------|-------------------------|
| Minimum                | 0.00                    |
| Maximum                | 46.00                   |
| Mean                   | 5.05                    |
| Variance               | 56.24                   |
| Standard deviation     | 7.49                    |

Source: Soares Filho, Carvalho Ribeiro et al. (2015)

**RUBBER**

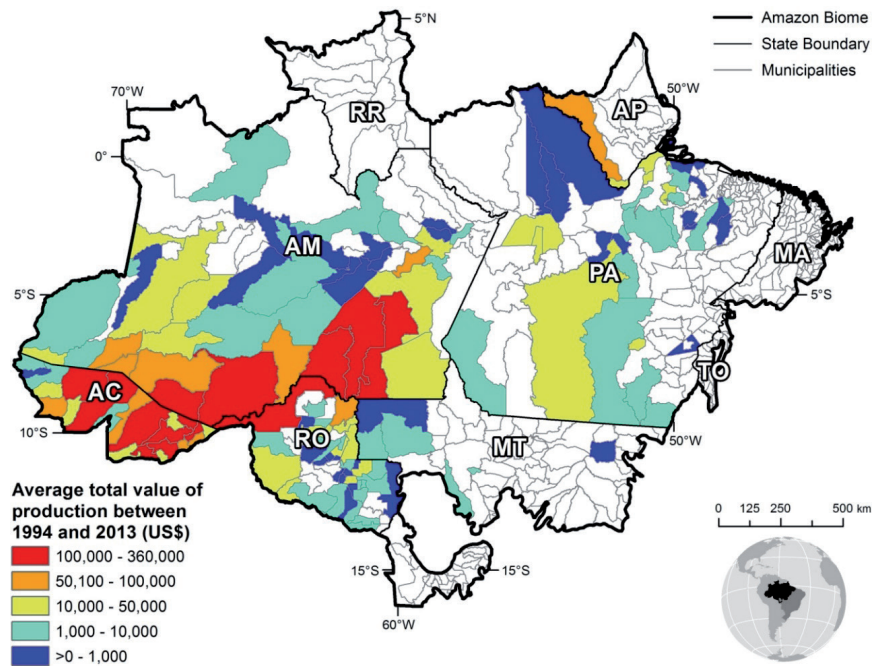
*Hevea brasiliensis* is the main source of natural rubber in the world (Soares Filho, Carvalho Ribeiro et al. 2015). The natural rubber has numerous applications with uses that go beyond 50 thousand objects; hence, it is one of the highest applicability products in industry. Paradoxically the rubber market is very dependent on the automobile (tiers) industry that consumes 80 to 90 % of the rubber extracted in Brazil (SEAPROF 2014).

Natural rubber (not derived from petroleum) can be gathered either in native forests or in forest plantations, thus having two different production systems and production chains. In the Amazon, the prevalent system is the rubber tapping in native forests by the traditional extractivism system. Currently, rubber tapping in the Amazon still constitutes an income source for livelihoods of 5 to 10 thousand families, mainly located in Acre and Amazonas states (IBGE 2015). In the last 20 years (1994-2013), the mean total production, by municipality ranged from 1 to 400 ton (Figure 6). The higher mean values of production occurred in states of Amazonas, Acre, and Rondônia. Southern part of Amazonas and Acre also reached the higher mean total production values with a maximum of US\$ 360 thousand (Figure 7).



**Figure 6 | Mean total production by municipality from 1990 to 2013.**

Source: IBGE (2015).



**Figure 7 | Average total value of production (1994-2013).**

Source: Soares Filho, Carvalho Ribeiro et al. (2015).

As in the case of Brazil nut, the average annual production for rubber hides a great annual variability. In 2013, only four municipalities (one in Acre and 3 in Amazonas) produced a maximum of 300 tons of rubber. The production of rubber ranged from 50 to 100 tons but the majority of the municipalities in the Brazilian Amazon had no production at all (Table 7).

**Table 7 | Rubber yields for the Brazilian Amazon.**

| Rubber yield (kg/ha) | Brazilian Amazon |
|----------------------|------------------|
| Minimum              | 0.00             |
| Maximum              | 14.00            |
| Mean                 | 3.28             |
| Variance             | 4.84             |
| Standard deviation   | 2.20             |

Source: Soares Filho et al. (2017)

As in the case of Brazil nut, the price paid to extractivists varies much depending on the year/season. According to Soares Filho et al (2015) the maximum price paid to extractivists by the cooperatives in the period 2013 to 2014 (Table) from the CONAB dataset.

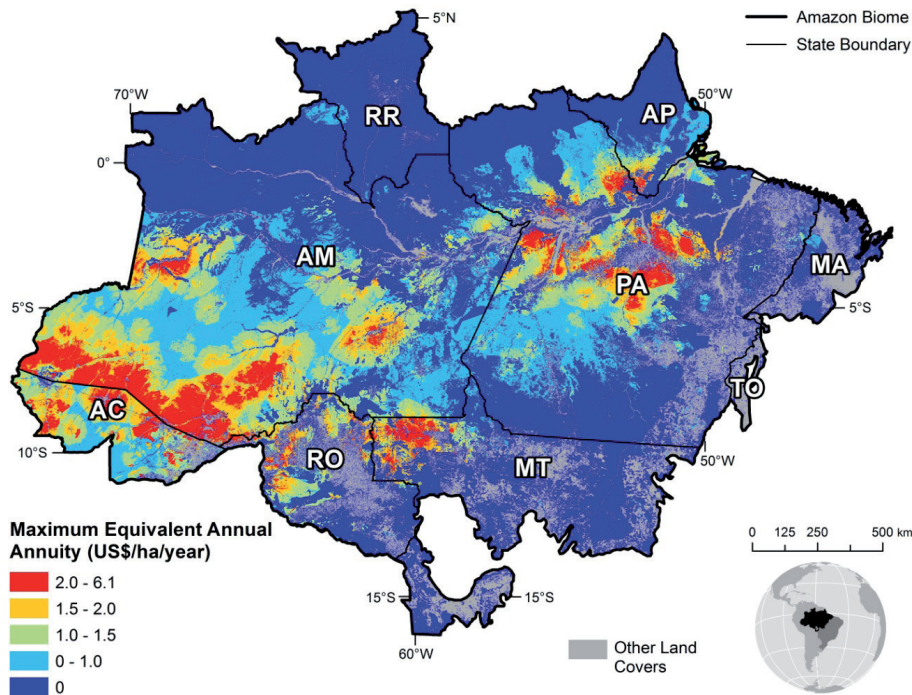
**Table 8 | Price paid to producer.**

| State       | US\$ per kg |
|-------------|-------------|
| Acre        | 0.80        |
| Amapá       | 1.09        |
| Amazonas    | 1.09        |
| Pará        | 1.21        |
| Maranhão    | 1.09        |
| Mato Grosso | 1.25        |
| Tocantins   | 1.09        |
| Rondônia    | 1.12        |

Source: Soares Filho et al. (2017)



The areas in red in Figure 8 show the locations with highest EAA. Rubber extraction in the Amazon is not profitable in areas of low productivity even with subsidies to guarantee a minimum price to rubber tappers. In the presence of governmental subsidies, rents average US\$ 0.56 ha<sup>-1</sup>year<sup>-1</sup>, varying from 0 to US\$ 6.13 ha<sup>-1</sup> year<sup>-1</sup> (Figure 8, Table 9).



**Figure 8 | EAA for rubber extraction.**

Source: Soares Filho et. al. (2017).

**Table 9 | Rents for rubber.**

| Rents (US\$/ha)    | Brazilian Amazon |
|--------------------|------------------|
| Minimum            | 0.00             |
| Maximum            | 6.13             |
| Mean               | 0.56             |
| Variance           | 0.57             |
| Standard deviation | 0.76             |

Source: Soares Filho et. al. (2017).

### 3.3. MULTI SCALE GOVERNANCE FOR ENHANCED SOCIOBIODIVERSITY CHAINS IN AMAZONIA AND CERRADO BIOMES

This work aimed at gathering data on the socio-ecology of extractivist landscapes in Brazil for exploring possible multi scale governance able to implement enhanced sociobiodiversity chains. We estimate 43 and 58 NTFPs for Amazon and Cerrado respectively (see an extensive list of the products of Amazon and Cerrado in ANEXE 1). Although there is a vast repertoire of empirical data for characterizing sociobiodiversity in Brazil this body of literature is mostly case study driven, focusing on a very limited number of products and using different methodological approaches. Therefore, although there is a robust research legacy meaningful comparison are very challenging.

So far we have a fragmented view of extractivist dynamics at the biome scale. There is thus the need to upscale from the socio ecology of individual NTFP to the biome scale encompassing a variety of products and its associated livelihoods. The new Legal Framework on Brazilian Biodiversity (Law 13,123),

provides for access to genetic heritage, protection and access to associated traditional knowledge and the sharing of benefits for the conservation and sustainable use of biodiversity. This Law by the Federal Government (May 20, 2015) replaces the old national legislation, Provisional Measure 2186-16 / 2001. This Law acknowledges Traditional Ecological Knowledge (TEK) to traditional communities such as indigenous peoples, quilombolas, and family farmers.

In Brazil, Governmental bodies (e.g. ICMBIO, CONAB) universities and research institutes and the work by Non Governmental institutions have been active on safeguarding traditional knowledge and Brazilian genetic heritage. In the Amazonas state alone the number of communities assisted by income-generating social programs such as the Bolsa Floresta (PBF) —the largest Payment for Environmental Services (PES) program in tropical forests in the world— has been developing since 2008.

According to Fundação Amazônia Sustentável (FAS 2016), in 2015 alone more than 9 thousand families received benefits from income generation programs which often require community engagement through workshops, meetings surveys involving mapping and other data collection instruments for improving resource management. Similarly, in the Cerrado biome the sustainable management of NTFPs particularly Pequi has been explored for decades. Many possibilities come from the production of NTFPs and its derivatives, including the manipulation of other products. For example the Kalunga quilombola women group, besides producing and marketing the pequi and indaiá oils, produce pequi (dry pequi pulp) and traditional tingui soap (*Magonia* sp.). Similarly, the women's groups of the Jequitinhonha Valley (MG), in addition to produce and commercialize the vegetable oils of macaúba, pequi and ruffão make traditional soaps using macaúba oil.

Also, the group of women from Santa Rita do Novo Destino (GO) have been implementing agroforestry systems with the use of the Gueroba palm intercropped with other oilseeds such as black sesame and sunflower. These agroforestry products are gathered into cooperatives, rural and indigenous communities, technicians and other types of organizations that wish to collect in a sustainable way these NTFPs. The pequi is undubtably part of the traditions of the people of the cerrado and its consumption has also spread to other regions, including being marketed in large cities. However, its exploitation is still carried out in an extractive way, with few commercial cultivation initiatives.

Exception is a producer from Mato Grosso, who transformed almost 60% of its 90 ha property into a large pequizal, with more than 50,000 feet. According to Oliveira W.L de; Aldicir, S. (2010), usually the collection of the pequi is carried out in the extractivist lands themselves, in extractive reserves, sustainable use reserves, national or state forests or in third-party properties, where some owners work in partnership with the extractivists asking part of the production in return.

The conservation of the native species of the cerrado and Amazon become therefore of extreme importance, Several communities have already joined in cooperatives, many of them intermunicipal or even interstate, in order to provide greater value and diversity of the products that the two major biomes in Brazil presents. There are also several research and development projects conducted by organizations such as Embrapa, Emater, and several NGOs such as “The central of the Cerrado”, “The cooperative of the small agroextractive producers of Lago do Junco - COPPALJ (MA)”, (MA / TO), “Extractivist producers of Esperantinópolis - COPAESP (MA)”, “Association of Rural Women Workers of Lago do Junco and Lago Rodrigues - AMTR (MA)”, “Fruta Sã - Indústria, Comércio e Exportação LTDA Promise of Future (Pirenópolis - GO)”, “Community Development Association of Caxambu (GO)”, to cite a few examples.

Industry and agribusiness are direct users of this genetic heritage and traditional knowledge, mainly for the development of commercial products such as medicines, cosmetics, food, etc., and the government is also directly involved.

Many of these communities also act in the buffer zones of many state and federal parks, further protecting these areas, or even as resistance to large producers to deprive the use of babaçu coconut

palms (ATMR). Another good example is the community of Fruta Sã<sup>8</sup> that harvest fruits in extractive areas but also manage new plantations into a domestication process Through organic management Fruta sã promotes partnerships with other economic enterprises of similar character in the states of Tocantins, Maranhão and next to the indigenista work center.<sup>9</sup>

The work developed so far received the Prize Chico Mendes in 2004, from the Ministry of the Environment, Brazil bank (Banco do Brasi) as well as the Foundation Social Technology Award, in the 2005 edition. Recently an international prize by United Nations was awarded to the collection process of *sempre vivas*<sup>10</sup>. There are therefore several initiatives and organizations that work for enhancing sociobiodiversity that created chains for specific products. However, many initiatives still act in a very incipient way and still have not reached a production and market that guarantee its social, environmental and economic sustainability. It also seems that acting on a product by product basis hampers the view of the whole socio ecological systems of extractivist landscapes. In addition to the previous, these initiatives from a bottom up perspective are dispersed and scatered across the vast areas of the two biomes and there is not a coordinated broad scale view of the extractivism in the Amazonia and Cerrado.

## 4 DISCUSSION AND CONCLUSION

This work aimed at assessing the dynamics of NTFP in two important biomes such as Amazon and Cerrado. We aimed at looking at sociobiodiversity at the biome scale exploring the diversity of NTFPs in each biome. The reason underlying the the goal of this paper was the awareness that each NTFP is part of a livelihood to which often contribute several NTFPs altogether with small scale farming and off farm labor (see table with the example from Acre).

Our approach extended well beyond the focus individual products to instead build a view of Amazon and Cerrado extractivist landscapes. We argue that this vision of the whole is much bigger than the sum of the parts. The problem is that the data available at the biome scale is scarce this hampering the vision and the potentialities of the sociobiodiversity at the biome scale. In our view this issue needs addressing. So far there is not the vision of sociobiodiversity of the whole biome comprising the diversity of NTFPs and its associated livelihoods.

The vast majority of the work so far focuses on a per product basis. This critique holds true for research agencies, governmental bodies (IBGE, MMA) and Non Governmental Organizations. In our view this is hampering sociobiodiversity plans in Brazil to move forward. Indeed there is a vast number of products in Amazonia and Cerrado but higher level governmental organizations such as IBGE data sets and MMA socio biodiversity plan (MMA 2009) report on a byproduct basis. From a bottom up perspective also the work by NGOs often work on a product by product basis. In our view this work and reporting on a by NTFP basis brings difficulties to forge strategies to move towards sustainability.

Because we adopted the biome scale analysis this inevitably allows a comparison between Amazonia and Cerrado Biomes. While there is a higher number of NTFPs in Cerrado, the sociobiodiversity plan by the MMA only awards 2 of them (Pequi and Buriti). Using multi-level perspective, it is possible to analyze socio technical transitions to sustainability (Geels 2011). The multi-level perspective theory analyses the socio-technical landscape and how it can be influenced by various factors. Additionally, it shows how the socio-technical landscape can be changed through the adoption of niche innovations. In this case study we were able to list two types of policies that can be seen as socio technical landscapes initiatives. One of them is the National Sociobiodiversity plan by MMA (2009) and other is the Framework on Brazilian Biodiversity (Law 13,123). As far as niche innovations is concerned, although we listed a number of organizations working on successful initiatives to deal with sociobiodiversity products we cannot assess if those initiatives are able to build *momentum* in such a way they are likely to lead the system to a transition to a more sustainable state.

We therefore argue that pressure is not put on extractivist Socio-technical regimes either in Amazon either in Cerrado. When pressure is put on regimes, it creates windows of opportunity for niche innovations. However, not all innovative technologies will succeed to become part and transform the new regime without outside influence. Some initiatives require some extra input from outside, such as finances, legislation or education. The problem is that neither the sociobiodiversity plan nor the new biodiversity law seem to provide such mechanisms in order to nurture the successful initiatives already occurring scattered across the two biomes. We call for a systematic analysis at the biome scale for better understand the role of vegetal extarctivist activities in Brazil.

## NOTES

- 1 | Traditional communities that live near the river
- 2 | Traditional communities' descents from African slaves
- 3 | <http://cmbbbc.cpac.embrapa.br/socioeconomia.htm> (accessed 25/03/2019)
- 4 | <http://www.mma.gov.br/desenvolvimento-rural/sociobiodiversidade>
- 5 | Açai is the NTFP from the Amazon generating the highest incomes in the states of Pará, Amazonas and Maranhão.
- 6 | <https://csr.ufmg.br/amazones/>
- 7 | The Equivalent Annual Annuity (EAA) approach is one of two methods used in capital budgeting to compare mutually exclusive projects with unequal lives.
- 8 | <http://www.centraldocerrado.org.br/comunidades/frutasa/>
- 9 | <https://trabalhoindigenista.org.br/home/>
- 10 | <https://nacoesunidas.org/agricultura-tradicional-de-flores-sempre-vivas-pode-ser-1o-patrimonio-agricola-mundial-brasileiro/>

## REFERENCES

- BEDÊ, L.C. 2005. **Alternativas para o uso sustentado de sempre-vivas: efeitos do manejo extrativista sobre *Syngonanthus elegantulus ruhlund* (Eriocaulaceae)**. Universidade Federal de Minas Gerais, Instituto de Ciências Biológicas. Dissertação de Mestrado. 184 p, 2005.
- CARVALHO RIBEIRO, S. M., B. SOARES FILHO, W. LELES COSTA, L. BACHI, A. RIBEIRO DE OLIVEIRA, P. BILOTTA, A. SAADI, E. LOPES, T. O'RIORDAN, H. LÔBO PENNACCHIO, L. QUEIROZ, S. HECHT, R. RAJÃO, U. OLIVEIRA and C. CIOCE SAMPAIO. Can multifunctional livelihoods including recreational ecosystem services (RES) and non timber forest products (NTFP) maintain biodiverse forests in the Brazilian Amazon? **Ecosystem Services**, 31: 517-526, 2018.
- FAS, F. A. S. **Relatório de Atividades 2015**. Relatórios de Gestão da FAS. Manaus. 8: 120, 2016.
- FERREIRA, L. T. **"A seringueira no Brasil."** Biotecnologia Ciência & Desenvolvimento, 2008.
- GEELS, F. W. The multi-level perspective on sustainability transitions: Responses to seven criticisms. **Environmental Innovation and Societal Transitions**, 2011. 1(1): p. 24-40, 2011.
- GIULIETTI AM, WANDERLEY MGL, LONGHI-WAGNER HM, PIRANI JR & PARRA LR. Estudos em sempre-vivas: taxonomia com ênfase nas espécies de Minas Gerais, Brasil. **Acta bot. Bras.** 10(2):329-377, 1996.
- GIULIETTI N, GIULIETTI A, PIRANI JR & MENEZES NL. Estudos em sempre-vivas: importância econômica do extrativismo em Minas Gerais, Brasil. **Acta bot. Bras.** 1(2):179-193, 1988.
- GRANDIN, G. **Fordlandia**, Rocco, 2010.
- HOMMA, A. K. O. **Extrativismo, Biodiversidade e Biopirataria na Amazônia**. EMBRAPA, Texto para Discussão 27, ISSN 1677-5473, 2008.

HUMPHRIES, S., T. P. HOLMES, K. KAINER, C. G. G. KOURY, E. CRUZ AND R. DE MIRANDA ROCHA. "Are community-based forest enterprises in the tropics financially viable? Case studies from the Brazilian Amazon." **Ecological Economics** 77: 62-73, 2012.

Instituto Terra Brasilis de Desenvolvimento Socioambiental – ITB / Centro Cape /SEBRAE / Mãos de Minas. **Projeto Sempre-Viva: Perspectivas de seu Uso Sustentado**. ITB, Belo Horizonte, 1999.

IBGE. Instituto Brasileiro de Geografia e Estatística. **Produção vegetal** (2015) Disponível em:<<http://www.ibge.gov.br/home/estatistica/economia/pevs/2013/default.shtm>>. Acesso em: 25 mar. 2019

IBGE. Instituto Brasileiro de Geografia e Estatística. **Produção vegetal** (2015). Disponível em:<<http://www.ibge.gov.br/home/estatistica/economia/pevs/2013/default.shtm>>. Acesso em: 25 mar. 2019

IMPA. **Frutos Nativos da Amazônia: comercializados nas feiras de Manaus** - AMISBN: 9788521100737 Editora: INPA - Instituto Nacional de Pesquisas da Amazônia. Edição: 1ª: 388 páginas, 2012.

MMA (2009). **National plan for Sociobiodiversity chains Plano Nacional de Promoção das Cadeias da Sociobiodiversidade (PNPSB)**. Ministry of Environment- MMA Ministerio Meio Ambiente (Brazil).

NUNES, F., B. SOARES-FILHO, R. GIUDICE, H. RODRIGUES, M. BOWMAN, R. SILVESTRINI AND E. MENDOZA. Economic benefits of forest conservation: assessing the potential rents from Brazil nut concessions in Madre de Dios, Peru, to channel REDD+ investments. **Environmental Conservation** doi:10.1017/S0376892911000671, 2012.

MOREIRA, F.C. **Avaliação de sistemas de cultivo das sempre vivas Comanthera elegans (Bong.) L.R. Parra & Giul. E C. bisulcata (Körn) L.R. Parra & Giul.** Universidade Federal dos Vales do Jequitinhonha e Mucuri, Programa de Pós-Graduação em Produção Vegetal. Dissertação de Mestrado. 99p., 2010.

PERES, C. A. et al. Demographic Threats to the Sustainability of Brazil Nut Exploitation. **Science** 302(5653): 2112-2114, 2003.

PETERS, C. M., A. H. Gentry and R. O. Mendelsohn. "Valuation of an Amazonian rainforest." **Nature** 339: 655-656, 1989.

Rocha, E. **Aspetos ecológicos e socio-econômicos do manejo de Euterpe precatoria Mart (Açaí) em áreas extrativistas no Acre, Brasil**. Mestrado, Universidade de S. Paulo, 2002.

SEAPROF. **Diagnóstico da Cadeia de Valor da Borracha**, Secretaria de Estado de Extensão Agroflorestal e Produção Familiar-SEAPROF, Governo do Estado do Acre, 2014.

SEAPROF. **Diagnóstico das cadeias de valor da castanha do Brasil**, Secretaria de Estado de Extensão Agroflorestal e Produção Familiar – SEAPROF, Governo do Estado do Acre, 2014.

SCATENA, V. L.; CARDOSO, V. A.; GIULIETTI, A. M. Morfoanatomia de espécies de Blastocaulon Ruhland (Eriocaulaceae). **Acta Botanica Brasílica**, Porto Alegre, v. 13, p. 29-41, 1999.

SCHMIDT IB. **Etnobotânica e ecologia populacional de Syngonanthus nitens: sempre-viva utilizada para artesanato no Jalapão, Tocantins**. Universidade de Brasília, Instituto de Ciências Biológicas. Tese de Mestrado. 91 p., 2005.

TICTIN T. The ecological implications of harvesting non-timber forest products. **Journal of Applied Ecology**, 41 (1): 11-21, 2004.

SOARES FILHO, B., S. CARVALHO RIBEIRO, L. LIMA, W. COSTA, A. RIBEIRO, F. MERRY, W. GOMES, D. OLIVEIRA, I. LORENZINI AND H. RODRIGUES. **Economic Valuation of Changes in the Amazon Forest Area: Value maps for Timber and Non Timber Forest Products (NTFP)**. Centro Sensoriamento Remoto [https://csr.ufmg.br/amazones/wp-content/uploads/2017/05/Report\\_NonTimber.pdf](https://csr.ufmg.br/amazones/wp-content/uploads/2017/05/Report_NonTimber.pdf), 2015.

WUNDER, S., A. ANGELSEN AND B. BELCHER. **Forests, Livelihoods, and Conservation: Broadening the Empirical Base**. World Development 64, Supplement 1(0): S1-S11, 2014.

# The handwriting of society on the landscape: modeling of the Environmental Changes on the Borders of Protected Areas located in the Espinhaço Mountain Range, state of Minas Gerais, Brazil<sup>1</sup>

*A caligrafia da sociedade na paisagem: modelagem ambiental  
das transformações ambientais no entorno de Unidades de  
Conservação da Serra do Espinhaço, Minas Gerais, Brasil*

Ana Pimenta Ribeiro<sup>a</sup>

José Augusto Drummond<sup>b</sup>

Eduardo Magalhães Ribeiro<sup>c</sup>

<sup>a</sup>Doctor, Institut for Environmental Planning - Leibniz Universität Hannover, Hannover, Germany.  
E-mail: piperaceae@gmail.com

<sup>b</sup>Ph. D., Centro de Desenvolvimento Sustentável, Universidade de Brasília, Brasília, DF, Brazil.  
E-mail: jaldrummond@uol.com.br

<sup>c</sup>Doctor, Instituto de Ciências Agrárias, Universidade Federal de Minas Gerais,  
Montes Claros, MG, Brazil.  
E-mail: eduardoribeiramacuni@gmail.com

doi:10.18472/SustDeb.v11n2.2020.28393

Received: 28/11/2019  
Accepted: 01/04/2020

ARTICLE- DOSSIER

## ABSTRACT

This paper analyzes the contexts of the creation of two protected areas located on the Espinhaço Mountain Range, in the state of Minas Gerais (Brazil): Rio Preto State Park and Serra Negra State Park. It compares the social and natural contexts of the creation process of both protected areas between the years 1986 and 2009. To this end, we sought to understand the patterns of natural resources use by local populations, relating them to the outcomes of land use dynamics over time, identified through monitoring with orbital imagery images and through environmental modeling. Regarding land use analysis, changes in the landscape around the Rio Preto State Park corroborated field surveys, which registered an increase in the local population's perception of environmental problems and in the inspection after the park's creation. No relevant relation was found for the Serra Negra State Park. Environmental modeling of the Rio Preto State Park recorded a positive result in terms of environmental protection, because a trend of natural resource degradation was contained after the park's creation. For the Serra Negra State Park, although protection of the area did not influence landscape changes, the dynamics of resource use by the local population did not degrade the natural environment.

**Keywords:** Protected Areas. Land Use Change. Environmental Conflicts. Geoprocessing. Environmental Modeling. Deforestation.

## RESUMO

*Este artigo analisa os contextos da criação de duas áreas protegidas localizadas na Serra do Espinhaço, no estado de Minas Gerais (Brasil): Parque Estadual do Rio Preto e Parque Estadual de Serra Negra. O trabalho compara os contextos sociais e naturais do processo de criação das duas áreas protegidas entre os anos de 1986 e 2009. Para tanto, buscamos entender os padrões de uso dos recursos naturais pelas populações locais, relacionando-os com os resultados da dinâmica do uso da terra ao longo do tempo, identificados através do monitoramento com imagens orbitais e através da modelagem ambiental. Quanto à análise do uso do solo, as mudanças na paisagem ao redor do Parque Estadual do Rio Preto corroboraram os levantamentos de campo, que registraram um aumento na percepção da população local sobre os problemas ambientais e na fiscalização após a criação do parque. Nenhuma relação relevante foi encontrada para o Parque Estadual de Serra Negra. A modelagem ambiental do Parque Estadual do Rio Preto registrou um resultado positivo em termos de proteção ambiental, pois uma tendência de degradação dos recursos naturais foi contida após a criação do parque. Para o Parque Estadual de Serra Negra, embora a proteção da área não tenha influenciado as mudanças na paisagem, a dinâmica de uso dos recursos pela população local não degradou o ambiente natural.*

**Palavras-chave:** Áreas Protegidas. Mudança no uso do solo. Conflitos ambientais. Geoprocessamento. Modelagem Ambiental. Desmatamento.

## 1 INTRODUCTION

Interpretations of the ways by which humans relate to the natural environment come from different fields of knowledge, such as anthropology, sociology and geography (KUGLER et al., 2019; MORAN, 2011). These relationships can be studied by field research aimed at understanding local activities in the day-to-day life of communities that use natural resources (GALIZONI, 2000; RIBEIRO et al., 2005). Studies such as Guadilla-Sáez et al. (2020) and Brugger et al. (2016) allow us to understand how local communities use available resources over the span of centuries.

Another way to seek this understanding is by monitoring continuity and change in the soil cover of a defined study area (BRONDÍZIO, 2009). Spatial analyses, typically used in biophysical studies, provide important information for social research. Geographic Information Systems (GIS) and Remote Sensing (RS) techniques, applied to surveys about landscape fragmentation, help verify data collected in the field (TUCKER and OSTROM, 2009; YOUNG et al., 2020). Orbital images display portraits of the landscape at a given moment, helping to identify the possibilities of preferred future situations or to improve these possibilities. Kugler et al. (2019) offer an extensive overview of how orbital images help understand interactions between humans and the natural environment, presenting a history of the improvements achieved in this field of research over the last 20 years.

Silva et al. (2016), using sequential analysis, identified the drivers of land use change in remnants of the Brazilian Atlantic Forest in different time periods. Li et al. (2019) used orbital images to examine the dynamics of land use and related it to the dynamics of local social contexts. According to Moran (2011), spatially explicit analyses have caused the greatest revolution in the history of studies about human-environment interactions. The author discusses cases in which landscape analysis over time helps understand cultural narratives, because “human actions carried out in the past leave marks on the current landscape” (Moran, 2011, p. 126).

Using different methodologies, adapted to different environmental realities, can help identify these ‘marks on the landscape’. Shimabukuro et al. (2019) present a semi-automatic procedure to monitor deforestation and degradation of the Amazon rainforest. Bicudo da Silva et al. (2017) evaluated land use changes in the Atlantic Forest over a period of almost 30 years. Silveira et al. (2018) developed an

innovative method of detecting land use change in the Cerrado, a biome that contains a wide range of environments and seasonal changes. The authors use spatial context assessment to eliminate the effects of phenology on classification. Li et al. (2017) propose a system to simulate global land use and cover change (LUCC) regarding human-environment interactions, applying simulations of future uses. These products are important tools that provide information that aids the assessment of impacts and the effectiveness of planning procedures and policies.

Starting from these LUCC analyses - which seek to understand the past or present status of landscapes - and seeking to predict future developments, environmental modeling emerges as a new tool. According to Evans et al. (2009), environmental modeling helps forecast alternative scenarios. By simplifying processes, modeling provides the possibility of examining the elements that interact and influence these processes.

The creation of protected areas (PAs) is one of the most frequent measures for conserving nature (Carranza et al., 2014; Heringer et al., 2020; Schulze et al., 2018; Silveira et al., 2018). Devising methods to evaluate their effectiveness generates important sources of data that can be used for making decisions. This efficiency can be evidenced by understanding how neighboring population relate to the PA.

Abukari and Mwalyosi (2018) evaluated how different communities relate to the parks, analyzing what factors, such as knowledge of the park's rules, residents employed in the conservation unit, distance between the communities and the park, and access to non-logging forest products were significant in changing people's attitude in this relationship. Cetas and Yasué (2017) concluded that emphasis on social justice and welfare of the neighboring populations aided the success of biodiversity protection in PAs.

PAs also play an important role in maintaining peoples' connection with the natural environment. According to Cazalis and Prévot (2019), pro-environment behavior decreases with longer distances between communities and parks. In addition to the effect caused by exposure to the natural landscape, the institutional context created by PAs has a strong influence on people's environmental awareness.

In this article we sought to identify land cover changes that occurred between 1986 and 2009 in the state parks of Rio Preto (RPSP) and Serra Negra (SNSP), at intervals that varied between six and eleven years<sup>2</sup>. This research exercise was conducted (i) to produce a portrait of the landscapes following the creation of both PAs and (ii) to compare it to the landscapes as they were before the PAs, allowing the quantification of land use changes. Additionally, through interviews conducted in the field, we sought to understand the patterns of natural resources use by local populations, relating them to the land use dynamics over time.

We also undertook an environmental modeling analysis, resulting in the identification of landscape use trends before the establishment of the two PAs. By classifying images taken on dates prior to the creation of the PAs, we obtained a model of how the landscape would be in the years 2003 and 2009 if the PAs had not been established. This allowed us to check the effectiveness of the two PAs in conserving the vegetation.

## 2 MATERIAL AND METHODS

### 2.1 STUDY AREAS AND INTERVIEWS

This study was conducted in the southern section of the Espinhaço Mountain Range, in the state of Minas Gerais, Brazil. It focused on two state parks: the Rio Preto (RPSP – created by State Decree #35.611 of June 1st 1994) and Serra Negra (SNSP, created by State Decree #39.970 of September 22nd 1998). They are located respectively in the counties of São Gonçalo do Rio Preto and Itamarandiba (Image 1). Both parks were included in a collective management arrangement called “The Conservation Unit Mosaic of Alto do Jequitinhonha – Serra do Cabral”, along with 10 other PAs. The study area is located near the headwaters of the Jequitinhonha River, commonly known as Alto Jequitinhonha.



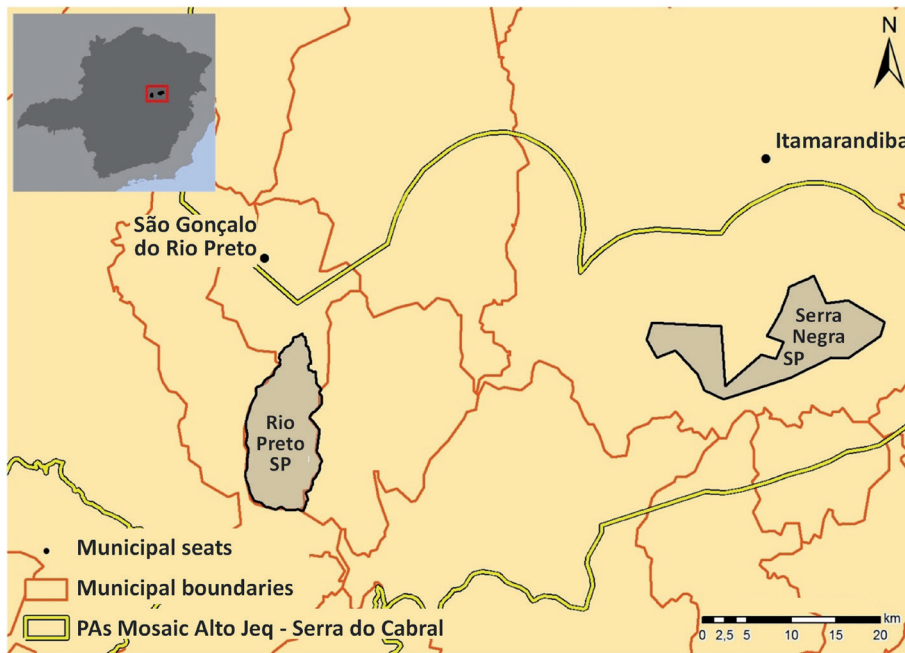


Image 1 | Location of the Rio Preto and Serra Negra State Parks, state of Minas Gerais, Brazil.

Sources: IBGE; IEF; Instituto Biotrópicos, (2013).

Several reasons explain why these two PAs were selected for this study (Ribeiro, 2013). First, they are state units that belong to the same class of PAs; second, their dates of implementation are close to each other (RPSP – 1994; SNSP – 1998); third, both belong to the aforementioned mosaic (established by the Ministry of Environment by Ordinance #444, of November 26th 2010); fourth, they are inserted in differing institutional contexts. This study found that these institutional differences led the parks to reach different results until 2012 in their common goal of environmental conservation.

To analyze the context of the two PAs, we considered the regional political situation, the *Instituto Estadual de Florestas de Minas Gerais* (IEF – Minas Gerais State Forestry Institute), and the *Secretaria de Estado do Meio Ambiente e Desenvolvimento Sustentável de Minas Gerais* (SEMAD – Minas Gerais State Secretariat of the Environment and Sustainable Development). The first round of interviews was conducted between May and June 2012, in Belo Horizonte, the state capital. Interviewees were academics from the UFMG (Federal University of Minas Gerais) engaged in research in the study area; employees of the IEF central office (Department of Protected Areas Creation, Department of Conservation Units, and Regional Coordination of Conservation Units); and employees of the Environment Department of the Agricultural Workers Federation of the state of Minas Gerais (FETAEMG – a workers' union).

A second round of interviews was conducted between July and August 2012 in the municipalities of Diamantina, São Gonçalo do Rio Preto, and Itamarandiba. Interviewees were academics from UFVJM (Federal University of the Valleys of Jequitinhonha and Mucuri) who conduct research in the area; members of the NGO *Biotrópicos*; IEF employees (management, inspectors, and park rangers of the RPSP; managers of the SNSP; employees of the IEF office in Itamarandiba); the president of the Itamarandiba Rural Workers Union; and farmers from communities located on the borders and inside both PAs.

The purpose of the interviews was to understand the creation processes of the two PAs (motivations, community-park relationships, community organizations) and to identify the institutions that influenced these processes. They also sought to pinpoint the characteristics of the surrounding communities, identify the natural resources used locally, check the makeup of the parks' advisory councils, evaluate the degree of formalization of a proposed biosphere reserve in the study area, evaluate the viability and workings of the mosaic, and examine the impacts of and incentives for regional tourism. We chose to omit the names of the interviewees, clarifying the relevance of each of them in the context of the research.

### 3 LAND USE MONITORING

To monitor land use in the PAs under analysis, images generated by the Thematic Mapper (TM), based on the Landsat 5 platform, were selected and obtained free of charge on the INPE website<sup>3</sup>, in September 2012. The images are from the years 1986 and 1992, generated between the months of August and October. One scene was selected for each year analyzed. These dates were chosen in order to compare two moments prior to the creation of the studied PAs.

Access to the database called *Inventário Florestal da Flora Nativa e dos Reflorestamentos de Minas Gerais* ("Forest Inventory of the Native Flora and of the Tree Plantations of the State of Minas Gerais") (Scolforo and Carvalho, 2006) was granted by the IEF, along with the agency's land use classification referring to 2003, 2005, 2007, and 2009. Only data referring to 2003 and 2009 were used in our research, in order to have four different dates with a consistent distribution inside the period of time under study (1986, 1992, 2003, and 2009).

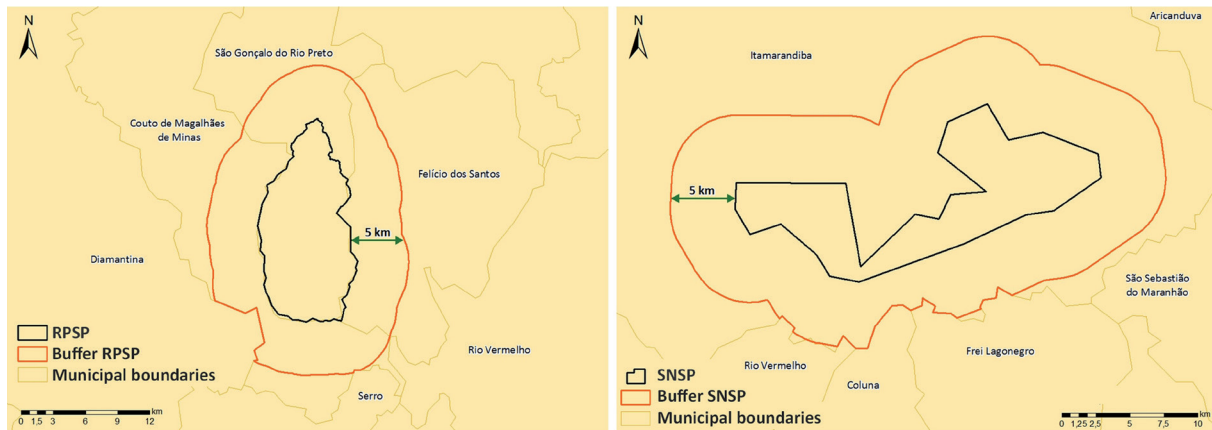
Unsupervised image classification was performed with the aid of the ERDAS Imagine program. This was complemented by the visual adjustment of classes. Forty clusters were defined for our research. Grouping based on spectral similarities resulted in two classes of soil use: native landscapes (NL) and cultural landscapes (CL). Native landscapes, as the term implies, are those not altered by human action. Cultural landscapes encompass the several formations shaped by human actions capable of transforming the natural environment (Corrêa, 1995).

Classifications obtained from the *Inventário Florestal...* went through a generalization that reduced its original classes to NL and CL, as well as the images selected for this research. The original classes converted to CL were: eucalyptus, pine, urbanization and "other" – a class that encompasses anthropic uses such as farming areas and roads. According to Lange and Blaschke (2009), although there are few standardized solutions to monitor and analyze changes in land use, they must be based on images generated by the same sensor, they must be selected considering close temporal intervals, and they must adopt the same classification methodology.

Due to the insufficient availability of images, it was not possible to apply the same classification method to all scenes. This limitation was taken into account when analyzing the results and does not affect them or the validity of the methodology. The official data of the aforementioned *Inventário Florestal...*, although not available for all the years under study, served as a basis for checking classifications for previous years, through visual inspection of the reflectance patterns of each class of the Landsat 5 images corresponding to the classified years. This procedure also ensured the standardization of classifications.

When research was conducted, the RPSP had a management plan indicating its buffer zone; the SNSP did not have such a plan. Thus, in order to define the area of analysis around the PAs, a buffer swath with a width of 5 kilometers was defined. This dimension was arbitrated as a conservative estimate based on the CONAMA (National Environment Council) Resolution # 426, of November 26, 2010, which defines a buffer zone of 3 kilometers wide for PAs lacking a management plan (INSTITUTO CHICO MENDES, 2010). The buffer zone is a swath defined around the borders of PAs in which there are restrictions to human uses and activities, aiming to reduce negative impacts on protected areas (Brasil, 2000).

In the case of the SNSP, the polygon generated by the arbitrated buffer zone touched small portions of the municipalities of Rio Vermelho, Coluna, and Frei Lagonegro. Adjustments were made so that the area under analysis was limited to the municipality of Itamarandiba, because it was found in the field that the three other neighboring municipalities, despite being close to the park, are not influenced by its situation (Image 2).



**Image 2 |** Rio Preto and Serra Negra State Parks, including demarcated areas and buffer zones.

Source: IBGE, IEF (2013).

In the case of the RPSP, the buffer zone reached the municipalities of Diamantina and Serro, not included in the park's management plan as part of its area of influence. In order to avoid including areas not relevant to the analysis, the polygon was also corrected to affect only the municipalities of São Gonçalo do Rio Preto, Couto de Magalhães de Minas and Felício dos Santos (Image 2). The areas analyzed for each park were 41,293 hectares (RPSP) and 54,384 hectares (SNSP). All processing considered these polygons as the areas to be analyzed in each park.

To quantify land use changes, the chosen tool was the extension of the ArcGis program called LUCAT (Land-Use Change Analysis Tools), developed by the *Laboratório de Hidrologia Florestal* (Laboratory of Forest Hidrology) of the Department of Forest Science, linked to the Luiz de Queiroz School of Agriculture.<sup>1</sup> This tool makes it easy to measure the proportion and the amount of each use class in the landscape. These measurements make it possible to automatically obtain the variation of each class of landscape use in a given period of time (Ferraz et al., 2009). Soil use changes were analyzed for the intervals 1986 - 1992, 1992 - 2003, and 2003 - 2009.

## 4 LAND USE TRENDS

To identify trends in land use, the chosen software was IDRISI Selva (EASTMAN, 2012) and its land use change modeling module called Land Change Modeler (LCM). The purpose was to obtain a scenario in which the PAs did not exist, in order to check if there is a measurable effectiveness of the PAs' conservation goals.

In the model adopted here, the variables selected to explain land use change were (i) proximity among deforestation activities between 1986 and 1992, (ii) terrain slopes, (iii) trends in land use changes between 1986 and 1992, and (iv) terrain elevation. These variables had their explanatory powers<sup>2</sup> tested by a specific tool within LCM before selection, aiming to check the weight of their correlation with the causes of soil use change. Results reached a 70% accuracy rate, i.e., the model correctly predicted future soil use in 70% of the area under analysis.

In order to validate the model generated by the LCM, a new classification was made in reference to a date subsequent to the creation of the parks. The chosen images were generated in 1994 and were interpreted based on Landsat 5 TM images, following the same methodology used in the images for 1986 and 1992.

Modeling was done initially for 1994. The result was compared to the 1994 classification, in order to check the validity of the model. A null model was also generated, in which land uses in 1994 and 1992 were compared. The purpose of this analysis was to check if the model generated by LCM predicted

the vegetation cover of 1994 more accurately than the comparison with the vegetation cover of 1992. In other words: could the model understand how the landscape would be in 1994? Or, would the percentage of correctness be higher, considering that there has been no change since 1992 (stationary model)?

## 5 RESULTS AND DISCUSSION

### 5.1 INTERVIEWS

Municipalities that contain the studied PAs originated from mining activities, which historically shaped the occupation of the region. São Gonçalo do Rio Preto was founded around 1820, when a small village formed around the church, on the banks of the Preto River (SEMAD, 2004). Itamarandiba, formerly São João Batista, is older: It was founded by colonizers in the 17th century (Prefeitura Municipal de Itamarandiba, 2012).

The RPSP was created in the 1980s, as a consequence of the convergence the local population's interests in protecting natural resources, on the one hand, and the priorities of the state agency in charge of the area's conservation, on the other. Interviewees informed that local communities supported the creation of the park, that a management plan was being drafted, and that the local population participated in planning events.

In the case of the SNSP, little information is available from printed sources. All information presented herein was collected in the field. Ever since its creation, in 1998, the park's management had to deal with the controversial issue of establishing its limits. In 2012, about 160 families were still residing in inside the park. Lack of land tenure titles and lack of government resources to compensate families slated for removal created a conflict between land owners and squatters, on the one side, and park managers on the other (ALMG, 2010).

In addition to the different manners by which the proposals of each park reached the environmental agency and to the different implementation procedures, there was a clear contrast between one area with arable land and another area with poor soils, used only or mainly for the collection of natural resources in a common use regime. In the SNSP, where environmental relevance and the possibility of land use coexist, there was a conflict over the human occupation of the PA. In the RPSP, the ecological importance of the area is not associated with the possibility of agricultural exploration, minimizing competition over resources. Further detail about the context of the creation of both PAs and about the patterns of resources use in the area is provided in Ribeiro et al. (2018) and Ribeiro (2013). The research that originated this paper encompasses the period before the creation of the parks until the end of 2012.

### 5.2 MONITORING OF SOIL COVERAGE

Landsat 5 classified images and classification published in the *Inventário Florestal...* resulted in the cover percentages presented in Table 1.

**Table 1 |** Percentage of native floral cover in the Rio Preto and Serra Negra State Parks, 1986, 1992, 2003, and 2009.

|                | <i>classifications</i> | <i>1986</i> | <i>1992</i> | <i>2003</i> | <i>2009</i> |
|----------------|------------------------|-------------|-------------|-------------|-------------|
| RIO PRETO SP   | native landscapes      | 64%         | 61%         | 69%         | 69%         |
|                | cultural landscapes    | 36%         | 39%         | 31%         | 31%         |
| SERRA NEGRA SP | native landscapes      | 62%         | 58%         | 63%         | 61%         |
|                | cultural landscapes    | 38%         | 42%         | 37%         | 39%         |

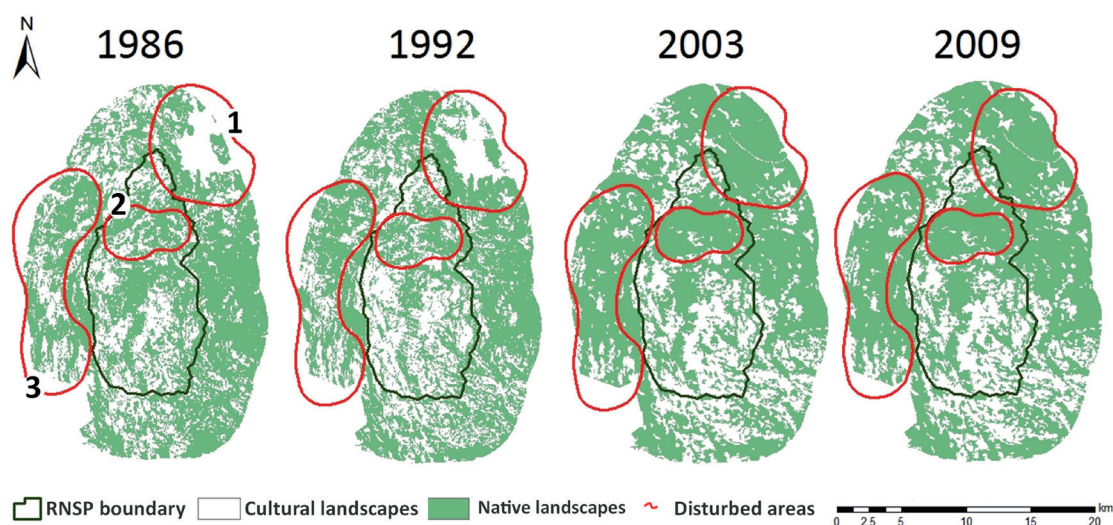
*Source: Ribeiro (2013).*

### 5.2.1 RIO PRETO STATE PARK

Quantification of vegetation in the RPSA shows its efficiency in maintaining native vegetation. Between 1992 and 2009, the percentage of native vegetation cover increased by about 8%, equivalent to 3,785 hectares.

Regarding the areas classified as CL, a methodological caveat is required. Some of these areas are actually rocky outcrops. These areas have no vegetation cover. In this text, we sought to take advantage of the official data of the *Inventário Florestal...*, which focused on plant species. The methodological choice was to maintain areas with rocky outcrops as CL. Considering that vegetation cover can vary in the landscape, but that this never happens in rocky outcrops, the latter have not changed over time nor appear in the monitoring as a decline of the native vegetation.

Image 3 shows landscape changes in RPSA and surrounding areas in the years under study.



**Image 3** | Soil cover changes in the Rio Preto State Park and surrounding area between 1986 and 2009.

Source: IEF (2013).

The areas circled in red in Image 3 are those that had the strongest increases in native vegetation during the period under study. The area marked with the number '1' was classified as CL, because in the years studied (1986 and 1992) their orbital images displayed burning scars. This same encircled area is crossed by the only road in the study area. It connects downtown São Gonçalo do Rio Preto to the RPSA.

This unpaved road runs parallel to the Preto River for a few kilometers. The recovery of this area's vegetation probably resulted from the park's creation. A recurrent comment made by interviewed local residents and landowners was that inspection enforcement was strengthened after the creation of the park. Comparing pre- and post-park landscapes, this is confirmed, since area '1', in addition to being included in the management plan as a buffer zone, is characterized as APP<sup>3</sup> (permanent preservation area), as it lies along a river (Brasil, 2012). Another possible explanation for the recovery of this area is the increase in tourism focused on the Preto River. Interviewed residents of local communities reported the arrival of people from other municipalities who buy land along the banks of the Preto River for recreational use. According to them, after the creation of the RPSA, lands closest to the river became highly valued, giving rise to opportunities for former residents to sell parts of their properties at good prices.

In Image 3, the area circled with the number '2' also experienced an increase in native vegetation. This area corresponds to the park's "intensive use" area, where campsites, visitor lodging, a restaurant

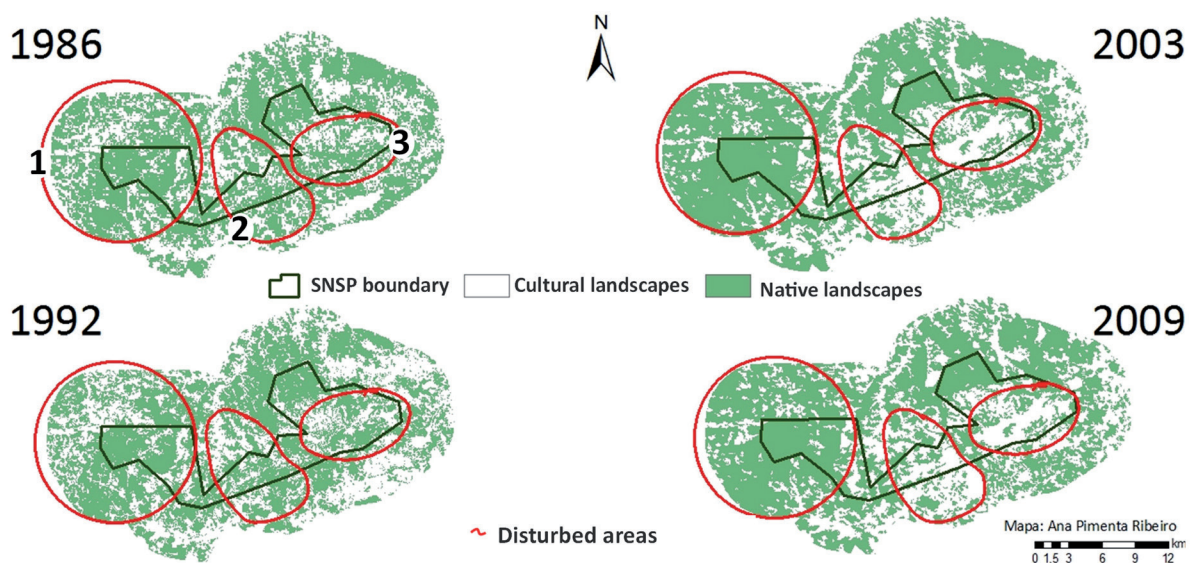
and the visitor center are located. Before the creation of the RPSP, this area hosted charcoal kilns, a definite clue of native vegetation cutting. The campsite is located in the former corral of the Boleiras Farm. The IEF architect responsible for the park's buildings informed that its "intensive use" zone was plotted in this point in order to take advantage of areas in which the native *cerrado* vegetation had been significantly altered and to build facilities necessary for the PA's operation. It is remarkable that native vegetation made a comeback in this section despite previous uses and despite the RPSP itself.

Examining the circled area number '3' in Image 3, we see that it was also affected by a considerable regeneration of native vegetation. Factors mentioned in the case of the '1' area, such as stronger inspection over the opening of cultivation fields and vegetation burning, are probable reasons for regeneration in area '3'. However, a factor specific to this area, which lays within the municipality of Couto de Magalhães de Minas, is the presence of another PA, the Rio Manso Área de Proteção Ambiental (environmental preservation area - APA, an official PA category). It was created by the municipal government. Although APAs allow the sustainable use of their areas, the presence of this APA may have restricted deforestation in area '3'.

### 5.2.2 SERRA NEGRA STATE PARK

As shown by the data in Table 1, until 2003 the vegetation cover of the SNSP followed the same trend as the RPSP: native vegetation shrunk between 1986 and 1992 and increased between 1992 and 2003. However, in the case of the SNSP, between 2003 and 2009 the native floral cover decreased slightly, while in the RPSP it remained constant. Image 4 shows these changes.

Fluctuations in vegetation cover shown in Table 1, when superimposed on information collected in field interviews, shape a remarkable scenario. A common observation came out of the interviews conducted with the representative of the Rural Workers Union of Itamarandiba and those conducted with IEF employees (both from the local office and the central office in Belo Horizonte) about the SNSP's implementation. According to interviewees, after the park's creation (1998), there was a period of stagnation until it was set up. This stagnation lasted until 2007, when the team responsible for demarcating the unit's boundaries informed landowners that the area had become a park and that they would be expropriated soon, receiving compensation for their properties.



**Image 4** | Soil cover changes in the Serra Negra State Park and surrounding area between 1986 and 2009.

*Source: IEF, Ribeiro (2013).*

Some farmers abandoned their properties after learning this, because they believed that the compensation would follow soon. The park lies in a transition area between the Cerrado biome and the Atlantic Forest biome (the latter is protected against various types of use by Law 11.428, of December 22, 2006). This area has available water, fertile soils and fragments of native vegetation that function as sources of seeds and propagules of native species. It also hosts the fauna that can carry out seed dispersion, which means that the recovery of native vegetation tends to happen quickly. The aforementioned law stipulates that fragments of regenerating Atlantic Forest, even if they have only non-woody pioneer species, cannot be cut (Brasil, 2006). The fact that these regenerating fragments lie within a protected area further restricts cutting, even outside the Atlantic Forest domain. As the park's implementation lingered, in 2010 farmers formed an association to request compensation or permission to start cultivating their lands again.

Comparing the history of conflicts generated by the creation of the SNSP with the history of local land use, the facts reported by interviewees and the history of landscape changes fit each other quite well. Although the percentage of the area covered by native vegetation expanded between 1992 and 2003, this period coincides in part to the lack of park implementation – the park was created in 1998. In the following period, 2003 to 2009, when the park agency officially informed the local population about the park's existence and about restrictions to the opening of new agricultural areas, the regrowth of native vegetation cover could be expected. However, this did not happen, maybe because there was no time for such a recovery to be captured by the 2009 images.

Among the areas marked in Image 4 as having gone through the strongest change in the SNSP landscape in the years under study, only the reduction of native vegetation cover in area number '2' can be associated with an impacting anthropic factor - a road. A state highway cuts through the park's narrower portion. In several cases, mainly in the Brazilian Amazon region, roads are a typical factor in the expansion of human occupation and productive activities - including deforestation (Brondizio et al., 2009; Li et al., 2019). Areas '1' and '3' correspond to the SNSP's highest altitudes.

Some hypotheses can be proposed about changes in the SNSP landscape. First hypothesis: Despite being used traditionally in landscape monitoring and having achieved relevant results in the RPSP, the methodology adopted in our research may not be adequate to capture the relationship between changes in the landscape and human actions. This may be checked by a study that uses orbital images with a higher resolution.

Second hypothesis: the population did not feel the effect of the PA and therefore the PA did not lead to changes in land uses. In other words: the effect of the park's creation was not reflected in changes in the landscape. Indeed, there was a small variation in the percentage of native vegetation cover, but this could be caused by the traditional management system of the environment employed by populations residing in the PA and its surroundings.

Third hypothesis: given the emerging effects of the growth of economies of scale in agriculture, the reduced gains from small-scale agriculture, the relative aging of the rural population, and the growth of social programs such as rural retirement and Bolsa Família,<sup>4</sup> there could be a reduction in cultivated areas leading to the increase of areas with native landscapes, conserved "structurally" by encompassing socioeconomic circumstances.

## 6 LANDSCAPE USE PROJECTIONS

The image generated by the model for 1994 was compared to the Landsat 5 image classified for the same year. According to Pontius et al. (2004), comparison between the image generated by the model and the real classification ( $T_{2R}$  – image of time  $T_2$  generated from the Landsat image classification) by itself does not guarantee the validity of the model. There is no universally accepted criterion for

assessing the validity of a land use prediction model. In this same work, the authors suggest that it is of central importance in any validation process to compare the  $T_{2R}$  image to the classified image that was the basis of the model's creation ( $T_{1R}$  - image of time  $T_1$  generated from Landsat classification image). The landscape generated by the model ( $T_{2M}$  - image of time  $T_2$  generated by the model) must be closer to  $T_{2R}$  than to  $T_{1R}$ , thus justifying the use of the model. Here,  $T_1$  was considered as the year 1992 and  $T_2$  the year 1994.

The result of the comparison between vegetation cover in image  $T_{2R}$  with image  $T_{2M}$  was a coincidence of 70%. The null model (comparison of image  $T_{2R}$  to image  $T_{1R}$ ) resulted in a correctness of 61%. In other words, the generated model made a better explanation landscape changes occurring between  $T_1$  and  $T_2$  than the null model. For the purpose of our study, the model's percentage of correctness was considered satisfactory, despite being lower than the percentages obtained by other studies that used LCM and different validation methods (see Faleiro et al., 2013).

## 6.1 RIO PRETO STATE PARK

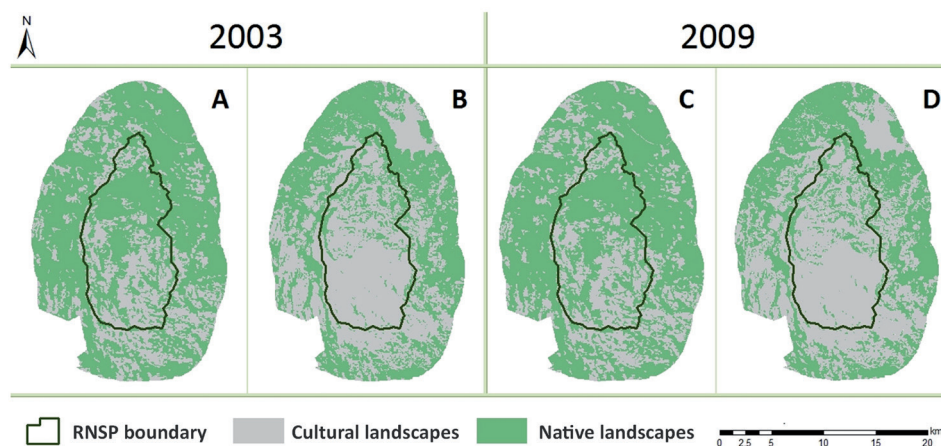
The values of the estimated extension of native cover in the RPSP for the years 2003 and 2009 are shown in Table 2.

**Table 2 |** Comparison between the native vegetation cover of the official classification (Official Native Percentage - ONP) and the native vegetation cover estimated by the model (Estimated Native Percentage - ENP) applied to the Rio Preto State Park.

|         | 2003 | 2009 |
|---------|------|------|
| NPO     | 69%  | 69%  |
| NPE     | 47%  | 45%  |
| NPO-NPE | 22%  | 24%  |

Source: Ribeiro (2013).

According to the model generated for the RPSP and its surrounding area, in a scenario in which the park did not exist the native vegetation cover in the area would be around 47% in 2003 and 45% in 2009. According to the model, the existence of the park guaranteed the conservation of 24% of native vegetation cover until 2009. Image 5 shows the classifications and projections for each year. This result indicates that the PA is fulfilling its function of conserving native vegetation, because if the trend of land use prior to its creation continued, almost a quarter of the area under analysis would have been converted into a cultural landscape by 2009.



**Image 5 |** Comparison between landscapes obtained by the *Inventário Florestal de Minas Gerais* (A and C) and landscapes generated by the Land Change Modeler (B and D) in the Rio Preto State Park.

Source: IEF, Ribeiro (2013).



Analyzing the landscapes used in the construction of the model, there was a 3% reduction in native cover between 1986 and 1992 (Image 3). The cover projection is not computed solely on the base of this information. The other variables used in the construction of the model are also included in the determination of this future landscape.

Connecting this data to the region's history, it is clear that the conservationist trend, which emerged in the municipality of São Gonçalo do Rio Preto in the late 1980s and resulted in the creation of the PA in 1994, possibly had no direct effect - or maybe such an effect could not have been captured - on landscape changes between 1986 and 1992. The movement to protect the Preto River came about from the initiative of the urban population of the municipality of São Gonçalo do Rio Preto, but neighboring farmers did not participate in the movement for the creation of the RPSP or in the definition of its limits.

## 6.2 SERRA NEGRA STATE PARK

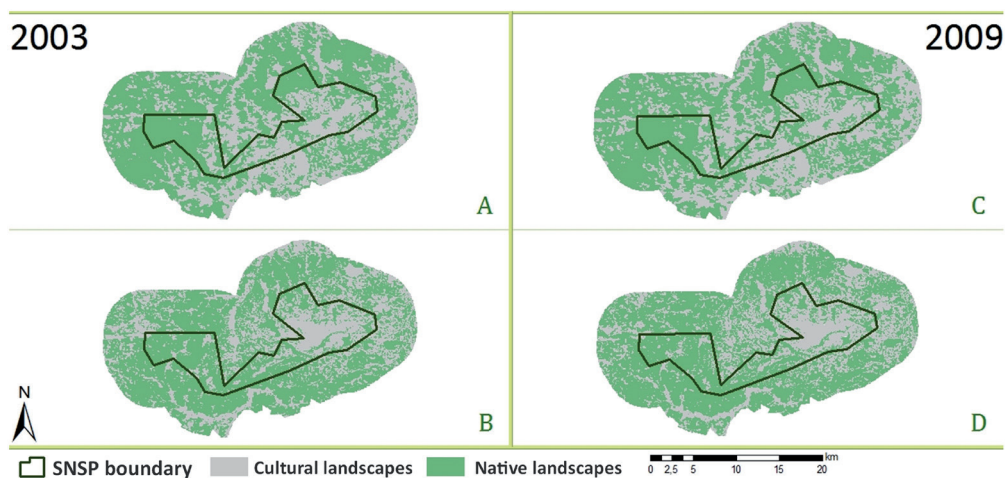
Native cover data estimated by the model for the SNSP is shown in Table 3.

**Table 3 | Comparison between the native vegetation cover of the official classification (Official Native Percentage - ONP) and the native vegetation cover estimated by the model (Estimated Native Percentage - ENP) applied to the Serra Negra State Park.**

|         | 2003 | 2009 |
|---------|------|------|
| NPO     | 63%  | 61%  |
| NPE     | 65%  | 66%  |
| NPO-NPE | -2%  | -5%  |

Source: Ribeiro (2013).

The images generated by the model indicated that, without the existence of the park, the landscape's native coverage would have been about 2% greater in 2003 and 5% greater in 2009 (Image 6). This difference is equivalent to a deficit of more than 2,700 hectares of native vegetation for the year 2009. The result indicates that the SNSP has not been fulfilling its role of maintaining native vegetation, because the projection that does not consider the existence of the park estimated that, in its absence, there would be a more extensive native vegetation cover. Problems in the establishment of the park's boundaries, the way these limits were established, and IEF's delay in 'taking over' the park may have conditioned this result. Schleicher et al. (2019) obtained similar results, identifying lack of inspection and lack of proper land entitlement as major challenges in PA management.



**Image 6 | Comparison between landscapes obtained by *Inventário Florestal de Minas Gerais* (A and C) and landscapes generated by Land Change Modeler (B and D) in the Serra Negra State Park.**

Source: IEF, Ribeiro (2013).

Another inference emerges from this diagnosis. The magnitude of these differences, 2 and 5%, shows that the land use trend between 1986 and 1992 in the RPSP, analyzed by the model, caused considerably less impact on vegetation cover when compared to the trend recorded in the SNSP. For the SNSP, the trend would lead to an increase in native vegetation, which would grow from 58% in 1992 to 65% in 2003. The model resulted in a landscape with a tendency for recovery in the years to come.

Analyzing the effectiveness of parks in conserving biodiversity in tropical regions, Bruner et al. (2001) found that the number of people residing inside the PAs did not have a positive correlation with PAs' effectiveness. Despite this finding being questioned by ecological scientific bases (Françoso et al., 2015) such as in the Cerrado, where opportunities for conservation are rapidly diminishing. We evaluate how different categories of protected areas (PAs, the authors concluded that effectiveness was strongly correlated with the number of PA employees, for example. Bruner et al. (2001) also showed that 17% of the sampled parks (23 years old, on average) experienced net losses in vegetation cover after the installation of the PAs. The trends identified in the SNSP are in line with these findings and those of several authors (such as Engen et al. 2018; Schleicher et al. 2019; Young et al. 2020), because the impact of the resident population inside the park was small, despite losses in native vegetation.

In the case of the SNSP, the families interviewed during our field research and their representative in the local Rural Workers Union revealed that they maintain a close connection with their environment, practicing low-impact agriculture, as reported by GALIZONI (2007). Even with the impossibility of opening new areas for cultivation and with the need to keep previously cleared land in cultivation, the trends in landscape use remained practically unchanged. Guadilla-Sáez et al. (2020) obtained results that follow the same logic, observing the effect of replacing traditional community governance in an area of common use in Spain: state intervention destabilized a management system that had worked well since the Middle Ages. Management that involves traditional communities, using local solutions, is more likely to solve conflicts around PAs (Branco et al., 2020).

Research in LUCC allows us to understand interactions between different components of the process. Brondizio et al. (2009) sustain that there is a direct link between the communities' economic / cultural / social context and the 'mark' that they leave on landscapes - in this case, the 'mark' is the product captured by the orbital images. Integrating field research with remote sensing techniques allows us to produce an explanation of the whole that would not be possible if only one of the two 'techniques' were to be applied separately. This allows for a deeper and more complex understanding of the processes that communities go through and the specific needs of each one of them. However, on their own, data about LUCC do not help understand the processes and causes of changes (Lambin et al., 2001).

## 7 FINAL REMARKS

Landscape changes in the period under study, inferred from images and their treatment, corroborated field studies that have found an increase in the population's perception of environmental problems and more severe direct control over deforestation and fires in the municipality of São Gonçalo do Rio Preto after the creation of the RPSP (Ribeiro et al., 2018). As for the SNSP, few relationships were found. This may be due to the scale used in our research. A major challenge is to integrate the local view scale - characteristic of field-based social science studies - with a more regional and global view, commonly used in the ecological and biophysical sciences. The strength of studies about land use change lies in the ability to integrate different areas of knowledge and their different theoretical and methodological approaches.

If, on the one hand, modeling results indicated the effectiveness of the RPSP in the conservation of local native vegetation, on the other hand there was also evidence that the pre-existing local trend of degradation of natural resources was changed after the PA's installation. One factor that may have influenced the identification of this trend was the failure to identify the rocky outcrops (that we classified as CL) and that the model understood as a product of human action, thus reinforcing the

alteration trend. A new classification that includes the detailed identification of outcrops must be made to test whether their size and their representativeness in the landscape really change the projections.

A future analysis that can complement the present study is the construction of models that (i) isolate PA areas from their surroundings and (ii) use more recent data that allow capturing the context. Quantifying and understanding trends and checking for differences in this area can improve the model and bring valuable information for understanding interactions between local populations and their natural environments.

*The research that generated these results was funded by Brazil's CNPq Foundation (Conselho Nacional de Pesquisas) and by the European Union, through the FP7 – 2010, under accord #o SSH-CT-2010-266710.*

## NOTES

1 | CNPq Foundation (Brazil' National Research Council) A previous version was presented at the conference entitled "VI Seminário Brasileiro and I Encontro Latino-Americano Sobre Áreas Protegidas e Inclusão Social" (Belo Horizonte - Brazil, September 2013). A summary was presented at the IALE European Congress 2017" (Ghent - Belgium). The annals of both events published this previous version.

2 | The years that demarcate the intervals are 1986, 1992, 2003 e 2009.

3 | INPE is the *Instituto Nacional de Pesquisas Espaciais*, Brazil's federal agency in charge of space science. Then selected images were obtained at <http://www.dgi.inpe.br/CDSR/>

3 | Further information available at <http://goo.gl/s5Tla>

4 | Ability of the variable to explain the occurrence of land use change.

5 | Brazilian forest use legislation defines several types of "APPs" to be found - and preserved - inside in all private and public rural properties. Swaths along rivers banks are one of these types; hilltops, steep slopes, lake borders, mesa edges and mangroves are some of the other types.

6 | *Bolsa Família* is an income transfer program created by the federal government in 2004. It targets Brazilians who have the lowest levels of family per capita income. Currently the program benefits more than 11 million families.

## REFERENCES

ALMG. **Notas taquigráficas da 28a Reunião Ordinária da Comissão de Direitos Humanos**, 2010.

BRANCO, P.S., MERKLE, J.A., PRINGLE, R.M., KING, L., TINDALL, T., STALMANS, M., LONG, R.A. **An experimental test of community-based strategies for mitigating human-wildlife conflict around protected areas**. *Conserv. Lett.* 13. <https://doi.org/10.1111/conl.12679>, 2020.

BRASIL, **LEI No 12.651**, DE 25 DE MAIO DE 2012.

BRASIL, **Lei no 11.428**, DE 22 DE DEZEMBRO DE 2006. Dispõe sobre a utilização e proteção da vegetação nativa do Bioma Mata Atlântica, e dá outras providências, 2006.

BRASIL, **LEI No 9.985**, DE 18 DE JULHO DE 2000. Art. 2o, paragrafo XVIII, 2000.

BRONDIZIO, E.S., OSTROM, E., YOUNG, O.R., 2009. **Connectivity and the Governance of Multilevel Social-Ecological Systems**: The Role of Social Capital. *Annu. Rev. Environ. Resour.* 34, 253–278. <https://doi.org/10.1146/annurev.environ.020708.100707>, 2009

BRUGGER, S.O., GOBET, E., VAN LEEUWEN, J.F.N., LEDRU, M.-P., COLOMBAROLI, D., VAN DER KNAAP, W.O., LOMBARDO, U., ESCOBAR-TORREZ, K., FINSINGER, W., RODRIGUES, L., GIESCHE, A., ZARATE, M., VEIT, H., TINNER, W. **Long-term man-environment interactions in the Bolivian Amazon**: 8000 years of vegetation dynamics. *Quat. Sci. Rev.* 132, 114–128. <https://doi.org/10.1016/J.QUASCIREV.2015.11.001>, 2016.

BRUNER, A.G., GULLISON, R.E., RICE, R.E., DA FONSECA, G.A.B. Effectiveness of parks in protecting tropical biodiversity. *Science* (80-. ). 291, 125–128. <https://doi.org/10.1126/science.291.5501.125>, 2001.

CARRANZA, T., MANICA, A., KAPOV, V., BALMFORD, A. **Mismatches between conservation outcomes and management evaluation in protected areas: A case study in the Brazilian Cerrado.** *Biol. Conserv.* 173, 10–16. <https://doi.org/10.1016/J.BIOCON.2014.03.004>, 2014.

CORRÊA, R.L. A dimensão cultural do espaço: alguns temas. *Espaço e Cult.* 1–22, 1995.

EASTMAN, J.R. IDRISI *Selva*, 2012.

ENGEN, S., RUNGE, C., BROWN, G., FAUCHALD, P., NILSEN, L., HAUSNER, V. Assessing local acceptance of protected area management using public participation GIS (PPGIS). *J. Nat. Conserv.* 27–34, 2018.

FALEIRO, F. V., MACHADO, R.B., LOYOLA, R.D. **Defining spatial conservation priorities in the face of land-use and climate change.** *Biol. Conserv.* 158, 248–257. <https://doi.org/10.1016/j.biocon.2012.09.020>, 2013.

FERRAZ, S.F. DE B., VETTORAZZI, C.A., THEOBALD, D.M. **Using indicators of deforestation and land-use dynamics to support conservation strategies: A case study of central Rondônia, Brazil.** *For. Ecol. Manage.* 257, 1586–1595. <https://doi.org/10.1016/J.FORECO.2009.01.013>, 2009.

FRANÇOSO, R.D., BRANDÃO, R., NOGUEIRA, C.C., SALMONA, Y.B., MACHADO, R.B., COLLI, G.R. Habitat loss and the effectiveness of protected areas in the Cerrado Biodiversity Hotspot. *Nat. Conserv.* 13, 35–40. <https://doi.org/10.1016/J.NCON.2015.04.001>, 2015.

GALIZONI, F.M. **A terra construída: família, trabalho e ambiente no Alto do Jequitinhonha, Minas Gerais.** Editora do Banco do Nordeste, Fortaleza, 2000.

GUADILLA-SÁEZ, S., PARDO-DE-SANTAYANA, M., REYES-GARCÍA, V. Forest commons, traditional community ownership and ecological consequences: Insights from Spain. *For. Policy Econ.* 112, 102107. <https://doi.org/10.1016/J.FORPOL.2020.102107>, 2020.

HERINGER, G., ALMEIDA, T.E., DITTRICH, V.A. DE O., SALINO, A. Assessing the effectiveness of protected areas for the conservation of ferns and lycophytes in the Brazilian state of Minas Gerais. *J. Nat. Conserv.* 53, 125775. <https://doi.org/10.1016/J.JNC.2019.125775>, 2020.

INSTITUTO CHICO MENDES. **Conama aprova regulamentação de zona de amortecimento de unidades de conservação** [WWW Document]. Portal Bras. URL <http://goo.gl/UyhYW> (accessed 12.30.12), 2010.

KUGLER, T.A., GRACE, K., WRATHALL, D.J., DE SHERBININ, A., VAN RIPER, D., AUBRECHT, C., COMER, D., ADAMO, S.B., CERVONE, G., ENGSTROM, R., HULTQUIST, C., GAUGHAN, A.E., LINARD, C., MORAN, E., STEVENS, F., TATEM, A.J., TELLMAN, B., VAN DEN HOEK, J. **People and Pixels 20 years later: the current data landscape and research trends blending population and environmental data.** *Popul. Environ.* 41, 209–234. <https://doi.org/10.1007/s11111-019-00326-5>, 2019.

LAMBIN, E.F., TURNER, B.L.L., GEIST, H.J., AGBOLA, S.B., ANGELSEN, A., BRUCE, J.W., COOMES, O.T., DIRZO, R., FISCHER, G., FOLKE, C., GEORGE, P.S.S., HOMEWOOD, K., IMBERNON, J., LEEMANS, R., LI, X., MORAN, E.F., MORTIMORE, M., RAMAKRISHNAN, P.S.S., RICHARDS, J.F., SKÅNES, H., STEFFEN, W., STONE, G.D., SVEDIN, U., VELDKAMP, T.A., VOGEL, C., XU, J., BRUCE, J.W., COOMES, O.T., DIRZO, R., GEORGE, P.S.S., HOMEWOOD, K., IMBERNON, J., LEEMANS, R., LI, X., MORAN, E.F., MORTIMORE, M., RAMAKRISHNAN, P.S.S., RICHARDS, J.F., STEFFEN, W., STONE, G.D., SVEDIN, U., VELDKAMP, T.A. **The causes of land-use and land-cover change: moving beyond the myths.** *Glob. Environ. Chang.* 11, 261–269. [https://doi.org/10.1016/S0959-3780\(01\)00007-3](https://doi.org/10.1016/S0959-3780(01)00007-3), 2001.

LI, G., LU, D., MORAN, E., CALVI, M.F., DUTRA, L.V., BATISTELLA, M. **Examining deforestation and agropasture dynamics along the Brazilian TransAmazon Highway using multitemporal Landsat imagery.** *GIScience Remote Sens.* 56, 161–183. <https://doi.org/10.1080/15481603.2018.1497438>, 2019.

MORAN, E.F. **O desafio de pesquisa em interações homem-ambiente, in: Moran, E.F. (Ed.), Meio Ambiente e Ciências Sociais: Interação Homem-Ambiente e Sustentabilidade.** Senac, São Paulo, pp. 21–50, 2011.

PONTIUS, R.G., HUFFAKER, D., DENMAN, K., GILMORE, R., JR, P. Useful techniques of validation for spatially explicit land-change models. *Ecol. Modell.* 179, 445–461. <https://doi.org/10.1016/j.ecolmodel.2004.05.010>, 2004.

PREFEITURA MUNICIPAL DE ITAMARANDIBA. **Itamarandiba MG** [WWW Document]. URL <http://www.itamarandiba.mg.gov.br> (accessed 10.18.12), 2012.

RIBEIRO, A.P. **A caligrafia da sociedade na paisagem Transformações no entorno de unidades de conservação da Serra do Espinhaço – MG**. Universidade de Brasília - UnB. <https://doi.org/10.13140/2.1.4897.4726>, 2013.

RIBEIRO, A.P., DRUMMOND, J.A., RIBEIRO, E.M., CALDAS, A.L. **OS PARQUES E SEUS ENTORNOS: DOIS ESTUDOS DE CASO NO VALE DO JEQUITINHONHA MINEIRO**, in: XXI Encontro Nacional de Estudos Populacionais. Poços de Caldas - MG. <https://doi.org/978-85-85543-32-7>, 2018.

RIBEIRO, E.M., GALIZONI, F.M., CALIXTO, J.S., ASSIS, T.D.P., AYRES, E.B., SILVESTRE, L.H. **Gestão, uso e conservação de recursos naturais em comunidades rurais do Alto Jequitinhonha**. *Rev. Bras. Estud. Urbanos e Reg.* 7, 77. <https://doi.org/10.22296/2317-1529.2005v7n2p77>, 2005.

SCHLEICHER, J., PERES, C.A., LEADER-WILLIAMS, N. **Conservation performance of tropical protected areas: How important is management?** *Conserv. Lett.* 12. <https://doi.org/10.1111/conl.12650>, 2019.

SCHULZE, K., KNIGHTS, K., COAD, L., GELDMANN, J., LEVERINGTON, F., EASSOM, A., MARR, M., BUTCHART, S.H.M., HOCKINGS, M., BURGESS, N.D. **An assessment of threats to terrestrial protected areas**. *Conserv. Lett.* 11, e12435. <https://doi.org/10.1111/conl.12435>, 2018.

SCOLFORO, J.R., CARVALHO, L.M.T. **Mapeamento da Inventario Flora Nativa e dos Reflorestamentos de Minas Gerais**. Ed. UFLA, Lavras, Minas Gerais, 2006.

SEMAD. **Plano de Manejo do Parque Estadual do Rio Preto**. Curitiba, 2004.

SILVA, R.F.B. DA, BATISTELLA, M., MORAN, E.F. **Drivers of land change: Human-environment interactions and the Atlantic forest transition in the Paraíba Valley, Brazil**. *Land use policy* 58, 133–144. <https://doi.org/10.1016/J.LANDUSEPOL.2016.07.021>, 2016.

SILVEIRA, F.A.O., FERREIRA, M.C., PERILLO, L.N., CARMO, F.F., NEVES, F.S. **Brazil's protected areas under threat**. *Science* 361, 459. <https://doi.org/10.1126/science.aau4222>, 2018.

TUCKER, C.M., OSTROM, E. **Pesquisa multidisciplinar relacionando instituições e transformações florestais**, in: Moran, E.F., Ostrom, E. (Eds.), *Ecossistemas Florestais – Interação Homem-Ambiente*. Senac, São Paulo, pp. 109–138, 2009.

YOUNG, N.E., EVANGELISTA, P.H., MENGITSU, T., LEISZ, S. **Twenty-three years of forest cover change in protected areas under different governance strategies: A case study from Ethiopia's southern highlands**. *Land use policy* 91, 104426. <https://doi.org/10.1016/J.LANDUSEPOL.2019.104426>, 2020.

# Simulated deforestation versus satellite data in Roraima, Northern Amazonia, Brazil

*Desmatamento simulado versus dados de satélite em Roraima, extremo norte da Amazônia, Brasil*

Paulo Eduardo Barni<sup>a</sup>

Reinaldo Imbrozio Barbosa<sup>b</sup>

Antônio Ocimar Manzi<sup>c</sup>

Philip Martin Fearnside<sup>d</sup>

<sup>a</sup>*Universidade Estadual de Roraima, Rorainópolis, RR, Brasil  
E-mail: pbarni@uerr.edu.br*

<sup>b</sup>*Instituto Nacional de Pesquisas da Amazônia, Boa Vista, RR, Brasil  
E-mail: reinaldo@inpa.gov.br*

<sup>c</sup>*Instituto Nacional de Pesquisas Espaciais, Cachoeira Paulista, SP, Brasil  
E-mail: aomanzi@gmail.com*

<sup>d</sup>*Rede Brasileira de Pesquisas sobre Mudanças Climáticas Globais, Instituto Nacional de Pesquisas da Amazônia, Coordenação de Dinâmica Ambiental (CDAM), Manaus, AM, Brasil  
E-mail: pmfearn@inpa.gov.br*

doi:10.18472/SustDeb.v11n2.2020.27493

Received: 06/10/2019  
Accepted: 16/04/2020

ARTICLE- DOSSIER

## ABSTRACT

Scenario analyses of land-use and land-cover change in the Amazon are necessary steps to support decisions that can avoid the emission of millions of tons of CO<sub>2</sub> into the atmosphere. It is important to evaluate models that aim to simulate future scenarios. The present study evaluated scenarios generated for the 2011-2017 period in Roraima state, in northern Amazonia. Simulated deforestation was compared to PRODES satellite data. The mapping for the evaluations comprised (i) a “silvopastoral use area” (excluding indigenous lands, conservation units and non-forest areas) intersected with (ii) a grid of nine (9) 10,000-km<sup>2</sup> (100 × 100-km) sub-areas. The 2013 scenario had the greatest similarity (55.2%) with the corresponding PRODES map. Despite divergences between simulated deforestation in the scenarios and PRODES deforestation, the evaluations generally demonstrated the model’s validity and its ability to produce scenarios that realistically represent the deforestation that occurred in Roraima state during the analyzed period.

**Keywords:** Land-use change. Environmental modeling. Remote sensing. Amazon. Brazil.

## RESUMO

*Analises de cenários de mudança de uso e cobertura da terra na Amazônia são passos necessários para subsidiar decisões que podem evitar a emissão de milhões de toneladas de CO<sub>2</sub> para a atmosfera. Portanto, é importante avaliar modelos que visem a simulação de cenários futuros. O atual estudo avaliou cenários simulados no período 2011-2017, em Roraima, situado na porção norte da Amazônia brasileira. Comparou-se o desmatamento simulado com os dados de satélite do PRODES. O mapeamento para as avaliações compreendeu (i) uma Área de Uso Silvo-pastoril – AUS (excluindo terras indígenas, unidades de conservação e não floresta) intersectada com (ii) uma grade de 09 (nove) sub-áreas de 10.000 km<sup>2</sup> (100 × 100 km). O cenário de 2013 apresentou a maior similaridade (55,2%) com o mapa correspondente do PRODES. Apesar das divergências entre o desmatamento simulado nos cenários e o desmatamento oficial, no geral, as avaliações demonstraram a validade do modelo e a sua habilidade para gerar cenários que representam, de forma realística, o desmatamento ocorrido em Roraima no período analisado.*

*Palavras-chave:* Mudança de uso da terra, Modelagem ambiental, Sensoriamento remoto, Amazônia, Brasil.

## 1 INTRODUCTION

### DEFORESTATION ACTORS AND MOTIVES

#### ACTORS

Deforestation is done by a wide variety of actors for a wide variety of reasons. Roraima, located in the northern portion of Brazil's Amazon region, has almost all of the actors and processes that are present in other parts of the region, although the relative importance of each varies greatly in different parts of Amazonia and in different parts of the state of Roraima. Actors include migrants, that is, family farmers (small farmers) who come from other states to settle in Roraima. These are mostly individual migrants, although Roraima has had some activity by organized groups (“*sem-terras*”).

Many of these actors obtain lots in government “settlement projects” of different types (YANAI et al. 2017). However, deforestation expands further when squatters illegally occupy land beyond the settlement boundaries, often resulting in endogenous roads extending from the access roads (*vicinais*) in the official settlement projects. An example is an illegal road extending from access road No. 7 in the Jatapú Settlement project in Roraima's municipality of Caroebe (BARNI et al. 2012). Also important are actors with more wealth than the small farmers for whom settlement projects are created. These include an Amazon-wide pattern of wealthy newcomers purchasing multiple lots in a settlement project and operating them as a single medium or large landholding (FEARNSIDE 1986, 1989; CARRERO and FEARNISIDE 2011; YANAI et al. 2020).

Roraima also has its share of “grileiros,” or “land grabbers,” who illegally appropriate government land and usually later subdivide it for sale to others. Grileiros often use violence and threats of violence to remove other claimants, and can obtain official recognition of their claims through corrupt means (FEARNSIDE 2008a; TORRES et al. 2017). A series of recent laws now facilitates land grabbing, for example the limit on the area that can be “legalized” per claimant was increased from 100 ha to 1500 ha in 2009 by Law No. 11,952 (PR 2009), and in 2017 Law No. 13,465 increased this area to 2500 ha (PR, 2017).

Land grabbing is now further facilitated by a provisional measure (MP910) signed by President Bolsonaro on 10 December 2019 allowing legalization of land claims through a mere “self-declaration” of ownership (PR 2019). The provisional measure has the force of law for 120 days after it was signed by the president and can be made permanent if approved by the National Congress, as is expected (see: BRANFORD and BORGES 2019). In addition, a wide-ranging dismantling of Brazil's environmental agencies and policies under the presidential administration that took office on 1 January 2019 means that regulations restricting deforestation and logging are often not enforced (FERRANTE and FEARNISIDE, 2019).

An important group of deforestation actors is made up of mostly urban individuals who invest money from other sources in purchasing rural properties and in deforestation, mostly for pasture. The funds may be from legal sources, such as pharmacies, gas stations and other businesses, or from illegal sources such as trafficking in drugs, arms or people, or from government corruption, truck hijacking and tax evasion (FEARNSIDE 2005, 2008a). In Roraima funds from illegal gold mining in indigenous lands can be invested this way, both by wealthy patrons of this activity and by individual “garimpeiros” (“wildcat” miners) (e.g., MACMILLAN 1995).

Actors on the other side – those who try to slow and contain deforestation – include environmental agencies such as the federal government’s IBAMA (Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis) and the state government’s FEMARH (Fundação Estadual do Meio Ambiente e Recursos Hídricos). The Federal Public Ministry (MPF), a public prosecutor’s office created by Brazil’s 1988 constitution, also has an important role through its ability to threaten punishment for the heads of the federal and state environmental agencies when they fail to enforce regulations governing deforestation.

Other actors include associations of producers of present or likely future crops, such as soy and palm oil (e.g., NEPSTAD et al. 2014). Non-governmental organizations at the local, national and international level are also actors that can press for deforestation control (e.g., FEARNSIDE 2017). Governments and consumers in other parts of the world also influence Brazilian policies affecting deforestation through the threat of boycotts of Brazil’s agricultural exports and through contribution of funds that assist in Brazil’s deforestation control efforts (e.g., WEST et al. 2019). The effectiveness of these different actors is, of course, highly varied. Roraima has long been notorious for having a state government with environmentally destructive policies and an aversion to environmental protection; Roraima was one of the three states in Brazil’s nine-state Legal Amazonia region that was informally classified by the World Bank as a “red” state to indicate this pattern (FEARNSIDE 2016).

### **MOTIVES**

The different actors have different motives, and often there are more than one factor that contribute to a decision to deforest. One often hears statements emphasizing deforestation for subsistence, that is, for farmers to feed their families directly from the crops they harvest. However, this represents a minimal contribution to the total. A much larger fraction comes from agriculture and cattle ranching activities that generate products for sale. This applies both to small farmers and to larger landholders. However, this “normal” economic logic is only part of the motivation for deforestation. Profits in deforested areas can be boosted by various kinds of government subsidies, such as loans at interest below market rates and “amnesties” forgiving or indefinitely postponing loan debts whenever crops fail or other adversities appear (FEARNSIDE 2001, 2020). In Roraima subsidies currently include support for biofuel production (FERRANTE and FEARNSIDE 2020).

Profits from timber also motivate clearing, both from the sale of wood from trees felled in the areas that are cleared and by the licenses permitting the clearing being used to give an appearance of legality to wood cut in unauthorized selective logging being carried out either in the same property or elsewhere. This practice is widespread in Amazonia (BRANCALION et al. 2018).

A major motivation for deforestation in Amazonia is to establish and maintain land tenure (FEARNSIDE, 1979). Before a land title is obtained, deforestation is regarded as an “improvement” proving “productive use” of the land, which is a requirement for official recognition (e.g., INCRA, 2019). After official recognition is obtained, deforestation is still motivated by land-tenure concerns (especially for large landholders) as a means of guaranteeing that the land will not be invaded by squatters (especially organized “sem-terras”), and that it will not be considered “unproductive” and therefore confiscated by the government for agrarian reform.



## THE IMPORTANCE OF SIMULATION MODELS

Future scenarios of land-use and land-cover change in the Amazon are important tools for regional analyses in space and time. They anticipate possible deforestation trajectories and offer valuable inputs for decision making to protect the forest and its environmental services, preventing, for example, millions of tons of CO<sub>2</sub> from being released into the atmosphere (FEARNSIDE 2008b; IPCC 2013; LE CLECH et al. 2019; SIIKAMÄKI et al. 2019; SOARES-FILHO et al. 2010).

A catastrophic forecast generated by a simulation model can mobilize organized society and the media to fight against a possible future and prevent it from actually happening (SOARES-FILHO et al. 2006). However, it is impossible to measure the extent to which catastrophic scenarios, like the BAU (Business As Usual) scenario of Soares-Filho et al. (2006), have contributed to the reduction of deforestation in the Amazon and the emission of carbon into the atmosphere. Although the importance of scenarios cannot be denied, they are only rudimentary simplifications of reality. Notable cases include “The Limits to Growth” (MEADOWS et al. 1973) and the “Brundtland Report” (CMMAD, 1988), both of which spurred discussions on the environment at the global level and influenced conservation policies worldwide (OLIVEIRA, 2012; FEARNSIDE, 2019).

Few environmental-modeling studies have had as much repercussion as that of Soares-Filho et al. (2006), which was carried out in the mid-2000s and foresaw the destruction of the eastern half of the Amazon rainforest by 2050 (BAU scenario). The importance of these scenarios lies precisely in their “non-effectiveness.” In other words, the fact that the scenario does not entirely match what has happened in reality may be its greatest merit.

The great Roraima fire during the El Niño of 1997/98 was an event of enormous national and international repercussion (BARBOSA and FEARNSIDE, 1999; NEPSTAD et al. 1999). This event can be considered as a catastrophic scenario, and it motivated the beginning of discussions that culminated in the creation of public policies for preventing and fighting fires in the state (BARBOSA et al. 2003; FONSECA-MORELLO et al. 2017). The great advantage of creating computer simulations, unlike the real event, is that they can be manipulated in terms of their spatial reach (e.g., the affected area), the intensity of the events (e.g., tree mortality) and their timing (e.g., their relation to the frequency of climatic events). They can also generate public policies that ensure the conservation of forest carbon stocks without the need to burn or damage a single tree.

Despite the importance of land-use models, there are few studies in the literature that seek to demonstrate their validity or effectiveness by comparing the simulated results with the real phenomenon after the event in question has occurred. This step is generally used for the calibration of simulation models in the training phase (e.g., ROSA et al. 2015). In calibrating these models, known data from a short historical time period is used for calibration, and the model is expected to reproduce the same patterns based, for example, on weights-of-evidence or on a Markov chain. After the training or calibration rounds of the modeling, the simulated scenario is validated by comparison with the “real” scenario that occurred in a “validation period” subsequent to that used in the calibration, thus ensuring independence (SOARES FILHO et al. 2013).

The present study aimed to evaluate scenarios that had been generated to predict the deforestation that would occur between 2011 and 2017 in the state of Roraima. We sought to evaluate the model’s efficiency in representing future deforestation by comparing the deforestation simulated by the model with what actually occurred in the region. For this we used official deforestation data from the Project for Monitoring Deforestation in Amazonia by Satellite (PRODES) (INPE 2018). The following variables were used as criteria for evaluating the scenarios in the comparison: annual occurrence of deforestation (km<sup>2</sup>, ha); frequency (n); polygon size (ha) and; similarity (%) between the generated maps.

The scenarios were simulated between 2011 and 2050 and modeled using Dinamica-EGO 2.4.1 software (<https://csr.ufmg.br/dinamica/>) considering the MT-GOV scenario simulated by BARNI et al. (2015a).

In this governance scenario it was assumed that deforestation would be controlled in the state only beginning in 2020, in line with the commitment voluntarily made by Brazil under the Paris Agreement at COP-15 of the United Nations Framework Convention on Climate Change (GONÇALVES et al. 2009). In the period prior to 2020 (2011 to 2019), deforestation was assumed to continue in accord with the trends observed between 2005 and 2010.

The state of Roraima can be considered to represent the most recent large agricultural frontier in the Brazilian Amazon. This condition still exists due to Roraima's isolation from most of the rest of the Brazilian Amazon (BARNI et al. 2015b). In the near future one can expect the creation of new municipalities and settlement projects, the implementation of major infrastructure projects including reconstruction of Highway BR-319 (Manaus - Porto Velho) and building the Bem Querer hydroelectric dam on the Rio Branco. These developments would attract migrants to Roraima and intensify disorderly land occupation, in addition to increasing emissions of greenhouse gases.

## 2 MATERIALS AND METHODS

### 2.1 STUDY AREA

The study area covered the entire state of Roraima, with the exception of protected areas, which are defined here as indigenous lands and conservation units (both national and state). Also excluded were the savanna areas (locally called *lavrado*) in the northeastern portion of the state and areas of oligotrophic ecosystems (locally known as *campinas*) that are characterized by sparse vegetation on seasonally flooded sandy soils, which are located in the central and southwestern portions of the state (BARBOSA et al. 2007). The remaining area, after exclusion of the "silvo-pastoral use area" (SUA) (65,150.0 km<sup>2</sup>: BARNI et al. 2016), is a strip of land along federal highways BR-174 and BR-210 and state highway RR-070. All of these highways are associated with secondary roads that provide access to the farm lots in settlement projects.

In order to better understand the assessment of the scenarios, the (SUA) was overlaid with a grid of nine "sub-areas" (SUBs). This set of sub-areas totaled 53,871.4 km<sup>2</sup> (82.7% of the (SUA)), but it did not exclude any of the deforestation that had occurred in the SAU during the period (Figure 1).

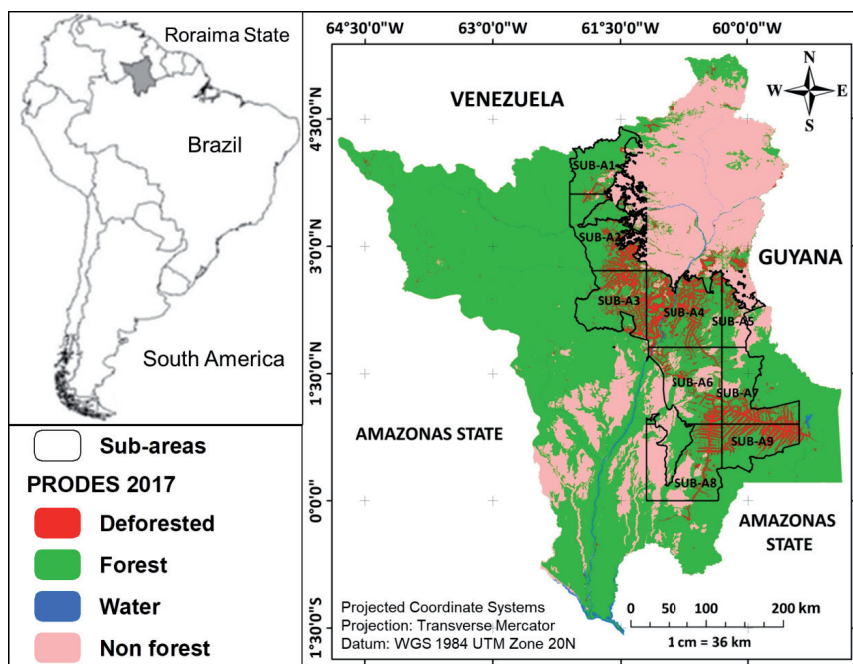
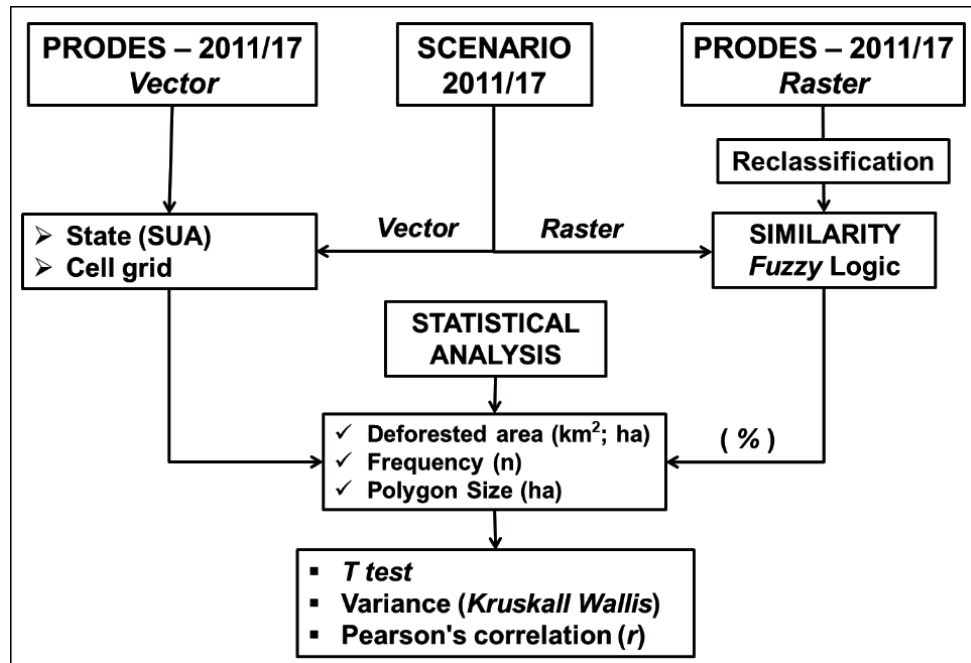


Figure 1 | Study area comprising the "silvo-pastoral use area" (SUA) and the grid of nine sub-areas.

Source: Authors (2020).

## 2.2 DATABASE

The simulation output for the interval between 2011 and 2017, with 1-ha (100 × 100-m) spatial resolution (BARNI et al. 2015a), was used for comparison with deforestation data for the same period from the PRODES deforestation-monitoring program of the National Institute for Space Research (INPE) (INPE 2018). The PRODES data represent the “real” or official deforestation in the state during the analyzed period. Figure 2 presents a simplified flowchart of the methodology.



**Figure 2 |** Flowchart of the methods applied in the systematic evaluation of the simulated scenarios and the PRODES data. “SUA” is the acronym for “Silvo-pastoral Use Area”.

Source: Authors (2020).

The areas (km<sup>2</sup>) as of 2017 of the land-cover classes that are included in the attribute table of the PRODES vector file (Mainclass). This represents the SAU landscape. Data manipulation (mapping) was performed using QGIS 2.18.1 “Las Palmas” software ([https://www.qgis.org/pt\\_BR/site/](https://www.qgis.org/pt_BR/site/)) and Dinamica-EGO.

## 2.3 METHOD

To assess the scenarios, simulated annual deforestation and PRODES annual deforestation were both vectorized and were evaluated considering only the SAU. Then the SAU was intersected with the grid of nine sub-areas, each sub-area originally measuring 10,000 km<sup>2</sup> (100 × 100 km). However, when crossing the vector layers (Intersection of the SAU with the grid), all sub-areas, without exception, lost part of their original area.

The simulation model was calibrated using one of the nine sub-areas, which was chosen at random during the training phase. This approach can be considered to be an independent alternative to using either ecological-climatic criteria (e.g., BARNI et al. 2015c) or municipal boundaries (e.g., SOARES-FILHO et al. 2008) to subdivide the study area. This follows the example of Soares-Filho et al. (2013), who used 12 sub-areas, each corresponding to a Landsat-TM scene, to evaluate methods for calibrating land-use models in the Amazon.

## 2.4 SIMILARITY ANALYSIS

For this procedure, the 2017 PRODES map in raster format was first degraded from 30-m to 100-m spatial resolution in order to be compatible with the resolution of the scenarios, after which it was reclassified in the years of the analysis to represent the areas of the classes (1) (deforestation) and (2) (forest). To make the 2011 map, for example, the deforested areas of the subsequent years (2012 to 2017) had to be reclassified to the value (2) (forest) because these areas had not yet been deforested in 2011. The “non-forest” and “water” classes were reclassified as “no data;” “cloud” areas were reclassified as “forest” and residual areas for each year and were assigned to class (1) (deforestation) in their respective years of deforestation. This procedure was carried out for all years after 2011.

Subsequently, the similarity between the simulated maps and the reclassified PRODES annual deforestation maps of the SAU as a whole and within each sub-area was evaluated using the reciprocal similarity comparison technique developed by Soares-Filho et al. (2008) as a modification of the fuzzy-similarity method (HAGEN, 2003; BARNI et al. 2015b). This method employs several “windows” of increasing number of cells and considers the state of the central cell as a factor of comparison between the maps (SOARES-FILHO et al. 2008).

## 2.5 STATISTICAL ANALYSIS

Statistical analysis was carried out using R 3.1.1 software (<https://www.r-project.org/>). The evaluations consisted of analysis of variance and the “t” test, using the raw data obtained from the crossing of vector maps with the (SUA) and the grid of sub-areas. Tests were made for differences in “deforested area” (ha: “t” test), “Frequency” (n) and “Polygon size” (ha) (non-parametric: Kruskal-Wallis). Pearson’s correlation (r) was applied to test whether the percentage values (%) obtained from the reciprocal-similarity test in a 3900 × 3900-m window in each scenario from 2011 to 2017 and in each sub-area in the grid are correlated with the values of the variables considered above (COHEN 1988).

## 3 RESULTS AND DISCUSSION

Comparing simulated deforestation (total in the analyzed period = 949.9 km<sup>2</sup>: annual mean = 135.7 ± 28.7 km<sup>2</sup>) and real deforestation detected by PRODES (total in the analyzed period = 1,144.0 km<sup>2</sup>: annual mean = 163.4 ± 33.2 km<sup>2</sup>), there was no significant difference ( $t = 2.1788$ ;  $p = 0.1474$ ;  $\alpha = 0.05$ ) between the means (Figure 3). The real deforestation rates in this period were 41.1% lower than the historical average (277.0 km<sup>2</sup>) computed for the state up to 2010 (BARBOSA et al. 2008; BARNI et al. 2015c). Despite the significant decrease in deforestation rates in Roraima, this decrease was 20% less than the 61.8% decrease in deforestation observed for the Amazon as a whole in the same period.

The more modest decline in deforestation rates in Roraima up to 2010 may be related to the state’s own deforestation dynamics, which, on average, seem to be disconnected from the deforestation dynamics in the rest of the Amazon (e.g., RODRIGUES et al. 2009; FEARNESIDE 2017; FONSECA-MORELLO et al. 2017). This was not considered by the model. In fact, one would expect Roraima’s deforestation to be restrained by the lack of road connection with most of the rest of the country and by the low rural population in the state, which was 23.4% of the state’s total population in the last census (IBGE 2019).

However, this expected brake on deforestation was not seen in practice (e.g., BARNI et al. 2012, 2015c). The lower deforestation rate (~17.0%) in the analysis interval shown in the simulated scenarios to the PRODES data as compared was due to the presumption of a decrease in deforestation rates such that consequent CO<sub>2</sub> emissions in the state would be consistent with what was voluntarily proposed by the Brazil at COP 15 for the entire Brazilian Amazon (GONÇALVES et al. 2009; BARNI et al. 2015a).

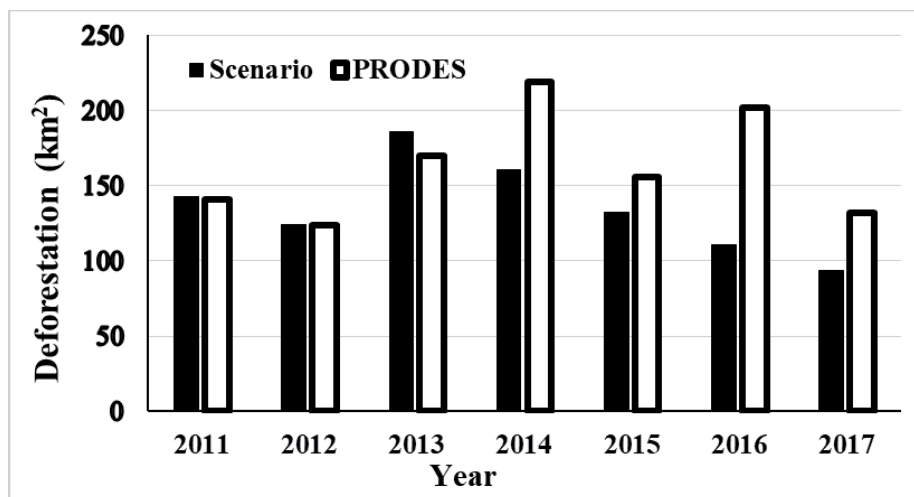


Figure 3 | Comparison between simulated (Scenario) and "real" (PRODES) deforestation.

Source: Authors (2020).

Considering the annual deforestation in the nine sub-areas (covering 82.7% of the 65,150-km<sup>2</sup> SAU), modeled deforestation (period total = 851.2 km<sup>2</sup>: annual mean = 121.6 ± 27.2 km<sup>2</sup>), representing 89.7% of the total simulated deforestation in the SAU, it also did not differ from the real deforestation (period total = 987.3 km<sup>2</sup>: annual mean = 141.0 ± 43.5 km<sup>2</sup>), representing 86.3% of the deforestation recorded in the SAU between 2011 and 2017 ( $t = 2.23$ ;  $p = 0.34$ ;  $\alpha = 0.05$ ).

However, there were some divergences in the total area deforested (ha) and in the frequency (n) when considering the annual deforestation computed by the model as compared to that found by PRODES within each sub-area individually. For example, there was a significant difference (Kruskal-Wallis) between the means for deforested area within the SUB-A4 sub-area (Difference between polygons = 39.3;  $p = 0.04$ ) and SUB-A8 (Difference between polygons = 39.9;  $p = 0.04$ ), while the frequency of polygons was significantly different only in SUB-A4 ( $p = 0.02$ ) (Figure 4).

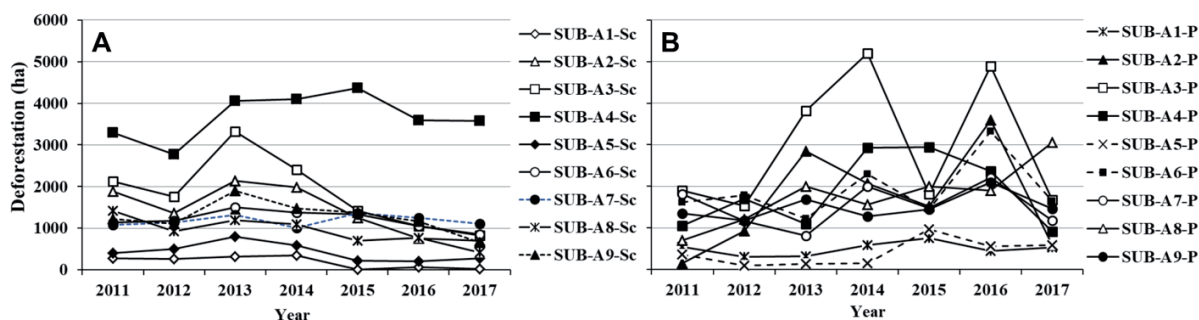
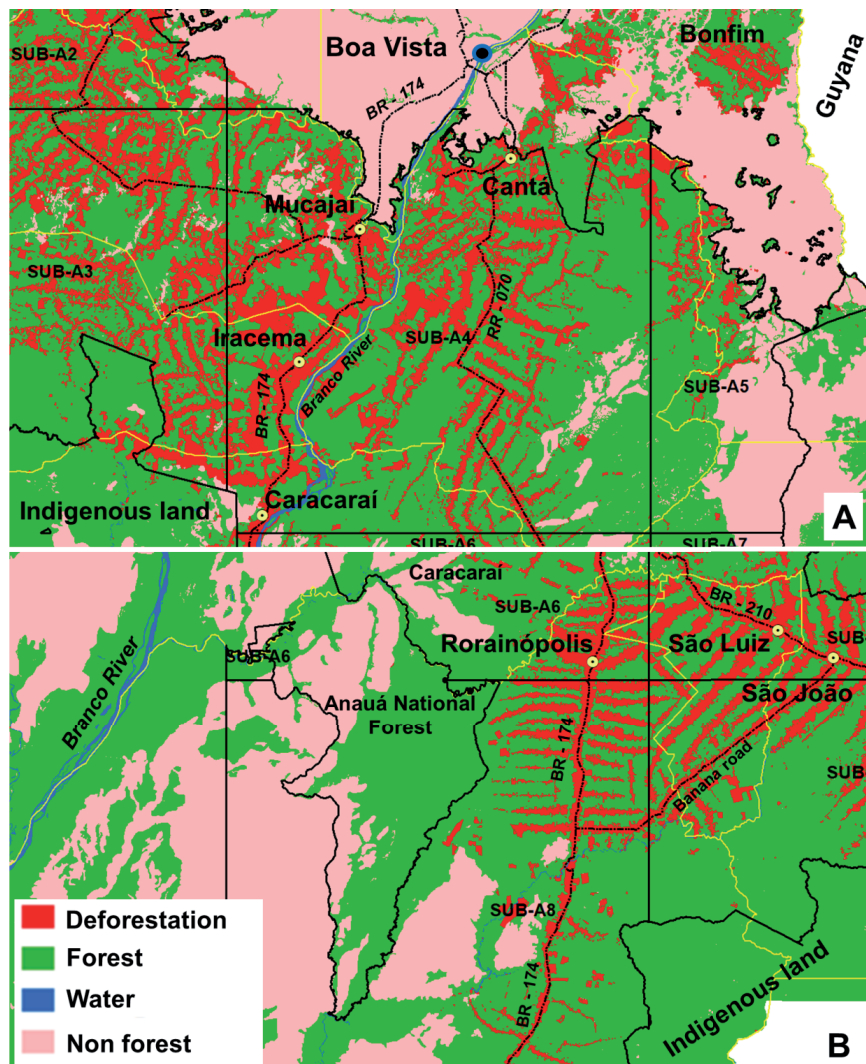


Figure 4 | Variation in deforested area (ha) in the scenarios computed by the model (A: SUB-Ax-Sc) and detected by PRODES (B: SUB-Ax-P) within each sub-area throughout the analysis period.

Source: Authors (2020).

These inconsistencies are explained by the large deforestation seen in these sub-areas both before and during the analysis period. This made it difficult for the model to "capture" the dynamics of deforestation, sometimes deforesting "too much" (SUB-A4) and sometimes deforesting "too little" (SUB-A8) based on the comparison with PRODES. SUB-A4, for example, is a region that historically has had greater deforestation pressure due to its proximity to the state's capital city of Boa Vista (BARNI et al. 2015b); this sub-area covers part of the municipalities of Mucajaí, Iracema (right bank of the Rio Branco, cut by BR-174), Cantá (left bank and cut by RR-070) and Caracarái (both banks and cut by both highways) (Figure 5a).

In 2009, for example, the municipality of Mucajaí was on the “black list” of the municipalities that most deforested in Brazil’s Amazon region (PR 2007). Currently Mucajaí leads the ranking of municipalities in the state in terms of the absolute area deforested (1898.2 km<sup>2</sup>), followed by Cantá (1583.0 km<sup>2</sup>) and Rorainópolis (1235.8 km<sup>2</sup>) (INPE 2018), the latter being covered by SUB-A8.



**Figure 5** | In (A), location of subarea four (SUB-A4) between subareas three (SUB-A3) and five (SUB-A5); and in (B), subarea eight (SUB-A8) to the left of subarea nine (SUB-A9). The black lines represent the outlines of the grid sub-areas and the yellow lines represent the borders of the municipalities.

Source: Authors (2020).

All these considerations concerning SUB-A4 are even more worrying due to the fragility of the ecotone forests (contact zone between ombrophilous forest and the savannas) that characterize this sub-area. Due to their proximity to the savanna (locally called the “*lavrado*”), these forests have repeatedly been affected by major forest fires, especially in El Niño years (BARBOSA and FEARNSSIDE 1999; BARNI et al. 2015c).

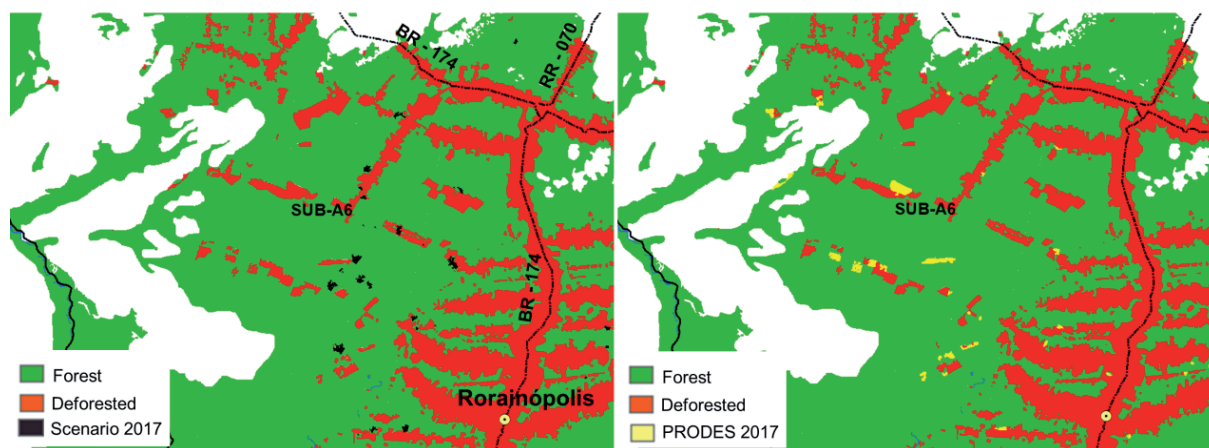
Contrary to what was seen in sub-area SUB-A4, where our model had its worst performance, SOARES-FILHO et al. (2013) reported that their models performed best (with highest accuracy) for deforestation frontiers that were already consolidated, as is the case in SUB-A4. SOARES-FILHO et al. (2013) found that the worst performances were for recent deforestation frontiers and for those that were in transition, with multiple actors present and where changes in the deforestation processes were underway.

This is the case in sub-area SUB-A8, which covers a large part of the municipality of Rorainópolis and, as mentioned above, contains both a large consolidated deforested area close to the municipal seat and other deforestation frontiers in different stages of consolidation, ranging from frontiers that have begun to be occupied only recently (2014-2015), are in transition (2008-2009) and are already consolidated (1985-2002) (BARNI et al. 2012, 2018a; MOURÃO 2011). All of these processes are related to the creation of settlement projects (YANAI et al. 2017) and to the invasion of public lands that lack any protection status (FEARNSIDE 2017).

In SUB-A8, deforestation has been speeded by the role that authorizations granted for the use of wood in areas approved for “clearcutting” (deforestation) plays in laundering wood from illegal selective logging (G1 2018; NUNES 2018; CONDÉ et al. 2019). The clearcutting projects are licensed by the State Foundation for the Environment and Water Resources (FEMARH) upon the written request of the land owner.

Considering the average polygon size simulated annually by the model ( $9.7 \pm 12.5$  ha) and the average polygon size detected by PRODES ( $12.6 \pm 17.6$  ha) within the grid of sub-areas ( $n = 9$ ), a significant difference was observed only in sub-area SUB-A6 ( $p < 0.01$ ). In this sub-area, the average size of the simulated polygons was  $9.6 \pm 2.5$  ha, while the average size of polygons detected by PRODES was  $18.9 \pm 5.6$  ha, or almost twice as large as the simulated polygons. Sub-area SUB-A6 includes a new settlement project (~700 km<sup>2</sup>) that was in the process of opening lots via clearcutting projects obtained for the purpose of selective logging (CONDÉ et al. 2019; SOARES-FILHO et al. 2013). This finding is of special interest because FEMARH releases up to 20% of the lot area to be felled, than it is likely that this factor contributed to the occurrence of larger deforestation polygons, and therefore to the fact that they were detected by the PRODES system in this sub-area. The settlement in question with lots of 500 to 1000 ha was created to meet the demands of logging entrepreneurs and other business owners living in the municipal seat of Rorainópolis (BARNI et al. 2018a, p. 168). This contrasts with other settlement projects in the southern portion of Roraima where, in general, lot sizes have ranged from 50 to 100 ha, and the lots were distributed to landless farmers (BARNI et al. 2012; YANAI et al. 2017).

Figure 6 exemplifies the situation discussed above, showing deforestation in 2017 in a settlement project that had been recently opened to meet the demands of businesspeople in Rorainópolis (BARNI et al. 2018a). Note that the size of the deforestation polygons detected by the PRODES system far exceeds the area of the polygons simulated by the model.



**Figure 6** | Visual comparison between simulated deforestation polygons (black) and observed in 2017 (yellow) by PRODES in a part of the SUB-A6 sub-area where a settlement project with unusually large lots had been recently opened.

Source: Authors (2020).

### 3.1 SIMILARITY ASSESSMENT IN THE SAU

The results of the similarity tests (%) between the annual deforestation scenarios and the PRODES data for the SAU registered the overall mean of 46.4% in a 3900 x 3900-m window (39 x 39 cells). The annual scenario that showed the greatest similarity with the PRODES data was that of 2013 with 55.2%, and the lowest was that of 2017, with 24.0% similarity in a 3900 x 3900-m window (Figure 7).

The result for 2017 positively influenced the mean similarity of the scenarios below the limit value of 50.0%, together with the years 2012 (42.3%), 2016 (48.0%) and 2015 (49.0%), while the years 2013, 2011 (54.5%) and 2014 (52.0%) registered values above this value. With the exception of 2012 and the inversion observed between the values for 2013 and 2011, the results agree with the data of Rosa et al. (2015). Studying the calibration / validation response (accuracy of predictions) of land-use change models according to the choice of the time period used in this phase, these authors observed that the closer or shorter the interval used for the calibration / validation of models the better was their performance. In other words, the longer the interval used, the less accurate the models were in predicting future deforestation.

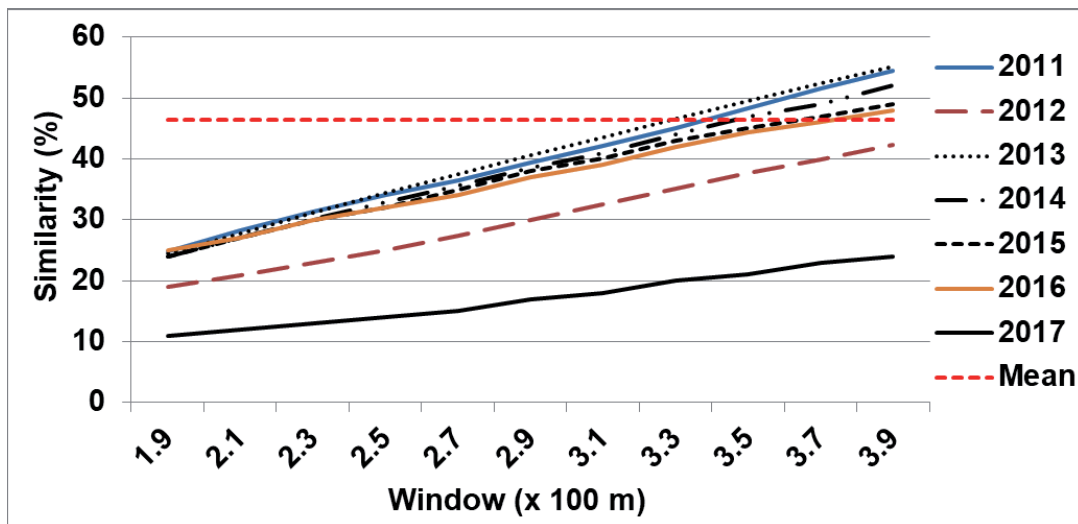


Figure 7 | Similarity test between scenarios for the SUA and PRODES data.

Source: Authors (2020).

The overall mean similarity achieved by each annual scenario, within each sub-area in a 3900 x 3900-m window, was 48.9%. The lowest similarity recorded was 4.0%, which was in sub-area SUB-A1 in 2017, and the highest (91.9%) was in e SUB-A5 in 2014. SUB-A1 showed the greatest variability in the annual scenarios (SD = 26.7%), followed by SUB-A5 (SD = 26.3%), with the least variability being found in SUB-A7 (SD = 7.1%). The mean variability was 16.1%.

When the data matrix is inverted, the 2017 scenario shows the greatest variability (SD = 17.4%), followed by the 2012 scenario (SD = 16.5%). The mean deviation was 14.0% considering all scenarios (Figure 8).

In Figure 8 it can be seen that the 2017 scenario increases the similarity starting from the north (SUB-A1) to the south (SUB-A8). The opposite behavior can be seen in the 2013 scenario, in which the similarity decreases considering the same direction of growth as in the 2017 scenario.



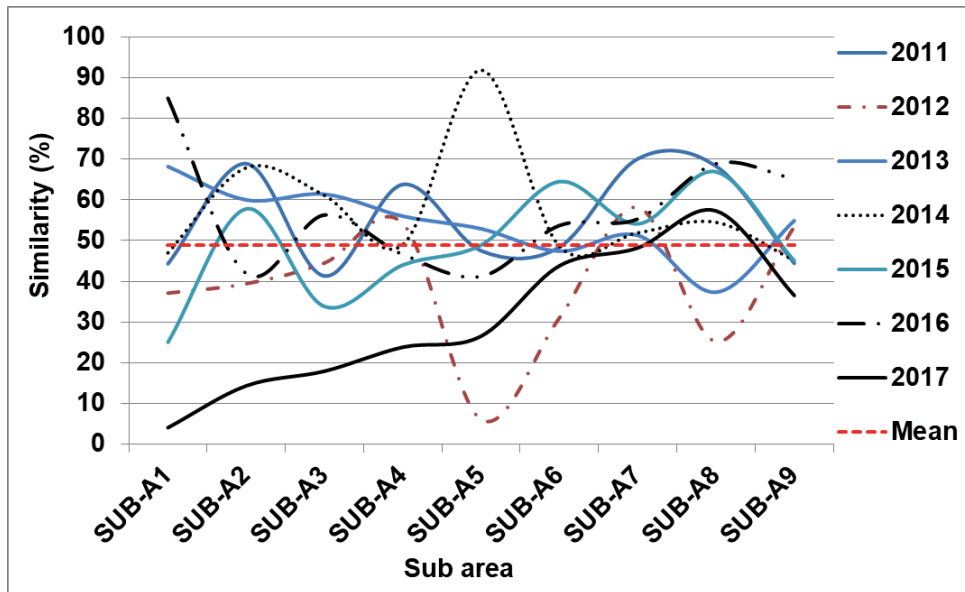


Figure 8 | Similarity behavior of the sub-areas in each annual scenario.

Source: Authors (2020).

### 3.2 CORRELATION ANALYSIS

Correlation analysis was used to test whether the deforested area (ha), the frequency of polygons (n) and the size of the average polygon (ha) deforested in each sub-area influenced the similarity in each scenario within the sub-areas.

The results indicate that the frequency or number of polygons provided by the simulation of the scenarios and also from the PRODES data, in the sub-areas, contributed more strongly to the similarity than did the other variables. Even so, the variable “deforested area,” for example, showed a strong correlation with similarity in sub-areas SUB-A1, SUB-A2, SUB-A3 and SUB-A9.

Considering the variable “polygon size,” the highest mean sizes of the deforestation polygons detected by PRODES in 2014 (14.3 ha) and 2017 (14.7 ha) versus the smaller mean sizes of simulated polygons in the scenarios (11.6 ha for 2014 and 6.5 ha for 2017) may have inversely influenced the similarity in the sub-areas. In this case, the larger size of the polygons detected by the PRODES system in these years implied less similarity between the simulated scenarios and the real data in sub-areas SUB-A6, SUB-A8 and SUB-A9.

### 4 FINAL CONSIDERATIONS

The lessons learned from the approach applied in our study suggest that the behavior of deforestation is not linear and that it can change depending on time (from one year to the next) and space (from one location to another). This is consistent with the idea that the occurrence of deforestation in different parts of the study area in the period was favored by road construction, creation of settlement projects, cumulative previous deforestation close to roads, proximity to urban consumer centers (SOARES-FILHO et al. 2004; BARNI et al. 2015b; ROSA et al. 2015) and the application of public policies, such as the stimulation of illegal selective logging through timber laundering through authorizations for clearcutting in settlement projects.

The problem of divergence between the simulated deforestation results and the real or official deforestation that occurred in some sub-areas of the study area, shown by the similarity tests, does

not jeopardize the validity of the scenario analysis. These divergences are difficult to predict and can often be related to the origin and culture of the landholders, who base their decision to deforest or not to deforest an area on the basis of market behavior (RODRIGUES et al., 2009; FEARNSSIDE, 2017).

Considering these issues, the probability of deforestation in our study area was increased by the creation of settlement projects for large landholders and by invasions of public lands (government areas “without destination”). The creation of settlement projects for large landholders and the action of land grabbers (*grileiros*), for example, opened thousands of hectares of untouched forests as areas for speculation in the real estate market, then to the selective logging market and finally to the meat market ending (FEARNSSIDE, 2017).

This process may take several years to stabilize the cumulative deforested area in the properties, which, by law, can deforest a maximum of 20% of the lot area. During this time the area is transformed into a zone “producing” deforestation. The process can be accelerated with the arrival of loggers who open roads for landholders in exchange for permission to remove timber from the lots.

Despite the divergences pointed out above between deforestation simulated in the scenarios and official PRODES deforestation, in general the evaluations demonstrated the validity of the model and the ability of future scenarios to realistically represent the deforestation that occurred in the study area, considering the clearing from 2011 to 2017. The correlation analysis, for example, offered excellent inputs for the simulation model calibration phase. Prioritizing the frequency (n) and the mean polygon size (ha) of deforestation during the calibration phase of a simulation model can substantially improve the model’s performance.

## ACKNOWLEDGMENTS

We thank the reviewers of the manuscript and the State University of Roraima (UERR), the National Institute for Research in Amazonia (INPA) and the National Institute for Space Research (INPE) for the institutional support offered to the authors. The Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq - Brazil) provided a fellowship for R.I. Barbosa (CNPq 304204/2015-3).

## REFERENCES

- BARBOSA, R.I.; FEARNSSIDE, P.M. Incêndios na Amazônia: estimativa da emissão de gases de efeito estufa pela queima de diferentes ecossistemas de Roraima na passagem do evento —El-Niño (1997/1998). **Acta Amazonica**, v. 29, pp. 513-534. 1999. doi:10.1590/1809-43921999294534
- BARBOSA, R.I.; XAUD, M.R.; SILVA, G.N.F.; CATTÂNEO, A.C. Forest Fires in Roraima, Brazilian Amazonia. **International Forest Fire News** (IFFN), No. 28, pp. 51-56. 2003.
- BARBOSA, R.I.; CAMPOS, C.; PINTO, F.; FEARNSSIDE, P.M. The “Lavrados” of Roraima: Biodiversity and Conservation of Brazil’s Amazonian Savannas. **Functional Ecosystems and Communities**, 1(1): 29-41. 2007.
- BARBOSA, R.I.; PINTO, F.S.; SOUZA, C.C. **Desmatamento em Roraima: Dados históricos e distribuição espaço-temporal. Relatório Técnico**. Ministério da Ciência e Tecnologia, Instituto Nacional de Pesquisas da Amazônia-INPA, Núcleo de Pesquisas de Roraima. 10 pp. 2008.
- BARNI, P.E.; FEARNSSIDE, P.M.; GRAÇA, P.M.L.A. Desmatamento no Sul do Estado de Roraima: padrões de distribuição em função de Projetos de Assentamento do INCRA e da distância das principais rodovias (BR-174 e BR-210). **Acta Amazonica**, v. 42, n. 2, pp. 183-192. 2012. doi:10.1590/S0044-59672012000200003
- BARNI, P.E.; BARBOSA, R.I.; MANZI, A.O. **Estimativa de emissão de gases de efeito estufa em Roraima (2011 a 2050): o efeito da reconstrução da BR-319 nas fitofisionomias florestais**. XVII Simpósio Brasileiro de Sensoriamento Remoto, João Pessoa-Brasil, pp. 7327-7334. 2015a. <http://www.dsr.inpe.br/sbsr2015/files/p1635.pdf>.

BARNI, P.E.; FEARNSSIDE, P.M.; GRAÇA, P.M.L.A. Simulating deforestation and carbon loss in Amazonia: impacts in Brazil's Roraima state from reconstructing Highway BR-319 (Manaus-Porto Velho). **Environmental Management**, v. 55, n. 2, pp. 259-278. 2015b. doi:10.1007/s00267-014-0408-6.

BARNI, P.E.; PEREIRA, V.B.; MANZI, A.O.; BARBOSA, R.I. Deforestation and forest fires in Roraima and their relationship with phytoclimatic regions in the Northern Brazilian Amazon. **Environmental Management**, v. 55, n. 5, pp. 1124-1138. 2015c.

BARNI, P.E.; MANZI, A.O.; CONDÉ, T.M.; BARBOSA, R.I.; FEARNSSIDE, P.M. Spatial distribution of forest biomass in Brazil's state of Roraima, northern Amazonia. **Forest Ecology and Management**, v. 377, pp. 170–181. 2016.

BARNI, P.E.; FEARNSSIDE, P.M.; GRAÇA, P.M.L.A. Simulando desmatamento e perda de carbono na Amazônia: impactos no Estado de Roraima devido à reconstrução da BR-319 (Manaus-Porto Velho). In: OLIVEIRA, S.K.S.; FALCÃO, M.T. **Roraima: biodiversidade e diversidades**. Boa Vista: editora da UERR, 2018a. pp. 154-168.

BARNI, P.E.; SILVA, E.B.R.; SILVA, F.C.F. **Incêndios florestais de sub-bosque na zona de florestas úmidas do sul de Roraima: área atingida e biomassa morta**. In: ANAIS DO SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO, 2017. Anais eletrônicos... Campinas, GALOÁ, 2018b. p. 6280-6287. Available at: <<https://proceedings.science/sbsr/papers/incendios-florestais-de-sub-bosque-na-zona-de-florestas-umidas-do-sul-de-roraima--area-atingida-e-biomassa-morta>>. Last access: 30 Mar. 2019.

BRANCALION, P.H.S.; DE ALMEIDA, D.R.A.; VIDAL, E.; MOLIN, P.G.; SONTAG, V.E.; SOUZA, S.E.X.F.; SCHULZE, M.D. **Fake legal logging in the Brazilian Amazon**. **Science Advances**, v. 4, art. eaat1192. 2018. <https://advances.sciencemag.org/content/4/8/eaat1192>

BRANDO, P.M.; BALCH, J.K.; NEPSTAD, D.C.; MORTON, D.C.; PUTZ, F.E.; COE, M.T.; SILVÉRIO, D.; MACEDO, M.N.; DAVIDSON, E.A.; NÓBREGA, C.C.; ALENCAR, A.; SOARES-FILHO, B.S. Abrupt increases in Amazonian tree mortality due to drought–fire interactions. **Proceedings of the National Academy of Sciences USA**, v. 111, n. 17, pp. 6347-6352. 2014. <http://www.pnas.org/cgi/doi/10.1073/pnas.1305499111>

BRANFORD, S.; BORGES, T. **Bolsonaro's Brazil: 2019 brings death by 1,000 cuts to Amazon - part one**. Mongabay, 30 December 2019. 2019. <https://news.mongabay.com/2019/12/bolsonaros-brazil-2019-brings-death-by-1000-cuts-to-amazon-part-one/>

CARRERO, G.C.; FEARNSSIDE, P.M. Forest clearing dynamics and the expansion of land holdings in Apuí, a deforestation hotspot on Brazil's Transamazon Highway. **Ecology and Society**, v. 16, n. 2, art. 26. 2011. <http://www.ecologyandsociety.org/vol16/iss2/art26/>

CMMAD (Comissão Mundial sobre Meio Ambiente e Desenvolvimento). **Nosso Futuro Comum** (Relatório Brundtland). Rio de Janeiro: Fundação Getúlio Vargas, 1988.

COHEN, J. **Statistical power analysis for the behavioral sciences**. Hillsdale, NJ, USA: Erlbaum. 1988. Available at: <[www.utstat.toronto.edu/~brunner/oldclass/378f16/readings/Cohen Power.pdf](http://www.utstat.toronto.edu/~brunner/oldclass/378f16/readings/Cohen%20Power.pdf)>. Last access: 16 Feb. 2019.

CONDÉ, T.M.; HIGUCHI, N.; LIMA, A.J.N. Illegal Selective Logging and Forest Fires in the Northern Brazilian Amazon. **Forests**, 10(1), 61. 2019. doi:10.3390/f10010061.

FEARNSSIDE, P.M. Deforestation of the Brazilian Amazon. In: SHUGART, H. (Ed.) **Oxford Research Encyclopedia of Environmental Science**. New York, U.S.A.: Oxford University Press. 2017. doi:10.1093/acrefore/9780199389414.013.102.

FEARNSSIDE, P.M. Desenvolvimento da floresta amazônica: Problemas prioritários para a formulação de diretrizes. **Acta Amazonica**, v. 9, n. 4 suplemento, pp. 123129. 1979. doi:10.1590/1809-43921979094s123

FEARNSSIDE, P.M. **Human Carrying Capacity of the Brazilian Rainforest**. New York, NY, U.S.A.: Columbia University Press. 293 pp. 1986.

FEARNSSIDE, P.M. Ocupação Humana de Rondônia: Impactos, Limites e Planejamento. **Relatórios de Pesquisa**, No. 5, Brasília, DF: Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq). 76 pp. 1989.

FEARNSIDE, P.M. Land-tenure issues as factors in environmental destruction in Brazilian Amazonia: The case of southern Pará. **World Development**, v. 29, n. 8, pp. 1361-1372. 2001. doi:10.1016/S0305-750X(01)00039-0

FEARNSIDE, P.M. **Deforestation in Brazilian Amazonia: History, rates and consequences**. **Conservation Biology**, v. 19, n. 3, pp. 680-688. 2005. doi:10.1111/j.1523-1739.2005.00697.x

FEARNSIDE, P.M. The roles and movements of actors in the deforestation of Brazilian Amazonia. **Ecology and Society**, v. 13, n. 1, art. 23. 2008a. <http://www.ecologyandsociety.org/vol13/iss1/art23/>

FEARNSIDE, P.M. **Amazon forest maintenance as a source of environmental services**. *Anais da Academia Brasileira de Ciências*, v. 80, p. 101-114. 2008b. doi:10.1590/S0001-37652008000100006

FEARNSIDE, P.M. Environmental policy in Brazilian Amazonia: Lessons from recent history. **Novos Cadernos NAEA**, v. 19, n. 1, pp. 27-46. 2016. doi:10.5801/ncn.v19i1.1379

FEARNSIDE, P.M. Sustainable development. In: GIBSON, D. (Ed.) *Oxford Bibliographies in Ecology*. New York, NY, U.S.A.: Oxford University Press. 2019. doi:10.1093/OBO/9780199830060-0227

FEARNSIDE, P.M. **Sustentabilidade da agricultura na Amazônia**. *Amazônia Real, Série completa*. 2020. [http://philip.inpa.gov.br/publ\\_livres/2020/Sustentabilidade\\_da\\_agricultura\\_na\\_Amaz%C3%B4nia-Serie\\_completa.pdf](http://philip.inpa.gov.br/publ_livres/2020/Sustentabilidade_da_agricultura_na_Amaz%C3%B4nia-Serie_completa.pdf)

FERRANTE, L.; FEARNSIDE, P.M. Brazil's new president and "ruralists" threaten Amazonia's environment, traditional peoples and the global climate. **Environmental Conservation**, v. 46, n. 4, pp. 261-263. 2019. doi:/10.1017/S0376892919000213

FERRANTE, L.; FEARNSIDE, P.M. Brazil's biofuel plans drive deforestation. **Nature** v. 577, p. 170. 2020. <https://doi.org/10.1038/d41586-020-00005-8>

FONSECA-MORELLO, T.; RAMOS, R.; STEIL, L.; PARRY, L.; BARLOW, J.; MARKUSSON, N.; FERREIRA, A. Queimadas e incêndios florestais na Amazônia brasileira: porque as políticas públicas têm efeito limitado? **Ambiente & Sociedade**, v. XX, n. 4, pp. 19-40. 2017.

G1. **PF faz operação de combate à exploração ilícita de madeira da Amazônia**. Available at: <<https://g1.globo.com/am/amazonas/noticia/pf-desmonta-esquema-bilionario-de-exploracao-ilicita-de-madeira-da-amazonia.ghml>>. Last access: 15 Apr. 2020. 2018.

GONÇALVES, M.A.; PIRES, M.O.; SCHOLL, J.; VELOSO, W.; FEITOSA, C.; OZORIO, P.; HERNÁNDEZ, M. **The Brazilian REDD Strategy: How the country has achieved major deforestation reduction in the Amazon**. 15th Conference of the Parties to the United Nations Framework Convention on Climate Change. Copenhagen, December 2009. 2009. Available at: <[http://www.mma.gov.br/estruturas/182/\\_arquivos/reddcop15\\_ingles\\_182.pdf](http://www.mma.gov.br/estruturas/182/_arquivos/reddcop15_ingles_182.pdf)>. Last access: 12 Mar. 2019.

HAGEN, A. Fuzzy set approach to assessing similarity of categorical maps. **International Journal Geographical Information Science**, v. 17, pp. 235-249. 2003.

IBGE (Instituto Brasileiro de Geografia e Estatística). Rio de Janeiro, RJ. 2019. Available at: <<https://noticias.uol.com.br/censo-2010/populacao/rr>>. Last access 17 Feb; 2019.

INCRA (Instituto Nacional de Colonização e Reforma Agrária). **Instrução Normativa N°100 de 30 de Dezembro de 2019**. Diário Oficial da União, 30 December 2019. 2019. <http://www.in.gov.br/en/web/dou/-/instrucao-normativa-n-100-de-30-de-dezembro-de-2019-236096030>

INPE (Instituto Nacional de Pesquisas Espaciais). Projeto PRODES – **Monitoramento da Floresta Amazônica por Satélite**. São José dos Campos, SP. 2018. Available at: <<http://www.obt.inpe.br/OBT/assuntos/programas/amazonia/prodes>>. Last access 10 Dec. 2018.

IPCC. Summary for Policymakers. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Stocker, T.F., Qin, D., Plattner, G.-K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.). Cambridge University Press, Cambridge, UK. 2013.

LE CLECH, S.; DUFOUR, S.; BUCHELI, J.; GRIMALDI, M.; HUBER, R.; MIRANDA, I.S.; MITJA, D.; COSTA, L.G.S.; OSZWALD, J. Uncertainty in ecosystem services maps: the case of carbon stocks in the Brazilian Amazon forest using regression analysis. **One Ecosystem** 4: e28720. 2019. doi: 10.3897/oneeco.4.e28720.

MACMILLAN, G. **At the end of the rainbow? Gold, land and people in the Brazilian Amazon**. New York, NY, U.S.A.: Columbia University Press. 1995.

MEADOWS, D.H.; MEADOWS, D.L.; RANDERS, J.; BEHRENS III, W.W. **Limites do Crescimento: Um relatório para o projeto do Clube de Roma sobre o dilema da humanidade**. São Paulo: Editora Perspectiva, 1973.

MOURÃO, G.M.N. El sureste de Roraima: de un marco natural muy contrastado a unos grandes asentamientos rurales. **Revista Geográfica de América Central**, Número Especial EGAL, pp. 1-15. 2011. Available at: <<http://www.revistas.una.ac.cr/index.php/geografica/article/viewFile/2412/2308>>. Last access: 23 Jan. 2018.

NEPSTAD, D.C.; VERÍSSIMO, A.; ALENCAR, A.; NOBRE, C.; LIMA, E.; LEFEBVRE, P., et al. Large-scale impoverishment of Amazonian forests by logging and fire. **Nature**, v. 398(6727), pp. 505-508. 1999. <https://www.nature.com/articles/19066>

NEPSTAD, D.C.; MCGRATH, D.; STICKLER, C.; ALENCAR, A.; AZEVEDO, A.; SWETTE, B.; BEZERRA, T.; DIGIANO, M.; SHIMADA, J.; DA MOTTA, R.S.; ARMIJO, E.; CASTELLO, L.; BRANDO, P.; HANSEN, M.C.; MCGRATH-HORN, M.; CARVALHO, O.; HESS, L. Slowing Amazon deforestation through public policy and interventions in beef and soy supply chains. **Science**, v. 344, pp. 1118-1123. 2014. doi:10.1126/science.1248525

NOGUEIRA, E.M.; YANAI, A.M.; FONSECA, F.O.R.; FEARNESIDE, P.M. Carbon stock loss from deforestation through 2013 in Brazilian Amazonia. **Global Change Biology**, 21, pp. 1271–1292. 2015. doi:10.1111/gcb.12798.

NUNES, J.C. **Ibama apreende 7 mil toras de madeira extraídas ilegalmente da Terra Indígena Pirititi**. Available at: <<http://radioagencianacional.ebc.com.br/geral/audio/2018-05/ibama-apreende-7-mil-toras-de-madeira-extraidas-ilegalmente-da-terra-indigena>>. Last access: 12 May 2018. 2018.

OLIVEIRA, L.D. Os “Limites do Crescimento” 40 anos Depois: Das “Profecias do Apocalipse Ambiental” ao “Futuro Comum Ecologicamente Sustentável”. **Revista Continentes (UFRRJ)**, v. 1, n. 1, 2012. Available at: <<http://www.tiagomarino.com/continentes/index.php/continentes/article/download/8/7/>>. Last access: 1 Mar. 2019.

PR (Presidência da República). **DECRETO Nº 6.321**, DE 21 DE DEZEMBRO DE 2007. Available at: <[http://www.planalto.gov.br/ccivil\\_03/\\_Ato2007-2010/2007/Decreto/D6321.htm](http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2007/Decreto/D6321.htm)>. Last access: 7 Feb. 2019.

PR (Presidência da República). **Lei Nº 11.952, de 25 de junho de 2009**. 2009. [http://www.planalto.gov.br/ccivil\\_03/\\_Ato2007-2010/2009/Lei/L11952.htm](http://www.planalto.gov.br/ccivil_03/_Ato2007-2010/2009/Lei/L11952.htm)

PR (Presidência da República). **Lei Nº 13.465, de 11 de julho de 2017**. 2017. [http://www.planalto.gov.br/ccivil\\_03/\\_Ato2015-2018/2017/Lei/L13465.htm](http://www.planalto.gov.br/ccivil_03/_Ato2015-2018/2017/Lei/L13465.htm)

PR (Presidência da República). **Medida Provisória Nº 910, de 10 de dezembro de 2019**. 2019. [http://www.planalto.gov.br/ccivil\\_03/\\_ato2019-2022/2019/Mpv/mpv910.htm](http://www.planalto.gov.br/ccivil_03/_ato2019-2022/2019/Mpv/mpv910.htm)

RODRIGUES, A.S.L.; EWERS, R.M.; PARRY, L.; SOUZA JR., C.; VERÍSSIMO, A.; BALMFORD, A. Boom-and-bust development patterns across the Amazon deforestation frontier. **Science**, v. 324, pp. 1435–1437. 2009.

ROSA, I.M.D.; PURVES, D.; CARREIRAS, J.M.B.; EWERS, R.M. Modelling land cover change in the Brazilian Amazon: Temporal changes in drivers and calibration issues. **Regional Environmental Change**, v. 15, pp. 123–137. 2015.

ROSA, I.M.D.; SOUZA, C.; EWERS, R.M. Changes in size of deforested patches in the Brazilian Amazon. **Conservation Biology**, v. 26, pp. 932–937. 2012. doi:10.1111/j.1523-1739.2012.01901.x.

SIKAMÄKI, J.V.; KRUPNICK, A.; STRAND, J.; VINCENT, J.R. **International Willingness to Pay for the Protection of the Amazon Rainforest**. World Bank Document, 2019. 29 p. Available at: <<http://documents.worldbank.org/curated/en/334711552333303292/pdf/WPS8775.pdf>>. Last access: 19 Mar. 2019.

SOARES-FILHO, B.; ALENCAR, A.; NEPSTAD, D.; CERQUEIRA, G.; DIAZ, M. DEL C.V.D.; RIVERO, S.; SOLORZANOS, L. & VOLL, E. Simulating the response of land-cover changes to road paving and governance along a major Amazon highway: the Santarém–Cuiabá corridor. **Global Change Biology**, v. 10, pp. 745-764. 2004.

SOARES-FILHO, B.S.; NEPSTAD, D.C.; CURRAN, L.; CERQUEIRA, G.C.; GARCIA, R.A.; RAMOS, C.A.; VOLL, E.; MCDONALD, A.; LEFEBVRE, P. & SCHLESINGER, P. Modelling conservation in the Amazon basin. **Nature**, v. 440, n. 23, pp. 520-523. 2006.

SOARES-FILHO, B.S., GARCIA, R.A., RODRIGUES, H., MORO, S., NEPSTAD, D. Nexos entre as dimensões socioeconômicas e o desmatamento: A caminho de um modelo integrado. In: Batistella, M., Alves, D., Moran, E. (Eds.). **Amazônia. Natureza e Sociedade em Transformação**. São Paulo, SP: Editora da Universidade de São Paulo. 2008.

SOARES-FILHO, B.; MOUTINHO, P.; NEPSTAD, D.; ANDERSON, A.; RODRIGUES, H.; GARCIA, R.; et al. **Role of Brazilian Amazon protected areas in climate change mitigation**. Proceedings of the National Academy of Sciences USA, v. 107, pp. 10821–10826. 2010.

SOARES-FILHO, B.S.; RODRIGUES, H.O.; FOLLADOR, M. **A hybrid analytical-heuristic method for calibrating land-use change models**. Environmental Modelling Software, v. 43, pp. 80–87. 2013.

TORRES, M.; DOBLAS, J.; ALARCON, D.F. **Dono é Quem Desmata: Conexões entre Grilagem e Desmatamento no Sudoeste Paraense**. São Paulo, SP & Instituto Agrônomo da Amazônia, Altamira, PA: Urutu-branco. 243 pp. 2017. [https://www.socioambiental.org/sites/blog.socioambiental.org/files/nsa/arquivos/dono\\_e\\_quem\\_desmata\\_conexoes\\_entre\\_gril1.pdf](https://www.socioambiental.org/sites/blog.socioambiental.org/files/nsa/arquivos/dono_e_quem_desmata_conexoes_entre_gril1.pdf)

WEST, T.A.P.; BÖRNER, J.; FEARNESIDE, P.M. Climatic benefits from the 2006–2017 avoided deforestation in Amazonian Brazil. **Frontiers in Forests and Global Change**, v. 2, art. 52. 2019. doi:10.3389/ffgc.2019.00052

YANAI, A.M.; NOGUEIRA, E.M.; GRAÇA, P.M.L.A.; FEARNESIDE, P.M. Deforestation and carbon-stock loss in Brazil's Amazonian settlements. **Environmental Management**, v. 59, n. 3, pp. 393-409. 2017. <https://link.springer.com/article/10.1007/s00267-016-0783-2>

YANAI, A.M.; GRAÇA, P.M.L.A.; ESCADA M.I. S.; ZICCARDI, L.G.; FEARNESIDE, P.M. Deforestation dynamics in Brazil's Amazonian settlements: Effects of land-tenure concentration. **Journal of Environmental Management**, v. 268, 2020. <https://doi.org/10.1016/j.jenvman.2020.110555>

# Use of multicriteria analysis to define priority areas for reforestation in the Piranga River Basin, MG, Brazil

*Uso da análise multicritério para definição de áreas prioritárias para reflorestamento na Bacia do Rio Piranga, MG, Brasil*

Caroline de Souza Cruz Salomão<sup>a</sup>

Luiz Gustavo de Souza Paula<sup>b</sup>

Marcos Antônio Timbó Elmiro<sup>c</sup>

<sup>a</sup>Programa de Pós Graduação em Análise e Modelagem de Sistemas Ambientais, Universidade Federal de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil  
E-mail: carolinescalomao2@gmail.com

<sup>b</sup>Programa de Pós Graduação em Análise e Modelagem de Sistemas Ambientais, Universidade Federal de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil  
E-mail: lgustavosouzap@gmail.com

<sup>c</sup>Programa de Pós Graduação em Análise e Modelagem de Sistemas Ambientais, Universidade Federal de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil  
E-mail: timboelmiro@gmail.com

doi:10.18472/SustDeb.v11n2.2020.30468

Received: 28/11/2019  
Accepted: 01/04/2020

ARTICLE- DOSSIER

## ABSTRACT

The Piranga River Basin is one of the main sub-basins of the Doce River, being one of the most historically explored, which culminated in an emblematic episode, the rupture of the mining tailings dam in Mariana. Those responsible for the damage had to develop solutions to repair the territory, mainly the definition of priority areas for conservation. One factor to consider for this definition was the institution of protected spaces in rural properties, such as the Permanent Preservation Areas (PPAs), consolidated by the new Forest Code (Law No. 12,651 / 2012). For the allocation of intervention areas, the Multicriteria Analysis was adopted, widely used in decision-making processes. The results showed that the southeast area of the Doce River State Park is more likely to receive initiatives to restore native vegetation. The opposite occurs in the more urbanized regions of the basin, which are also coincident with the steepest areas.

**Keywords:** Multicriteria analysis. Permanent preservation areas. Reforestation of native vegetation. Piranga River Basin.

## RESUMO

A Bacia do Rio Piranga é uma das principais sub-bacias do Rio Doce, sendo uma das mais exploradas historicamente, que culminou em um episódio emblemático, o rompimento da barragem de rejeitos de

mineração em Mariana. Os responsáveis pelo dano precisaram desenvolver soluções para reparação do território, destacando-se a definição de áreas prioritárias para conservação. Um fator a considerar para essa definição foi à instituição de espaços protegidos em imóveis rurais, como as Áreas de Preservação Permanente (APPs), consolidadas pelo novo Código Florestal (Lei nº 12.651/2012). Para alocação das áreas de intervenção foi adotada a Análise Multicritério, amplamente utilizada em processos de tomadas de decisão. Os resultados mostraram que as áreas a sudeste do Parque Estadual do Rio Doce apresentam maiores propensões a receber iniciativas de restauração de vegetação nativa. Ocorre o contrário nas regiões mais urbanizadas da bacia, que coincidem, também, com as áreas de maior declividade.

**Palavras-chave:** Análise Multicritério. Áreas de preservação permanente. Reflorestamento de vegetação nativa. Bacia do Rio Piranga.

## 1 INTRODUCTION

The management techniques concerning the planning practices are fundamental for development of environmental nature projects, either to generate knowledge about the considered territories or to organize the resources and formulate the most appropriate proposals and decisions for the work. In general, such planning practices include documents and materials that make up a diagnosis for first analyzes. For building the subsequent phases, focused on the prognosis, it is pertinent to adequately define the criteria that will justify the variables observed in the diagnosis.

This process becomes complex when the number of actors involved and interested is large. To overcome these types of difficulties, some techniques have been developed in order to simplify this organization of information and determining where environmental actions would need to take place. The use of such tools becomes even more important taking into account geographic sections of considerable extension, such as river basins.

Another ecological and regulatory issue to be considered when defining priority areas for conservation in river basins is the institution of protected spaces within rural properties with the general objective of compensating for the improper economic uses developed in these properties. In addition, several environmental experts emphasize that public areas under protection are insufficient for the conservation of the planet's biodiversity, another strong justification for the institution of these territories (GOTTFRIED et al., 1996).

Thus, the new Forestry Code (Law No. 12,651 / 2012) included the consolidation of two instruments for the restoration and sustainable use of native vegetation within rural properties, the Permanent Preservation Areas (PPA) and the Legal Reserve (RL). The current environmental scenario is one of intense degradation and exploitation of these areas, whether due to urban occupation or agricultural activities. Therefore, actions for the environmental restoration of these systems are necessary in order to restore them to their original conditions and so that they can perform the ecological function for which they were created.

Nunes et al, 2017, classified the forest restoration process into three groups: passive, intermediate and active, depending on the strategy that will be adopted. Natural regeneration is mentioned as a passive method, the conduction of regeneration and its enrichment is considered an intermediary method, and the reforestation of species with or without economic purpose is taken as an active method. The focus of the study is reforestation by using species with no economic purpose.

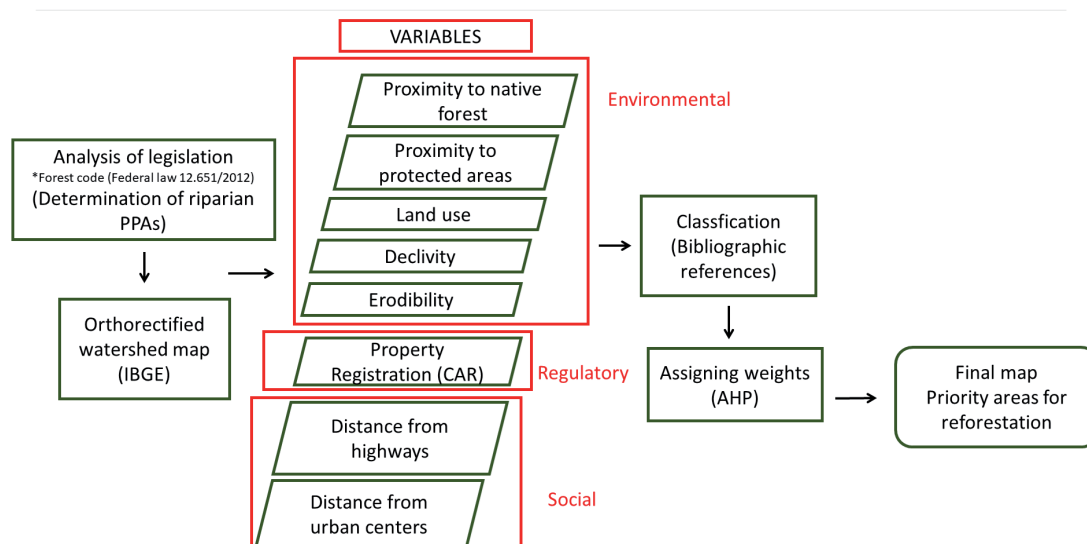
In this sense, the multicriteria analysis has been widely used in order to simplify certain decision making processes (FRANCO et al., 2013). Many scientific investigations such as Ferraz and Vettorazzi, 2003; Valente, 2005; Vettorazzi, 2006; Sartori, 2012; Uribe, 2014; Francisco et al., 2008; Valente and Vettorazzi, 2017, have already developed studies to define priority areas for reforestation, without economic ends, using multicriteria analysis as a tool for this choice, and have had satisfactory results in their research.



It is worth mentioning that, for the restoration of PPAs located in the study area, some premises are assumed and may guide the choice of variables and the process of multicriteria analysis. PPAs located close to urban centers or near highways have a history of greater degradation and for this reason should be prioritized. On the other hand, some geographical conditions must be taken into account. Areas with more fertile soils will be prioritized because they are easier to complete the restoration process, as well as areas located on a higher slope and with soil more susceptible to erosion should be prioritized because they present a strong tendency to degrade with anthropic and natural actions. Finally, this article aims to identify priority areas for reforestation in PPAs located in the Piranga River Basin.

## 2 METHODOLOGY

The study methodological approach was divided into four steps, the first being dedicated to the geographic characterization of the section under study, the second to the regulatory status necessary for analysis, while the third and fourth, explaining the model in focus, its methodology, processing, variables and weights. Following is an organization chart showing each of the steps and their relationships (Figure 1).



**Figure 1 |** Methodological organization chart  
Source: The authors (2018).

### 2.1 STUDY AREA

The study area is the Piranga River Basin (Figure 2) located in the southwestern part of the Doce River hydrographic basin, in the State of Minas Gerais. In fact, it is the continuation of the Piranga River that receives the name of the Doce River, after receiving the waters of the Carmo River, thus Piranga is effectively the main forming of Doce River. The Piranga basin contains 77 municipalities, 62 of which have their headquarters located within the contribution area. Its population is 711,026 inhabitants (480,882 urban, 230,144 rural), according to data from the IBGE / Census 2010, in a total area of 17,562.5 km<sup>2</sup>, representing about 25% of the Doce River Basin. The main biodiversity conservation area within the Doce River Basin is the Doce River State Park (PERD), which is also within the Piranga basin area.

The headwaters of the Piranga River are located in the Serra da Mantiqueira, in the municipality of Ressaquinha and its main tributaries are the Xopotó and Turvo Limpo rivers. It presents two hydroelectric plants along its course - HPP Brecha, in the municipality of Guaraciaba and PCH Brito, in Ponte Nova, in addition to having a relatively intense industrial and productive activity, including mineral production, where the Samarco Mining Company also stands out.

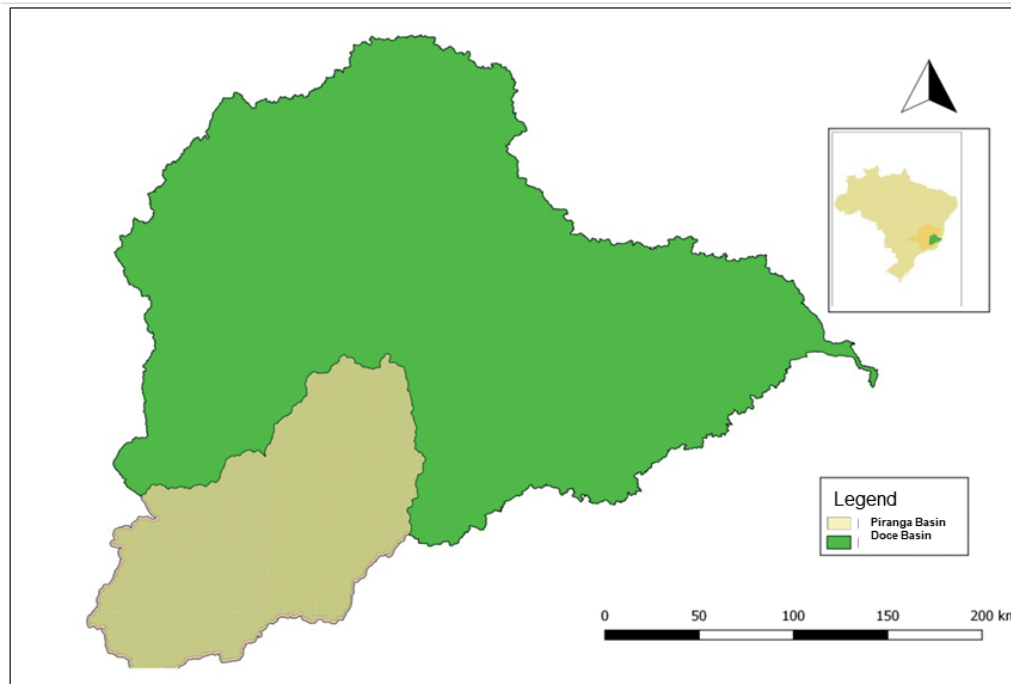


Figure 2 | Piranga River Basin

Source: The authors (2018).

Regarding the predominant economic activities in the Basin, although the entire extension of the Doce River Basin stands out as a milk producer basin, denoted by the high numbers of cattle herds (PPM, 2018), the municipalities northeast of the Piranga River Basin make up an important local economic and logistically strategic region for the entire state of Minas Gerais, named the Vale do Aço region. In addition, between 1920 and 1930 the region was chosen in Minas Gerais to receive the eucalyptus forest culture through government programs and incentives from steel mills. An example was Companhia Siderúrgica Belgo Mineira, and later Acesita, in 1949. The company was a pioneer in the creation of forest services in the region and encouraged other subsidiary companies to operate in the reforestation sector (GUERRA, 1995). Such a profile can be evidenced by the land use and occupation map of the Basin (Modelo Optimizagro. SOARES FILHO et al., 2013), where it is possible to identify large extensions focused on forest plantation (525,766 ha).

As a consequence of this land use and occupation, the Piranga River Basin, as well as all the territory of the Doce River Basin, has a history of intense soil degradation and inadequate use of its natural resources, such as water. According to latest data, the territory in almost all its extension, 83.3%, was classified as moderately degraded or degraded (UFMG; UFV; Fundação Renova, 2018), and the Piranga River Basin is located in this regional section.

In 2015, with the collapse of the Fundão dam, located in the municipality of Mariana and operated by the Samarco mining company, this scenario worsened. According to Pires et al (2017), 40 to 63 million m<sup>3</sup> of mining tailings were discharged in the river. The damaging consequences, in addition to the destruction of total or partial districts such as Bento Rodrigues, Paracatu and Gesteira, were losses in biodiversity, economic losses for the riverside populations and intense pollution of the entire Doce River. According to Fernandes et al. (2016), the event was the last straw in a long lasting degradation process, which affected the provision of ecosystem services for more than 1 million people, with an estimated loss of US \$ 5.21 billion per year in the region (GARCIA et al., 2017). Forest restoration, the focus of the study, in this area is one of the mechanisms capable of guaranteeing the quality and quantity of water in the Doce River Basin (Figure 3).

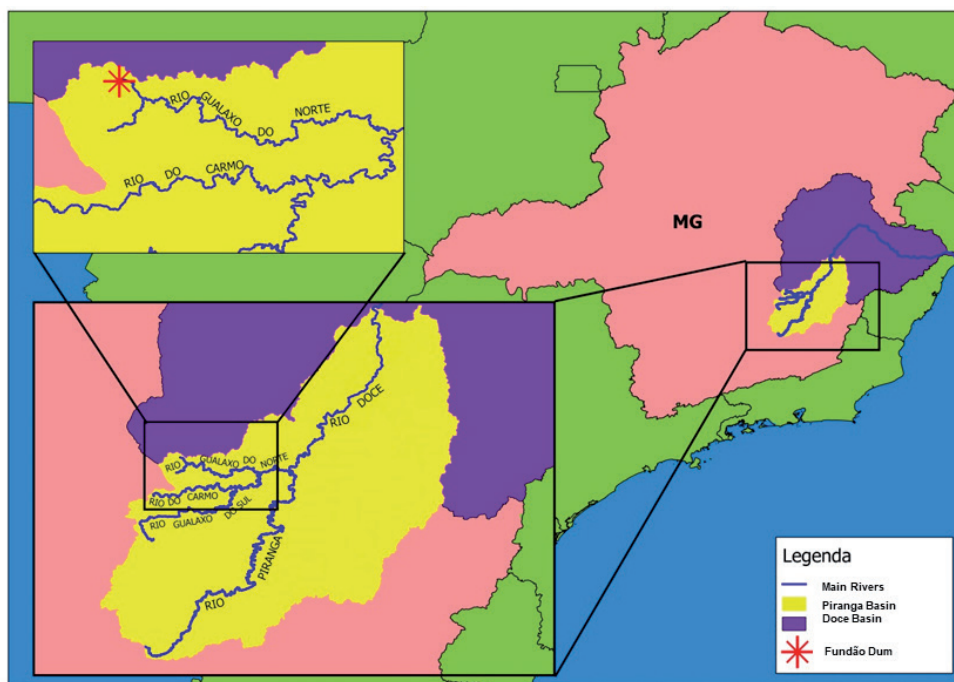


Figure 3 | Tailings mud path from the Fundão dam, municipality of Mariana

Source: EPSJV/Fiocruz

## 2.2 WATER BODY PERMANENT PRESERVATION AREAS

The Forest Code (Law No. 12,651 / 2012) brought about the consolidation of two instruments for restoration and sustainable use of native vegetation within private rural properties, the Legal Reserve (RL) and the Permanent Preservation Areas (PPA). According to the Forest Code, PPAs are defined as: “the protected area, covered or not by native vegetation, with the environmental function of preserving water resources, the landscape, geological stability and biodiversity, facilitating the gene flow of fauna and flora, protecting the soil and ensure the well-being of human populations.” (Item III, of Article 3 of Law 12.651 / 2012). In this sense, the need to preserve and restore these areas becomes clear.

These areas, whether or not covered by native vegetation, are located neighboring the banks of rivers and other water bodies in bands of varying width, on steep slopes, hill tops, in addition to other locations specified by law. However, the current scenario is one of intense degradation and the occupation of these protected areas for agricultural activities and urban use. According to data from Soares Filho et al (2014), the environmental liability debt of PPAs is approximately 220,000 hectares for the whole of Brazil, and this scenario is even worse in the Atlantic Forest biome, which occupies more than 98% of the Doce River Basin, where only 12% to 16% of native vegetation remains. It is worth mentioning that when assessing the environmental liability with higher resolution images and a denser hydrographic network, this liability may increase.

The new Forest Code (Law No. 12,651 / 2012) also includes changes to the establishment of these PPAs. Article 4, item I defines PPA as being the marginal areas of any natural, perennial or intermittent watercourse from the edge of the regular riverbed, in a minimum width that can vary from 30 m to 500 m, according to the width of the river between less than 10 m and more than 600 m, respectively.

Federal Law 12.651 / 2012 also specifies which areas should carry out forest restoration and which method to use. According to device 13 of article 61A, the forest restoration in the marginal bands can be done, isolated or together, by means of:

I - conducting natural regeneration of native species;

II - planting native species;

III - planting of native species in conjunction with conducting the natural regeneration of native species;

IV - intercalated planting of woody, perennial or long-cycle, exotic species with native species of regional occurrence, in up to 50% (fifty percent) of the total area to be recomposed, in the case of rural properties with up to 4 fiscal modules, as well as to demarcated indigenous lands and other areas entitled to traditional peoples and communities that make collective use of their territory (BRASIL, 2012, Art. 3, item I to IV and Single Paragraph).

These three forms of recomposition refer to three restoration processes classified by Nunes et al (2017), as passive, intermediate and active. Passive restoration or natural regeneration is a process of natural succession with minimal human intervention (HOLL and AIDE, 2011). It is a slow but low-cost process. The active, on the other hand, is a process of restoration by total planting with native species without economic ends. This latter technique is the focus of the approach in this article.

In order to a PPA area minimally fulfill its environmental functions, as determined by the Forest Code, its use must be compatible with the previously existing native vegetation preservation regime. In this sense, the mapping of land use and coverage, preferably in high spatial resolution, is an important tool for the analysis of legal compliance in the scale of rural properties and the landscape, as in the case of the Doce River Basin. The National Water Agency (ANA) and the Brazilian Institute of Geography and Statistics (IBGE) provide hydrographic maps of the entire country, but the scale of 1:100,000 or less available in these maps does not allow a detailed analysis of the Doce River Basin. For this reason, the hydrographic network mapping carried out by the Brazilian Foundation for Sustainable Development (FBDS) was used in this study. The FBDS mapping project was carried out through supervised classification of RapidEye remote sensing images for the year 2013, on a scale of 1:10,000, producing maps of land use and coverage on the scale of 1:20,000.

## 2.3 MULTICRITERIA ANALYSIS

Spatial analysis represents one of the most efficient and economical methods in the management of watersheds, especially when it is necessary to carry out a prioritization of areas. In a practical way, it is an integration of different landscape information plans and their characteristics and, or, processes, together with the Geographic Information Systems GIS (VALENTE, 2005). In this sense, the Multicriteria Analysis (MCA) can be highlighted, according to Malczewski (2004), this method can be described as a process that transforms and combines spatial and non-spatial data resulting in a decision.

MCA as a methodology is based on the observation of alternatives in order to clarify issues, where different criteria involved with a given study object are used for identifying the best options available within the analyzed universe (FRANCISCO et al., 2007, apud FRANCO et al., 2013). This analysis is based on criteria that can be factors and restrictions and can refer to individual attributes or the whole set. Despite the selection of criteria as well as the definition of the relative importance of each criterion present a certain degree of subjectivity, the results obtained have shown great coherence with reality (VETTORAZZI, 2006).

Thus, in order to define the MCA weights, which will guide the formulation of the final analysis, one of the main techniques used is the Analytical Hierarchical Process (AHP), where the weights are assigned according to their relative importance. According to Souza et al. (2013), this technique is based on the identification of a decision problem and its decomposition into “sub problems”, where each one can be analyzed independently (SILVA JÚNIOR, 2015).

The attribution of weights to the criteria consists of quantifying the importance of each one in the decision-making process. Several methods have been developed to assist in the definition of the factor compensation weights, including the ordering, the point scale, the point distribution and the method based on the comparison of criteria two by two (RAMOS and MENDES, 2001). To elaborate the comparison matrix, the factors were compared, two by two, using Eastman (2001) as a reference, with the continuous scale of nine points (Table 1). The compensation weights, which express the importance or order of importance of the factors in the decision-making process, were determined based on the literature review from projects developed using the Participatory Technique. The software used to support the application of multicriteria analysis method was ArcGIS.

**Table 1 | Intensity of importance between criteria**

| <i>Intensity of importance</i> | <i>Definition and explanation</i>  |
|--------------------------------|--|
| 1                              | Equal importance - both factors contribute equally for the goal  |
| 3                              | Moderate importance - one factor is slightly more important than the other   |
| 5                              | Essential importance - one factor is clearly more important than the other   |
| 7                              | Demonstrated importance - One factor is strongly favored and its greater relevance has been demonstrated in practice |
| 9                              | Extreme importance - The evidence that differentiates factors is of the highest order possible                       |
| 2,4,6                          | Intermediate values between judgments - possibility of additional commitments  |

*Source: Adapted from Eastman (2001).*

## 2.4 DEFINITION OF VARIABLES AND WEIGHTS USED

In the period from 2002 to 2017, many studies were developed with the objective of identifying priority areas for conservation through multicriteria analysis. In this process, one of the most important methodological steps is the definition of variables. In this sense, the following related researches produced by Borges (2009); Lima et al. (2011); Francisco (2006), Ferraz, S.F.B. & Vettorazzi, C.A, (2003); Bertoni & Lombardi (1985), Mannigel et al., (2002) can be highlighted as foundations for choosing variables and others parameters. In addition, Uribe (2014) presents a study in which the choice of variables was made through interviews with stakeholders in an area in the southern portion of Mexico of 11,631 km<sup>2</sup> covering wholly or partially (50%) 124 municipalities. Table 2 below details which variables stand out according to the percentage in which they appeared in the interviews.

**Table 2 | Ranking of the criteria used in AHP most mentioned in interviews by stakeholders**

| <i>Ranking</i> | <i>Criterion</i>  | <i>Frquency</i> |
|----------------|---|-----------------|
| 1              | Forest fragment distance  | 64,3            |
| 2              | Land use and land use changes   | 57,1            |
| 3              | Erosion risk (soil erodibility and rain erosivity)                    | 53,6            |
| 4              | Biodiversity index and natural corridors                              | 46,4            |
| 5              | Declivity   | 42,9            |
| 6              | Crop distance   | 39,3            |
| 7              | Demographic density, distance from highways, distance from rivers     | 35,7            |
| 8              | Distance from human settlements, marginality index and social capital | 32,1            |
| 9              | Depth of soil   | 28,6            |
| 10             | Land tenure (CAR)   | 17,9            |

| Ranking | Criterion  | Frquency |
|---------|--|----------|
| 11      | Distance from protected areas (PPAs)   | 10,7     |
| 12      | Soil fertility   | 7,1      |
| 13      | Distance from point sources of greenhouse gas emissions, migration rate, forest fragmentation, precipitation, livestock presence, use of biodiversity, temperature | 3,6      |

Source: Adapted from Uribe et al, (2014).

The action of these stakeholders (landowners, local development associations, etc.) in the decision-making process is legitimate and necessary since they are the agents of the forest restoration process, in addition, it ends up bringing a transdisciplinary approach integrating scientific knowledge and local knowledge. These users or interest groups in the basin are directly linked to primary development and / or conservation activities since they enjoy the landscape for their subsistence and are thus directly linked to the generation of ecosystem services. This type of study brings a methodology for building bottom-up policies that are considered more effective for maintaining restored areas, in contrast to the top-down ones that bring strictly technical criteria for discussion (LINDBORG et al., 2008).

Thus, for the present study, variables were chosen and segmented by typologies (ecological, regulatory and social) with the respective study used to support them (Table 3).

**Table 3 | Chosen Variables for applying in MCA**

| Criteria                     | Type       | Source  |
|------------------------------|------------|---|
| Proximity to native forest   | Ecological | Catelani et al., 2012; Franco; Hernandez; Moraes, 2013; Orsi; Geneletti; Newton, 2011 |
| Proximity to protected áreas |            | Orsi; Geneletti, 2010; Valente; Vettorazzi, 2008)                                     |
| Land use                     |            | Catelani et al., 2012; Franco; Hernandez; Moraes, 2013; Orsi; Geneletti; Newton, 2011 |
| Declivity                    |            | Sartori, 2012; Valente, Valente; Petean; Vettorazzi, 2017; Valente; Vettorazzi, 2008  |
| Erodibility                  |            | Mannigel et al, 2002; BERTONI, J.; LOMBARDI NETO, F, 1990                             |
| Property Registration (CAR)  | Regulatory | Uribe et al., 2014  |
| Distance from highways       | Social     | Fabbro Neto et al., 2014; Valente; Valente; Vettorazzi, 2008                          |
| Distance from urban centers  |            | Fabbro Neto et al., 2014; Uribe et al., 2014; Valente; Valente; Vettorazzi, 2008      |

Source: The authors (2018).

Regarding the assignment of grades and the resulting classification, the areas were segmented into high, medium and low priority for reforestation. Following is a description of some of the criteria and how the grades were assigned according to the authors mentioned:

- Slope: Slope is important because the higher its index, the greater the risk of erosion, which makes the steeper areas more interesting for reforestation, and they also have a lower propensity for agricultural use, which also favors the less flat areas having a higher priority for planting native species.
- Land use: Land use is an indicator of favorable or even inappropriate areas. Examples of areas that do not apply the possibility of reforestation with native species are areas that are already covered by native trees, urban areas, highways, surfaces covered by water. Forestry and traditionally agricultural areas are also not favorable.

- Susceptibility to erosion: Reforestation is a tool to combat erosion. Therefore, its implementation becomes more interesting in places where this type of problem occurs, considering that where there is erosion, generally, there are also no other types of economic interest.
- Erodibility: Soil erodibility factor K (t.ha.h./ha.MJ.mm) was used as a reference; where: t = ton, ha = hectare, h = hour, MJ = mega joule and mm = millimeter. Its determination requires field visits and validations, according to local conditions. Due to the inexistence of these data, factors estimated from soil characteristics were used, according to Bertoni & Lombardi Neto (1985; 1990) and cited by Mannigel et al (2002).
- Proximity to Native Woods: Reforestation with native species is favored with the proximity of other native forests as this implies ecological connectivity. Thus, we used the variable that makes up the bands of areas that are up to 50 meters away from the native forests already existing in the researched PPAs.
- Proximity to Urban Areas: Generally, the proximity to urban areas is not a favorable factor for the implementation of reforestation of native forest. This is due to the fact that, in general, urban expansion and real estate speculation are factors of considerable pressure and detract from the sustainability of these areas. In this way, we used the variable that composes the bands of areas that are up to 200 meters away from the urban areas present in the surveyed PPAs.
- Proximity to Highways: Similar to that explained in the previous item, proximity to highways is also a factor considered unfavorable. Thus, we used the variable that makes up the bands of areas that are up to 200 meters away from the highways.

After the variables previous study, the maps to be used in the multicriteria analysis were selected. As a process, the selected maps were reclassified by assigning a grade to each class, as previously explained. At the end, weights were given for each of the variables separated according to the authors cited in studies of the AHP method. Table 4 shows the weights used in the final analysis.

**Table 4 |** Weights used in the final analysis

|                                 | <i>Proximity to native forest</i> | <i>Declivity</i> | <i>Erodibility</i> | <i>Proximity to urban áreas / roads</i> | <i>Land use</i> | <i>CAR registra-tion</i> | <i>Weights</i> |
|---------------------------------|-----------------------------------|------------------|--------------------|---|-----------------|--------------------------|----------------|
| Proximity to native forest      | 1                                 | -                | -                  | -                                       | -               | -                        | 0,28           |
| Declivity                       | 5                                 | 1                | -                  | -                                       | -               | -                        | 0,12           |
| erodibility                     | 7                                 | 9                | 1                  | -                                       | -               | -                        | 0,18           |
| Proximity to urban areas/ roads | 3                                 | 3                | 3                  | 1                                       | -               | -                        | 0,17           |
| Land use                        | 7                                 | 5                | 7                  | 7                                       | 1               | -                        | 0,15           |
| CAR registration                | 7                                 | 7                | 5                  | 3                                       | 5               | 1                        | 0,10           |

Source: The authors (2018).

### 3 RESULTS AND DISCUSSIONS

The results are different from other works available in the literature, such as those seen in the studies of Francisco (2006) and Ferraz and Vettorazzi (2003) because the great challenge to be faced is the large extension of the chosen basin, since most of the previous research was developed for small basins. Another important difference is the focus on permanent protection areas of watercourses. For this,

an intense work of remote sensing was necessary due to the great differences in width among the watercourses found in the basin.

In a practical way and observing by a general overview, Figure 4 shows that the areas to the southeast of the Doce River State Park are more likely to receive restoration initiatives with native species. The opposite occurs in the most urbanized regions of the basin and also similarly in those regions with a lower density of native vegetation. The latter are coincident with the areas of the steepest relief.

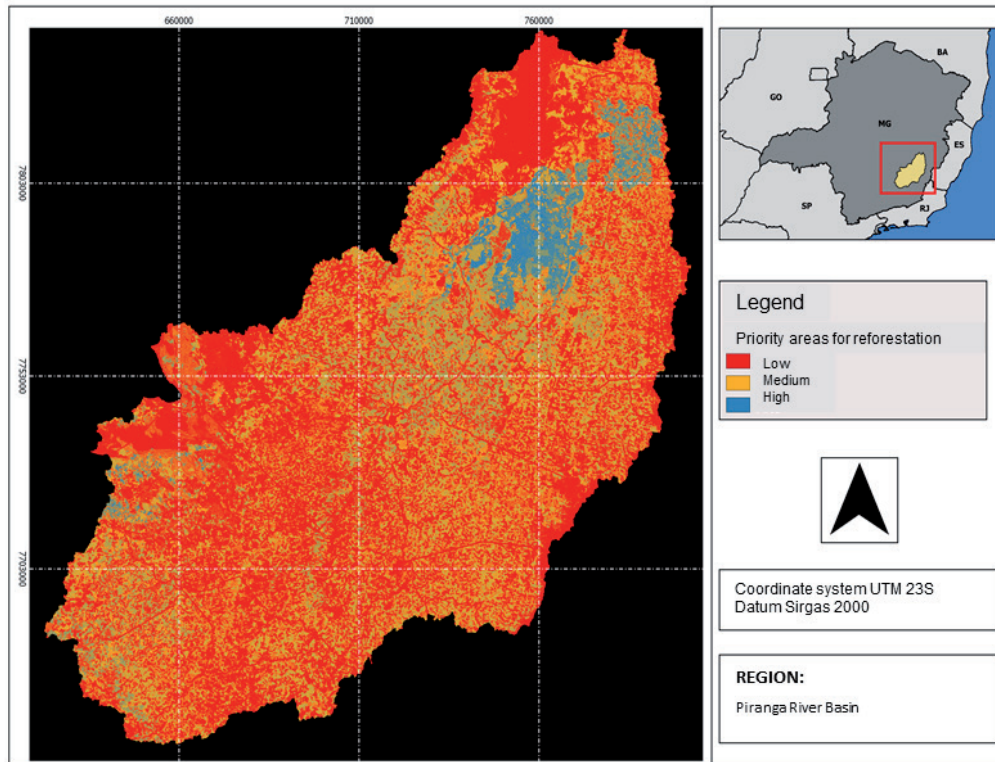


Figure 4 | Map of Priority Areas for Reforestation

Source: The authors (2018).

However, it can be inferred that the present study takes on great importance due to the historical scenario of degradation due to agricultural activities in these protection territories, especially if taken into account the environmental importance of these areas (water recharge, containment of erosive processes, carbon storage, refuge of fauna) and the urgency to reestablish the ecological processes after the tailings dam rupture in Mariana.

Another point to discuss is that reforestation is just one of the restoration strategies that can be mentioned. There are also forest plantations for economic purposes, normally it is a mix of exotic and native species, which can be chosen according to the farmer's desire and also based on the edaphoclimatic characteristics of the territory. In this sense, it is mentioned that each of these formats for restoration has peculiarities that may require other variables than those used in this study and highlight other necessary approaches for the restoration chain, such as the need for investment in nurseries of plant species, training of local labor and other actions already evidenced by other studies (SALOMÃO, 2019).

However, it is necessary to highlight that there was no validation of these results in the field, but some indications can explain about the coherence of the results. One of the criteria considered in the analysis as facilitating restoration was the proximity to native vegetation and land use. At the landscape



level, connectivity with forest fragments can provide gene flow and accelerate the restoration process (NUNES et al, 2017), this point ends up explaining the concentration of activities around the PERD, which is a State Conservation Unit.

Another issue is regarding the proximity of the road network. Access around the Park is limited, the nearest highway (LMG 760) had a troubled environmental licensing process and only in 2018 the paving process was resumed. A third explanatory point would be the pedological characteristic of the region, the yellow latosol is the dominant classification. These soils are deep and well structured, being attractive for planting native species, but poor in nutrients for crops (CONSÓRCIO ECOPLAN-LUME).

In addition, another necessary issue in this on-site validation is popular participation. This social control is crucial for the realization of restoration. If the rural owner does not feel part of the process, it will be very difficult in the medium and long term to succeed. For this reason, a “bottom up” process is necessary since the construction of public policies such as the Environmental Regularization Program - PRA, as discussed in Salomão (2019).

## 4 CONCLUSIONS

The next step of the research to be continued is concerned to the development of some scenarios that may influence public policies. According to (Soares Filho et al 2016) the first scenario to be outlined aims to verify what percentages of priority areas for restoration are within areas in debt according to the Forest Code and so to establish a hierarchy by municipalities. For that purpose, the maps of the aforementioned authors will be retrieved, an analysis of which municipalities are in greater debt will be established and how this issue can be partially solved by the model will be decided. For the second scenario, an assessment will be made of the extent of priority areas for passive restoration and contrasting this with the extent provided for in instruments for the recovery of the Piranga River Basin. It can be mentioned as instruments the Basin Master Plan and the PPAs Recovery Program established in the TTAC - Conduct Adjustment Transaction Term established between public and private entities, thanks to the consequences of the Fundão Dam Disruption.

## REFERENCES

BERTONI, J.; LOMBARDI NETO, F. **Conservação do solo**. Piracicaba: Ícone, 1985.

\_\_\_\_\_. \_\_\_\_\_. São Paulo: Ícone, 1990.

BORGES, L. A. C. et al. Evolução da Legislação Ambiental no Brasil. **Rama: Revista em Agronegócio e Meio Ambiente**, Maringá, PR, v. 2, p. 447-466, 2009.

BRASIL. **Lei Nº 12.651, de 25 de maio de 2012**. Dispõe sobre a proteção da vegetação nativa; altera as Leis no 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis no 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória no 2.166-67, de 24 de agosto de 2001; e dá outras providências.

EASTMAN, J. R. **Decision support: decision strategy analysis**. Idrisi 32 Release 2: guide to GIS and image processing. Worcester: Clark Labs, Clark University, 2001.

FERNANDES, G. W. et al. Deep into the mud: ecological and socio-economic impacts of the dam breach in Mariana, Brazil. **Natureza & Conservação**, v.14, n. 2, p. 35-45, 2016.

FERRAZ, S. F. B.; VETTORAZZI, C. A. Identificação de áreas prioritárias para recomposição florestal com base em princípios de ecologia de paisagem. **Revista Árvore**, v. 27, n. 4, 2003.

- FRANCISCO, C. E. F. **Áreas de preservação permanente na Bacia do Ribeirão das Anhumas: estabelecimento de prioridades para recuperação por meio de análise multicriterial.** Dissertação (Mestrado) – Instituto Agrônomo de Campinas (IAC), 2006.
- FRANCISCO, C. E. S. et al. Análise multicriterial na seleção de bacia hidrográfica para recuperação ambiental. **Ciência Florestal**, v. 18, n. 1, p.1-13, 2008.
- FRANCISCO, C. E. S. et al. Espacialização de análise multicriterial em SIG: prioridade para recuperação de Áreas de Preservação Permanentes. In: XIII SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO. Florianópolis. **Anais...** São José dos Campos: Inpe, p. 2643-2650, 2007.
- FRANCO, G. B. et al. Relação qualidade da água e fragilidade ambiental da Bacia do Rio Almada, Bahia. **Brazilian Journal of Geology**, São Paulo, v. 42, suppl. 1, p. 114-127, 2013.
- GARCIA, L. C. et al. Brazil's worst mining disaster: corporations must be compelled to pay the actual environmental costs. **Ecological Applications**, v. 27, n. 1, p. 5-9, 2017.
- GOTTFRIED, R.; WEAR, D.; LEE, R. Institutional solutions to market failure on the landscape scale. **Ecological Economics**, v. 18, n. 2, p. 133-140, 1996.
- GUERRA, C. **Meio ambiente e trabalho no mundo do eucalipto.** 2. ed. Belo Horizonte, Agência Terra, 1995.
- HOLL, K. D.; AIDE, T. M. When and where to actively restore eco-systems? **For. Ecol. Manage**, v. 261, p. 1558-63, 2011.
- LIMA, L. P. Z. et al. Análise da vulnerabilidade natural para implantação de unidades de conservação na microrregião da Serra de Carrancas, MG. **Cerne**, Lavras, v. 17, n. 2, p. 151-159, 2011.
- LINDBORG, R. et al. A landscape perspective on conservation of semi-natural grasslands. **Agriculture, Ecosystems & Environment**, v. 125, n. 1-4, p. 213-222, 2008.
- MANNIGEL, A. R. et al. Fator erodibilidade e tolerância de perda dos solos do estado de São Paulo. **Acta Scientiarum**, Maringá, v. 24, n. 5, p. 1335-1340, 2002.
- NUNES, et al. Enabling large-scale forest restoration in Minas Gerais state, Brazil. **Environ. Res. Lett.**, v. 12, n. 044022, 2017.
- PESQUISA DA PECUÁRIA MUNICIPAL. Disponível em: <<https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9107-producao-da-pecuaria-municipal.html>>. Acesso em: ago. 2019.
- PIRES, A. P. F. et al. Forest restoration can increase the Rio Doce watershed resilience. **Perspectives in Ecology and Conservation**, v. 15, n. 3, p. 187-193, 2017.
- RAMOS, R. A. R.; MENDES, J. F. G. Avaliação de aptidão do solo para localização industrial: o caso de Valença. **Revista Engenharia Civil**, v. 10, n. 1, p. 7-29, 2001.
- SALOMÃO, C. S. C. **Sistemas agroflorestais como estratégia para restauração ecológica da Bacia do Rio Doce.** Dissertação (Mestrado) – Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, 2019.
- SILVA JUNIOR, C. H. L. Lógica Fuzzy e Processo Analítico Hierárquico (AHP) aplicados ao Zoneamento de Áreas Suscetíveis a Deslizamentos: uma revisão. **Revista Monografias Ambientais – Remoa.** Revista do Centro de Ciências Naturais e Exatas – UFSM, v. 14, n. 3, p. 42-58, 2015.
- SOARES FILHO, B. S.; RODRIGUES, H.; FOLLADOR, M. A hybrid analytical-heuristic method for calibrating land-use change models Environ. **Modell Software**, v. 43, p. 80-87, 2013.
- SOARES FILHO, B. S. et al. **Modelagem das Oportunidades Econômicas e Ambientais do Restauo Florestal sob o Novo Código Florestal.** Impacto de políticas públicas voltadas à implementação do novo Código Florestal. Relatório de Projeto. Centro de Sensoriamento Remoto, UFMG, Belo Horizonte-MG, 2014.

SOUZA, D. F. DE et al. **Aplicação do método AHP-Fuzzy**. ENCONTRO NACIONAL DOS ESTUDANTES DE MATEMÁTICA DA REGIÃO SUL, 2010. Porto Alegre/RS. Disponível em: <<http://www.pucrs.br/edipucrs/erematsul/comunicacoes/10DEBORAFERRODESOUZA.pdf>>. Acesso em: 20 jan. 2013.

UFMG; UFV; FUNDAÇÃO RENOVA. **Definição de áreas prioritárias para restauração florestal na Bacia do Rio Doce**, 2018.

URIBE, D. et al. Integrating Stakeholder Preferences and GIS-Based Multicriteria Analysis to Identify Forest Landscape Restoration Priorities. **Sustainability**, v. 6, p. 935-951 2014.

VALENTE, R. O. A. **Definição de áreas prioritárias para a conservação e preservação florestal por meio da abordagem multicritério em ambiente SIG**, 2005. 121 f. Tese (Doutorado em Recursos Florestais) – Escola Superior de Luiz de Queiroz, Universidade de São Paulo, Piracicaba, 2005.

VALENTE, R. A.; VETTORAZZI, C. A. Multicriteria Decision Analysis for Prioritizing Areas for Forest Restoration. **Cerne**, v. 23, n. 1, p. 53-60, 2017.

VETTORAZZI, C. A. **Avaliação multicritério em ambiente SIG, na definição de áreas prioritárias à restauração florestal visando à conservação dos recursos hídricos**. 151 f. Tese (Livre Docência em Topografia) – Escola Superior de Luiz de Queiroz, Universidade de São Paulo, Piracicaba. 2006.

# Uso da análise multicritério para definição de áreas prioritárias para reflorestamento na Bacia do Rio Piranga, MG, Brasil

*Use of multicriteria analysis to define priority areas for reforestation in the Piranga River Basin, MG, Brazil*

Caroline de Souza Cruz Salomão<sup>a</sup>

Luiz Gustavo de Souza Paula<sup>b</sup>

Marcos Antônio Timbó Elmiro<sup>c</sup>

<sup>a</sup>Programa de Pós-Graduação em Análise e Modelagem de Sistemas Ambientais, Universidade Federal de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil  
End. Eletrônico: carolinescsalomao2@gmail.com

<sup>b</sup>Programa de Pós-Graduação em Análise e Modelagem de Sistemas Ambientais, Universidade Federal de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil  
End. Eletrônico: lgustavosouzap@gmail.com

<sup>c</sup>Programa de Pós-Graduação em Análise e Modelagem de Sistemas Ambientais, Universidade Federal de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil  
End. Eletrônico: timboelmiro@gmail.com

doi:10.18472/SustDeb.v11n2.2020.30468

Received: 28/11/2019  
Accepted: 01/04/2020

ARTICLE- DOSSIER

## RESUMO

A Bacia do Rio Piranga é uma das principais sub-bacias do Rio Doce, sendo uma das mais exploradas historicamente, que culminou em um episódio emblemático, o rompimento da barragem de rejeitos de mineração em Mariana. Os responsáveis pelo dano precisaram desenvolver soluções para reparação do território, destacando-se a definição de áreas prioritárias para conservação. Um fator a considerar para essa definição foi a instituição de espaços protegidos em imóveis rurais, como as Áreas de Preservação Permanente (APPs), consolidadas pelo novo Código Florestal (Lei nº 12.651/2012). Para alocação das áreas de intervenção, foi adotada a Análise Multicritério, amplamente utilizada em processos de tomadas de decisão. Os resultados mostraram que as áreas a sudeste do Parque Estadual do Rio Doce apresentam maiores propensões a receber iniciativas de restauração de vegetação nativa. Ocorre o contrário nas regiões mais urbanizadas da bacia, que coincidem, também, com as áreas de maior declividade.

**Palavras-chave:** Análise Multicritério. Áreas de preservação permanente. Reflorestamento de vegetação nativa. Bacia do Rio Piranga.

## ABSTRACT

The Piranga River Basin is one of the main sub-basins of the Doce River, being one of the most historically explored, which culminated in an emblematic episode, the rupture of the mining tailings dam in Mariana.

*Those responsible for damage had to develop solutions to repair the territory, mainly the definition of priority areas for conservation. One factor to consider for this definition was the institution of protected spaces in rural properties, such as the Permanent Preservation Areas (PPAs), consolidated by the new Forest Code (Law No. 12,651 / 2012). For the allocation of intervention areas the Multicriteria Analysis, widely used in decision-making processes, was adopted. The results showed that the areas southeast of the Doce River State Park are more likely to receive initiatives to restore native vegetation. The opposite occurs in the more urbanized regions of the basin, which are also coincident with the steepest areas.*

**Keywords:** Multicriteria analysis. Permanent preservation areas. Reforestation of native vegetation. Piranga River Basin.

## 1 INTRODUÇÃO

As técnicas de gestão direcionadas às práticas de planejamento são fundamentais para o desenvolvimento de projetos de cunho ambiental, seja para gerar conhecimentos sobre os territórios contemplados, seja para organizar os recursos e formular as propostas e as decisões mais adequadas para os trabalhos. De uma maneira geral, tais práticas de planejamento incluem documentos e materiais que compõem um diagnóstico para as primeiras análises. Para a construção das fases subsequentes, voltadas para os prognósticos, é pertinente definir adequadamente os critérios que embasarão as variáveis observadas no diagnóstico.

Esse processo torna-se complexo quando o número de atores envolvidos e interessados é grande. Para contornar esses tipos de dificuldade, foram desenvolvidas algumas técnicas que buscam simplificar essa organização de informações e determinam onde as ações ambientais precisariam ocorrer, ainda mais levando em consideração recortes geográficos de extensão considerável, como as bacias hidrográficas.

Outra questão ecológica e regulatória a se considerar na definição das áreas prioritárias para conservação em bacias hidrográficas é a instituição de espaços protegidos dentro de imóveis rurais com o objetivo geral de compensar os usos econômicos indevidos desenvolvidos nessas propriedades. Além disso, vários especialistas ressaltam que as áreas públicas sob proteção são insuficientes para a conservação da biodiversidade do planeta, outra justificativa para a instituição desses territórios (GOTTFRIED et al., 1996).

Dessa forma, o novo Código Florestal (Lei nº 12.651/2012) trouxe a consolidação de dois instrumentos de recomposição e uso sustentável da vegetação nativa dentro dos imóveis rurais, as Áreas de Preservação Permanente (APP) e as de Reserva Legal (RL). O cenário atual é de intensa degradação e exploração dessas áreas, seja pela ocupação urbana, seja por atividades agropecuárias. Para isso, tornam-se necessárias ações para restauração ambiental desses sistemas a fim de retomar as suas condições iniciais e para que possam fazer a função ecológica para a qual foram criados. Nunes et al. (2017) classificaram o processo de restauração florestal em três grupos: passivo, intermediário e ativo, a depender da estratégia que será adotada. Cita-se como passivo a regeneração natural, como intermediário a condução da regeneração e o enriquecimento, e como ativo o reflorestamento de espécies com ou sem finalidade econômica. O foco do estudo é o reflorestamento com espécies sem finalidade econômica.

Nesse sentido, a análise multicritério tem sido amplamente utilizada com objetivo de descomplicar determinados processos de tomadas de decisão (FRANCO et al., 2013). Ferraz e Vettorazzi (2003); Francisco et al. (2008); Sartori (2012); Uribe (2014); Valente (2005); Valente e Vettorazzi (2017); e Vettorazzi (2006) já desenvolveram estudos para definição de áreas prioritárias para reflorestamento, sem fins econômicos, utilizando a análise de multicritério como ferramenta para essa escolha, e tiveram resultados satisfatórios em suas pesquisas.

Vale destacar que, para restauração das APPs localizadas na área de estudo, algumas premissas são assumidas e poderão nortear a escolha das variáveis e o processo da análise de multicritério. APPs localizadas próximas a centros urbanos ou rodovias possuem um histórico de degradação maior e, por

essa razão, deverão ser priorizadas. Por outro lado, algumas condições geográficas devem ser levadas em consideração. Áreas com solos mais férteis serão priorizadas por terem maior facilidade de se concluir o processo de restauração, assim como áreas localizadas em maior declive e com solos mais susceptíveis à erosão devem ser priorizadas por terem uma maior tendência a se degradar com as ações antrópicas e naturais. Por fim, o presente artigo tem como objetivo identificar áreas prioritárias para reflorestamento em APPs na Bacia do Rio Piranga.

## 2 METODOLOGIA

A descrição metodológica do estudo foi dividida em quatro itens, sendo a primeira dedicada à caracterização geográfica do recorte em estudo, a segunda ao *status* regulatório necessário à análise e, por fim, a terceira e a quarta explicitando o modelo em questão, sua metodologia, processamento, variáveis e pesos. Segue um organograma demonstrando cada uma das etapas citadas acima (Figura 1).

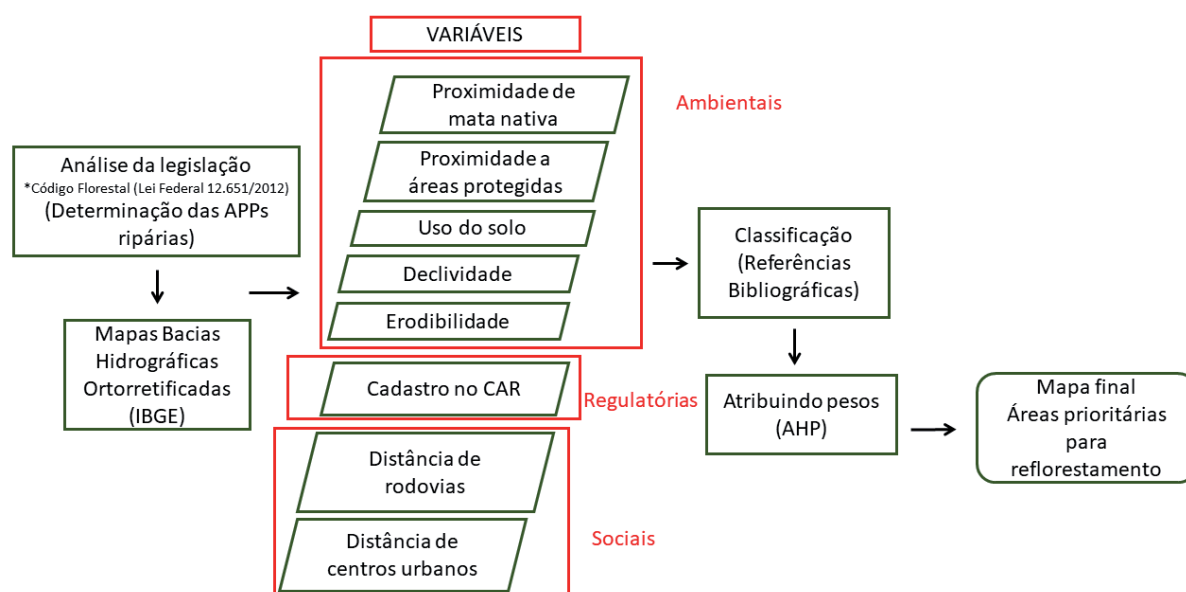


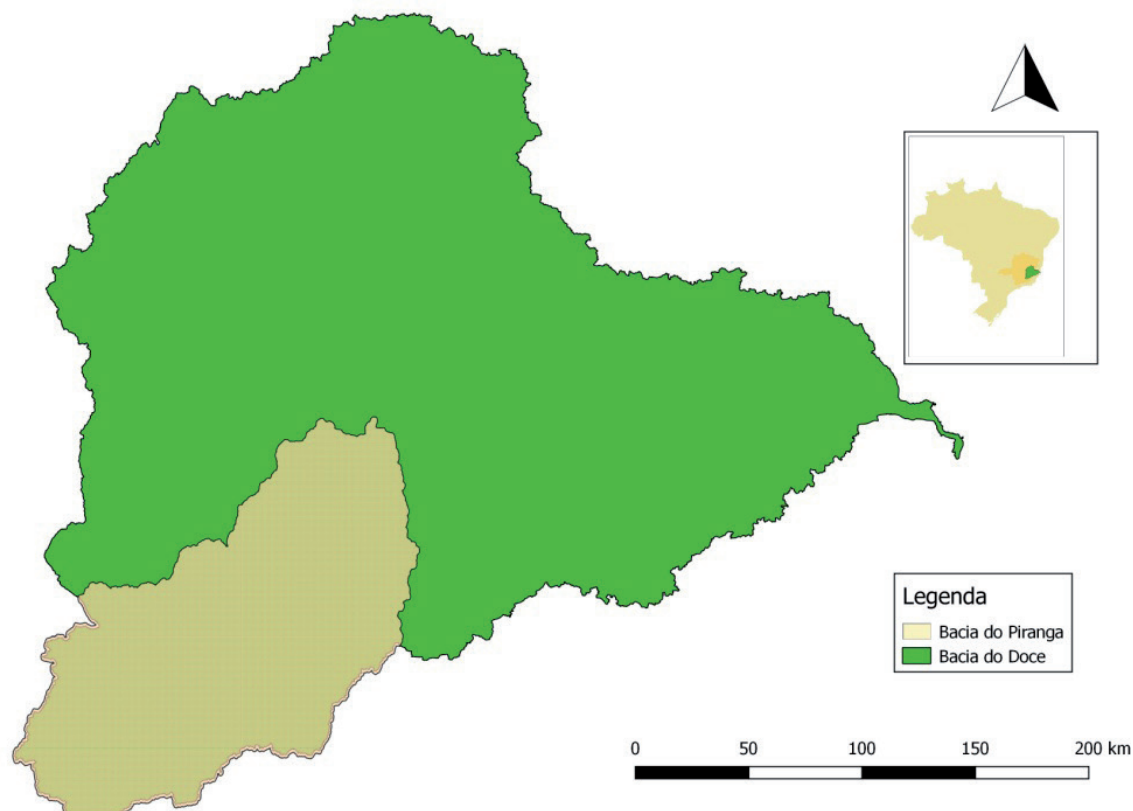
Figura 1 | Organograma metodológico

Fonte: Elaborada pelos autores (2018).

### 2.1 ÁREA DE ESTUDO

A área de estudo é a Bacia do Rio Piranga (Figura 2) localizada na parte sudoeste da Bacia Hidrográfica do Rio Doce, no estado de Minas Gerais. Inclusive, é a continuação do Rio Piranga que recebe o nome de Rio Doce, após receber as águas do Rio Carmo, dessa forma, sendo o seu principal rio formador. A Bacia do Piranga contém 77 municípios, e 62 destes possuem suas sedes localizadas dentro da área de contribuição. Sua população é de 711.026 habitantes (480.882 urbana e 230.144 rural), segundo dados do IBGE/Censo 2010, em uma área total de 17.562,5 km<sup>2</sup>, representando cerca de 25% da Bacia do Rio Doce. A principal área de conservação da biodiversidade da Bacia do Rio Doce é o Parque Estadual do Rio Doce (Perd), que também está dentro da área da Bacia do Piranga.

As nascentes do Rio Piranga situam-se na Serra da Mantiqueira, no município de Ressaquinha, e seus principais afluentes são os rios Xopotó e Turvo Limpo. Possui duas usinas hidrelétricas – UHE Brecha, no município de Guaraciaba, e PCH Brito, em Ponte Nova, além de ter uma atividade industrial e produtiva relativamente intensa, incluindo produção mineral, onde podemos apontar também a Mineradora Samarco.



**Figura 2 | Bacia do Rio Piranga**  
*Fonte: Elaborada pelos autores (2018).*

No que tange às atividades econômicas predominantes na Bacia, apesar de toda a extensão da Bacia do Rio Doce se destacar como uma bacia leiteira, denotada pelos altos números de rebanhos bovinos (PPM, 2018), os municípios a nordeste da Bacia do Rio Piranga compõem uma importante região econômica local e estratégica do ponto de vista logístico para todo o estado de Minas Gerais, a região do Vale do Aço.

Além disso, entre 1920 e 1930 a região foi escolhida em Minas Gerais para receber a cultura do eucalipto por meio de programas governamentais e incentivo de usinas siderúrgicas. Um exemplo foi a Companhia Siderúrgica Belgo Mineira, e posteriormente a Acesita, em 1949. A empresa foi a pioneira na criação de serviços florestais na região e impulsionou outras empresas subsidiárias a operarem no setor de reflorestamento (GUERRA, 1995). Tal perfil pode ser evidenciado pelo mapa de uso e ocupação do solo da Bacia – Modelo Otimizagro (SOARES FILHO et al., 2013), onde é possível identificar grandes extensões voltadas para a silvicultura (525.766 ha).

Como consequência desse uso e ocupação do solo, a Bacia do Rio Piranga, assim como todo o território da Bacia do Rio Doce, possui um histórico de intensa degradação do solo e uso inadequado dos seus recursos naturais, como a água. Como últimos dados, o território, em quase toda a sua extensão, 83,3%, foi classificado como moderadamente degradado ou degradado (UFMG; UFV; FUNDAÇÃO RENOVA, 2018), e a Bacia do Rio Piranga localiza-se nesse recorte.

Em 2015, com o rompimento da Barragem de Fundão, localizada no município de Mariana e de operação da empresa Samarco, tal cenário agravou-se. De acordo com Pires et al. (2017), 40 a 63 milhões de m<sup>3</sup> de rejeitos oriundos da mineração foram dispostos no rio e tiveram como consequências, além da destruição de distritos total ou parcial, como Bento Rodrigues, Paracatu e Gesteira, perdas na biodiversidade, perdas econômicas para as populações ribeirinhas e uma poluição intensa de todo o Rio Doce (Figura 3).

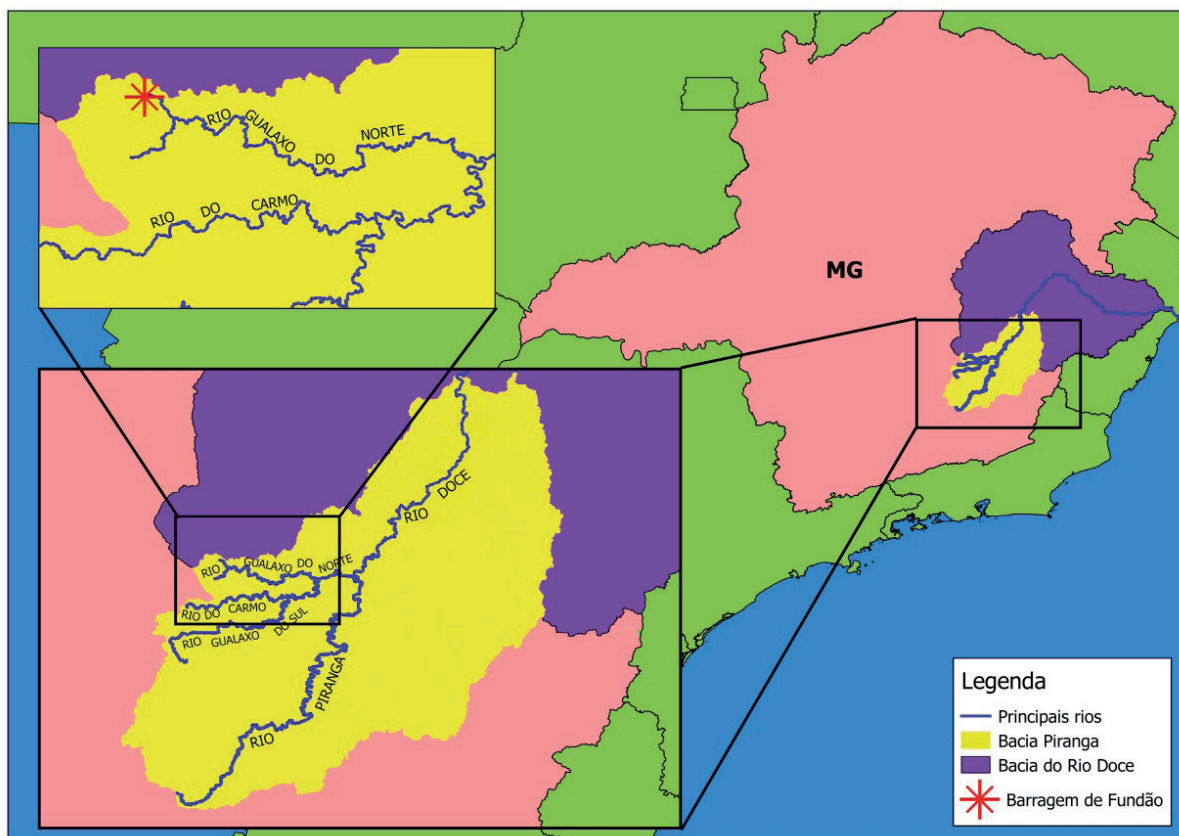


Figura 3 | Caminho da lama desde o município de Mariana

Fonte: EPSJV/Fiocruz

Segundo Fernandes et al. (2016), o acontecimento foi a última gota em um processo de degradação duradouro, que afetou o provisionamento de serviços ecossistêmicos para mais de 1 milhão de pessoas, com uma perda estimada em US\$ 5,21 bilhões por ano na região (GARCIA et al., 2017). A restauração florestal, foco do estudo dessa área, é um dos mecanismos capazes de garantir a qualidade e a quantidade da água na Bacia do Rio Doce.

## 2.2 ÁREAS DE PRESERVAÇÃO PERMANENTE DE CURSOS DE ÁGUA

O Código Florestal (Lei nº 12.651/2012) trouxe a consolidação de dois instrumentos de recomposição e uso sustentável da vegetação nativa dentro das propriedades privadas rurais: as Reservas Legais (RL) e as Áreas de Preservação Permanente (APPs). De acordo com o Código Florestal, as APPs são definidas como: “a área protegida, coberta ou não por vegetação nativa, com a função ambiental de preservar os recursos hídricos, a paisagem, a estabilidade geológica e a biodiversidade, facilitar o fluxo gênico de fauna e flora, proteger o solo e assegurar o bem-estar das populações humanas” (Inciso III, do art. 3º da Lei 12.651/2012). Nesse sentido, fica clara a necessidade de preservação e restauração dessas áreas.

Essas áreas, cobertas ou não por vegetação nativa, localizam-se às margens de rios e outros corpos-d’água em faixas de largura variável, nas encostas íngremes, topos de morro, além de outros locais especificados pela lei. Todavia, o cenário atual é de intensa degradação e da ocupação dessas áreas protegidas para atividades agropecuárias e uso urbano. Segundo dados de Soares Filho et al. (2014), o passivo ambiental de APPs é de aproximadamente 220.000 hectares para todo o Brasil, e esse cenário ainda é pior no bioma Mata Atlântica, bioma que ocupa mais de 98% da Bacia do Rio Doce, onde restam apenas 12% a 16% de cobertura vegetal nativa. Vale ressaltar que, ao avaliar o passivo, com imagens de maior resolução e malha hidrográfica mais adensada, este pode aumentar.



O novo Código Florestal (Lei nº 12.651/2012) ainda trouxe mudanças no estabelecimento dessas APPs. De acordo com o artigo 4º, inciso I, define-se como área de APP as faixas marginais de todo curso-d'água natural, perene ou intermitente, desde a borda do leito regular, em largura mínima que pode variar de 30 m a 500 m, de acordo com a largura do rio entre menos de 10 m a mais de 600 m, respectivamente.

A Lei Federal 12.651/2012 também explicita quais áreas deverão realizar a recomposição florestal e qual método utilizar. De acordo com o dispositivo 13 do artigo 61A, a recomposição nas faixas marginais poderá ser feita isolada ou conjuntamente, por meio de:

- I - condução de regeneração natural de espécies nativas;
- II - plantio de espécies nativas;
- III - plantio de espécies nativas conjugado com a condução da regeneração natural de espécies nativas;
- IV - plantio intercalado de espécies lenhosas, perenes ou de ciclo longo, exóticas com nativas de ocorrência regional, em até 50% (cinquenta por cento) da área total a ser recomposta, no caso dos imóveis rurais com até 4 módulos fiscais, bem como às terras indígenas demarcadas e às demais áreas tituladas de povos e comunidades tradicionais que façam uso coletivo do seu território (BRASIL, 2012, Art. 3, inciso I a IV e Parágrafo Único).

Essas três formas de recomposição fazem alusão a três processos de restauração classificados por Nunes et al. (2017), como passivo, intermediário e ativo. A restauração passiva ou regeneração natural trata-se de um processo de sucessão natural com a mínima intervenção antrópica (HOLL; AIDE, 2011). Trata-se de um processo lento, mas de baixo custo. Já o ativo trata-se de um processo de restauração por plantio total com espécies nativas sem fins econômicos, sendo essa técnica o foco do presente artigo.

Para que uma área de APP cumpra minimamente suas funções ambientais, conforme determina o Código Florestal, seu uso deve ser compatível com o regime de preservação da vegetação nativa previamente existente. Nesse sentido, o mapeamento do uso e cobertura da terra, preferencialmente em alta resolução espacial, é um importante instrumento para a análise da conformidade legal na escala das propriedades rurais e da paisagem, como no caso da Bacia Hidrográfica do Rio Doce. A Agência Nacional de Águas (ANA) e o Instituto Brasileiro de Geografia e Estatística (IBGE) disponibilizam mapas da hidrografia de todo o País, porém a escala de 1:100.000 ou inferior presente nesses mapas não permite uma análise detalhada da Bacia do Rio Doce. Por isso, foi utilizado neste estudo o mapeamento da rede hidrográfica realizado pela Fundação Brasileira para o Desenvolvimento Sustentável (FBDS), por meio de classificação supervisionada de imagens *RapidEye* para o ano de 2013, na escala de 1:10.000, produzindo mapas de uso e cobertura na escala de 1:20.000.

## 2.3 ANÁLISE MULTICRITÉRIO

A espacialização representa um dos métodos mais eficientes e econômicos no manejo de bacias hidrográficas, principalmente quando é necessário executar uma priorização de áreas. De forma prática, trata-se de uma integração de diferentes planos de informação da paisagem e suas características e, ou, processos, juntamente com os Sistemas de Informações Geográficas – SIGs (VALENTE, 2005). Nesse sentido, surge a Análise de Multicritério (AMC), que, segundo Malczewski (2004), pode ser descrita como um processo que transforma e combina dados espaciais e não espaciais resultando em uma decisão.

A AMC como metodologia se fundamenta na observação de alternativas para esclarecimento de questões, onde são utilizados diferentes critérios envolvidos com determinado objeto de estudo, com objetivo de identificar as melhores opções disponíveis dentro do universo analisado (FRANCISCO et al., 2007 apud FRANCO et al., 2013). Essa análise fundamenta-se em critérios que podem ser fatores e restrições, e podem referir-se a atributos individuais ou ao conjunto todo. Apesar de a seleção dos

critérios e a definição da importância relativa de cada um deles apresentarem certo grau de subjetividade, os resultados obtidos têm apresentado uma grande coerência com a realidade (VETTORAZZI, 2006).

Dessa forma, para definição dos pesos da AMC, que irá orientar a formulação da análise final, uma das principais técnicas utilizadas é o Processo Analítico Hierárquico (AHP), no qual os pesos são atribuídos de acordo com a sua importância relativa. De acordo com Souza et al. (2013), essa técnica se baseia na identificação de um problema de decisão e na sua decomposição em “subproblemas”, onde cada um pode ser analisado de forma independente (SILVA JÚNIOR, 2015).

A atribuição de pesos aos critérios consiste em definir a quantificação da importância de cada um deles no processo de decisão. Vários métodos foram desenvolvidos para auxiliar a definição dos pesos de compensação dos fatores, entre eles o da ordenação, da escala de pontos, da distribuição de pontos e do método baseado na comparação de critérios dois a dois (RAMOS; MENDES, 2001). Para elaboração da matriz de comparação, os fatores foram comparados, dois a dois, utilizando como referência Eastman (2001), a escala contínua de nove pontos (Tabela 1). Os pesos de compensação, que expressam a importância, ou ordem de importância dos fatores no processo de tomada de decisão, foram determinados com base na revisão de literatura, em projetos desenvolvidos na Técnica Participatória.

**Tabela 1 | Intensidade da importância entre critérios**

| <i>Intensidade da importância</i> | <i>Definição e explicação</i>  |
|-----------------------------------|--|
| 1                                 | Importância igual – os dois fatores contribuem igualmente para o objetivo                                    |
| 3                                 | Importância moderada – um fator é ligeiramente mais importante que o outro                                   |
| 5                                 | Importância essencial – um fator é claramente mais importante que o outro                                    |
| 7                                 | Importância demonstrada – um fator é fortemente favorecido e sua maior relevância foi demonstrada na prática |
| 9                                 | Importância extrema – a evidência que diferencia os fatores é da maior ordem possível                        |
| 2, 4, 6                           | Valores intermediários entre julgamentos – possibilidade de compromissos adicionais                          |

*Fonte: Adaptada de Eastman (2001).*

O *software* utilizado para realização do método de análise multicritério foi o ArcGIS.

## 2.4 DEFINIÇÃO DAS VARIÁVEIS E DOS PESOS UTILIZADOS

No período de 2002 a 2017 muitos estudos foram desenvolvidos com o objetivo de identificar áreas prioritárias para conservação por análise de multicritério. Nesse processo, uma das etapas metodológicas mais importantes é a definição das variáveis. Nesse sentido, podemos ressaltar como fundamentação para escolha das bases os trabalhos de Bertoni e Lombardi (1985); Borges (2009); Ferraz e Vettorazzi (2003); Francisco (2006); Lima et al. (2011); e Mannigel et al. (2002).

Além disso, Uribe (2014) apresenta um estudo no qual a escolha das variáveis se deu por meio de entrevistas com as partes interessadas em uma área na porção sul do México, de 11.631 km<sup>2</sup>, contemplando integralmente ou parcialmente (50%) 124 municípios. Segue a Tabela 2 detalhando quais as variáveis de destaque segundo a porcentagem em que elas apareceram nas entrevistas.

**Tabela 2 | Ranking dos critérios para AHP mais citados nas entrevistas**

| <i>Ranking</i> | <i>Critério</i>   | <i>Citação</i> |
|----------------|---|----------------|
| 1              | Distância de fragmento florestal  | 64,3           |
| 2              | Uso do solo e mudanças no uso deste   | 57,1           |
| 3              | Risco de erosão (erodibilidade do solo e erosividade pela chuva)  | 53,6           |
| 4              | Índice de biodiversidade e corredores naturais  | 46,4           |
| 5              | Declividade   | 42,9           |
| 6              | Distância de cultivos   | 39,3           |
| 7              | Densidade demográfica, distância de rodovias, distância de rios   | 35,7           |
| 8              | Distância de assentamentos humanos, índice de marginalidade e capital social  | 32,1           |
| 9              | Profundidade do solo  | 28,6           |
| 10             | Posse de terra (CAR)  | 17,9           |
| 11             | Distância de áreas protegidas (APPs)  | 10,7           |
| 12             | Fertilidade do solo   | 7,1            |
| 13             | Distância de fontes pontuais de emissão de gases de efeito estufa, taxa de migração, fragmentação florestal, precipitação, presença de gado, uso da biodiversidade, temperatura | 3,6            |

*Fonte: Adaptada de Uribe et al. (2014).*

A ação destes *stakeholders* (proprietários da terra, associações de desenvolvimento local, etc.) no processo decisório é legítima e necessária, já que são eles os agentes do processo de restauração florestal. Além disso, acaba por trazer uma abordagem transdisciplinar integrando o conhecimento científico e os saberes locais. Esses usuários ou grupos de interesse da bacia estão ligados diretamente às atividades primárias de desenvolvimento e/ou conservação, já que usufruem da paisagem para sua subsistência estando assim diretamente vinculados à geração de serviços ecossistêmicos. Este tipo de estudo traz uma metodologia de construção de políticas *bottom-up*, que são consideradas mais efetivas para manutenção de áreas restauradas, ao contrário das *top-down*, que trazem para discussão critérios estritamente técnicos (LINDBORG et al., 2008).

Dessa forma, para o presente artigo, foram escolhidas as variáveis e segmentadas por tipologias (ecológico, regulatório e social) com o respectivo estudo utilizado para embasá-las (Tabela 3).

**Tabela 3 | Variáveis escolhidas**

| <i>Critérios</i>               | <i>Tipo</i> | <i>Fonte</i>   |
|--------------------------------|-------------|--|
| Proximidade à mata nativa      | Ecológico   | Catelani et al. (2012); Franco, Hernandez e Moraes (2013); Orsi, Geneletti e Newton (2011) |
| Proximidade a áreas protegidas |             | Orsi e Geneletti (2010); Valente e Vettorazzi (2008)                                       |
| Uso do solo                    |             | Catelani et al. (2012); Franco, Hernandez e Moraes (2013); Orsi, Geneletti e Newton (2011) |
| Declividade                    |             | Sartori (2012); Valente, Petean e Vettorazzi (2017); Valente e Vettorazzi (2008)           |
| Erodibilidade                  |             | Bertoni e Lombardi Neto (1990); Mannigel et al. (2002)                                     |
| Cadastro do imóvel (CAR)       | Regulatório | Uribe et al. (2014)  |
| Distância de rodovias          | Social      | Fabbro Neto et al. (2014); Valente e Vettorazzi (2008)                                     |
| Distância de centros urbanos   |             | Fabbro Neto et al. (2014); Uribe et al. (2014); Valente e Vettorazzi (2008)                |

*Fonte: Elaboração dos autores (2018).*

Quanto à atribuição das notas e à consequente classificação, as áreas foram segmentadas em alta, média e baixa prioridade para o reflorestamento. Segue abaixo a descrição de alguns dos critérios e como se deu essa atribuição segundo os autores citados:

- **Declividade:** a declividade é importante porque quanto maior seu índice, maior o risco de erosão, o que torna as áreas mais íngremes mais interessantes ao reflorestamento, e também possuem menor a propensão para o uso agrícola, o que também favorece as áreas menos planas terem uma prioridade maior ao plantio de espécies nativas.
- **Uso do solo:** o uso do solo é indicador de áreas favoráveis ou até mesmo impróprias. Exemplos de áreas que não se aplica a possibilidade de reflorestamento com espécies nativas são as áreas que já são cobertas por árvores nativas, áreas urbanas, rodovias e superfícies cobertas por água. Silviculturas e áreas tradicionalmente agrícolas também não são favoráveis.
- **Susceptibilidade à erosão:** o reflorestamento é uma ferramenta de combate à erosão. Portanto, sua implantação torna-se mais interessante em lugares onde ocorre este tipo de problema, tendo em vista que onde há erosão, geralmente, também não há outros tipos de interesse de cunho econômico.
- **Erodibilidade:** usou-se como referência o fator de erodibilidade do solo K (t.ha.h./ha.MJ. mm), onde: t = tonelada, ha = hectare, h = hora, MJ = mega joule e mm = milímetro. Sua determinação requer visitas e validações em campo, de acordo com as condições locais. Devido à inexistência desses dados, utilizaram-se fatores estimados a partir das características dos solos, conforme Bertoni e Lombardi Neto (1985, 1990) e Mannigel (2002).
- **Proximidade às matas nativas:** o reflorestamento com espécies nativas é favorecido pela proximidade de outras matas nativas, uma vez que isso implica na conectividade ecológica. Dessa forma, utilizou-se a variável que compõe as faixas de áreas que apresentam até 50 metros de distância das matas nativas já existentes nas APPs pesquisadas.
- **Proximidade às áreas urbanas:** a proximidade de áreas urbanas não é um fator favorável à implantação de reflorestamentos de mata nativa, de uma maneira geral. Isso se deve ao fato de que, geralmente, a expansão urbana e a especulação imobiliária são fatores de considerável pressão e desfavorecem a sustentabilidade dessas áreas. Dessa maneira, utilizou-se a variável que compõe as faixas de áreas que apresentam até 200 metros de distância das áreas urbanas presentes nas APPs pesquisadas.
- **Proximidade às rodovias:** de modo análogo ao explicitado no item anterior, a proximidade às rodovias também é um fator considerado desfavorável. Assim, utilizou-se a variável que compõe as faixas de áreas que apresentam até 200 metros de distância das rodovias.

Após o estudo prévio das variáveis, foram selecionados os mapas a serem utilizados na análise de multicritério. Como processo foi feita a reclassificação dos mapas selecionados atribuindo-se nota para cada classe, conforme já exposto anteriormente. Ao final foram dados pesos para cada uma das variáveis separadas de acordo com os autores citados pelo método AHP. A Tabela 4 expressa os pesos finais utilizados na análise final.

**Tabela 4 | Pesos finais utilizados na análise final**

|                   | <i>Prox. veg. nativa</i> | <i>Declividade</i> | <i>Erodibilidade</i> | <i>Prox. áreas urb.</i> | <i>Uso do solo</i> | <i>Possui CAR</i> | <i>Pesos</i> |
|-------------------|--------------------------|--------------------|----------------------|-------------------------|--------------------|-------------------|--------------|
| Prox. veg. nativa | 1                        | -                  | -                    | -                       | -                  | -                 | 0,28         |
| Declividade       | 5                        | 1                  | -                    | -                       | -                  | -                 | 0,12         |

|                                | <i>Prox. veg. nativa</i> | <i>Declividade</i> | <i>Erodibilidade</i> | <i>Prox. áreas urb.</i> | <i>Uso do solo</i> | <i>Possui CAR</i> | <i>Pesos</i> |
|--------------------------------|--------------------------|--------------------|----------------------|-------------------------|--------------------|-------------------|--------------|
| Erodibilidade                  | 7                        | 9                  | 1                    | -                       | -                  | -                 | 0,18         |
| Prox. áreas urbanas e rodovias | 3                        | 3                  | 3                    | 1                       | -                  | -                 | 0,17         |
| Uso do solo                    | 7                        | 5                  | 7                    | 7                       | 1                  | -                 | 0,15         |
| Possui CAR                     | 7                        | 7                  | 5                    | 3                       | 5                  | 1                 | 0,10         |

Fonte: Elaborada pelos autores (2018).

### 3 RESULTADOS E DISCUSSÕES

Os resultados diferenciam dos outros da literatura, vistos em estudos como Francisco (2006) e Ferraz e Vettorazzi (2003), no momento em que se tem como desafio a grande extensão da bacia escolhida, já que a maioria das pesquisas foram desenvolvidas para pequenas bacias. Outra diferença é o foco para as áreas de proteção permanente de cursos de água. Para isso foi necessário um intenso trabalho de sensoriamento remoto devido às grandes diferenças de larguras entre os cursos-d'água encontrados na bacia.

De forma prática, em uma visão geral, a Figura 4 mostra que as áreas a sudeste do Parque Estadual do Rio Doce apresentam maiores propensões a receber as iniciativas de restauração com espécies nativas. Ocorre o contrário nas regiões mais urbanizadas da bacia e também nas de menor densidade de vegetação nativa, estas últimas coincidem com as áreas de relevo mais declivoso.

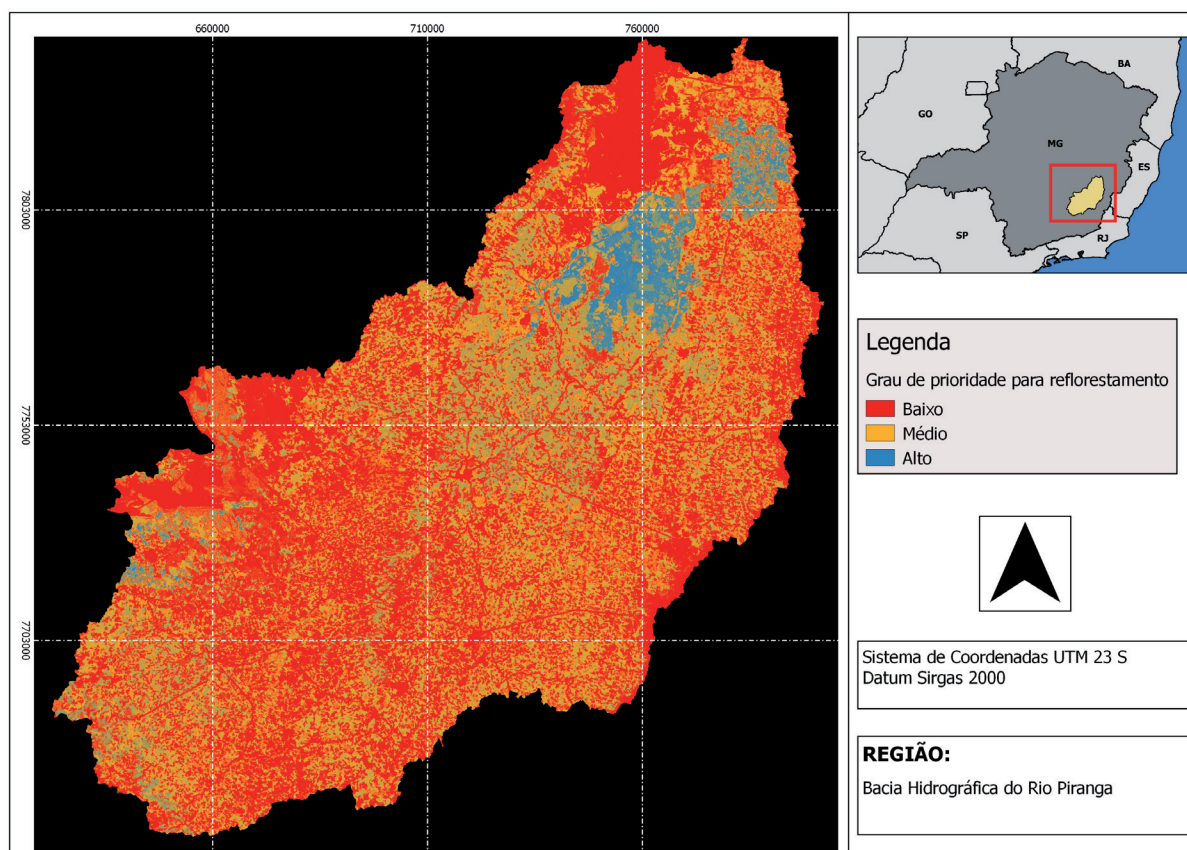


Figura 4 | Mapa de Áreas Prioritárias

Fonte: Elaborada pelos autores (2018).

Entretanto, entende-se que o presente estudo é de grande importância devido ao cenário histórico de degradação das atividades agropecuárias nesses territórios de proteção, principalmente se levadas em consideração a importância ambiental dessas áreas (recarga hídrica, contenção de processos erosivos, estocagem de carbono e refúgio da fauna) e a urgência para que sejam reestabelecidos os processos ecológicos pós-rompimento da barragem de rejeitos em Mariana.

Outro ponto a discutir é que o reflorestamento é apenas uma das estratégias de restauração que podem ser citadas. Existem também os plantios com fins econômicos, normalmente trata-se de um mix de espécies exóticas e nativas, que podem ser escolhidas de acordo com a vontade do agricultor e também a partir de características edafoclimáticas do território. Nesse sentido, cita-se que cada um desses formatos para restauro apresentam peculiaridades que podem demandar outras variáveis que as utilizadas neste estudo e evidenciar outras abordagens necessárias para a cadeia da restauração, como a necessidade de investimento em viveiros, capacitação da mão de obra local, etc., já evidenciados por outros estudos (SALOMÃO, 2019).

Todavia é necessário destacar que não houve a validação desses resultados em campo, porém alguns indicativos podem nos dizer sobre a coerência dos resultados. Um dos critérios considerados na análise como facilitador da restauração foi a proximidade da vegetação nativa e o uso do solo. No âmbito da paisagem, a conectividade com fragmentos florestais pode propiciar o fluxo gênico e acelerar o processo de restauração (NUNES et al., 2017). Esse ponto acaba por explicar a concentração das atividades no entorno do Perd, que é uma Unidade de Conservação estadual.

Outra questão é quanto à proximidade da malha viária. O acesso no entorno do Parque, pela LMG-760, é limitado. A rodovia mais próxima teve um processo de licenciamento ambiental conturbado e somente no ano de 2018 retomou o processo de pavimentação. E um terceiro ponto seria a característica pedológica da região, o latossolo amarelo é a classificação dominante. Esses solos são profundos e bem estruturados, sendo atrativos para o plantio de espécies nativas, porém pobres em nutrientes para culturas (CONSÓRCIO ECOPLAN-LUME, 2010).

Além disso, outra questão necessária nessa validação *in loco* é a participação popular. Esse controle social é determinante para que de fato se atinja a restauração. Se o proprietário rural não se sentir parte do processo, muito dificilmente no médio e longo prazo se terá sucesso. Por essa razão, um processo “*bottom up*” se faz necessário desde a construção de políticas públicas, como o Programa de Regularização Ambiental – PRA, conforme visto em Salomão (2019).

## 4 CONCLUSÕES

Como próximos passos da pesquisa realizada, indica-se o desenvolvimento de alguns cenários que podem influenciar inclusive as políticas públicas. O primeiro cenário a ser traçado tem como objetivo, segundo Soares Filho et al. (2016), verificar qual a porcentagem de áreas prioritárias para restauração encontra-se em áreas em débito de acordo com o Código Florestal e estabelecer uma hierarquização municipal. Para isso, serão resgatados os mapas dos citados autores e estabelecida uma análise de quais municípios estão com maior débito e como isso pode ser em parte solucionado pelo modelo. Para o segundo cenário, será realizada uma avaliação da extensão das áreas prioritárias para restauração passiva e contrastar com qual extensão está prevista em instrumentos para recuperação da Bacia do Rio Piranga. Como instrumento, cita-se o Plano Diretor de Bacias e também o Programa de Recuperação de APPs estabelecido no Termo de Transação de Ajustamento de Conduta – TTAC firmado entre entes públicos e privados devido às consequências do Rompimento da Barragem de Fundão.

## REFERÊNCIAS

BERTONI, J.; LOMBARDI NETO, F. **Conservação do solo**. Piracicaba: Ícone, 1985.

\_\_\_\_\_. \_\_\_\_\_. São Paulo: Ícone, 1990.

BORGES, L. A. C. et al. Evolução da Legislação Ambiental no Brasil. **Rama: Revista em Agronegócio e Meio Ambiente**, Maringá, PR, v. 2, p. 447-466, 2009.

BRASIL. **Lei Nº 12.651, de 25 de maio de 2012**. Dispõe sobre a proteção da vegetação nativa; altera as Leis no 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis no 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória no 2.166-67, de 24 de agosto de 2001; e dá outras providências.

EASTMAN, J. R. **Decision support**: decision strategy analysis. Idrisi 32 Release 2: guide to GIS and image processing. Worcester: Clark Labs, Clark University, 2001.

FERNANDES, G. W. et al. Deep into the mud: ecological and socio-economic impacts of the dam breach in Mariana, Brazil. **Natureza & Conservação**, v.14, n. 2, p. 35-45, 2016.

FERRAZ, S. F. B.; VETTORAZZI, C. A. Identificação de áreas prioritárias para recomposição florestal com base em princípios de ecologia de paisagem. **Revista Árvore**, v. 27, n. 4, 2003.

FRANCISCO, C. E. F. **Áreas de preservação permanente na Bacia do Ribeirão das Anhumas**: estabelecimento de prioridades para recuperação por meio de análise multicriterial. Dissertação (Mestrado) – Instituto Agrônomo de Campinas (IAC), 2006.

FRANCISCO, C. E. S. et al. Análise multicriterial na seleção de bacia hidrográfica para recuperação ambiental. **Ciência Florestal**, v. 18, n. 1, p.1-13, 2008.

FRANCISCO, C. E. S. et al. Espacialização de análise multicriterial em SIG: prioridade para recuperação de Áreas de Preservação Permanentes. In: XIII SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO. Florianópolis. **Anais...** São José dos Campos: Inpe, p. 2643-2650, 2007.

FRANCO, G. B. et al. Relação qualidade da água e fragilidade ambiental da Bacia do Rio Almada, Bahia. **Brazilian Journal of Geology**, São Paulo, v. 42, suppl. 1, p. 114-127, 2013.

GARCIA, L. C. et al. Brazil's worst mining disaster: corporations must be compelled to pay the actual environmental costs. **Ecological Applications**, v. 27, n. 1, p. 5-9, 2017.

GOTTFRIED, R.; WEAR, D.; LEE, R. Institutional solutions to market failure on the landscape scale. **Ecological Economics**, v. 18, n. 2, p. 133-140, 1996.

GUERRA, C. **Meio ambiente e trabalho no mundo do eucalipto**. 2. ed. Belo Horizonte, Agência Terra, 1995.

HOLL, K. D.; AIDE, T. M. When and where to actively restore eco-systems? **For. Ecol. Manage**, v. 261, p. 1558-63, 2011.

LIMA, L. P. Z. et al. Análise da vulnerabilidade natural para implantação de unidades de conservação na microrregião da Serra de Carrancas, MG. **Cerne**, Lavras, v. 17, n. 2, p. 151-159, 2011.

LINDBORG, R. et al. A landscape perspective on conservation of semi-natural grasslands. **Agriculture, Ecosystems & Environment**, v. 125, n. 1-4, p. 213-222, 2008.

MANNIGEL, A. R. et al. Fator erodibilidade e tolerância de perda dos solos do estado de São Paulo. **Acta Scientiarum**, Maringá, v. 24, n. 5, p. 1335-1340, 2002.

NUNES, et al. Enabling large-scale forest restoration in Minas Gerais state, Brazil. **Environ. Res. Lett.**, v. 12, n. 044022, 2017.

PESQUISA DA PECUÁRIA MUNICIPAL. Disponível em: <<https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9107-producao-da-pecuaria-municipal.html>>. Acesso em: ago. 2019.

PIRES, A. P. F. et al. Forest restoration can increase the Rio Doce watershed resilience. **Perspectives in Ecology and Conservation**, v. 15, n. 3, p. 187-193, 2017.

RAMOS, R. A. R.; MENDES, J. F. G. Avaliação de aptidão do solo para localização industrial: o caso de Valença. **Revista Engenharia Civil**, v. 10, n. 1, p. 7-29, 2001.

SALOMÃO, C. S. C. **Sistemas agroflorestais como estratégia para restauração ecológica da Bacia do Rio Doce**. Dissertação (Mestrado) – Universidade Federal de Minas Gerais (UFMG), Belo Horizonte, 2019.

SILVA JUNIOR, C. H. L. Lógica Fuzzy e Processo Analítico Hierárquico (AHP) aplicados ao Zoneamento de Áreas Suscetíveis a Deslizamentos: uma revisão. **Revista Monografias Ambientais – Remoa**. Revista do Centro de Ciências Naturais e Exatas – UFSM, v. 14, n. 3, p. 42-58, 2015.

SOARES FILHO, B. S.; RODRIGUES, H.; FOLLADOR, M. A hybrid analytical-heuristic method for calibrating land-use change models Environ. **Modell Software**, v. 43, p. 80-87, 2013.

SOARES FILHO, B. S. et al. **Modelagem das Oportunidades Econômicas e Ambientais do Restauo Florestal sob o Novo Código Florestal**. Impacto de políticas públicas voltadas à implementação do novo Código Florestal. Relatório de Projeto. Centro de Sensoriamento Remoto, UFMG, Belo Horizonte-MG, 2014.

SOUZA, D. F. DE et al. **Aplicação do método AHP-Fuzzy**. ENCONTRO NACIONAL DOS ESTUDANTES DE MATEMÁTICA DA REGIÃO SUL, 2010. Porto Alegre/RS. Disponível em: <<http://www.pucrs.br/edipucrs/erematsul/comunicacoes/10DEBORAFERRODESOUZA.pdf>>. Acesso em: 20 jan. 2013.

UFMG; UFV; FUNDAÇÃO RENOVA. **Definição de áreas prioritárias para restauração florestal na Bacia do Rio Doce**, 2018.

URIBE, D. et al. Integrating Stakeholder Preferences and GIS-Based Multicriteria Analysis to Identify Forest Landscape Restoration Priorities. **Sustainability**, v. 6, p. 935-951 2014.

VALENTE, R. O. A. **Definição de áreas prioritárias para a conservação e preservação florestal por meio da abordagem multicritério em ambiente SIG**, 2005. 121 f. Tese (Doutorado em Recursos Florestais) – Escola Superior de Luiz de Queiroz, Universidade de São Paulo, Piracicaba, 2005.

VALENTE, R. A.; VETTORAZZI, C. A. Multicriteria Decision Analysis for Prioritizing Areas for Forest Restoration. **Cerne**, v. 23, n. 1, p. 53-60, 2017.

VETTORAZZI, C. A. **Avaliação multicritério em ambiente SIG, na definição de áreas prioritárias à restauração florestal visando à conservação dos recursos hídricos**. 151 f. Tese (Livre Docência em Topografia) – Escola Superior de Luiz de Queiroz, Universidade de São Paulo, Piracicaba. 2006.



# Geotechnologies as an environmental licensing support tool in the state of Piauí, Brazil

*Utilização de programas abertos de geotecnologia para o emprego no licenciamento ambiental no estado do Piauí, Brasil*

Bruna de Freitas Iwata<sup>a</sup>

Danielly dos Santos Ferreira<sup>b</sup>

Adriano D'Carlos Batista Oliveira<sup>c</sup>

<sup>a</sup>Doutora em Ciências do Solo pela Universidade Federal do Ceará, UFC, Professora do Instituto Federal de Educação, Ciência e Tecnologia do Piauí, IFPI, Teresina, PI, Brasil. End. Eletrônico: iwata@ifpi.edu.br

<sup>b</sup>Mestranda no Programa de Pós-Graduação em Análise e Planejamento Espacial pelo Instituto Federal de Educação, Ciência e Tecnologia do Piauí, IFPI, Teresina, PI, Brasil End. Eletrônico: danielly.santosferreira@gmail.com

<sup>c</sup>Mestrando no Programa de Pós-Graduação em Análise e Planejamento Espacial pelo Instituto Federal de Educação, Ciência e Tecnologia do Piauí, IFPI, Professor do Instituto Federal de Educação, Ciência e Tecnologia do Piauí, Teresina, PI, Brasil End. Eletrônico: adriano.dcarlos@ifpi.edu.br

doi:10.18472/SustDeb.v11n2.2020.29253

Received: 20/01/2020  
Accepted: 02/07/2020

ARTICLE- DOSSIER

## ABSTRACT

Geotechnologies are a set of technologies geared towards collection, processing, analysis and availability of information with geographic reference. Therefore, the objective of this research is to demonstrate through the spatial analysis the environmental characteristics of an enterprise located in the municipality of Currais – PI, object of the environmental licensing procedure of the state competent body, using the tools of geotechnologies. The methodology consisted in using the Geographic Information System Quantum GIS (QGIS) for the creation and processing of the geographic database. Through the generation of thematic maps, it was possible to conclude that the uses of geotechnologies aid in the control and environmental monitoring, in which, it facilitates the visualization and characterization of several environmental features in the environmental licensing procedure. It was also possible to identify the areas that deserve greater attention from the environmental agency due to some damage to the environment, as well as, it assists in environmental inspection and current legislation.

**Keywords:** Environmental Licensing. Geotechnology. Geographic Information System.

## RESUMO

As geotecnologias são um conjunto de tecnologias voltadas para coleta, processamento, análise e disponibilização da informação com referência geográfica. Diante disso, o objetivo dessa pesquisa é demonstrar por meio das análises espaciais as características ambientais de um empreendimento

*localizado no município de Currais – PI, objeto do procedimento de licenciamento ambiental do órgão competente estadual, utilizando as ferramentas das geotecnologias. A metodologia consistiu na utilização do Sistema de Informações Geográficas Quantum GIS (QGIS) para a criação e tratamento do banco de dados geográfico. Por meio da geração de mapas temáticos, foi possível concluir que as utilizações das geotecnologias auxiliam no controle e monitoramento ambiental, no qual facilita a visualização e caracterização de diversas feições ambientais no procedimento de licenciamento ambiental. Também foi possível identificar as áreas que merecem uma maior atenção do órgão ambiental em virtude de algum dano ao meio ambiente, bem como auxilia na fiscalização ambiental e legislação vigente.*

*Palavras-chave: Licenciamento Ambiental. Geotecnologias. Sistema de Informações Geográficas.*

## 1 INTRODUCTION

Landscapes are continually altered by human interference on the natural environment, and knowledge of the processes that occurred in the past is essential to understand the changes. The observation on land use is relevant due to the necessity to ensure sustainability facing the environmental, social, and economic issues related to it and taken to emerge in the debate on sustainable development. (LIRA; SOUTO; DUARTE, 2019).

The earth's surface is the place of different situations in terms of occupation, these come from the needs of society's production and reproduction, being modified in an abundant and fast way (LEITE et al., 2018). For meeting society's demands, vegetation is suppressed, triggered by the use of agricultural land, and if this transformation is not managed, it harms the natural conditions of the environment (PEREIRA, 2014).

In this sense, designing analyzes of the environment helps in its manipulation, enabling management and environmental planning of functionalities by the public administration as for those that come effectively from the environment (ALBUQUERQUE; SOUSA, 2019). In order to provide the management of natural resources in a sustainable manner conciliated with economic development, there is an Environmental Licensing as an instrument of inspection and control, which was established by Law No. 6,938, of August 31, 1981 (vide BRASIL, 1981) of the National Environment Policy to ensure efficient and controlled management.

Environmental licensing, discussed by Feitosa et al. (2004), is the administrative procedure whereby the competent environmental agency licenses the location, installation, expansion, and operation of companies and activities that use environmental resources considered effective or potentially polluting, or of those that, in whichever form, may cause environmental degradation, considering the legal and regulatory provisions and technical standards applicable to the case. The Government, exercising its control prerogatives, will dispatch the following licenses: Preliminary License (PL), Installation License (IL), and Operation License (OL) (CONAMA, 1997).

A preliminary license is granted in the initial planning phase of the enterprise, or activity, approving its location and conception, attesting the environmental feasibility, and establishing the basic requirements and conditions to be fulfilled in the next stages of its implementation (CONAMA, 1997). As a considerable aid to this stage, geotechnologies are diagnostic procedures for areas highlighting their respective uses, since they intend to characterize the enterprise spatially, ensuring support for the granting of the environmental license provided by the inspection agency.

Geotechnologies are characterized by equipment and methods of mathematical and computational processing. It has as principal purposes the treatment and analysis of geographic data, allowing for more specific and precise responses. Increasingly the use of geotechnologies has contributed to environmental analysis and characterization. Its utilization provides to user knowledge concerning past and current situations, besides enabling the simulation of future scenarios. Some tools widely utilized in geotechnology are Geographic Information Systems (GIS), remote sensing, and GPS (Global Positioning System) (MENDES, 2019).

GIS is a computer-assisted system that can insert, analyze, and display geographically referenced information useful for environmental management (SUBRAMANI; VENKATACHALA; PRIYANKA, 2017). One of the most important roots of GIS is the automated cartographic workflows, with the additional objective of integrating and analyzing geospatial information (JONES, 2013).

According to Mendonça et al. (2011, p. 9), Remote Sensing is a science used to detect objects without direct contact with them. The physical properties of the interaction of electromagnetic energy make it possible to characterize such objects. This thematic plurality towards which the use of Geotechnologies has converged comes from different theoretical and methodological matrices, especially the integrative approaches that seek to analyze the Society-Nature relationship (SILVA; ROCHA; AQUINO, 2017).

The main intention of using geotechnologies in environmental monitoring is to contribute efficiently so that production in the licensed area occurs sustainably. Thus, the use of these tools has fundamental importance for the processing and generation of information in reports and maps, aside from being suitable for providing and synthesizing information for the environmental study (SOBRAL et al., 2017). These mappings influence the speed of inspection and, consequently, compliance with relevant laws (LUPPI et al., 2015).

Mapping, which is used within Geoprocessing techniques (Rocha, 2000, Fitz, 2008), is an effective way of analyzing and visualizing data. Conceived of Kerski (2015) as one of the five converging global trends within geographic research, Geotechnologies have found extensive application, granting to map and analyze a large variety of phenomena, with unprecedented speed and precision. This may also be found in Fitz (2008) and Medeiros (2011).

Based on the previously mentioned, this study aimed to present, through a case study of rural property, in the state of Piauí, how the geotechnologies would help the public environmental manager on the characterization and monitoring of the enterprise that desires to apply for the environmental license.

## **2 MATERIALS AND METHODS**

In order to carry out this work, an enterprise from the State of Piauí was used to exemplify the study, which required a Preliminary License (PL) of the establishment from the environmental agency. Data necessary for the analysis of the project and its environmental characteristics to conclude the record have been obtained by the Geoprocessing sector belonging to the Land and Environmental Geotechnology Center (Portuguese acronym, CGEO) of the Secretariat for the Environment and Water Resources of the State of Piauí (Portuguese acronym, SEMAR/PI), which has a data bank containing information on hydrography, biome, vegetation, and other items that provide a spatial visualization of the property, facilitating the making of some decisions by the auditors and environmental managers.

In this research, the free version of QUANTUM GIS (QGIS) 2.14 software was used to create the geographic database. In which the files of the property were inserted in the shapefile format with the following features: property area, PPA (permanent protection area), legal reserve and intervention area, all in the SIRGAS 2000 projection system and with the UTM (Universal Transverse Mercator) as a function of property location (23 or 24).

Posteriorly, data processing was carried out integrating the spatial information from the archives of SEMAR/PI and other official sources such as the Brazilian Institute of Geography and Statistics (Portuguese acronym, IBGE), National Water Agency of Brazil (Portuguese acronym, ANA), and the National Rural Environmental Registry System of Brazil (Portuguese acronym, SICAR). After the spatial analysis, it is possible to overlay the georeferenced information of the property area with the official available databases and satellite images.

The free satellite image used was that of the SENTINEL-2A satellite, acquired on 24 June 2017, with a spatial resolution of 10 meters, scene T23 LNL available on the website <https://earthexplorer.usgs.gov/>. For the classification of the true image, the bands 4,3,2 RGB Red (red) Green (green) Blue (blue) were used in the QGIS software. For analyzing an environmental licensing process, the following activities are usually carried out, which vary from case to case:

- a. download satellite images,
- b. treatment and classification of downloaded images;
- c. overlapping of the process files with the CGEO base;
- d. pre-analysis of the rural environmental registry (RER) of the property, etc.

For issuing the technical report on Geoprocessing, the Microsoft Office Word text editor and the Microsoft Office Excel spreadsheet editor were used, both present in the Microsoft Office 2003 package.

The digital cartographic bases used were acquired from IBGE, ANA, Chico Mendes Institute for Biodiversity Conservation (ICMbio), Ministry of the Environment (MMA), and SICAR in shapefile format, where elements such as those shown in the table below are selected.

**Table 1 | Bases used in the construction of the SEMAR/PI technical report on Geoprocessing.**

| FEATURE                      | Digital Archive (A) |    | Reference Document (B) |    | Difference | CAR       |
|------------------------------|---------------------|----|------------------------|----|------------|-----------|
|                              | ha                  | %  | ha                     | %  | ha         | ha        |
| a) TOTAL AREA                |                     |    |                        |    |            | 67,112.33 |
| b) PPA                       |                     |    |                        |    |            | 1,278.85  |
| c) LEGAL RESERVE             |                     |    |                        |    |            | 2,1080.17 |
| d) AREA FOR DEFORESTATION    |                     |    |                        |    |            |           |
| e) DEFORESTED AREA           |                     |    |                        |    |            |           |
| f) REMNANT NATIVE VEGETATION |                     |    |                        |    |            | 21,031.17 |
| g) CONSOLIDATED AREA         |                     |    |                        |    |            | 46,031.44 |
| TOTAL                        | 0,00                | 0% | 0,00                   | 0% | 0,00       |           |

Source: Centro de Geotecnologia Fundiária e Ambiental do Piauí (2018).

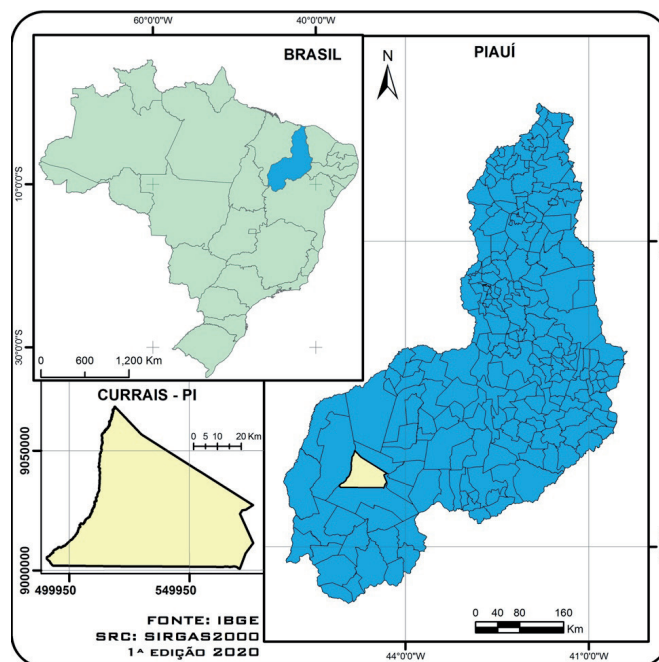
In addition to the digital files, the entrepreneur must present, at the beginning of the environmental licensing process, the Georeferenced Property Plant, and the RER receipt for the property. By this information, a spreadsheet is created comparing the values of the enterprise's features in the three files: Digital media in shapefile format, Georeferenced property plan, and what was declared in SICAR, according to the model in the table below.

**Table 2 |** Area chart used in the construction of SEMAR/PI Geoprocessing technical report.

| LAYER                           | SOURCE            |
|---------------------------------|-------------------|
| COUNTY                          | IBGE 2018         |
| WATERCOURSE                     | ANA 2017          |
| PROPERTY                        | SICAR 2018        |
| Legal Reserve                   |                   |
| Property area                   |                   |
| Intervention area               |                   |
| Permanent protection area (PPA) |                   |
| IMAGEM SENTINEL 2017            | USGS/JUN. of 2017 |

Source: Piauí Land and Environmental Geotechnology Center (2018).

The area calculation was done in the Quantum GIS software, and the opinion was filled out by analyzing this documentation and files presented.



**Figure 1 |** Location Map of Brazil highlighting the state of Piauí and the municipality of Currais.

Source: Oliveira (2018).

### 3 RESULTS AND DISCUSSIONS

The maps generation of the environmental characteristics of the rural property by geotechnologies showed, above all, the study area has its legal reserve fragmented into three distinct parts within the property, which does not represent an ecological corridor, and also, the existence of occupations in the east portion of the legal reserve area of the enterprise was verified, as well as possible Permanent Preservation Areas (PPA's) not declared by the owner. Such observations were made possible based on the spatial analysis tools that provide substantial subsidies to environmental planning, from the perspective of mitigating the intense process of use and occupation in areas of recognized fragility and environmental vulnerability (SILVA; ROCHA; AQUINO, 2017).

According to Piauí State Law No. 6,947 of 01/09/2017 (Piauí, 2017), which deals with the criteria and regulations of State environmental licensing, in the licensing stage, an analysis of the Geoprocessing

sector is held. Thus, it is established the approval of the intended area for enterprise implementation based on spatial analysis using geotechnologies and respecting legal and environmental restrictions.

The results generated in the Geoprocessing report are obtained with the data of the property overlaid with other official bases of the sector (water resources, biomes, among others). Thus, it possible to get an expanded and grounded view of the situation from the integration of different georeferenced parameters. Based on the use of these methodologies, it could be developed an available database; elaboration of diagnoses; in addition to contributing to the planning and orientation of public policies and environmental actions in the regions, among others (MENDES,2019).

In this case study, environmental licensing in the State of Piauí follows an analysis flowchart and criteria according to a database containing the geospatial information of the property with all its attributes. Through geographic database verification, at QGIS, they made it possible to identify whether the data declared by the entrepreneur were in accordance with the official bases of SEMAR/PI. Furthermore, it was possible to easily visualize the spatial distribution of the legal reserve corridor proposed by the developer compared to neighboring properties using the SICAR base. It was also possible to verify if all the PPA's of the enterprise were declared.

Through the spatial visualization of the real estate information on the maps, SEMAR/PI environmental auditors and managers, when issuing an environmental license, the agility, and efficiency in technical reports become more agile. The results obtained show the state of preservation of the legal reserve and PPA of rivers and streams.

According to the routine of data verification and information to be compiled during the spatial analysis at QGIS, thematic maps are generated on the environmental characteristics of rural properties, with a certain level of details, enabling a more reliable and efficient environmental assessment.

Figure 2 presents the general view of the project according to what has been informed by the owner. Therefore, it is possible to see that the property's legal reserve is fragmented into three areas and that the sum of them corresponds to the minimum percentage required for the biome relative to the property.

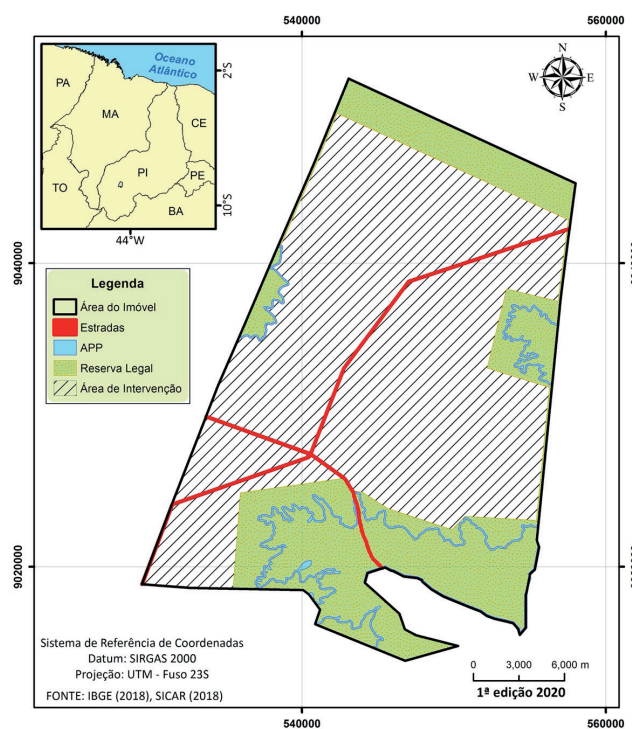


Figure 2 | Thematic map representing the features of the property under study.

Source: Ferreira (2018).

Figure 3 shows the satellite image SENTINEL 2A with the features of the area under study. Through the images, it is seen to verify possible occupations in the legal reserve area of the eastern portion of the project, as well as to verify possible areas of PPA. LRs (Legal Reserves) have as the main function to ensure the differentiated ecological role in the distinct Brazilian biomes and also have an important role in the water infiltration into the soil, as this process favors the recharge of the aquifer (PEREIRA, et al, 2017).

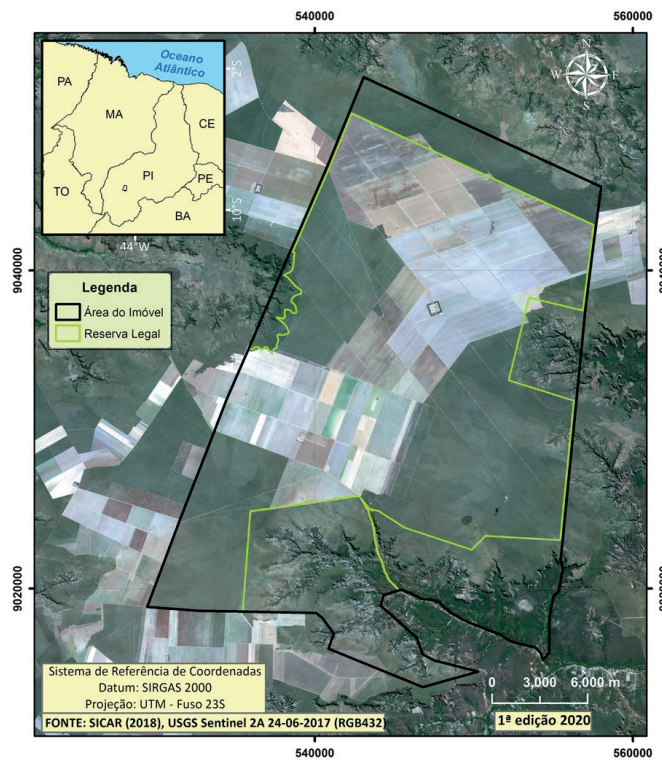


Figure 3 | Thematic map of the property's features and the satellite image SENTINEL 2A (06/24/2017).

Source: Ferreira (2018).

In figure 4, through the satellite images, it is verified possible occupations in the legal reserve and PPA area of the enterprise under study, which is not allowed according to the law. The detail level with the monitoring of on-site inspection points favors environmental inspection and monitoring.

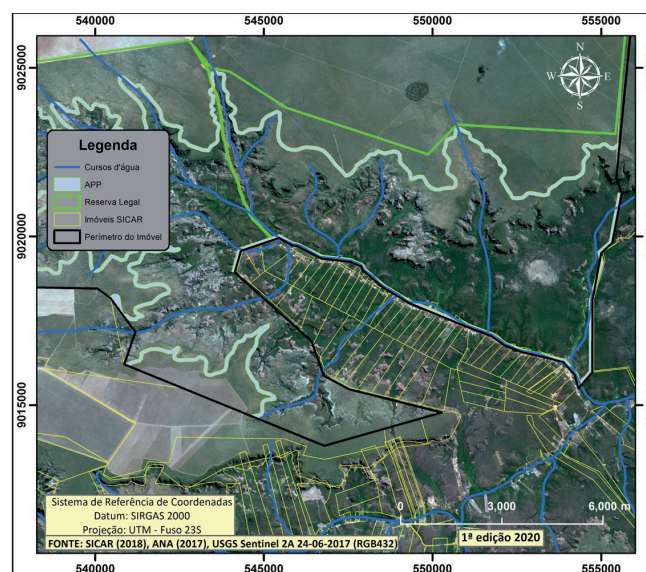


Figure 4 | Occupations in the areas of PPA and Legal Reserve of the property.

Source: Ferreira (2018).

In figure 5, it is possible to identify the properties registered in the SICAR base (Oct/2018) that are in overlap with the studied legal reserve area. In this sense, geotechnologies play a significant role in aggregating diverse and multiple data from various platforms, generating information with clarity and integration.

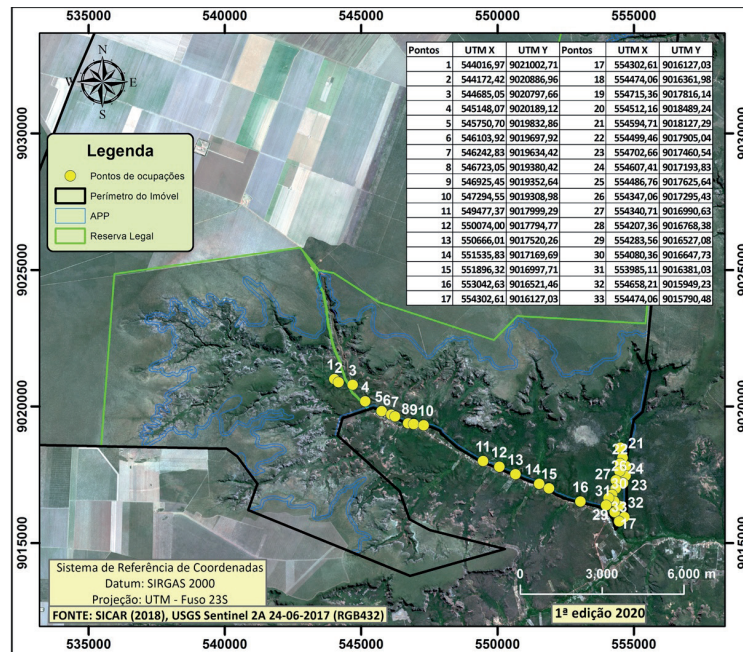


Figure 5 | Properties registered with SICAR in overlap with the Legal Reserve.

Source: Ferreira (2018).

In figure 6, it is possible to verify that all PPA's were declared by the owner in SICAR, by overlapping with the official watercourse base of ANA 2017. Environmental auditors also do the verification on the field, however, due to the large area, this is sometimes impossible. And through geotechnologies, this verification may be conducted in an agile, fast, and efficient way. PPA's are essential for the prevention of negative anthropic impacts on water resources and erosion dynamics. In this sense, it is essential to characterize the riverside forest structure in order to a better understanding of its functions, as suggested by Pereira et al. (2017).

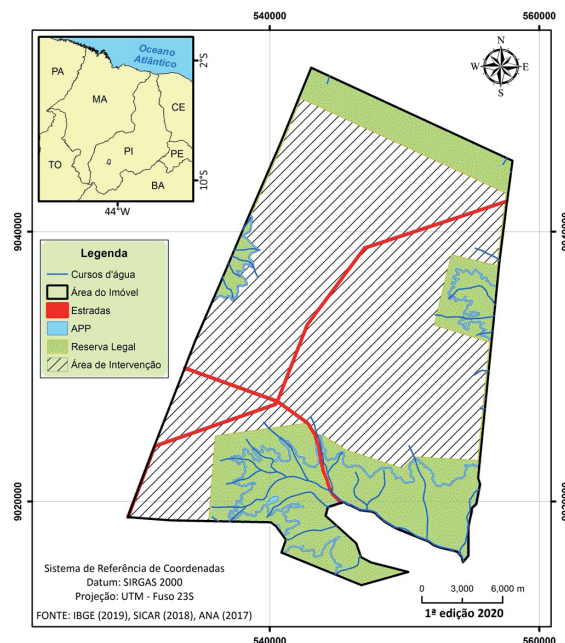


Figure 6 | Watercourses, ANA 2017.

Source: Ferreira (2018).



Given all the mapping of the case under study, geotechnologies applied to environmental licensing help to reduce costs, considering that several analyzes of the property may be performed through satellite images and data integration, thus generating more accessibility information and data accuracy.

#### 4 FINAL CONSIDERATIONS

This study has been provided the identification of areas susceptible to the process of environmental degradation associated with human activities through geotechnologies, as they deserve greater attention from the environmental agency, as well as assisting in environmental inspection and compliance with current legislation. The characterization of the rural property by this methodology facilitates the control and monitoring of preserved areas with vegetation linked to the substitution by economic activities without the proper environmental license.

The georeferenced data in the GIS environment facilitate the storage, manipulation, consultation, evaluation, spatial view, and analysis of the mapped information. At SEMAR/PI, the GIS is used in the daily environmental licensing, being useful mainly in environmental monitoring, enabling quality in the analysis, as well as a broad spatial view of the territory, which makes it essential for the inspection and preservation of environmental resources.

Given this, the GIS tool becomes essential in the analysis of projects, besides serving as a basis for strengthening the inspection of already consolidated projects, observing that they continue to obey the standards of the legislation. It is worth mentioning that in addition to the employment of open programs, such as QGIS and GVSIG, the use of these tools can be associated with the use of flight execution technologies with unmanned aerial vehicle (UAV), such as those with fixed-wing (large and medium properties), or drones (small and medium properties).

In this sense, geotechnologies become an important tool to be used in environmental studies since these techniques set has allowed to quickly and effectively identify the environmental status of the spatial elements of a given territory. Thus, it makes it possible to carry out the integration of the spatial elements from different sources, to determine the sustainable use of the land, and to ensure more efficiency and reliability in the decision making of the public environmental manager.

#### REFERENCES

AGÊNCIA NACIONAL DE ÁGUAS. **Base Hidrográfica Ottocodificada Multiescalas 2017 (BHO 2017)**. Disponível em: <<https://metadados.ana.gov.br/geonetwork/srv/pt/main.home>>. Acesso em: 22 set. 2018.

ALBUQUERQUE, D. S.; SOUSA, M. R. M. Análise Geoambiental como subsídio ao Planejamento no município de Pereiro/Ceará/Brasil. **Revista Equador**, v. 8, n. 2, p. 348-364. Universidade Federal do Piauí. Disponível em: <<http://www.ojs.ufpi.br/index.php/equador>>. Acesso em: 22 set. 2018.

BRASIL. Conselho Nacional do Meio Ambiente. Resolução n. 237, de 22 de dezembro de 1997. Regulamenta os aspectos de licenciamento ambiental estabelecidos na Política Nacional do Meio Ambiente. **Diário Oficial [da] República Federativa do Brasil**, Brasília, DF, 22 dez. 1997. Disponível em: <<http://www.planalto.gov.br/>>. Acesso em: 22 set. 2018.

BRASIL. Lei nº. 6.938, de 31 de agosto de 1981. Dispõe sobre a Política Nacional do Meio Ambiente, seus fins e mecanismos de formulação e aplicação, e dá outras providências. **Diário Oficial da República Federativa do Brasil**, Brasília, DF, 2 de setembro de 1981. Disponível em: <<http://www.planalto.gov.br/>>. Acesso em: 22 set. 2018.

BRASIL. Ministério do Meio Ambiente. Programa Nacional de Capacitação de gestores ambientais: licenciamento ambiental. Ministério do Meio Ambiente. Brasília: MMA, 2009.

CAMARA, G.; DAVIS, C. **Introdução à Ciência da Geoinformação**. São José dos Campos, INPE, 2004 (Cap. 01). Disponível em: <<http://www.dpi.inpe.br/gilberto/livro/introd/cap1-introdução.pdf>>. Acesso em: 23 set. 2018.

FEITOSA, I. R.; LIMA, L. S.; FAGUNDES, R. L. **Manual de Licenciamento ambiental**: guia de procedimento passo a passo. Rio de Janeiro: GMA, 2004.

FITZ, P. R. **Geoprocessamento sem complicação**. São Paulo, SP: Oficina de Texto. 2008.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Malha municipal**. 2006. Disponível em: <<https://www.ibge.gov.br/geociencias/organizacao-do-territorio/15774-malhas>>. Acesso em: 22 set. 2018.

JONES, C. **Geographical information systems and computer cartography**. 2. ed. New York: Routledge. Taylor & Francis. 2013.

LEITE, M. E. et al. Geotecnologias aplicadas à estimativa da temperatura de superfície em diferentes usos e ocupações do solo na Área de Proteção Ambiental do Rio Pandeiros – Minas Gerais. **Caderno de Geografia**, [s.l.], v. 28, n. 53, p. 490-509, 12 maio 2018. Pontifícia Universidade Católica de Minas Gerais.

LIRA, M. V.; SOUTO, M. V. S.; DUARTE, C. R. Multitemporal Analysis of the Landscape Dynamics for the Municipalities of Barroquinha and Chaval, Northwest of the State of Ceará – Brazil, for Land Use and Coverage. **Anuário do Instituto de Geociências – UFRJ**, [s.l.], v. 42, n. 1, p. 471-482, 13 maio 2019. Instituto de Geociências – UFRJ.

LUPPI, A. S. L. et al. **Utilização de Geotecnologia para o Mapeamento de Áreas de Preservação Permanente no Município de João Neiva, ES**. *Floresta e Ambiente*, Seropédica, v. 22, n. 1, p. 13-22, mar. 2015. Disponível em: <[http://www.scielo.br/scielo.php?script=sci\\_arttext&pid=S217980872015000100013&lng=en&nrm=iso](http://www.scielo.br/scielo.php?script=sci_arttext&pid=S217980872015000100013&lng=en&nrm=iso)>. Acesso em: 10 out. 2018.

MEDEIROS, A. **Norteando seus conhecimentos sobre Geotecnologias**. Disponível em: <<http://andersonmedeiros.com/norteando-seusconhecimentos-sobre-geotecnologias/2011>>. Acesso em: 24 out. 2018.

MENDES, I. A. S. O Uso de Geotecnologias na Organização do Espaço. **Cadernos do Leste**, v. 19, n. 19, 2019. Universidade Federal de Minas Gerais. Belo Horizonte. Disponível em: <<https://periodicos.ufmg.br/index.php/caderleste/article/view/13157/10398>>. Acesso em: 11 out. 2018.

MENDONÇA, R. A. M. et al. **Uso das Geotecnologias para Gestão Ambiental**: experiências na Amazônia Meridional. Disponível em: <<http://www.icv.org.br/wp-content/uploads/2013/08/uso-das-geocnologias-paragest%C3%A3o-ambiental.pdf>>. Acesso em: 24 out. 2018.

PEREIRA, C. C. **Temperatura de Superfície na Bacia da Usina Hidrelétrica (UHE) Barra dos Coqueiros, utilizando climatologia e sensoriamento remoto**. Goiás. 2014. Dissertação (Mestrado em Geografia) – Universidade Federal de Goiás. 2014.

PEREIRA, D. G. S. P. et al. Environmental Protection Areas: the case of the Bebedouro Stream Watershed. **Ambiente & Sociedade**, [s.l.], v. 20, n. 1, p. 105-126, mar. 2017. FapUNIFESP (SciELO).

PIAUI. **Lei estadual Nº 6.947, de 09 de janeiro de 2017**. Dispõe sobre as diretrizes do licenciamento ambiental estadual, estabelece os prazos e procedimentos para a emissão de licenças, declarações e autorizações ambientais e dá outras providências. Disponível em: <<https://www.legisweb.com.br/legislacao/?id=335723>>. Acesso em: 23 set. 2018.

QGIS. **Sistema de Informação Geográfica QGIS versão 2.14**. Projeto da Fundação Geoespacial de Código Aberto. Disponível em: <<http://qgis.osgeo.org>>. Acesso em: 14 out. 2018.

ROCHA, C. H. B. **Geoprocessamento**: tecnologia transdisciplinar – Juiz de Fora, MG: Ed do Autor, 2000.

SILVA, F. J. L. T. da.; ROCHA, D. F.; AQUINO, C. M. S. de. Geografia, Geotecnologias e as novas Tendências da Geoinformação: indicação de estudos realizados na Região Nordeste. **Interespaço – Revista de Geografia e Interdisciplinaridade**, [s.l.], v. 2, n. 6, p. 176-197, 9 mar. 2017. Universidade Federal do Maranhão.

SISTEMA NACIONAL DE CADASTRO AMBIENTAL RURAL. Disponível em: <<http://www.car.gov.br/#/sobre>>. Acesso em: 22 set. 2018.

SOBRAL, M. do C. et al. **Geotecnologias na gestão de reservatórios**: uma revisão e uma proposta de integração. Eng. Sanit. Ambient., Rio de Janeiro, v. 22, n. 5, p. 841-852, Oct. 2017. Disponível em: <[http://www.scielo.br/scielo.php?script=sci\\_arttext&pid=S141341522017000500841&lng=en&nrm=iso](http://www.scielo.br/scielo.php?script=sci_arttext&pid=S141341522017000500841&lng=en&nrm=iso)>. Acesso em: 24 out. 2018.

SUBRANI, T.; VENKATACHALA, K. K. M.; PRIYANKA, S. Assessment Of Impact On Aquaculture Using Remote Sensing Data And Gis In Tiruchendur. **International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)**, v. 6, n. 3, May-June 2017, p. 157-166, ISSN 2278-6856.

UNITED STATES GEOLOGICAL SURVEY. Earth Explorer. **Sentinel 2A S2A\_MSIL1C\_20170624T132231\_N0205\_R038\_T23LNL\_20170624T132231.SAFE**. Data da imagem: 24 de junho de 2017. Disponível em: <<https://earthexplorer.usgs.gov/>>. Acesso em: 20 set. 2018.

# Utilização de programas abertos de geotecnologia para o emprego no licenciamento ambiental no estado do Piauí

*Geotechnologies as an environmental licensing support tool in the state of Piauí*

Bruna de Freitas Iwata<sup>a</sup>

Danielly dos Santos Ferreira<sup>b</sup>

Adriano D'Carlos Batista Oliveira<sup>c</sup>

<sup>a</sup>Doutora em Ciências do Solo pela Universidade Federal do Ceará, UFC, Professora do Instituto Federal de Educação, Ciência e Tecnologia do Piauí, IFPI, Teresina, PI, Brasil.  
End. Eletrônico: iwata@ifpi.edu.br

<sup>b</sup>Mestranda no Programa de Pós-Graduação em Análise e Planejamento Espacial pelo Instituto Federal de Educação, Ciência e Tecnologia do Piauí, IFPI, Teresina, PI, Brasil  
End. Eletrônico: danielly.santosferreira@gmail.com

<sup>c</sup>Mestrando no Programa de Pós-Graduação em Análise e Planejamento Espacial pelo Instituto Federal de Educação, Ciência e Tecnologia do Piauí, IFPI, Professor do Instituto Federal de Educação, Ciência e Tecnologia do Piauí, Teresina, PI, Brasil  
End. Eletrônico: adriano.dcarlos@ifpi.edu.br

doi:10.18472/SustDeb.v11n2.2020.29253

Received: 20/01/2020  
Accepted: 02/07/2020

ARTICLE- DOSSIER

## RESUMO

As geotecnologias são um conjunto de tecnologias voltadas para coleta, processamento, análise e disponibilização da informação com referência geográfica. Diante disso, o objetivo dessa pesquisa é demonstrar por meio das análises espaciais as características ambientais de um empreendimento localizado no município de Currais – PI, objeto do procedimento de licenciamento ambiental do órgão competente estadual, utilizando as ferramentas das geotecnologias. A metodologia consistiu na utilização do Sistema de Informações Geográficas Quantum GIS (QGIS) para a criação e tratamento do banco de dados geográfico. Por meio da geração de mapas temáticos, foi possível concluir que as utilizações das geotecnologias auxiliam no controle e monitoramento ambiental, no qual facilita a visualização e caracterização de diversas feições ambientais no procedimento de licenciamento ambiental. Também foi possível identificar as áreas que merecem uma maior atenção do órgão ambiental em virtude de algum dano ao meio ambiente, bem como auxilia na fiscalização ambiental e legislação vigente.

**Palavras-chave:** Licenciamento Ambiental. Geotecnologias. Sistema de Informações Geográficas.

## ABSTRACT

*Geotechnologies are a set of technologies geared towards collection, processing, analysis and availability of information with geographic reference. Therefore, the objective of this research is to*

*demonstrate through the spatial analysis the environmental characteristics of an enterprise located in the municipality of Currais – PI, object of the environmental licensing procedure of the state competent body, using the tools of geotechnologies. The methodology consisted in using the Geographic Information System Quantum GIS (QGIS) for the creation and processing of the geographic database. Through the generation of thematic maps, it was possible to conclude that the uses of geotechnologies aid in the control and environmental monitoring, in which, it facilitates the visualization and characterization of several environmental features in the environmental licensing procedure. It was also possible to identify the areas that deserve greater attention from the environmental agency due to some damage to the environment, as well as, it assists in environmental inspection and current legislation.*

**Keywords:** Environmental Licensing. Geotechnology. Geographic Information System.

## 1 INTRODUÇÃO

As paisagens são alteradas continuamente pelas interferências do homem no meio natural, e o conhecimento dos processos que aconteceram no passado é importante para entender as modificações. A observação sobre o uso da terra é relevante pela necessidade de garantir a sustentabilidade diante das questões ambientais, sociais e econômicas a ele relacionadas, e levadas a emergir no debate sobre desenvolvimento sustentável (LIRA; SOUTO; DUARTE, 2019).

A superfície terrestre é lugar de diferentes conjunturas no que diz respeito à sua ocupação, sendo provenientes das necessidades da produção e reprodução da sociedade e modificadas de maneira abundante e veloz (LEITE et al., 2018). Para suprir as demandas da sociedade, ocorre supressão da vegetação, desencadeada pela utilização de terras agricultáveis, e se essa transformação não for gerenciada, prejudica as condições naturais do ambiente (PEREIRA, 2014).

Nesse contexto, conceber análises do ambiente auxilia indubitavelmente na manipulação deste, possibilitando o gerenciamento e o planejamento ambiental de funcionalidades por parte da gestão pública, assim como por aqueles que se proveem efetivamente do ambiente (ALBUQUERQUE; SOUSA, 2019). Com o intuito de prover a gestão dos recursos naturais de forma sustentável, conciliada ao desenvolvimento econômico, tem-se o licenciamento ambiental como instrumento de fiscalização e controle, que foi estabelecido pela Lei nº 6.938, de 31 de agosto de 1981 (BRASIL, 1981), da Política Nacional do Meio Ambiente para garantir a gestão eficiente e controlada.

O licenciamento ambiental, abordado em Feitosa et al. (2004), é o procedimento administrativo pelo qual o órgão ambiental competente licencia a localização, instalação, ampliação e a operação de empreendimentos e atividades utilizadores de recursos ambientais, considerados efetivos ou potencialmente poluidores ou daqueles que, sob qualquer forma, possam causar degradação ambiental, considerando as disposições legais e regulamentares e as normas técnicas aplicáveis ao caso. O Poder Público, no exercício de sua competência de controle, expedirá as seguintes licenças: Licença Prévia (LP), Licença de Instalação (LI) e Licença de Operação (LO) (CONAMA, 1997).

A licença prévia é concedida na fase preliminar do planejamento do empreendimento ou atividade aprovando sua localização e concepção, atestando a viabilidade ambiental e estabelecendo os requisitos básicos e condicionantes a serem atendidos nas próximas fases de sua implementação (CONAMA, 1997). Como vultuoso auxílio a essa etapa, as geotecnologias são procedimentos de diagnóstico de áreas ressaltando seus respectivos usos, pois visam caracterizar espacialmente o empreendimento garantindo o apoio à concessão da licença ambiental fornecida pelo órgão fiscalizador.

As geotecnologias se caracterizam por equipamentos e métodos de processamento matemático e computacional. Apresentam como objetivos principais o tratamento e a análise dos dados geográficos, permitindo dar respostas mais específicas e precisas. Cada vez mais o uso das geotecnologias tem contribuído para a análise e caracterização ambiental. Sua utilização proporciona aos usuários conhecimento de

situações passadas e atuais, além de permitir a simulação de cenários futuros. Algumas ferramentas muito utilizadas na geotecnologia são os Sistemas de Informações Geográficas (SIGs), o sensoriamento remoto e o GPS (*Global Positioning System* – Sistema de Posicionamento Global) (MENDES, 2019).

O SIG é um sistema assistido por computador que pode inserir, analisar e exibir informações geograficamente referenciadas úteis para o gerenciamento ambiental (SUBRAMANI; VENKATACHALA; PRIYANKA, 2017). Uma das raízes mais importantes do SIG é a automação de fluxos de trabalho cartográficos, com o objetivo adicional de integrar e analisar informações geoespaciais (JONES, 2013).

De acordo com Mendonça et al. (2011, p. 9), o sensoriamento remoto é uma ciência utilizada para a detecção de objetos sem contato direto com eles. As propriedades físicas da interação da energia eletromagnética possibilitam caracterizar tais objetos. Essa pluralidade temática para a qual o uso das geotecnologias tem convergido advém de diferentes matrizes teórico-metodológicas, mormente as abordagens integrativas que procuram analisar a relação Sociedade-Natureza (SILVA; ROCHA; AQUINO, 2017).

A proposta principal da utilização das geotecnologias no monitoramento ambiental é contribuir de forma eficiente para que a produção na área licenciada ocorra de forma sustentável. Assim, a utilização dessas ferramentas é de fundamental importância para o processamento e a geração de informações em relatórios e mapas, além de serem importantes para fornecer e sintetizar informações para o estudo ambiental (SOBRAL et al., 2017). Esses mapeamentos influenciam a agilidade para fiscalização e, conseqüentemente, para o cumprimento de leis pertinentes (LUPPI et al., 2015).

O mapeamento, que é empregado dentro das técnicas de geoprocessamento (FITZ, 2008; ROCHA, 2000), é uma forma eficaz de análise e visualização de dados. Concebidas por Kerski (2015) como uma das cinco tendências globais convergentes no seio da pesquisa geográfica, as geotecnologias têm encontrado larga utilização permitindo mapear e analisar uma grande variedade de fenômenos, com uma rapidez e precisão sem precedentes. Isso pode ser constatado também em Fitz (2008) e Medeiros (2011).

Nesse sentido, considerando toda a base teórica anteriormente apresentada, tem-se que o objetivo deste trabalho contempla: apresentar como as geotecnologias podem auxiliar o gestor público ambiental na caracterização e monitoramento do empreendimento que deseja requerer a licença ambiental por meio de um estudo de caso de um imóvel rural no estado do Piauí.

## 2 MATERIAIS E MÉTODOS

Para a realização deste trabalho foi utilizado para exemplificação do estudo um empreendimento no estado do Piauí que requereu ao órgão ambiental a licença prévia do estabelecimento. Para a análise do empreendimento e suas características ambientais para conclusão do parecer, o setor de Geoprocessamento, pertencente ao Centro de Geotecnologia Fundiária e Ambiental (CGEO) da Secretaria do Meio Ambiente e de Recursos Hídricos do Estado do Piauí (Semar/PI), conta com um banco de dados contendo informações de hidrografia, bioma, vegetação e outros itens que propiciam uma visualização espacial do imóvel, facilitando a tomada de algumas decisões por parte dos auditores e gestores ambientais.

Nesta pesquisa foi utilizado o *software* gratuito QUANTUM GIS (QGIS) 2.14 para a criação do banco de dados geográfico. Neste foram inseridos os arquivos do imóvel no formato *shapefile* com as seguintes feições: área do imóvel, Área de Proteção Permanente (APP), Reserva Legal (RL) e área de intervenção, todas no sistema de projeção SIRGAS 2000 e com o fuso UTM (Universal Transverso de Mercator) em função da localização do imóvel (23 ou 24).

Posteriormente, foi realizado um tratamento dos dados integrando as informações espaciais dos arquivos da Semar/PI e de outras fontes oficiais como do Instituto Brasileiro de Geografia e Estatística

(IBGE), Agência Nacional de Águas (ANA) e Sistema Nacional de Cadastro Ambiental Rural (Sicar). Logo após a análise espacial, é possível sobrepor as informações georreferenciadas da área do imóvel com as bases de dados disponíveis oficiais e as imagens de satélite.

A imagem de satélite gratuita utilizada foi a do satélite Sentinel 2A, do dia 24 de junho de 2017, resolução espacial de 10 metros, cena T23 LNL disponibilizado no site da Internet <https://earthexplorer.usgs.gov/>. Para a classificação da imagem verdadeira, foram utilizadas as bandas 4,3,2 RGB *Red* (vermelho), *Green* (verde) e *Blue* (azul) no software QGIS.

Para analisar um processo de licenciamento ambiental, geralmente são realizadas as seguintes atividades, que variam caso a caso:

- a. *download* de imagens de satélite;
- b. tratamento e classificação das imagens baixadas;
- c. sobreposição dos arquivos do processo com a base do CGEO;
- d. Pré-análise do Cadastro Ambiental Rural (CAR) do imóvel etc.

Para emissão do parecer técnico de geoprocessamento, foi usado o editor de textos Microsoft Office Word e o editor de planilhas eletrônicas Microsoft Office Excel, ambos presentes no pacote Microsoft Office 2003.

As bases cartográficas digitais utilizadas foram adquiridas no IBGE, ANA, Instituto Chico Mendes de Conservação da Biodiversidade (ICMBIO), Ministério do Meio Ambiente (MMA) e Sicar, em formato *shapefile*, onde foram selecionados elementos tais como os demonstrados na tabela abaixo.

**Tabela 1 | Bases de referência utilizadas na construção do parecer técnico de geoprocessamento da Semar, PI.**

| <i>CAMADA</i>        | <i>FONTE</i>      |
|----------------------|-------------------|
| MUNICÍPIO            | IBGE 2018         |
| CURSO D'ÁGUA         | ANA 2017          |
| IMÓVEL               | SICAR 2018        |
| Reserva Legal        |                   |
| Área do imóvel       |                   |
| Área de intervenção  |                   |
| APP                  |                   |
| IMAGEM SENTINEL 2017 | USGS/JUN. of 2017 |

*Fonte: Centro de Geotecnologia Fundiária e Ambiental do Piauí (2018).*

Além dos arquivos digitais, o empreendedor deve apresentar no início do processo de licenciamento ambiental a Planta do imóvel georreferenciada e o recibo do CAR do imóvel. Mediante essas informações, é criada uma planilha comparando os valores das feições do empreendimento nos três arquivos: Mídia digital formato *shapefile*, Planta do imóvel georreferenciado e do que foi declarado no Sicar, conforme modelo de tabela abaixo.

**Tabela 2 |** Quadro de áreas utilizado na construção do parecer técnico de geoprocessamento da Semar, PI

| FEIÇÃO |                             | Arquivo Digital (A) |    | Documento de Referência <sup>1</sup> (B) |    | Diferença | CAR       |
|--------|-----------------------------|---------------------|----|--|----|-----------|-----------|
|        |                             | ha                  | %  | ha                                       | %  |           |           |
| a)     | ÁREA TOTAL                  |                     |    |  |    |           | 67,112.33 |
| b)     | APP                         |                     |    |  |    |           | 1,278.85  |
| c)     | RESERVA LEGAL               |                     |    |  |    |           | 2,1080.17 |
| d)     | ÁREA PARA DESMATE           |                     |    |  |    |           |           |
| e)     | ÁREA DESMATADA              |                     |    |  |    |           |           |
| f)     | REMANESCENTE DE VEG. NATIVA |                     |    |  |    |           | 21,031.17 |
| g)     | ÁREA CONSOLIDADA            |                     |    |  |    |           | 46,031.44 |
| TOTAL  |                             | 0,00                | 0% | 0,00                                     | 0% | 0,00      |           |

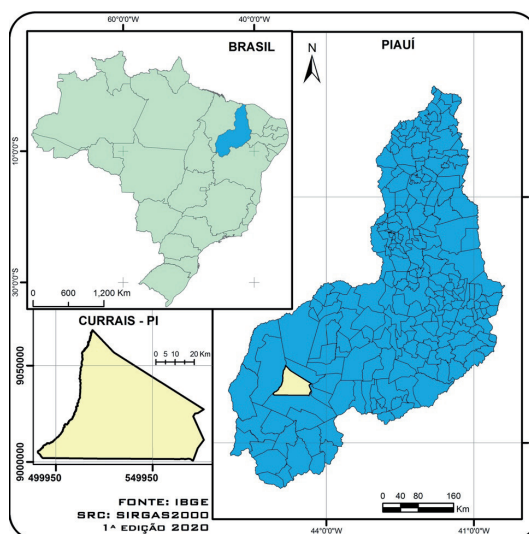
Fonte: Centro de Geotecnologia Fundiária e Ambiental do Piauí (2018).

O cálculo de área é feito no *software* Quantum GIS e o parecer é preenchido mediante análises dessas documentações e arquivos apresentados.

Por meio da visualização do imóvel, sobrepondo com o banco de dados do CGEO, pode ser realizada uma consulta espacial dentro do próprio ambiente do Sistema de Informação Geográfica (SIG) e verificação para obter respostas como: O percentual de reserva legal corresponde ao bioma da fazenda? A Área de Preservação Permanente (APP) foi delimitada corretamente? As imagens de satélite são utilizadas como importante ferramenta de diagnóstico da área e verificação em relação ao remanescente de vegetação nativa na área, se a reserva legal está preservada, se já ocorreu algum tipo de supressão vegetal e os cursos de água.

Depois das consultas realizadas, são confeccionados os mapas temáticos no *layout* do *software* QGIS colocando todos os elementos cartográficos do mapa, tais como: norte geográfico, escala gráfica, grade de coordenadas, legenda, etc.

O imóvel aplicado neste artigo localiza-se no município de Currais, no estado do Piauí. Segue abaixo a Figura 1 demonstrando a área.



**Figura 1 |** Mapa de localização do Brasil destacando o estado do Piauí e a cidade de Currais.

Fonte: Oliveira (2018).



### 3 RESULTADOS E DISCUSSÕES

A geração de mapas das características ambientais do imóvel rural pelas geotecnologias evidenciou, sobretudo, que a área em estudo apresenta sua reserva legal fragmentada em três porções distintas dentro do imóvel, o que não representa um corredor ecológico, e, também, foi verificada a existência de ocupações na porção leste da área de reserva legal do empreendimento, bem como possíveis Áreas de Preservação Permanente (APPs) não declaradas pelo proprietário. Tais observações foram possíveis tendo como base as ferramentas de análise espacial que fornecem importantes subsídios ao planejamento ambiental, na perspectiva de mitigar o intenso processo de uso e ocupação em áreas de reconhecida fragilidade e vulnerabilidade ambiental (SILVA; ROCHA; AQUINO, 2017).

De acordo com a Lei Estadual do Piauí nº 6.947, de 09 de janeiro de 2017 (PIAÚÍ, 2017), que trata dos critérios e normativas dos licenciamentos ambientais estaduais, tem-se que a etapa de licenciamento conta com uma análise do setor de Geoprocessamento que estabelece a aprovação da área pretendida para implantação do empreendimento baseada nas análises espaciais utilizando as geotecnologias e respeitando as restrições legais e ambientais.

Os resultados gerados no parecer do geoprocessamento são obtidos com os dados do imóvel sobrepostos a outras bases oficiais do setor (recursos hídricos, biomas, entre outras) gerando assim uma visão ampliada e embasada da situação a partir da integração de diferentes parâmetros georreferenciados. Com base na utilização dessas metodologias, podem ser desenvolvidas bases de dados disponíveis e elaboração de diagnósticos, além de contribuir para o planejamento e orientação das políticas públicas e das ações no meio ambiente das regiões, entre outros (MENDES, 2019).

No caso em estudo, o licenciamento ambiental no estado do Piauí segue um fluxograma de análise e critérios conforme uma base de dados contendo as informações geoespaciais do imóvel com todos os seus atributos. Por meio de consultas ao banco de dados geográfico no QGIS, foi possível identificar se os dados declarados pelo empreendedor estavam de acordo com as bases oficiais da Semar/PI, bem como visualizar com mais facilidade a distribuição espacial do corredor de reserva legal proposto pelo empreendedor em comparação aos imóveis vizinhos utilizando a base do Sicar. Também foi possível verificar se foram declaradas todas as APPs do empreendimento.

Mediante visualização espacial das informações dos imóveis nos mapas, os auditores e gestores ambientais da Semar/PI, ao emitirem uma licença ambiental, têm mais agilidade e eficácia nos seus laudos técnicos. Os resultados obtidos evidenciam o estado de preservação da reserva legal e APP de rios e/ou riachos.

Conforme rotina de verificação dos dados e informações a serem compilados durante a análise espacial no QGIS, tem-se a geração de mapas temáticos sobre as características ambientais dos imóveis rurais, com confiável nível de detalhes, possibilitando uma melhor e mais eficiente avaliação ambiental.

Na Figura 2 é apresentada a visão geral do empreendimento segundo o que foi informado pelo proprietário. Assim, é possível visualizar que a reserva legal do imóvel se encontra fragmentada em três áreas, e que a somatória delas equivale ao percentual mínimo exigido para o bioma correspondente ao imóvel.

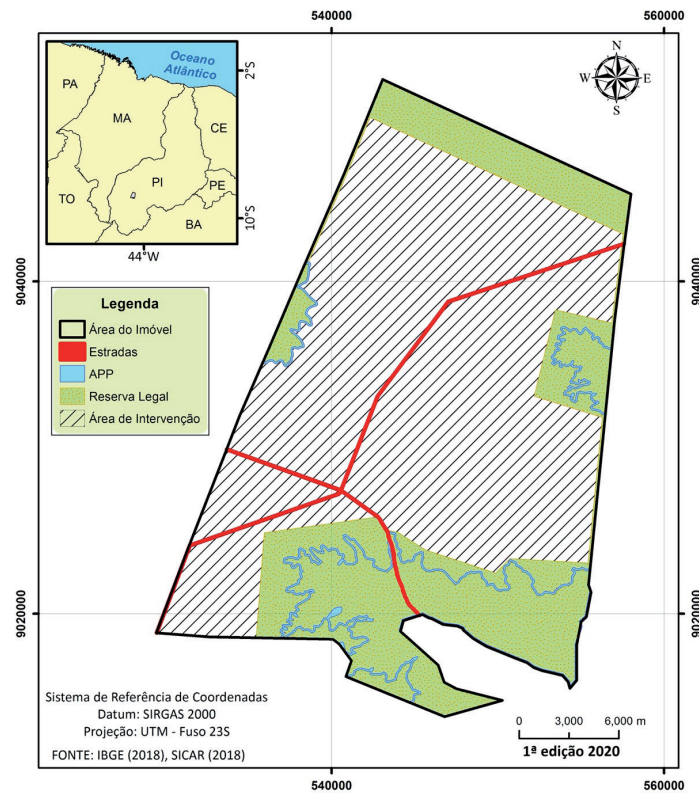


Figura 2 | Mapa temático representando as feições do imóvel em estudo.

Fonte: Ferreira (2018).

Na Figura 3 é demonstrada a imagem de satélite Sentinel 2A com as feições da área em estudo. Por meio das imagens, é possível verificar prováveis ocupações na área de reserva legal da porção leste do empreendimento, bem como verificar possíveis áreas de APP. As RLs têm como principal função garantir o papel ecológico diferenciado em biomas brasileiros distintos e também têm um importante papel na infiltração de água no solo, pois tal processo favorece a recarga dos aquíferos (PEREIRA et al., 2017).

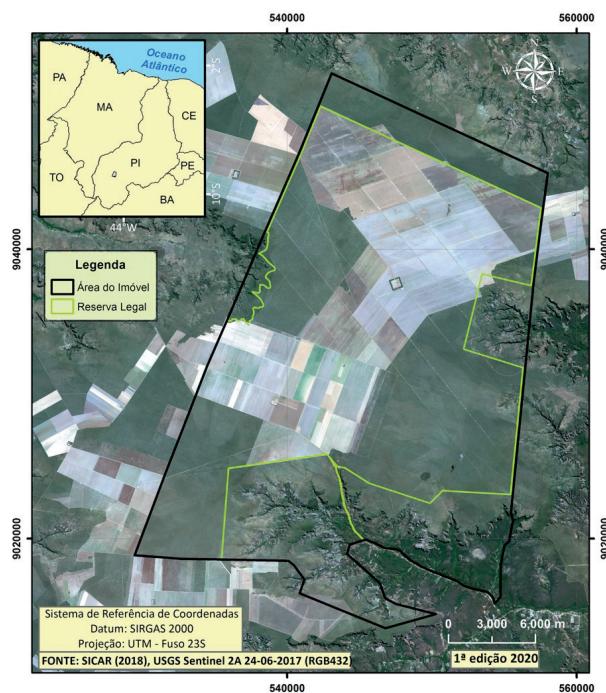


Figura 3 | Mapa temático das feições do imóvel e a imagem de satélite Sentinel 2A (24/06/2017).

Fonte: Ferreira (2018).

Na Figura 4, por meio das imagens de satélite, é possível verificar possíveis ocupações na área de reserva legal e APP do empreendimento em estudo, as quais não são permitidas segundo a lei. O nível de detalhamento com o acompanhamento dos pontos de vistoria *in loco* favorece a fiscalização e o monitoramento ambiental.

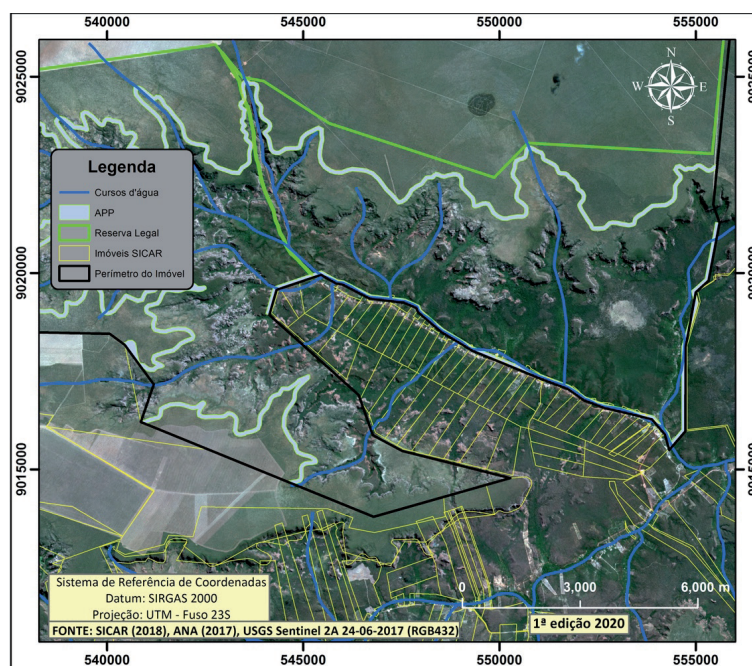


Figura 4 | Ocupações nas áreas de APP e reserva legal do imóvel

Fonte: Ferreira (2018).

Na Figura 5 é possível identificar os imóveis cadastrados na base do Sicar (Out/2018) que se encontram em sobreposição à área de reserva legal estudada. Nesse sentido, as geotecnologias desempenham uma significativa importância por agregar diversos e múltiplos dados de várias plataformas, gerando informações com clareza e integridade.

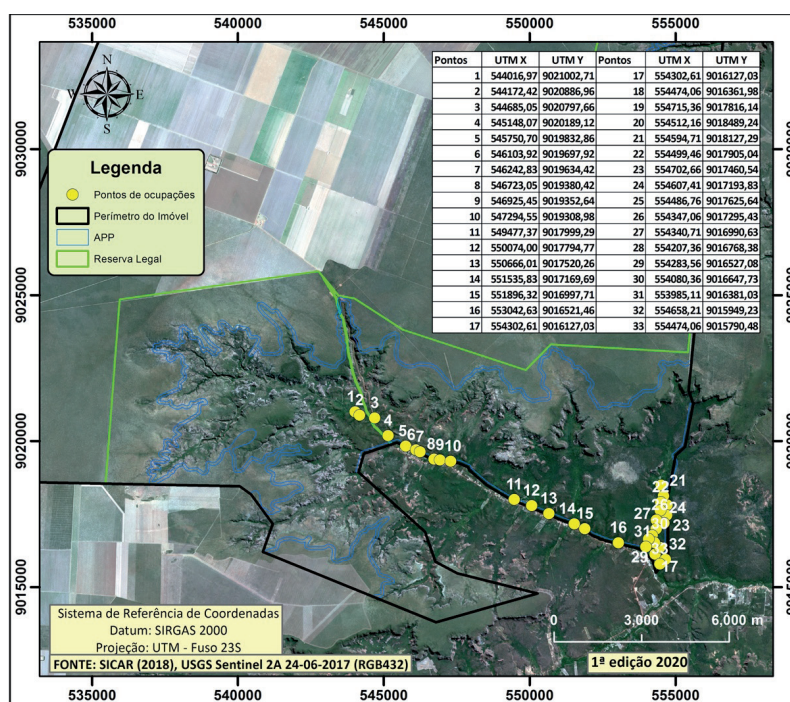


Figura 5 | Imóveis cadastrados no Sicar em sobreposição à reserva legal.

Fonte: Ferreira (2018).

Na Figura 6 é possível verificar se todas as APPs foram declaradas pelo proprietário no Sicar, mediante a sobreposição com a base oficial de curso de água da ANA 2017. Os auditores ambientais fazem a verificação em campo também, porém, pela grande extensão da área, isso é impossibilitado algumas vezes. Por meio das geotecnologias, pode-se fazer essa verificação de forma ágil, rápida e eficiente. As APPs são importantes para a prevenção de impactos antrópicos negativos sobre os recursos hídricos e a dinâmica erosiva. Nesse sentido, é importante caracterizar a estrutura de florestas ribeirinhas para melhor entendermos suas funções, o que é proposto em Pereira et al. (2017).

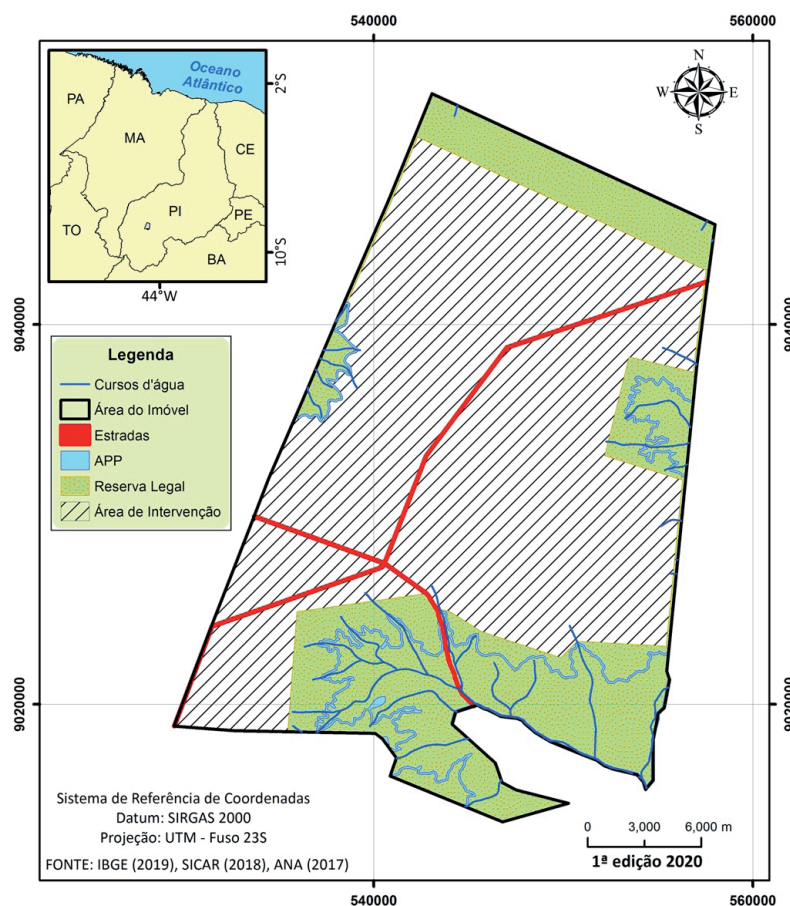


Figura 6 | Cursos de água ANA 2017

Fonte: Ferreira (2018).

Tendo em vista todo o mapeamento do caso em estudo, as geotecnologias aplicadas ao licenciamento ambiental auxiliam na redução de custos, levando em consideração que muitas das análises do imóvel podem ser feitas por meio das imagens de satélite e da integração dos dados, gerando assim mais acessibilidade às informações e precisão dos dados.

## 4 CONSIDERAÇÕES FINAIS

Este trabalho proporcionou a identificação de áreas suscetíveis ao processo de degradação ambiental associadas às atividades antrópicas por meio das geotecnologias, que merecem uma maior atenção do órgão ambiental, bem como auxilia na fiscalização ambiental e no cumprimento da legislação vigente. A caracterização do imóvel rural por intermédio dessa metodologia facilita o controle e o monitoramento de áreas preservadas com vegetação ligadas à substituição por atividades econômicas sem a devida licença ambiental.

Os dados georreferenciados no ambiente SIG facilitam o armazenamento, manipulação, consulta, avaliação, visão espacial e análise das informações mapeadas. O uso de SIG neste estudo é utilizado

no cotidiano do licenciamento ambiental realizado na Semar/PI, sendo útil principalmente no monitoramento ambiental, possibilitando qualidade na análise, bem como visão espacial ampla do território, o que torna fundamental para a fiscalização e preservação dos recursos ambientais.

Nesse contexto, as geotecnologias proporcionaram visualizar de maneira mais eficaz e ampla a realidade do empreendimento. Diante disso, essa ferramenta torna-se essencial na análise de negócios, como também servindo de base para o fortalecimento da fiscalização dos empreendimentos já consolidados, observando se estes continuam obedecendo aos padrões da legislação. Isso inclui não apenas o emprego de programas abertos e que podem ser utilizados gratuitamente, a exemplo do QGIS e do GVSIG. Adicionalmente, também podem ser empregadas tecnologias de execução de voos com veículos aéreos não tripulados (Vants), tal como os de asa fixa (grandes e médias propriedades) ou drones (pequenas e médias propriedades).

Nesse sentido, as geotecnologias se tornam um importante instrumento a ser utilizado nos estudos ambientais, uma vez que esse conjunto de técnicas tem permitido identificar de forma rápida e eficaz o estado ambiental dos elementos espaciais de determinado território, propiciando realizar uma integração dos elementos espaciais provenientes de diversas fontes, a fim de determinar o uso sustentável das terras e garantir mais eficiência e confiabilidade na tomada de decisão do gestor público ambiental.

## REFERÊNCIAS

AGÊNCIA NACIONAL DE ÁGUAS. **Base Hidrográfica Ottocodificada Multiescalas 2017 (BHO 2017)**. Disponível em: <<https://metadados.ana.gov.br/geonetwork/srv/pt/main.home>>. Acesso em: 22 set. 2018.

ALBUQUERQUE, D. S.; SOUSA, M. R. M. Análise Geoambiental como subsídio ao Planejamento no município de Pereiro/Ceará/Brasil. **Revista Equador**, v. 8, n. 2, p. 348-364. Universidade Federal do Piauí. Disponível em: <<http://www.ojs.ufpi.br/index.php/equador>>. Acesso em: 22 set. 2018.

BRASIL. Conselho Nacional do Meio Ambiente. Resolução n. 237, de 22 de dezembro de 1997. Regulamenta os aspectos de licenciamento ambiental estabelecidos na Política Nacional do Meio Ambiente. **Diário Oficial [da] República Federativa do Brasil**, Brasília, DF, 22 dez. 1997. Disponível em: <<http://www.planalto.gov.br/>>. Acesso em: 22 set. 2018.

BRASIL. Lei nº. 6.938, de 31 de agosto de 1981. Dispõe sobre a Política Nacional do Meio Ambiente, seus fins e mecanismos de formulação e aplicação, e dá outras providências. **Diário Oficial da República Federativa do Brasil**, Brasília, DF, 2 de setembro de 1981. Disponível em: <<http://www.planalto.gov.br/>>. Acesso em: 22 set. 2018.

BRASIL. Ministério do Meio Ambiente. **Programa Nacional de Capacitação de gestores ambientais: licenciamento ambiental**. Ministério do Meio Ambiente. Brasília: MMA, 2009.

CAMARA, G.; DAVIS, C. **Introdução à Ciência da Geoinformação**. São José dos Campos, INPE, 2004 (Cap. 01). Disponível em: <<http://www.dpi.inpe.br/gilberto/livro/introd/cap1-introdução.pdf>>. Acesso em: 23 set. 2018.

FEITOSA, I. R.; LIMA, L. S.; FAGUNDES, R. L. **Manual de Licenciamento ambiental: guia de procedimento passo a passo**. Rio de Janeiro: GMA, 2004.

FITZ, P. R. **Geoprocessamento sem complicação**. São Paulo, SP: Oficina de Texto. 2008.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Malha municipal**. 2006. Disponível em: <<https://www.ibge.gov.br/geociencias/organizacao-do-territorio/15774-malhas>>. Acesso em: 22 set. 2018.

JONES, C. **Geographical information systems and computer cartography**. 2. ed. New York: Routledge. Taylor & Francis. 2013.

LEITE, M. E. et al. Geotecnologias aplicadas à estimativa da temperatura de superfície em diferentes usos e ocupações do solo na Área de Proteção Ambiental do Rio Pandeiros – Minas Gerais. **Caderno de Geografia**, [s.l.], v. 28, n. 53, p. 490-509, 12 maio 2018. Pontifícia Universidade Católica de Minas Gerais.

LIRA, M. V.; SOUTO, M. V. S.; DUARTE, C. R. Multitemporal Analysis of the Landscape Dynamics for the Municipalities of Barroquinha and Chaval, Northwest of the State of Ceará – Brazil, for Land Use and Coverage. **Anuário do Instituto de Geociências – UFRJ**, [s.l.], v. 42, n. 1, p. 471-482, 13 maio 2019. Instituto de Geociências – UFRJ.

LUPPI, A. S. L. et al. **Utilização de Geotecnologia para o Mapeamento de Áreas de Preservação Permanente no Município de João Neiva, ES**. *Floresta e Ambiente*, Seropédica, v. 22, n. 1, p. 13-22, mar. 2015. Disponível em: <[http://www.scielo.br/scielo.php?script=sci\\_arttext&pid=S217980872015000100013&lng=en&nrm=iso](http://www.scielo.br/scielo.php?script=sci_arttext&pid=S217980872015000100013&lng=en&nrm=iso)>. Acesso em: 10 out. 2018.

MEDEIROS, A. **Norteando seus conhecimentos sobre Geotecnologias**. Disponível em: <<http://andersonmedeiros.com/norteando-seusconhecimentos-sobre-geotecnologias/2011>>. Acesso em: 24 out. 2018.

MENDES, I. A. S. O Uso de Geotecnologias na Organização do Espaço. **Cadernos do Leste**, v. 19, n. 19, 2019. Universidade Federal de Minas Gerais. Belo Horizonte. Disponível em: <<https://periodicos.ufmg.br/index.php/caderleste/article/view/13157/10398>>. Acesso em: 11 out. 2018.

MENDONÇA, R. A. M. et al. **Uso das Geotecnologias para Gestão Ambiental**: experiências na Amazônia Meridional. Disponível em: <<http://www.icv.org.br/wp-content/uploads/2013/08/uso-das-geocnologias-paragest%C3%A3o-ambiental.pdf>>. Acesso em: 24 out. 2018.

PEREIRA, C. C. **Temperatura de Superfície na Bacia da Usina Hidrelétrica (UHE) Barra dos Coqueiros, utilizando climatologia e sensoriamento remoto**. Goiás. 2014. Dissertação (Mestrado em Geografia) – Universidade Federal de Goiás. 2014.

PEREIRA, D. G. S. P. et al. Environmental Protection Areas: the case of the Bebedouro Stream Watershed. **Ambiente & Sociedade**, [s.l.], v. 20, n. 1, p. 105-126, mar. 2017. FapUNIFESP (SciELO).

PIAUI. **Lei estadual Nº 6.947, de 09 de janeiro de 2017**. Dispõe sobre as diretrizes do licenciamento ambiental estadual, estabelece os prazos e procedimentos para a emissão de licenças, declarações e autorizações ambientais e dá outras providências. Disponível em: <<https://www.legisweb.com.br/legislacao/?id=335723>>. Acesso em: 23 set. 2018.

QGIS. **Sistema de Informação Geográfica QGIS versão 2.14**. Projeto da Fundação Geoespacial de Código Aberto. Disponível em: <<http://qgis.osgeo.org>>. Acesso em: 14 out. 2018.

ROCHA, C. H. B. **Geoprocessamento**: tecnologia transdisciplinar – Juiz de Fora, MG: Ed do Autor, 2000.

SILVA, F. J. L. T. da.; ROCHA, D. F.; AQUINO, C. M. S. de. Geografia, Geotecnologias e as novas Tendências da Geoinformação: indicação de estudos realizados na Região Nordeste. **Interespaço – Revista de Geografia e Interdisciplinaridade**, [s.l.], v. 2, n. 6, p. 176-197, 9 mar. 2017. Universidade Federal do Maranhão.

SISTEMA NACIONAL DE CADASTRO AMBIENTAL RURAL. Disponível em: <<http://www.car.gov.br/#/sobre>>. Acesso em: 22 set. 2018.

SOBRAL, M. do C. et al. **Geotecnologias na gestão de reservatórios**: uma revisão e uma proposta de integração. *Eng. Sanit. Ambient.*, Rio de Janeiro, v. 22, n. 5, p. 841-852, Oct. 2017. Disponível em: <[http://www.scielo.br/scielo.php?script=sci\\_arttext&pid=S141341522017000500841&lng=en&nrm=iso](http://www.scielo.br/scielo.php?script=sci_arttext&pid=S141341522017000500841&lng=en&nrm=iso)>. Acesso em: 24 out. 2018.

SUBRANI, T.; VENKATACHALA, K. K. M.; PRIYANKA, S. Assessment Of Impact On Aquaculture Using Remote Sensing Data And Gis In Tiruchendur. **International Journal of Emerging Trends & Technology in Computer Science (IJETTCS)**, v. 6, n. 3, May-June 2017, p. 157-166, ISSN 2278-6856.

UNITED STATES GEOLOGICAL SURVEY. Earth Explorer. **Sentinel 2A S2A\_MSIL1C\_20170624T132231\_N0205\_R038\_T23LNL\_20170624T132231.SAFE**. Data da imagem: 24 de junho de 2017. Disponível em: <<https://earthexplorer.usgs.gov/>>. Acesso em: 20 set. 2018.

# The use of remote sensing techniques by Modis (MCD45A1) images using to identify and evaluate burned areas in the metropolitan region of Belo Horizonte- MG, Brazil

*Uso de técnicas de sensoriamento remoto utilizando imagens Modis (MCD45A1) para identificação e avaliação de áreas queimadas na Região Metropolitana de Belo Horizonte - MG, Brasil*

Luiza Cintra Fernandes<sup>a</sup>

Marcelo Antonio Nero<sup>b</sup>

Plínio Temba<sup>c</sup>

Marcos Antônio Timbó Elmiro<sup>d</sup>

<sup>a</sup>*Mestre em Análise e Modelagem de Sistemas Ambientais, Departamento de Cartografia do Instituto de Geociências da Universidade Federal de Minas Gerais. Belo Horizonte, MG, Brasil  
End. Eletrônico: luizacintraf@gmail.com*

<sup>b</sup>*Doutor em Engenharia de Transportes, professor no Departamento de Cartografia do Instituto de Geociências da Universidade Federal de Minas Gerais. Belo Horizonte, MG, Brasil  
End. Eletrônico: marcelo.nero@gmail.com*

<sup>c</sup>*Doutor em Engenharia Civil, professor no Departamento de Cartografia do Instituto de Geociências da Universidade Federal de Minas Gerais. Belo Horizonte, MG, Brasil  
End. Eletrônico: temba.mobile@gmail.com*

<sup>d</sup>*Doutor em Computação Aplicada, professor no Departamento de Cartografia do Instituto de Geociências da Universidade Federal de Minas Gerais. Belo Horizonte, MG, Brasil  
End. Eletrônico: timboelmiro@gmail.com*

doi:10.18472/SustDeb.v11n2.2020.28145

Received: 07/11/2019  
Accepted: 16/06/2020

ARTICLE- DOSSIER

## ABSTRACT

The study of fire burned areas is very important, since they corroborate with control measures, prevention and monitoring of fires. Forest fires causes numerous impacts, among them, there is biodiversity lost and human health prejudice. So, it is a problem of environmental sphere as well as a social and political sphere. A way of monitoring this is using remote sensing techniques. So the propose of the present article is to use the Modis product (MCD45A1) to identify and evaluated the burned areas in metropolitan region of Belo Horizonte, among the years of 2012 to 2016, which is validated with Landsat-8/OLI sensor data. With the use of Landsat data it is possible to define the size of the

burned area with greater precision, but requiring technical operational knowledge and specialized technical staff for both, on the other side, Modis is easier to operate, and have direct application and higher availability. It was observed that the study area has high burned area occurrences, mainly in spring and winter. The results found here could be used for future studies to decrease the forest fires incidence in the region and thus preserve the biodiversity of important biomes present in it.

**Keywords:** Forest fires. Landsat. Modis MCD45A1. Environmental Preservation.

## RESUMO

*Estudos sobre a ocorrência de queimadas são muito importantes, visto que eles corroboram medidas de controle, prevenção e monitoramento destas. Incêndios florestais causam vários impactos, entre eles perda da biodiversidade e prejuízo à saúde humana, sendo um problema tanto na esfera ambiental quanto social e política. Uma forma de monitoramento desses incêndios é a utilização de técnicas de sensoriamento remoto. Assim, a proposta do presente trabalho foi a utilização de imagens Modis (MCD45A1) para identificação e avaliação de áreas queimadas na região metropolitana de Belo Horizonte, entre os anos de 2012 e 2016, validando-o com dados do sensor Landsat-8/OLI. Com o emprego dos dados Landsat, é possível delimitar com melhor precisão a dimensão da área queimada, mas exigindo-se conhecimento técnico operacional e corpo técnico especializado para tanto. Já o produto decorrente do Modis, é mais acessível e de fácil utilização, sendo de aplicação direta, pois já informa os focos de incêndio. Observou-se grande ocorrência de queimadas na região de estudo, principalmente na primavera e no inverno. Os resultados encontrados aqui poderão ser utilizados em estudos futuros para diminuir a incidência de queimadas na região e assim preservar a biodiversidade de biomas importantes nela presente.*

**Palavras-chave:** Incêndios Florestais. Landsat/OLI. Modis MCD45A1. Preservação Ambiental.

## 1 INTRODUCTION

The occurrences of wildfire in vegetation represent serious concerns related to the environment, as they devastate large proportions of forests, fields and agricultural regions, causing changes in the environment. Guimarães et al. (2014) proffer the main impacts of wildfires as the following: soil warming, erosion, reduction of soil nutrients, reduction of organic matter content, soil acidity, alteration of local microclimate, reduction of water quality, animal mortality, wood weakening, cleaning of underwood, impacts on agricultural crops, interference in plant succession, reduction of microorganism activity and pasture renewal, disturbance to the surrounding population, landscape impacts and destruction of recreational areas. Ichoku and Kaufman (2005) state that wildfires cause impacts on the albedo, changes in the radiative balance of the atmosphere, changes in biogeochemical and hydrological cycles, in addition to greenhouse gases release into the atmosphere. In addition, wildfire occurrences are widely associated with the climate, vegetation conditions and especially human activities (Santos, Soares and Batista, 2006). It is also worth highlighting the approach to the subject in Louzada-Silva and Carneiro (2014) and Lima and Nasuti (2017), among others.

When a natural environment is destroyed, many plant and animal species are lost if not properly studied, which amounts to a great loss for science and humanity. Therefore, protecting and defending biodiversity becomes vital. A citable example of biodiversity loss is the Brazilian savanna known as *Cerrado*, where approximately 40 to 50% of the soil has been transformed into agriculture use in the last 50 years. This biome represents 23% of Brazil's land coverage being one of the most important biodiversity conservation hotspots. Another Biome heavily affected is the Atlantic Forest, which comprises 7% of the remaining original forests (GIUSTINA, SILVA and MARTINS, 2018).

The burning process in Brazil is growing and intensifies mainly in the driest periods of the year, and can be divided between natural and anthropic hotspots. The subject is also dealt with in detail in Louzada-Silva and Carneiro (2014) and Lima and Nasuti (2017). As for anthropic processes these are usually linked to the clearing of areas for agricultural and livestock expansion, in addition to being a form of management in some crops such as sugarcane (FERNANDES et al., 2016).



Among the groups of causes of wildfires classified by FAO (Food and Agriculture Organization of the United Nations), are mostly anthropic factors including: wildfires breakout for reasons such as retaliation, revenge, land tenure disputes, urbanization and mental incapacity, among others; burning for clearing areas for agricultural purposes; smokers, due to negligence in throwing cigarette butts or lit match; forest operations and recreation (Juvanhol, 2014). It is noteworthy that it is possible to develop automated systems for monitoring and preventing disasters, as applicable to the landslide area, as cited by Saito, Lima and Dias (2019). However, it is also worth mentioning, researches focused on the area of fire prevention, presented in Ribeiro et al (2008), Ribeiro (2009), Prudente (2010), Zhang et al (2011), Oliveira and Nero (2012, 2013), Oliveira (2013), Oliveira et al (2017), Fernandes (2019), Fernandes et al (2018a, 2018b, 2019).

In addition to the impacts of biodiversity loss, wildfires pose a major risk to human health, as they emit tiny particulate matter that damages the respiratory system. These particles are deposited in the terminal bronchi and in the alveoli, aggravating respiratory problems. Thus, municipalities located near the burned areas have increasingly recorded public health problems. Thus, it is estimated that in the next 20 years air pollution will be responsible for about 156,000 deaths, 4 million cases of asthma and 300,000 children health related problems consulting (CASTRO *et al.*, 2016)

Considering all that has been discussed here, it can be said that the problem of burning involves both social issues, such as public health issues, and environmental issues related to biodiversity losses. Therefore, in taking measures to prevent and controlling this phenomenon, it is necessary first to study and understand it. Hereby, awareness of the highest place of occurrence, frequency of events, times of the year, among others, are of vital importance. From this data it becomes possible to identify the causes and the best ways to control and prevent wildfires. Thus, it is important to have a quick and efficient way of detecting forest fires, to improve the control, and monitor burned areas, obtain cost reductions in combat operations, allow damage mitigation and estimate the impacts caused in the region. Detection can be carried out in different ways, such as through: surveillance posts, observation towers, aerial patrolling and monitoring through satellite images (BATISTA, 2013).

Remote sensing techniques stands out as a good solution when the objective is to map wildfires in areas with difficult access, such as conservation units and rural areas. Since there are no monitoring in these areas and the registration is done only through denouncements. Remote sensing consists in obtaining information from an object or target, without physical contact with it, and the information obtained using electromagnetic radiation reflected and/or emitted by the targets (ROSA, 2011). In addition, remote sensing allows the identification of thematic classes on the earth's surface, as well as the area of occurrence, exploring the classes of land use. Additionally, due to its temporal domain, it also identifies changes in objects on the surface, very important mainly for planning and environment monitoring. With the integration of its spectral and spatial characteristics it is possible to extract information regarding the product from a single date or a few dates. As an example, we have the Normalized Difference Vegetation Index (NDVI), where, through the use of reflectance in the red band and near infrared band ranges, information is provided on the amount of photosynthetically active green biomass of vegetation (PEREIRA FILHO, 2014). Thus, remote sensing techniques can be used for wildfire occurrence awareness, as well as in the quantification of the area and biomass affected by the wildfire (FRANÇA and FERREIRA, 2005).

In terms of environment, it is noteworthy mentioning several works that apply remote sensing, such as: 1) that performed by Barbalho et al (2019) with the use of 'Rapideye images' together with geoprocessing techniques; 2) the use of ArcGIS (Geographic Information Systems processing program, GIS) with the use of Google Earth images, as described in Viera et al (2018); 3) research with the application of GIS and temporal analysis of environmental devastation studies, reported in Guistina et al (2018).

Three sources of radiation are involved in the detection of wildfires by remote sensing: the emission of the fire itself, as combustion substances, the emission and reflection of the hotspots area, and the reflection of other sources, such as exposed soil. The use of surface changes between vegetation and

exposed soil is one of the most used ways to detect burned areas, as an example, we have the use of satellite images from the LANDSAT and SPOT systems, are immensely potential for this purpose, owing to their minute spatial resolution in relation to other sensors (França and Ferreira, 2005). Another form of detection is that used by Resende et al. (2017), who have used the Linear Spectral Mixing Model (LSMM) (Shimabukuro and Smith, 1991) from Moderate Resolution Imaging Spectroradiometer (MODIS) sensor images to identify the burned area in the Northeast portion of the *Cerrado* within the years 2012 to 2015.

Another related study is that of Fornazari et al (2015) where LANDSAT-5/TM sensor images was used to map the scars of the burned parts in the *Serra do Cipó* National Park (MG), in its study it was concluded that this method showed limitations when analyzing the permanence of the scars associated with the variables' "size" and "precipitation". The presence of clouds promoted the obscuration of several scenes acquired by the LANDSAT-5/TM sensor due to its low temporal resolution, so that possible scars present in this clouded region were left unmapped. Despite the difficulty of the method, it was noted that there is a considerable increase in the incidence of wildfire in the region in the months of June, September and October.

Rodrigues et al (2018) used an automatic estimate of the burned area in the *Serrana* Region of Rio de Janeiro in October 2014, through information from the operational land imager (OLI) sensor on board LANDSAT-8 satellite. Due to the low time frequency of the LANDSAT-8 images (16 days) and the frequent presence of high cloudiness in the region, it was only possible to map the burned areas two months after the event. The quantitative results indicate a total of approximately 4000 ha of burnt area in the Conservation Unit. The importance of using products with greater temporal frequency is noted, since in this study it was possible to detect the phenomenon only two months after the event, there may be loss of information.

The MODIS sensor, aboard the TERRA and AQUA orbital platforms, is configured to provide data on the dynamics of the Earth's biosphere, allowing the generation of images with spatial resolution between 250 and 1000 meters, in addition to presenting a frequency of revisit between 1 and 2 days to the equator (Piromal *et al.*, 2008). The MCD45A1 is a product obtained from images of both MODIS sensors with a monthly frequency and spatial resolution of 500 m, containing wildfire identified by pixel and presenting quality information of the data. The algorithm used to generate this product is based on changes in coal and ash deposits, removal and alteration of vegetation structure. Thus, the date of the burning is detected by locating the occurrence of rapid changes in the data of the daily surface reflectance time series, and a comparison is made between the reflectance data from the previous days, resulting in a statistical measure to determine whether the difference between predicted and observed reflectance denotes a significant change (ROY *et al.*, 2005).

The LANDSAT series of satellites, which presents spatial resolution between 15 and 30 m (depending on the spectral band), has been consolidated as one of the main tools for analysis and evaluation of environmental impacts, land use and land cover, estimation of biophysical parameters, georeferencing, as well as agricultural and environmental planning (ALVES *et al.*, 2017). Examples of recent related work are in Bittencourt and Guasselli (2017), Sotille *et al.* (2016), Andrade and Lourenço (2016), and Paula *et al.* (2016).

Data from LANDSAT satellites are widely used in the validation of methodologies for wildfire detection as a result of outstanding outcome derived from their applications, as portrayed by the citable authors who applied this validation. These authors include Jesus *et al.* (2011), Matos and Leal (2014), Piromal *et al.* (2008) and Tomzhinski *et al.* (2011). In the same vein, Araújo and Ferreira Junior (2011) validated the MCD45A1 product with data from LANDSAT-5, in the *Cerrado* region, and obtained 100% of the polygons found by MODIS were positively labeled as burned, due to the good accuracy of the algorithm. Cardozo *et al.* (2012) did the same validation for a region of the Amazon Rainforest and obtained more than 90% omission of burned areas. The advantages of using LANDSAT data is related to its better spatial resolution among the satellite data with free access.

In this context, the present work aimed at evaluating the occurrence of fires in the metropolitan region of Belo Horizonte, during the dry season, from the year 2012 through 2016. For this purpose, MCD45A1 product data from the MODIS sensor were used. In addition, the obtained results in relation to the estimated burned area were compared with the same data generated from orbital images of the LANDSAT-8/OLI sensor.

## 2 MATERIALS AND METHODS

The investigation of the occurrence of fires consisted of two main steps. The first dealt with the acquisition of MCD45A1 product data from the year 2012 to 2016, treatment of the data and the estimation of the extent of burned area. The second step was comparing the results of MCD45A1 with images from the LANDSAT-8/OLI system, as it has better spatial resolution and better spectral response to the occurrence of wildfires and it is widely used in studies for this purpose. The comparison was made only as for the periods of higher wildfire occurrences in this study.

### 2.1 FIELD OF STUDY

The Metropolitan Region of Belo Horizonte (*Região Metropolitana de Belo Horizonte*—RMBH), lies in the State of Minas Gerais and its main accesses are by highways BR-040, BR-381 (*Fernão Dias Highway*), BR-356 and BR-262, as shown in Figure 1. The region is composed of 34 municipalities, with a territorial extension of 9460 Km<sup>2</sup>, being the 3rd largest metropolitan region in Brazil and the 7th largest in Latin America. It has a population of approximately 5 million inhabitants and a GDP of 56.8 million, corresponding to 40% of the state's GDP (Agencia RMBH, 2016). The region covers three hydrographic basins: *Rio das Velhas* Basin, *Rio Paraopeba* Basin and *Rio Pará* Basin, all sub-basins of the *São Francisco* River (RMBH AGENCY, 2016).

The RMBH is present between two biomes: Atlantic Forest and the *Cerrado*. The former is predominantly characterized by the ombrophilous and seasonal forest physiognomies (semideciduous and deciduous). While the *Cerrado* is predominantly characterized by the savanna physiognomies (OLIVEIRA FILHO, 2006), apart from forestry and pasture. The Atlantic Forest represents the second largest tropical rainforest in the Americas, being one of the 25 world *hotspots* of biodiversity. Despite having been largely destroyed, it is still home to over 8,000 endemic species of vascular plants, amphibians, reptiles, birds and mammals (MYERS *et al.*, 2000). The *Cerrado* is one of the main savanna formations in the tropics, being the second largest biome in South America, occupying 22% of the Brazilian territory, and at the same time, being the biome that concentrates the largest agricultural production in the country (MARQUES *et al.*, 2017).

The climate classification of the region covers four climate zones defined by Nimer (1979). The zones of the greatest expression are: Tropical Central Brazil mild mesothermal semi-humid and Tropical Central Brazil sub-humid climate. The Tropical Central Brazil semi-humid climate stands out for an annual rainfall regime characterized by a pronounced concentration of tropical instabilities in summer, while the winter is strongly marked by drought (for around 4 to 5 months).

The low humidity makes the region prone to forest fires. According to data provided by FEAM (2017) there was the burning of over 2783 ha between 2012 and 2016 in the state conservation units.

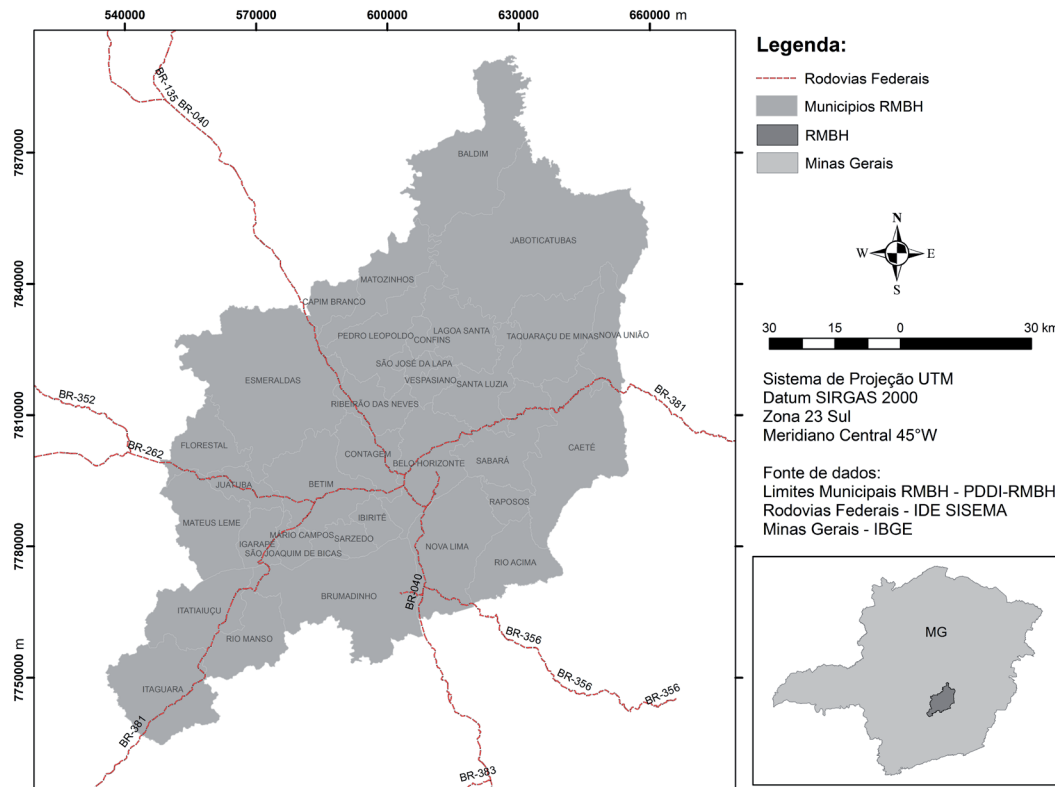


Figure 1 | Location of the area and study.

Source: Authors, based on PDDI (2014), ESRI (2015), IBGE (2017).

## 2.2 ASSESSMENT OF BURNED AREAS BY MODIS SENSOR

The acquisition of the product MCD45A1 was made in NASA (2017), from <https://ladsweb.modaps.eosdis.nasa.gov>, where the images were acquired in *geotiff* format. In this image acquisition, the geographical limits of RMBH which is inserted in tiles *H13V11*, *H13V10*, *H14V11* were considered and the area of interest where isolated. The images obtained considered the situation from January to December, from 2012 to 2016, totaling 60 images.

The product MCD45A1 provides eight by-products, of which only two were used in this analysis, the by-product *ba\_qa* (reliability index and pixel labeled as burned) and the by-product *burndate* (index that indicates if the area is burned). In order to obtain the pixels with high reliability index, the two bands were crossed. The value of the pixels of the by-product *ba\_qa*, varies from 0 to 5, and only pixels with value 1, which represent the highest reliability, were selected. The values of the pixels of the by-product *burndate* represent the day of the wild fire occurrence, in the format of the Julian calendar, allowing the awareness of the exact days in which more wildfires occurred.

The burned area for each year was calculated, taking the product's spatial resolution, which is 500 m, into account. All data were treated using procedures developed in Interactive Data Language (IDL), an interactive computer programming environment integrated with ENVI software (version 5.2), a platform for remote sensing data treatment and digital image processing.

## 2.3 ASSESSMENT OF BURNED AREAS WITH LANDSAT DATA

LANDSAT-8/OLI images were acquired from the Earth Explorer website(USGS, 2017), through the link <https://earthexplorer.usgs.gov>, referring to the orbit/point 218/74 that covers part of the study region. The images were chosen considering the smallest cloud coverage possible. Thus, 4 images were

acquired (September and November 2014, August and September 2016). As it was not possible to find images with total absence of clouds, we used clippings that obeyed this condition, besides data with LANDSAT-8/OLI quality to verify their presence.

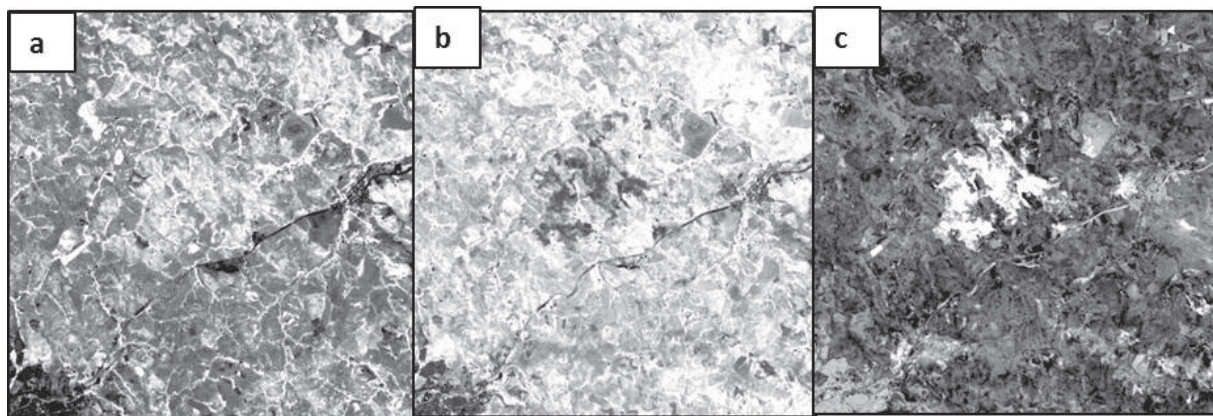
The raw digital values of the images were converted into apparent reflectance for image correction using the LANDSAT-8/OLI radiometric image correction method provided by USGS (*United States Geological Survey*), which is based on the relationships proposed by Markham and Barker (1987).

For the recognition of wildfire scars, the NDVI images were calculated (Equation 1) by an operation between the near infrared (IR) and red (R) bands. Assuming that the greater the amount of vegetation, the greater the reflection in the infrared band and smaller in the red band, increasing the ratio value and enhancing the vegetation (MELO, SALES and OLIVEIRA, 2011).

$$\text{NDVI} = (\text{NIR} - \text{R}) / (\text{NIR} + \text{R}) \quad (1)$$

From NDVI images, from the period before the burn (T1) and the period after (T2), the differences of these images (T1-T2) are calculated to help verify the burned part scars.

### 3 RESULTS

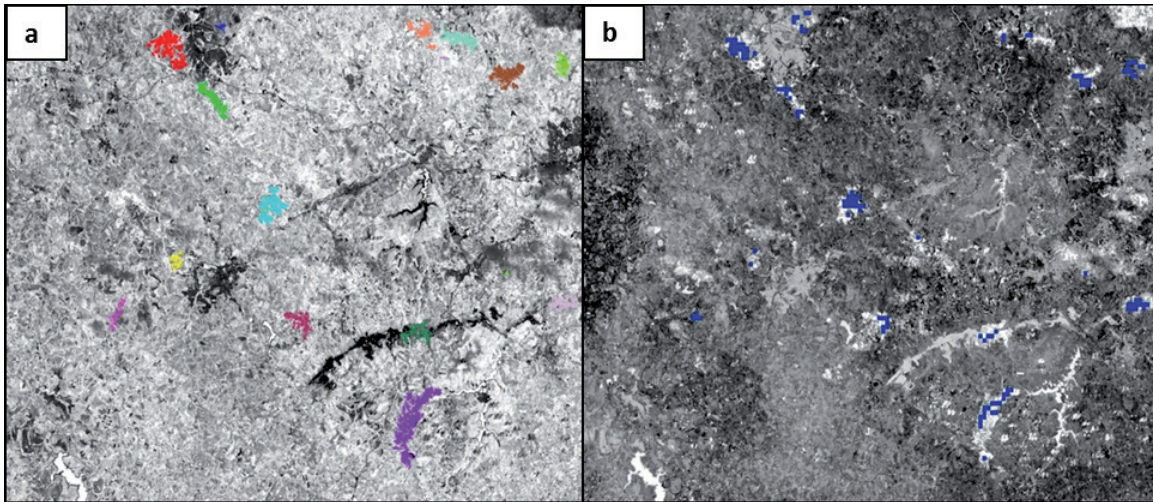


**Figure 2** | NDVI T1 (August 2014) (a), NDVI T2 (September 2014) (b) and T1-T2 (c).

*Source : Authors, based Landsat/OLI 8 images.*

As shown in Figure 2, the image difference allows the identification of pixels where there was no difference with values close to 0, places with vegetation removal, values close to 1 and vegetation growth, values close to -1 (CARVALHO; SCOLFORO,2008). It is possible to identify and demarcate the scars through regions of interest (ROI). Using the ROI (*Region of Interest*) tool, available in the ENVI software, a number of representative pixels (seed pixels) are selected from growth methods of regions based on the similarity of seed pixels with their neighbors, delineating the region efficiently, producing an optimized and accurate outline of the scar.

*The pixel* quantities of burned areas by LANDSAT-8/OLI and MODIS were compared and whether the areas were corresponding. It was noted that all burned polygons found based on the MODIS sensor data were also identified in the LANDSAT-8/OLI images, an example is shown in Figure 3. Nevertheless, when pixel matching was checked, it was observed that MODIS data was able to verify 72% of the wildfire pixels in 2014 and 60% of the fire *pixels* for 2016.

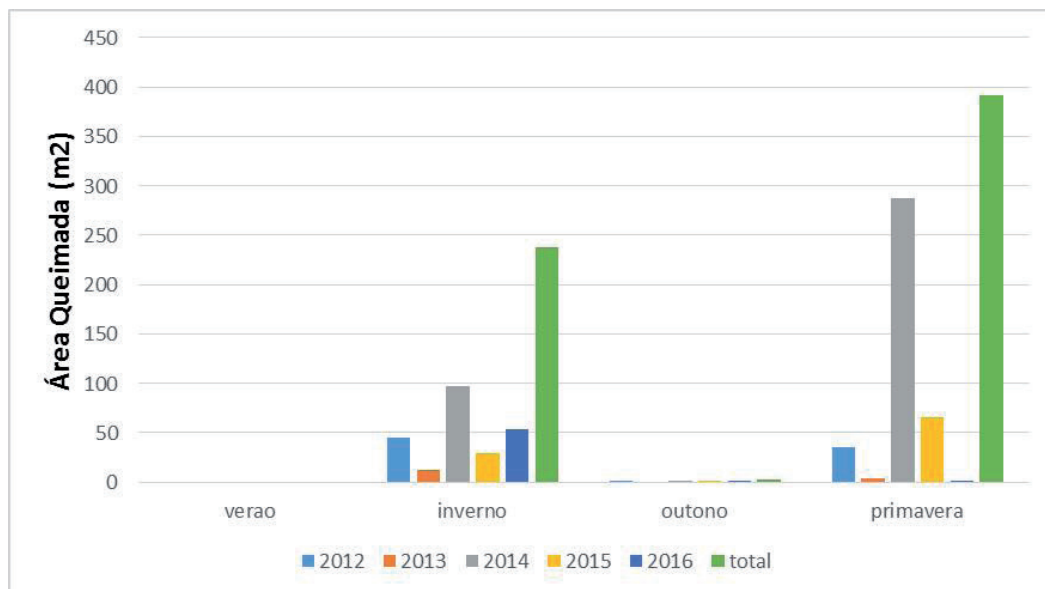


**Figure 3** | Comparison of burned polygons detected by LANDSAT-8/OLI images (colors only to differentiate each burn scar) (a) and MODIS sensor (b)

Source: Authors, based Landsat/OLI 8 images.

### 3.1 ANALYSIS OF THE WILDFIRE OCCURRENCE

With the burned area data obtained by the product MCD45A1 some analyses were made. Therefore, it was possible to notice that the seasons of the year in which wildfire occur mostly are winter and spring, though there were few points of wildfires in autumn, whereas in summer none was detected (figure 4).



**Figure 4** | Burned area by seasons.

Source: Authors.

Comparing the annual total (figure 5), it can be seen that the year 2014 gained prominence as the year with the highest incidence of wildfire, with 350 km<sup>2</sup> of affected area. It was followed by the year 2015, with 81 km<sup>2</sup> of affected area.

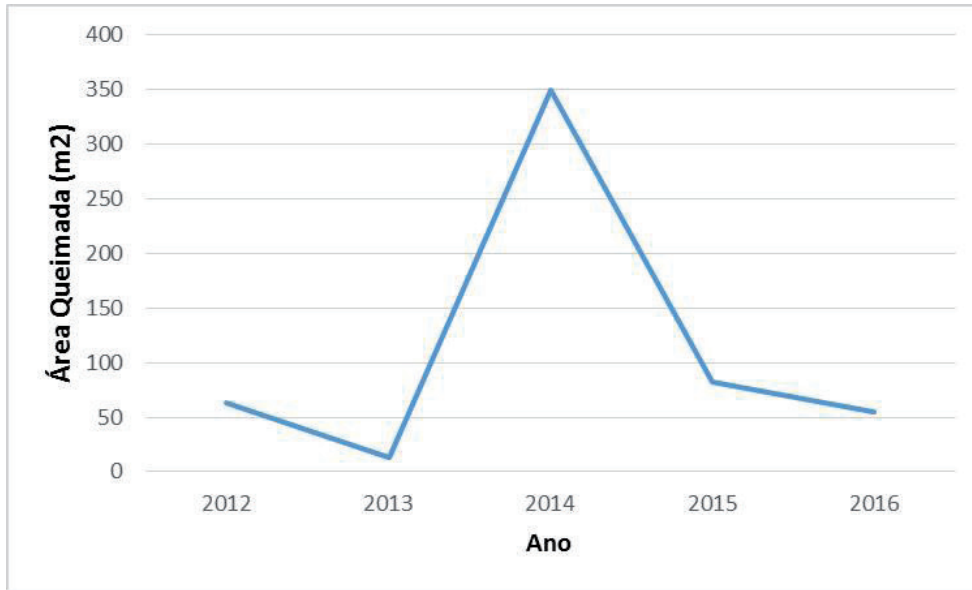


Figure 5 | Burned area by year

Source: Authors.

Between the months (figure 6) those with the highest concentration of wildfire are August, September and October. It should also be noted that the month of October presented an expressive value due to the year 2014, where wildfires occurrences were registered at a considerably high rate, reaching an area of approximately 183 km<sup>2</sup>, escalating to the record of the month with highest value of burned area throughout the years studied.

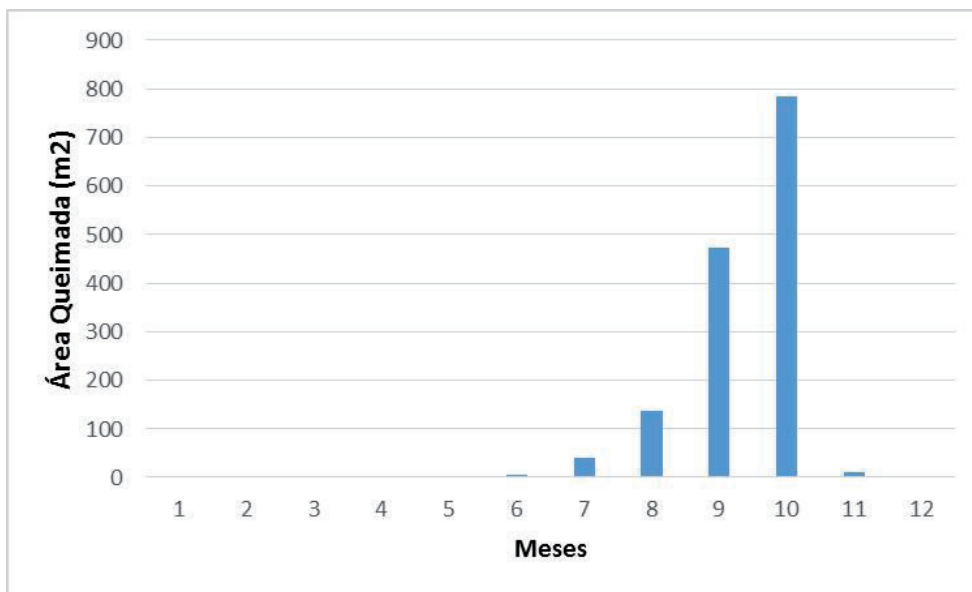


Figure 6 | Burned area by months

Source: Authors.

From the land use and land cover mapping data made available by MapBiomas (2017), it was possible to make an analysis of the types of land cover most affected by fire. The data was cross-checked with the burned areas data from MODIS (figure 7), and the most affected areas for the years of study were: 33% of burned areas in Forest Formation areas, 26% in pasture areas and 12% in mosaic areas of agriculture and pasture.

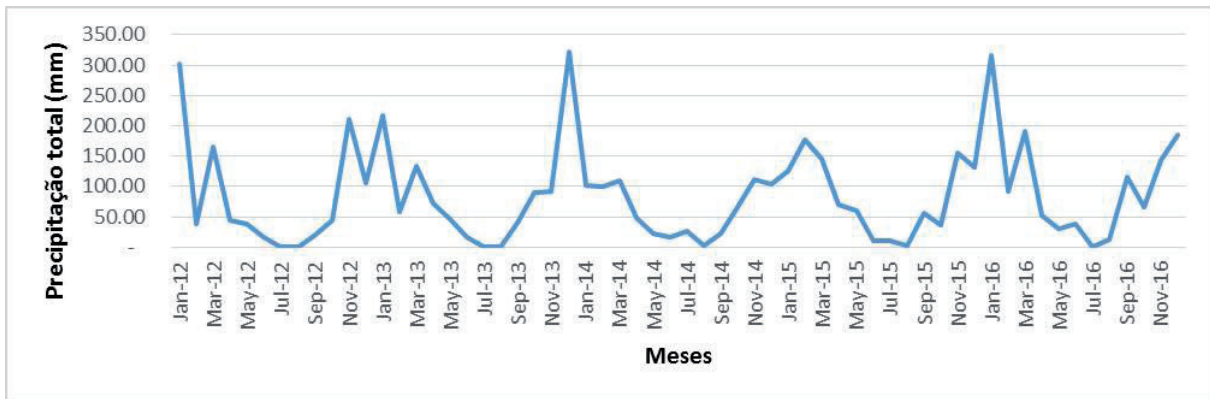


Figure 7 | Types of land cover where pixels from wildfires were detected during the years of study.

Source: Authors.

## 4 DISCUSSIONS

In figure 8, it is possible to better understand the results, since the variation in total precipitation during the studied years is presented. It is possible to understand the relationship between precipitation and burned areas, in the year 2014 a large decrease in precipitation was identified, since most months had a total precipitation of less than 50 mm. The year 2015 was the second year with the highest rate of wildfires, which may still be due to the low precipitation the state was suffering then. In 2016, coincidentally, there was the increase in the precipitation and decrease in the burned area.

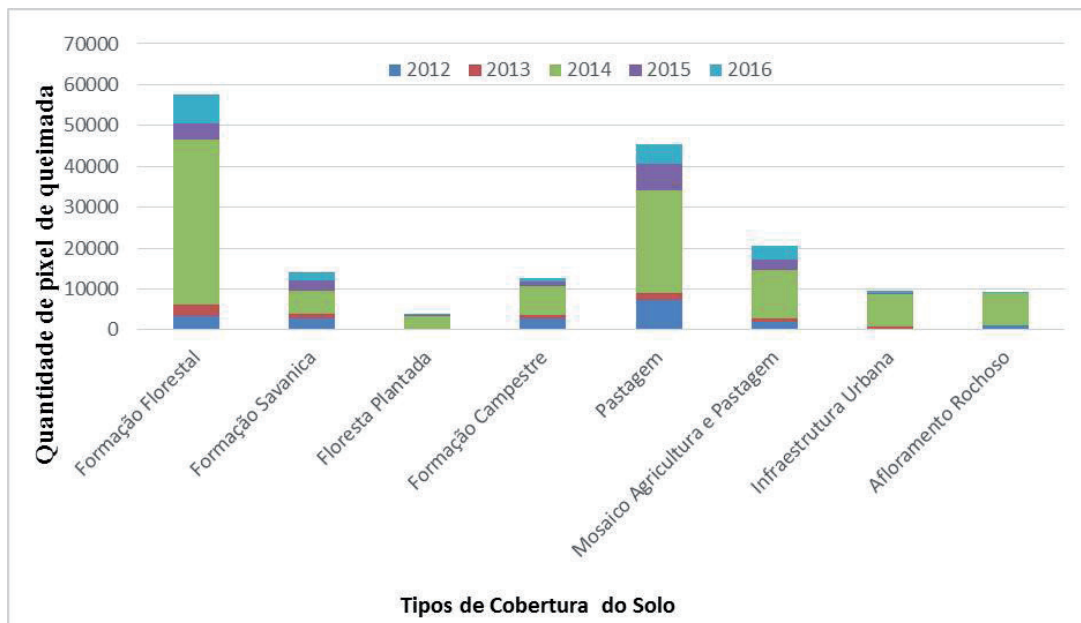


Figure 8 | RMBH accumulated precipitation.

Source: (ANA, 2018).

It is possible to observe the coherence of the data in figure 4, since the seasons with lower rainfall values are during winter and spring, which are also the seasons with the highest rate of wildfires. It can be observed that the highest occurrence was registered in spring. This fact can be attributed to the combination of low precipitation together with higher temperatures.

The above cited study of Fornazari (2015) also shows a considerable increase in the wildfire incidence in the region in June, September and October. This is in line with what was detected in this study, remembering that part of *Serra do Cipó* lies in the RMBH.



The most affected areas by wildfires are forest areas, which mostly comprise areas of Atlantic Forest, showing the importance of verifying the occurrence of wildfires in the region. This is because it is a very rich region in biodiversity, which ends up being a loss with the occurrence of forest fires.

Other highly affected areas are areas used for agriculture and pasture. This can be related to burning for cleaning areas, which can also be associated with the occurrence of fire outbreaks in other regions.

Since fire needs an ignition to start and it is often associated with human causes. The fact that it has a higher incidence in drier season does not mean that the climate is the only “culprit”. What happens is that with the decrease in precipitation and the consequent drop in air humidity, there is a drop in the humidity of the combustible material (wood), which makes it more prone to ignition. Plus, the drop in soil humidity, which is more prone to spread fire, burning larger areas, which are easier to identify by satellites. This highlights the importance of greater surveillance in these regions, especially in times of lower precipitation.

As for the way of satellite detection of wildfire, it was found that using MODIS sensor data instead of LANDSAT-8/OLI data to detect the sites with burnt area, does not affect the result, as the polygons have overlapped.

The use of LANDSAT images, on the other hand, due to its better spatial resolution, allows to better identify the dimension and delimitation of burnt areas. It should be noted, however, that only the most reliable pixels of the MODIS sensor were used (value 1 of ba\_qa index). If other arrangements were used, considering lower reliability indexes, it would be possible to achieve a better matching of the areas.

The handling of LANDSAT-8/OLI data requires more time and processing and depends on the user for the identification of the areas as presented in “figure 2c” and the selection of the seed pixel for area growth. Whereas, the MODIS sensor data was practically ready for direct use.

Another advantage of the MODIS sensor in relation to LANDSAT-8/OLI is its temporal resolution, the former having a resolution of 1 and 2 days, while the latter has a frequency of 16 days and still has the aggravating factor of having many images with the presence of clouds, which makes detection difficult, as evidenced in Rodrigues et al (2018).

## 5 CONCLUSIONS AND FUTURE PROSPECTS

The availability of detailed and up-to-date information on the spatial (location and extent) and temporal distributions of burned areas is currently crucial, not only for the better management of natural resources, but also for atmospheric chemistry and climate change studies.

The large occurrence of fires associated with both meteorological and anthropic factors is a growing concern, since it causes impacts on the society and the environment. Therefore, it is very important to develop research and scientific studies that cooperate with the monitoring of fire outbreaks and risks. It was observed that the greatest amount of fires occurred mainly in the months of September and October, where larger quantities of burned areas were found. At that time of the year the humidity of the air becomes low, while the temperature gets higher, which decreases the humidity in the fuel material and in the soil, which cooperates with the spread of fires. It was noted that the burned areas are strongly linked to the occurrence of precipitation, and in the times of occurrence of less precipitation the largest amounts of burned areas were found.

Remote sensing techniques are important in the burn detection process, as remote monitoring is possible, having a lot of quality data available. The option of using LANDSAT system data or MODIS sensor data for wildfire studies depends on the purpose of the application.

With the use of the first sensor it is possible to delimit the size of the burned area more precisely, but the use of this method requires more processing work, in addition to external references, as it depends on radiometric transformations, vegetation index calculations and visual interpretation of image data. In addition, the difficulty of finding images with no clouds, depending on the time of interest was encountered. On the other hand, the product resulting from MODIS does not delimit the outline of the burnt area with the same accuracy, but it detects the places where the wildfire occurred, being of direct application, high availability and easy to use. This fact greatly favors public management, where often there may not be such a skilled technical staff, either due to lack of resources or due to unawareness of the managers themselves.

Therefore, the MCD45A product of the MODIS sensor is a readily available resource, which adds speed and simplicity to wildfire studies, particularly in the verification of higher risk areas and their regular monitoring, presenting additional advantages over other existing methods. However, it should be noted that the present study does not exhaust the subject matter, which is indeed very broad and deserves further investigation.

Another possibility is the use of the Normalized Burn Ratio (NBR) instead of the NDVI in other studies. It is suggested in other studies to divide the study into two periods of the year: early (from October 16 to August 15) and late (from August 16 to October 15). It should be emphasized that these periods are those adopted by the management bodies in decision making regarding the management of fire occurrences applied to protected areas. Other possibilities would also include carrying out other analyses in order to prevent and fight wildfires in the study area, such as: maximum and average extension of wildfires (affected area) each year; frequency of wildfires (number of times each pixel burned in the analysis period), seeking to identify the critical areas and highest risk for protected areas correlating with the type of soil, for example; differences in fire occurrences inside and outside the protection areas; identification of the protected areas most vulnerable to fire outbreaks (quantified by the frequency of wildfires and higher extension).

Additionally, it is important to validate these with field data to verify that the pixels actually correspond to burned areas. The availability of wildfire data is a difficulty, these were requested from the Fire Department and could not be made available for safety reasons. An attempt was made to request these data from the agency responsible for forests protection in *Minas Gerais*, *Instituto Estadual de Florestas de Minas Gerais (IEF)*, which also did not have this type of data observed and computed. It is therefore important to verify ways of monitoring and recording these fires in order to improve detection techniques.

The results obtained in this work can effectively contribute to the prevention of socio-environmental impacts in the study region and can serve as a model for application in other metropolitan regions aiming at sustainability.

## REFERENCES

AGÊNCIA NACIONAL DE ÁGUAS. **Séries Históricas de Estações**. Disponível em: <[http://www.snirh.gov.br/hidroweb/publico/medicoes\\_historicas\\_abas.jsf](http://www.snirh.gov.br/hidroweb/publico/medicoes_historicas_abas.jsf)>. Acesso em: 1 jun. 2018.

AGÊNCIA RMBH. **RMBH e Colar Metropolitano**, 2016. Disponível em: <<http://www.agenciarmbh.mg.gov.br/rmbh-e-colar-metropolitano/>>. Acesso em: 20 out. 2016.

ALVES, L. E. R. et al. Balanço de radiação através do satélite Landsat-8 na Bacia do Rio Pajeú. **Geography Department University of São Paulo**, v. 33, p. 117, 2017.

ANDRADE, F. M.; LOURENÇO, R. W. Uso do Solo e Cobertura Vegetal na Bacia Hidrográfica do Rio Una – Ibiúna/SP. **Geography Department University of São Paulo**, v. 32, n. 0, p. 48, 2016.

BARBALHO, M. G. DA S. et al. Permanent preservation, coverage area and use of the land in the hydrographic basin of the Almas River, microregion of Ceres, Goiás, Brazil. **Sustentabilidade em Debate**, v. 10, n. 3, p. 147-178. 2019. Disponível em: <<https://doi.org/10.18472/SustDeb.v10n3.2019.24751>>. Acesso em: 04 jun. 2020.

BATISTA, A. C. Detecção de Incêndios Florestais por Satélites. **Journal of Chemical Information and Modeling**, v. 53, n. 9, p. 1689–1699, 2013.

BITTENCOURT, D. Z.; GUASSELLI, L. A. Dinâmica de Inundação do Banhado a partir do índice NDPI, Reserva Biológica de São Donato – RS. **Geography Department University of São Paulo**, v. 33, p. 85, 2017.

CASTRO, F. R. DE et al. Impactos das Queimadas sobre a Saúde da População Humana na Amazônia Maranhense. **Revista de Pesquisa em Saúde**, v. 7, n. 3, p. 141–146, 2016.

FERNANDES, A. C. G. et al. Utilização de intervalos de índices de vegetação e temperatura da superfície para detecção de queimadas. **Caderno de Ciências Agrárias**, v. 8, n. 2, p. 30–40, 2016.

FERNANDES, L. C. **Modelagem de risco de incêndios florestais utilizando redes neurais artificiais aplicada às regiões metropolitanas**. Dissertação (Mestrado) – Universidade Federal de Minas Gerais, Belo Horizonte, 2019, 146p.

FERNANDES, L. C. et al. **Fire Risk Modeling Using Artificial Neural Networks**. EngOpt 2018. Proceedings of the 6th International Conference on Engineering Optimization. Springer International Publishing, 2019, p. 938-948.

FERNANDES, L. C. et al. Modelagem de Risco de Incêndios Florestais: uma visão geral. **Sodebrás**, v. 13, p. 79-84, 2018a.

FERNANDES, L. C. et al. **Modelagem de risco de incêndio utilizando Redes Neurais Artificiais**. In: XXVI JORNADAS DE JÓVENES INVESTIGADORES DE LA AUGM, 2018b, Mendoza-Argentina. XXVI JORNADAS DE JÓVENES INVESTIGADORES DE LA AUGM. Mendoza-Argentina: AUGM, 2018.

FRANÇA, D. DE A.; FERREIRA, N. J. Considerações sobre o uso de satélites na detecção e avaliação de queimadas. In: XII SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO. **Anais...** Goiânia, GO: Inpe, 2005.

FUNDAÇÃO ESTADUAL DO MEIO AMBIENTE. Dados conseguidos junto ao órgão responsável, 2017.

GIUSTINA, C. C. DELLA; SILVA, S. D. E.; MARTINS, E. D. S. Geographic reconstruction of a Central-West Brazilian landscape devastated during the first half of the 20th century: Mato Grosso de Goiás. **Sustentabilidade em Debate**, v. 9, n. 3, p. 44–63, 2018.

GUIMARÃES, P. P. et al. Análise dos impactos ambientais de um incêndio florestal. **Agrarian Academy**, v. 1, n. 1, p. 38, 2014.

ICHOKU, C.; KAUFMAN, Y. J. A method to derive smoke emission rates from Modis fire radiative energy measurements. **IEEE Transactions on Geoscience and Remote Sensing**, v. 43, n. 11, p. 2636–2649, nov. 2005.

JESUS, S. C.; SETZER, A. W.; MORELLI, F. Validação de focos de queimadas no Cerrado em imagens TM/Landsat-5. In: XV SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO – SBSR. **Anais...** Curitiba, PR: Inpe, 2011

JUVANHOL, R. S. **Modelagem da vulnerabilidade à ocorrência e propagação de incêndios florestais**. [s.l.] Universidade Federal do Espírito Santo, 2014.

LIMA, V. DA S., NASUTI, S. Universo Quebradeiras. **Sustentabilidade em Debate**, v. 8, n. 2, p. 147-169. 2017. Disponível em: <<https://doi.org/10.18472/SustDeb.v8n2.2017.26924>>. Acesso em: 04 jun. 2020.

MAPBIOMAS. **Projeto MapBiomas – Coleção [3] da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil**. Disponível em: <<http://mapbiomas.org>>. Acesso em: 1 jun. 2018.

MARKHAM, B. L.; BARKER, J. L. Thematic Mapper bandpass solar exoatmospheric irradiances. In: **International Journal of Remote Sensing**. [s.l.: s.n.]. v. 8, p. 517–523.

MARQUES, C. B. et al. **Análise de correspondência entre mapas de vegetação florestal do bioma Cerrado**. XVIII SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO – SBSR. **Anais...** 2017. Disponível em: <<http://urlib.net/8JMKD3MGP6W34M/3PSM4HJ>>. Acesso em: 1 jun. 2018.

MATOS, N. M. DE; LEAL, F. A. Mapeamento temporal e validação de áreas queimadas por meio do produto Modis MCD45A1 para o bioma Pantanal. 5o SIMPÓSIO DE GEOTECNOLOGIAS NO PANTANAL. **Anais...** Campo Grande – MS, 2014.

MELO, E. T.; SALES, M. C. L.; OLIVEIRA, J. G. B. DE. Aplicação do índice de vegetação por diferença normalizada (NDVI) para análise da degradação ambiental da microbacia hidrográfica do Riacho dos Cavalos, Crateús-CE. **Raega – O Espaço Geográfico em Análise**, v. 23, n. 23, p. 520–533, 2011.

MYERS, N. et al. Biodiversity hotspots for conservation priorities. **Nature**, v. 403, p. 853, 2000.

NASA. **Dados Modis**. Disponível em: <<https://ladsweb.modaps.eosdis.nasa.gov/>>. Acesso em: 1 jun. 2018.

NIMER, E. **Climatologia do Brasil**. Rio de Janeiro, 1979.

OLIVEIRA, A. L. S. **Modelagem espacial de predição de riscos de incêndios com lógica fuzzy, comparação e validação**. Dissertação (Mestrado) – Universidade Federal de Pernambuco, Recife, 2013, 161p.

OLIVEIRA, A. L. S. et al. Comparação e validação da modelagem espacial de riscos de incêndios considerando diferentes métodos de predição. **Boletim de Ciências Geodésicas**, v. 23, p. 556-577, 2017.

OLIVEIRA, A. L. S.; NERO, M. A. Application of Fuzzy Logic in Prediction of Fire in João Pessoa City – Brazil. **Communications in Computer and Information Science** (Print), v. 399, p. 323-334, 2013.

\_\_\_\_\_. Mapa de análise de risco de incêndios florestais: estudo de caso no município de João Pessoa – Paraíba, Brasil. In: 9º SINAGEO – SIMPÓSIO NACIONAL DE GEOMORFOLOGIA, 2012, Rio de Janeiro – RJ. **Anais...** Rio de Janeiro – RJ, 2012.

OLIVEIRA FILHO, A. T. DE. Definição e delimitação de domínios e subdomínios das paisagens naturais do estado de Minas Gerais. In: SCOLFORO, J. R.; CARVALHO, L. M. T. DE (Ed.). **Mapeamento e inventário da flora nativa e dos reflorestamentos de Minas Gerais**. 2. ed. Lavras: UFLA, 2006. p. 21–35.

PAULA, M. R. DE; BENEDETTI, A. C. P.; PEREIRA FILHO, W. Influência do Uso e Cobertura da Terra aliada à Precipitação Pluviométrica na Qualidade da Água da Bacia Hidrográfica do Rio Ingaí – RS/Brasil. **Geography Department University of São Paulo**, v. 32, p. 143, 2016.

PEREIRA FILHO, W. Cartografia e sensoriamento remoto na avaliação de dados com abordagem espaço e tempo. **Geography Department University of São Paulo**, v. Especial C, n. spe, p. 426, 2014.

PINTO FILHO, J. L. DE O.; PETTA, R. A.; SOUZA, R. F. Caracterização Socioeconômica e Ambiental da População do Campo Petrolífero Canto do Amaro, RN, Brasil. **Sustentabilidade em Debate**, v. 7, n. 2, 2016. Disponível em: <<https://doi.org/10.18472/SustDeb.v7n2.2016.17489>>. Acesso em: 04 jun. 2020.

PIROMAL, R. A. S. et al. Utilização de dados Modis para a detecção de queimadas na Amazônia. **Acta Amazonica**, v. 38, n. 1, p. 77–84, 2008.

RESENDE, F. C.; CARDOZO, F. D. S.; PEREIRA, G. Análise Ambiental da Ocorrência das Queimadas na Porção Nordeste do Cerrado. **Geography Department University of São Paulo**, v. 34, p. 31, 2017.

ROSA, R. Geotecnologias na geografia aplicada. **Revista do Departamento de Geografia**, v. 16, p. 81–90, 2011.

ROY, D. P. et al. Prototyping a global algorithm for systematic fire-affected area mapping using Modis time series data. **Remote Sensing of Environment**, v. 97, n. 2, p. 137–162, 2005.

SANTOS, J. F.; SOARES, R. V.; BATISTA, A. C. Perfil dos incêndios florestais no Brasil em áreas protegidas no período de 1998 a 2002. **Floresta**, v. 36, n. 1, p. 93–100, 2006.

SILVA, D. L.; CARNEIRO, M. H. DA S. Biodiversidade, conservação e sustentabilidade no livro didático de Biologia no Brasil. **Sustentabilidade em Debate**, v. 5, n. 1, p. 98-116. 2014. Disponível em: <<https://doi.org/10.18472/SustDeb.v5n1.2014.9914>>. Acesso em: 04 jun. 2020.

SIMIONI, J. P. D. et al. Caracterização da precipitação pluviométrica na bacia hidrográfica do Rio Ibicuí, RS. **Geography Department University of São Paulo**, v. 28, n. 0, p. 112, 2015.

SOTILLE, M. E.; BREMER, U. F.; SIMÕES, J. C. Avanço e retração de área glacial no extremo norte da Península Trinity, Antártica, entre 1988 e 2015. **Geography Department University of São Paulo**, v. 31, p. 72, 2016.

TOMZHINSKI, G. W.; COURA, P. H. F.; FERNANDES, M. DO C. Avaliação da detecção de focos de calor por Sensoriamento Remoto para o Parque Nacional do Itatiaia. **Biodiversidade Brasileira**, v. 1, n. 2, p. 201–211, 2011.

UNITED STATES GEOLOGICAL SURVEY. **Dados Landsat-8**, 2017. Disponível em: <<https://earthexplorer.usgs.gov/>> Acesso em: 1 jun. 2017.

# Uso de técnicas de sensoriamento remoto utilizando imagens Modis (MCD45A1) para identificação e avaliação de áreas queimadas na Região Metropolitana de Belo Horizonte - MG, Brasil

*The use of remote sensing techniques by Modis (MCD45A1) images using to identify and evaluate burned areas in the metropolitan region of Belo Horizonte – MG, Brazil*

Luiza Cintra Fernandes<sup>a</sup>

Marcelo Antonio Nero<sup>b</sup>

Plínio Temba<sup>c</sup>

Marcos Antônio Timbó Elmiro<sup>d</sup>

<sup>a</sup>Mestre em Análise e Modelagem de Sistemas Ambientais, Departamento de Cartografia do Instituto de Geociências da Universidade Federal de Minas Gerais. Belo Horizonte, MG, Brasil  
End. Eletrônico: luizacintraf@gmail.com

<sup>b</sup>Doutor em Engenharia de Transportes, professor no Departamento de Cartografia do Instituto de Geociências da Universidade Federal de Minas Gerais. Belo Horizonte, MG, Brasil  
End. Eletrônico: marcelo.nero@gmail.com

<sup>c</sup>Doutor em Engenharia Civil, professor no Departamento de Cartografia do Instituto de Geociências da Universidade Federal de Minas Gerais. Belo Horizonte, MG, Brasil  
End. Eletrônico: temba.mobile@gmail.com

<sup>d</sup>Doutor em Computação Aplicada, professor no Departamento de Cartografia do Instituto de Geociências da Universidade Federal de Minas Gerais. Belo Horizonte, MG, Brasil  
End. Eletrônico: timboelmiro@gmail.com

doi:10.18472/SustDeb.v11n2.2020.28145

Received: 07/11/2019  
Accepted: 16/06/2020

ARTICLE- DOSSIER

## RESUMO

Estudos sobre a ocorrência de queimadas são muito importantes, visto que eles corroboram medidas de controle, prevenção e monitoramento destas. Incêndios florestais causam vários impactos, entre eles perda da biodiversidade e prejuízo à saúde humana, sendo um problema tanto na esfera ambiental quanto social e política. Uma forma de monitoramento desses incêndios é a utilização de técnicas de sensoriamento remoto. Assim, a proposta do presente trabalho foi a utilização de imagens Modis (MCD45A1) para identificação e avaliação de áreas queimadas na região metropolitana de Belo Horizonte, entre os anos de 2012 e 2016, validando-o com dados do sensor Landsat-8/OLI. Com o emprego dos dados Landsat, é possível delimitar com melhor precisão a dimensão da área queimada,

mas exigindo-se conhecimento técnico operacional e corpo técnico especializado para tanto. Já o produto decorrente do Modis, é mais acessível e de fácil utilização, sendo de aplicação direta, pois já informa os focos de incêndio. Observou-se grande ocorrência de queimadas na região de estudo, principalmente na primavera e no inverno. Os resultados encontrados aqui poderão ser utilizados em estudos futuros para diminuir a incidência de queimadas na região e assim preservar a biodiversidade de biomas importantes nela presente.

**Palavras-chave:** Incêndios Florestais. Landsat/OLI. Modis MCD45A1. Preservação Ambiental.

## ABSTRACT

*The study of fire burned areas is very important, since they corroborate with control measures, prevention and monitoring of fires. Forest fires causes numerous impacts, among them, there is biodiversity lost and human health prejudice. So, it is a problem of environmental sphere as well as a social and political sphere. A way of monitoring this is using remote sensing techniques. So the propose of the present article is to use the Modis product (MCD45A1) to identify and evaluated the burned areas in metropolitan region of Belo Horizonte, among the years of 2012 to 2016, which is validated with Landsat-8/OLI sensor data. With the use of Landsat data it is possible to define the size of the burned area with greater precision, but requiring technical operational knowledge and specialized technical staff for both, on the other side, Modis is easier to operate, and have direct application and higher availability. It was observed that the study area has high burned area occurrences, mainly in spring and winter. The results found here could be used for future studies to decrease the forest fires incidence in the region and thus preserve the biodiversity of important biomes present in it.*

**Keywords:** Forest fires. Landsat. Modis MCD45A1. Environmental Preservation.

## 1 INTRODUÇÃO

As ocorrências de queimadas na vegetação representam sérias preocupações relacionadas ao meio ambiente, pois devastam grandes proporções de florestas, campos e regiões agrícolas, causando alterações no meio ambiente. Guimarães et al. (2014) verificaram como principais impactos dos incêndios: aquecimento do solo, erosão, redução de nutrientes do solo, redução do teor de matéria orgânica, acidez do solo, alteração do microclima local, redução da qualidade da água, mortandade de animais, enfraquecimento da madeira, limpeza do sub-bosque, impactos às culturas agrícolas, interferência na sucessão vegetal, redução da atividade de microrganismos e renovação da pastagem, transtornos à população do entorno, impactos paisagísticos e destruição de áreas de recreação.

Ichoku e Kaufman (2005) afirmam que as queimadas causam impactos no albedo, modificações do balanço radiativo da atmosfera, alterações nos ciclos biogeoquímicos e hidrológicos, além da liberação de gases de efeito estufa na atmosfera. Além disso, as ocorrências de queimadas estão amplamente associadas ao clima, às condições da vegetação e principalmente às atividades humanas (SANTOS; SOARES; BATISTA, 2006). Vale destacar também a abordagem do assunto em Lima e Nasuti (2017), Silva e Carneiro (2014), entre outros.

Quando um ambiente natural é destruído, se este não foi propriamente estudado, muitas espécies de plantas e animais são perdidas, o que é uma grande perda para a ciência e para a humanidade. Por isso, a importância da proteção e defesa da biodiversidade. Um exemplo a ser citado como perda de biodiversidade é o Cerrado brasileiro, onde aproximadamente 40% a 50% do solo foi transformado em agricultura nos últimos 50 anos. Esse bioma representa 23% da cobertura do Brasil e é um dos mais importantes *hotspots* de conservação da biodiversidade. Outro bioma muito afetado é a Mata Atlântica, a qual compreende 7% de matas remanescentes do original (GIUSTINA; SILVA; MARTINS, 2018).

O processo de queimadas no Brasil é crescente e se intensifica principalmente nos períodos mais secos do ano, podendo ser divididos entre focos naturais e antrópicos. O assunto é também tratado com

detalhe em Lima e Nasuti (2017) e Silva e Carneiro (2014). Quanto aos processos antrópicos, esses são geralmente ligados à limpeza de áreas para expansão agrícola e pecuária, além de ser uma forma de manejo em algumas culturas, como a cana-de-açúcar (FERNANDES et al., 2016).

Entre os grupos de causas de incêndios classificados pela Organização das Nações Unidas para a Alimentação e a Agricultura (FAO, sigla do inglês Food and Agriculture Organization), a maioria envolve fatores antrópicos, tais como: incêndios propositais, por motivos como retaliação, vingança, disputa pela posse de terras, urbanização e incapacidade mental, entre outros; queima para limpeza, para fins agrícolas; fumantes, devido à negligência de jogar pontas de cigarro ou fósforo acesos; operações florestais e recreação (JUVANHOL, 2014). Vale destacar que é possível desenvolver sistemas automatizados de monitoramento e prevenção de desastres, tal como é aplicado na área de deslizamento, por exemplo, como citado por Saito, Lima e Dias (2019). No entanto, vale ressaltar, também, pesquisas voltadas para a área de prevenção de incêndios, apresentadas em Fernandes (2019), Fernandes et al. (2018a, 2018b, 2019), Oliveira (2013), Oliveira e Nero (2012, 2013), Oliveira et al. (2017), Prudente (2010), Ribeiro (2009), Ribeiro et al. (2008) e Zhang et al. (2011).

Além dos impactos de perda de biodiversidade, as queimadas representam grande risco à saúde humana, pois emitem material particulado fino que prejudica o sistema respiratório. Essas partículas se depositam nos brônquios terminais e nos alvéolos, agravando problemas respiratórios. Assim, municípios situados nas imediações das áreas de queimadas têm problemas crescentes com saúde pública. Dessa maneira, estima-se que nos próximos 20 anos a poluição do ar será responsável por 156 mil mortes, 4 milhões de casos de asma e 300 mil atendimentos médicos em crianças (CASTRO et al., 2016).

Considerando-se tudo o que já foi exposto aqui, pode-se afirmar que a problemática das queimadas envolve tanto questões sociais e de saúde pública quanto questões ambientais, relacionadas às perdas de biodiversidade. Portanto, na tomada de medidas de prevenção e controle desse fenômeno, é necessário primeiro o estudo e entendimento deste. Dessa maneira, o conhecimento do local onde mais ocorrem as queimadas, frequência de acontecimentos, épocas do ano, entre outros, são de vital importância.

A partir desses dados, torna-se possível identificar as causas e estudar as melhores formas de controle e prevenção de incêndios. Assim, é importante dispor de uma forma rápida e eficiente de detecção de incêndios florestais para melhorar o controle das queimadas, monitorar as áreas afetadas, obter reduções dos custos nas operações de combate, permitir atenuação dos danos e estimar os impactos causados na região. As formas de detecção podem ser realizadas de diferentes maneiras, tais como por meio de: postos de vigilância, torres de observação, patrulhamento aéreo e monitoramento por imagens de satélite (BATISTA, 2013).

Técnicas de sensoriamento remoto se tornam uma boa solução quando o objetivo é mapear incêndios em áreas de acesso dificultado, como, por exemplo, unidades de conservação e áreas rurais, já que não existem monitoramentos nessas áreas e o registro é feito apenas por meio de denúncias.

O sensoriamento remoto consiste em obter informações de um objeto ou alvo, sem que haja contato físico com ele, sendo as informações obtidas utilizando-se radiação eletromagnética refletida e/ou emitida pelos alvos (ROSA, 2011). Além disso, o sensoriamento remoto permite a identificação de classes temáticas na superfície terrestre, assim como a área de ocorrência, explorando as classes de uso do solo. Adicionalmente, devido a seu domínio temporal, identifica também alterações em objetos da superfície, muito importante principalmente para o planejamento e ambiente.

Com a integração de suas características espectrais e espaciais, é possível extrair informações em relação ao produto de uma única data ou de poucas datas. Como exemplo, tem-se o Índice de Vegetação por Diferença Normalizada (do inglês Normalized Difference Vegetation Index – NDVI), onde, mediante a utilização da reflectância nas faixas do vermelho e infravermelho próximo, são fornecidas informações da quantidade da biomassa verde fotossinteticamente ativa da vegetação (PEREIRA FILHO, 2014). Assim,



técnicas de sensoriamento remoto podem ser utilizadas para conhecimento de ocorrências de queimadas, bem como a quantificação da área e da biomassa afetadas pelo fogo (FRANÇA; FERREIRA, 2005).

Em termos da temática de meio ambiente vale destacar diversos trabalhos que aplicam sensoriamento remoto, tais como: 1) o realizado por Barbalho et al. (2019) com o emprego de imagens Rapideye em conjunto com técnicas de geoprocessamento; 2) o emprego do ArcGIS (programa de processamento na área de Sistemas de Informação Geográfica, SIG) com a utilização de imagens Google Earth; 3) pesquisa com a aplicação de SIG e análise temporal de estudos de devastação ambiental, relatada em Guistina et al. (2018).

Para a detecção de queimadas por meio do sensoriamento remoto, são envolvidas três fontes de radiação: a emissão da queimada em si, como substâncias da combustão, a emissão e reflexão da área em que ocorre a queimada, e a reflexão de outras fontes, como solo exposto. A utilização de mudanças na superfície entre vegetação e solo exposto é uma das formas mais utilizadas para detecção de áreas queimadas, como exemplo tem-se o uso de imagens de satélites dos sistemas Landsat e Spot, que possuem grande potencial para tal fim, devido a sua fina resolução espacial em relação a outros sensores (FRANÇA; FERREIRA, 2005). Outra forma de detecção é a utilizada por Resende et al. (2017) o bioma Cerrado se tornou um dos ambientes mais favoráveis para a expansão da fronteira agrícola. Uma das consequências consiste no desmatamento e no aumento do número de queimadas, ocasionando a degradação e supressão de extensas áreas de ecossistemas naturais do bioma. Neste contexto, o presente trabalho teve como objetivo principal analisar a distribuição espacial das áreas queimadas na porção nordeste do bioma Cerrado. Desta forma, foi realizado o mapeamento das áreas queimadas em imagens do sensor Moderate Resolution Imaging Spectroradiometer (MODIS, que utilizaram o Modelo Linear de Mistura Espectral – MLNE (SMITH; SHIMABUKURO, 1991) a partir de imagens do sensor Modis (Moderate Resolution Imaging Spectroradiometer) para identificar a área queimada na porção nordeste do Cerrado nos anos de 2012 a 2015.

Outro estudo relacionado é o de Fornazari (2015) em que este utilizou-se de imagens do sensor Landsat 5 TM para mapear as cicatrizes de queimada no Parque Nacional da Serra do Cipó (MG). Em seu estudo foi concluído que o método demonstrou limitações diante da análise da permanência das cicatrizes associadas às variáveis “tamanho” e “precipitação”. A presença de nuvens promoveu o obscurecimento de diversas cenas adquiridas pelo sensor Landsat 5 TM devido à sua baixa resolução temporal, de modo que possíveis cicatrizes presentes na região não tenham sido mapeadas. Apesar da dificuldade do método, notou-se que há um aumento considerável de incidência de fogo na região, nos meses de junho, setembro e outubro.

Rodrigues (2014) utilizou uma estimativa automática da área queimada na Região Serrana do Rio de Janeiro em outubro de 2014, por meio de informações do sensor OLI a bordo do satélite Landsat-8. Devido à baixa frequência temporal das imagens Landsat-8 (16 dias) e à frequente presença de alta nebulosidade na região, somente foi possível mapear as áreas queimadas após dois meses do evento. Os resultados quantitativos indicam um total de aproximadamente 4000 ha de área queimada na Unidade de Conservação. Nota-se a importância de utilizar produtos com maior frequência temporal, já que nesse estudo foi possível detectar o fenômeno apenas dois meses após o ocorrido, podendo ter perda de informações.

O sensor Modis, a bordo das plataformas orbitais Terra e Aqua, é configurado para fornecer dados da dinâmica da biosfera terrestre, permitindo a geração de imagens com resolução espacial entre 250 e 1000 metros, além de apresentar frequência de revisita entre 1 e 2 dias no Equador (PIROMAL et al., 2008). O MCD45A1 é um produto obtido a partir de imagens de ambos os sensores Modis com frequência mensal e resolução espacial de 500 m, contendo queimadas identificadas por *pixel* e que apresenta informações de qualidade dos dados.

O algoritmo utilizado na geração desse produto se baseia nas mudanças de depósito de carvão e cinzas, remoção e alteração da estrutura da vegetação. Assim, detecta-se a data da queimada localizando-se

a ocorrência de mudanças rápidas nos dados da série temporal de reflectância da superfície diária, sendo realizada uma comparação entre os dados de reflectância dos dias anteriores, resultando em uma medida estatística para determinar se a diferença entre a reflectância prevista e observada é uma mudança significativa (ROY *et al.*, 2005).

A série de satélites Landsat, que apresenta resolução espacial entre 15 m e 30 m (dependendo da banda espectral), tem se consolidado como uma das principais ferramentas para análise e avaliação de impactos ambientais, uso e cobertura do solo, estimativa de parâmetros biofísicos, georreferenciamento e planejamento agrícola e ambiental (ALVES *et al.*, 2017).

Exemplos de trabalhos recentes estão em Andrade e Lourenço (2016), Bittencourt e Guasselli (2017) que são periodicamente inundadas por reflexo lateral de rios e de lagos, pela precipitação direta ou por água subterrânea. Para compreender a dinâmica desses ambientes – em especial o banhado da Reserva Biológica de São Donato - RS, a partir de processamento de imagens Landsat 5 e Landsat 8, foi utilizado o índice NDPI (Normalized Difference Pond Index ou Índice de Diferença Normalizada de Corpos de água, Paula *et al.* (2016), Prado *et al.* (2016) e Sotille *et al.* (2016). Por ter se destacado em suas aplicações, dados dos satélites Landsat são muito utilizados na validação de metodologias para detecção de queimadas, podendo citar os autores que aplicaram essa validação, como Jesus *et al.* (2011), Matos e Leal (2014), Piromal *et al.* (2008) e Tomzhinski *et al.* (2011). Araújo e Ferreira Júnior (2011) fizeram a validação do produto MCD45A1 com dados do Landsat 5, na região do Cerrado, sendo que 100% dos polígonos encontrados pelo Modis foram rotulados positivamente como queimadas, devido à boa precisão do algoritmo.

Já Cardozo *et al.* (2012) fizeram a mesma validação para uma região da Floresta Amazônica e obtiveram mais de 90% de omissão de áreas queimadas. As vantagens em se utilizar os dados Landsat estão relacionadas com sua melhor resolução espacial entre os dados de satélite que tem acesso gratuito.

Nesse contexto, o presente trabalho teve por objetivo avaliar a ocorrência de queimadas na região metropolitana de Belo Horizonte, nas épocas de seca, entre os anos de 2012 e 2016. Para tanto, foram utilizados os dados do produto MCD45A1 do sensor Modis. Além disso, foi realizada a comparação dos resultados obtidos em relação à área queimada estimada com os mesmos dados gerados a partir de imagens orbitais do sensor Landsat-8/OLI.

## 2 MATERIAIS E MÉTODOS

A investigação da ocorrência de queimadas consistiu em duas etapas principais. A primeira tratou da aquisição dos dados do produto MCD45A1 para os anos de 2012 a 2016, tratamento dos dados e a estimativa da extensão de área queimada. A segunda etapa foi a comparação dos resultados do MCD45A1 com imagens do sistema Landsat/OLI 8, já que este apresenta melhor resolução espacial e melhor resposta espectral para a ocorrência de incêndios e é amplamente utilizado em estudos para esse fim. A comparação foi feita apenas nos períodos de maior ocorrência de queimadas no presente estudo.

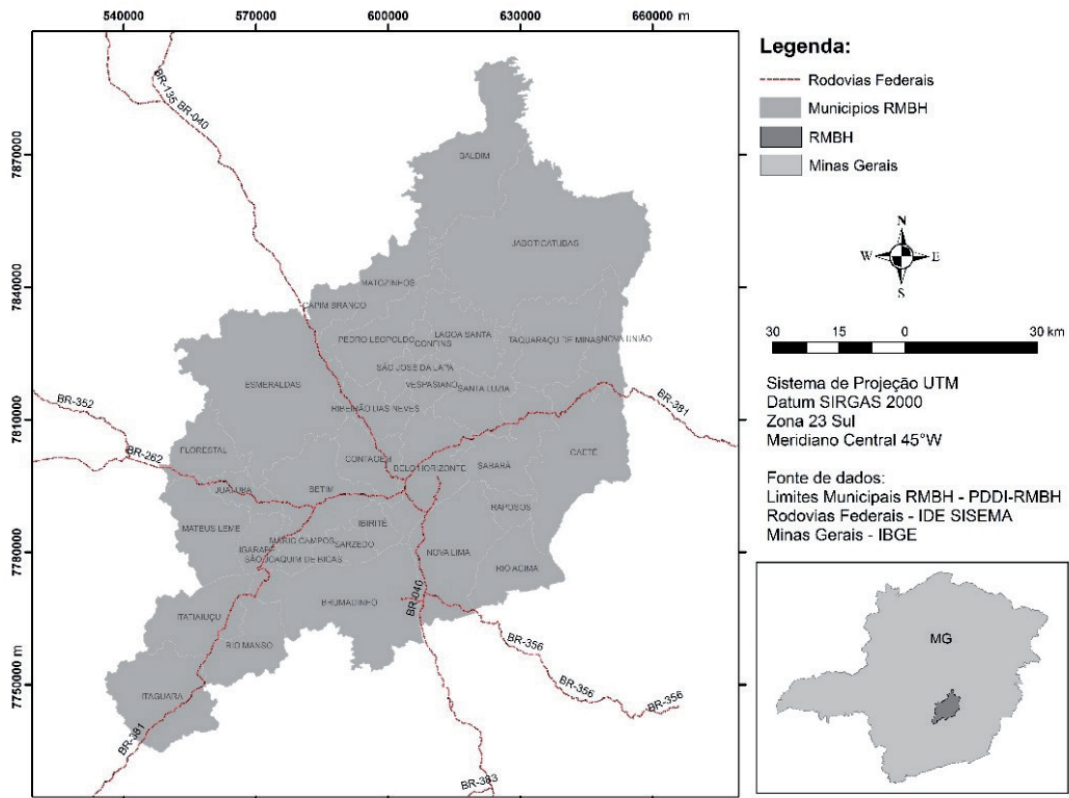
### 2.1 ÁREA DE ESTUDO

A Região Metropolitana de Belo Horizonte (RMBH) está inserida no estado de Minas Gerais e seus acessos principais são pelas rodovias BR-040, BR-381 (Rodovia Fernão Dias), BR-356 e BR-262, como mostrado na Figura 1. A região é composta por 34 municípios, com uma extensão territorial de 9.460 km<sup>2</sup>, sendo a 3ª maior Região Metropolitana do Brasil e a 7ª maior Região Metropolitana da América Latina. Possui uma população de aproximadamente 5 milhões de habitantes e um PIB de 56,8 milhões, correspondente a 40% do PIB estadual (AGÊNCIA RMBH, 2016). A região abrange três bacias hidrográficas: Bacia do Rio das Velhas, Bacia do Rio Paraopeba e Bacia do Rio Pará, todas sub-bacias do Rio São Francisco (AGÊNCIA RMBH, 2016).

A RMBH está presente entre dois biomas: Mata Atlântica e o Cerrado. O primeiro se caracteriza pela predominância de fisionomias florestais ombrófilas e estacionais (semidecíduais e decíduais), enquanto que o Cerrado é caracterizado pela predominância de fisionomias savânicas (OLIVEIRA FILHO, 2006), além de florestais e campestres. A Mata Atlântica representa a segunda maior floresta pluvial tropical do continente americano, sendo um dos 25 *hotspots* mundiais de biodiversidade. Embora tenha sido em grande parte destruída, ela ainda abriga mais de 8.000 espécies endêmicas de plantas vasculares, anfíbios, répteis, aves e mamíferos (MYERS et al., 2000). O Cerrado é uma das principais formações de savana nos trópicos, sendo o segundo maior bioma da América do Sul, ocupando 22% do território brasileiro, sendo o bioma que mais concentra a produção agropecuária do País (MARQUES et al., 2017).

A classificação climática da região abrange quatro zonas climáticas definidas por Nimer (1979). As zonas de maior expressão são: Tropical Brasil Central mesotérmico brando semiúmido e Tropical Brasil Central subquente semiúmido. O clima Tropical Brasil Central semiúmido se destaca por um regime anual de chuvas caracterizado por uma acentuada concentração de chuvas de instabilidades tropicais no verão, enquanto o inverno é fortemente marcado pela seca (entre 4 a 5 meses).

A baixa umidade faz com que a região esteja propícia a incêndios florestais. Segundo dados fornecidos pela Feam (2017), em unidades de conservação estaduais houve a queima de mais de 2.783 ha entre 2012 e 2016.



**Figura 1 |** Localização da área de estudo.

Fonte: Elaboração própria, baseada em bases PDDI (2014), ESRI (2015), IBGE (2017)

## 2.2 AVALIAÇÃO DE ÁREAS QUEIMADAS PELO SENSOR MODIS

A aquisição do produto MCD45A1 foi feita em Nasa (2017), a partir do site <https://landsweb.modaps.eosdis.nasa.gov>, onde foram adquiridas as imagens em formato *geotiff*. Nessa aquisição de imagens, foram considerados os limites geográficos da RMBH que estão inseridos nos tiles *H13V11*, *H13V10*, *H14V11* e recorte da área de interesse. As imagens obtidas consideraram a situação nos meses de janeiro a dezembro, dos anos de 2012 a 2016, totalizando 60 imagens.

O produto MCD45A1 fornece oito subprodutos, sendo que na presente análise foram utilizados apenas dois, o subproduto *ba\_qa* (índice de confiabilidade e do *pixel* rotulado como queimada) e o subproduto *burndate* (índice que indica se a área está queimada). Para a obtenção dos *pixels* com alto índice de confiabilidade, foi realizado o cruzamento das duas bandas. O valor dos *pixels* do subproduto *ba\_qa* varia de 0 a 5, sendo que foram selecionados apenas *pixels* com valor 1, que representam a mais alta confiabilidade. Os valores dos *pixels* do subproduto *burndate* representam o dia de ocorrência da queimada, no formato do calendário Juliano, o que possibilitou o conhecimento exato dos dias nos quais ocorreram mais queimadas.

A área queimada para cada ano foi calculada levando em consideração a resolução espacial do produto, que é de 500 m. Todos os dados foram tratados usando procedimentos desenvolvidos no *Interactive Data Language* (IDL), um ambiente computacional interativo de programação integrado ao *software* Envi (versão 5.2), uma plataforma voltada para tratamento de dados de sensoriamento remoto e processamento digital de imagens.

### 2.3 AVALIAÇÃO DE ÁREAS QUEIMADAS COM DADOS LANDSAT

Foram adquiridas imagens Landsat-8/OLI, no site do *Earth Explorer* (USGS, 2017), por meio do link <https://earthexplorer.usgs.gov>, referentes à órbita/ponto 218/74 que recobre parte da região do estudo. As imagens foram escolhidas considerando a menor cobertura de nuvens possível. Assim, foram adquiridas 4 imagens (setembro e novembro de 2014, agosto e setembro de 2016). Como não foi possível encontrar imagens com ausência total de nuvens, foram utilizados recortes que obedeciam a essa condição, além de dados com a qualidade do Landsat-8/OLI para verificar a presença de áreas queimadas.

Os valores digitais brutos das imagens foram convertidos em reflectância aparente para correção das imagens, por meio do método de correção radiométrica de imagens Landsat/OLI 8, disponibilizado pelo USGS (*United States Geological Survey* – Levantamento Geológico dos Estados Unidos da América), que é baseado nas relações propostas por Markham e Barker (1987).

Para reconhecimento das cicatrizes de queimado, são calculadas as imagens NDVI cujo cálculo (Equação 1) é feito mediante uma operação entre as bandas do infravermelho próximo (IR) e a do vermelho (R), partindo do princípio que quanto maior a quantidade de vegetação, maior a reflexão no infravermelho e menor no vermelho, aumentando o valor da razão e realçando a vegetação (MELO, SALES; OLIVEIRA, 2011).

$$\text{NDVI} = (\text{NIR} - \text{R}) / (\text{NIR} + \text{R}) \quad (1)$$

A partir de imagens NDVI, do período anterior à queimada (T1) e do período posterior (T2), são calculadas as diferenças dessas imagens (T1-T2) para ajudar na verificação das cicatrizes de queimada.

### 3. RESULTADOS

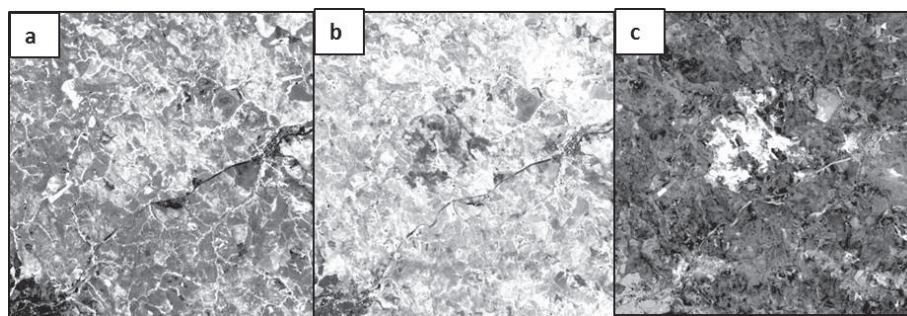
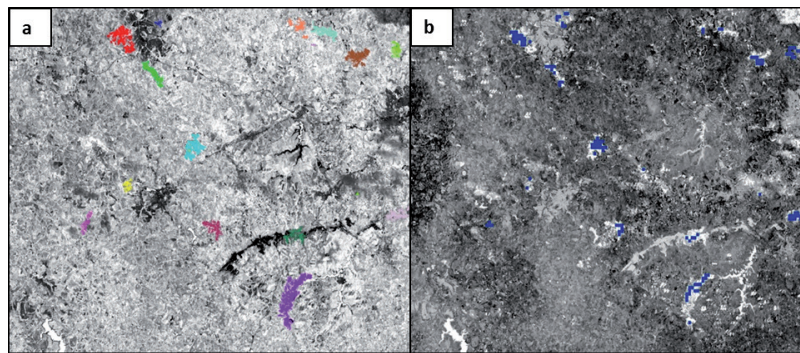


Figura 2 | Recorte NDVI T1 (agosto de 2014) (a), Recorte NDVI T2 (setembro de 2014) (b) e Recorte imagem diferença (T1-T2) (c)

Fonte: Elaboração própria, baseada em imagens Landsat/OLI 8

Conforme apresentado na Figura 2, a imagem diferença permite identificar os *pixels* onde não se registrou diferença com valores próximos de 0, locais com remoção de vegetação, valores próximos de 1 e de crescimento de vegetação, valores próximos de -1 (CARVALHO; SCOLFARO, 2008), sendo possível identificar e demarcar as cicatrizes de queimada por meio de regiões de interesse (ROI). Com uso da ferramenta ROI (*Region of Interest*), disponível no *software* Envi, é selecionada uma quantidade de *pixels* representativos (*pixel* semente), a partir de métodos de crescimento de regiões baseados na similaridade dos *pixels* semente com seus vizinhos, faz-se o delineamento da região de forma eficiente, produzindo um contorno otimizado e preciso da cicatriz.

Foram comparadas as quantidades de *pixels* de áreas queimadas pelo Landsat/OLI 8 e pelo Modis, e se as áreas eram correspondentes. Foi possível notar que todos os polígonos de queimadas encontrados com base nos dados do sensor Modis também foram identificados nas imagens Landsat/OLI 8, um exemplo é apresentado na Figura 3. Apesar disso, quando foi verificada a correspondência de *pixels*, observou-se que os dados Modis conseguiram verificar 72% dos *pixels* de incêndio em 2014 e 60% dos *pixels* para 2016.

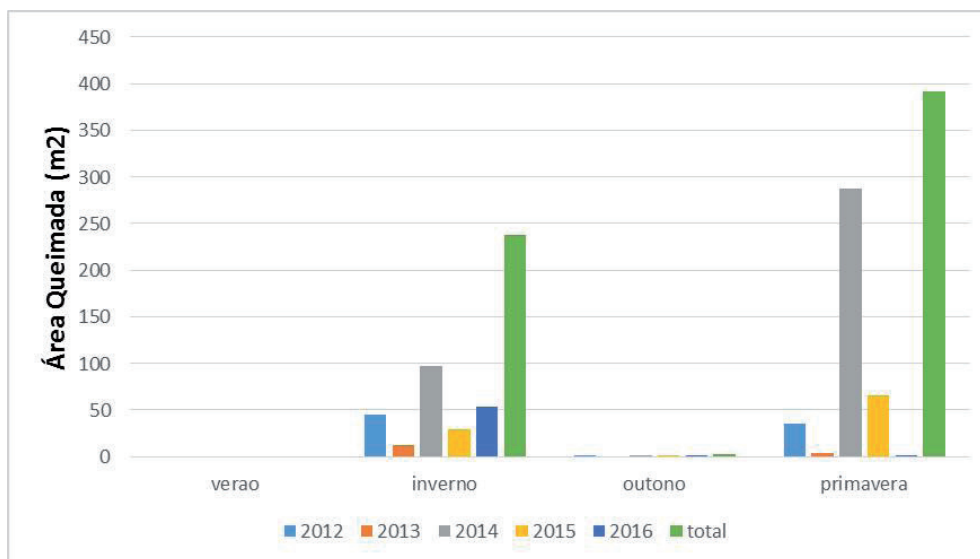


**Figura 3** | Comparação de polígonos de queimadas encontrados pelas imagens Landsat/OLI 8 (cores apenas para diferenciar cada cicatriz de queimada) (a) e pelo sensor Modis (b)

Fonte: Elaboração própria, baseada em imagens Landsat/OLI 8

### 3.1 ANÁLISE DA OCORRÊNCIA DE QUEIMADAS

Com os dados de áreas queimadas obtidos pelo produto MCD45A1, foram feitas algumas análises. Portanto, foi possível notar que as estações do ano em que ocorrem mais queimadas são o inverno e a primavera, sendo que no outono registraram-se poucos pontos de queimadas, e no verão não foi encontrado nenhum (Figura 4).



**Figura 4** | Área queimada por estações do ano

Fonte: Elaboração própria.

Comparando o total anual (Figura 5), nota-se que o ano de 2014 ganhou destaque como o de maior incidência de queimadas, com 350 km<sup>2</sup> de área atingida, seguido de 2015, com 81 km<sup>2</sup> de área atingida.

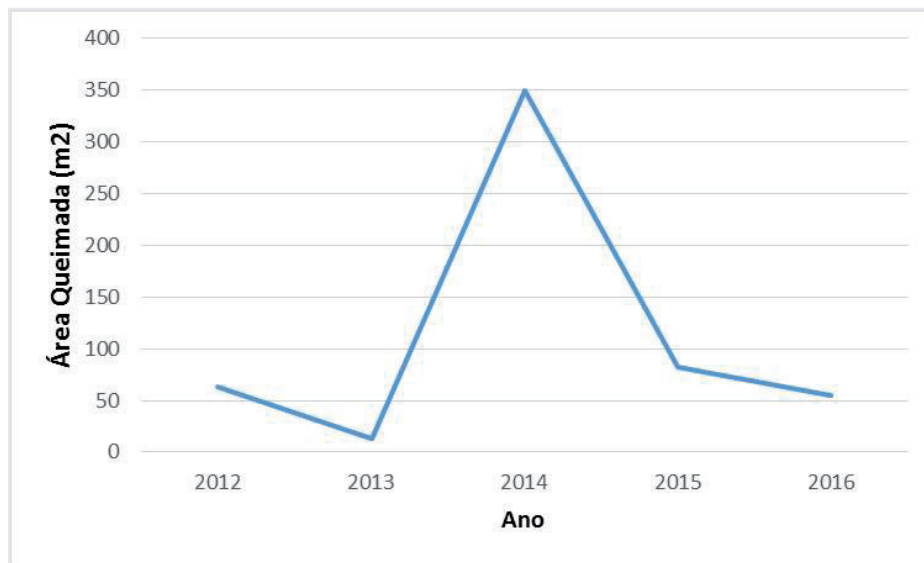


Figura 5 | Área queimada por ano  
Fonte: Elaboração própria

Entre os meses (Figura 6), os que têm uma maior concentração de queimadas são agosto, setembro e outubro. Deve-se destacar, ainda, que o mês de outubro apresentou valor expressivo devido ao ano de 2014, quando se registraram as ocorrências em quantidade considerável de queimadas e atingindo uma área de aproximadamente 183 km<sup>2</sup>, sendo o mês, de todos os anos estudados, o que apresentou o maior valor de área queimada.

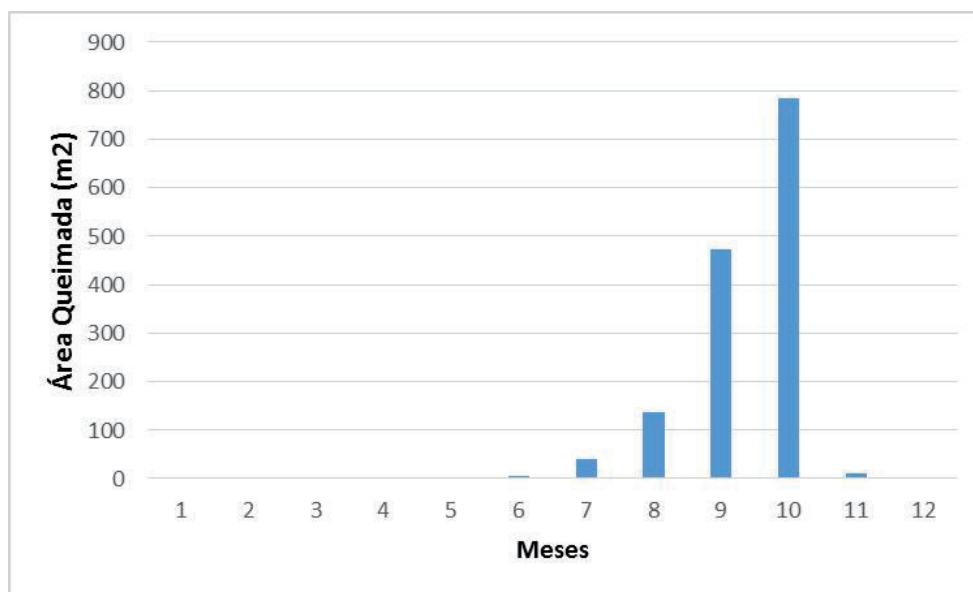


Figura 6 | Área queimada por meses  
Fonte: Elaboração própria

A partir dos dados do mapeamento do uso e cobertura do solo disponibilizados pelo MapBiomas (2017), foi possível fazer uma análise dos tipos de cobertura mais afetados pelo fogo. Os dados foram cruzados com os dados de áreas queimadas do Modis (Figura 7), sendo verificado que as áreas mais afetadas, para os anos de estudo, foram: 33% de queimadas em áreas de Formação Florestal, 26% em áreas de pastagem e 12% em áreas de mosaico de agricultura e pastagem.

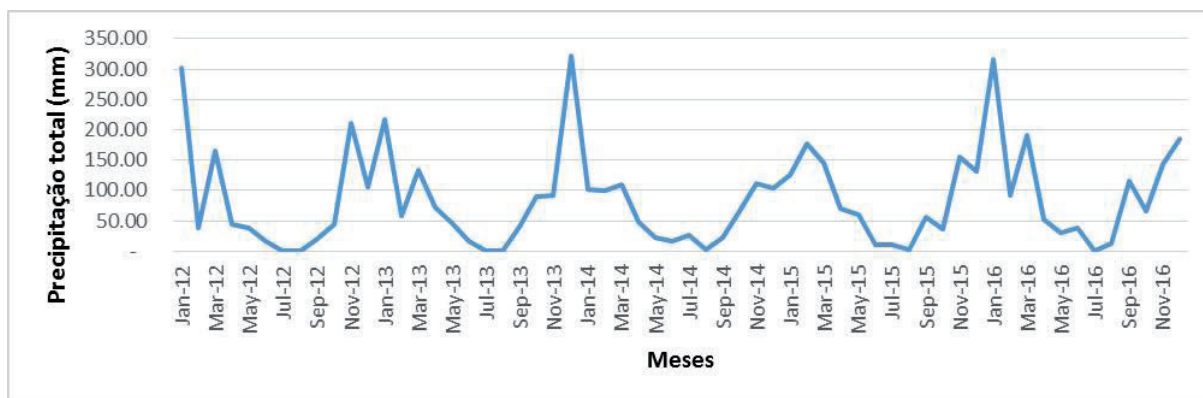


Figura 7 | Tipos de cobertura do solo onde foram identificados pixels de queimadas durante os anos de estudo

Fonte: Elaboração própria

## 4 DISCUSSÕES

Na Figura 8, é possível compreender melhor os resultados, já que é apresentada a variação da precipitação total durante os anos estudados. É possível perceber a relação entre a precipitação e as áreas queimadas. No ano de 2014 é identificada uma grande baixa da precipitação, já que a maior parte dos meses apresentou uma precipitação total menor que 50 mm. Já o ano de 2015 foi o segundo ano com maior índice de queimadas, o que pode ainda ser devido à baixa precipitação que o estado estava sofrendo. Em 2016 a quantidade de área queimada diminuiu e isso coincidiu com o aumento da precipitação no ano.

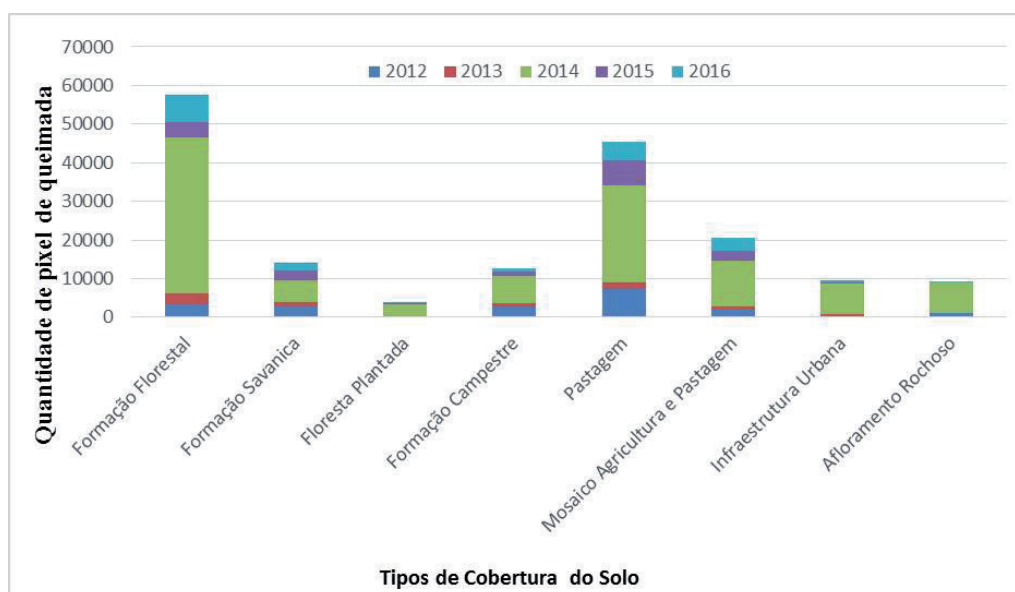


Figura 8 | Precipitação acumulada na RMBH.

Fonte: Elaboração própria, baseada em dados da ANA (2018).

É possível observar a coerência dos dados na Figura 4, já que as estações em que ocorrem menores valores de precipitação são durante o inverno e a primavera, que são também as estações com maior índice de queimadas. Nota-se que na primavera registrou-se a maior ocorrência. Esse fato pode ser explicado devido à combinação de baixa precipitação aliada às temperaturas mais altas.

No estudo de Fornazari (2015) citado acima, também é verificado um aumento considerável de incidência de fogo na região, nos meses de junho, setembro e outubro, o que vai ao encontro do observado neste estudo, lembrando que parte da Serra do Cipó está inserida na RMBH.

Quanto às áreas mais afetadas por incêndios, estão as áreas florestais, que em sua maioria compreendem áreas de Mata Atlântica, mostrando a importância em verificar a ocorrência de incêndios na região. Isso porque é uma região muito rica em biodiversidade, que acaba se perdendo com a ocorrência dos incêndios florestais.

Outras áreas muito afetadas são as utilizadas para agricultura e pastagem. Isso pode estar relacionado com as queimas para limpeza de áreas, o que pode também estar associado à<sup>1</sup> ocorrência de incêndios em outras regiões.

Já que o fogo precisa de uma ignição para iniciar e muitas vezes está associado a causas humanas, o fato de ter maior quantidade de incidência em épocas mais secas não significa que o clima seja o único “culpado”. O que ocorre é que, com a diminuição de precipitação e a consequente queda na umidade do ar, há uma queda na umidade do material combustível (madeira), o que o torna mais propenso à ignição. Além disso, há queda na umidade do solo, que fica mais propenso a propagar o fogo, queimando áreas maiores, que são mais fáceis de serem identificadas pelos satélites, ressaltando, assim, a importância de maior fiscalização nessas regiões, principalmente em épocas de menor precipitação.

Quanto à forma de detecção de queimadas por satélite, foi constatado que utilizar os dados do sensor Modis em vez de dados do Landsat/OLI 8 para detecção dos locais com área queimada não afeta o resultado, pois os polígonos se sobrepuseram.

Já a utilização de imagens Landsat, devido à sua melhor resolução espacial, consegue identificar melhor a dimensão e delimitação das áreas queimadas. Cabe destacar, entretanto, que foram utilizados somente os *pixels* de maior confiabilidade do sensor Modis (valor 1 do índice *ba\_qa*). Caso fossem utilizados outros arranjos, considerando índices de menor confiabilidade, seria possível atingir uma melhor correspondência das áreas.

A manipulação dos dados Landsat/OLI 8 exige mais tempo e processamento, além de depender do usuário para a identificação das áreas, como apresentado na “figura 2c”, e da seleção do *pixel* semente para crescimento da área, enquanto os dados do sensor Modis estão praticamente prontos para uso direto.

Outra vantagem do sensor Modis em relação ao Landsat/OLI 8 é a resolução temporal deste, sendo que o primeiro tem resolução de 1 e 2 dias, enquanto o segundo apresenta uma frequência de 16 dias e ainda tem o agravante de ter muitas imagens com presença de nuvens, o que dificulta a detecção, como ocorre em Rodrigues (2014).

## 5 CONCLUSÕES E PERSPECTIVAS FUTURAS

A disponibilidade de informações detalhadas e atualizadas sobre as distribuições espaciais (localização e extensão) e temporais das áreas queimadas é atualmente crucial, não só para a melhor gestão dos recursos naturais, mas também para estudos de química da atmosfera e de mudanças climáticas.

A grande ocorrência de queimadas associadas tanto a fatores meteorológicos quanto antrópicos é uma preocupação crescente, já que causa impactos na sociedade e no meio ambiente. Portanto, é muito importante que se desenvolvam trabalhos de pesquisa e estudos científicos que cooperem com o monitoramento dos focos e os riscos de incêndio. Observou-se que a maior quantidade de queimadas ocorreu principalmente nos meses de setembro e outubro, quando foram encontradas maiores quantidades de áreas queimadas. Nessa época do ano, a umidade do ar torna-se baixa e a temperatura fica mais elevada, o que diminui a umidade no material combustível e no solo, facilitando a propagação de incêndios. Notou-se que as queimadas estão muito ligadas à ocorrência de precipitação, sendo que nas épocas de menor ocorrência desta foram encontradas as maiores quantidades de áreas queimadas.



Técnicas de sensoriamento remoto são importantes no processo de detecção de queimadas, já que se faz possível o monitoramento de forma remota, tendo muitos dados de qualidade disponíveis. A opção de se utilizar dados do sistema Landsat ou dados do sensor Modis para estudos de queimadas depende do objetivo da aplicação. Com uso do primeiro sensor, consegue-se delimitar com melhor precisão a dimensão da área queimada, mas a utilização desse método exige mais trabalhos de processamento, além de referenciais externos, já que depende de transformações radiométricas, cálculos de índices de vegetação e interpretação visual de dados das imagens. Além disso, existe a dificuldade de encontrar imagens com ausência de nuvens, dependendo da época de interesse. Por outro lado, o produto decorrente do Modis não delimita com a mesma exatidão o contorno da área queimada, porém identifica bem os lugares onde os focos ocorreram, sendo de aplicação direta, de alta disponibilidade e de fácil utilização. Esse fato favorece amplamente uma gestão pública, que muitas vezes pode não dispor de corpo técnico tão capacitado, seja por ausência de recursos ou por desconhecimentos dos próprios gestores.

Portanto, o produto MCD45A do sensor Modis é um recurso prontamente disponível, que agrega rapidez e simplicidade aos estudos de queimadas, particularmente na verificação de áreas com maior risco e no seu monitoramento regular, apresentando vantagens adicionais sobre outros métodos existentes. Entretanto, ressalta-se que o presente estudo não esgota o assunto que é, de fato, muito amplo e merece mais aprofundamento.

Outra possibilidade é a utilização do Raio de Calor Normalizado (do inglês *Normalized Burn Ratio* – NBR) em vez do NDVI em outros estudos. Sugere-se, em outros trabalhos, dividir o estudo em dois períodos do ano, a saber: precoce (de 16 de outubro a 15 de agosto) e tardio (de 16 de agosto a 15 de outubro). Deve-se ressaltar que esses períodos utilizados são os adotados pelos órgãos gestores na tomada de decisão com respeito ao manejo de ocorrências de incêndios aplicadas às áreas protegidas. Novas possibilidades também incluiriam a realização de outras análises, de modo a prevenir e combater os incêndios na área de estudo, tais como: extensão máxima e média dos incêndios (área atingida) a cada ano; frequência de incêndios (número de vezes que cada *pixel* queimou no período de análise), buscando-se identificar as áreas críticas e de maior risco para as áreas protegidas correlacionando ao tipo de solo, por exemplo; diferenças de ocorrências de incêndio dentro e fora das áreas de proteção; e identificação das áreas protegidas mais vulneráveis aos incêndios (quantificados pela frequência dos incêndios e de maior extensão).

Além disso, é importante validar com dados de campo para verificar se os *pixels* realmente correspondem a áreas de incêndio. A disponibilidade de dados de incêndio é uma dificuldade, estes foram solicitados ao Corpo de Bombeiros e não puderam ser disponibilizados por questões de segurança. Foi feita uma tentativa de pedido desses dados ao órgão responsável pelas florestas em Minas Gerais, o Instituto Estadual de Florestas de Minas Gerais (IEF), e este também não possuía esse tipo de dados observados e computados. Assim, é importante verificar maneiras de monitoramento e registro desses incêndios para melhorar cada vez mais as técnicas de detecção destes.

Os resultados obtidos neste trabalho podem contribuir efetivamente para a prevenção de impactos socioambientais na região de estudo e servir de modelo para a aplicação em outras regiões metropolitanas visando à sustentabilidade.

## REFERÊNCIAS

AGÊNCIA NACIONAL DE ÁGUAS. **Séries Históricas de Estações**. Disponível em: <[http://www.snirh.gov.br/hidroweb/publico/medicoes\\_historicas\\_abas.jsf](http://www.snirh.gov.br/hidroweb/publico/medicoes_historicas_abas.jsf)>. Acesso em: 1 jun. 2018.

AGÊNCIA RMBH. **RMBH e Colar Metropolitano**, 2016. Disponível em: <<http://www.agenciarmbh.mg.gov.br/rmbh-e-colar-metropolitano/>>. Acesso em: 20 out. 2016.

ALVES, L. E. R. et al. Balanço de radiação através do satélite Landsat-8 na Bacia do Rio Pajeú. **Geography Department University of São Paulo**, v. 33, p. 117, 2017.

ANDRADE, F. M.; LOURENÇO, R. W. Uso do Solo e Cobertura Vegetal na Bacia Hidrográfica do Rio Una – Ibiúna/SP. **Geography Department University of São Paulo**, v. 32, n. 0, p. 48, 2016.

BARBALHO, M. G. DA S. et al. Permanent preservation, coverage area and use of the land in the hydrographic basin of the Almas River, microregion de Ceres, Goiás, Brazil. **Sustentabilidade em Debate**, v. 10, n. 3, p. 147-178. 2019. Disponível em: <<https://doi.org/10.18472/SustDeb.v10n3.2019.24751>>. Acesso em: 04 jun. 2020.

BATISTA, A. C. Detecção de Incêndios Florestais por Satélites. **Journal of Chemical Information and Modeling**, v. 53, n. 9, p. 1689–1699, 2013.

BITTENCOURT, D. Z.; GUASSELLI, L. A. Dinâmica de Inundação do Banhado a partir do índice NDPI, Reserva Biológica de São Donato – RS. **Geography Department University of São Paulo**, v. 33, p. 85, 2017.

CASTRO, F. R. DE et al. Impactos das Queimadas sobre a Saúde da População Humana na Amazônia Maranhense. **Revista de Pesquisa em Saúde**, v. 7, n. 3, p. 141–146, 2016.

FERNANDES, A. C. G. et al. Utilização de intervalos de índices de vegetação e temperatura da superfície para detecção de queimadas. **Caderno de Ciências Agrárias**, v. 8, n. 2, p. 30–40, 2016.

FERNANDES, L. C. **Modelagem de risco de incêndios florestais utilizando redes neurais artificiais aplicada às regiões metropolitanas**. Dissertação (Mestrado) – Universidade Federal de Minas Gerais, Belo Horizonte, 2019, 146p.

FERNANDES, L. C. et al. **Fire Risk Modeling Using Artificial Neural Networks**. EngOpt 2018. Proceedings of the 6th International Conference on Engineering Optimization. Springer International Publishing, 2019, p. 938-948.

FERNANDES, L. C. et al. Modelagem de Risco de Incêndios Florestais: uma visão geral. **Sodebrás**, v. 13, p. 79-84, 2018a.

FERNANDES, L. C. et al. **Modelagem de risco de incêndio utilizando Redes Neurais Artificiais**. In: XXVI JORNADAS DE JÓVENES INVESTIGADORES DE LA AUGM, 2018b, Mendoza-Argentina. XXVI JORNADAS DE JÓVENES INVESTIGADORES DE LA AUGM. Mendoza-Argentina: AUGM, 2018.

FRANÇA, D. DE A.; FERREIRA, N. J. Considerações sobre o uso de satélites na detecção e avaliação de queimadas. In: XII SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO. **Anais...** Goiânia, GO: Inpe, 2005.

FUNDAÇÃO ESTADUAL DO MEIO AMBIENTE. Dados conseguidos junto ao órgão responsável, 2017.

GIUSTINA, C. C. DELLA; SILVA, S. D. E.; MARTINS, E. D. S. Geographic reconstruction of a Central-West Brazilian landscape devastated during the first half of the 20th century: Mato Grosso de Goiás. **Sustentabilidade em Debate**, v. 9, n. 3, p. 44–63, 2018.

GUIMARÃES, P. P. et al. Análise dos impactos ambientais de um incêndio florestal. **Agrarian Academy**, v. 1, n. 1, p. 38, 2014.

ICHOKU, C.; KAUFMAN, Y. J. A method to derive smoke emission rates from Modis fire radiative energy measurements. **IEEE Transactions on Geoscience and Remote Sensing**, v. 43, n. 11, p. 2636–2649, nov. 2005.

JESUS, S. C.; SETZER, A. W.; MORELLI, F. Validação de focos de queimadas no Cerrado em imagens TM/Landsat-5. In: XV SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO – SBSR. **Anais...** Curitiba, PR: Inpe, 2011

JUVANHOL, R. S. **Modelagem da vulnerabilidade à ocorrência e propagação de incêndios florestais**. [s.l.] Universidade Federal do Espírito Santo, 2014.

LIMA, V. DA S., NASUTI, S. Universo Quebradeiras. **Sustentabilidade em Debate**, v. 8, n. 2, p. 147-169. 2017. Disponível em: <<https://doi.org/10.18472/SustDeb.v8n2.2017.26924>>. Acesso em: 04 jun. 2020.

MAPBIOMAS. **Projeto MapBiomás – Coleção [3] da Série Anual de Mapas de Cobertura e Uso de Solo do Brasil**. Disponível em: <<http://mapbiomas.org>>. Acesso em: 1 jun. 2018.

MARKHAM, B. L.; BARKER, J. L. Thematic Mapper bandpass solar exoatmospheric irradiances. In: **International Journal of Remote Sensing**. [s.l.: s.n.]. v. 8, p. 517–523.

MARQUES, C. B. et al. **Análise de correspondência entre mapas de vegetação florestal do bioma Cerrado.** XVIII SIMPÓSIO BRASILEIRO DE SENSORIAMENTO REMOTO – SBSR. **Anais...** 2017. Disponível em: <<http://urlib.net/8JMKD3MGP6W34M/3PSM4HJ>>. Acesso em: 1 jun. 2018.

MATOS, N. M. DE; LEAL, F. A. Mapeamento temporal e validação de áreas queimadas por meio do produto Modis MCD45A1 para o bioma Pantanal. 5o SIMPÓSIO DE GEOTECNOLOGIAS NO PANTANAL. **Anais...** Campo Grande – MS, 2014.

MELO, E. T.; SALES, M. C. L.; OLIVEIRA, J. G. B. DE. Aplicação do índice de vegetação por diferença normalizada (NDVI) para análise da degradação ambiental da microbacia hidrográfica do Riacho dos Cavalos, Crateús-CE. **Raega – O Espaço Geográfico em Análise**, v. 23, n. 23, p. 520–533, 2011.

MYERS, N. et al. Biodiversity hotspots for conservation priorities. **Nature**, v. 403, p. 853, 2000.

NASA. **Dados Modis.** Disponível em: <<https://ladsweb.modaps.eosdis.nasa.gov/>>. Acesso em: 1 jun. 2018.

NIMER, E. **Climatologia do Brasil.** Rio de Janeiro, 1979.

OLIVEIRA, A. L. S. **Modelagem espacial de predição de riscos de incêndios com lógica fuzzy, comparação e validação.** Dissertação (Mestrado) – Universidade Federal de Pernambuco, Recife, 2013, 161p.

OLIVEIRA, A. L. S. et al. Comparação e validação da modelagem espacial de riscos de incêndios considerando diferentes métodos de predição. **Boletim de Ciências Geodésicas**, v. 23, p. 556-577, 2017.

OLIVEIRA, A. L. S.; NERO, M. A. Application of Fuzzy Logic in Prediction of Fire in João Pessoa City – Brazil. **Communications in Computer and Information Science (Print)**, v. 399, p. 323-334, 2013.

\_\_\_\_\_. Mapa de análise de risco de incêndios florestais: estudo de caso no município de João Pessoa – Paraíba, Brasil. In: 9º SINAGEO – SIMPÓSIO NACIONAL DE GEOMORFOLOGIA, 2012, Rio de Janeiro – RJ. **Anais...** Rio de Janeiro – RJ, 2012.

OLIVEIRA FILHO, A. T. DE. Definição e delimitação de domínios e subdomínios das paisagens naturais do estado de Minas Gerais. In: SCOLFORO, J. R.; CARVALHO, L. M. T. DE (Ed.). **Mapeamento e inventário da flora nativa e dos reflorestamentos de Minas Gerais.** 2. ed. Lavras: UFLA, 2006. p. 21–35.

PAULA, M. R. DE; BENEDETTI, A. C. P.; PEREIRA FILHO, W. Influência do Uso e Cobertura da Terra aliada à Precipitação Pluviométrica na Qualidade da Água da Bacia Hidrográfica do Rio Ingaí – RS/Brasil. **Geography Department University of São Paulo**, v. 32, p. 143, 2016.

PEREIRA FILHO, W. Cartografia e sensoriamento remoto na avaliação de dados com abordagem espaço e tempo. **Geography Department University of São Paulo**, v. Especial C, n. spe, p. 426, 2014.

PINTO FILHO, J. L. DE O.; PETTA, R. A.; SOUZA, R. F. Caracterização Socioeconômica e Ambiental da População do Campo Petrolífero Canto do Amaro, RN, Brasil. **Sustentabilidade em Debate**, v. 7, n. 2, 2016. Disponível em: <<https://doi.org/10.18472/SustDeb.v7n2.2016.17489>>. Acesso em: 04 jun. 2020.

PIROMAL, R. A. S. et al. Utilização de dados Modis para a detecção de queimadas na Amazônia. **Acta Amazonica**, v. 38, n. 1, p. 77–84, 2008.

RESENDE, F. C.; CARDOZO, F. D. S.; PEREIRA, G. Análise Ambiental da Ocorrência das Queimadas na Porção Nordeste do Cerrado. **Geography Department University of São Paulo**, v. 34, p. 31, 2017.

ROSA, R. Geotecnologias na geografia aplicada. **Revista do Departamento de Geografia**, v. 16, p. 81–90, 2011.

ROY, D. P. et al. Prototyping a global algorithm for systematic fire-affected area mapping using Modis time series data. **Remote Sensing of Environment**, v. 97, n. 2, p. 137–162, 2005.

SANTOS, J. F.; SOARES, R. V.; BATISTA, A. C. Perfil dos incêndios florestais no Brasil em áreas protegidas no período de 1998 a 2002. **Floresta**, v. 36, n. 1, p. 93–100, 2006.

SILVA, D. L.; CARNEIRO, M. H. DA S. Biodiversidade, conservação e sustentabilidade no livro didático de Biologia no Brasil. **Sustentabilidade em Debate**, v. 5, n. 1, p. 98-116. 2014. Disponível em: <<https://doi.org/10.18472/SustDeb.v5n1.2014.9914>>. Acesso em: 04 jun. 2020.

SIMIONI, J. P. D. et al. Caracterização da precipitação pluviométrica na bacia hidrográfica do Rio Ibicuí, RS. **Geography Department University of São Paulo**, v. 28, n. 0, p. 112, 2015.

SOTILLE, M. E.; BREMER, U. F.; SIMÕES, J. C. Avanço e retração de área glacial no extremo norte da Península Trinity, Antártica, entre 1988 e 2015. **Geography Department University of São Paulo**, v. 31, p. 72, 2016.

TOMZHINSKI, G. W.; COURA, P. H. F.; FERNANDES, M. DO C. Avaliação da detecção de focos de calor por Sensoriamento Remoto para o Parque Nacional do Itatiaia. **Biodiversidade Brasileira**, v. 1, n. 2, p. 201–211, 2011.

UNITED STATES GEOLOGICAL SURVEY. **Dados Landsat-8**, 2017. Disponível em: <<https://earthexplorer.usgs.gov/>> Acesso em: 1 jun. 2017.

# Case study of a model of local solar radiation potential and discussion on the associated sustainable applications and potentials

*Construção de um modelo de potencial de radiação solar local e discussão das aplicações sustentáveis e potenciais associados*

Marcelo Antonio Nero<sup>a</sup>

Daniel Henrique Carneiro Salim<sup>b</sup>

Caio César de Sousa Mello<sup>c</sup>

Rafael Tarantino Amarante<sup>d</sup>

Bráulio Magalhães Fonseca<sup>e</sup>

Plínio da Costa Temba<sup>f</sup>

<sup>a</sup>Department of Cartography, Institute of Geosciences, Federal University of Minas Gerais. Belo Horizonte, MG, Brazil  
E-mail: marcelo.nero@gmail.com

<sup>b</sup>Department of Cartography, Institute of Geosciences, Federal University of Minas Gerais. Belo Horizonte, MG, Brazil  
E-mail: danielhcsalim@gmail.com

<sup>c</sup>Department of Environmental and Sanitary Engineering, Engineering School, Federal University of Minas Gerais. Belo Horizonte, MG, Brazil  
E-mail: caiocsmello@gmail.com

<sup>d</sup>Department of Cartography, Institute of Geosciences, Federal University of Minas Gerais. Belo Horizonte, MG, Brazil  
E-mail: rafaeltarantino@outlook.com

<sup>e</sup>Department of Cartography, Institute of Geosciences, Federal University of Minas Gerais. Belo Horizonte, MG, Brazil  
E-mail: brauliomagalhaes@ufmg.br

<sup>f</sup>Department of Cartography, Institute of Geosciences, Federal University of Minas Gerais. Belo Horizonte, MG, Brazil  
E-mail: temba.mobile@gmail.com

doi:10.18472/SustDeb.v11n2.2020.27773

Received: 22/10/2019  
Accepted: 02/04/2020

ARTICLE- DOSSIER

## ABSTRACT

The demand for a sustainable transition to energy matrices of lower environmental impact is global and current. In this sense, the modelling of solar radiation in high spatial resolution is used to assess the potential of photovoltaic generation on any type of surface and provide information for the planning and dimensioning of photovoltaic systems. From the technical potential of generation, it is possible to estimate the systems payback time and the avoided greenhouse gas emissions when adopting photovoltaic energy. In the quantitative context, the objective of this article was to briefly address the technical methodology and build a model of solar radiation of EE-IGC-UFMG buildings. In the context of sustainable applications of the tool, the objective was to address relevant topics, such as the construction of radiation models and the associated potentials, the application scales, and the difficulties and limitations of the modelling.

**Keywords:** GIS. Photovoltaic Energy. Model. Photogrammetry.

## RESUMO

*A transição sustentável para matrizes energéticas mais sustentáveis é uma demanda mundial e atual. Nesse sentido, a modelagem da radiação solar em alta resolução espacial é utilizada para avaliar o potencial de geração fotovoltaica em qualquer tipo de superfície e fornecer informações para planejamento e dimensionamento de sistemas fotovoltaicos. A partir do potencial técnico de geração, pode-se estimar o tempo de retorno do investimento do sistema fotovoltaico e a quantidade de gás carbono que deixou de ser emitido ao adotar a energia fotovoltaica. No contexto quantitativo, o objetivo deste artigo foi abordar brevemente a metodologia técnica e construir um modelo de radiação solar incidente em prédios da EE-IGC-UFMG. No contexto da discussão das aplicações sustentáveis da ferramenta, o objetivo foi tratar de temas relevantes, tais como a construção de modelos de radiação e os potenciais associados, as escalas de aplicação e dificuldades e limitações da modelagem.*

**Palavras-Chave:** SIG. Energia Fotovoltaica. Modelo. Fotogrametria.

## 1 INTRODUCTION

Transforming the global energy matrix, which is mainly characterized by the use of fossil fuels, into sustainable and renewable is one of the principal ways of meeting the targets stipulated in the Paris Agreement (UN, 2015; GIELEN et al., 2016; IEA, 2018; FALKNER, 2016; ENCYCLOPAEDIA BRITANNICA Inc., 2019; HOWARD et al., 2020; MULVANEY et al., 2020; NISBET et al., 2020; TOLLIVER et al., 2020; and ZHANG et al., 2020), which aims to maintain the increase in global temperatures below the limit of 2°C. Within this context, one of the main solutions for achieving targets in the reduction of greenhouse gas emissions is the distributed generation of photovoltaic electrical energy, given its capacity to supply electricity from a renewable source directly to users close to the capitation source in urban environments (FREITAS et al., 2015; ZINK et al., 2015; LEE, 2018; and BESSER et al., 2019).

Photovoltaic energy has a relevant influence on the changing of patterns of energy consumption and distribution in urban centers, bearing in mind that public policies for the reduction of greenhouse gases have promoted a drop in the cost of low carbon technologies.

Thus, photovoltaic energy generation systems have begun being of relevant cost-benefit, with drops in the price of modules on a scale of 10% per year being observed since 1980 (FALKNER, 2016 and FARMER and LAFOND, 2016). Moreover, in 2012, Brazil adopted Normative Resolution 482/2012 (ANEEL, 2012), regulating micro and mini-generation of electrical energy through photovoltaic generation, which, in terms of trends in Brazil, China, E.U.A and the World can be observed in BP (2019) and IEA (2019), for example.

Knowing an urban center's potential for solar electricity generation, its geospatial distribution, and the characteristics of the best sites for the deployment of photovoltaic systems could foster public policies for the development of intelligent, energy sustainable cities. As such, local governments are responsible for applying strategies that promote efficiency in solar energy production and distribution in their cities

(SANTOS et al., 2014). In order to facilitate decision-making, administrators should have detailed data on the urban infrastructure allied to geographic intelligence tools for the elaboration of models and future scenarios with robust quantitative analyses. Such decision-making should consider environmental and energy targets, besides directing public policies towards changes in legislation and investment incentives. The development of solar radiation models in a GIS environment would provide crucial information for the achievement of the aforementioned items, this being the purpose of this study.

The specific objectives of the present study are: (i) to apply a solar radiation model algorithm to the buildings of the Engineering School and the Institute of Geosciences of the Federal University of Minas Gerais (Escola de Engenharia e do Instituto de Geociências da Universidade Federal de Minas Gerais - EE-IGC-UFMG) due to the topographic differences and variability in standards and constructions of the buildings; and (ii) to discuss the following relevant aspects in regard to models of photovoltaic potential: distinct elevation models adopted as input data; the technical, economic, social, and environmental potential that the solar radiation model could explore; the practical applications for planning and decision-making; and the use of online tools and the associated difficulties.

The article is introduced by a brief summary of the theoretical basis, in which radiation models and types of DSM are discussed. Then, the methodology and results obtained in the construction of the solar radiation model for EE-IGC-UFMG are presented, whereby the greatest innovation is in the use of DRONE images. Subsequently, discussions related to the models are presented, addressing the applications and limitations of the technology.

## 2 MODELS AND ALGORITHMS OF INCIDENT SOLAR RADIATION

Modelling of incident solar radiation can be computed using: (i) geostatistical interpolation or extrapolation of weather station data (ASSOULINE et al., 2017; ESCOBAR et al., 2015 and Wan et al., 2015), accuracy being dependent on the density of stations – which is generally insufficient for the context of solar register; (ii) satellites coupled with thermal sensors (Melius et al., 2013), such as those of the SoDA, *European Solar Radiation Data*<sup>1</sup> project, and that provided by the NREL, *National Renewable Energy Laboratory*<sup>2</sup>, which manage to cover practically the entire planet (more than 95 %). However, these are limited to an insufficient spatial resolution (they do not reach centimeter precision) and low accuracy (presenting displacements and low levels of precision); or (iii) mathematical models associated with modelling on GIS, which is the context of the present study.

The solar models based on GIS can be applied on different scales, such as in various countries, like Australia (ROBERTS et al. 2018), Sweden (LINGFORS et al., 2017), and Saudi Arabia (ASIF, 2016), in the province of Salta, in Argentina (Sarmiento et al., 2019), in the city of Berlin (KRÜGER and KOLBE, 2012), and in villages (MAVROMATIDIS et al., 2015). More recently, as a result of advances in the sphere of machine learning and processing of satellite images, it is worth mentioning solar platforms that have great potential as they are online, free, and international: *Google Sunroof*<sup>3</sup>(recently used by MARTÍN-JIMENEZ et al, 2020) and *Mapdwell*<sup>4</sup> (MAPDWELL, 2018, FOX-PENNER, 2020, HEINRICH et al 2020, and LIAO, 2019).

Literature reviews approach the theme considering different application contexts, generation methods, and solar model calibration techniques. These can be consulted in greater detail in Freitas et al. (2015), Martín et al. (2015), Yang et al. (2018), Jakica (2018), and Choi et al. (2019).

The solar radiation model contemplates latitude, elevation, roof surface orientation, shade projected by the surrounding topography, seasonal variation of the trajectory of the sun, and atmospheric attenuations. Bearing in mind that not all urban infrastructure is suited to the installation of solar panel systems, due to the projection of shade from other constructions, as well as tree planting in the surrounding area (LEE, 2018), upon using DSM of the surroundings of an analyzed building it has to be possible to identify all the characteristics necessary for modelling incident solar radiation. It is also worth remembering that the more detail captured in the digital elevation model survey, the more

realistic the quantification of the influence of projected shade on the reduction of photovoltaic solar energy production potential. These observations will be considered later in the article.

The GIS tools most commonly used are Solar Analyst of ArcGis and r.sun from GRASS. Both use DSM - digital matrix files with pixels that possess altitude values - and are employed in the calculation of solar irradiance on a determined surface. DSMs can be generated through Light Detection and Ranging (LiDAR) sensors, aerial photogrammetry (including the use of VANTs), or satellite images. In general, DSMs are used to compute surface elevation, inclination, and orientation, as well as shade caused by buildings, trees, or physical structures capable of blocking solar rays. Furthermore, DSMs are used in the solving of solar distance and angle equations foreseen in the models.

### **3 DSM FOR RADIATION MODELS IN THE GIS ENVIRONMENT**

The DSMs used as input data in the solar models in GIS can be produced using remote sensing techniques with the employment of LiDAR sensors, photogrammetry, and satellite image processing. The use of satellite images to generate DSMs of sufficient resolution to be adopted in photovoltaic energy projects is recent and lacks studies, according to the knowledge of the authors of the present article. However, photogrammetry and LiDAR are consecrated technologies for the elaboration of DSMs of sufficient positional quality and sub-metric spatial resolution for the addressed context (LUDWIG and MCKINLEY, 2010; ZINK et al., 2015; and MOUDRÝ et al., 2019).

Currently, technology using LiDAR is the most adopted for urban surveys. This uses active sensors that capture the topographic surface with a much greater wealth of detail of real world elements (vegetation and construction elements, among others) through the emission of electromagnetic pulses with wavelengths between 10 and 250 nm (Lukac et al., 2016). The survey result consists of a point cloud, measured in points/m<sup>2</sup>, which requires post-processing and classification to separate buildings, roads, structures, and vegetation. This stage is generally carried out by the service provider, who should present the adopted methodology (LINGFORS et al., 2017).

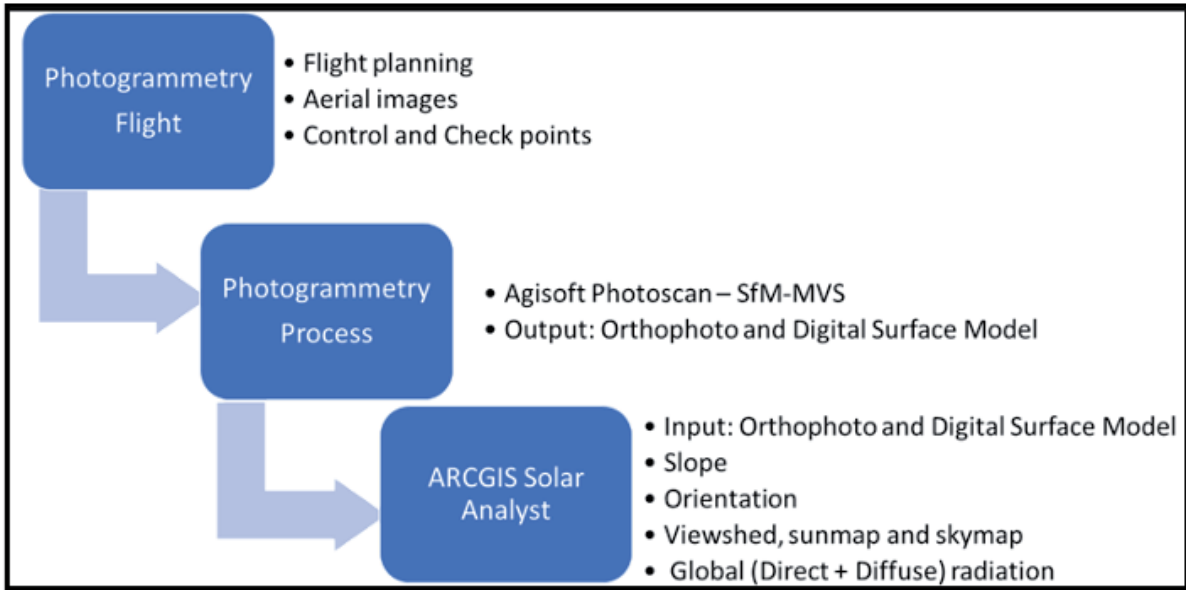
Photogrammetry is a science that has gained new dimensions with the technological popularization and advance of VANTs and computational vision algorithms, especially the Structure from Motion – MultiView Stereo (SfM-MVS) algorithm. In short, to generate DSMs and orthophotos via SfM-MVS, a photogrammetric flight should be carried out with photos sufficiently overlaid, both frontally and laterally, so that during computational processing it is possible to identify the common points in different photos. This enables three-dimensional model formation, whereby these points, containing three-dimensional information, are then used to compose a dense cloud, which is subsequently interpolated to generate the DSM and then the orthophoto (COLOMINA and MOLINA, 2014 and TONKIN and MIDGLEY, 2016). In comparison with the processing in traditional photogrammetry, the bundle adjustment stage is carried out using SfM-MVS, considering a block of images and not only one stereoscopic pair (ZINK et al., 2015).

## **4 CASE STUDY METHODOLOGY**

### **4.1 CONSTRUCTION OF THE LOCAL SOLAR MODEL**

The aerophotogrammetric survey was carried out at EE-IGC-UFMG, located in Belo Horizonte, MG. For an overall idea of the methodology used for construction of the solar model, Figure 1 presents a flowchart with details of each stage. The VANT used in the present study was a DJI Phantom 4 Professional (P4P).





**Figure 1 |** General scheme of the developed methodology.

Source: Authors.

## 4.2 PHOTOGRAMMETRY–FLIGHT PARAMETERS AND CONTROL POINTS

The program used to plan the photogrammetry flight was the DJI Ground Station Pro (commercial program), which was also applied in research by Remondino et al. (2012) and Jakica (2018). Flight parameters, such as altitude, lateral and frontal overlaps, and spatial resolution of the orthophoto and the DSM exported in .tif format are presented in Table 1.

**Table 1 |** Flight parameters.

| Description                          | Configuration |
|--------------------------------------|---------------|
| Fkight altitude (m)                  | 85            |
| Sidelap (%)                          | 75            |
| Overlap (%)                          | 80            |
| Orthophoto spatial res. (cm pixel-1) | 2.0           |
| DSM spatial res.(cm pixel-1)         | 50.0          |

Source: Authors.

A GNSS CHC X91+ geodesic receptor was used for acquisition of the field coordinates of the ground control points (GCP). The present study adopted the RTK via NTRIP (Networked Transport of RTCM via Internet Protocol) positioning method, which is described with more detail in Weber et al. (2005), Dammalage et al. (2006), and Cintra et al (2011), for example.

## 4.3 PHOTOGRAMMETRY APPLICATION VIA AGISOFTPHOTOSCAN

Photogrammetric processing of aerial images with the final objective of constructing an orthophoto and a DSM of the surveyed area was carried out using the AgisoftPhotoscan 1.4 program. This program uses the combination of SfM-MVS algorithms to generate the cloud of three-dimensional points. In general, photogrammetry programs are considered powerful tools that are efficient, innovative, and of great impact in the field of remote sensing. For more information on the functioning of the program, articles by Colomina and Molina (2014) and Remondino et al. (2012) are recommended.

Nine control points were used, which is enough in terms of mathematical redundancy for more accurate geo-referencing of a point cloud (Figure 2), and, consequently, of the digital files arising from the same, such as the DSM and the orthophoto. The points represent a virtual 3D scene, which is invariable in relation to the scale, direction, and position of the images. The DSM was exported in controlled resolution of 50 cm/pixel for subsequent computer processing. The DSM and the orthophoto were then manipulated in the following stages using the ARCGIS 10.4 program. Vectorization of the roofs was performed manually using the same program.

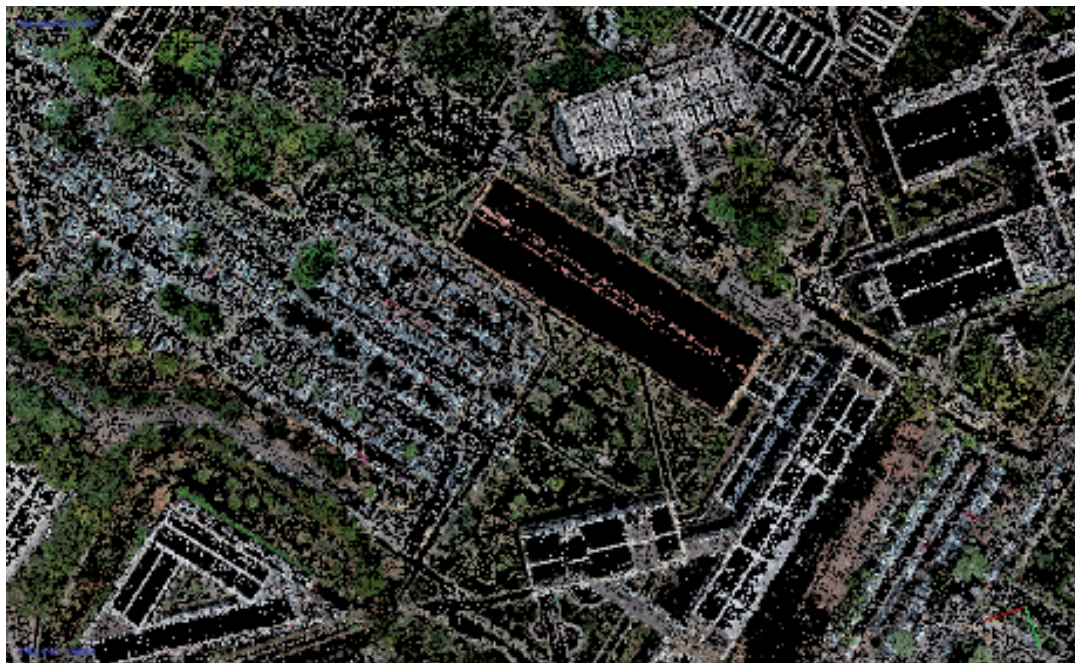


Figure 2 | Sparse point cloud.

Source: Authors.

#### 4.4 SOLAR RADIATION MODELLING TOOL – ARCGIS SOLAR ANALYST, AVAILABLE IN THE ARCGIS 10.2 PACKAGE, OR MORE RECENT

The tool adopted in this research was the ARCGIS Solar Analyst, which first creates a set of views to the sky through calculation of the maximum horizontal angles of obstruction – caused by the topography and nearby structures. The angles are then converted into a matrix file indicating the hemispherical vision for each cell of the DSM, called viewshed.

Then, overlaying with the sunmap, showing the position of the sun over time, and the skymap is carried out; both maps (sunmap and skymap) are available in the closed package of the ArcGIS application, containing the origin sites of the diffuse radiation. In this operation, the algorithm, available on ArcGIS Solar Analyst, computes the direct radiation considering whether the sun is visible at a specific time and place, and simultaneously, the origin of the diffuse radiation. Fu and Rich (1999) addressed the processing of the Solar Analyst tool in more detail, the most recent version being that used in the present study. The obtained results were the matrix files that represent the incident radiation on the surface (KWh/m<sup>2</sup>) during the time interval, such as annual, monthly, or daily.

The main parameters of the ARCGIS Solar Analyst are latitude, skysize resolution, day and hour intervals, time configuration, slope and orientation, number of calculation directions, zenith and azimuth angle intervals, and diffusion and transmissivity coefficients (CHOW et al. 2014). For the case study in question, standard values of the algorithm were adopted, except for skysize resolution, which was improved to 512 x 512 in order to improve the shading calculation, this being sufficient and demanding more processing.

## 5 CASE STUDY RESULTS

### 5.1 DIGITAL CARTOGRAPHIC PRODUCTS (ORTHOPHOTO AND DSM)

The aerophotogrammetric survey carried out using VANT and supported by control points had an output file of an orthophoto with spatial resolution of 2 cm/pixel and a DSM of 50cm/pixel, presented in figures 3 and 4, respectively. Positional quality was verified through comparison of 9 pairs of coordinates (control points, that is, checkpoints, the general view of the location being presented in the sub-figure in the bottom right-hand corner, and the closer view, in the region of Belo Horizonte, in the sub-figure in the top right-hand corner, both without defined scale and used only for location reference, see figure 3) from the orthophoto and the DSM with those obtained from the more precise collection and processing from the GNSS geodesic receptor. With mean absolute errors less than 10 cm and standard deviations less than 13 cm, it can be verified that both possess high accuracy, which is sufficient for the objective of the present study, as per that already found by Tonkin and Midgley (2016).

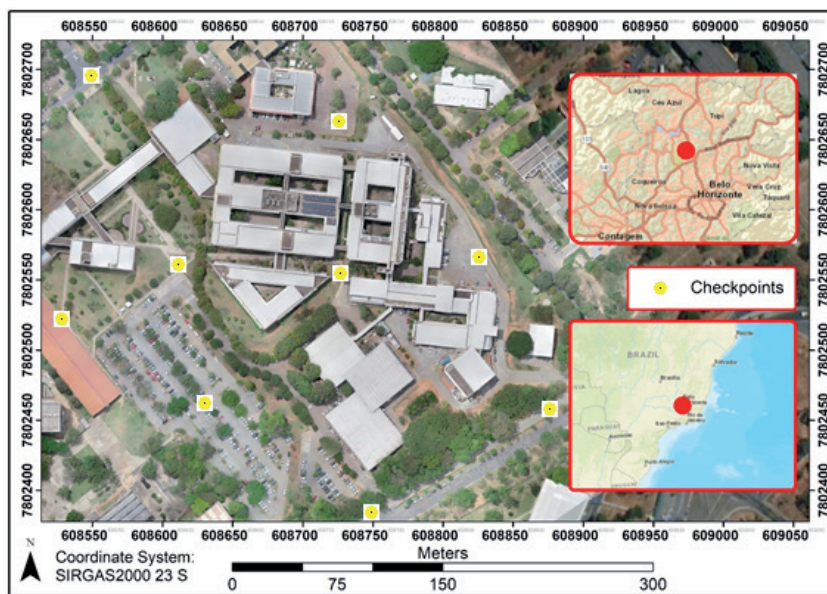


Figure 3 | Orthophoto with spatial resolution of 2 cm/pixel.

Source: Authors.

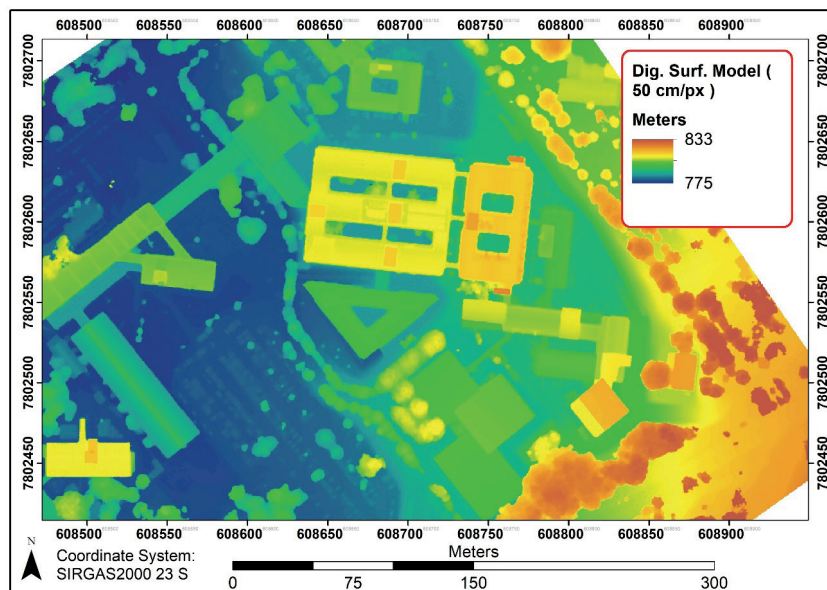


Figure 4 | Digital Surface Model with spatial resolution of 50 cm/pixel.

Source: Authors.

## 5.2 SOLAR RADIATION MAPS

The incident solar radiation on the surface is obtained as a result of the inclination and orientation of the same. Figures 5 and 6 present this information for the roofs of EE-IGC-UFGM. It can be noted that the roofs possess different orientations and inclinations, resulting in different results of incident radiation.



Figure 5 | Slope of the roofs of EE-IGC-UFGM.

Source: Authors.

On analyzing the radiation maps, it could be noted that some roofs have annual incident radiation of up to 1800 kWh/m<sup>2</sup>, as shown in figure 7, the current demand varying and requiring better quantification. With the DSM resolution used in the computational processing of data, of 50 cm/pixel, it was possible to identify structures that impede the installation of photovoltaic systems on the roofs, thereby reducing the available area. It was also possible to observe the influence of shading caused by trees and neighboring buildings. Moreover, it can be perceived that there is greater solar incidence in the summer months in comparison with those of the winter.

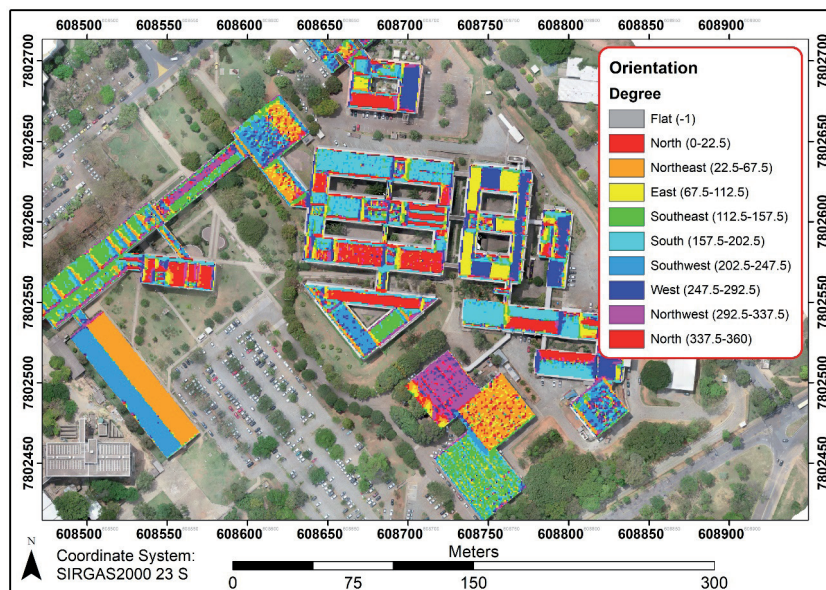


Figure 6 | Surface orientation of the roofs of EE-IGC-UFGM.

Source: Authors.

The main results of the ARCGIS Solar Analyst tool, which are the calculation of global annual and monthly radiation, are presented in figures 7 and 8.

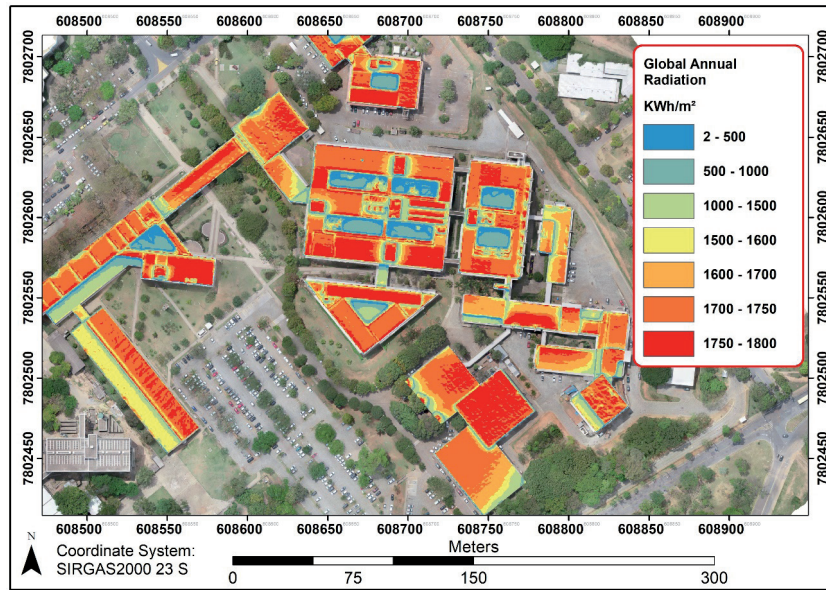


Figure 7 | Global Annual Radiation of EE-IGC-UFMG.

Source: Authors.

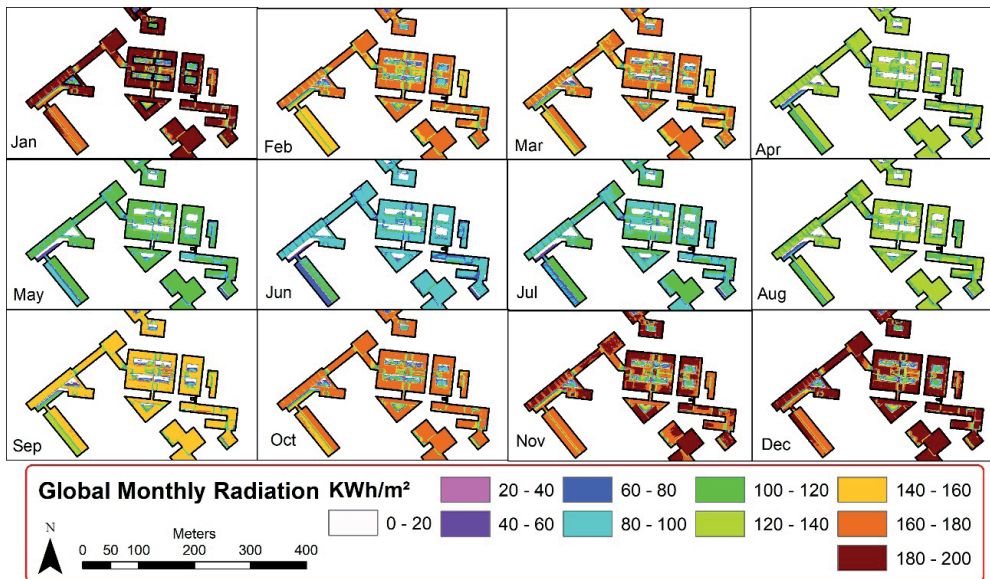


Figure 8 | Global Monthly Radiation of EE-IGC-UFMG.

Source: Authors.

## 6 DISCUSSION

### 6.1 LIDAR VS PHOTOGRAMMETRY WITH VANTS

The comparison between photogrammetry and LiDAR has already been the subject of discussion of various authors. The two technologies are viable for surveys in urban environments for the installation of photovoltaic systems. In summary, LiDAR surveys have higher relative cost per building and require greater expertise for operation and processing, and would rarely be contracted for use by a company or

small city (SZABÓ et al., 2016). When it comes to large areas, greater than 1 km<sup>2</sup>, photogrammetry can be used, but it also demands computational effort and expertise similar to LiDAR (TENEDÓRIO et al., 2016). It should be mentioned that for small regions, photogrammetry can generate data periodically, with spontaneity and low cost.

For the resolution of the DSM inserted into the solar modelling, it can be observed that it is mostly 1.0 m/pixel and was obtained through LiDAR. Moudrý et al. (2019) and Schuffer et al. (2015) state that DSMs with sub metric spatial resolutions are unnecessary as the variation over the year due to atmospheric conditions is significantly greater than the variation caused by different resolutions. In contrast, Besser et al. (2019) and Zink et al. (2015) indicate that on DSMs of 1.0 m/pixel it is not possible to clearly identify the area available for the deployment of photovoltaic systems, as there is no detailed representation of objects on the roofs that could impede installation, such as chimneys, elevator housings, and water tanks, among others.

Zink et al. (2015) conclude that the ideal resolution to solve this difficulty is 0.25 m/pixel and they warn that more detailed resolutions negatively interfere in the slope and orientation calculation matrix operation of the pixel, leading to false estimations of radiation. Evaluation of the sufficient resolution for identification of structures and the computational demand is recommended, which basically depends on the desired resolution and the size of the surveyed area. In the present study, 0.50 m/pixel was adopted, but more sensitive exploration of the variation in resolution is necessary.

## 6.2 THEORETICAL, TECHNICAL, ECONOMIC, SOCIAL, AND ENVIRONMENTAL POTENTIAL

The matrix file of the solar radiation model is expressed in KWh/m<sup>2</sup>. A hierarchical methodology commonly adopted by various authors to transform theoretical potential into technical and economic potential is presented by Izquierdo et al. (2008). It consists of three stages: (i) the physical potential (theoretical), which is the solar radiation sum total; (ii) the technical potential (electrical, geographic, or urban), which reports the available area by roof and the efficiency and performance of the photovoltaic panel during the transformation of solar energy into electrical energy; (iii) the economic potential, which considers the cost of the photovoltaic system during its life cycle, which is basically the deployment and maintenance costs, local electricity prices, and the time for return on investment (ASSOULINE et al., 2017; CHENG et al., 2018; and MARTÍN et al., 2015).

The technical potential has adequate precision when the DSM has enough resolution to represent the morphologies of the buildings, the urban arrangement, and the incidental shading, as well as identifying structures on the roofs (La Gennusa et al., 2011), such as the presence of elevator housings and water tanks, among others. Another relevant detail is the correct use of algorithms for the segmentation and extraction of roofs on aerial or high-resolution satellite images, so that the measurement of the area available for deployment of photovoltaic (PV) panels on roofs is as close as possible to reality. GIS is also used for this crucial stage. The revision proposed by Crommelynck et al. (2016) discusses techniques for the vectorization of roofs in photogrammetric surveys with VANTS, while Camargo et al. (2018) used the open tool of PKTools, and Ninsawat and Hossain (2016) used eCognition software to carry out roof segmentation. It is also worth highlighting the work carried out by Faria (2017).

The efficiency and performance of the photovoltaic system will depend on the model, inverter, and time of use, as indicated by Wigton et al. (2010) and Lukac et al. (2014). Non-linearity is a factor inherent to the semi-conductor materials that make up the photovoltaic panel and to the maximum points of inversion (LUKAC et al., 2014). Thus, the more information in respect to the efficiency of the adopted material (organic, amorphous silicon, monocrystalline or polycrystalline, etc), the greater the accuracy of the estimation of energy produced, and, consequently, the better the strategic planning will be. For example, monocrystalline and polycrystalline silicon panels have more than double the efficiency of the others cited (BERGAMASCO and ASINARI, 2011).

Other authors have considered it relevant to work with the information generated by the solar radiation model to evaluate the possible environmental impacts (IZKARA et al., 2019, DESTHIEUX et al., 2018, and NOWACKA and REMONDINO, 2018). Through the electrical-energy generation potential it is possible to obtain the quantity of CO<sub>2</sub> that would have been emitted, if a fossil fuel had been used as a source of energy (PENG et al. 2013), also known as carbon equivalent, or CO<sub>2</sub>e. Esclapés et al. (2014) define the conversion rate as 0.60 KgCO<sub>2</sub>e / KWh produced, while Lukac et al. (2016) estimated 0.53 KgCO<sub>2</sub>e / KWh.

With this information, public administration has quantitative data to develop environmental policies combatting climate change (CAMARGO et al., 2015) and can include CO<sub>2</sub>e arising from distributed microgeneration in environmental targets. Mavromatidis et al. (2015) state that in the case of absence of environmental policies, it is common to follow economic criteria in decision-making processes.

Regarding the social dimension, two approaches proposed by Swam and Ugursal (2009) can be highlighted; top-down and bottom-up. The first consists of considering residential sectors in blocks, whereas the second consists of individually evaluating the final consumers. The scale and purpose of mapping solar radiation defines which approach to adopt. Santos et al. (2014) estimated the energy demand of each building and classified the buildings into groups based on mean local demand per capita, volumes, area and height of the buildings, and population distribution. Wigton et al. (2010) adopted population density and roof-area demand per capita to quantify photovoltaic potential in Ontario (Canada) for public renewable energy policies. Gooding et al. (2013) established socioeconomic criteria such as income, education, environmental awareness, quantity of buildings, and owners to identify places with greater potential. In a study on microgeneration diffusion using solar tools, Kauzika et al. (2017) also indicated four social criteria of greater relevance to harnessing photovoltaic potential on buildings: income, property value, neighbors that already have photovoltaic panels, and energy consumption.

### 6.3 APPLICATION OF THE SOLAR RADIATION MAP

The availability of data on photovoltaic energy has been increasing, as has the number of cities making this information available. When it comes to sustainable targets, modelling the phenomenon of solar radiation on roofs is interesting to public administrators and investors looking to integrate urban planning and microgeneration (Fonseca et al., 2015).

Therefore, town planners and public administrators require a comprehensive vision of the opportunities and the cost-benefit to optimize energy performance of the buildings. They also have the responsibility to reveal and effectively communicate to the population the information on photovoltaic and economic potential, in order to maintain the population informed and shorten the energy transition at the site. Notably, solar models on GIS are tools that should be exploited to meet these demands. Castellanos, et al. (2017) maintain that having precise, accessible tools of easy understanding to evaluate photovoltaic potential is expected for the development of suitable public policies. They also warn that policy decisions are difficult, as administrators depend on generic information from low-resolution solar models, or they need to invest high amounts in researching a certain area in high resolution.

According to Santos et al. (2014), basic planning for investment in photovoltaic systems should contain information in relation to energy demand and generation capacity. Furthermore, adopting a bottom-up approach, of building discretization, is essential to whole scale planning. For this, it is necessary to model the urban environment, incident solar radiation, and the areas available on the roofs. In general, public interest is in increasing the participation of microgeneration and private interest is in deploying photovoltaic systems to generate profit (CAMARGO et al., 2015).

More recently, authors have analyzed the energy situation more deeply, considering the maximization of the participation of microgeneration in the electricity network and the minimization of investment (MAVROMATIDIS et al., 2015; CAMARGO et al., 2015; and LINGFORS et al., 2017) rather than the direct analysis of maximum potential capacity based on technical criteria. Objectively deciding the appropriate

penetration percentage and having a concrete plan to achieve it is, without doubt, a contribution to shaping energy sustainability and optimizing use of space.

However, the excessive increase in the participation of microgeneration can be harmful to the entire sector, which will be discussed in the next section. It is important to present studies that quantify the total area that is suitable for the installation of photovoltaic systems, such as that of Hofierka and Kaňuk (2009), who classified 59% of the available roof area in Bardejov, Slovakia, as suitable, 39% being residences. In a study in the district of Gangnam in Seoul, South Korea, Lee et al. (2018) classified buildings into four categories, using photovoltaic potential and profitability as technical and financial criteria respectively.

In the context of a city's sustainable transition, Radzi and Droege (2013) recommend mapping renewable energy capacity and energy flows, and understanding which roofs and open spaces are available for deployment of renewable systems of conversion into electrical and thermal energy as a basis for achieving energy independence, in a structured and purposeful manner. Moreover, De Waal and Stremke (2014) recommend solar models as tools that can provide the first steps in the debate on energy transition and precede and support the creation of spatial scenarios and strategic visions. Desthieux et al. (2018) justify that the developed online tool has the main aim of promoting energy transition on a local scale in Geneva, Switzerland.

In the context of solar mapping in urban areas, there is a trend in the adoption of online tools with an easily-understood interface for vectoring roofs to compose a solar register and for presenting objective data. Besser et al. (2019) state that this approach results in more rational, effective decisions, and the population easily obtain transparent information. Freitas et al. (2015) consider that the final stage in an evaluation of photovoltaic potential is the development of an online platform. Such platforms include: Krüger and Kolbe (2012); Jakubiec and Reinhart (2013) - which resulted in the Mapdwell project; Desthieux et al. (2018); Roberts et al. (2018) – which resulted in the APVI Solar Potential Tool (SunSPoT) project; and Izkara et al. (2019).

Websites should define their target public, adapt their content to the final consumer, and avoid hiding information or losing information quality. Besser et al. (2019) list five main duties of an online platform: (i) identification of roof parts available for photovoltaic system installation and annual production capacity; (ii) definition of the size of available area (m<sup>2</sup>), potential installation capacity (MW) and potential generation capacity (MWh), and environmental and economic indicators; (iii) visualization of colored maps of potentials and graphs related to photovoltaic generation and economy for each roof; (iv) making information available in reference to each roof, such as orientation and inclination, among others that assist in the installation and design of the photovoltaic system; and (v) generation of PDF or CSV reports.

## 6.4 DIFFICULTIES AND LIMITATIONS

Despite GIS solar models being considered administration tools that solve problems and clarify decisions, they still present aspects and methodologies that are being perfected and optimized. Quantification of the maximum penetration of photovoltaic energy into the electricity grid, solar model calibration, extrapolation from solar models with dubious resolution, the relatively high costs of LiDAR surveys, and the lack of efficient communication with the target public can all be cited as examples.

One of the greatest difficulties the photovoltaic sector still confronts is the imbalance between electrical energy generation and consumption through the day. The obvious solution would be to export electricity to the electricity grid, however, for cases in which there is high photovoltaic energy penetration into the grid, this excess electricity would cause instabilities in the distribution and reduce the quality of the service, besides reducing the electrical energy tariff due to the high offer (JANKO et al., 2016; and TONKOSKI et al., 2012).



In addition, in the financial analysis, the combination of temporal gaps between production and consumption and the phenomenon of high penetration lead to a reduction in investment values and an increase in the time for a return on investment, as the cost of energy is reduced with high offer during the day while in the hours of highest consumption - at night, when tariffs are higher – there is no generation of photovoltaic energy (CAMARGO et al., 2018). Camargo et al. (2018) conclude that photovoltaic energy participation in the grid of around 20% does not generate considerable impact on the distribution and reliability of the electricity grid, whereas over 40% results in a drop in quality indicators and reliability.

Also, they state that establishing targets for a specific location requires technical and economic factor analyses to define the limit of photovoltaic participation. In a similar study, but with a village as example, Mavromatidis et al. (2015) indicate 29% as the ideal participation value so that the maximum energy demand is satisfied with the inclusion of photovoltaic generation, without the necessity to store energy. However, 58% would be the ideal participation, if there were storage, meaning that all the energy demand would be supplied by photovoltaic energy.

Regarding model calibration, Szewczyk (2018) presents calibration of cloud presence in the GRASS r.sun model and warns that in relation to the solar register, the two biggest difficulties are obtaining three-dimensional data of the urban area and the insertion of information in respect to nebulosity over the year. This was the case of Roberts et al. (2018), who used ARCGIS Solar Analyst and data from NREL for calibration, while Szewczyk (2018) adjusted the GRASS r.sun model using data from the SoDa project and pointed out that the algorithm is precise for days with clear sky, even without adjustment. Adjusting the GIS models using ground data or data from satellites with thermal sensors is extremely relevant for energy, financial, environmental, and policy planning to be developed based on real values, avoiding excesses or losses in private projects or larger scale projects.

It is worth mentioning a comparative study carried out by Castellanos et al. (2017), in which solar models based on LiDAR found in reviewed literature are compared with solar models based on satellite data, and therefore of lower resolution, such as Google Sunroof, Mapdwell, and that of the International Energy Agency. The principal results indicate variations of up to 207% between low resolution models and 115% between models of different resolutions. They also computed the percent error, accounting for differences greater than 300%. Therefore, the decision-makers are found in a difficult position, as they are dependent on low accuracy information, or will have to invest in LiDAR research, which is recognized for its high cost (CASTELLANOS et al., 2017).

Another barrier that has been discussed by authors is the functionality of the tool in the face of practicality and acceptance and participation of the target public. Jakica (2018), after reviewing hundreds of solar models, highlights the low quality in the dynamic visualization of information and criticizes the low availability of open-source algorithms. Wijeratne et al. (2018) reviewed 27 programs and applications of solar system design and management and indicated 14 problems related to the tools. It is worth highlighting: (i) the lack of meteorological data with low time intervals between the samples, high-quality 3D modelling, and roof individualization; (ii) the lack of local data on products and services related to the photovoltaic sector; (iii) the lack of information in relation to tariffs and financial analysis; (iv) the lack of information in relation to government incentives; and (v) program and application interfaces not being user friendly.

## 7 CONCLUSION

This article achieved its aims of constructing a solar radiation model for the buildings of EE-IGC-UFMG and discussing relevant aspects in respect to models of photovoltaic potential, such as the distinct elevation models adopted as input data; the technical, economic, social, and environmental potential that solar radiation modelling can explore; the practical applications for planning and decision-making; and use of online tools and certain associated difficulties.

It is suggested that this type of study, which is mostly based on geographical aspects of the region, is added to multi-criteria analyses that consider CO2 emission reduction targets, the cost of the tariff and the forms of financing, capacity of the electrical energy distribution system, and the energy demand, forming a robust data set for decision-making by private and public sector administrators. It should be emphasized that estimating the photovoltaic potential on buildings supports financial, energy, and environmental planning to meet social demands on a local scale.

For future research, the authors of this article plan to expand the application of solar models to the entire UFMG campus or to a small city, besides investigating further the applications and potentials addressed throughout the text.

## NOTES

- 1 | European Solar Radiation Data: <http://www.soda-is.com>
- 2 | National Renewable Energy Laboratory: <https://maps.nrel.gov/nsrdb-viewer>
- 3 | Google Sunroof: <https://www.google.com/get/sunroof>
- 4 | Mapdwell: <https://www.mapdwell.com/en/solar>

## REFERENCES

- AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA. Resolução Normativa Nº 482, de 17 de Abril de 2012. Disponível em: <<http://www.aneel.gov.br/cedoc/ren2012482.pdf>>. Acesso em: 09 maio 2019.
- AMADO, M.; POGGI, F.; AMADO, A. R. Energy efficient city: a model for urban planning. **Sustainable Cities and Society**, v. 26, p. 476-485, 2016.
- ASIF, M. Urban scale application of solar PV to improve sustainability in the building and the energy sectors of KSA. **Sustainability**, v. 8, n. 11, p. 1127, 2016.
- ASSOULINE, D.; MOHAJERI, N.; SCARTEZZINI, J-L. Quantifying rooftop photovoltaic solar energy potential: a machine learning approach. **Solar Energy**, v. 141, p. 278-296, 2017.
- BERGAMASCO, L.; ASINARI, P. Scalable methodology for the photovoltaic solar energy potential assessment based on available roof surface area: application to Piedmont Region (Italy). **Solar energy**, v. 85, n. 5, p. 1041-1055, 2011.
- BESSER, A. et al. A Customized Decision Support System for Renewable Energy Application by Housing Association. **Sustainability**, v. 11, n. 16, p. 4377, 2019.
- CAMARGO, L. R. et al. Spatio-temporal modeling of roof-top photovoltaic panels for improved technical potential assessment and electricity peak load offsetting at the municipal scale. **Computers, Environment and Urban Systems**, v. 52, p. 58-69, 2015.
- CAMARGO, L. R.; STOEGLEHNER, G. Spatiotemporal modelling for integrated spatial and energy planning. **Energy, Sustainability and Society**, v. 8, n. 1, p. 32, 2018.
- CASTELLANOS, S.; SUNTER, D. A.; KAMMEN, D. M. Rooftop solar photovoltaic potential in cities: how scalable are assessment approaches?. **Environmental Research Letters**, v. 12, n. 12, p. 125005, 2017.
- CHENG, L. et al. Use of LiDAR for calculating solar irradiance on roofs and façades of buildings at city scale: methodology, validation, and analysis. **ISPRS Journal of Photogrammetry and remote sensing**, v. 138, p. 12-29, 2018.
- CHOI, Y.; SUH, J.; KIM, S-M. GIS-Based Solar Radiation Mapping, Site Evaluation, and Potential Assessment: a review. **Applied Sciences**, v. 9, n. 9, p. 1960, 2019.

CHOW, A.; FUNG, A.; LI, S. GIS modeling of solar neighborhood potential at a fine spatiotemporal resolution. **Buildings**, v. 4, n. 2, p. 195-206, 2014.

CINTRA, J.; NERO, M.; RODRIGUES, D. GNSS/NTRIP service and technique: accuracy tests. **Boletim de Ciências Geodésicas**, v. 17, n. 2, p. 257-271, 2011.

COLOMINA, I.; MOLINA, P. Unmanned aerial systems for photogrammetry and remote sensing: a review. **ISPRS Journal of Photogrammetry and remote sensing**, v. 92, p. 79-97, 2014.

DAMMALAGE, T. L. et al. Potential accuracy and practical benefits of NTRIP protocol over conventional RTK and DGPS observation methods. **Map Asia**, v. 29, 2006.

DE WAAL, R.; STREMKER, S. Energy transition: missed opportunities and emerging challenges for landscape planning and designing. **Sustainability**, v. 6, n. 7, p. 4386-4415, 2014.

DESTHIEUX, G. et al. Solar cadaster of Geneva: a decision support system for sustainable energy management. In: **From Science to Society**. Springer, Cham, 2018. p. 129-137.

ESCLAPÉS, J. et al. A method to evaluate the adaptability of photovoltaic energy on urban façades. **Solar Energy**, v. 105, p. 414-427, 2014.

ESCOBAR, R. A. et al. Estimating the potential for solar energy utilization in Chile by satellite-derived data and ground station measurements. **Solar Energy**, v. 121, p. 139-151, 2015.

FALKNER, R. The Paris Agreement and the new logic of international climate politics. **International Affairs**, v. 92, n. 5, p. 1107-1125, 2016.

FARIA, T. S. **Classificação em área urbana apoiada em imagens aéreas e dados LiDAR**. Dissertação (Mestrado) – Universidade Federal de Minas Gerais, 2017, 94p.

FARMER, J. D.; LAFOND, F. How predictable is technological progress? **Research Policy**, v. 45, n. 3, p. 647-665, 2016.

FONSECA, J. A.; SCHLUETER, A. Integrated model for characterization of spatiotemporal building energy consumption patterns in neighborhoods and city districts. **Applied Energy**, v. 142, p. 247-265, 2015.

FREITAS, S. et al. Modelling solar potential in the urban environment: state-of-the-art review. **Renewable and Sustainable Energy Reviews**, v. 41, p. 915-931, 2015.

GIELEN, D.; BOSHELL, F.; SAYGIN, D. Climate and energy challenges for materials science. **Nature materials**, v. 15, n. 2, p. 117, 2016.

GOODING, J. et al. Solar City Indicator: a methodology to predict city level PV installed capacity by combining physical capacity and socio-economic factors. **Solar Energy**, v. 95, p. 325-335, 2013.

HOFIERKA, J. et al. The solar radiation model for Open source GIS: implementation and applications. In: **Proceedings of the Open source GIS-Grass users conference**. 2002. p. 51-70.

HOFIERKA, J.; KAŇUK, J. Assessment of photovoltaic potential in urban areas using open-source solar radiation tools. **Renewable energy**, v. 34, n. 10, p. 2206-2214, 2009.

INTERNATIONAL ENERGY AGENCY. **Energy Outlook 2018**. International Energy Agency Paris, France, 2018.

IZKARA, J. L.; EGUSQUIZA, A.; VILLANUEVA, A. GIS-3D Platform to Help Decision Making for Energy Rehabilitation in Urban Environments. In: **IOP Conference Series: earth and environmental science**. IOP Publishing, 2019. p. 012122.

IZQUIERDO, S.; RODRIGUES, M.; FUEYO, N. A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations. **Solar Energy**, v. 82, n. 10, p. 929-939, 2008.

JAKICA, N. State-of-the-art review of solar design tools and methods for assessing daylighting and solar potential for building-integrated photovoltaics. **Renewable and Sustainable Energy Reviews**, v. 81, p. 1296-1328, 2018.

JAKUBIEC, J. A.; REINHART, C. F. A method for predicting city-wide electricity gains from photovoltaic panels based on LiDAR and GIS data combined with hourly Daysim simulations. **Solar Energy**, v. 93, p. 127-143, 2013.

JANKO, S. A.; ARNOLD, M. R.; JOHNSON, N. G. Implications of high-penetration renewables for ratepayers and utilities in the residential solar photovoltaic (PV) market. **Applied Energy**, v. 180, p. 37-51, 2016.

KAUSIKA, B. B.; DOLLA, O.; VAN SARK, W. Assessment of policy based residential solar PV potential using GIS-based multicriteria decision analysis: a case study of Apeldoorn, The Netherlands. **Energy Procedia**, v. 134, p. 110-120, 2017.

KODYSH, J. B. et al. Methodology for estimating solar potential on multiple building rooftops for photovoltaic systems. **Sustainable Cities and Society**, v. 8, p. 31-41, 2013.

KRÜGER, A.; KOLBE, T. H. Building analysis for urban energy planning using key indicators on virtual 3D city models – The energy atlas of Berlin. **International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences**, v. 39, n. B2, p. 145-150, 2012.

LA GENNUSA, M. et al. A model for predicting the potential diffusion of solar energy systems in complex urban environments. **Energy Policy**, v. 39, n. 9, p. 5335-5343, 2011.

LEE, M. et al. Development of a rooftop solar photovoltaic rating system considering the technical and economic suitability criteria at the building level. **Energy**, v. 160, p. 213-224, 2018.

LINGFORS, D. et al. Comparing the capability of low-and high-resolution LiDAR data with application to solar resource assessment, roof type classification and shading analysis. **Applied Energy**, v. 205, p. 1216-1230, 2017.

LUDWIG, D.; MCKINLEY, L. Solar Atlas of Berlin-Airborne Lidar in Renewable Energy Applications. **GIM Int**, v. 24, n. 3, p. 17-22, 2010.

LUKAC, N. et al. Buildings roofs photovoltaic potential assessment based on LiDAR (Light Detection And Ranging) data. **Energy**, v. 66, p. 598-609, 2014.

LUKAC, N. et al. Economic and environmental assessment of rooftops regarding suitability for photovoltaic systems installation based on remote sensing data. **Energy**, v. 107, p. 854-865, 2016.

MARTÍN, A. M.; DOMÍNGUEZ, J.; AMADOR, J. Applying LiDAR datasets and GIS based model to evaluate solar potential over roofs: a review. **AIMS Energy**, v. 3, n. 3, p. 326-343, 2015.

MAVROMATIDIS, G.; OREHOUNIG, K.; CARMELIET, J. Evaluation of photovoltaic integration potential in a village. **Solar Energy**, v. 121, p. 152-168, 2015.

MELIUS, J.; MARGOLIS, R.; ONG, S. **Estimating rooftop suitability for PV: a review of methods, patents, and validation techniques**. National Renewable Energy Lab. (NREL), Golden, CO (United States), 2013.

MOUDRÝ, V.; BEKOVÁ, A.; LAGNER, O. Evaluation of a high resolution UAV imagery model for rooftop solar irradiation estimates. **Remote Sensing Letters**, v. 10, n. 11, p. 1077-1085, 2019.

NINSAWAT, S.; HOSSAIN, M. Identifying potential area and financial prospects of rooftop solar photovoltaics (PV). **Sustainability**, v. 8, n. 10, p. 1068, 2016.

NOWACKA, A.; REMONDINO, F. Geospatial data for energy efficiency and low carbon cities – overview, experiences and new perspectives. **International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences**, 2018.

PENG, J.; LU, L.; YANG, H. Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. **Renewable and sustainable energy reviews**, v. 19, p. 255-274, 2013.

PEREIRA, E. B. et al. **Atlas brasileiro de energia solar**. São José dos Campos: Inpe, 2006.

POLO, J.; PEREZ, R. Solar radiation modeling from satellite imagery. In: **Solar Resources Mapping**. Springer, Cham, 2019. p. 183-197.

- RADZI, A.; DROEGE, P. Governance tools for local energy autonomy. In: **Climate Change Governance**. Springer, Berlin, Heidelberg, 2013. p. 227-242.
- REMONDINO, F. et al. Low-cost and open-source solutions for automated image orientation – A critical overview. In: **Euro-Mediterranean Conference**. Springer, Berlin, Heidelberg, 2012. p. 40-54.
- ROBERTS, M. B.; COPPER, J.; BRUCE, A. Analysis of Rooftop Solar Potential on Australian Residential Buildings. In: **Asia Pacific Solar Research Conference**. 2018.
- SANTOS, T. et al. Applications of solar mapping in the urban environment. **Applied Geography**, v. 51, p. 48-57, 2014.
- SARMIENTO, N. et al. A solar irradiation GIS as decision support tool for the Province of Salta, Argentina. **Renewable Energy**, v. 132, p. 68-80, 2019.
- SCHUFFERT, S. et al. Quality assessment of roof planes extracted from height data for solar energy systems by the EAGLE platform. **Remote Sensing**, v. 7, n. 12, p. 17016-17034, 2015.
- SZABÓ, S. et al. Automated registration of potential locations for solar energy production with Light Detection And Ranging (LiDAR) and small format photogrammetry. **Journal of Cleaner Production**, v. 112, p. 3820-3829, 2016.
- SZEWCZYK, M.; SZEWCZYK, L. Modelling of real solar radiation spatial distribution as a tool for solar energy cadastre in the cities. **Energy & Environment**, v. 29, n. 2, p. 204-215, 2018.
- TENEDÓRIO, J. A. et al. Remote sensing from unmanned aerial vehicles for 3D urban modelling: case study of Loulé, Portugal. In: **Back to the Sense of the City**: international monograph book. Centre de Política de Sòl i Valoracions, 2016. p. 1118-1128.
- TONKIN, T.; MIDGLEY, N. Ground-control networks for image based surface reconstruction: an investigation of optimum survey designs using UAV derived imagery and structure-from-motion photogrammetry. **Remote Sensing**, v. 8, n. 9, p. 786, 2016.
- TONKOSKI, R.; TURCOTTE, D.; EL-FOULY, T. H. M. Impact of high PV penetration on voltage profiles in residential neighborhoods. **IEEE Transactions on Sustainable Energy**, v. 3, n. 3, p. 518-527, 2012.
- UNITED NATIONS. **Paris agreement 2015**. Disponível em: <[https://unfccc.int/sites/default/files/english\\_paris\\_agreement.pdf](https://unfccc.int/sites/default/files/english_paris_agreement.pdf)>. Acesso em: 12 set. 2019.
- WAN, C. et al. Photovoltaic and solar power forecasting for smart grid energy management. **CSEE Journal of Power and Energy Systems**, v. 1, n. 4, p. 38-46, 2015.
- WEBER, G.; DETTMERING, D.; GEBHARD, H. Networked transport of RTCM via internet protocol (NTRIP). In: **A Window on the Future of Geodesy**. Springer, Berlin, Heidelberg, 2005. p. 60-64.
- WIGINTON, L. K.; NGUYEN, H. T.; PEARCE, J. M. Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. **Computers, Environment and Urban Systems**, v. 34, n. 4, p. 345-357, 2010.
- WIJERATNE, W. M. P. U. et al. Design and development of distributed solar PV systems: Do the current tools work? **Sustainable cities and society**, 2018.
- YANG, D. et al. History and trends in solar irradiance and PV power forecasting: a preliminary assessment and review using text mining. **Solar Energy**, v. 168, p. 60-101, 2018.
- ZINK, R. et al. Photogrammetric point clouds for GIS-based high-resolution estimation of solar radiation for rooftop solar systems. In: **Surface Models for Geosciences**. Springer, Cham, 2015. p. 293-305.

# Construção de um modelo de potencial de radiação solar local e discussão das aplicações sustentáveis e potenciais associados

*Case study of a model of local solar radiation potential and discussion on the associated sustainable applications and potentials*

Marcelo Antonio Nero<sup>a</sup>

Daniel Henrique Carneiro Salim<sup>b</sup>

Caio César de Sousa Mello<sup>c</sup>

Rafael Tarantino Amarante<sup>d</sup>

Bráulio Magalhães Fonseca<sup>e</sup>

Plínio Temba<sup>f</sup>

<sup>a</sup>*Departamento de Cartografia, Instituto de Geociências, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
End. Eletrônico: marcelo-nero@ufmg.br*

<sup>b</sup>*Departamento de Cartografia, Instituto de Geociências, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
End. Eletrônico: danielhcsalim@gmail.com*

<sup>c</sup>*Departamento de Engenharia Sanitária e Ambiental, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
End. Eletrônico: caiocsmello@gmail.com*

<sup>d</sup>*Departamento de Cartografia, Instituto de Geociências, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
End. Eletrônico: rafaeltarantino@outlook.com*

<sup>e</sup>*Departamento de Cartografia, Instituto de Geociências, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
End. Eletrônico: brauliomagalhaes@ufmg.br*

<sup>f</sup>*Departamento de Cartografia, Instituto de Geociências, Universidade Federal de Minas Gerais, Belo Horizonte, MG, Brasil  
End. Eletrônico: temba.mobile@gmail.com*

doi:10.18472/SustDeb.v11n2.2020.27773

Received: 22/10/2019  
Accepted: 02/04/2020

ARTICLE- DOSSIER

## RESUMO

A transição sustentável para matrizes energéticas mais sustentáveis é uma demanda mundial e atual. Nesse sentido, a modelagem da radiação solar em alta resolução espacial é utilizada para avaliar o potencial de geração fotovoltaica em qualquer tipo de superfície e fornecer informações para planejamento e dimensionamento de sistemas fotovoltaicos. A partir do potencial técnico de geração, pode-se estimar o tempo de retorno do investimento do sistema fotovoltaico e a quantidade de gás carbônico que deixou de ser emitido ao adotar a energia fotovoltaica. No contexto quantitativo, o objetivo deste artigo foi abordar brevemente a metodologia técnica e construir um modelo de radiação solar incidente em prédios da EE-IGC-UFMG. No contexto da discussão das aplicações sustentáveis da ferramenta, o objetivo foi tratar de temas relevantes, tais como a construção de modelos de radiação e os potenciais associados, as escalas de aplicação e dificuldades e limitações da modelagem.

**Palavras-chave:** SIG. Energia Fotovoltaica. Modelo. Fotogrametria.

## ABSTRACT

*The demand for a sustainable transition to energy matrices of lower environmental impact is global and current. In this sense, the modeling of solar radiation in high spatial resolution is used to assess the potential of photovoltaic generation on any type of surface and provide information for the planning and dimensioning of photovoltaic systems. From the technical potential of generation, it is possible to estimate the systems payback time and the avoided greenhouse gas emissions when adopting photovoltaic energy. In the quantitative context, the objective of this article was to briefly address the technical methodology and build a model of solar radiation of EE-IGC-UFMG buildings. In the context of sustainable applications of the tool, the objective was to address relevant topics, such as the construction of radiation models and the associated potentials, the application scales, and the difficulties and limitations of the modeling.*

**Keywords:** GIS. Photovoltaic Energy. Model. Photogrammetry.

## 1 INTRODUÇÃO

Transformar a matriz energética global, majoritariamente pautada no uso de combustíveis fósseis, em sustentável e renovável é uma das principais formas de alcançar as metas estipuladas pelo Acordo de Paris (FALKNER, 2019; GIELEN et al. 2016; IEA, 2018; UN, 2015), as quais visam manter o aumento nas temperaturas globais abaixo do valor limite de 2°C. Nesse contexto, uma das principais soluções para atingir as metas de redução da emissão de gases de efeito estufa é a geração distribuída de energia elétrica fotovoltaica, tendo em vista sua capacidade de fornecer eletricidade a partir de uma fonte renovável e suprir diretamente os usuários próximos à fonte de captação em ambiente urbano (BESSER et al., 2019; FREITAS et al., 2015; LEE, 2018; ZINK et al., 2015).

A energia fotovoltaica tem relevante influência na mudança dos padrões de consumo e distribuição energética em centros urbanos, tendo em vista que as políticas públicas para redução da emissão de gases de efeito estufa promoveram a queda nos custos para as tecnologias de baixo carbono. Assim, os sistemas de geração de energia fotovoltaicos começaram a possuir custo-benefício relevante, sendo observadas as quedas nos preços de módulos fotovoltaicos na escala de 10% ao ano, desde 1980 (FALKNER, 2016; FARMOR; LAFOND, 2016). Além disso, no Brasil, foi adotada em 2012 a Resolução Normativa 482/2012 (ANEEL, 2012) que regulamenta a micro e a minigeração de energia elétrica por meio de geração fotovoltaica.

Saber o potencial de geração elétrica solar de um centro urbano, sua distribuição geoespacial e as características dos melhores lugares para a implementação de sistemas fotovoltaicos pode fomentar políticas públicas para o desenvolvimento de cidades inteligentes e energeticamente sustentáveis. Para tanto, os governos locais são responsáveis por aplicar, em suas cidades, as estratégias que fomentam a eficiência na produção e distribuição de energia solar (SANTOS et al., 2014).

Para facilitar a tomada de decisão, os gestores devem possuir como base de informação dados detalhados sobre a infraestrutura urbana, aliados às ferramentas de inteligência geográfica, para a elaboração de modelos e cenários futuros com análises quantitativas e robustas. Tais tomadas de decisão devem considerar as metas ambientais e energéticas, bem como direcionar políticas públicas para mudanças em legislações e incentivos ao investimento. O desenvolvimento de modelos solares de radiação em ambiente de Sistema de Informações Geográficas (SIG) é uma informação crucial para atingir os itens supracitados, que é o sentido desta pesquisa.

Os objetivos específicos desta pesquisa são dois: (i) aplicar um algoritmo de modelo solar de radiação para os prédios da Escola de Engenharia e do Instituto de Geociências da Universidade Federal de Minas Gerais (EE-IGC-UFMG) e (ii) discutir os seguintes aspectos de relevância no tocante aos modelos de potencial fotovoltaico: distintos modelos de elevação adotados como dado de entrada; os potenciais técnico, econômico, social e ambiental que a modelagem da radiação solar pode explorar; as aplicações práticas para planejamento e tomada de decisão; uso de ferramentas on-line e algumas dificuldades associadas.

O artigo é introduzido inicialmente por uma breve fundamentação teórica, onde são abordados os modelos de radiação e tipos de Modelos Digitais de Superfície (MDS). Em seguida, apresentam-se a metodologia e resultados obtidos na construção no modelo de radiação solar para a EE-IGC-UFMG. Na sequência apresentam-se as discussões relativas aos modelos, abordando aplicações e limitações da tecnologia.

## 2 MODELOS E ALGORITMOS DE RADIAÇÃO SOLAR INCIDENTE

A modelagem da radiação solar incidente pode ser computada por: (i) interpolação ou extrapolação geoestatística de dados de estações meteorológicas (ASSOULINE et al., 2017, ESCOBAR et al., 2015, WAN et al., 2015), sendo a precisão dependente da densidade de estações – geralmente insuficiente para o contexto de cadastro solar; (ii) satélites acoplados com sensores termais (MELIUS et al., 2013), como, por exemplo, os projetos SoDA, *European Solar Radiation Data*<sup>1</sup>, e o provido pelo NREL, *National Renewable Energy Laboratory*<sup>2</sup>, que conseguem abranger praticamente todo o planeta. No entanto, estes são limitados à resolução espacial insuficiente e pouca acurácia; ou (iii) modelos matemáticos associados à modelagem em SIG, que é o contexto desta pesquisa.

Os modelos solares baseados em SIG podem ser aplicados em diferentes escalas, como, por exemplo, em diversos países, tal como na Austrália (ROBERTS et al., 2018), na Suécia (LINGFORS et al., 2017), na Arábia Saudita (ASIF, 2016), na província de Salta, na Argentina (SARMIENTO et al., 2019), na cidade de Berlim (KRUGER; KOLBE, 2012) e em vilarejos (MAVROMATIDIS et al., 2015). Mais recentemente, em função de avanços na esfera do aprendizado de máquinas e processamento de imagens de satélite, vale ressaltar as plataformas solares que possuem grande potencial, por serem on-line, gratuitas e internacionais: *Google Sunroof*<sup>3</sup> e *Mapdwell*<sup>4</sup>.

As revisões de literatura abordam o tema considerando diferentes contextos de aplicação, metodologias de geração e técnicas de calibração de modelos solares, podendo ser consultadas para maiores detalhes em Choi et al. (2019), Freitas et al. (2015), Jakica (2018), Martín et al. (2015) e Yang et al. (2018).

O modelo da radiação solar contempla latitude, elevação, orientação da superfície do telhado, sombras projetadas pela topografia ao redor, a variação sazonal do trajeto do Sol e as atenuações atmosféricas. Tendo em vista que nem todas as infraestruturas urbanas são aptas à instalação de sistemas de painéis solares, devido à projeção de sombras de construções, bem como da arborização nas proximidades (LEE, 2018), tem-se que, ao se utilizar o MDS do entorno de uma edificação analisada, é possível identificar todas as características necessárias para a modelagem da incidência de radiação solar. Vale ressaltar, ainda, que quanto mais detalhe for captado no levantamento do modelo digital de elevação, mais realista será a quantificação da influência das sombras projetadas na redução do potencial de produção de energia solar fotovoltaica.



As ferramentas de GIS mais comumente utilizadas são o *Solar Analyst* do ArcGis e o *r.sun* do GRASS. Ambas utilizam MDS – arquivos digitais matriciais com *pixels* que possuem valores de altitudes – e são empregados no cálculo da irradiância solar em uma determinada superfície. Os MDSs podem ser gerados através de sensores *Light Detection And Ranging* (LiDAR), fotogrametria aérea tripulada, fotogrametria com Veículos Aéreos Não Tripulados (VANTs) ou imagens de satélites. De modo geral, os MDSs são utilizados para computar a elevação, inclinação e orientação de superfícies, bem como os sombreamentos causados por prédios, árvores ou estruturas físicas capazes de bloquear os raios solares. Além disso, empregam-se na solução das equações de distâncias e ângulos solares previstas nos modelos.

### 3 MDS PARA MODELOS DE RADIAÇÃO EM AMBIENTE SIG

Os MDSs utilizados como dado de entrada nos modelos solares em SIG podem ser produzidos por técnicas de sensoriamento remoto, com o emprego de sensores LiDAR, fotogrametria e processamento de imagens de satélites. O uso de imagens de satélites para gerar MDSs de resolução suficiente para adotar em projetos de energia fotovoltaica ainda é recente e carece de estudos. Entretanto, a fotogrametria e o LiDAR são tecnologias consagradas para levantamento de MDSs de qualidade posicional e resolução espacial submétricas, suficientes para o contexto abordado (LUDWIG; MCKINLEY, 2010; MOUDRY et al., 2019; ZINK et al., 2015).

Atualmente, a tecnologia com emprego do LiDAR é a mais adotada para levantamentos urbanos. Estes contêm sensores ativos que capturam a superfície topográfica com bastante detalhe por meio da emissão de pulsos eletromagnéticos com comprimentos de onda entre 10 e 250 nm (LUKAC et al., 2014). O resultado do levantamento consiste em uma nuvem de pontos, medida em pontos/m<sup>2</sup>, que necessita de pós-processamento e classificação de modo a separar as edificações, as ruas, as estruturas e a vegetação. Esta etapa geralmente é realizada pelo provedor do serviço, que deve apresentar a metodologia adotada (LINGFORS et al., 2017).

A fotogrametria é uma ciência que ganhou novas dimensões com a popularização e avanço tecnológico dos VANTs e algoritmos de visão computacional, principalmente o algoritmo Structure from Motion – MultiView Stereo (SfM-MVS). Resumidamente, para gerar MDSs e ortofotos via SfM-MVS, deve-se realizar voo fotogramétrico com fotos suficientemente sobrepostas de maneira frontal e lateral, para que durante o processamento computacional seja possível identificar os pontos em comum em diferentes fotos.

Isso possibilita a formação do modelo tridimensional, sendo que esses pontos, contendo informações tridimensionais, são então utilizados para compor uma nuvem mais densa, que posteriormente é interpolada para gerar o MDS e, em sequência, a ortofoto (COLOMINA; MOLINA, 2014; TONKIN; MIDGLEY, 2016). Em comparação com o processamento na fotogrametria tradicional, a etapa de *bundle adjustment* é realizada pelo SfM-MVS, considerando um bloco de imagens, e não apenas um par estereoscópico (ZINK et al., 2015).

## 4 METODOLOGIA DO ESTUDO DE CASO

### 4.1 CONSTRUÇÃO DO MODELO SOLAR LOCAL

O levantamento aerofotogramétrico foi realizado na EE-IGC-UFMG, localizados em Belo Horizonte, MG. Para se ter uma ideia mais global da metodologia da construção do modelo solar, é apresentado o fluxograma da Figura 1, sendo o detalhe de cada etapa apresentado no decorrer do texto. O VANT utilizado nessa pesquisa foi o DJI Phantom 4 Professional (P4P).

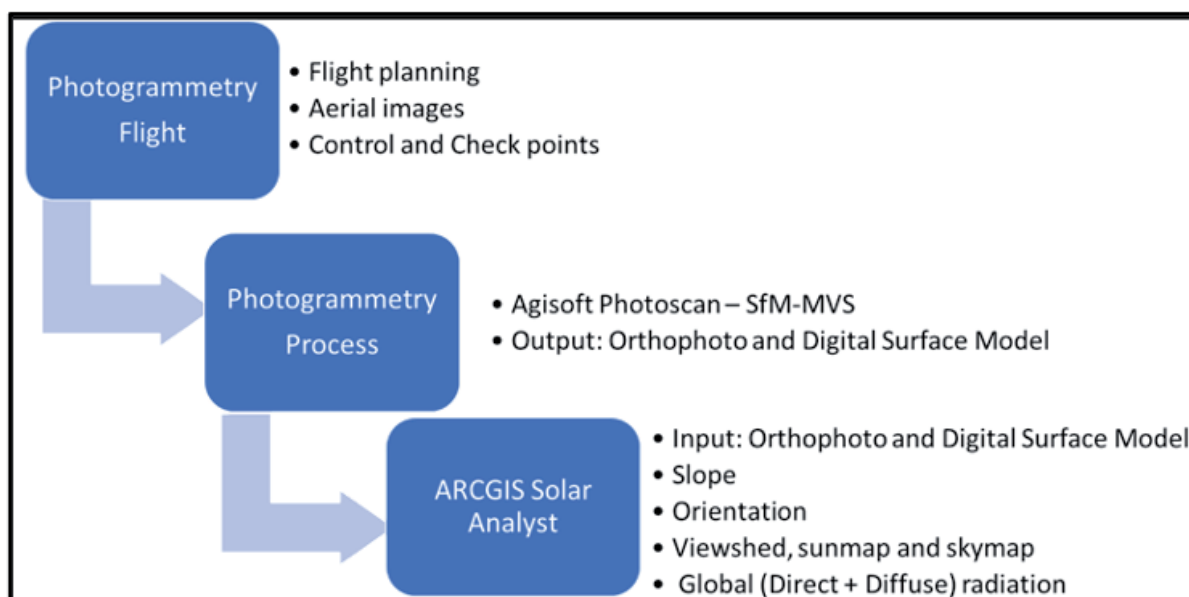


Figura 1 | Esquema geral da metodologia desenvolvida.

Fonte: Autores

## 4.2 FOTOGRAMETRIA – PARÂMETROS DE VOO E PONTOS DE CONTROLE

O programa utilizado para o planejamento de voo fotogramétrico foi o DJI Ground Station Pro. Os parâmetros de voo, tais como altitude, sobreposições lateral e frontal e a resolução espacial da ortofoto e do MDS exportados em formato .tif são apresentadas na Tabela 1.

Tabela 1 | Parâmetros dos voos.

| Descrição                           | Configuração |
|-------------------------------------|--------------|
| Altura do voo (m)                   | 85           |
| Sidelap (%)                         | 75           |
| Overlap (%)                         | 80           |
| Res. espacial ortofoto (cm pixel-1) | 2,0          |
| Res. espacial MDS (cm pixel-1)      | 50,0         |

Fonte: Autores

Para a aquisição das coordenadas em campo dos pontos de controle em solo (PCS) foi utilizado um receptor geodésico GNSS CHC X91+. Nessa pesquisa, adotou-se o método de posicionamento RTK via NTRIP (*Networked Transport of RTCM via Internet Protocol*), o qual é descrito com mais detalhe em Cintra et al. (2011), Dammalage et al. (2006) e Weber et al. (2005), por exemplo.

## 4.3 APLICAÇÃO DA FOTOGRAMETRIA VIA AGISOFT PHOTOSCAN

O processamento fotogramétrico de imagens aéreas com objetivo final de construção de ortofoto e MDS da área levantada foi realizado empregando o programa *Agisoft Photoscan 1.4*. Esse programa utiliza a combinação dos algoritmos SfM-MVS para gerar a nuvem de pontos tridimensionais. De modo geral, os programas de fotogrametria são considerados ferramentas poderosas, eficientes, inovadoras e de grande impacto no campo do sensoriamento remoto. Para saber mais sobre o funcionamento do programa, recomendam-se os artigos de Colomina e Molina (2014) e Remondino et al. (2012).

Foram utilizados 11 pontos de controle para georreferenciamento mais acurado da nuvem de pontos (Figura 2), e, conseqüentemente, dos arquivos digitais dela oriundos, como o MDS e a ortofoto. Os

pontos representam uma cena virtual 3D, invariável em relação à escala e direção e posição das imagens. O MDS foi exportado em resolução controlada de 50 cm/pixel para processamentos computacionais posteriores. O MDS e a ortofoto foram então manipulados nas etapas seguintes utilizando o programa ARCGIS 10.4. A vetorização dos telhados foi feita de modo manual no mesmo programa.

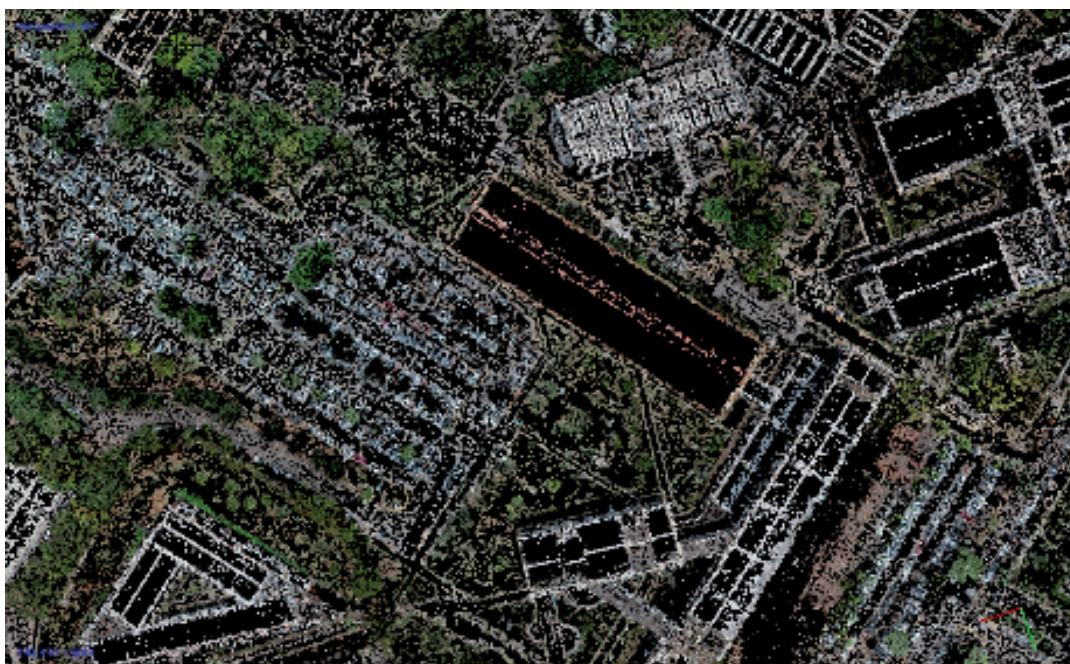


Figura 2 | Nuvem esparsa de pontos.

Fonte: Autores

#### 4.4 FERRAMENTA DE MODELAGEM DA RADIAÇÃO SOLAR INCIDENTE – ARCGIS SOLAR ANALYST

A ferramenta adotada nessa pesquisa foi o *ARCGIS Solar Analyst*, que inicialmente cria um conjunto de vistas para o céu por meio do cálculo dos máximos ângulos horizontais de obstrução – causados pelas topografias e estruturas próximas. Os ângulos são então convertidos para um arquivo matricial indicando a visão hemisférica para cada célula do MDS, chamado de *viewshed*.

Em seguida, realizou-se a sobreposição com o mapa solar, *sunmap*, que mostra a posição do Sol ao longo do tempo, e o mapa do céu, *skymap*, contendo os sítios de origem da radiação difusa. Nessa operação, o algoritmo computa a radiação direta considerando se o Sol é visível em um local e tempo específico, e, simultaneamente, a origem da radiação difusa. Fu e Rich (1999) abordam com mais detalhe o processamento da ferramenta *Solar Analyst*. Os resultados obtidos foram os arquivos matriciais que representam as radiações incidentes na superfície (KWh/m<sup>2</sup>) durante intervalo de tempo, como anual, mensal ou diário.

Os principais parâmetros do *ARCGIS Solar Analyst* são: latitude, resolução do *skysize*, intervalos de dia e hora, configuração de tempo, declividade e orientação, número de direções de cálculo, intervalos do ângulo zênite e azimute, e coeficientes de difusão e transmissividade (CHOW et al., 2014). Para o estudo de caso em questão, adotaram-se os valores padrões do algoritmo, exceto a resolução do *skysize* que foi aumentada para 512 x 512 para aprimorar o cálculo de sombreamento.

## 5 RESULTADOS DO ESTUDO DE CASO

### 5.1 PRODUTOS CARTOGRÁFICOS DIGITAIS (ORTOFOTO E MDS)

O levantamento aerofotogramétrico realizado com VANT e apoiado com pontos de controle teve como arquivo de saída a ortofoto com resolução espacial de 2 cm/pixel e MDS de 50 cm/pixel, apresentados nas figuras 3 e 4, respectivamente. Foi verificada a qualidade posicional por meio da comparação de 11 pares de coordenadas da ortofoto e do MDS com as obtidas a partir da coleta e processamento mais acurado a partir do receptor GNSS geodésico. Com erros médios absolutos menores que 10 cm e desvios padrão menores que 13 cm, verifica-se que ambos possuem alta precisão, suficiente para o objetivo dessa pesquisa, conforme o que já foi constatado também em Tonkin e Midgley (2016).

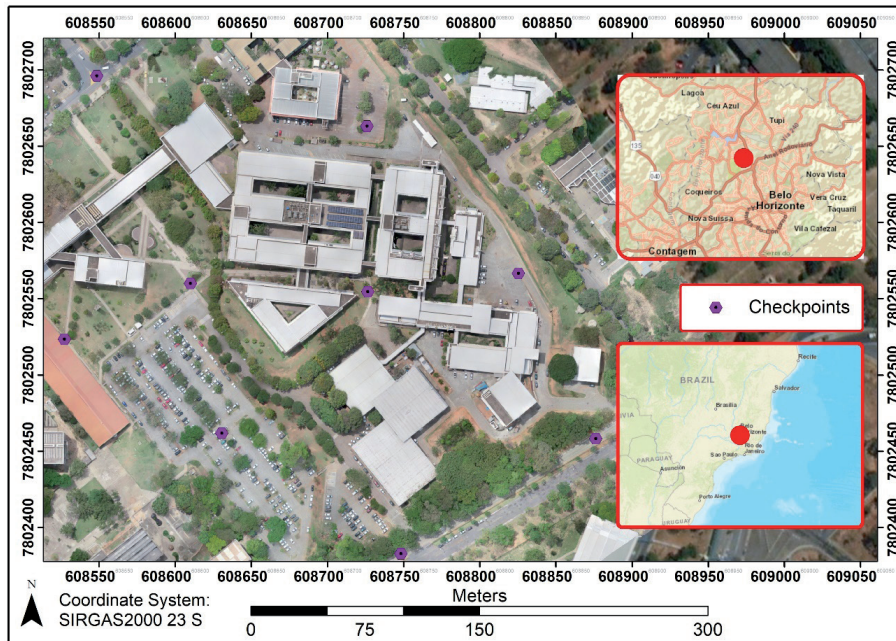


Figura 3 | Ortofoto com resolução espacial de 2 cm/pixel.

Fonte: Autores

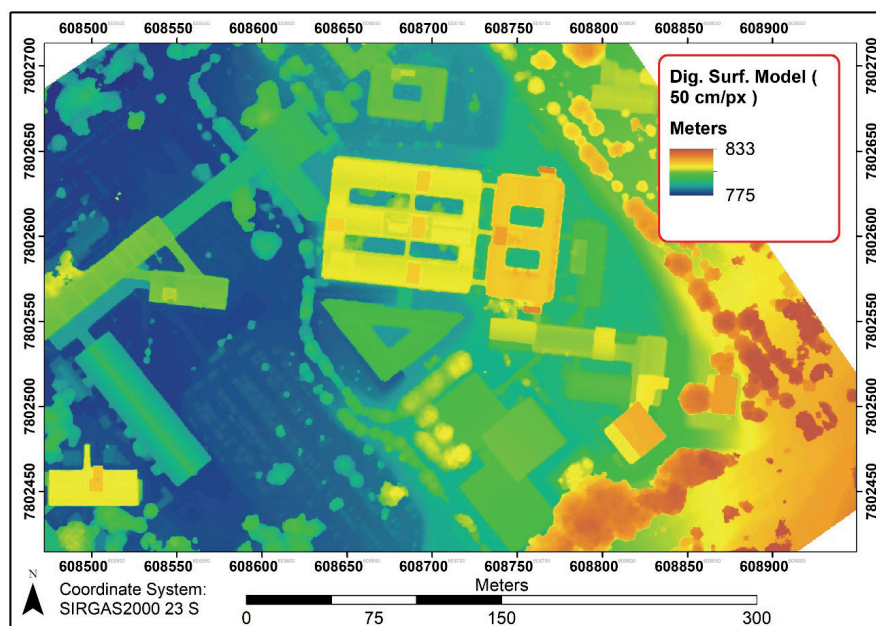


Figura 4 | Modelo Digital de Superfície de resolução espacial de 50 cm/pixel.

Fonte: Autores

## 5.2 MAPAS DE RADIAÇÃO SOLAR

A radiação solar incidente sobre uma superfície é obtida em função da inclinação e orientação desta. As figuras 5 e 6 apresentam essas informações para os telhados da EE-IGC-UFMG. Pode-se notar que os telhados possuem diferentes orientações e inclinações, resultando em diferentes resultados de radiação incidente.



Figura 5 | Declividade dos telhados da EE-IGC-UFMG.

Fonte: Autores

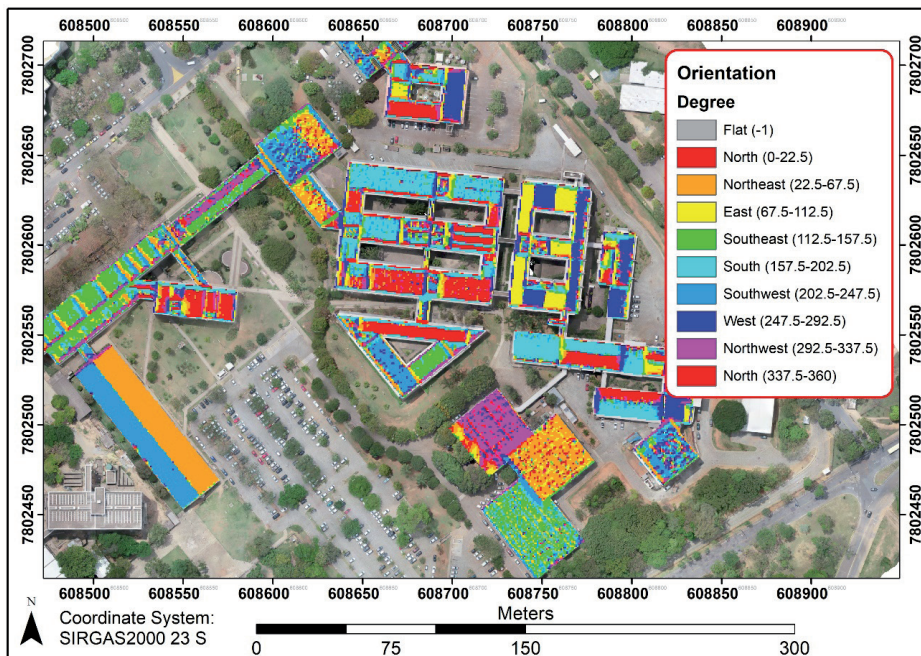


Figura 6 | Orientação da superfície dos telhados da EE-IGC-UFMG.

Fonte: Autores

Os principais resultados da ferramenta do *ARCGIS Solar Analyst*, que são o cálculo da radiação global anual e mensal, são apresentados nas figuras 7 e 8.

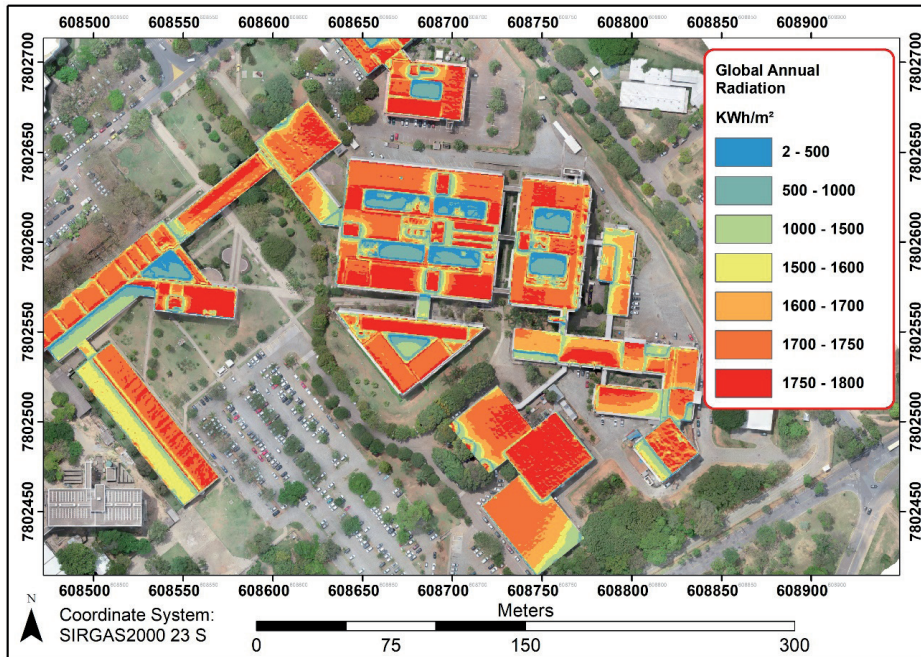


Figura 7 | Irradiância global anual da EE-IGC-UFMG.

Fonte: Autores

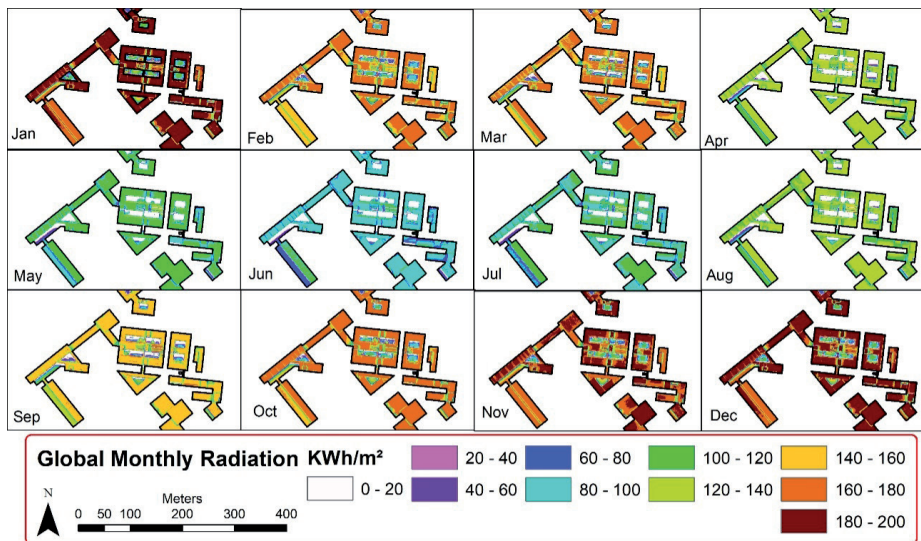


Figura 8 | Irradiância global mensal da EE-IGC-UFMG.

Fonte: Autores

Ao analisar os mapas de radiação, foi possível notar que alguns telhados possuem radiação incidente anual de até 1800 KWh/m<sup>2</sup>. Com a resolução do MDS utilizado, de 50 cm/pixel, foi possível identificar estruturas que impediriam a instalação de sistemas fotovoltaicos nos telhados, reduzindo assim a área disponível para tal. Também foi possível notar a influência do sombreamento causado por árvores e prédios vizinhos. Percebe-se também a maior incidência solar nos meses de verão em comparação com os de inverno.

## 6 DISCUSSÃO

### 6.1 LIDAR VS FOTOGRAMETRIA COM VANTS

A comparação entre a fotogrametria e o LiDAR já foi alvo de discussão de diversos autores. As duas tecnologias são viáveis para levantamentos em ambientes urbanos para instalação de sistemas fotovoltaicos. Em suma, levantamentos LiDAR tem o maior custo relativo por prédio e requer maior *expertise* para operação e processamento, dificilmente seria contratado por uma empresa ou uma pequena cidade (SZABO et al., 2016). Ao se tratar de grandes áreas, maior que 1 km<sup>2</sup>, a fotogrametria pode ser utilizada, mas também exige esforço computacional e *expertise* similar ao LiDAR (TENEDÓRIO et al., 2016). Vale destacar que, para pequenas regiões, a fotogrametria pode gerar dados de maneira periódica, com espontaneidade e baixo custo.

Há de se atentar para a resolução do MDS inserido na modelagem solar, que em sua maioria é de 1,0 m/pixel e obtido via levantamento LiDAR. Moudry et al. (2019) e Schuffer et al. (2015) apontam que MDSs com resoluções espaciais submétricas são desnecessários, pois a variação ao longo do ano devido às condições atmosféricas é significativamente maior que a variação causada pelas diferentes resoluções.

Em oposição, Besser et al. (2019) e Zink et al. (2015) apontam que em MDS de 1,0 m/pixel não é possível identificar com clareza a área disponível para implantação de sistemas fotovoltaicos, pois não há representação detalhada de objetos sobre os telhados que impediram a instalação, tais como chaminés, caixas de máquinas de elevadores, caixas-d'água, etc. Zink et al. (2015) concluem que a resolução ideal para solucionar essa dificuldade é 0,25 m/pixel, e avisa que resoluções mais detalhadas interferem negativamente na operação matricial de cálculo de declividade e orientação do pixel, levando às falsas estimativas de radiação.

Recomenda-se avaliar a resolução suficiente para identificação de estruturas e a demanda computacional, que depende basicamente da resolução desejada e tamanho da área levantada. Nesta pesquisa foi adotado 0,50 m/pixel, mas há necessidade de explorar com mais sensibilidade a variação de resolução.

### 6.2 POTENCIAIS TEÓRICO, TÉCNICO, ECONÔMICO, SOCIAL E AMBIENTAL

O arquivo matricial do modelo de radiação solar é expresso em KWh/m<sup>2</sup>. Uma metodologia hierárquica comumente adotada por diversos autores para transformar o potencial teórico em técnico e econômico é apresentada por Izquierdo et al. (2008). Consiste em três etapas: (i) o potencial físico (teórico), que é a soma total das radiações solares; (ii) o potencial técnico (elétrico, geográfico ou urbano), que relaciona a área disponível por telhado e a eficiência e a *performance* da placa fotovoltaica durante a transformação de energia solar em elétrica; e (iii) o potencial econômico, que considera o custo do sistema fotovoltaico durante o ciclo de vida, basicamente os custos de implantação e manutenção, preços locais da eletricidade e o tempo de retorno de investimento (ASSOULINE et al., 2017; CHENG et al., 2018; MARTÍN et al., 2015).

O potencial técnico terá precisão adequada quando o MDS tiver resolução suficiente para representar as morfologias dos prédios, o arranjo urbano e o sombreamento decorrente, além de identificar estruturas sobre os telhados (LA GENNUSA et al., 2011), como, por exemplo, a presença de casas de máquinas de elevadores, caixas-d'água, etc.

Outro detalhe relevante é a utilização correta de algoritmos para segmentação e extração de telhados em imagens aéreas ou de satélite de alta resolução para que a medida da área disponível para implantar placas PV em telhados seja mais próxima da realidade. SIG também são utilizados para esta etapa crucial. A revisão proposta por Crommelinck et al. (2016) discute técnicas para vetorização de telhados em levantamentos fotogramétricos com Vants, enquanto Camargo et al. (2015) utilizaram a

ferramenta aberta PKTools, e Ninsawat e Hassin (2016) utilizaram o *software* eCognition para realizar a segmentação de telhados. Também vale destacar o trabalho realizado por Faria (2017).

A eficiência e *performance* do sistema fotovoltaico dependerão do modelo, inversor e tempo de uso, como apontado por Lukac et al. (2014) e Wigiton et al. (2010). A não linearidade é um fator inerente aos materiais semicondutores que compõem a placa fotovoltaica e aos pontos máximos de inversão (LUKAC et al., 2014). Dessa forma, quanto mais informações a respeito das eficiências do material adotado (orgânico, silício amorfo, monocristalino ou policristalino, entre outros), maior será a acurácia da estimativa de energia produzida, e, conseqüentemente, melhor serão os planejamentos estratégicos. Por exemplo, as placas de silício monocristalino e policristalino possuem mais que o dobro de eficiência das demais citadas (BERGAMASCO; ASINARI, 2011).

Outros autores consideraram relevante trabalhar as informações geradas pelo modelo de radiação solar para avaliar os possíveis impactos ambientais (DESTHIEUX et al., 2018; IZKARA et al., 2019; NOWACKA; REMONDINO, 2018). Por meio do potencial de geração de energia elétrica, é possível obter a quantidade de CO<sub>2</sub> que deixou de ser emitida caso fosse utilizada uma fonte de energia fóssil (ANSELMA, 2012; PENG et al., 2013), também conhecida como carbono equivalente, ou CO<sub>2e</sub>. Esclapes et al. (2014) definiram a taxa de conversão de 0,60 KgCO<sub>2e</sub> / KWh produzido, enquanto Lukac et al. (2016) estimaram 0,53 KgCO<sub>2e</sub> / KWh.

Com essa informação, a administração pública possui dados quantitativos para desenvolver políticas ambientais de combate às mudanças climáticas (CAMARGO et al., 2015) e pode incluir o CO<sub>2e</sub> oriundo da microgeração distribuída nas metas ambientais. Mavromatidis et al. (2015) afirmam que, em caso de ausência de políticas ambientais, é comum que o critério econômico seja seguido no processo de tomada de decisão.

Em relação à dimensão social, apontam-se duas abordagens propostas por Swam e Ugursal (2009): *top-down* e *bottom-up*. A primeira consiste em considerar setores residenciais em blocos, enquanto que a segunda consiste em avaliar individualmente os consumidores finais. A escala e a finalidade do mapeamento da radiação solar definem qual das abordagens adotar. Santos et al. (2014) estimularam a demanda energética de cada prédio e a classificaram em grupos com base na demanda local média *per capita*, nos volumes, áreas e altura de prédios, e na distribuição populacional.

Wigiton et al. (2010) adotaram a densidade populacional e a demanda de área de telhado *per capita* para quantificar o potencial fotovoltaico de Ontário (Canadá) para políticas públicas de energias renováveis. Gooding et al. (2011) estabeleceram critérios socioeconômicos para identificar locais de maior potencial, tais como renda, educação, consciência ambiental, quantidade de prédios e de proprietários. Kauzika et al. (2017), em estudo sobre a difusão da microgeração utilizando ferramentas solares, também apontaram quatro critérios sociais de maior relevância para aproveitamento fotovoltaico em prédios: renda, valor da casa, vizinhos que já possuem placas fotovoltaicas e consumo energético.

### 6.3 APLICAÇÃO DO MAPA DE RADIAÇÃO SOLAR

A disponibilidade de dados de energia fotovoltaica vem crescendo, assim como as cidades que disponibilizam essa informação. Na linha de metas sustentáveis, modelar o fenômeno da radiação solar em telhados é interessante para administradores públicos e investidores que desejam integrar planejamento urbano com a microgeração (FONSECA et al., 2016).

Nesse contexto, urbanistas e gestores públicos requerem visão compreensiva das oportunidades e do custo-benefício para otimizar a *performance* energética dos prédios. Também têm responsabilidades de revelar e comunicar de modo eficaz à população as informações sobre o potencial fotovoltaico e econômico, para mantê-la esclarecida e encurtar a transição energética no local. Notadamente, modelos solares em SIG são ferramentas que devem ser exploradas para atender a essas demandas.



Castellanos et al. (2017) sustentam que ter ferramentas precisas, acessíveis e de fácil compreensão para avaliar o potencial fotovoltaico é esperado para o desenvolvimento de políticas públicas apropriadas. Alertam também que decisões políticas são difíceis, pois administradores dependem de informações genéricas de modelos solares de baixa resolução ou precisam investir altas quantias para fazer a pesquisa de uma certa área em alta resolução.

De acordo com Santos et al. (2014), o planejamento básico para investimento em sistemas fotovoltaicos deve conter informações em relação à demanda energética e à capacidade de geração. Mais ainda, adotar a abordagem *bottom-up*, de discretização de prédios, é fundamental para um planejamento integral. E para tal, é necessário modelar o ambiente urbano, a radiação solar incidente e as áreas disponíveis nos telhados. Em sua maioria, o interesse público é de aumentar a participação da microgeração, e o interesse privado é implantar sistemas fotovoltaicos para gerar lucros (CAMARGO et al., 2015).

Mais recentemente, autores analisam a situação energética de forma mais aprofundada, considerando a maximização da participação de microgeração na rede elétrica e a minimização de investimentos (CAMARGO et al., 2015; LINGFORS et al., 2017; MAVROMATIDIS et al., 2015) e não uma análise direta da capacidade de potencial máximo com base em critérios técnicos. Decidir objetivamente a porcentagem adequada de penetração e ter um plano concreto para alcançá-la é, sem dúvida, uma contribuição para moldar a sustentabilidade energética e otimizar o uso do espaço.

O aumento excessivo da participação de microgeração apresenta prejuízos para todo o setor, que serão discutidos na seção seguinte. É importante evidenciar estudos que quantificaram a área total apropriada para instalação de sistemas fotovoltaicos, como Hofierka e Kanuk (2009) que classificaram 59% da área de telhados disponíveis em Bardejov, Eslováquia, como sendo apropriada, sendo 39% residências. Lee et al. (2018), em estudo no distrito de Gangnam, em Seoul, Coreia do Sul, classificaram prédios em quatro categorias, tendo como critérios técnico e financeiro, o potencial fotovoltaico e a rentabilidade.

No contexto de transição sustentável em uma cidade, Radzi e Droege (2013) indicam que mapear a capacidade de energias renováveis, os fluxos de energia, entender quais telhados e espaços abertos estão disponíveis para implantar sistemas renováveis de conversão em energia elétrica e termal são a base para alcançar a independência energética, de modo estruturado e com propósito. Ademais, De Waal e Stremke (2014) indicam que modelos solares são ferramentas que podem dar os primeiros passos para o debate de transição energética e preceder e auxiliar a criação de cenários espaciais e de visões estratégicas. Desthieux et al. (2018) justificam que a ferramenta *on-line* desenvolvida teve como meta principal promover a transição energética na escala local de Genebra, Suíça.

No contexto de mapeamento solar em áreas urbanas, a adoção de ferramentas *on-line*, de interface de fácil compreensão, que vetorizam telhados para compor o cadastro solar e que expõem dados objetivos é uma tendência. Besser et al. (2019) afirmam que essa abordagem resulta em decisões mais racionais e efetivas, e a população obtém informações de maneira fácil e transparente. Freitas et al. (2015) consideram que a última etapa em uma avaliação do potencial fotovoltaico é o desenvolvimento de uma plataforma *on-line*. Como exemplo de plataformas, têm-se: Jakubiec e Reinhart (2013) e Kruger e Kolbe (2012) – que resultou no projeto Mapdweel –, Desthieux et al. (2018) e Roberts et al. (2018) – que resultou no projeto APVI Solar Potential Tool (SunSPoT) – e Izkara et al. (2019).

Os *websites* devem definir o público-alvo, adaptar o conteúdo para o consumidor final e evitar esconder ou perder a qualidade da informação. Besser et al. (2019) elencam cinco principais atribuições de uma plataforma *on-line*: (i) identificação de partes disponíveis em telhados para instalação de sistemas fotovoltaicos e a capacidade anual de produção; (ii) quantidade de área disponível (m<sup>2</sup>), capacidade potencial de instalação (MW), capacidade potencial de geração (MWh) e indicadores ambientais e econômicos; (iii) visualização de mapas coloridos de potenciais e gráficos relacionando a geração fotovoltaica e economia para cada telhado; (iv) disponibilização de informações referentes ao telhado, como orientação, inclinação, entre outras que auxiliem na instalação e *design* do sistema fotovoltaico; e (v) geração de relatórios em PDF ou CSV.

## 6.4 DIFICULDADES E LIMITAÇÕES

Os modelos solares em SIG, apesar de serem considerados ferramentas para gestão que solucionam problemas e esclarecem decisões, ainda assim apresentam aspectos e metodologias que estão sendo aprimorados e otimizados. Podemos citar como exemplo a quantificação da penetração máxima de energia fotovoltaica na rede elétrica, a calibração de modelos solares, a extrapolação de modelos solares de resolução duvidosa, os custos relativamente altos para levantamentos LiDAR e a falta de comunicação eficiente com o público-alvo.

Uma das maiores dificuldades que o setor fotovoltaico ainda enfrenta é o desequilíbrio entre a geração e o consumo de energia elétrica ao longo do dia. A solução óbvia seria exportar eletricidade para a rede elétrica, porém, para casos em que há alta penetração de energia fotovoltaica na rede, esse excesso de eletricidade causaria desestabilidades na distribuição e reduziria a qualidade do serviço, além de reduzir a tarifa da energia elétrica devido à alta oferta (JANKO et al., 2016; TONKOSKI et al., 2012).

Para completar, na análise financeira, a combinação dos espaços temporais entre produção e consumo e o fenômeno de alta penetração implicam em redução nos valores de investimento e aumento do tempo de retorno de investimento, pois o custo da energia reduz com grande oferta durante o dia e nas horas de maior consumo – à noite, quando as tarifas podem ser maiores – não há geração de energia fotovoltaica (CAMARGO et al., 2018; ORIOLI; DI GANGI, 2013).

Camargo e Stoeglehner (2018) concluíram que participações de energia fotovoltaica na rede em torno de 20% não geram impactos consideráveis na distribuição e confiabilidade da rede elétrica, enquanto que mais de 40% resultam em queda dos indicadores de qualidade e confiabilidade. Também afirmam que estabelecer metas para um local específico requer análises técnicas e fatores econômicos para definir o limite de participação fotovoltaica. Mavromatidis et al. (2015), em estudo similar, mas tendo uma vila como exemplo, apontam 29% o valor ideal de participação para que o máximo da demanda energética seja satisfeito à geração fotovoltaica, sem a necessidade de armazenamento de energia, enquanto que 58% seria a participação ideal, caso houvesse armazenamento, fazendo com que toda a demanda energética seja suprida pela geração fotovoltaica.

No tocante à calibração de modelos, Szewczyk (2018) apresenta calibração de presença de nuvens no modelo *GRASS r.sun* e adverte que, em relação ao cadastro solar, as duas maiores dificuldades são obter dados tridimensionais da área urbana e a inserção de informações a respeito da nebulosidade ao longo do ano. Como é o caso de Roberts et al. (2018), que utilizaram *ARCGIS Solar Analyst* e dados do NREL para calibragem, enquanto Adelek e Smit (2016) utilizaram *GRASS r.sun* e adotaram os dados da *Surface meteorology and Solar Energy* (SSE) Nasa.

Szewczyk (2018) ajustou seu modelo *GRASS r.sun* utilizando dados do projeto SoDa e salienta que o algoritmo é preciso para dias de céu limpo, mesmo sem ajustes. Ajustar os modelos SIG utilizando dados em solo ou de satélites com sensores termais é de extrema relevância para que planejamentos energéticos, financeiros, ambientais e políticos sejam desenvolvidos com base em valores reais, evitando excessos e perdas em projetos particulares ou de escalas maiores.

Vale ressaltar estudo comparativo realizado por Castellanos et al. (2017) em que compara modelos solares com base em LiDAR encontrados na literatura revisada com modelos solares com base em dados de satélite e, portanto, de menor resolução, como do Google Sunroof, do Mapdwell e da Agência Internacional de Energia. Os principais resultados indicam variações de até 207% entre modelos de baixa resolução e 115% entre modelos de diferentes resoluções. Computaram também o desvio percentual do erro, contabilizando diferenças maiores que 300%. Dessa forma, os tomadores de decisão se encontram em uma posição difícil, pois ficam dependentes de informações de baixa precisão, ou terão que investir em pesquisas de LiDAR, reconhecidas pelo seu alto custo (CASTELLANOS et al., 2017).

Outra barreira discutida por autores é a funcionalidade da ferramenta perante a praticidade e a aceitação e a participação do público-alvo. Jakica (2018), após revisar centenas de modelos solares, realça a baixa qualidade da visualização dinâmica das informações e critica a baixa disponibilidade de algoritmos com código aberto. Wijeratne et al. (2018) revisaram 27 programas e aplicativos de gerenciamento e projeto de sistemas solares e apontaram 14 problemas relacionados às ferramentas. Vale destacar: (i) a falta de dados meteorológicos com baixo intervalo de tempo entre as amostras, modelagem 3D de alta qualidade e individualização de telhados; (ii) falta de dados locais de serviços e produtos relativos ao setor fotovoltaico; (iii) falta de informação em relação às tarifas e análise financeiras; (iv) falta de informações em relação a incentivos governamentais; e (v) interfaces dos programas e aplicativos não são amigáveis.

## 7 CONCLUSÃO

Este artigo teve os objetivos atingidos, que foram construir um modelo de radiação solar para os prédios da EE-IGC-UFMG; discutir aspectos de relevância no tocante aos modelos de potencial fotovoltaico, diante de distintos modelos de elevação adotados como dado de entrada; os potenciais técnico, econômico, social e ambiental que a modelagem da radiação solar pode explorar; as aplicações práticas para planejamento e tomada de decisão; uso de ferramentas *on-line* e algumas dificuldades associadas.

Sugere-se que este tipo de estudo, pautado majoritariamente em aspectos geográficos da região, seja agregado a análises de multicritérios que ponderem as metas de redução de emissão de CO<sub>2</sub>, o custo da tarifa e as formas de financiamento, a capacidade do sistema de distribuição de energia elétrica e a demanda energética, formando um conjunto robusto de dados para tomada de decisão pelos gestores do setor privado e do público. Ressalta-se que estimar o potencial fotovoltaico em prédios auxilia o planejamento financeiro, energético e ambiental para atender às demandas sociais em escala local.

Para pesquisa futura, os autores deste artigo planejam expandir a escala de aplicação dos modelos solares para o *campus* da UFMG ou uma cidade de menor porte, assim como também aprofundar nas aplicações e potenciais abordados ao longo do texto. Este artigo apresenta apenas os resultados iniciais de uma pesquisa mais ampla.

## NOTAS

1 | European Solar Radiation Data: <http://www.soda-is.com>

2 | National Renewable Energy Laboratory: <https://maps.nrel.gov/nsrdb-viewer>

3 | Google Sunroof: <https://www.google.com/get/sunroof>

4 | Mapdwell: <https://www.mapdwell.com/en/solar>

## REFERÊNCIAS

AGÊNCIA NACIONAL DE ENERGIA ELÉTRICA. Resolução Normativa Nº 482, de 17 de Abril de 2012. Disponível em: <<http://www.aneel.gov.br/cedoc/ren2012482.pdf>>. Acesso em: 09 maio 2019.

AMADO, M.; POGGI, F.; AMADO, A. R. Energy efficient city: a model for urban planning. **Sustainable Cities and Society**, v. 26, p. 476-485, 2016.

ASIF, M. Urban scale application of solar PV to improve sustainability in the building and the energy sectors of KSA. **Sustainability**, v. 8, n. 11, p. 1127, 2016.

ASSOULINE, D.; MOHAJERI, N.; SCARTEZZINI, J-L. Quantifying rooftop photovoltaic solar energy potential: a machine learning approach. **Solar Energy**, v. 141, p. 278-296, 2017.

- BERGAMASCO, L.; ASINARI, P. Scalable methodology for the photovoltaic solar energy potential assessment based on available roof surface area: application to Piedmont Region (Italy). **Solar energy**, v. 85, n. 5, p. 1041-1055, 2011.
- BESSER, A. et al. A Customized Decision Support System for Renewable Energy Application by Housing Association. **Sustainability**, v. 11, n. 16, p. 4377, 2019.
- CAMARGO, L. R. et al. Spatio-temporal modeling of roof-top photovoltaic panels for improved technical potential assessment and electricity peak load offsetting at the municipal scale. **Computers, Environment and Urban Systems**, v. 52, p. 58-69, 2015.
- CAMARGO, L. R.; STOEGLEHNER, G. Spatiotemporal modelling for integrated spatial and energy planning. **Energy, Sustainability and Society**, v. 8, n. 1, p. 32, 2018.
- CASTELLANOS, S.; SUNTER, D. A.; KAMMEN, D. M. Rooftop solar photovoltaic potential in cities: how scalable are assessment approaches?. **Environmental Research Letters**, v. 12, n. 12, p. 125005, 2017.
- CHENG, L. et al. Use of LiDAR for calculating solar irradiance on roofs and façades of buildings at city scale: methodology, validation, and analysis. **ISPRS Journal of Photogrammetry and remote sensing**, v. 138, p. 12-29, 2018.
- CHOI, Y.; SUH, J.; KIM, S-M. GIS-Based Solar Radiation Mapping, Site Evaluation, and Potential Assessment: a review. **Applied Sciences**, v. 9, n. 9, p. 1960, 2019.
- CHOW, A.; FUNG, A.; LI, S. GIS modeling of solar neighborhood potential at a fine spatiotemporal resolution. **Buildings**, v. 4, n. 2, p. 195-206, 2014.
- CINTRA, J.; NERO, M.; RODRIGUES, D. GNSS/NTRIP service and technique: accuracy tests. **Boletim de Ciências Geodésicas**, v. 17, n. 2, p. 257-271, 2011.
- COLOMINA, I.; MOLINA, P. Unmanned aerial systems for photogrammetry and remote sensing: a review. **ISPRS Journal of Photogrammetry and remote sensing**, v. 92, p. 79-97, 2014.
- DAMMALAGE, T. L. et al. Potential accuracy and practical benefits of NTRIP protocol over conventional RTK and DGPS observation methods. **Map Asia**, v. 29, 2006.
- DE WAAL, R.; STREMKER, S. Energy transition: missed opportunities and emerging challenges for landscape planning and designing. **Sustainability**, v. 6, n. 7, p. 4386-4415, 2014.
- DESTHIEUX, G. et al. Solar cadaster of Geneva: a decision support system for sustainable energy management. In: **From Science to Society**. Springer, Cham, 2018. p. 129-137.
- ESCLAPÉS, J. et al. A method to evaluate the adaptability of photovoltaic energy on urban façades. **Solar Energy**, v. 105, p. 414-427, 2014.
- ESCOBAR, R. A. et al. Estimating the potential for solar energy utilization in Chile by satellite-derived data and ground station measurements. **Solar Energy**, v. 121, p. 139-151, 2015.
- FALKNER, R. The Paris Agreement and the new logic of international climate politics. **International Affairs**, v. 92, n. 5, p. 1107-1125, 2016.
- FARIA, T. S. **Classificação em área urbana apoiada em imagens aéreas e dados LiDAR**. Dissertação (Mestrado) – Universidade Federal de Minas Gerais, 2017, 94p.
- FARMER, J. D.; LAFOND, F. How predictable is technological progress? **Research Policy**, v. 45, n. 3, p. 647-665, 2016.
- FONSECA, J. A.; SCHLUETER, A. Integrated model for characterization of spatiotemporal building energy consumption patterns in neighborhoods and city districts. **Applied Energy**, v. 142, p. 247-265, 2015.
- FREITAS, S. et al. Modelling solar potential in the urban environment: state-of-the-art review. **Renewable and Sustainable Energy Reviews**, v. 41, p. 915-931, 2015.

GIELEN, D.; BOSHELL, F.; SAYGIN, D. Climate and energy challenges for materials science. **Nature materials**, v. 15, n. 2, p. 117, 2016.

GOODING, J. et al. Solar City Indicator: a methodology to predict city level PV installed capacity by combining physical capacity and socio-economic factors. **Solar Energy**, v. 95, p. 325-335, 2013.

HOFIERKA, J. et al. The solar radiation model for Open source GIS: implementation and applications. In: **Proceedings of the Open source GIS-Grass users conference**. 2002. p. 51-70.

HOFIERKA, J.; KAŇUK, J. Assessment of photovoltaic potential in urban areas using open-source solar radiation tools. **Renewable energy**, v. 34, n. 10, p. 2206-2214, 2009.

INTERNATIONAL ENERGY AGENCY. **Energy Outlook 2018**. International Energy Agency Paris, France, 2018.

IZKARA, J. L.; EGUSQUIZA, A.; VILLANUEVA, A. GIS-3D Platform to Help Decision Making for Energy Rehabilitation in Urban Environments. In: **IOP Conference Series: earth and environmental science**. IOP Publishing, 2019. p. 012122.

IZQUIERDO, S.; RODRIGUES, M.; FUEYO, N. A method for estimating the geographical distribution of the available roof surface area for large-scale photovoltaic energy-potential evaluations. **Solar Energy**, v. 82, n. 10, p. 929-939, 2008.

JAKICA, N. State-of-the-art review of solar design tools and methods for assessing daylighting and solar potential for building-integrated photovoltaics. **Renewable and Sustainable Energy Reviews**, v. 81, p. 1296-1328, 2018.

JAKUBIEC, J. A.; REINHART, C. F. A method for predicting city-wide electricity gains from photovoltaic panels based on LiDAR and GIS data combined with hourly Daysim simulations. **Solar Energy**, v. 93, p. 127-143, 2013.

JANKO, S. A.; ARNOLD, M. R.; JOHNSON, N. G. Implications of high-penetration renewables for ratepayers and utilities in the residential solar photovoltaic (PV) market. **Applied Energy**, v. 180, p. 37-51, 2016.

KAUSIKA, B. B.; DOLLA, O.; VAN SARK, W. Assessment of policy based residential solar PV potential using GIS-based multicriteria decision analysis: a case study of Apeldoorn, The Netherlands. **Energy Procedia**, v. 134, p. 110-120, 2017.

KODYSH, J. B. et al. Methodology for estimating solar potential on multiple building rooftops for photovoltaic systems. **Sustainable Cities and Society**, v. 8, p. 31-41, 2013.

KRÜGER, A.; KOLBE, T. H. Building analysis for urban energy planning using key indicators on virtual 3D city models – The energy atlas of Berlin. **International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences**, v. 39, n. B2, p. 145-150, 2012.

LA GENNUSA, M. et al. A model for predicting the potential diffusion of solar energy systems in complex urban environments. **Energy Policy**, v. 39, n. 9, p. 5335-5343, 2011.

LEE, M. et al. Development of a rooftop solar photovoltaic rating system considering the technical and economic suitability criteria at the building level. **Energy**, v. 160, p. 213-224, 2018.

LINGFORS, D. et al. Comparing the capability of low-and high-resolution LiDAR data with application to solar resource assessment, roof type classification and shading analysis. **Applied Energy**, v. 205, p. 1216-1230, 2017.

LUDWIG, D.; MCKINLEY, L. Solar Atlas of Berlin-Airborne Lidar in Renewable Energy Applications. **GIM Int**, v. 24, n. 3, p. 17-22, 2010.

LUKAC, N. et al. Buildings roofs photovoltaic potential assessment based on LiDAR (Light Detection And Ranging) data. **Energy**, v. 66, p. 598-609, 2014.

LUKAC, N. et al. Economic and environmental assessment of rooftops regarding suitability for photovoltaic systems installation based on remote sensing data. **Energy**, v. 107, p. 854-865, 2016.

MARTÍN, A. M.; DOMÍNGUEZ, J.; AMADOR, J. Applying LiDAR datasets and GIS based model to evaluate solar potential over roofs: a review. **AIMS Energy**, v. 3, n. 3, p. 326-343, 2015.

- MAVROMATIDIS, G.; OREHOUNIG, K.; CARMELIET, J. Evaluation of photovoltaic integration potential in a village. **Solar Energy**, v. 121, p. 152-168, 2015.
- MELIUS, J.; MARGOLIS, R.; ONG, S. **Estimating rooftop suitability for PV: a review of methods, patents, and validation techniques**. National Renewable Energy Lab. (NREL), Golden, CO (United States), 2013.
- MOUDRÝ, V.; BEKOVÁ, A.; LAGNER, O. Evaluation of a high resolution UAV imagery model for rooftop solar irradiation estimates. **Remote Sensing Letters**, v. 10, n. 11, p. 1077-1085, 2019.
- NINSAWAT, S.; HOSSAIN, M. Identifying potential area and financial prospects of rooftop solar photovoltaics (PV). **Sustainability**, v. 8, n. 10, p. 1068, 2016.
- NOWACKA, A.; REMONDINO, F. Geospatial data for energy efficiency and low carbon cities – overview, experiences and new perspectives. **International Archives of the Photogrammetry, Remote Sensing & Spatial Information Sciences**, 2018.
- PENG, J.; LU, L.; YANG, H. Review on life cycle assessment of energy payback and greenhouse gas emission of solar photovoltaic systems. **Renewable and sustainable energy reviews**, v. 19, p. 255-274, 2013.
- PEREIRA, E. B. et al. **Atlas brasileiro de energia solar**. São José dos Campos: Inpe, 2006.
- POLO, J.; PEREZ, R. Solar radiation modeling from satellite imagery. In: **Solar Resources Mapping**. Springer, Cham, 2019. p. 183-197.
- RADZI, A.; DROEGE, P. Governance tools for local energy autonomy. In: **Climate Change Governance**. Springer, Berlin, Heidelberg, 2013. p. 227-242.
- REMONDINO, F. et al. Low-cost and open-source solutions for automated image orientation – A critical overview. In: **Euro-Mediterranean Conference**. Springer, Berlin, Heidelberg, 2012. p. 40-54.
- ROBERTS, M. B.; COPPER, J.; BRUCE, A. Analysis of Rooftop Solar Potential on Australian Residential Buildings. In: **Asia Pacific Solar Research Conference**. 2018.
- SANTOS, T. et al. Applications of solar mapping in the urban environment. **Applied Geography**, v. 51, p. 48-57, 2014.
- SARMIENTO, N. et al. A solar irradiation GIS as decision support tool for the Province of Salta, Argentina. **Renewable Energy**, v. 132, p. 68-80, 2019.
- SCHUFFERT, S. et al. Quality assessment of roof planes extracted from height data for solar energy systems by the EAGLE platform. **Remote Sensing**, v. 7, n. 12, p. 17016-17034, 2015.
- SZABÓ, S. et al. Automated registration of potential locations for solar energy production with Light Detection And Ranging (LiDAR) and small format photogrammetry. **Journal of Cleaner Production**, v. 112, p. 3820-3829, 2016.
- SZEWCZYK, M.; SZEWCZYK, L. Modelling of real solar radiation spatial distribution as a tool for solar energy cadastre in the cities. **Energy & Environment**, v. 29, n. 2, p. 204-215, 2018.
- TENEDÓRIO, J. A. et al. Remote sensing from unmanned aerial vehicles for 3D urban modelling: case study of Loulé, Portugal. In: **Back to the Sense of the City: international monograph book**. Centre de Política de Sòl i Valoracions, 2016. p. 1118-1128.
- TONKIN, T.; MIDGLEY, N. Ground-control networks for image based surface reconstruction: an investigation of optimum survey designs using UAV derived imagery and structure-from-motion photogrammetry. **Remote Sensing**, v. 8, n. 9, p. 786, 2016.
- TONKOSKI, R.; TURCOTTE, D.; EL-FOULY, T. H. M. Impact of high PV penetration on voltage profiles in residential neighborhoods. **IEEE Transactions on Sustainable Energy**, v. 3, n. 3, p. 518-527, 2012.
- UNITED NATIONS. **Paris agreement 2015**. Disponível em: <[https://unfccc.int/sites/default/files/english\\_paris\\_agreement.pdf](https://unfccc.int/sites/default/files/english_paris_agreement.pdf)>. Acesso em: 12 set. 2019.

WAN, C. et al. Photovoltaic and solar power forecasting for smart grid energy management. **CSEE Journal of Power and Energy Systems**, v. 1, n. 4, p. 38-46, 2015.

WEBER, G.; DETTMERING, D.; GEBHARD, H. Networked transport of RTCM via internet protocol (NTRIP). In: **A Window on the Future of Geodesy**. Springer, Berlin, Heidelberg, 2005. p. 60-64.

WIGINTON, L. K.; NGUYEN, H. T.; PEARCE, J. M. Quantifying rooftop solar photovoltaic potential for regional renewable energy policy. **Computers, Environment and Urban Systems**, v. 34, n. 4, p. 345-357, 2010.

WIJERATNE, W. M. P. U. et al. Design and development of distributed solar PV systems: Do the current tools work? **Sustainable cities and society**, 2018.

YANG, D. et al. History and trends in solar irradiance and PV power forecasting: a preliminary assessment and review using text mining. **Solar Energy**, v. 168, p. 60-101, 2018.

ZINK, R. et al. Photogrammetric point clouds for GIS-based high-resolution estimation of solar radiation for rooftop solar systems. In: **Surface Models for Geosciences**. Springer, Cham, 2015. p. 293-305.

# Dry port location optimization to foster sustainable regional development

*Otimização locacional de portos secos para fomentar o desenvolvimento regional sustentável*

Marlon Fernandes de Souza<sup>a</sup>

Paulo H. Góes Pinto<sup>b</sup>

Raphael B. Alves Teixeira<sup>c</sup>

Carla de O. Leite Nascimento<sup>d</sup>

Rodrigo A. de Albuquerque Nóbrega<sup>e</sup>

<sup>a</sup>University of Campinas (UNICAMP), School of Agricultural Engineering, Campinas, SP, Brazil.  
E-mail: marlonfernandesdesouza@gmail.com

<sup>b</sup>Federal University of Minas Gerais (UFMG), School of Engineering, Belo Horizonte, MG, Brazil.  
E-mail: paulo-goes@ufmg.br

<sup>c</sup>Federal University of Minas Gerais (UFMG), School of Engineering, Belo Horizonte, MG, Brazil.  
E-mail: teixeiraraph@outlook.com

<sup>d</sup>Federal University of Minas Gerais (UFMG), School of Engineering, Belo Horizonte, MG, Brazil.  
E-mail: carla.olin@gmail.com

<sup>e</sup>Federal University of Minas Gerais (UFMG), Geosciences Institute and School of Engineering, Belo Horizonte, MG, Brazil.  
E-mail: raanobrega@ufmg.br

doi:10.18472/SustDeb.v11n2.2020.27073

Received: 06/09/2019  
Accepted: 01/06/2020

ARTICLE- DOSSIER

## ABSTRACT

The saturation of hinterland accentuates adverse environmental impacts and socio-spatial conflicts, demanding logistical alternatives. As a solution, the dry port enables the decentralization of customs, handling, and storage operations, which mitigates part of the problems, in addition to stimulating the economy in the region where it operates. Thus, its location is crucial for the efficiency of import and export logistic systems. This paper aimed to evaluate the spatial distribution of dry ports in Minas Gerais, Brazil, and to identify the best locations for a new installation. The methodology put together two recognized methods for location definition: the Spatial Multicriteria Analysis and the Location-Allocation Problem. The first, in line with the most current practices in transportation planning, integrated social, environmental and technical criteria. The second adopted the first's result as weighted demand and applied a metaheuristic to solve an optimization problem. Findings show the regional disparity and the deficiency of logistic infrastructures in the north of Minas Gerais. All scenarios point to the Montes



Claros region as a candidate for the installation of a dry port. The possibility of reconciling society, environment and economy in infrastructure planning was demonstrated.

**Keywords:** AHP. Transportation Planning. Sustainable Regional Development. Inland Port. Location-Allocation.

## RESUMO

*A saturação das zonas de influência portuária acentua impactos ambientais e conflitos socioespaciais, demandando alternativas logísticas. O porto seco possibilita a descentralização de atividades aduaneiras, de manuseio e armazenagem, mitigando parte dos problemas, além de estimular a economia na região onde é inserido. Dessa forma, a sua localização é crucial para a eficiência dos sistemas logísticos de importação e exportação. O objetivo deste trabalho foi avaliar a distribuição espacial dos portos secos em Minas Gerais e identificar os melhores locais para uma nova instalação. A metodologia agregou dois métodos reconhecidos de definição locacional: a Análise Multicritério Espacial e o Problema de Localização-Alocação. O primeiro, em consonância com as práticas mais atuais no planejamento de transporte, integrou critérios sociais, ambientais e técnicos. O segundo, adotou o resultado da análise multicritério como demanda ponderada e aplicou uma meta heurística para solução do problema de otimização. Os resultados evidenciam a disparidade regional e a deficiência de infraestruturas logísticas no norte de Minas. Todos os cenários apontam a região de Montes Claros como candidata à instalação de um porto seco. A possibilidade de conciliar sociedade, ambiente e economia no planejamento de infraestrutura foi demonstrada.*

**Palavras-chave:** AHP. Planejamento de Transportes. Desenvolvimento Regional Sustentável. Estação Aduaneira Interior. Localização-Alocação.

## 1 INTRODUCTION

Globalization was responsible for growth in commercial operations around the world with a consequent increase in the movement of goods and tax procedures for imports and exports. This high demand scenario for cargo transportation has saturated the ports and affected the costs of the international trading operation (GERMANO; FREIRE JUNIOR, 2017; NG; PADILHA; PALLIS, 2013). In addition to the economic and bureaucratic losses, the saturation of the seaport hinterlands intensifies the environmental impacts and socio-spatial conflicts (AWAD-NÚÑEZ et al., 2016a).

As for the environmental standpoint, the construction or even the expansion of a seaport invariably affects the local ecosystem. The ecological impacts are amplified as most seaports are located in estuaries (DINWOODIE et al., 2012; GOULIELMOS, 2013). Sinay, Carvalho and Braga (2017), Oliveira et al. (2013), and Jaffee (2015) report a series of social and environmental impacts related to the port operation. In addition, Sinay, Carvalho and Braga (2017) affirm the principal consequences of a port operation comes from the supplementary activities in the port vicinity where the overlapping areas of influence and the intensity of the activities produce cumulative and synergistic effects (KOEHLER; ASMUS, 2010).

In Brazil, the situation is even worst due to the elevated growth of exports experienced along the last decades in association with the deficient conservation of the existing logistic infrastructure and the lack of investments in new infrastructure (CHINELATO; CRUZ; ZIVIANI, 2011; MEDEIROS, 2014; WANKE; HIJJAR, 2009). Between 2010 and 2018 the port activity in Brazil increased by 33.2% (ANTAQ, 2018). Limiting space for the growth of yards and warehouses is a reality for most Brazilian seaports, which increases truck traffic on highways and long queues for loading and unloading in port cities (GERMANO; FREIRE JUNIOR, 2017).

In this context the dry ports (DP) emerge as an alternative, acting as facilitators for storage, customs clearance, consolidation, and handling of cargo. (AWAD-NÚÑEZ et al., 2016b; GERMANO; FREIRE JUNIOR, 2017). Thus, the DP can be understood as intermodal land terminals strongly connected to seaports through a frequent and/or a high capacity transport service (NGUYEN; NOTTEBOOM, 2016; ROSO; WOXENIUS; LUMSDEN, 2009). In practice, a DP operates as logistic hinterlands, i.e. an inland

region lying behind a port to facilitate moving cargo between the seaport and the interior with improved performance (LOUREIRO; FREITAS; GONÇALVES, 2015).

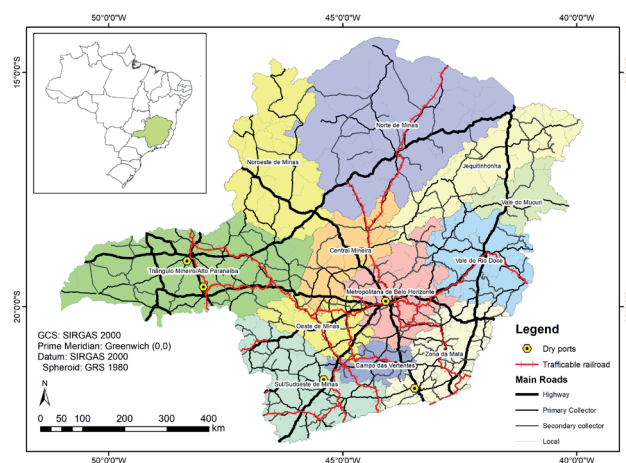
The decentralization of part of the seaport activities stands out among the main advantages of a DP, since it brings the customs activities closer to the cargo's origin or destination. Other than the enhanced logistic solutions, DP also drives revenue and job creation in the region where it operates. Moreover, it creates the possibility to continuously release imports and exports over time, distributing customs expenses evenly during the financial year instead of a single large payment. Roso, Woxenius and Lumsden (2009) also highlight the DP reinforces the changing from road transportation to a more efficient and environmentally friendly transportation mode.

With this in mind, the objective of this paper was to assess the spatial distribution of the DP in Minas Gerais - Brazil, therefore indicating the best-feasible sites for proposing new DP in the state. The methodology that supported the analysis integrated two well-known methods used for geospatial location: the Spatial Multi-Criteria Analysis (SMCA) (LIGMANN-ZIELINSKA; JANKOWSKI, 2014; RAHMAN et al., 2013; SADASIVUNI et al., 2009) and the Location-Allocation Problem (LAP) (HILLSMAN, 1984; LORENA et al., 2001; MAPA; LIMA, 2012). The first can be understood as an integrating solution with distinct objectives, often conflicting (SAATY, 2008). The second is characterized as an application of the p-median problem, being widely used in the location of logistics facilities (LORENA et al., 2001).

Strategically, the study was conducted in Minas Gerais because it is an inner country state with great logistical and economic importance in Brazilian foreign trade and with no direct access to seaports. Thus, the state presents an interesting condition for the viability of a distant DP, where the distance and the size of the goods flow make the railroad viable under a strict cost perspective (ROSO; WOXYNIUS; LUMSDEN, 2009). Indeed, the investigation considered the interregional inequalities of the state and the concept of Sustainable Social Economic Development (SSED), presented in the Minas Gerais Integrated Development Plan (MINAS GERAIS, 2015). This enlarged the traditional perspective of transportation planning beyond the logistical and economic aspects, and including also social and environmental ones.

## 2 CHARACTERIZATION OF THE STUDY AREA AND CRITERIA SELECTION

The state of Minas Gerais presents high biophysical, socioeconomic, and cultural heterogeneity, which reflects on the unbalanced spatial distribution of public equipment and transportation infrastructure. Figure 1 illustrated the study area by presenting the mesoregions, railways, state and federal roads, and the existing DP.



**Figure 1** | Study site: Minas Gerais state's mesoregions overlaid by the existing dry ports, roads and rails in 2016 according to the Brazilian Institute of Geography and Statistics (IBGE) database.

Source: Authors' elaboration based on IBGE (2018) and Brasil (2014) data.

The choice of the sites for new DP considered five criteria (environmental, competition, economic, logistics, and social aspects), four of them considered sub-criteria as presented in Table 1. The criteria were chosen upon specialized literature concerning the location of logistic facilities such as in Barboza and Vieira (2014); Bolturk et al. (2016); Ka(2011); Loureiro, Freitas and Gonçalves (2015); Nguyen and Notteboom (2016); Roso, Woxenius and Lumsden (2009); Sopha et al. (2016). Other criteria, such as legal aspects, the stability of the political scenario, construction costs, as well as engineering aspects are also reported in the literature (BOLTURK et al., 2016; ROSO; WOXENIUS; LUMSDEN, 2009). However, these aspects were not considered since they are not directly assigned to the spatial questions related to the scope of the investigation.

Regarding the logistic accessibility, the road network of Minas Gerais is the most extensive among the Brazilian states. Besides the unequal distribution, over 50% of the federal highways in southeast Brazil are in Minas Gerais (CNT, 2018). As for the railroads, the state has the second-longest network in the country (MINAS GERAIS, 2015).

**Table 1 |** Criteria, input data, data source, and method used to convert data for the geospatial model.

| <i>Group</i>  | <i>Criterion</i>            | <i>Data Source</i>  | <i>Year-base</i> | <i>Original Data Format</i> | <i>Spatialization Method</i> |
|---------------|-----------------------------|---------------------|------------------|-----------------------------|------------------------------|
| Economic      | Exports FOB price           | MDIC                | 2015             | Tabular                     | Interpolation (IDW)          |
|               | Imports FOB price           | MDIC                | 2015             | Tabular                     | Interpolation (IDW)          |
|               | Number of jobs              | RAIS                | 2010             | Tabular                     | Interpolation (IDW)          |
|               | GDP                         | FGV                 | 2015             | Tabular                     | Interpolation (IDW)          |
| Competition   | Avoid existing dry port     | PNLT2010            | 2010             | Vector - Point              | Euclidian Distance           |
| Logistics     | Highway distance            | DEER/SETOP          | 2015             | Vector - Line               | Euclidian Distance           |
|               | Main road distance          | DEER/SETOP          | 2015             | Vector - Line               | Euclidian Distance           |
|               | Rail distance               | PNLT2010            | 2010             | Vector - Line               | Euclidian Distance           |
| Social        | Non-employed people         | IBGE                | 2010             | Tabular                     | Interpolation (IDW)          |
|               | Social Index                | Atlas Brasil        | 2010             | Tabular                     | Interpolation (IDW)          |
| Environmental | Avoid urban area*           | Embrapa Territorial | 2015             | Vector - Polygon            | Euclidian Distance           |
|               | Avoid hydrography PPA**     | IBGE                | 2015             | Vector - Line               | Euclidian Distance           |
|               | Avoid buffer zone of CUs*** | ICMBio/SEMAD        | 2015             | Vector - Polygon            | Euclidian Distance           |

\*Influence zone limited to 5km away from the urban areas.

\*\*Despite the Act Nº 12.651 of May 25, 2012, that created the new Brazilian Forest Code (BRASIL, 2012) says the Permanent Protection Areas (PPA) of riparian forest must be protected by a maximum buffer of 500 meters, in this investigation we used a decaying gradient until 1000 meters as a conservatory polity to avoid proposing infrastructure in environmentally sensitive areas nearby rivers.

\*\*\*Although CONAMA revoked CONAMA Resolution 13/1990 (BRASIL, 1990) in 2010, shrinking the 10,000 meters buffer zone for Conservation Units (CUs) without a management plan at to 3,000 meters, we adopted a buffer of 10,000 m considering the importance of these zones for the ecosystems surrounding the Conservation Units.

*Source: Primary research data with the respective data source in the table.*

The mining industry, in special the iron ore represents a significant share of the state's export revenue (29%), with logistics infrastructure, supported by dedicated railroads and pipelines, highly efficient. However, other commodities also play important roles in the state's economy, therefore the exportation activities that can directly or indirectly benefit from strategically located DP. Other than iron ore, the main products exported are raw grained coffee (12%), soybean grains and meal (8.5%), and industrialized iron-alloys (8.0%) (BRASIL, 2018).

The imports of the state are more fractional, with emphasis on fertilizers or chemical fertilizers (8.9%), coal (7.7%), chemical compounds (4.6%) and other products from the manufacturing industry (4.3%) (BRASIL, 2018). To measure exports and imports, the Free-On-Board (FOB) price was applied to the municipalities considering the year-base 2015, as reported by the Brazilian Ministry of Industry, Foreign Trade, and Services (MDIC). The Gross Domestic Product (GDP) and the number of jobs related to the segments of mineral extraction, processing industry, agriculture, and public utility industrial services, from the Annual Catalogue of Social Information (*Relação Anual de Informações Sociais - RAIS*), were integrated to represent the economic activity.

As for the environmental characteristics, in 2010 the preserved natural areas corresponded to 6.4% of the state's territory. The Atlantic Forest, which originally covered up to 46% of the state, currently reaches 5.3% of the territory (MINAS GERAIS, 2015). Thus, there is a real need for investments in infrastructure that neither accentuate environmental impacts nor jeopardize the already scarce preserved areas.

Concerning social characteristics, the northern municipalities present the worst rates of the state, with per capita income below the average, as well as way below the Human Development Index (HDI) (MINAS GERAIS, 2015). Despite the Northwest, North, Jequitinhonha, and Mucuri mesoregions altogether hold 15.6% of the state's population, the block represents only 7.4% of the state's GDP (IBGE, 2012).

The indicator of non-employed people was obtained from Table 3580 pulled from System of Automatic Recovery (SIDRA) of the Brazilian Institute of Geography and Statistics (IBGE), which uses the 2010 Census Database (IBGE, 2012). The Social Index (SI) was proposed in this investigation to consider, in addition to the demand for port services, the potential for the socioeconomic regional impact of the DP. SI is proportional to the population and inversely proportional to the square of the HDI as shown in Equation 1.

$$SI = \frac{Pop}{HDI^2} \quad (1)$$

Where: HDI: Human Development Index (Atlas Brasil/Censo of 2010)

Pop: Population as reported by Atlas Brasil (PNUD; FJP; IPEA, 2013)

Due to their nature, each criterion presents a different unit. To allow comparison and integration, the criteria have been standardized. The values range from 0 to 10, where zero (0) represents the absence of influence of the variable, one (1) represents the lowest cost, and 10 the highest. The lower the value, the greater the attractiveness of the region for installing a DP.

As a key condition to the proposed investigation, the criteria were georeferenced using the methodology as indicated in Table 1. Due to the geographic nature of the spatial analyzes and the geographic dimension of the study area, all maps were set to equidistant conical projection to minimize cartographic distortions in distance measurements (MITCHEL, 2005; SNYDER, 1987).

### 3 METHODOLOGY

The methodology integrated, in a sequential way, two well know methods of location into a single model. Thus, the inverse of the index resulting from SMCA was used as weighted demand into the LAP, as illustrated in Figure 2. The selected scenarios enabled to assess the location of the existing DP and also the impact of socio-environmental prioritization when choosing the location of a new facility.

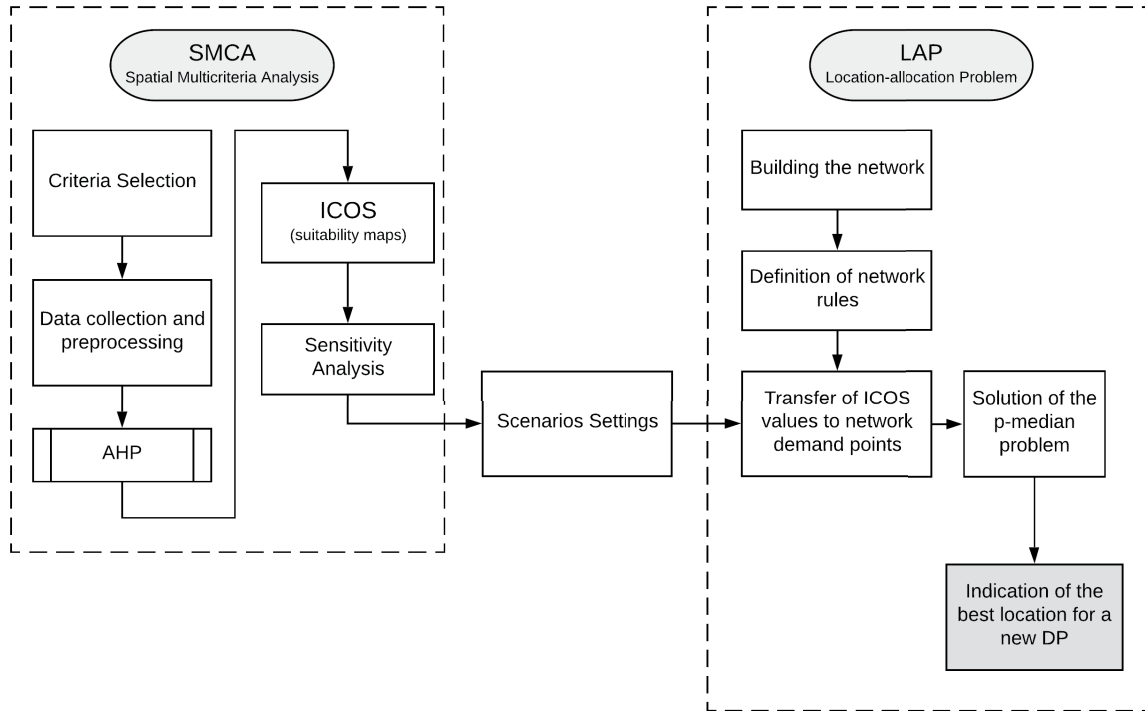


Figure 2 | Representative flowchart of the main methodological steps.

Source: Authors' elaboration.

### 3.1 SPATIAL MULTI-CRITERIA ANALYSIS (SMCA)

The hierarchy and the weights of the criteria were assigned following the Analytic Hierarchy Process (AHP) method (SAATY, 1977, 2008). The investigation counted with 10 experts in logistics that pair-wise evaluated the criteria. A spreadsheet developed by Goepel (2013) was used to perform the calculation. The weight value of each criterion ( $w_i$ ) was defined by the eigenvector of the largest eigenvalue ( $\lambda$ ) of the paired comparison matrix (CHEN; YU; KHAN, 2010; SAATY, 1977). The resulting hierarchy of criteria is illustrated in Figure 3.

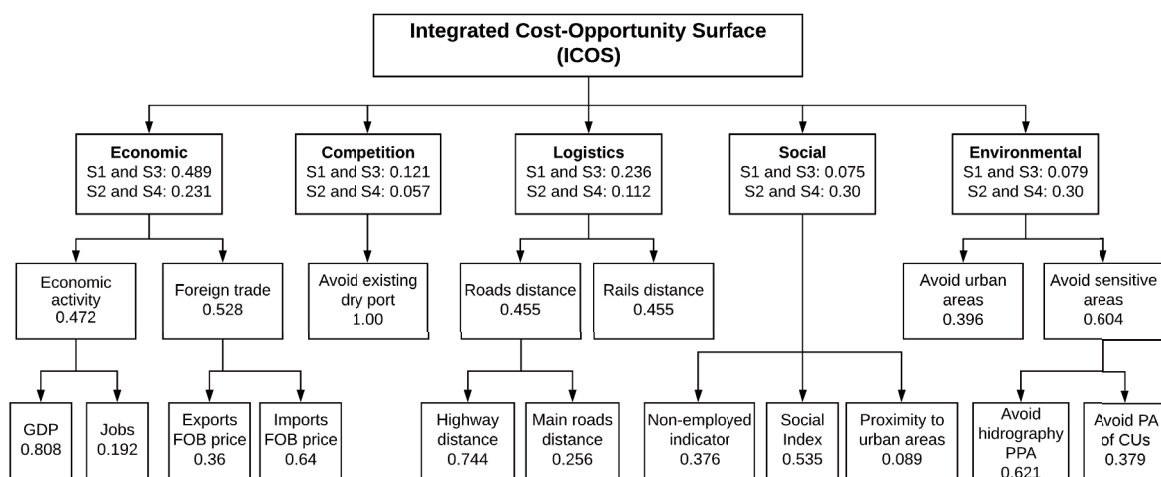


Figure 3 | Hierarchy of the criteria and the respective weights used in the Spatial Multi-Criteria Analysis (SMCA).

Source: Authors' elaboration.

In order to assure the quality of the inputs, the normalized matrix was assessed through the consistency rate (CR), the consensus among specialists (SC), and the geometric consistency index (GCI), proposed by Crawford e Williams (1985). The threshold of CR was 0.10 (APOSTOLOU; HASSELL, 1993; CHEN; YU; KHAN, 2010). Further details about the AHP can be found in Chen, Yu and Khan (2010) and Saaty (1977, 2008), and its application in spatial analysis for transportation planning in Sadasivuni et al. (2009).

The solution was georeferenced to enable spatial analysis, visualization, clear and comprehensive understanding. Two Integrated Cost-Opportunity Surfaces (ICOS) were generated as resulting from SMCA processes: [ICOS - A] with weighted criteria based on the logistic experts' opinion, determined by the AHP, and [ICOS -B] that favored the social and environmental perspectives. Details about the ICOS-B cost-opportunity surface is available in section 3.3-Scenario Settings. In short, the analysis was computed in a Geographic Information System (GIS). The municipalities were classified to present the best-feasible alternatives to locate new DPs.

Each ICOS represents the weighted sum of the criteria (Equation 2). By following the hierarchy established in the AHP, an ICOS-like calculation method was used for each criterion to compute the sub-criteria. An exception was the environmental criterion, computed upon conditional overlap. The buffer zones, urban areas, and Environmental Protected Areas (EPA) must be mandatorily avoided by this type of enterprise. Thus, there should be no weighting for these sub-criteria when computing the environmental criterion.

$$ICOS(x_i, y_i) = \sum_{j=1}^n P_n \times C_n(x_i, y_i) \quad (2)$$

Where:  $ICOS(x_i, y_i)$  = value of the Integrated Cost-Opportunity at point i with coordinates  $(x_i, y_i)$ .

$P_n$  = weight of the criterion  $n$  as determined by AHP.

$C_n(x_i, y_i)$  = value of the criterion  $n$  at coordinate  $(x_i, y_i)$ .

The Sensitivity Analysis (SA) of the SMCA results considered the social and environmental criteria using the One-Factor-At-A-Time method (OAT) (CHEN; YU; KHAN, 2013; DANIEL, 1958). The goal was to assess the strength of these criteria and the possible impact of socio-environmental prioritization over the other traditional criteria. For each criterion, the weights ranged from 0 to 100% with increments of 10%, while the other criteria had the proportion of their weight maintained.

### 3.2 LOCATION-ALLOCATION PROBLEM (LAP)

Alike the SMCA, the LAP was also developed on a GIS platform, but based on vector data architecture. The problem was built on a GIS network with connectivity defined in two groups: highways and railways. The network topology has been corrected and validated. Five rules have been specified for the network: two of them related to cost (the length of the section, and the type of road); one related to the hierarchy according to the function class of the road (railway: 1; highways and primary collectors: 2; secondary collectors: 3; local roads: 4); and the last two related to preference (one for rail-based cargo transit and the other for avoiding traffic on local roads).

The input values of the demand points were fed from the corresponding cost-opportunity surface per scenario. Thus, the LAP solution considered the decision rules defined for the network, and also the weighted demand of economic, logistic, social, environmental, and competition criteria. 94 points were selected along with the network as candidates for the location of the new facilities.

The DP candidate points were distributed in all the mesoregions of the state, being preferably road-rail connections.

Next, the PLA solver was formulated as a p-median problem, where problem consists in locating p logistic facilities (medians) in a network, regarding the compromise in minimizing the total sum of the distances of each demand node to its nearest median (CHRISTOFIDES; BEASLEY, 1982; HAKIMI, 1964; TEITZ; BART, 1968). The goal of the solution was to attend as many demand points as possible. The solver used heuristic techniques, because the solution space, for a mathematical solution, grows until becomes extremely large. Thus, the solver built an Origin-Destination (OD) cost matrix. Next, the edition of Hillsman (HILLSMAN, 1984) was applied to edit the matrix. To refine the solution, a set of semi-randomized solutions was generated and the solver applied a vertex substitution heuristic (TEITZ; BART, 1968). Finally, a GRASP meta-heuristic (FEO; RESENDE, 1995; LORENA et al., 2001), returned the best solution out of a group of good solutions.

### 3.3 SCENARIOS SETTINGS

Four scenarios were defined in this investigation. Six facility locations were selected out of the 94 candidates for each of the four scenarios to meet the 79,535 points of demand. In short, these scenarios integrate different combinations of consideration/no consideration of existing DP with the computed SMCA cost-surfaces, as follow:

- **Scenario 1:** No existing DP + ICOS-A (AHP weighted criteria);
- **Scenario 2:** No existing DP + ICOS-B (socio-environmental prioritization);
- **Scenario 3:** Existing-mandatory DP + ICOS-A (AHP weighted criteria);
- **Scenario 4:** Existing-mandatory DP + ICOS-B (socio-environmental prioritization);

Two scenarios (2 and 4) had socio-environmental prioritization. Environmental prioritization was carried out with a view to minimizing impacts on the environment and reducing project efforts by avoiding environmentally sensitive areas (MONTAÑO et al., 2012). The favoring of social criteria pushes the choice of the new DP to serve as an instrument that stimulates regional development by focusing on the generation of jobs and the improvement of social indicators. The weights of the social and environmental criteria were arbitrarily set at 30% each. The other three criteria had their weight-adjusted keeping the proportion determined by the AHP.

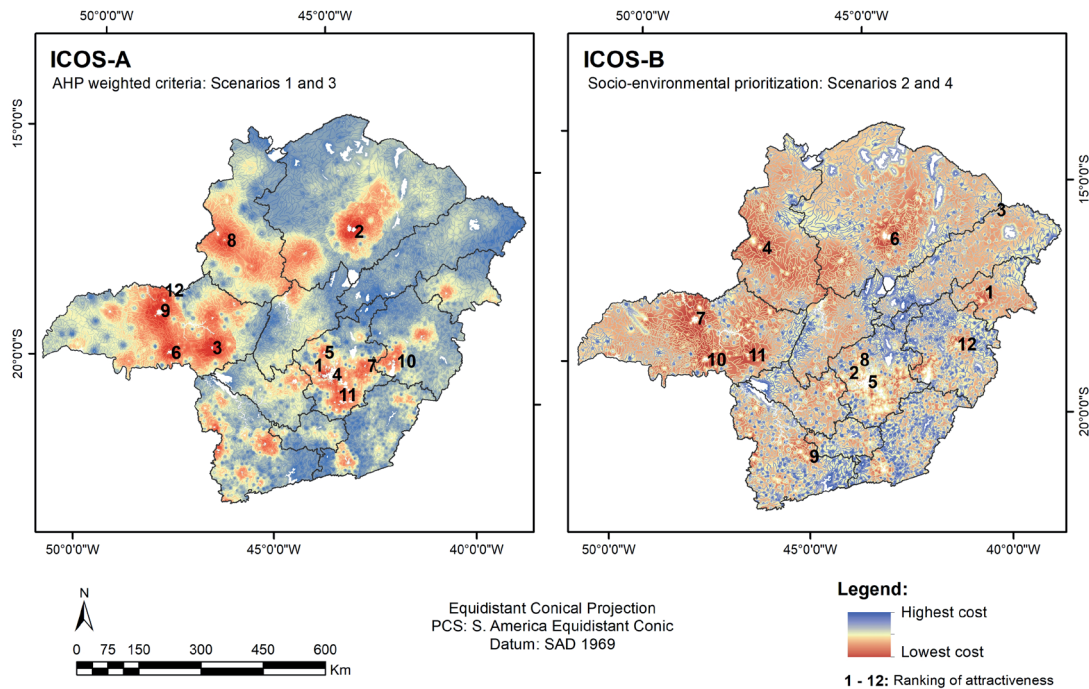
To assess the location of the existing DP, the model was executed without considering these facilities (scenarios 1 and 2). Although, in reality, all existing DPs are mandatory in the solution since the goal of the investigation is to be inclusive and does not consider identifying logistic facilities to be deactivated in the study area.

## 4 RESULTS AND DISCUSSIONS

The SMCA weights as determined by AHP were attested by  $CR = 0.008$  and  $\lambda = 5.035$ . The resulting CR value ( $<0.10$ ) indicates acceptable consistency of the input values to the pair-wised comparison matrix (APOSTOLOU; HASSELL, 1993; CHEN; YU; KHAN, 2010). The GCI was equal to 0.03 and the consensus of opinions was 84.6%.

The two integrated cost-opportunity surfaces are shown in Figure 4. ICOS-A (left) considered the weights of the criteria determined by the AHP. On the right side, ICOS-B considers weights set to prioritize the

socio-environmental standpoints. By comparing the two maps, it can be seen that socio-environmental prioritization reduces the economic burden and, in a certain way, attempts to equalize the regions. However, this prioritization does not change the spatial configuration of the solution, where some regional hubs remain more attractive for the installation of the DP.



**Figure 4 |** Integrated cost-opportunity surfaces (ICOS) modeled to located dry ports in Minas Gerais. The model used criteria and weights computed from the Analytic Hierarchy Process (ICOS-A) and prioritization of socio-economic perspectives (ICOS-B), respectively.

Source: Authors' elaboration.

At ICOS-A (scenarios 1 and 3) the maximum opportunity cost for localization of DP was 8.3993 (Arantina, in the south of Minas) and the minimum 2.8601 (Betim). Table 2 shows that the most attractive municipalities in the state are Betim, Montes Claros, and Araxá. However, it is important to consider the existence of DP relatively close to some of these top-attractive municipalities, with special regards to the first and third alternatives, where there will probably be a lot of competition. Thus, findings highlight the municipality of Montes Claros (2nd in the ranking), as it presents high attractiveness and no DP within a radius of 350 km.

Regarding the ICOS-B (scenarios 2 and 4), the costs-opportunity ranged from 9.2408 (Arantina) to 3.4524 (Teófilo Otoni). Thus, the order of classification of the municipalities by attractiveness shown in Table 2 has been changed. However, eight candidates remain as good alternatives in both SMDC approaches: Betim, Montes Claros, Araxá, Belo Horizonte, Sete Lagoas, Uberaba, Paracatu, and Uberlândia. In ICOS-B, Montes Claros falls from the 2nd to the 6th position in the classification, due to its proximity to the Lapa Grande State Park and the large urbanized area.

**Table 2 |** Municipalities that presented high attractiveness for proposing new dry ports, as a result of spatial multi-criteria analysis using traditional macro logistics standpoint with no prioritization of socio-environmental values (ICOS-A).

| Ranking | Cost | Municipality  | Micro region   | Meso region         | X coord (m) | Y coord (m) |
|---------|------|---------------|----------------|---------------------|-------------|-------------|
| 1       | 2,86 | Betim         | Belo Horizonte | Metropolitana de BH | 1.571.640,7 | 1.248.247,0 |
| 2       | 3,07 | Montes Claros | Montes Claros  | Norte de Minas      | 1.644.675,2 | 1.596.149,6 |



| Ranking | Cost | Municipality       | Micro region   | Meso region                | X coord (m) | Y coord (m) |
|---------|------|--------------------|----------------|----------------------------|-------------|-------------|
| 3       | 3,22 | Araxá              | Araxá          | Triângulo / Alto Paranaíba | 1.302.431,1 | 1.315.568,9 |
| 4       | 3,25 | Belo Horizonte     | Belo Horizonte | Metropolitana de BH        | 1.590.851,3 | 1.251.391,4 |
| 5       | 3,30 | Sete Lagoas        | Sete Lagoas    | Metropolitana de BH        | 1.571.917,2 | 1.304.824,2 |
| 6       | 3,37 | Uberaba            | Uberaba        | Triângulo / Alto Paranaíba | 1.202.742,4 | 1.304.367,2 |
| 7       | 3,75 | Itabira            | Itabira        | Metropolitana de BH        | 1.675.155,0 | 1.272.323,9 |
| 8       | 3,75 | Paracatu           | Paracatu       | Noroeste de Minas          | 1.336.801,3 | 1.574.621,2 |
| 9       | 3,78 | Uberlândia         | Uberlândia     | Triângulo / Alto Paranaíba | 1.177.431,2 | 1.405.099,9 |
| 10      | 3,83 | Santana do Paraíso | Ipatinga       | Vale do Rio Doce           | 1.746.041,6 | 1.282.858,3 |
| 11      | 3,96 | Itabirito          | Ouro Preto     | Metropolitana de BH        | 1.606.038,8 | 1.212.047,3 |
| 12      | 3,97 | Araguari           | Uberlândia     | Triângulo / Alto Paranaíba | 1.186.257,2 | 1.432.014,4 |

Source: Authors' elaboration.

Figure 5 shows the SA of the environmental criterion to the 12 top-attractive candidate localities for the installation of a new DP based on the lowest value in ICOS-A. All localities presented a linear increase in cost, with a consequent reduction in attractiveness. Paracatu (A87) was the alternative that showed the lowest rate of decrease in cost. The few locations (6 out of 94) that reduced the cost by increasing the environmental weight are not among the first 12 in the ranking.

Although, the behavior of the SA of the social criterion was different from the environmental one. The results show a small<sup>1</sup> cost variation and, unlike the environmental criterion, most locations (66) present cost reductions as the weight of the criterion increases. The locations that presented an increase in cost-opportunity already present higher costs before the increase in weight.

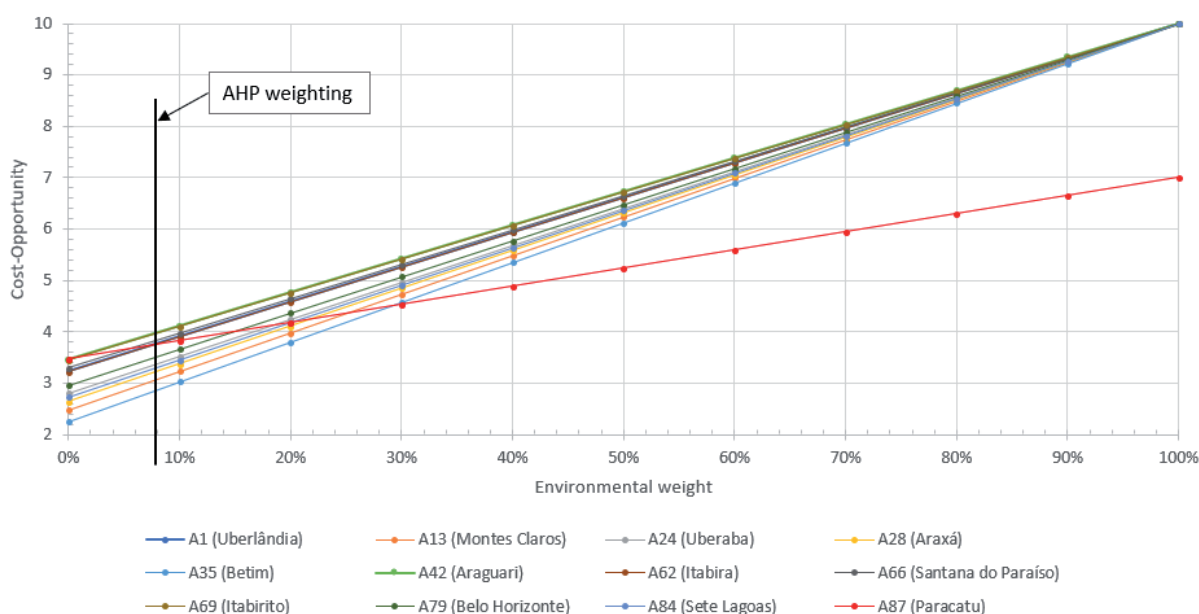


Figure 5 | Sensibility analysis of the environmental criteria with observed variation in cost-opportunity for the 12 municipalities with high attractiveness for new dry ports based on ICOS-A.

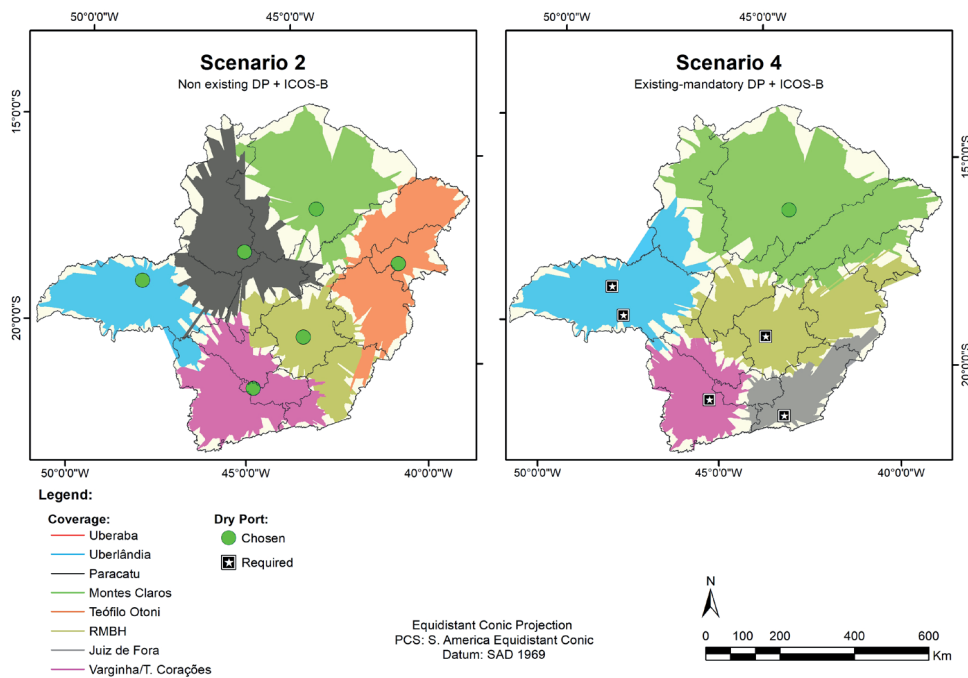
Source: Authors' elaboration.

In scenarios 1 and 2, the locations selected were the same due to the similar spatial configuration of ICOS-A and ICOS-B (as showed in Figure 4). Nevertheless, there were only minor differences in the coverage area of each DP. The model pointed to three new DPs to be located in places where

facilities already exist (Uberlândia, Varginha, and Contagem). Another three were positioned in the municipalities of Paracatu, Teófilo Otoni, and Montes Claros, and it is important to highlight the model choose these places over those that DP already exist, such as Uberaba and Juiz de Fora.

Indeed, the results point to the logistic deficiency in the north of the state (North, Northwest, Jequitinhonha, and Mucuri mesoregions). Despite the demand and consequently potential for installation, there is neither DP installed nor operating in these regions. Furthermore, due to the gravitational characteristic of the LAP, the model resulted in a more balanced spatial distribution of the DP than the current distribution. The coverage area of each DP was very similar to the area of the others. Scenarios 3 and 4, where five existing DP were mandatorily included, the model resulted in a single addition. Thus, Montes Claros was chosen as the best solution in both scenarios. Despite the relative drop in attractiveness in socio-environmental prioritization scenarios, Montes Claros was selected in the LAP due to its key-strategic position (IBGE, 2008). The municipality can serve a wide region not yet served through customs terminals. Notwithstanding, in these two scenarios, one of the mandatory locations (Uberaba) was only accessed by demand points nearby.

Figure 6 illustrates the locations that were selected for new DPs with their respective coverage areas. Due to the close similarity of the results between scenarios 1 and 2, and also between 3 and 4, to simplify the presentation, only the results from scenarios 2 and 4 are presented.



**Figure 6 |** Dry ports and their respective LAP coverage areas within the state of Minas Gerais as resulting from the two scenarios that prioritized socio-environmental perspectives.

*Source: Authors' elaboration.*

Regarding the characteristics of Montes Claros, an important factor that influenced the choice is the concentration of export and import activities in the northern part of the state, some of them converging in Montes Claros and vicinity. According to BRASIL (2018), almost 99% of the FOB export value of the mesoregion in the north of Minas Gerais comes from only seven municipalities. Montes Claros alone is responsible for 49.9% (2017) and 38.3% (2018) of the total value exported by the mesoregion (BRASIL, 2018).

The results of this study corroborate to IBGE (2008) that established Montes Claros as Level B Regional Capital due to its rationality and area of influence in the state of Minas Gerais. According to the results (Figure 6) and with IBGE (2008), in addition to the northern mesoregion of Minas, Montes Claros also influences the northwestern, Vale do Jequitinhonha and Mucuri mesoregions.

The integration of two methods for geolocation was key important to the quality of the results if compared to each method individually. Instead, if the location methods considered only SMCA, the municipality of Betim would show up preference over Montes Claros. However, the Metropolitan Region of Belo Horizonte, where Betim is located, is already served by a DP. On the other hand, the LAP solution without weighting the cost-opportunity would be restricted to the optimization of the number of demand points served. Consequently, the importance of the social and environmental dimensions would probably be neglected. In addition, bringing this type of analysis early in the planning stage can facilitate the environmental licensing process, which requires the assessment of environmentally viable local alternatives (MONTAÑO et al., 2012).

The study reveals the consequences of a critical fact: the productive investment projects as directed to Minas Gerais between 2004 and 2014 were strongly spatial concentrated (MINAS GERAIS, 2015). Only four of the seventeen State Development Territories accounted for 70% of the investment intentions. Traditionally, the preference is to the most dynamic regions in detriment of the historically problematic areas regarding the environmental, economic, and social standpoints. In other words, state development transportation-related policies sanctioned a certain pre-existing productive and spatial configuration (MINAS GERAIS, 2015). It is necessary to overcome this scenario of regional inequality through SSED across the state.

## 5 CONCLUSION

Dry ports are alternatives for mitigating congestion and social conflicts in primary logistic areas, by reducing transportation costs, speeding up the process, and reducing environmental impacts. However, DP has been a subject traditionally limited to the area of transport. To bring the subject to a broader audience, this study presents subsidies to formulate a more comprehensive and participatory planning proposal involving DP. The investigation shows the social and environmental factors, which character often overlooked in the Cartesian view of traditional transportation engineering, that should be considered in the decision-making process for choosing the location for new facilities. Accordingly, the greatest benefit for all stakeholders can be achieved, promoting sustainable regional development.

As expected, by using two well-established methods for locating facilities drove different results for each method individually. However, the objective of the investigation was to integrate the two methods into a model. Thus, the contribution of the article was to demonstrate the gain achieved by the integration of modern and consolidated methods of decision support in transport planning. With that, it was possible to affirm that the research produced a model optimized from a logistical point of view, and at the same time inclusive since it met social and environmental demands.

Despite Minas Gerais has the most extensive road network in the country, the presents enormous regional disparities regarding transportation strategy and infrastructures. The results showed the northern mesoregions (North, Northwest, Jequitinhonha, and Mucuri) need for inland port and customs services. The study used multidimensional methods to assure that places with high potential are not neglected, as well as to assure the installation of new DP neither stress the inequality of infrastructure nor accentuates environmental and social issues. Thus, the locational analyzes developed from different scenarios resulted in the convergence of Montes Claros as a priority location for the installation of DP.

The authors understand the investigation achieved its major objective. The proposed methodology was broken down to be elucidative and to support the discussion. Moreover, it provided the identification of the most suitable locations for installing DP in the state of Minas Gerais, considering inputs from logistical, social, environmental, economic, and competition elements. This study is original and certainly can be enhanced. Future work may incorporate more criteria, evaluate the model's performance metrics, compare the results with other methods, and even apply a spatially explicit sensibility analysis.

## ACKNOWLEDGMENTS

The authors acknowledge CAPES, CNPq, and FAPEMIG for funding this research. We also would like to thank colleagues Vanilson Couto and Ana Ísis Moura for their contributions to the work.

## NOTES

1 | Average variation of the cost (mean difference among the cost at 0% weight and 100% weight of all alternatives) in the sensibility analysis of social perspective is 1.11 versus 4.32 of the environmental one.

## REFERENCES

- ANTAQ. **Anuário Antaq**. Disponível em: <<http://web.antaq.gov.br/Anuario/>>. Acesso em: 20 nov. 2018.
- APOSTOLOU, B.; HASSELL, J. M. An empirical examination of the sensitivity of the analytic hierarchy process to departures from recommended consistency ratios. **Mathematical and Computer Modelling**, 1993.
- AWAD-NÚÑEZ, S. et al. How should the Sustainability of the Location of Dry Ports be Measured? **Transportation Research Procedia**, v. 14, n. 2016, p. 936–944, 2016a.
- AWAD-NÚÑEZ, S. et al. A Methodology for Measuring Sustainability of Dry Ports Location Based on Bayesian Networks and Multi-criteria Decision Analysis. **Transportation Research Procedia**, v. 13, n. 2016, p. 124–133, 2016b.
- BARBOZA, P. D.; VIEIRA, J. G. V. Análise de decisão multicritério aplicada na seleção de investimento em armazenagem de soja em grão. **Produto & Produção**, v. 15, n. 2, p. 24–45, 2014.
- BOLTURK, E. et al. Multiattribute Warehouse Location Selection in Humanitarian Logistics Using Hesitant Fuzzy AHP. **International Journal of the Analytic Hierarchy Process**, v. 8, n. 2, 2016.
- BRASIL. Lei N. 12.651. Dispõe sobre a proteção da vegetação nativa; altera as Leis n. 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis n. 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória n. 2.166-67, de 24 de agosto de 2001; e dá outras providências. Brasília, Brasil: **Diário Oficial da União** – Seção 1 – 28/5/2012, p. 1-32.
- BRASIL. Ministério da Indústria, Comércio Exterior e Serviços. **Estatísticas de Comércio Exterior**. Disponível em: <<http://www.mdic.gov.br/comercio-exterior/estatisticas-de-comercio-exterior>>. Acesso em: 31 mar. 2018.
- BRASIL. Ministério dos Transportes. **Base de Dados Georreferenciados PNL 2010**. Brasília (on-line): Ministério dos Transportes, 2014. Disponível em: <<https://www.infraestrutura.gov.br/conteudo/2822-base-de-dados-georreferenciados-pnl-2010.html>>. Acesso em: 31 jul. 2018.
- BRASIL. Resolução Conama 013/1990. Dispõe sobre a área circundante, num raio de 10 (dez) quilômetros, das Unidades de Conservação. Brasília, Brasil: **Diário Oficial da União**, 28/12/1990, p. 25541.
- CHEN, Y.; YU, J.; KHAN, S. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. **Environmental Modelling & Software**, v. 25, n. 12, p. 1582–1591, 2010.
- \_\_\_\_\_. The spatial framework for weight sensitivity analysis in AHP-based multi-criteria decision making. **Environmental Modelling & Software**, v. 48, p. 129–140, 2013.
- CHINELATO, F. B.; CRUZ, D. B. DE F.; ZIVIANI, F. Made in Brazil: o impacto da infraestrutura logística brasileira nas operações de comércio exterior. **Revista Administração em Diálogo – RAD**, v. 13, n. 3, 2011.
- CHRISTOFIDES, N.; BEASLEY, J. E. A tree search algorithm for the p-median problem. **European Journal of Operational Research**, v. 10, n. 2, p. 196–204, 1982.
- CNT. **Pesquisa CNT de Rodovias 2018**. CNT | SEST SENAT. Brasília: Confederação Nacional do Transporte, 2018. Disponível em: <<http://pesquisarodovias.cnt.org.br/Home>>. Acesso em: 10 nov. 2018.

CRAWFORD, G.; WILLIAMS, C. A note on the analysis of subjective judgment matrices. **Journal of Mathematical Psychology**, 1985.

DANIEL, C. On Varying One Factor at a Time. **Biometrics**, v. 14, 1958.

DINWOODIE, J. et al. Sustainable Development of Maritime Operations in Ports. **Business Strategy and the Environment**, v. 21, n. 2, p. 111–126, 2012.

GERMANO, E. C.; FREIRE JÚNIOR, A. E. A importância do porto seco como facilitador na armazenagem e desembarço aduaneiro. **Revista Fatec Sebrae em Debate: Gestão, Tecnologias e Negócios**, v. 04, n. 6, 2017.

GOEPEL, K. D. Implementing the Analytic Hierarchy Process as a standard method for multi-criteria decision making in corporate enterprises – A new AHP Excel template with multiple inputs. **Proceedings of the International Symposium on the Analytic Hierarchy Process**. Kuala Lumpur: 2013. Disponível em: <<https://bpmmsg.com/new-ahp-excel-template-with-multiple-inputs/>>. Acesso em: 29 dez. 2018.

GOULIELMOS, A. M. European Policy on Port Environmental Protection. **Global Nest Journal**, v. 2, n. 2, p. 189–197, 2013.

HAKIMI, S. L. Optimum Locations of Switching Centers and the Absolute Centers and Medians of a Graph. **Operations Research**, v. 12, n. 3, p. 450–459, 1964.

HILLSMAN, E. L. The p-Median Structure as a Unified Linear Model for Location–Allocation Analysis. **Environment and Planning A**, v. 16, n. 3, p. 305–318, 1984.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Regiões de influência das cidades 2007**. Rio de Janeiro, RJ, Brasil: IBGE, 2008. Disponível em: <[www.ibge.gov.br](http://www.ibge.gov.br)>.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Censo 2010**. Rio de Janeiro, RJ, Brasil: IBGE, 2012. Disponível em: <<https://censo2010.ibge.gov.br/>>. Acesso em: 6 maio 2020.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Downloads Geociências | IBGE**. Rio de Janeiro (on-line): IBGE, 2018. Disponível em: <<https://www.ibge.gov.br/geociencias/downloads-geociencias.html>>. Acesso em: 31 jul. 2018.

JAFFEE, D. ‘A Deeper Channel Floats all Boats’: the port economy as urban growth engine. **Environment and Planning A: economy and space**, v. 47, n. 4, p. 783–800, 2015.

KA, B. Application of fuzzy AHP and Electre to China dry port location selection. **Asian Journal of Shipping and Logistics**, v. 27, n. 2, p. 331–354, 2011.

KOEHLER, P. H. W.; ASMUS, M. L. Gestão ambiental integrada em Portos Organizados: uma análise baseada no caso do porto de Rio Grande, RS – Brasil. **Revista da Gestão Costeira Integrada**, v. 10, n. 2, p. 53–67, 2010.

LIGMANN-ZIELINSKA, A.; JANKOWSKI, P. Spatially-explicit integrated uncertainty and sensitivity analysis of criteria weights in multicriteria land suitability evaluation. **Environmental Modelling and Software**, v. 57, p. 235–247, 2014.

LORENA, L. A. N. et al. Integração de modelos de localização a sistemas de informações geográficas. **Gestão & Produção**, v. 8, n. 2, p. 180–195, 2001.

LOUREIRO, J. F.; FREITAS, R. R. DE; GONÇALVES, W. Proposta de um método de localização para expansão de um terminal portuário por meio do Analytic Hierarchy Process (AHP). **Revista Espacios**, v. 36, n. 10, p. 7, 2015.

MAPA, S. M. S.; LIMA, R. DA S. Uso combinado de sistemas de informações geográficas para transportes e programação linear inteira mista em problemas de localização de instalações. **Gestão & Produção**, v. 19, n. 1, p. 119–136, 2012.

MEDEIROS, M. C. A geografia do mercado mundial de produtos agroalimentares e o papel do Brasil. **Raega – O Espaço Geográfico em Análise**, v. 31, p. 260, 2014.

MINAS GERAIS. Desenvolvimento econômico e social sustentável de Minas Gerais: redução das desigualdades sociais e regionais. **Plano Mineiro de Desenvolvimento Integrado (PMDI)**. Belo Horizonte, MG: Governo de Minas Gerais, 2015. Disponível em: <<https://www.mg.gov.br/conteudo/transicao/pmdi/pmdi>>.

MITCHEL, A. **The ESRI Guide to GIS analysis**. Redlands: ESRI Press, 2005. v. 2

MONTAÑO, M. et al. Integração de critérios técnicos, ambientais e sociais em estudos de alternativas locais para implantação de aterro sanitário. **Engenharia Sanitária e Ambiental**, v. 17, n. 1, p. 61–70, 2012.

NG, A. K. Y.; PADILHA, F.; PALLIS, A. A. Institutions, bureaucratic and logistical roles of dry ports: the Brazilian experiences. **Journal of Transport Geography**, v. 27, p. 46–55, 2013.

NGUYEN, L. C.; NOTTEBOOM, T. A Multi-Criteria Approach to Dry Port Location in Developing Economies with Application to Vietnam. **The Asian Journal of Shipping and Logistics**, v. 32, n. 1, p. 23–32, 2016.

OLIVEIRA, D. S. et al. Expansão Portuária, Desenvolvimento Municipal e Alterações Ambientais no Brasil: desafios para a gestão costeira. **Revista de Gestão Costeira Integrada**, v. 13, n. 1, p. 79–87, 2013.

PNUD; FJP; IPEA. **Atlas do Desenvolvimento Humano no Brasil**. Disponível em: <<http://atlasbrasil.org.br/2013/>>. Acesso em: 15 jun. 2020.

RAHMAN, M. A. et al. An integrated study of spatial multicriteria analysis and mathematical modeling for managed aquifer recharge site suitability mapping and site ranking at Northern Gaza coastal aquifer. **Journal of Environmental Management**, v. 124, p. 25–39, 2013.

ROSO, V.; WOXENIUS, J.; LUMSDEN, K. The dry port concept: connecting container seaports with the hinterland. **Journal of Transport Geography**, v. 17, n. 5, p. 338–345, 2009.

SAATY, T. L. A scaling method for priorities in hierarchical structures. **Journal of Mathematical Psychology**, 1977.

SAATY, T. L. Decision making with the analytic hierarchy process. **International Journal of Services Sciences**, v. 1, n. 1, p. 83–98, 2008.

SADASIVUNI, R. et al. A transportation corridor case study for Multi-criteria Decision Analysis. **Proceeding of ASPRS 2009 Annual Conference**. Baltimore, USA: ASPRS, 2009.

SINAY, M. C. F.; CARVALHO, S. D.; BRAGA, I. L. A Importância da Inclusão da Variável Ambiental na Gestão Portuária. **Revista de Administração, Sociedade e Inovação**, v. 3, n. 2, p. 124–135, 2017.

SNYDER, J. P. **Map Projections: a working manual**. Washington, DC, USA: United States Government Printing Office, 1987.

SOPHA, B. M. et al. Urban distribution center location: combination of spatial analysis and multi-objective mixed-integer linear programming. **International Journal of Engineering Business Management**, v. 8, p. 1–10, 2016.

TEITZ, M. B.; BART, P. Heuristic Methods for Estimating the Generalized Vertex Median of a Weighted Graph. **Operations Research**, v. 16, n. 5, p. 955–961, 1968.

WANKE, P. F.; HIJJAR, M. F. Exportadores brasileiros: estudo exploratório das percepções sobre a qualidade da infraestrutura logística. **Produção**, v. 19, n. 1, p. 143–162, 2009.

# Otimização locacional de portos secos para fomentar o desenvolvimento regional sustentável

*Dry port location optimization to foster sustainable regional development*

Marlon Fernandes de Souza<sup>a</sup>

Paulo H. Góes Pinto<sup>b</sup>

Raphael B. Alves Teixeira<sup>c</sup>

Carla de O. Leite Nascimento<sup>d</sup>

Rodrigo A. de Albuquerque Nóbrega<sup>e</sup>

<sup>a</sup>Universidade Estadual de Campinas (Unicamp), Faculdade de Engenharia Agrícola, Campinas, SP, Brasil.  
End. Eletrônico: marlonfernandesdesouza@gmail.com

<sup>b</sup>Universidade Federal de Minas Gerais (UFMG), Escola de Engenharia, Belo Horizonte, MG, Brasil.  
End. Eletrônico: paulo-goes@ufmg.br

<sup>c</sup>Universidade Federal de Minas Gerais (UFMG), Escola de Engenharia, Belo Horizonte, MG, Brasil.  
End. Eletrônico: teixeiraraph@outlook.com

<sup>d</sup>Universidade Federal de Minas Gerais (UFMG), Escola de Engenharia, Belo Horizonte, MG, Brasil.  
End. Eletrônico: carla.olin@gmail.com

<sup>e</sup>Universidade Federal de Minas Gerais (UFMG), Instituto de Geociências e Escola de Engenharia, Belo Horizonte, MG, Brasil.  
End. Eletrônico: raanobrega@ufmg.br

doi:10.18472/SustDeb.v11n2.2020.27073

Received: 06/09/2019  
Accepted: 01/06/2020

ARTICLE - DOSSIER

## RESUMO

A saturação das zonas de influência portuária acentua impactos ambientais e conflitos socioespaciais, demandando alternativas logísticas. O porto seco possibilita a descentralização de atividades aduaneiras, de manuseio e armazenagem, mitigando parte dos problemas, além de estimular a economia na região onde é inserido. Dessa forma, a sua localização é crucial para a eficiência dos sistemas logísticos de importação e exportação. O objetivo deste trabalho foi avaliar a distribuição espacial dos portos secos em Minas Gerais e identificar os melhores locais para uma nova instalação. A metodologia agregou dois métodos reconhecidos de definição locacional: a Análise Multicritério Espacial e o Problema de Localização-Alocação. O primeiro, em consonância com as práticas mais atuais no planejamento de transporte, integrou critérios sociais,

ambientais e técnicos. O segundo, adotou o resultado da análise multicritério como demanda ponderada e aplicou uma meta heurística para solução do problema de otimização. Os resultados evidenciam a disparidade regional e a deficiência de infraestruturas logísticas no norte de Minas. Todos os cenários apontam a região de Montes Claros como candidata à instalação de um porto seco. A possibilidade de conciliar sociedade, ambiente e economia no planejamento de infraestrutura foi demonstrada.

**Palavras-chave:** AHP. Planejamento de Transportes. Desenvolvimento Regional Sustentável. Estação Aduaneira Interior. Localização-Alocação.

## ABSTRACT

*The saturation of hinterland accentuates adverse environmental impacts and socio-spatial conflicts, demanding logistical alternatives. As a solution, the dry port enables the decentralization of customs, handling, and storage operations, which mitigates part of the problems, in addition to stimulating the economy in the region where it operates. Thus, its location is crucial for the efficiency of import and export logistics systems. The aim of this paper was to evaluate the spatial distribution of dry ports in Minas Gerais and to identify the best locations for a new installation. The methodology put together two recognized methods for location definition: the Spatial Multicriteria Decision Analysis and the Location-Allocation Problem. The first, in line with the most current practices in transportation planning, integrated social, environmental and technical criteria. The second adopted the first's result as weighted demand and applied a metaheuristic to solve an optimization problem. Findings show the regional disparity and the deficiency of logistic infrastructures in the north of Minas Gerais. All scenarios point to the Montes Claros region as a candidate for the installation of a dry port. The possibility of reconciling society, environment and economy in infrastructure planning was demonstrated.*

**Keywords:** AHP. Transportation Planning. Sustainable Regional Development. Inland Port. Location-Allocation.

## 1 INTRODUÇÃO

A globalização gerou crescimento das operações comerciais em todo o mundo com o consequente aumento da movimentação de mercadorias e dos trâmites fiscais de exportação e importação, que têm saturado os portos e afetado os custos do importador/exportador (GERMANO; FREIRE JÚNIOR, 2017; NG; PADILHA; PALLIS, 2013). Além dos prejuízos econômicos e burocráticos, a saturação das zonas de influência portuária acentua os impactos ambientais adversos e os conflitos socioespaciais (AWAD-NÚÑEZ et al., 2016a).

A instalação ou expansão de um porto marítimo invariavelmente afetam o ambiente. Os danos ao ecossistema são amplificados, visto que a maioria dos portos estão localizados em estuários (DINWOODIE et al., 2012; GOULIELMOS, 2013). Jaffee (2015), Oliveira et al. (2013) e Sinay, Carvalho e Braga (2017) citam uma série de impactos sociais e ambientais relacionados à atividade portuária. Sinay, Carvalho e Braga (2017) ainda afirmam que as principais consequências da instalação e operação do porto são advindas das atividades realizadas no seu entorno. As diversas atividades desenvolvidas e a sobreposição das áreas de influência produzem efeitos cumulativos e sinérgicos (KOEHLER; ASMUS, 2010).

No Brasil, a situação é agravada devido ao grande crescimento das exportações experimentado nas últimas décadas, associado à falta de conservação da infraestrutura logística existente e ao baixo investimento em novas estruturas (CHINELATO; CRUZ; ZIVIANI, 2011; MEDEIROS, 2014; WANKE; HIJJAR, 2009). Entre 2010 e 2018, a movimentação portuária aumentou 33,2% (ANTAQ, 2018). A limitação de espaço para crescimento de pátios e armazéns ocorre em diversas zonas portuárias brasileiras, causando o aumento do trânsito de caminhões nas rodovias e filas de espera nas cidades portuárias (GERMANO; FREIRE JÚNIOR, 2017).

Nesse contexto, os portos secos (PS) se apresentam como alternativa, funcionando como facilitadores para armazenagem, desembarço aduaneiro, consolidação e manuseio da carga (AWAD-NÚÑEZ et al., 2016b; GERMANO; FREIRE JÚNIOR, 2017). Os Portos Secos podem ser definidos como terminais intermodais terrestres fortemente conectados aos portos marítimos por meio de serviços de transporte frequentes e



de alta capacidade (NGUYEN; NOTTEBOOM, 2016; ROSO; WOXENIUS; LUMSDEN, 2009). Os PS funcionam como extensões das zonas de influência portuária em terra (*hinterlands*) para facilitar a movimentação de cargas entre porto e interior, proporcionando maior agilidade (LOUREIRO; FREITAS; GONÇALVES, 2015).

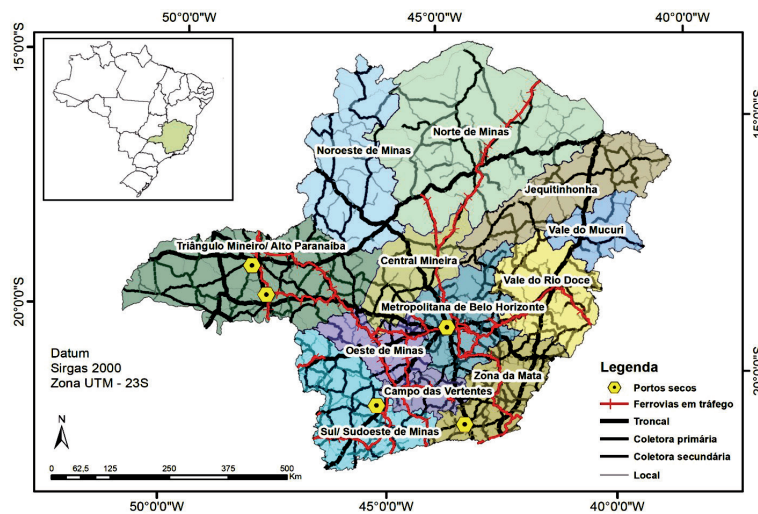
Entre suas principais vantagens, destaca-se a descentralização de parte das atividades portuárias, deixando-as mais próximas das regiões de captação ou de destino das cargas. Isso possibilita soluções logísticas aprimoradas e contribui para a geração de empregos e receita na região onde o PS é instalado. Outra vantagem é a possibilidade de liberar importações e exportações ao longo do tempo, distribuindo as despesas alfandegárias uniformemente durante o exercício financeiro em vez de um único grande pagamento. Roso, Woxenius e Lumsden (2009) destacam ainda a mudança do transporte rodoviário para um modal mais eficiente e menos prejudicial ao meio ambiente.

O objetivo deste artigo foi avaliar a distribuição espacial dos portos secos em Minas Gerais e identificar os melhores locais para uma nova instalação. A avaliação e a proposta foram subsidiadas por uma metodologia que integrou dois métodos bastante empregados na definição locacional: a Análise Multicritério Espacial – AMCE (LIGMANN-ZIELINSKA; JANKOWSKI, 2014; RAHMAN et al., 2013; SADASIVUNI et al., 2009) e o Problema de Localização-Alocação – PLA (HILLSMAN, 1984; LORENA et al., 2001; MAPA; LIMA, 2012). O primeiro caracteriza-se como solução integradora de objetivos distintos, muitas vezes conflitantes (SAATY, 2008). O segundo trata-se de uma aplicação do problema de p-medianas, sendo amplamente empregado na localização de instalações logísticas (LORENA et al., 2001).

O estudo foi realizado em Minas Gerais por ser um estado sem acesso a portos marítimos, mas com grande importância logística e econômica no comércio exterior brasileiro. Condição interessante para a viabilidade de um PS distante, onde a distância e o tamanho do fluxo de mercadorias tornam a ferrovia viável sob uma perspectiva estrita de custos (ROSO; WOXENIUS; LUMSDEN, 2009). Ainda, devido às desigualdades inter-regionais do estado, o conceito de Desenvolvimento Econômico e Social Sustentável (DESS), apresentado no Plano Mineiro de Desenvolvimento Integrado (MINAS GERAIS, 2015), foi considerado, implicando na adoção não só de aspectos logísticos e econômicos, mas também sociais e ambientais.

## 2 CARACTERIZAÇÃO DA ÁREA DE ESTUDO E SELEÇÃO DOS CRITÉRIOS

Minas Gerais possui alta heterogeneidade biofísica, socioeconômica e cultural, que se reflete na distribuição espacialmente desigual de equipamentos públicos e infraestrutura de transporte. Na Figura 1 é ilustrada a área de estudo, com suas mesorregiões, ferrovias em tráfego, principais rodovias (federais e estaduais) e a localização dos PS existentes.



**Figura 1** | Mesorregiões de Minas Gerais com os portos secos, ferrovias em tráfego e as principais rodovias existentes em 2016 segundo o IBGE.

Fonte: Elaborada pelos autores com dados do IBGE (2018) e BRASIL (2014).

A escolha do local para instalação do PS considerou cinco macrocritérios (ambiental, competição, econômico, logístico e social). Quatro desses critérios com subcritérios (Tabela 1). A seleção dos critérios foi baseada na literatura sobre localização de instalações logísticas, como Barboza e Vieira (2014); Bolturk et al. (2016); Ka (2011); Loureiro, Freitas e Gonçalves (2015); Nguyen e Notteboom (2016); Roso, Woxenius e Lumsden (2009) e Sopha et al. (2016). Outros critérios, referentes a aspectos legais, estabilidade e ambiente político, custos de construção e questões técnicas de engenharia também são encontrados (BOLTURK et al., 2016; ROSO; WOXENIUS; LUMSDEN, 2009). Entretanto, esses aspectos não foram considerados, uma vez que não se relacionam a questões espaciais e, portanto, extrapolam o objetivo do trabalho.

No que diz respeito à acessibilidade logística, a malha rodoviária mineira é a mais extensa do Brasil. Apesar da distribuição desigual, mais de 50% das rodovias da Região Sudeste do Brasil estão em Minas Gerais (CNT, 2018). Já a malha ferroviária é a segunda maior do Brasil em extensão, representando aproximadamente 17% da rede ferroviária (MINAS GERAIS, 2015).

**Tabela 1 | Critérios selecionados com fonte, data e método para espacialização dos dados.**

| Grupo          | Variável               | Fonte               | Data | Formato dado      | Método               |
|----------------|------------------------|---------------------|------|-------------------|----------------------|
| Econômico      | Valor FOB exp          | MDIC                | 2015 | Tabular           | Interpolação (IDW)   |
|                | Valor FOB imp          | MDIC                | 2015 | Tabular           | Interpolação (IDW)   |
|                | nº postos de trabalho  | RAIS                | 2010 | Tabular           | Interpolação (IDW)   |
|                | PIB                    | FGV                 | 2015 | Tabular           | Interpolação (IDW)   |
| Competição     | Distância PS existente | PNLT 2010           | 2010 | Vetor - Ponto     | Distância Euclidiana |
| Acessibilidade | Dist. Rod. Troncal     | DEER/Setop          | 2015 | Vetor - Linha     | Dist. Euclidiana     |
|                | Dist. Rod. Principal   | DEER/Setop          | 2015 | Vetor - Linha     | Dist. Euclidiana     |
|                | Distância ferrovias    | PNLT 2010           | 2010 | Vetor - Linha     | Dist. Euclidiana     |
| Social         | nº de não ocupados     | IBGE                | 2010 | Tabular           | Interpolação (IDW)   |
|                | Índice Social          | Atlas Brasil        | 2010 | Tabular           | Interpolação (IDW)   |
| Ambiental      | Dist. área urbana*     | Embrapa Territorial | 2015 | Vector - Polígono | Dist. Euclidiana     |
|                | Dist. Hidrografia**    | IBGE                | 2015 | Vector - Linha    | Dist. Euclidiana     |
|                | Dist. Ucs***           | ICMBio/Semad        | 2015 | Vector - Polígono | Dist. Euclidiana     |

\*Influência limitada a 5 km da área urbanizada.

\*\*Apesar da Lei Nº 12.651, de 25 de maio de 2012, que instituiu o novo Código Florestal (BRASIL, 2012) determinar que a maior Área de Proteção Permanente (APP) de mata ciliar é de 500 m, foi definida uma oneração gradual decrescente para áreas até 1000 m de cursos de água, a fim de se evitar a proposição de empreendimentos em áreas que possam impactar os recursos hídricos.

\*\*\*Apesar de o Conama ter revogado em 2010 a Resolução Conama 13/1990 (BRASIL, 1990) que determinava a zona de amortecimento das UCs sem plano de manejo em 10 mil metros, e determinado o novo valor de 3.000 metros, o estudo adotou um buffer de 10.000 m considerando a importância dessas zonas para o ecossistema das UCs.

Fonte: Dados primários da pesquisa com a respectiva fonte citada na tabela.

A mineração representa uma fatia significativa da receita de exportação do estado, com uma logística dedicada e eficiente. Entretanto, a pauta de exportações possui outras atividades relevantes que direta ou indiretamente podem ser beneficiadas com PS estrategicamente localizados. Os principais produtos exportados são: minério de ferro e seus concentrados (29%), café cru e em grãos (12%), soja em grãos ou triturada (8,5%) e ferroligas (8,0%) (BRASIL, 2018). A importação é mais fracionada, com destaque para adubos ou fertilizantes químicos (8,9%), carvão (7,7%), compostos químicos (4,6%) e demais produtos da indústria de transformação (4,3%) (BRASIL, 2018). Para medir exportação e importação, foi considerado o valor livre e desembaraçado sobre o navio, em inglês *Free On Board* (FOB), dos municípios mineiros no ano de 2015, conforme disponível no site do Ministério da Indústria, Comércio Exterior e Serviços (MDIC).

A atividade econômica foi representada pelo PIB e pelos postos de trabalho relativos aos segmentos de extrativismo mineral, indústria de transformação, agropecuária e serviços industriais de utilidade pública, constantes da Relação Anual de Informações Sociais (Rais).

Quanto às características ambientais, as áreas preservadas, em 2010, correspondiam a apenas 6,4% do território do estado. A Mata Atlântica correspondia originalmente a 46% do território total e hoje representa apenas 5,3% (MINAS GERAIS, 2015). Portanto, ressalta-se a necessidade de que os investimentos em infraestrutura não acentuem os impactos ambientais e nem coloquem em risco as áreas preservadas, já tão escassas.

No tocante às características sociais, os municípios do norte apresentam os piores índices, com renda *per capita* inferior à média do estado e baixo Índice de Desenvolvimento Humano – IDH (MINAS GERAIS, 2015). As mesorregiões Noroeste, Norte, Jequitinhonha e Mucuri, embora abriguem 15,6% da população, representam apenas 7,4% do PIB (IBGE, 2010). O indicador de não ocupados foi obtido a partir da Tabela 3580 no Sistema do Instituto Brasileiro de Geografia e Estatística (IBGE) de Recuperação Automática (Sidra) com base nos dados do Censo de 2010 (IBGE, 2010). O Índice Social (IS) foi proposto para ponderar, além da demanda por serviços portuários, também o potencial de impacto socioeconômico regional do PS. O IS é proporcional à população e inversamente proporcional ao quadrado do IDH conforme mostra a Equação 1.

$$IS = \frac{Pop}{IDH^2} \quad (1)$$

Em que: **IDH:** Índice de Desenvolvimento Humano (Atlas Brasil/Censo de 2010)

**Pop:** População obtida também no Atlas Brasil

Os critérios possuem diferentes unidades de medida, portanto foram normalizados para possibilitar a comparação e integração. A faixa de variação dos valores foi de 0 a 10. Zero (0) representa ausência de influência da variável, um (1) representa o menor custo e 10 o maior. Quanto menor o valor, maior a atratividade de instalação de PS.

Os subcritérios foram referenciados no espaço utilizando a metodologia indicada na Tabela 1. Por se tratarem de análises espaciais, e devido à dimensão geográfica da área de estudo, para minimizar distorções cartográficas em medidas de distâncias foi adotado o sistema de coordenadas em projeção cônica equidistante (MITCHEL, 2005; SNYDER, 1987).

### 3 METODOLOGIA

A metodologia integrou de forma sequencial dois métodos reconhecidos de definição locacional em um único modelo. Dessa forma, o inverso do índice produzido na AMCE foi utilizado como demanda ponderada no PLA, conforme descrito na Figura 2. A adoção de cenários propiciou a avaliação da localização dos PS existentes e também o impacto da priorização socioambiental na escolha da localização de uma nova instalação.

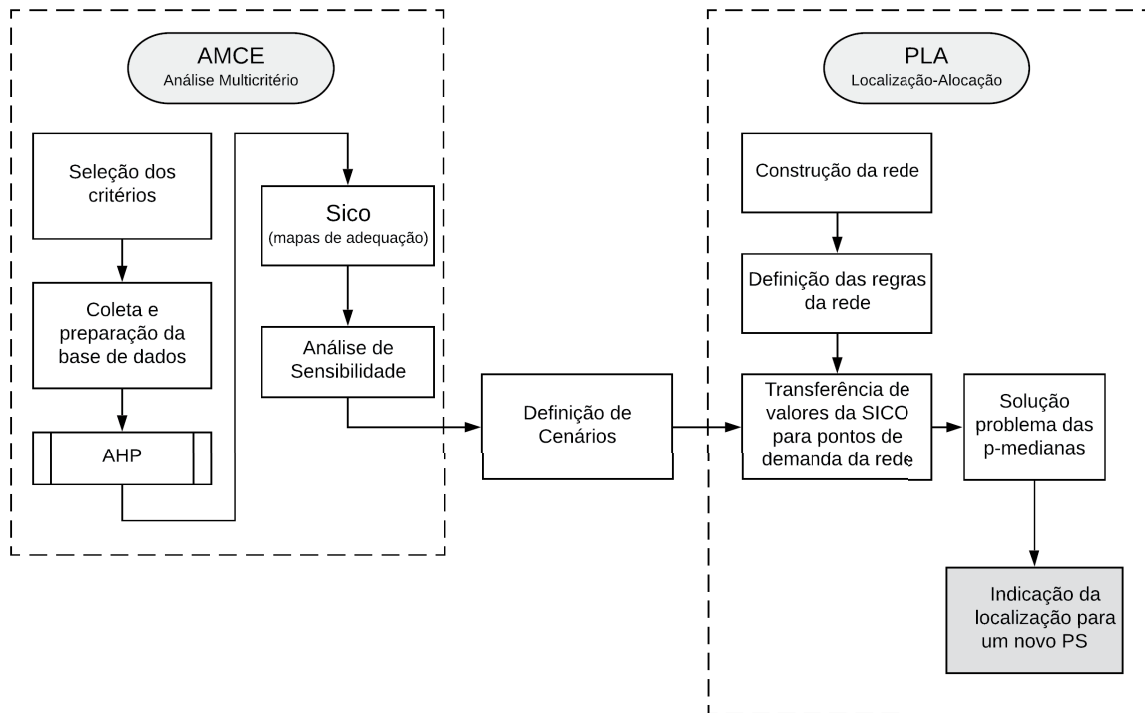


Figura 2 | Fluxograma dos procedimentos metodológicos desenvolvidos.

Fonte: Elaborada pelos autores.

### 3.1 ANÁLISE MULTICRITÉRIO ESPACIAL (AMCE)

A determinação da hierarquia e os pesos dos critérios foram atribuídos seguindo-se o método AHP (*Analytic Hierarchy Process*) (SAATY, 1977, 2008). A pesquisa contou com a participação de dez especialistas da área de logística na avaliação par a par dos critérios. Os cálculos foram realizados utilizando a planilha desenvolvida por Goepel (2013). O valor do peso de cada critério ( $w_i$ ) foi definido tomando o autovetor correspondente ao maior autovalor ( $\lambda$ ) da matriz de comparação pareada (CHEN; YU; KHAN, 2010; SAATY, 1977). A hierarquia dos critérios adotados na formulação do modelo é ilustrada na Figura 3.

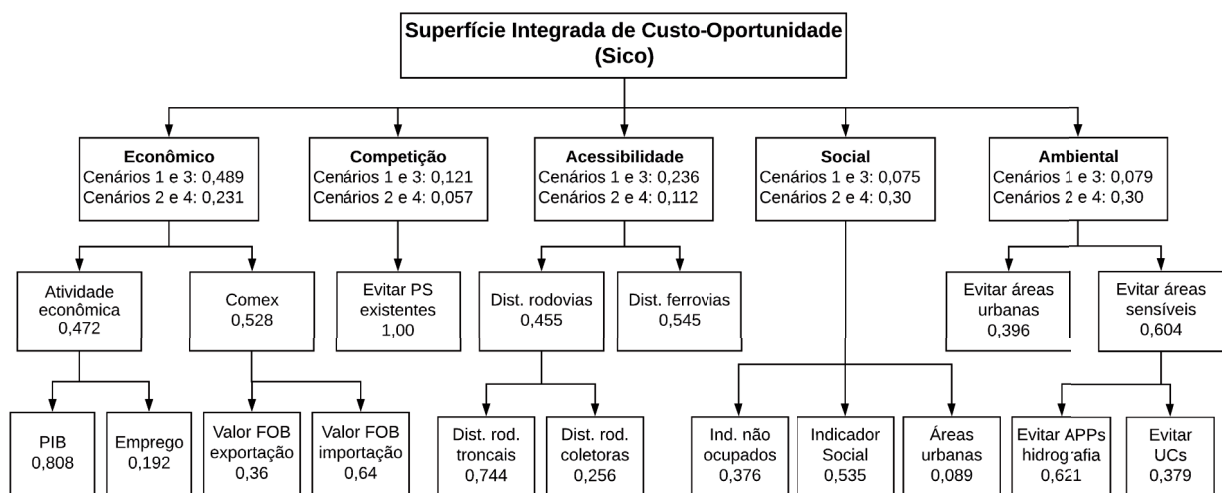


Figura 3 | Hierarquia dos critérios selecionados e seus respectivos pesos.

Fonte: Elaborada pelos autores.

A consistência da matriz normalizada foi medida por meio da taxa de consistência (CR), do consenso entre os especialistas (EC) e do índice de consistência geométrica (GCI), proposto por Crawford e

Williams (1985). Para a CR, foi adotado o valor limite de 0,10, usado em várias aplicações do AHP (APOSTOLOU; HASSELL, 1993; CHEN; YU; KHAN, 2010). Para maior detalhamento do AHP, sugere-se a leitura de Chen, Yu e Khan (2010) e Saaty (1977, 2008), e sua aplicação em análise espacial em Sadasivuni et al. (2009).

A AMCE foi referenciada no espaço para possibilitar análises espaciais e melhor visualização. Duas Superfícies Integradas de Custo-Oportunidade (Sico) foram geradas. Sico **A** com pesos dos critérios determinados pelo AHP e Sico **B** com favorecimento socioambiental. Maior detalhamento sobre a Sico **B** é apresentado na seção 3.3 DEFINIÇÃO DE CENÁRIOS. A análise foi desenvolvida em um Sistema de Informações Geográficas (SIG). Os municípios foram classificados com intuito de apresentar as melhores alternativas para localização de um novo PS.

Cada Sico representa a soma ponderada dos critérios (Equação 2). Seguindo a hierarquia estabelecida no AHP, cálculo semelhante à Sico foi empregado a cada critério para cômputo dos subcritérios. Exceção do critério ambiental, construído por sobreposição condicionada. As zonas de amortecimento, áreas urbanas e APPs são áreas que devem ser mandatoriamente evitadas para esse tipo de empreendimento, portanto não deve haver ponderação entre esses subcritérios no cálculo do critério ambiental.

$$Sico(x_i, y_i) = \sum_{j=1}^n P_n \times C_n(x_i, y_i) \quad (2)$$

Em que: Sico  $(x_i, y_i)$  = Valor da Superfície Integrada de Custo-Oportunidade no ponto  $i$  de coordenada  $(x_i, y_i)$ .

$P_n$  = Peso do critério  $n$ , conforme determinado no AHP.

$C_n(x_i, y_i)$  = Valor do critério  $n$  no ponto de coordenada  $(x_i, y_i)$ .

A Análise de Sensibilidade (AS) da AMCE foi realizada para os critérios social e ambiental utilizando-se o método de variação de um critério de cada vez (*One-Factor-At-A-Time*, OAT) (CHEN; YU; KHAN, 2013; DANIEL, 1958). A intenção foi avaliar a força desses critérios e o possível impacto da priorização socioambiental. O peso de cada critério variou de 0 a 100% com incrementos de 10%, enquanto os demais critérios tinham a proporção do seu peso mantida.

### 3.2 PROBLEMA DE LOCALIZAÇÃO-ALOCAÇÃO (PLA)

Assim como a etapa anterior (AMCE), o PLA também foi desenvolvido em uma plataforma SIG. O problema foi construído em uma rede com a conectividade definida em dois grupos: rodovias e ferrovias. A topologia da rede foi corrigida e validada. Foram especificadas cinco regras para a rede. Duas de custo, o comprimento do trecho e o tipo da via. Uma de hierarquia de acordo com a classe de função da via (ferrovia: 1; rodovias troncais e coletoras primárias: 2; coletoras secundárias: 3; vias locais: 4). Duas de preferência, uma para trânsito de cargas preferencialmente por ferrovias e outra para evitar trânsito em rodovias locais.

Os 79.535 pontos de demanda receberam valores transferidos da Sico correspondente de cada cenário. Dessa forma, a solução do PLA considera as regras definidas para a rede e também a demanda ponderada dos critérios econômicos, logísticos, sociais, ambientais e de competição. Como candidatos para localização do PS foram selecionados 94 pontos da rede, distribuídos em todas as mesorregiões do estado, sendo preferencialmente conexões rodoferroviárias.

O PLA foi enunciado como um problema de  $p$ -medianas. Esse problema consiste em localizar  $p$  instalações logísticas (medianas) em uma rede, de modo a minimizar a soma total das distâncias de

cada nó de demanda à sua mediana mais próxima (CHRISTOFIDES; BEASLEY, 1982; HAKIMI, 1964; TEITZ; BART, 1968). A solução foi gerada de forma a atender a maior quantidade de pontos de demanda. Técnicas heurísticas foram usadas, pois o espaço da solução cresce até ficar extremamente grande. O solucionador construiu uma matriz de custos origem-destino (OD). Em seguida, foi feita uma edição de Hillsman (HILLSMAN, 1984), e um conjunto de soluções semirrandomizadas foi gerado. Aplicou-se uma heurística de substituição de vértices (TEITZ; BART, 1968) para refinar as soluções. Finalmente, uma meta-heurística Grasp (FEO; RESENDE, 1995; LORENA et al., 2001) retornou a melhor solução de um grupo de boas soluções.

### 3.3 DEFINIÇÃO DE CENÁRIOS

Foram definidos quatro cenários, criados a partir da combinação da consideração, ou não, dos PS existentes com as Sicos computadas pela AMCE. Em cada um dos quatro cenários, seis localidades foram selecionadas entre as 94 candidatas para atender aos 79.535 pontos de demanda.

- **Cenário 1:** Sem PS existentes + Sico A (pesos critérios AHP).
- **Cenário 2:** Sem PS existentes + Sico B (priorização socioambiental).
- **Cenário 3:** PS existentes obrigatórios + Sico A (pesos critérios AHP).
- **Cenário 4:** PS existentes obrigatórios + Sico B (priorização socioambiental).

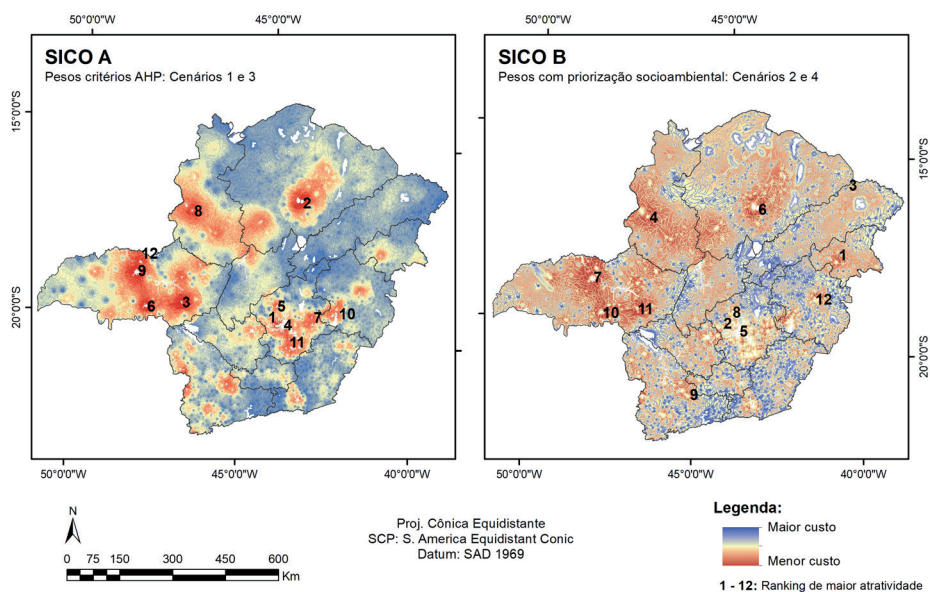
Dois cenários (2 e 4) tiveram priorização socioambiental. A priorização ambiental foi realizada visando a minimização dos impactos ao meio ambiente e a redução dos esforços do projeto ao evitar áreas ambientalmente sensíveis (MONTAÑO et al., 2012). Já o favorecimento dos critérios sociais busca tornar a instalação de um novo PS um instrumento de desenvolvimento regional, que possibilite a geração de empregos e melhora dos indicadores sociais. Os pesos dos critérios social e ambiental foram definidos arbitrariamente em 30% cada. Os outros três critérios tiveram seu peso ajustado, mantendo a proporção determinada pelo AHP.

Para avaliar a localização dos PS existentes, o modelo foi executado desconsiderando-os (cenários 1 e 2). Contudo, na realidade, os PS existentes são obrigatórios na solução, pois não faz parte do objetivo sugerir a desativação de nenhuma instalação logística, que inclusive pode ser privada.

## 4 RESULTADOS E DISCUSSÕES

Os pesos determinados pelo AHP para a AMCE foram atestados pela  $CR = 0,008$ , com  $\lambda = 5,035$ . O valor de  $CR$  observado ( $< 0,10$ ) assinala consistência aceitável da matriz de comparação pareada (APOSTOLOU; HASSELL, 1993; CHEN; YU; KHAN, 2010). O  $GCI$  foi igual a  $0,03$  e o consenso das opiniões foi de  $84,6\%$ .

As duas Sico são apresentadas na Figura 4. A superfície **A** (esquerda) considerou os pesos dos critérios determinados pelo AHP. Do lado direito, a Sico **B** teve priorização socioambiental. Comparando os dois mapas, observa-se que a priorização socioambiental reduz o peso econômico e, de certa forma, equaliza as regiões. Essa priorização, entretanto, não altera a configuração espacial da solução, onde alguns polos regionais permanecem mais atrativos para a instalação do PS.



**Figura 4 |** Superfícies integradas de custo-oportunidade para localização de PS em Minas Gerais. Pesos dos critérios determinados pelo AHP (Sico A) e priorização dos critérios social e ambiental (Sico B).

Fonte: Elaborada pelos autores.

Na Sico A (utilizada nos cenários 1 e 3), o custo de oportunidade máximo para localização de PS foi de 8,3993 (Arantina, no Sul de Minas) e o mínimo de 2,8601 (Betim). Observa-se na Tabela 2 que os municípios mais atrativos são Betim, Montes Claros e Araxá. Entretanto, por já existirem PS muito próximos da primeira e da terceira alternativas, provavelmente haverá uma grande competição. O destaque é Montes Claros (2º no ranking), pois apresenta grande atratividade e nenhum PS em um raio de 350 km.

A Sico B, empregada nos cenários com priorização socioambiental (2 e 4), teve os custos variando entre 9,2408 (Arantina) e 3,4524 (Teófilo Otoni). A ordem de classificação apresentada na Tabela 2 foi alterada. Porém, oito candidatas permanecem como boas alternativas nas duas AMCE: Betim, Montes Claros, Araxá, Belo Horizonte, Sete Lagoas, Uberaba, Paracatu e Uberlândia. Na Sico B, Montes Claros cai da 2ª para a 6ª posição na classificação, devido à sua proximidade ao Parque Estadual da Lapa Grande e à grande área urbanizada.

**Tabela 2 |** Localidades de maior atratividade para instalação do PS de acordo com a AMCE sem priorização socioambiental (Sico A).

| Ranking | Custo | Município          | Microrregião   | Mesorregião                | X coord (m) | Y coord (m) |
|---------|-------|--------------------|----------------|----------------------------|-------------|-------------|
| 1       | 2,86  | Betim              | Belo Horizonte | Metropolitana de BH        | 1.571.640,7 | 1.248.247,0 |
| 2       | 3,07  | Montes Claros      | Montes Claros  | Norte de Minas             | 1.644.675,2 | 1.596.149,6 |
| 3       | 3,22  | Araxá              | Araxá          | Triângulo / Alto Paranaíba | 1.302.431,1 | 1.315.568,9 |
| 4       | 3,25  | Belo Horizonte     | Belo Horizonte | Metropolitana de BH        | 1.590.851,3 | 1.251.391,4 |
| 5       | 3,30  | Sete Lagoas        | Sete Lagoas    | Metropolitana de BH        | 1.571.917,2 | 1.304.824,2 |
| 6       | 3,37  | Uberaba            | Uberaba        | Triângulo / Alto Paranaíba | 1.202.742,4 | 1.304.367,2 |
| 7       | 3,75  | Itabira            | Itabira        | Metropolitana de BH        | 1.675.155,0 | 1.272.323,9 |
| 8       | 3,75  | Paracatu           | Paracatu       | Noroeste de Minas          | 1.336.801,3 | 1.574.621,2 |
| 9       | 3,78  | Uberlândia         | Uberlândia     | Triângulo / Alto Paranaíba | 1.177.431,2 | 1.405.099,9 |
| 10      | 3,83  | Santana do Paraíso | Ipatinga       | Vale do Rio Doce           | 1.746.041,6 | 1.282.858,3 |

| Ranking | Custo | Município | Microrregião | Mesorregião                | X coord (m) | Y coord (m) |
|---------|-------|-----------|--------------|----------------------------|-------------|-------------|
| 11      | 3,96  | Itabirito | Ouro Preto   | Metropolitana de BH        | 1.606.038,8 | 1.212.047,3 |
| 12      | 3,97  | Araguari  | Uberlândia   | Triângulo / Alto Paranaíba | 1.186.257,2 | 1.432.014,4 |

Fonte: Elaborada pelos autores.

Na Figura 5 pode-se observar a AS do critério ambiental das 12 localidades candidatas à instalação do PS que apresentaram o menor custo na Sico A. Todas as localidades apresentaram aumento linear do custo, com conseqüente redução da atratividade. Paracatu (A87) foi a alternativa que apresentou menor taxa de crescimento do custo. As poucas localidades (6 das 94) que reduziram o custo ao se aumentar o peso ambiental não estão entre as 12 primeiras do ranking.

O comportamento da AS do critério social foi diferente do ambiental. A variação de custo observada é menor<sup>1</sup> e, ao contrário do critério ambiental, a maioria das localidades (66) apresenta redução do custo com o incremento no peso do critério. As localidades que apresentaram aumento do custo já tinham custos maiores antes do incremento no peso.

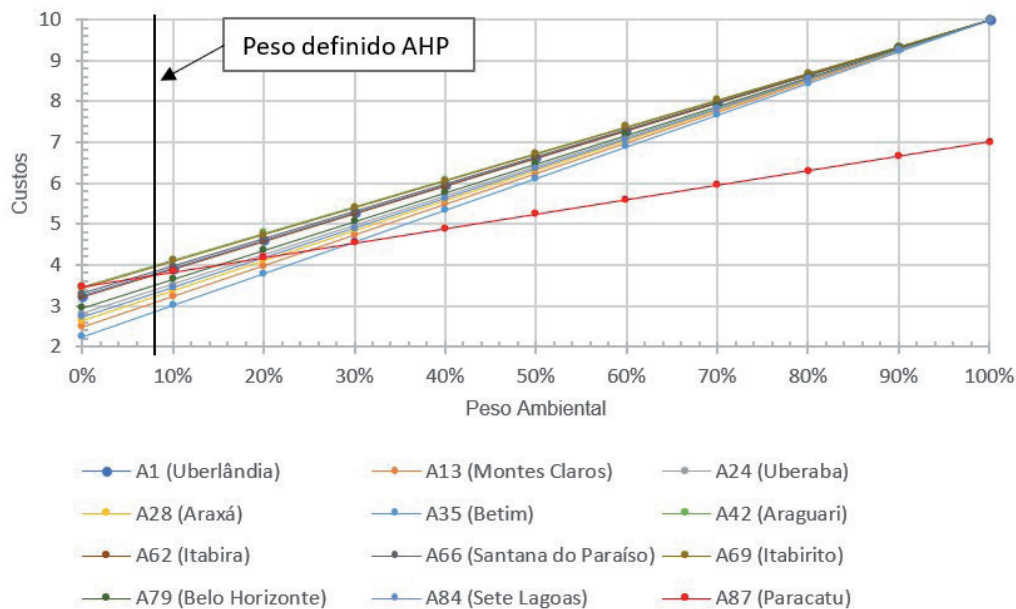


Figura 5 | Análise de Sensibilidade do critério ambiental, com a variação observada do custo nas 12 localidades candidatas à instalação do PS de maior atratividade na Sico A.

Fonte: Elaborada pelos autores.

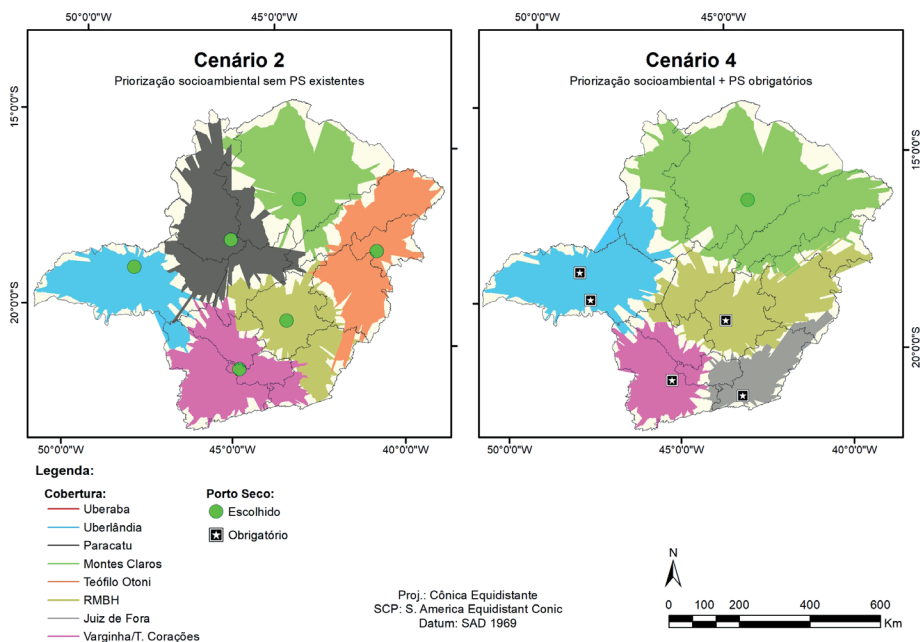
Nos cenários 1 e 2, devido à configuração espacial semelhante das Sico A e B (Figura 4), as localidades selecionadas foram as mesmas. Ocorreram apenas diferenças mínimas na área de cobertura de cada PS. Três PS foram localizados em locais onde já existem instalações na região (Uberlândia, Varginha e Contagem). Outros três foram posicionados nos municípios de Paracatu, Teófilo Otoni e Montes Claros, com preferência em relação aos que já existem em Uberaba e Juiz de Fora. O resultado aponta a deficiência de PS no norte do estado (mesorregiões Norte, Noroeste, Vale do Jequitinhonha e Mucuri), apesar da existência de demanda e, conseqüentemente, potencial para instalação. Além disso, devido à característica gravitacional do PLA, a distribuição espacial dos PS foi mais equilibrada do que a distribuição das instalações existentes. A área de cobertura de cada PS foi muito similar à área dos demais.

Nos cenários 3 e 4, onde os cinco PS existentes são obrigatórios na solução, apenas mais um é acrescido. Montes Claros é escolhida como a melhor solução em ambos os cenários. Apesar da queda na atratividade após a priorização socioambiental, Montes Claros foi selecionada no PLA devido à sua



posição estratégica (IBGE, 2008), que permite atender uma vasta região de Minas, ainda não servida por terminais alfandegados. Nesses dois cenários, uma das localidades obrigatórias, Uberaba, só foi acessada por pontos de demanda muito próximos e no seu entorno.

Na Figura 6 são apresentadas as localidades selecionadas para instalação dos PS, com sua respectiva área de cobertura. Devido aos resultados semelhantes nos cenários 1 e 2, assim como em 3 e 4, os mapas da Figura 6 apresentam apenas os resultados dos cenários 2 e 4.



**Figura 6 |** Portos secos e suas respectivas áreas de cobertura no estado de Minas Gerais para os dois cenários de priorização socioambiental (2 e 4).

Fonte: Elaborada pelos autores.

Um fator que influencia a escolha por Montes Claros é a concentração das atividades de exportação e importação da mesorregião Norte de Minas em poucos municípios, a maioria deles localizados no entorno de Montes Claros. De acordo com dados do MDIC (BRASIL, 2018), quase 99% do valor FOB de exportação da mesorregião é proveniente de apenas sete municípios. Montes Claros sozinho é responsável por 49,9% em 2017 e 38,3% em 2018, do valor total exportado pela mesorregião (BRASIL, 2018).

Os resultados deste estudo corroboram a condição de Capital Regional B e a grande área de influência atribuídas a Montes Claros pelo IBGE (2008) na pesquisa Regiões de Influência das Cidades (Regic). De acordo com os resultados (Figura 6) e com o IBGE (2008), além da mesorregião Norte de Minas, Montes Claros influencia também as mesorregiões Noroeste, Vale do Jequitinhonha e Mucuri.

A importância da integração de dois métodos de definição locacional é verificada pela diferença entre os resultados de cada método individualmente. Se tivéssemos considerado apenas a AMCE com pesos determinados pelo AHP, o município de Betim teria preferência em relação a Montes Claros. Contudo, já existe um PS na Região Metropolitana de Belo Horizonte, onde situa-se Betim, de forma a atender à respectiva demanda regional. Por outro lado, a solução do PLA sem a ponderação da Sico seria restrita à otimização do número de pontos de demanda atendidos, e a importância das dimensões social e ambiental provavelmente seria negligenciada. Além disso, esse tipo de análise na etapa de planejamento pode facilitar o processo de licenciamento ambiental, que exige a avaliação de alternativas locais ambientalmente viáveis (MONTAÑO et al., 2012).

Os projetos de investimentos produtivos direcionados a Minas Gerais entre 2004 e 2014 foram fortemente concentrados em termos espaciais. Apenas quatro Territórios de Desenvolvimento responderam por 70% das intenções de investimentos. As regiões mais dinâmicas foram preferidas, em detrimento das áreas historicamente problemáticas do ponto de vista ambiental, econômico e social, ou seja, as políticas de fomento estaduais sancionaram uma determinada configuração produtiva e espacial preexistente (MINAS GERAIS, 2015). É necessário superar esse cenário de desigualdade regional por meio do DESS de todo o estado.

## 5 CONCLUSÃO

Portos secos são alternativas para amenizar o congestionamento e os conflitos sociais nas zonas primárias, diminuir os custos logísticos, dar maior agilidade ao processo e reduzir impactos ambientais. Contudo, tradicionalmente, o assunto tem sido limitado à área de transportes. Este estudo apresenta subsídios para a formulação de propostas de planejamento mais abrangentes e participativas. Fatores de caráter social e ambiental, muitas vezes negligenciados na perspectiva cartesiana da engenharia de transportes, devem ser considerados no momento de escolha do local de uma nova instalação. Dessa forma, o maior benefício para todas as partes interessadas pode ser alcançado, promovendo o desenvolvimento regional sustentável.

A adoção conjunta de dois métodos reconhecidos e empregados para a localização de instalações apresentou resultados diferentes de cada método individualmente. Dessa forma, a contribuição do artigo foi demonstrar o ganho alcançado pela integração de métodos modernos e consolidados de suporte à decisão no planejamento de transportes. O modelo proposto foi otimizado do ponto de vista logístico ao mesmo tempo que atendeu às demandas sociais e ambientais.

Minas Gerais, embora possua a maior malha rodoviária do País, é um estado com grandes disparidades regionais. Os resultados demonstraram que as mesorregiões do norte (Norte, Noroeste, Jequitinhonha e Mucuri) são carentes de serviços portuários interiores. Estudos multidimensionais possibilitam que locais com alto potencial não sejam esquecidos, e que a eventual instalação de novos PS não acentue a desigualdade de infraestrutura e os problemas ambientais preexistentes. As análises locais desenvolvidas a partir de diferentes cenários resultaram na convergência de Montes Claros como localização prioritária para instalação de PS.

Os autores entendem que o objetivo principal foi alcançado. A metodologia foi discriminada para subsidiar a discussão e propiciar a identificação das localidades mais adequadas para instalação de PS, tendo em vista elementos logísticos, sociais, ambientais, econômicos e de competição. Trabalhos futuros podem incorporar mais variáveis, avaliar as métricas de desempenho do modelo, comparar os resultados com outros métodos e aplicar uma AS espacialmente explícita.

## AGRADECIMENTOS

Os autores agradecem à Capes, CNPq e Fapemig pelo suporte financeiro para o desenvolvimento da pesquisa. Também agradecem aos colegas Vanilson Couto e Ana Ísis Moura pelas contribuições ao trabalho.

## NOTA

1 | A variação média do custo (média das diferenças entre o custo a peso 0% e 100% de todas as alternativas) na AS Social é de 1,11 contra 4,32 na ambiental. REFERÊNCIAS

## REFERÊNCIAS

- ANTAQ. **Anuário Antaq**. Disponível em: <<http://web.antaq.gov.br/Anuario/>>. Acesso em: 20 nov. 2018.
- APOSTOLOU, B.; HASSELL, J. M. An empirical examination of the sensitivity of the analytic hierarchy process to departures from recommended consistency ratios. **Mathematical and Computer Modelling**, 1993.
- AWAD-NÚÑEZ, S. et al. How should the Sustainability of the Location of Dry Ports be Measured? **Transportation Research Procedia**, v. 14, n. 2016, p. 936–944, 2016a.
- AWAD-NÚÑEZ, S. et al. A Methodology for Measuring Sustainability of Dry Ports Location Based on Bayesian Networks and Multi-criteria Decision Analysis. **Transportation Research Procedia**, v. 13, n. 2016, p. 124–133, 2016b.
- BARBOZA, P. D.; VIEIRA, J. G. V. Análise de decisão multicritério aplicada na seleção de investimento em armazenagem de soja em grão. **Produto & Produção**, v. 15, n. 2, p. 24–45, 2014.
- BOLTURK, E. et al. Multiattribute Warehouse Location Selection in Humanitarian Logistics Using Hesitant Fuzzy AHP. **International Journal of the Analytic Hierarchy Process**, v. 8, n. 2, 2016.
- BRASIL. Lei N. 12.651. Dispõe sobre a proteção da vegetação nativa; altera as Leis n. 6.938, de 31 de agosto de 1981, 9.393, de 19 de dezembro de 1996, e 11.428, de 22 de dezembro de 2006; revoga as Leis n. 4.771, de 15 de setembro de 1965, e 7.754, de 14 de abril de 1989, e a Medida Provisória n. 2.166-67, de 24 de agosto de 2001; e dá outras providências. Brasília, Brasil: **Diário Oficial da União** – Seção 1 – 28/5/2012, p. 1-32.
- BRASIL. Ministério da Indústria, Comércio Exterior e Serviços. **Estatísticas de Comércio Exterior**. Disponível em: <<http://www.mdic.gov.br/comercio-exterior/estatisticas-de-comercio-exterior>>. Acesso em: 31 mar. 2018.
- BRASIL. Ministério dos Transportes. **Base de Dados Georreferenciados PNL 2010**. Brasília (on-line): Ministério dos Transportes, 2014. Disponível em: <<https://www.infraestrutura.gov.br/conteudo/2822-base-de-dados-georreferenciados-pnl-2010.html>>. Acesso em: 31 jul. 2018.
- BRASIL. Resolução Conama 013/1990. Dispõe sobre a área circundante, num raio de 10 (dez) quilômetros, das Unidades de Conservação. Brasília, Brasil: **Diário Oficial da União**, 28/12/1990, p. 25541.
- CHEN, Y.; YU, J.; KHAN, S. Spatial sensitivity analysis of multi-criteria weights in GIS-based land suitability evaluation. **Environmental Modelling & Software**, v. 25, n. 12, p. 1582–1591, 2010.
- \_\_\_\_\_. The spatial framework for weight sensitivity analysis in AHP-based multi-criteria decision making. **Environmental Modelling & Software**, v. 48, p. 129–140, 2013.
- CHINELATO, F. B.; CRUZ, D. B. DE F.; ZIVIANI, F. Made in Brazil: o impacto da infraestrutura logística brasileira nas operações de comércio exterior. **Revista Administração em Diálogo – RAD**, v. 13, n. 3, 2011.
- CHRISTOFIDES, N.; BEASLEY, J. E. A tree search algorithm for the p-median problem. **European Journal of Operational Research**, v. 10, n. 2, p. 196–204, 1982.
- CNT. **Pesquisa CNT de Rodovias 2018**. CNT | SEST SENAT. Brasília: Confederação Nacional do Transporte, 2018. Disponível em: <<http://pesquisarodovias.cnt.org.br/Home>>. Acesso em: 10 nov. 2018.
- CRAWFORD, G.; WILLIAMS, C. A note on the analysis of subjective judgment matrices. **Journal of Mathematical Psychology**, 1985.
- DANIEL, C. On Varying One Factor at a Time. **Biometrics**, v. 14, 1958.
- DINWOODIE, J. et al. Sustainable Development of Maritime Operations in Ports. **Business Strategy and the Environment**, v. 21, n. 2, p. 111–126, 2012.
- GERMANO, E. C.; FREIRE JÚNIOR, A. E. A importância do porto seco como facilitador na armazenagem e desembarço aduaneiro. **Revista Fatec Sebrae em Debate: Gestão, Tecnologias e Negócios**, v. 04, n. 6, 2017.

GOEPEL, K. D. Implementing the Analytic Hierarchy Process as a standard method for multi-criteria decision making in corporate enterprises – A new AHP Excel template with multiple inputs. **Proceedings of the International Symposium on the Analytic Hierarchy Process**. Kuala Lumpur: 2013. Disponível em: <<https://bpmmsg.com/new-ahp-excel-template-with-multiple-inputs/>>. Acesso em: 29 dez. 2018.

GOULIELMOS, A. M. European Policy on Port Environmental Protection. **Global Nest Journal**, v. 2, n. 2, p. 189–197, 2013.

HAKIMI, S. L. Optimum Locations of Switching Centers and the Absolute Centers and Medians of a Graph. **Operations Research**, v. 12, n. 3, p. 450–459, 1964.

HILLSMAN, E. L. The p-Median Structure as a Unified Linear Model for Location–Allocation Analysis. **Environment and Planning A**, v. 16, n. 3, p. 305–318, 1984.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Regiões de influência das cidades 2007**. Rio de Janeiro, RJ, Brasil: IBGE, 2008. Disponível em: <[www.ibge.gov.br](http://www.ibge.gov.br)>.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Censo 2010**. Rio de Janeiro, RJ, Brasil: IBGE, 2012. Disponível em: <<https://censo2010.ibge.gov.br/>>. Acesso em: 6 maio 2020.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Downloads Geociências | IBGE**. Rio de Janeiro (on-line): IBGE, 2018. Disponível em: <<https://www.ibge.gov.br/geociencias/downloads-geociencias.html>>. Acesso em: 31 jul. 2018.

JAFFEE, D. ‘A Deeper Channel Floats all Boats’: the port economy as urban growth engine. **Environment and Planning A: economy and space**, v. 47, n. 4, p. 783–800, 2015.

KA, B. Application of fuzzy AHP and Electre to China dry port location selection. **Asian Journal of Shipping and Logistics**, v. 27, n. 2, p. 331–354, 2011.

KOEHLER, P. H. W.; ASMUS, M. L. Gestão ambiental integrada em Portos Organizados: uma análise baseada no caso do porto de Rio Grande, RS – Brasil. **Revista da Gestão Costeira Integrada**, v. 10, n. 2, p. 53–67, 2010.

LIGMANN-ZIELINSKA, A.; JANKOWSKI, P. Spatially-explicit integrated uncertainty and sensitivity analysis of criteria weights in multicriteria land suitability evaluation. **Environmental Modelling and Software**, v. 57, p. 235–247, 2014.

LORENA, L. A. N. et al. Integração de modelos de localização a sistemas de informações geográficas. **Gestão & Produção**, v. 8, n. 2, p. 180–195, 2001.

LOUREIRO, J. F.; FREITAS, R. R. DE; GONÇALVES, W. Proposta de um método de localização para expansão de um terminal portuário por meio do Analytic Hierarchy Process (AHP). **Revista Espacios**, v. 36, n. 10, p. 7, 2015.

MAPA, S. M. S.; LIMA, R. DA S. Uso combinado de sistemas de informações geográficas para transportes e programação linear inteira mista em problemas de localização de instalações. **Gestão & Produção**, v. 19, n. 1, p. 119–136, 2012.

MEDEIROS, M. C. A geografia do mercado mundial de produtos agroalimentares e o papel do Brasil. **Raega – O Espaço Geográfico em Análise**, v. 31, p. 260, 2014.

MINAS GERAIS. Desenvolvimento econômico e social sustentável de Minas Gerais: redução das desigualdades sociais e regionais. **Plano Mineiro de Desenvolvimento Integrado (PMDI)**. Belo Horizonte, MG: Governo de Minas Gerais, 2015. Disponível em: <<https://www.mg.gov.br/conteudo/transicao/pmdi/pmdi>>.

MITCHEL, A. **The ESRI Guide to GIS analysis**. Redlands: ESRI Press, 2005. v. 2

MONTAÑO, M. et al. Integração de critérios técnicos, ambientais e sociais em estudos de alternativas locais para implantação de aterro sanitário. **Engenharia Sanitária e Ambiental**, v. 17, n. 1, p. 61–70, 2012.

NG, A. K. Y.; PADILHA, F.; PALLIS, A. A. Institutions, bureaucratic and logistical roles of dry ports: the Brazilian experiences. **Journal of Transport Geography**, v. 27, p. 46–55, 2013.

NGUYEN, L. C.; NOTTEBOOM, T. A Multi-Criteria Approach to Dry Port Location in Developing Economies with Application to Vietnam. **The Asian Journal of Shipping and Logistics**, v. 32, n. 1, p. 23–32, 2016.

OLIVEIRA, D. S. et al. Expansão Portuária, Desenvolvimento Municipal e Alterações Ambientais no Brasil: desafios para a gestão costeira. **Revista de Gestão Costeira Integrada**, v. 13, n. 1, p. 79–87, 2013.

PNUD; FJP; IPEA. **Atlas do Desenvolvimento Humano no Brasil**. Disponível em: <<http://atlasbrasil.org.br/2013/>>. Acesso em: 15 jun. 2020.

RAHMAN, M. A. et al. An integrated study of spatial multicriteria analysis and mathematical modeling for managed aquifer recharge site suitability mapping and site ranking at Northern Gaza coastal aquifer. **Journal of Environmental Management**, v. 124, p. 25–39, 2013.

ROSO, V.; WOXENIUS, J.; LUMSDEN, K. The dry port concept: connecting container seaports with the hinterland. **Journal of Transport Geography**, v. 17, n. 5, p. 338–345, 2009.

SAATY, T. L. A scaling method for priorities in hierarchical structures. **Journal of Mathematical Psychology**, 1977.

SAATY, T. L. Decision making with the analytic hierarchy process. **International Journal of Services Sciences**, v. 1, n. 1, p. 83–98, 2008.

SADASIVUNI, R. et al. A transportation corridor case study for Multi-criteria Decision Analysis. **Proceeding of ASPRS 2009 Annual Conference**. Baltimore, USA: ASPRS, 2009.

SINAY, M. C. F.; CARVALHO, S. D.; BRAGA, I. L. A Importância da Inclusão da Variável Ambiental na Gestão Portuária. **Revista de Administração, Sociedade e Inovação**, v. 3, n. 2, p. 124–135, 2017.

SNYDER, J. P. **Map Projections: a working manual**. Washington, DC, USA: United States Government Printing Office, 1987.

SOPHA, B. M. et al. Urban distribution center location: combination of spatial analysis and multi-objective mixed-integer linear programming. **International Journal of Engineering Business Management**, v. 8, p. 1–10, 2016.

TEITZ, M. B.; BART, P. Heuristic Methods for Estimating the Generalized Vertex Median of a Weighted Graph. **Operations Research**, v. 16, n. 5, p. 955–961, 1968.

WANKE, P. F.; HIJJAR, M. F. Exportadores brasileiros: estudo exploratório das percepções sobre a qualidade da infraestrutura logística. **Produção**, v. 19, n. 1, p. 143–162, 2009.

# Linking migration, climate and social protection in Brazilian semi-arid: case studies of Submédio São Francisco and Seridó Potiguar

*Conectando migração, clima e proteção social no  
semiárido brasileiro: estudos de caso do Submédio São  
Francisco e Seridó Potiguar*

Ana Claudia de Almeida<sup>a</sup>

Alisson Flávio Barbieri<sup>b</sup>

Saulo Rodrigues Filho<sup>c</sup>

<sup>a</sup>Mestre em Desenvolvimento Sustentável, Universidade de Brasília, UnB, Brasília, DF, Brasil  
Email: anaclaud.al@gmail.com

<sup>b</sup>Professor Associado do Departamento de Demografia da Universidade Federal  
de Minas Gerais, UFMG, Belo Horizonte, MG, Brasil  
Email: barbieri@cedeplar.ufmg.br

<sup>c</sup>Professor Adjunto do Centro de Desenvolvimento Sustentável, Universidade de Brasília, UnB,  
Brasília, DF, Brasil  
Email: saulofilhocds@gmail.com

doi:10.18472/SustDeb.v11n2.2020.31293

Received: 01/05/2020  
Accepted: 10/08/2020

ARTICLE- VARIA

## ABSTRACT

Over the known history of Brazilian sertões migration has been recorded as a human response to drought episodes. Social protection policies beginning around 2003 had dramatically diminished poverty rates and, within this context, migration changed compared to other periods, becoming more heterogeneous and diffuse. The article aims to explore the link between drought, migration and social protection in the Brazilian semi-arid region based upon the analysis and conceptual discussion about two case studies: Submédio São Francisco and Seridó Potiguar. In contrast with the past, actual migration holds an indirect relation to climate. Public policy softened the impacts of the climate over livelihoods and changed the coping strategies. In this sense, mobility outside the semi-arid was not a strategy to survive. Yet, the role of the state in the preceding decades and the region's historical path – inseparable from its climate – drew persistent migration flows that still reverberate in present dynamics.

**Keywords:** Population mobility. Drought. Cash transfer. Brazilian semi-arid Northeast.

## RESUMO

*Ao longo da história dos sertões, a migração foi registrada como resposta humana a episódios de seca. Políticas de proteção social iniciadas nos anos 2003 diminuíram drasticamente as taxas de pobreza, ao passo que a migração mudou comparada a outros períodos, tornando-se mais heterogênea e difusa.*

*O artigo visa explorar o nexos entre secas, migrações e proteção social na região, baseado na análise e discussão conceitual em torno de dois estudos de caso: o Submédio São Francisco e o Seridó Potiguar. Em contraste com o passado, a migração do presente tem uma relação indireta com o clima. Políticas públicas moderaram os impactos do clima sobre os meios de vida e estratégias. Portanto, deixar o semiárido não seria mais uma estratégia de sobrevivência. Ainda assim, o papel do estado nas décadas anteriores e a trajetória histórica da região – inseparável do clima – desenhou fluxos migratórios persistentes que ainda reverberam no presente.*

*Palavras-chave:* Mobilidade populacional. Secas. Transferência de renda. Semiárido nordestino.

## 1 INTRODUCTION

Migration, as a specific type of population mobility, has been historically associated with drought episodes in the Brazilian semiarid region. Over centuries, the population movement toward coastal cities or to the southern part of country was a subsistence and even survival strategy to avoid famine, diseases and the collapse of agricultural systems during periods of severe droughts.

The context underlying those drought episodes relates to the irregular rain regime, which is characteristic of the region's climate, combined with poor socioeconomic conditions. Brazilian semiarid is located mostly in Northeast Brazil and corresponds to approximately 11% of Brazilian territory. This area is delimited by its physical characteristics, notably its inter-annual rain variability, low water availability and rains concentrated in three to five months a year. Besides scarce rains, it is common the occurrence of drought episodes a year or a couple of years with precipitation way below average (MARENGO et al., 2011). Those aspects are especially problematic for rainfed agriculture, which is a persistent and relevant activity in Brazilian semiarid.

In addition, the semiarid region has held a large share of the poorest Brazilian population. Since colonization and for centuries that followed, land concentration shaped social and economic dynamics. Most of the population established a relation of dependence (and even subservience) with a local elite, in which they would use and produce in a landlord's lands, giving part of production as payment. This system was reinforced by climate, as land owners would provide means for survival – usually benefiting from dams built by federal government – to those kept under their influence. As result, during periods of droughts thousands of people would not have access to water or food (as their subsistence production collapsed), facing death or being forced to flee (ARAÚJO, 2000; BURSZTYN, 2008; CHACON, 2007).

During the 20th century, this dynamic shifted due to a more direct – and top-down – State action, as well as economic modernization processes. Investment in relief measures, such as cash transfer programs, as cash-for-work programs and water trucks progressively diminished famine, mortality and migration, thus increasing the resilience and adaptation capacity of the population living in the semi-arid. Still, centuries of inequality in the access to resources along with focalized and fragment development policies implemented mostly during military regime (1960's to 1980's) resulted in high and persistent poverty rates.

The last drought episode (2011-2017) was one of the longest and harshest ever registered in the region in terms of rain scarcity and irregularity, but it took place in a different social scenario. Between 2012 and 2015, the Ministry of Integration estimated a loss of 6 billion dollars in the agricultural sector, and the Federal Government declared state of emergency in 1,100 of the 1,794 municipalities in Brazilian semiarid (MARENGO; CUNHA; ALVES, 2016). Nevertheless, and in contrast with past contexts, the rate of poor people in the region dropped from 80% in 1991 to 41% in 2010, due largely to wide investment in cash transfer programs and advancements in social protection policies. Still reflecting social improvement, human development index (HDI) raised from 0,291 to 0,591 in the same period. Given this background, the human impact associated with the six years of low raining did not reflect past scenarios of disaster and increasing migration or population circulation (for example, seasonal or temporary mobility) that for so long characterized the long periods of rain scarcity.

This contrast between past and present raises questions about what elements mediate the link between migration and climate, more specifically droughts episodes. Furthermore, Brazilian semiarid recent history points to the role of social protection and cash transfer programs in modifying this relation. Human impacts related to droughts in the region throughout the last decades provide a picture of a changing social, economic and political scenario – which includes new and more heterogenic migration patterns – exposed to a known phenomenon.

This article explores the connections between climate, migration and social protection through the specificities of *Brazilian semiarid*. We ground this discussion based upon two case studies within the region: *Submédio São Francisco* (Pernambuco and Bahia states) and *Seridó Potiguar* (state of Rio Grande do Norte). The first section discusses the extant literature on the effects of drought on migration as well as the role social protection programs affecting this relationship. The second section brings the study cases on the Submédio São Francisco and Seridó region, followed by concluding remarks in the last section.

## 2 THE ASSOCIATION BETWEEN DROUGHTS AND SOCIAL PROTECTION PROGRAMS ON MIGRATION IN BRAZILIAN SEMIARID

Since the colonial occupation in Brazil, drought episodes and their effects have been registered as part of Brazilian semiarid social landscape. Missionaries in 16th century reported indigenous people fleeing to coastal regions due to the lack of rains, and settlers recorded massive loss of cattle in 17th century (MARENGO et al., 2011). One of the most dramatic episodes took place in 1877, during a three-years drought episode which killed around 500 thousand people and raised nationwide public commotion (NELSON; FINAN, 2009b).

Population mobility was associated with the drought episodes from the first written registers, as illustrated by the 16th missionary notes. In the 18th century, though, population in the semiarid grew significantly, and migration during famine outbreaks due to droughts became massive (CAMPOS, 2014). Gomes (2001) states that until the 20th century “the human disaster dimension was strictly associated with migration; facing famine and lack of water to even drink, those who did not die in ‘sertão’ fled to another place”. Even in the early 20th century, the number of migrants fleeing drought were so expressive that the Brazilian government created ‘concentration camps’ allegedly to assist population, in order to keep the “*retirantes*” from arriving in the cities of the coast. In 1932, the biggest camp in Ceará state contained 60 thousand people (NEVES, 1995).

Given this historical background, climate factors are commonly pointed in the literature as the root of migration flows originating in the region. Population displacement was one of the few survival strategies available to the poorest population when their survival capacity deteriorated (OJIMA; COSTA; CALIXTA, 2014). Nonetheless, different conceptual frameworks on environment and migration might provide a sight about different patterns associating population and the droughts in semiarid regions.

The debate about environmental migration gained momentum in the decade of 1980 due largely to the rising debate about the consequences of climate change on vulnerable populations. El-Hinnawi (1985), Jacobson (1988) and Myers (2002), among other authors, established and spread the term “environmental refugee” to name forced migratory movement provoked by environmental disturbances that undermine life conditions in a given place. In this context, pressures over natural resources where livelihoods were fragile would result directly in population displacements (CASTLES, 2002). Myers (2002) estimated 25 million environmental refugees worldwide in 1995 from out-migration from areas prone to environmental stress. Similarly, Rigaud et al. (2018) more recently calculated 143 million climate migrants fleeing slow-onset events within developing countries by 2050.

Following this debate, migration driven by droughts has been discussed as a “common sense” assumption (CASTLES, 2002; MORRISSEY, 2012). As Morrissey (2012) points out, migration is frequently understood by proponents of the environmental refugee concept as “an inevitable outcome of vulnerability” (p. 43).



In this sense, out-migration in Brazilian semiarid could be understood as a “natural” consequence of the impacts of the lack of rains over agricultural production, water availability, food security and possible social tensions arriving from this resource stress (such as famine outbreaks).

However, droughts are usually not the sole cause of mobility as adaptation strategy (WARNER ET AL., 2011). Several studies (BARBIERI, 2011; BLACK et al., 2011; CATTANEO et al., 2019; HUGO, 1996; KACZAN; ORGILL-MEYER, 2019; MCGREGOR, 1994; WARNER, 2010) discuss the high complexity in the association between climate and migration. First, migration in many cases is not so straightforwardly derived from livelihood conditions – on the contrary, it can be constrained by multiple factors such as institutions and social relations (see, e.g., BLACK ET AL., 2011).

In a review of empirical evidence, Kaczan and Orgill-Meyer (2019) highlight the role of income, land tenure and gender in the relationship between weather and migration. In addition, the human consequences that would lead to migration (e.g. food and water scarcity) might not themselves derive from environmental crisis. Sen (1983), for instance, argues that famine outbreaks during drought episodes in the African Sahel were due to a failure of individual entitlements – related to a broader social and political framework – rather than environmental conditions to food production. Some studies even conclude that the poorest and more vulnerable households cannot afford migrating during an environmental crisis (e.g. MCNAMARA et al., 2018; MUELLER et al., 2020). Overall, several authors have discussed migration (and other types of population mobility as well) as an adaptation strategy to droughts as highly contextual and dependent on factors in multiple dimensions (BLACK et al., 2011; ADGER and ADAMS, 2013).

Some conceptual frameworks analyzing the association between environmental factors and migration highlight the complexity of this link and draw attention to the multiple factors involved. According to Morrissey (2012), a main question regarding studies in the field is to clarify the “relationship between environmental and non-environmental variables in shaping mobility imperatives and decisions, in communities experiencing environmental stress”. Along these lines, Hugo (1996) discussed a model of environmentally driven migration in which “precipitating events” might trigger population movement under “predisposing conditions”. However, these conditions do not directly provoke migration; instead, they affect the constraints and facilitators to migration, as well as they might be modified by policy responses.

Similarly, Black et al. (2011) argue that the migration-environment nexus must be analyzed in multiple dimensions and levels. The conceptual framework suggested by the authors defines categories that encompass factors related to the wider context in which a person or group is inserted and that influences the decision to migrate; for example, due to employment opportunities (economic), existing conflicts (political) and land productivity (environmental). Likewise, individual characteristics (e.g. wealth, education, sex and personal preferences) and meso-level characteristics (e.g. social networks and institutions) may facilitate or undermine the decision to migrate or to stay (BLACK et al., 2011). Given these multiple levels, environmental change impacts this chain by modifying directly or indirectly macro conditions in environmental, political, economic, social and demographic spheres (BLACK et al., 2011). It is implicit in this discussion the impossibility to separate economic from environmental motivations to move (LILLEOR and VAN DEN BROECK, 2011), as well as the highly contextual, diverse factors affecting the relationship between migration and droughts (LEIGHTON, 2011)

Since frameworks like those proposed by Hugo (1996) and Black et al. (2011) assume that multiple drivers play a role in limiting or favoring the decision to migrate, the idea of “forced migration” itself is softened. Under this perspective, voluntary and forced movement are seen as ends of a continuum (with “completely voluntary” movement in one side, and “completely forced” movement in the other). The range of alternatives available to the individual, household or community posits them in this gradient – the movement is closer to a displacement whether migration is necessary to survival. The degree of willingness – a “subjective dimension” – and the elements of the underlying context in scenarios of environmental change might be bridged through the concept of vulnerability (degree in

which a group is susceptible to suffer impacts from an environmental change and unable to cope with it, mediated by the adaptive capacity this group presents) (BARBIERI, 2011).

In order to analyze Brazilian semiarid as a study case, we review the literature to identify on the plethora of (complex) factors addressing the region's socioeconomic, institutional and political background. Nelson and Finan (2009) point out that climate hazards is always present in Brazilian semiarid environment, but only in certain situations – determined by non-environmental factors – it results in human disasters (including high mortality) and/or people fleeing the region. In this sense, drought episodes exist primarily as a socio-environmentally driven phenomenon. On one hand, the region historically presents high levels of poverty and low access to basic services and assets. On the other hand, choices regarding politics and public policy towards the region also shaped the relationship between the population and their local climate.

Chacon (2007) synthesizes the questions underlying drought episodes in Brazilian semiarid in four points: a) land ownership structure; b) socioeconomic and productive structure; c) household disaggregation; and d) relationship between population and politics. Regarding the first, land uneven distribution is lasting. From colonial times, land was distributed among a restrict elite that raised and reinforced political and economic power by regulating population access to resources. From the productive perspective (b), rainfall agriculture was one of the cornerstones of the production in Brazilian semiarid until 20th century, mainly to the self-consumption of the most dispossessed population. It is still a central activity among small farmers and is highly sensitive to climate.

Chacon (2007) also draws attention to the fragilities derived from the departure of family members to other regions (c): migration itself makes population more sensible to the effects of drought. Finally, policies had been historically used by some groups in exchange to political “loyalty”, in a pattern named “*clientelismo*” (d). Thus, public policies were seen by the majority of population as a *gift* rather than a *right*. Although this path changed with advancements in the overall development of the region, much of these relations to policy and to politics remain a barrier to more effective and lasting coping strategies.

The relevance of observing multiple factors affecting migration flows is even more evident considering the changes in recent scenarios in the region. After mid-20th century and more intensely in 21th century, migration patterns shifted from massive movements towards the coast and the wealthier region of Southeast (cities like *São Paulo*) to more diffuse and heterogeneous movements to smaller cities and other areas within semiarid region, including return migration and circular mobility (BURSZTYN; CHACON, 2013; FUSCO; OJIMA, 2014; OJIMA, 2014; ALMEIDA, 2018).

At the same time, the socioeconomic scenario was also transformed. From the 1960s to the 1980s, Brazil faced an intense process of urbanization (PRIORI et al., 2012). During 1960s and 1970s, the Northeast region was target for policies oriented to the construction of development poles (such as priority areas to foster modernized agriculture established in *São Francisco* valley and dry lands of *Seridó* and other regions) (ARAÚJO, 2000; BURSZTYN, 2008). In the 2000, federal social protection policies were significantly expanded, involving federal expenditure in social assistance increased almost fivefold between 2002 and 2015, what caused poverty in the region to drop (ARAÚJO, 2013).

In general, migration (as well as other forms of population mobility such as commuting and seasonal mobility) seem to have transited along the continuum forced-voluntary movement: if massive flows of people fleeing characterized Brazilian semiarid in the past, the heterogeneous contemporary movements are closer to a choice of strategy than in the previous periods. This shift is related to the changes in social, economic and political landscape, as rain scarcity was not only constant through time but also is likely increasing due to climate changes (MARENGO et al., 2011).

Along these lines, Ojima, Costa and Calixta (2014) observed statistically a smaller association between migration and drought occurrence than between migration and social protection benefits, since people receiving cash transfers or social insurances were less likely to migrate. Similarly, Correia and

Barbieri (2019) observed the role of social protection programs in the mobility patterns and the coping mechanisms facing environmental hazards.

Evidences like those indicate that social protection is nowadays an important factor underlying population movement in the region. It is, thus, necessary to qualify this relation, particularly in terms of understanding how social protection alter the relation among population and climate events and how population vulnerabilities and fragilities still historically persist and respond to climate variations.

A nationwide system of social protection began to be structured in Brazil after the decade of 1980, following the process of redemocratization and an international trend towards the adoption of public policies focused on poverty reduction in a scenario of economic crisis (DRAIBE, 2005). Social protection was established as a right in the Brazilian Constitution of 1988. Despite the legal framework, social protection measures – mainly those framed as social assistance – were systematically implemented only in the decade of 2000 (VAITSMAN; ANDRADE; FARIAS, 2009). Policies such as wide-ranging cash transfer programs and rising minimum wage took effect mainly in the poorest regions, as is the case of the Brazilian semiarid.

Social protection is frequently defined as those policies aiming to reduce vulnerability and risks of groups facing poverty and exclusion (DEVEREUX; SABATES-WHEELER, 2004; KOZEL; FALLAVIER; BADIANI, 2008; OIT, 2014). This aim comprises two facets: shocks and structural conditions (BLANK; HANDA, 2008; DEVEREUX, 2016). On one hand, social protection protects a person or household from an isolated disturbance (e.g., economic, environmental or political) that could cause immediate and profound impacts on its means of living. On the other hand, social protection reduces vulnerabilities resulted from social exclusion and chronic poverty.

Devereux and Sabates-Wheeler (2004) proposed four categories of social protection measures according to their interaction with shocks and structural conditions: a) protective measures; b) preventive measures; c) promotive measures; d) transformative measures. Protective measures (a) aligns with the concept of *safety net measures*, which alleviate specific deprivations and avoid deeper impacts of disturbances. Preventive measures (b) seek to avoid rising deprivation, allowing individual or groups to cope with livelihood shocks (social insurances are included in this category). Promotive and transformative measures, in turn, aim to bring these population groups out of their current condition by enhancing capabilities (c) or modifying social structures (d). These measures are related to broader development policies and social justice.

Social protection in rural areas – and more specifically, protective measures – is closely linked to food security. In these contexts, disturbance (of environmental or economic order) affect directly production and thus production for self-consumption and income also used to acquire food. Kanbur (2015) highlights not only how shocks could generate food insecurity, but how some strategies adopted by household could deepen its long-term condition. Short-term measures, as temporary mobility, selling animals or restricting production variety, might undermine possibilities of future development. Protective measures such as cash and food transfers avoid immediate food insecurity and prevent poverty traps. In this sense, rain scarcity impact over rainfed agriculture in the Brazilian semiarid might affect self-consume, income and husbandry costs among poor rural population.

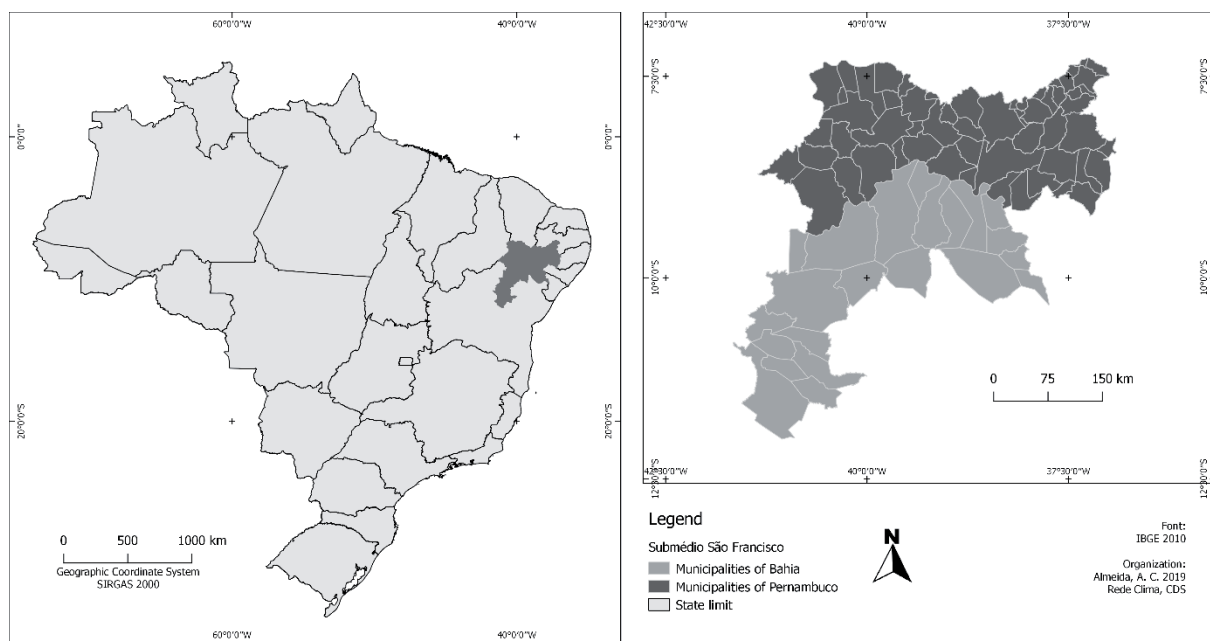
Thus, the effects of climate over migration might be modified by social protection measures in its two facets of action: by softening the impact of shocks over the livelihoods (AGRAWAL; PERRIN, 2009; TANLE, 2015) and by changing the poverty situation underlying the decision to migrate. Therefore, the concepts of *strategy* and *vulnerabilities* bridge migration, climate and social protection. People might migrate in order to improve their livelihood, to avoid life conditions to deteriorate, or even to survive in the face of oscillations in climate and other circumstances (economic, political, social). This motivation puts them within the spectrum of forced and voluntary movement. Social protection policies can modify the necessity to migrate as well as to provide and to change the alternatives available to the household strategies, thus reducing vulnerabilities. These policies can potentially shift migration from displacement-like patterns towards voluntary strategies.

### 3 STUDY CASES: DROUGHTS AND MIGRATION IN THE BRAZILIAN SEMI-ARID

We describe below two case studies which unveils the linkages between migration and droughts, and how social protection programs may affect it. We analyze data from two case studies collected in 2017, both financed by Brazilian Research Network for Climate Change (*Rede CLIMA – Rede Brasileira de Pesquisa em Mudanças Climáticas*). The first case – Submédio São Francisco – address the relation between migration, droughts and social protection through a temporal perspective apprehended by indicators and the memory and perception of local actors. The Seridó study case discuss the question through the results of a survey of the perception of the drought effects and its impacts over household strategies. Thus, the cases present an investigation of the link between migration, climate and social protection through different methodologies, as the first case emphasizes the qualitative analysis while the second focuses on quantitative results.

#### 3.1 THE SUBMÉDIO SÃO FRANCISCO

The *Submédio São Francisco* is a sub-basin of São Francisco river basin, the largest river crossing Brazilian semi-arid area. *Submédio* is a 110.000km<sup>2</sup> area entirely within the Brazilian semi-arid climate zone. Mean rainfall regime varies from 350 to 850 mm a year. It is a plural space, where family (rainfed) agriculture is, to date, a significant activity to a large share of the population and coexists with large public irrigation projects, oriented to agroindustrial and high-value production.



**Map 1 |** Study area of the Submédio São Francisco case.

*Source: elaborated by the authors*

This area comprises ninety-three municipalities partially or entirely within the sub-basin. Data supporting the case discussion was obtained from official statistic (e.g., censuses) and semi-structured interviews undertaken in 2017 with 41 community leaders and civil society entities members<sup>1</sup> within the integrative research project on Socio-Environmental Security (“PI-SSA” – *Projeto Integrativo de Segurança Socioambiental*), financed by *Rede CLIMA*. The questionnaire was comprised of open-ended questions about the recent drought, and broader observed changes and responses in multiple dimensions of daily life (e.g. mobility, water access, food security, income, health, family relations).

The study case investigates through the narratives of the interviewees and the temporal evolution of indicators the direct effects of drought, the changes caused by social protection measures and the migration paths. The changes in these three dimensions are compared to discuss the link between them.

As for the rest of the Brazilian semi-arid, *Submédio* is characterized by irregular rainfall and faced one of the longest droughts in the period 2012 - 2017. This drought illustrates the direct impacts of the lack of rain. Interviewees related that it prejudiced crops and in some cases even made agriculture unfeasible. Some interviewees mentioned that they have not harvested for the past seven or eight years. Even though the area is crossed by a large perennial stream – the São Francisco river – many farmers near to the riverbank are equally affected by the rain scarcity. As drought brings river level low (especially in the dam reservoirs constructed along São Francisco, where water volume reached 4% of capacity), riverside communities get more distant from the stream and frequently do not have adequate pumping technology or access to any technology at all. Public irrigation projects settlers, in contrast, were not affected. Farmers reported drought would not “reach” the irrigated perimeter and they would not lack water unless São Francisco river dried completely.

In this sense, the lack of rain has a direct effect over production of food crops – the main production of small farmers in the region are manioc, beans and corn – that would serve to self-consumption, income and cattle feeding. Moreover, rains below average also hinder fishery and extractive activities, such as the gathering of *umbu* (*Spondias tuberosa*) fruits that generate income mainly to women in the region. Thus, drought impacted income received as well as household budget.

Although rains were reported as having direct effects, the case study analyzed the socioeconomic path in the region as well, following the conceptual frameworks discussed in the previous section. The aim is to establish a connection with migration patterns. During the decade of 2000, economic resources available to the poorest *Submédio* population improved: the percentage of people living in poverty dropped from 64% to 44%, and the mean income of the poorest fifth increased 78% from 2000 to 2010. The reduction of poverty reflects mainly the higher investment in social insurances and cash transfers and growth of public administration sector, as agricultural grew less than other sectors and production value of small farming products stagnated in the decade.

At the same time, 51% of the households in *Submédio* were benefited by *Programa Bolsa Família*, the main federal cash transfer policy, aimed to reach families with children (390,000 beneficiaries in the ninety-three municipalities within the *Submédio* sub-basin, receiving a mean of R\$ 103 per month, according to Social Development Ministry – MDS data). By 2010, only 57.5% of the mean household income was from labor, indicating the relevance of social programs in the domestic finances. Regarding socioeconomic indicators, it is evident the contrast between two municipalities (*Petrolina* and *Juazeiro*) that were target of the development policy of irrigation sites construction and agricultural modernization during the 1970s and the other municipalities of the region. The poverty rates are significantly lower than the rest of the region (20% of population living in poverty in 2010) and a mean of 80% of the household income came from labor in this region – indicating social programs are less significant to household budget in those municipalities.

Interviews with community leaders (part of the groups interviewed) show that income from rural activities is rarely sufficient to sustain the household. Households frequently hold a range of activities, including temporary and informal jobs in other agricultural establishment or in urban centers. Still, most interviewees, especially the elderly, related changes in the life conditions in the past two decades. Some of them associated this shift to public policy; social insurance (rural retirement pension), cash transfer (*Programa Bolsa Família*), policies of public purchase (*Programa de Aquisição de Alimentos*) and the construction of rain collecting cisterns (*Programa 1 Milhão de Cisternas*).

Thus, life conditions in *Submédio* seem to have improved in recent years and led the region to avoid past scenarios of human disasters, even when rains are more scarce than usual. Some interviewees report that life quality in rural areas and small villages of *Submédio* is now “viable”. In other words, vulnerabilities where

reduce, increasing alternatives available. This improvement is associated to protective and preventive-like measures (namely cash transfer programs) as evidenced by the relative lack of labor opportunities and low income coming from productive activities. Moreover, there remains socioeconomic inequality of *Submédio* in relation to other Brazilian regions and the sub-space of *Petrolina* and *Juazeiro* (shaped by past development policy decisions), so the gap might indicate that structural conditions still were not fully addressed. Along with this, migration as a strategy facing the region's context also shifted.

*Submédio*, following Brazilian semiarid historic pattern, presents high rates of migration and negative net migration. The low net migration rate in the region was persistent among past decades: the net migratory rate (net migration in relation to total population) was -2,49 in the 1991 census, compared to -3,49 in 2010 – it means the region continued to lose population over this time. Even though, migration flows changed in the recent past in the area. In-migration in urban areas decreased between the decades of 1980 and 1990, while rural exodus became less intense among adult population during the 2000s, according to national demographic censuses. Destination places became more diffuse along time as well. *São Paulo* metropolitan area is the region that receives most of the migrants from *Submédio*, but its relative importance decreased along time in face of other less populated areas (in mid-1990, 20% of the migrants would go to *São Paulo*, compared to 10% in 2000s). Similarly, the relevance of *Petrolina* and *Juazeiro* as attraction poles to the rest of the region diminished compared to other areas near *Submédio* (as other municipalities in *Bahia* and *Pernambuco* semiarid). Moreover, the data available does not express more heterogeneous movements, as circular mobility arrangements and short-term migration that might have increased in the region as well.

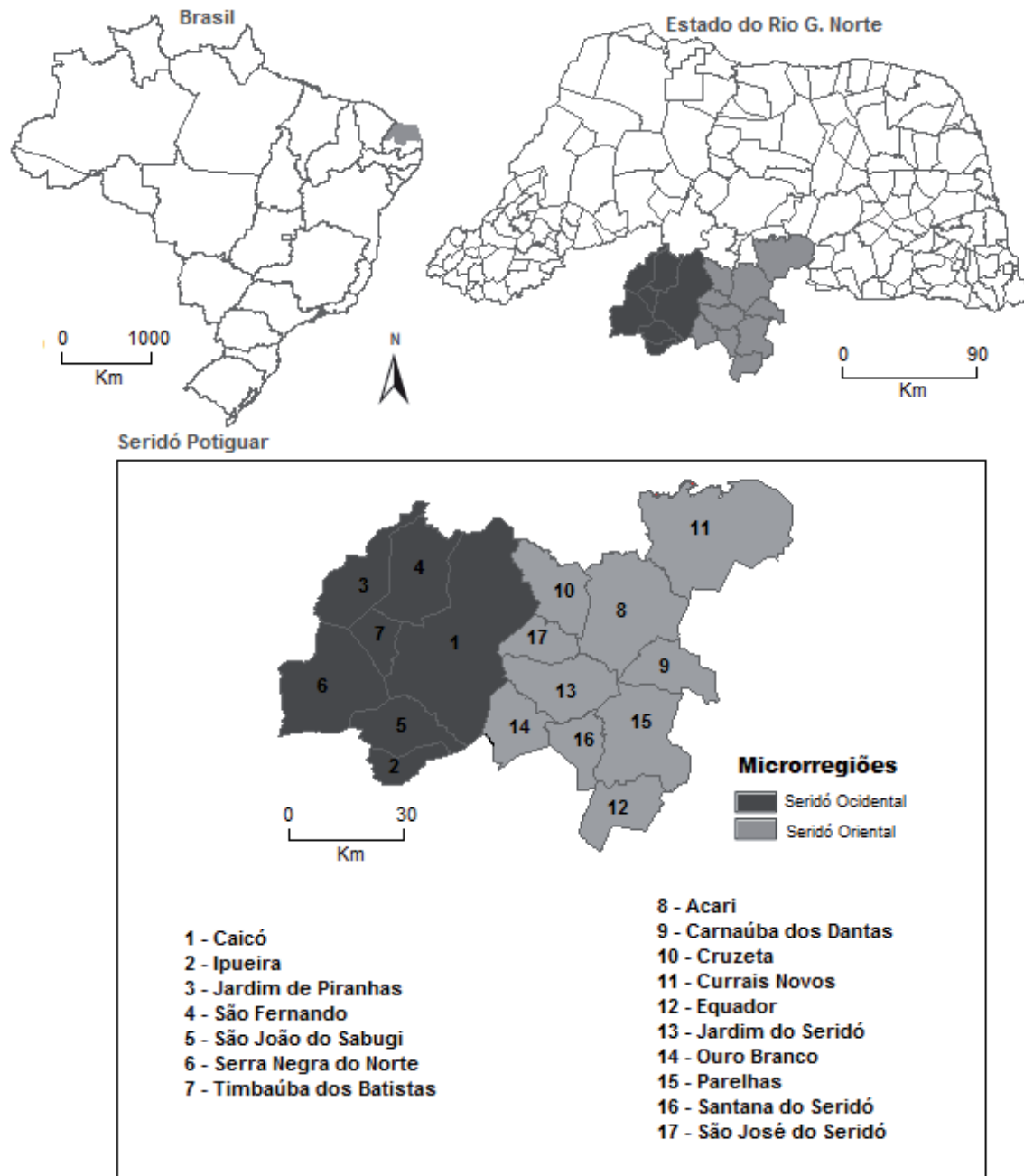
The meaning and purpose of the movements also changed, according to the perception of local actors. Older community leaders reported a contrast in their statements between migration in the past and today. Past movements are recalled as a change for the whole family, in which all or a few members would migrate to assure the survival of the group. In opposition, they highlight that actual migration is frequently a strategy by young members of the household for an urban way of life, associated with their devaluated perception of the region. In this sense, young people migrate seeking economic opportunities and social mobility despite the needs of the household.

It is noteworthy that most of the interviewees do not associate present migratory movements to the environment, as they remark improvements in living conditions in the region, mainly following social protection policies intensification. Nevertheless, the lack of income opportunities, especially during the prolonged drought (less agricultural production and less job options in larger farms) was also highlighted. This, by its turn, is mediated by non-environmental factors: some actors within the region do not “feel the drought” (as some interviewees state) for having access to water and resources (as pumping technology and rural technical assistance).

In sum, migration characteristics in *Submédio* followed the path suggested in the first section, as they have become closer to an alternative than a displacement. This shift might be associated to the protection of livelihoods in face of shocks (direct drought impacts). Even when production was not enough to guarantee income and food due to the lack of rains, the income provided by cash transfers programs and pensions allowed a food security scenario and dynamism in local economy. Policies that potentially foster structural changes by providing productive alternatives and deepening capabilities (we could associate with Devereux and Sabates-Wheeler's (2004) transformative and promotive measures) are existent – for instance, programs to spread accessible social technologies – but still not as widespread as social protection protective measures. Thus, improvement in life conditions have brought migration closer to a choice, but it faces a double threat: as environmental change could raise stresses, this new profile of the movements might depend on the continuity of the protective measures, since they are only effective while benefits are delivered.

### 3.2 THE SERIDÓ POTIGUAR

The Seridó Potiguar region involves 17 municipalities and 216,508 inhabitants (85% urban). The mean temperature is 28.6oC, with 23.2oC minimum and 35.4oC maximum on average. Rain regimes are irregular with low precipitation (mean 41.3 mm in 2007). As for the most non-irrigated semi-arid, natural soil fertility is low soil. The region is heavily dependent on agriculture and cash transfer programs, and water supply relies on few rivers and dams. Nonetheless, the Seridó, as in most parts of the contemporary Brazil, presents strong urban – rural articulations, with households diversifying livelihoods through both direct engagement in rural production or indirect linkages (e.g., agro-industries, services etc), urban employment (especially in the informal sector) and high dependence on cash-transfer programs.



**Map 2** | Study area of the Seridó Potiguar case, Rio Grande do Norte  
Source: CORREA (2018), data from IBGE, Malha Municipal Digital (2010).

In 2017, with financing from *Rede CLIMA*, it was implemented the first statistically representative household survey (n=1,064) in the Brazil's semi-arid, during one of worse periods of droughts in history of the semi-arid. The survey collected questions about socioeconomic, environmental and demographic issues, with a particular focus on vulnerability and adaptation to droughts. The survey used a three-stage probabilistic sample: municipalities (1<sup>st</sup>), urban sectors (2<sup>nd</sup>), households (3<sup>rd</sup>). In 2019 we implemented a follow up of 600 households from the 2017 sample.

The main purpose of the survey was to understand how population perceptions about droughts affect mobility as an adaptation strategy in the Brazilian semi-arid. Related to this, it was investigated how migration and temporary mobility (*vis-à-vis* immobility) is an effective strategy to reduce vulnerability for slow onset events (at least for this study case). The justification for this focus is that there are scanty evidences in the literature about the role of distinct types of mobility in adaptation strategies (types, timing, spatial range, residency status).

Barbieri et al. (2019) analyzed the linkages between mobility, droughts and social protection programs through bivariate descriptive analysis with significance tests, multiple multinomial regression using Probit Heckman selection models. Two main conclusions were reached. The first refers to understanding how distinct categories of mobility (migration, commuting, immobility) differ as adaptation strategies to droughts. The authors found that while higher exposition and experience with droughts decreases migration, it increases other types of mobility, especially commuting. Furthermore, migration is more likely in events not strictly related to droughts; in particular, it is more influenced by pre-existing socioenvironmental conditions, while commuting is more likely when experiences with droughts increase, acting as an immediate livelihood adaptation to droughts. Finally, the authors found that men are more mobile than women, and more likely than women to adopt migration *vis-a-vis* commuting.

The second conclusion refers to understanding how cash transfer programs (Bolsa Familia, rural retirement pensions etc) affect perceptions about droughts and adaptation strategies in terms of mobility. The authors found households with commuters (and not migrants) are always less likely to diversify livelihoods in terms of cash transfers (compared to households with migrants and no commuters), independent of perception about droughts. Households receiving social benefits are negatively associated with commuting (0.62 the odds of having a commuter compared to a non-mover) and are positively associated with migration (34% higher probability of having a migrant compared to non-movers, and 108% higher probability of having a migrant compared to commuters). Nonetheless, if a household receive cash transfers, there is a change in the level of mobility probabilities by age and perception about severity of droughts: each additional increase in one standard deviation of age increases the odds of migration in 3% compared to non-movers, or migrants compared to commuters.

## 4 CONCLUSIONS

The study case on the *Submédio São Francisco* illustrates how migration patterns are modified along with changing socioeconomic scenario. Among rural communities, the meaning around migration shifted from a survival measure to a search for economic opportunities social protection programs became an important component of household survival strategies, assuring basic needs and income during extreme events. This change corroborates the discussion in first section: the intensification of social protection policies in the region reduced poverty and protected households from direct climate impacts. Before this protection, migration might not decline (as it did not in Submédio) but rather approximate to the voluntary end of the continuum. On the other hand, the study case on the Seridó Potiguar shows the importance of understanding that perceptions about droughts may define, contingent on household characteristics and if they receive cash transfers or not, distinct mobility strategies, particularly in terms of migration and commuting.

The two case studies cases point to the relevance of protective measures as cash transfer in changing the socioeconomic scenario of Brazilian semi-arid, and maintaining migration as an alternative strategy



rather than a survival necessity. Social protection programs that foster alternative and sustainable livelihoods as well the reduction of power inequalities and resource distribution are still not as widespread as pensions and transfers. Protective measures are able to protect households while the benefits are delivered and assure food security in the short-run. Thus, adaptive strategies face a challenge as the uncertain political-institutional scenario might undermine the social protection effects. As the cases evidenced migration is highly sensitive to the socioeconomic context, migration paths that recently became similar to voluntary choices could regress to displacement-like movements.

## NOTES

1 | 16 interviewees from “Fundos de Pasto” (traditional agricultural communities); 9 from indigenous communities, 5 from associations of irrigated agriculture, 7 from other agricultural communities, 4 from related civil society organizations.

## REFERENCES

ADGER, W. N.; ADAMS, H. Migration as an adaptation strategy to environmental change. In: **Part 3: The consequences of global environmental change for society**.

OECD Publishing/UNESCO (Org.). World Social Science Report, 2013. 1ed.: OECD Publishing, p. 261-264, 2013. Disponível em <<https://unesdoc.unesco.org/ark:/48223/pf0000260413>>. Acesso em: 05 abr 2019.

AGRAWAL, A.; PERRIN, N. Climate adaptation, local institutions and rural livelihoods. In: ADGER, W. N.; LORENZONI, I.; O'BRIEN, K. (Eds.). **Adapting to Climate Change: Thresholds, Values, Governance**. Cambridge: Cambridge University Press, 2009.

ALMEIDA, A. C. **O nexo entre migrações, clima e proteção social: o caso do Submédio São Francisco**. Dissertação de Mestrado—Brasília: Universidade de Brasília, ago. 2018.

ARAÚJO, T. B. Desenvolvimento Regional Brasileiro e Políticas Públicas Federais no Governo Lula. In: SADER, E.; COSTA, A. M. (Eds.). **10 anos de governos pós-neoliberais no Brasil: Lula e Dilma**. 1a edição ed. São Paulo: Boitempo Editorial, 2013. p. 157–172.

ARAÚJO, T. B. **Ensaio sobre o desenvolvimento brasileiro: heranças e urgências**. Rio de Janeiro: Editora Revan, 2000.

BARBIERI, A. F. **Mudanças climáticas, mobilidade populacional e cenários de vulnerabilidade para o Brasil**. Revista Interdisciplinar da Mobilidade Humana, v. 19, n. 36, 2011.

BLACK, R. et al. **The effect of environmental change on human migration**. Global Environmental Change, v. 21, p. S3–S11, 2011.

BLANK, L.; HANDA, S. **Social Protection in Eastern and Southern Africa: A Framework and Strategy for UNICEF**. UNICEF, 2008. Disponível em: <[https://www.unicef.org/socialpolicy/files/Social\\_Protection\\_Strategy\(1\).pdf](https://www.unicef.org/socialpolicy/files/Social_Protection_Strategy(1).pdf)>. Acesso em: 15 abr 2019.

BURSZTYN, M. **O poder dos donos: planejamento e clientelismo no Nordeste**. 3. ed. Rio de Janeiro / Fortaleza: Garamond, 2008.

BURSZTYN, M.; CHACON, S. Ligações perigosas: proteção social e clientelismo no Semiárido Nordestino. **Estudos Sociedade e Agricultura**, v. 2, 2013.

CASTLES, S. **Environmental Change and Forced Migration: Making Sense of the Debate**. New Issues in Refugee Research, 1 jan. 2002.

CATTANEO, C. et al. Human Migration in the Era of Climate Change. **Review of Environmental Economics and Policy**, v. 13, n. 2, p. 189–206, 1 ago. 2019.

CHACON, S. **O sertanejo e o caminho das águas: políticas públicas, modernidade e sustentabilidade no semi-árido**. Fortaleza: Banco do Nordeste do Brasil, 2007.

CORREIA, I. A.; BARBIERI, A. F. Vulnerabilidade à seca e (i)mobilidade no Nordeste brasileiro: partir ou resistir? **Sustentabilidade em Debate**, v. 10, n. 2, p. 125–141, 31 ago. 2019.

DEVEREUX, S. **Social protection for rural poverty reduction**. Roma: Food and Agriculture Organization of the United Nations (FAO), 2016. Disponível em: <<http://www.fao.org/3/a-i5229e.pdf>>. Acesso em: 15 abr 2019.

DEVEREUX, S.; SABATES-WHEELER, R. **Transformative social protection**. Institute of Development Studies, 2004. Disponível em: <[https://www.unicef.org/socialpolicy/files/Transformative\\_Social\\_Protection.pdf](https://www.unicef.org/socialpolicy/files/Transformative_Social_Protection.pdf)>. Acesso em: 01 jun 2019.

DRAIBE, S. M. Brasil 1980-2000: **Proteção e Insegurança Sociais em Tempos Difíceis**. Caderno de Pesquisa NEPP, Núcleo de Estudos de Políticas Públicas da Universidade Estadual de Campinas - NEPP Unicamp. n. 65, 2005.

EL-HINNAWI, E. **Environmental refugees**. Nairobi: United Nations Environment Programme, 1985.

FUSCO, W.; OJIMA, R. Migrações e nordestinos pelo Brasil: uma breve contextualização. In: OJIMA, R.; FUSCO, W. (Eds). **Migrações nordestinas no século 21: um panorama recente**. São Paulo: Edgard Blucher, 2014.

GOMES, G. M. **Velhas secas em novos sertões: continuidade e mudanças na economia do semi-árido e dos cerrados nordestinos**. IPEA, 2001.

HUGO, G. **Environmental Concerns and International Migration**. The International Migration Review, v. 30, n. 1, p. 105–131, 1996.

JACOBSON, J. L. **Environmental refugees: a yardstick of habitability**. Worldwatch Institute, 1988.

KACZAN, D. J.; ORGILL-MEYER, J. The impact of climate change on migration: a synthesis of recent empirical insights. **Climatic Change**, 2019.

KANBUR, R. Mitigating risk: Social protection and the rural poor. In: INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE (Ed.). **2014-2015 Global food policy report**. Washington: International Food Policy Research Institute (IFPRI), 2015. p. 33–39. Disponível em: <<http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129072>>. Acesso em: 05 abr 2019.

KOZEL, V.; FALLAVIER, P.; BADIANI, R. **Risk and vulnerability analysis in World Bank analytic work: FY2000-FY2007**. The World Bank, 2008.

MARENGO, J. A. et al. **Caracterização do clima atual e definição das alterações climáticas para o território brasileiro ao longo do século XXI**: sumário técnico. Rio de Janeiro: Ministério do Meio Ambiente – MMA, 2007.

MARENGO, J. A. et al. Variabilidade e mudanças climáticas no semiárido brasileiro. In: MEDEIROS, S. (Ed.). **Recursos hídricos em regiões áridas e semiárida**. INSA, 2011.

MARENGO, J.; CUNHA, A. P.; ALVES, L. **A seca de 2012-15 no semiárido do Nordeste do Brasil no contexto histórico**. Climanalise, v. 04, p. 49–54, 2016.

MCGREGOR, J. Climate change and involuntary migration: implications for food security. **Food Policy**, v. 19, n. 2, p. 120–132, 1994.

MCNAMARA, K. E. et al. The complex decision-making of climate-induced relocation: adaptation and loss and damage. **Climate Policy**, v. 18, n. 1, p. 111–117, 2 jan. 2018.

MORRISSEY, J. Rethinking the “debate on environmental refugees”: From “maximalists and minimalists” to “proponents and critics”. **Journal of Political Ecology**, v. 19, p. 36–49, 2012.

MUELLER, V. et al. Do social protection programs foster short-term and long-term migration adaptation strategies? **Environment and Development Economics**, v. 25, n. 2, p. 135–158, abr. 2020.

MYERS, N. **Environmental refugees: a growing phenomenon of the 21st century**. Philosophical Transactions of the Royal Society B: Biological Sciences, v. 357, n. 1420, p. 609–613, 2002.

NELSON, D. R.; FINAN, T. J. Weak Winters: Dynamic Decision Making in the Face of Extended Drought in Ceará, Northeast Brazil. In: ERIC C.; ARTHUR D. (Eds.). **The Political Economy of Hazards and Disasters**. Lanham: Altamira Press, 2009.

ORGANIZAÇÃO INTERNACIONAL DO TRABALHO (OIT). **World Social Protection Report 2014/15: Building economic recovery, inclusive development and social justice**. Genebra: Organização Internacional do Trabalho (OIT), 2014. Disponível em: <[https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/publication/wcms\\_245201.pdf](https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/documents/publication/wcms_245201.pdf)>. Acesso em: 02 fev 2020.

OJIMA, R. Urbanização, dinâmica migratória e sustentabilidade no semiárido nordestino: o papel das cidades no processo de adaptação ambiental. In: OJIMA, R.; FUSCO, W. (Eds). **Migrações nordestinas no século 21: um panorama recente**. São Paulo: Edgard Blucher, 2014.

OJIMA, R.; COSTA, J. V.; CALIXTA, R. K. “Minha vida é andar por esse país...”: a emigração recente no semiárido setentrional, políticas sociais e meio ambiente. **Revista Interdisciplinar da Mobilidade Humana**, v. 22, n. 43, p. 149–167, dez. 2014.

PRIORI, A. et al. A modernização do campo e o êxodo rural. In: **História do Paraná: séculos XIX e XX**. SciELO Books - EDUEM, 2012.

RIGAUD, K. K. et al. **Groundswell: preparing for internal climate migration**. Washington: World Bank Group, 2018.

SEN, A. **Poverty and Famines: An Essay on Entitlement and Deprivation**. Oxford: Oxford University Press, 1983.

SILVA, R. M. Entre dois paradigmas: combate à seca e convivência com o semi-árido. **Sociedade e Estado**, v. 18, n. 1–2, p. 361–385, dez. 2003.

TANLE, A. Towards an integrated framework for analysing the links between migration and livelihoods. **Norsk Geografisk Tidsskrift**, v. 69, n. 5, p. 257–264, 2015.

VAITSMAN, J.; ANDRADE, G. R.; FARIAS, L. O. Proteção social no Brasil: o que mudou na assistência social após a Constituição de 1988. *Ciência & Saúde Coletiva*, v. 14, n. 3, p. 731–741, 2009.

# Short-term effect of adding nitrogen in forest soil of an urban rainforest

*Efeito a curto prazo da adição de nitrogênio no solo de uma floresta urbana*

Bruno Moraes Nascimento<sup>a</sup>

Fernando Vieira Cesário<sup>b</sup>

Fabiano de Carvalho Balieiro<sup>c</sup>

Renato de Aragão Rodrigues<sup>d</sup>

Henderson Silva Wanderley<sup>e</sup>

<sup>a</sup>Universidade Federal Fluminense (UFF), Niterói, RJ, Brasil  
E-mail: brunomoraesufrj@gmail.com

<sup>b</sup>Universidade Federal Fluminense (UFF), Niterói, RJ, Brasil  
E-mail: fernandovieiracesario@gmail.com

<sup>c</sup>Centro Nacional de Pesquisa de Solos (Embrapa Solos), Rio de Janeiro, RJ, Brasil  
E-mail: fabiano.balieiro@embrapa.br

<sup>d</sup>Centro Nacional de Pesquisa de Solos (Embrapa Solos), Rio de Janeiro, RJ, Brasil  
E-mail: renato.rodrigues@embrapa.br

<sup>e</sup>Universidade Federal Rural do Rio de Janeiro (UFRRJ), Seropédica, RJ, Brasil  
E-mail: hendynho@gmail.com

doi:10.18472/SustDeb.v11n2.2020.30339

Received: 27/03/2020  
Accepted: 10/07/2020

ARTICLE- VARIA

## ABSTRACT

The deposition of atmospheric nitrogen has been increased in urban forest ecosystems, yet it is not clear how this increase affects soil respiration in the short term. The soil respiration could contribute to CO<sub>2</sub> flux to the atmosphere; therefore, it is essential to understand how nitrogen addition affects soil respiration and its autotrophic and heterotrophic compartments. We established a randomized block experiment to investigate the effects of adding 2.5 kg ha<sup>-1</sup> (which corresponds to ~ 40% of the total annual deposition) in soil respiration during five days in an urban tropical forest. The CO<sub>2</sub> flux of the autotrophic and heterotrophic compartments was individualized and measured using an infrared gas analyzer (IRGA). Two measurements per day (9-11 and 21-23 hours) were assessed for five consecutive days. Days and nights show no difference in CO<sub>2</sub> flux among all compartments. The heterotrophic respiration was strong negatively affected by nitrogen addition, about 34%. Autotrophic respiration was positively impacted by nitrogen addition, but no significant differences were found. Heterotrophic respiration is the primary source of CO<sub>2</sub> from the forest soil.

**Keywords:** Autotrophic and Heterotrophic Respiration. Fertilized Experiment. Soil Respiration. CO<sub>2</sub> flux. Tijuca Forest.

## RESUMO

*A deposição de nitrogênio atmosférico aumentou nos ecossistemas florestais urbanos, mas não está claro como esse aumento afeta a respiração do solo a curto prazo. A respiração do solo pode contribuir para o fluxo de CO<sub>2</sub> na atmosfera, portanto, é essencial entender como a adição de nitrogênio afeta a respiração do solo e seus compartimentos autotróficos e heterotróficos. Estabelecemos um experimento em bloco randomizado para investigar os efeitos da adição de 2,5 kg ha<sup>-1</sup> (o que corresponde a ~ 40% da deposição anual total) na respiração do solo durante cinco dias em uma floresta tropical urbana. O fluxo de CO<sub>2</sub> dos compartimentos autotrófico e heterotrófico foi individualizado e medido usando um analisador de gás infravermelho (IRGA). Duas medidas por dia (9-11 e 21-23 horas) foram avaliadas por cinco dias consecutivos. Dias e noites não mostram diferença no fluxo de CO<sub>2</sub> entre todos os compartimentos. A respiração heterotrófica foi fortemente afetada negativamente pela adição de nitrogênio, cerca de 34%. A respiração autotrófica foi impactada positivamente pela adição de nitrogênio, mas não foram encontradas diferenças significativas. A respiração heterotrófica é a principal fonte de CO<sub>2</sub> do solo da floresta.*

**Palavras-chave:** Respiração Autotrófica e Heterotrófica. Experiment de Fertilização. Respiração do Solo. Fluxo de CO<sub>2</sub>. Floresta da Tijuca.

## 1 INTRODUCTION

Atmospheric deposition of nitrogen has grown in forest ecosystems (VITOUSEK et al., 1997) as a result of burning fossil fuels and fertilizer applications in agriculture (DAVIDSON, 2009). According to Magnani et al., (2007), nitrogen deposition is essential for carbon sequestration in forest ecosystems. However, the CO<sub>2</sub> emissions by autotrophic and heterotrophic respiration in tropical forest soils are still poorly studied. Soil respiration (Rs) represents the total flux of CO<sub>2</sub> emitted by the soil. It can be divided, in general, into two pools: i) Heterotrophic respiration (Rh) that represents the decomposition and mineralization process of organic materials in the soil (that is, organo-mineral fraction) and litter (that is, mostly organic fraction); ii) Autotrophic respiration (Ra) that mainly represents root growth and exudate production (BOND-LAMBERTY et al., 2004; SUBKE et al., 2006).

The Rs corresponds to the second-largest flux of carbon from the terrestrial system to the atmosphere (RAICH and SCHLESINGER, 1992; RAICH et al., 2002; SHAO et al., 2014), thus being an important indicator of climate change. Previous studies show that Rs is influenced by soil temperature and humidity (DAVIDSON et al., 2000; LIU et al., 2002; RUSTAD et al., 2001). Therefore, the contribution of each component of Rs must be known to understand the effects of global changes on net CO<sub>2</sub> exchanges between terrestrial ecosystems and the atmosphere (ZHOU et al., 2007).

In forest ecosystems, studies show that there is a reduction in heterotrophic respiration after the addition of N (JANSSENS et al., 2010). The addition of N can boost microbial activity and biomass; or decrease enzymatic activity and soil organic matter decomposition (JANSSENS et al., 2010; WANG et al., 2017). However, studies regarding the response of both heterotrophic and autotrophic respiration in a different forest and non-forest ecosystems after the addition of nitrogen have been the subject of considerable discussion (ALLISON et al., 2008; CHEN et al., 2017; GAO et al., 2014; JIA et al., 2010; LI et al., 2018; LIU and GREAVES, 2010; LU et al., 2011; MO et al., 2007; OLSSON et al., 2005; YAN et al., 2017; ZENG et al., 2018).

In a study conducted at the Tiantong Natural Forest Park GAO et al., (2014) points to a non-linear response between the amount of N added and the average flux of CO<sub>2</sub> from the soil. WANG et al., (2017) found a 27% drop in Ra after adding nitrogen.

To unravel the effect of nitrogen, we conducted an fertilized experiment with separation of Ra and Rh compartments in a tropical forest for five days. The objective is to understand how the addition of nitrogen separately affects respiration (i.e., Ra and Rh), as well as to verify possible differences between night and day fluxes from Ra and Rh pools.

## 2 MATERIALS AND METHODS

### 2.1 STUDY AREA

The city of Rio de Janeiro was established within two very uneven geomorphological compartments: the coastal massifs and the lowland areas. Among the massifs, Tijuca stands out (Figure 1), which among the massifs is what is found in the most densely populated area of the city of Rio de Janeiro. (FERNANDES; AVELAR; NETTO, 2006). The present study was carried out in the Tijuca Forest / Massif, one of the four (4) areas that make up the Tijuca National Park (PARNA-Tijuca) which is a conservation unit with 3,972 hectares located in the city of Rio de Janeiro between parallels 22 ° 55'S and 23 ° 00'S and the meridians 43 ° 11'W and 43 ° 19'W, its altitude is between 0 to 1,021m.

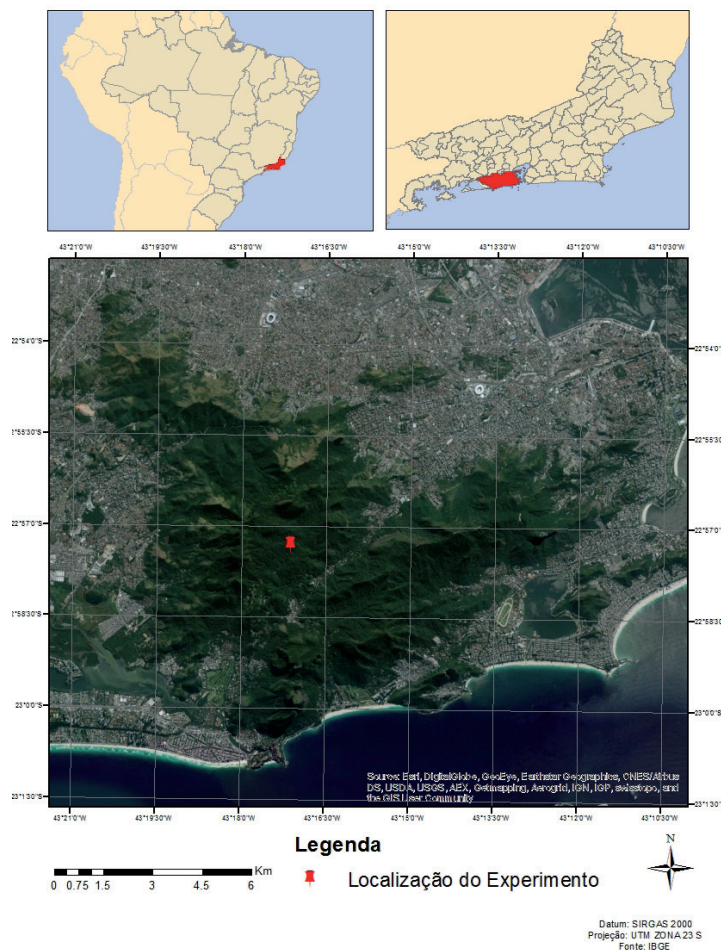


Figure 1 | Tijuca Forest massif and the location of the experiment (red pin).

Source: IBGE.

Currently, Tijuca landscape accommodates several types of land use and cover: grasses, rocky outcrops, areas occupied by buildings and forests in different successional stages (COELHO NETTO, 1992). According to COELHO NETTO (2005) the Tijuca massif is a formation from the Precambrian period, prevailing varied gneisses and granites. PARNA- Tijuca's climate is tropical in altitude with an average

annual temperature of 22°C. The average annual precipitation is between 2.000 and 2.500 mm, the rainiest period is concentrated in the first four months of the year while the months of May are characterized by the decrease in rainfall. PARNA-Tijuca is dominated by Oxisols with small pedological horizons differences and a deep profiles. In the lower lands there is a predominance of the red-yellow Oxisols, while in the lands with higher levels they may present small proportions of Leptosols and Cambisols (COELHO NETTO, 1992). Atmospheric nitrogen deposition is about 6.2 kg N ha<sup>-1</sup> year<sup>-1</sup> (A. DE SOUZA et al., 2017; PONETTE-GONZÁLEZ et al., 2017).

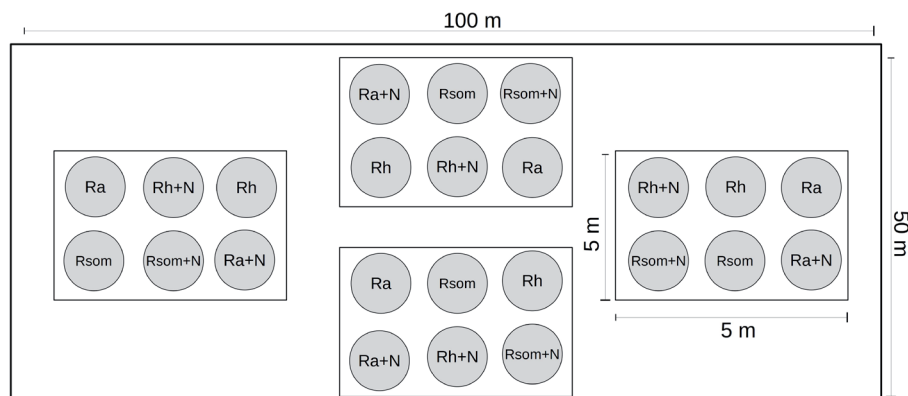
The vegetation is typical of the tropical evergreen-forest, characterized by large trees, palm trees, ferns, epiphytes and lianas (RIZZINI, 1979). The most frequent plant families are Leguminosae, Sapotaceae, Bombacaceae, Euphorbiaceae, Meliaceae, Lauraceae, Lecythidaceae, Moraceae and Melastomataceae (CCN, 1966). According to GÓES & QUINTELA, (2015) the families with the greatest number of individuals are: Asteraceae, Fabaceae, Myrtaceae; Bignoniaceae; Melastomataceae; Verbanaceae and Anacardiaceae. According to a survey by the Brazilian Forest Service (2018), the height of the individuals ranges from 1 to 12m, the average diameter is more than 10 cm, the average biomass is about 95.57 t ha<sup>-1</sup>, the average basal area is 21.07 m<sup>2</sup> ha<sup>-1</sup> and the average density is about 360 individuals / ha<sup>-1</sup> (BRAZILIAN FOREST SERVICE, 2018).

## 2.2 EXPERIMENTAL DESIGN

The experiment is located on the southern slope of the Tijuca Forest, 530m high, the slope is oriented to the North. The experiment was established in half of a hectare (100 m x 50m) using a randomized complete block design that includes four replicate 5 x 5 m<sup>2</sup> (Figure 2) of each the following treatments:

- I. Heterotrophic Respiration (Rh);
- II. Autotrophic Respiration (Ra);
- III. Organic Soil Matter Respiration (Rsom);
- IV. Heterotrophic Respiration + Nitrogen addition (Rh+N);
- V. Autotrophic Respiration + Nitrogen addition (Ra+N);
- VI. Organic Soil Matter Respiration + Nitrogen addition (Rsom+N);

The blocks were allocated so that the canopy and the forest floor were homogeneous (Figure 2).



**Figure 2** | Study site experimental plot layout. Plot treatment codes: Ra, Autotrophic respiration Rh, Heterotrophic respiration; Rsom, soil organic matter respiration; Ra+N, Autotrophic respiration + nitrogen addition; Rh+N, Heterotrophic respiration + nitrogen addition; Rsom+N, soil organic matter respiration + nitrogen addition.

Source: Personal archive.

## 2.3 TREATMENTS ESTABLISHMENT

Throughout this article study, we consider  $R_h$  to be the respiration with the presence of a litter and  $R_a$  to be the respiration due to root growth, both independent of  $R_{som}$  respiration. All treatments were established using PVC collars according to Marthewes et al., (2014). The treatments  $R_{som}$ ,  $R_h$ , and their repetitions with the addition of nitrogen were established using collars with 100 x 400 mm, diameter, and height respectively. Before, the collar's insertion the litter was removed and reserved leaving the soil exposed (that is, an extra PVC collar of 100mm diameter was used to cut the litter precisely).

Then the collars were inserted into the soil to a depth of 350mm leaving 50mm above the exposed soil. Finally, the litter removed and previously reserved was replaced inside the collar (i.e., 100 x 400mm). In these treatments (i.e.,  $R_{som}$ ,  $R_h$ ,  $R_{som}+N$ , and  $R_h+N$ ) the collars have four side holes, that is, two holes on opposite sides. Each hole has a diameter of ~ 3.5cm. On each side, the first hole is located 5cm along the collar, and the second one 5cm away from the first. That is, these 400mm high collars have two holes on each side, 5cm apart and 5cm away from the beginning of the collar. A 35-41  $\mu\text{m}$  mesh was used to cover all holes.

Regarding the  $R_a$  and  $R_a + N$  treatments, these were established using PVC collars of 100 x 150 mm, diameter, and height respectively. The collars were inserted into the soil to a depth of 100mm, leaving 50mm above the ground. For these treatments, the litter was previously removed, but it was not (re) allocated, thus allowing the quantification of autotrophic respiration, originating by roots growing through the bottom of the collar.

For this experiment it is important to clarify that we are considering mycorrhizal respiration in all treatments, thus allowing the comparison between them, and all measurements were made according to Marthewes et al., (2014).

## 2.4 CO<sub>2</sub> FLUX MEASUREMENT

The measurement of the flux of carbon dioxide (CO<sub>2</sub>) started on October 17, 2018, the flux of CO<sub>2</sub> in all treatments was measured for five days in two daily collections, between the periods from 9 to 11 and 21 to 23 hours.

The measurements of soil CO<sub>2</sub> flux were performed using a portable infrared gas analyzer - IRGA - (EGM-2, PP Systems, UK) connected to a CO<sub>2</sub> flux chamber that was attached to the PVC collars for reading the CO<sub>2</sub>. The IRGA was calibrated to take CO<sub>2</sub> readings in 120 seconds or until the flux is stable. Calculations for CO<sub>2</sub> quantification were performed according to equation (1).

$$R = \frac{\frac{C_n - C_o}{T_n} * V}{A} \quad (1)$$

Where  $R$  is the assimilation rate (CO<sub>2</sub> flux / unit of area / unit of time),  $C_o$  is the concentration of CO<sub>2</sub> at time zero ( $T = 0$ ) in hours and  $C_n$  is the concentration in the elapsed  $T_n$ ,  $A$  is the area of the exposed soil (m<sup>2</sup>) and  $V$  the total volume of the system (ie, chamber, 0.0012287 m<sup>3</sup>).

The collars inserted into the ground do not have a uniform height inside because its height depends on the presence or absence of litter, and when the litter is present its thickness is not the same among the collars. Therefore, to correct the added volume ( $V_{add}$ ) that may exist between the limit of the litter and the upper part of the collar, an iron disk with a diameter of ~ 9cm and a mass of 10g was used.



The disc was placed inside the collars, without pressure or compression of the litter, that is, only the weight of the disc exerted force on the litter. With the disc inside each collar in all treatments, the height between the disc and the upper limit of the collar was then measured. With the measured height (i.e., litter and collar limit) and the collar diameter,  $V_{add}$  was calculated. The  $V_{add}$  was used to correct the flux of each collar using equation 2, according to (MARTHEWS TR et al., 2014).

$$R_c = \frac{R_{uc} * V_d + V_{add}}{V_d} \quad (2)$$

Where,  $R_c$  is the corrected measurement,  $R_{uc}$  measurement without the correction of the additional volume of the collar (m<sup>3</sup>),  $V_{add}$  additional volume of the collar measured in the field (m<sup>3</sup>).

All measurements data were recorded in g m<sup>-2</sup> hr<sup>-1</sup>, and then converted to umol m<sup>-2</sup> s<sup>-1</sup> by multiplying the values by 6,312 according to Marthews TR et al., (2014).

## 2.5 METEOROLOGICAL MEASUREMENT DATA

During the experiment period data of soil temperature, soil relative humidity, and precipitation were measured at 15-minute intervals, with an automatic weather station Vantage Pro2 Davis. The station was located 10m far from the blocks within the Tijuca forest canopy, located at 22 ° 57'S, longitude 43 ° 17'W, and an altitude of 520 m.

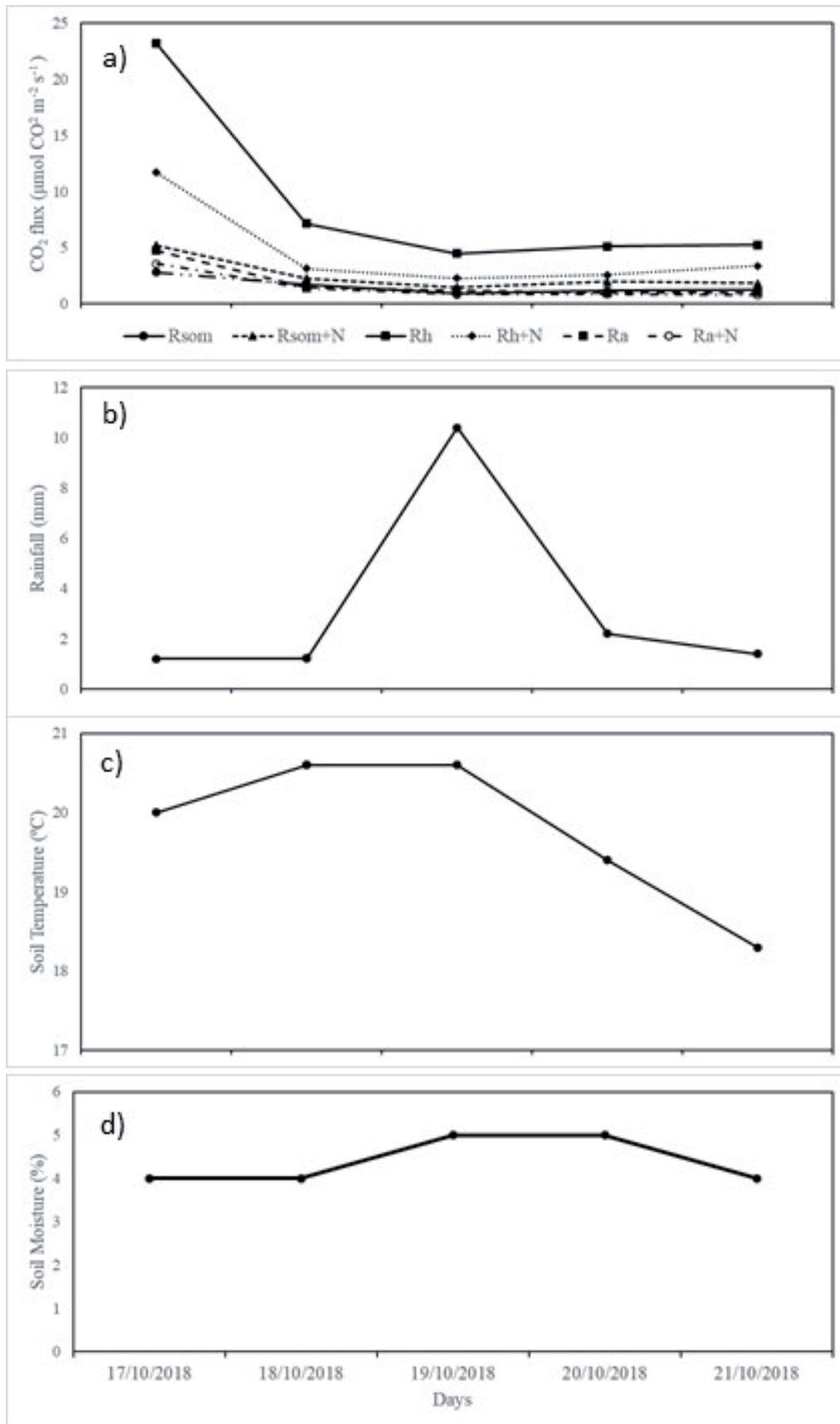
## 2.6 STATISTICAL ANALYSIS

Soil temperature and humidity data were calculated using the daily average. Precipitation was calculated by the daily sum. Regarding CO<sub>2</sub> fluxes, the normality of data distribution was assessed by Shapiro-Wilk, and the homogeneity of variance by the Fisher test (F) test. There is no difference among block, but the data did not show normality, so it was decided to use non-parametric tests. The Wilcoxon test was used to test differences in the CO<sub>2</sub> flux (n = 4).

# 3 RESULTS

## 3.1 SHORT-LIVED ABIOTIC CHARACTERISTICS

The total rainfall during the 5 days of exposure was 16.40 mm, with a daily average of 3.28 mm. The maximum fall occurred on the 19th and the minimum decrease on the 17th and 18th with 1.2 mm, respectively. On other days, the average was 1.4 mm of rain (Figure 3 b). Regarding the soil temperature, there were no major changes over the 5 days. The average soil temperature (n = 5) was 19.7°C, with a maximum and minimum temperature of 20.6 and 18.3°C on days 18 and 21, respectively (Figure 3 c). A soil density was measured with Meteorológica Vantage Pro2 Davis, during an experiment, on average 4.4%, with a maximum and minimum peak of 5 and 4% on days 18 and 20, respectively (Figure 3 d).



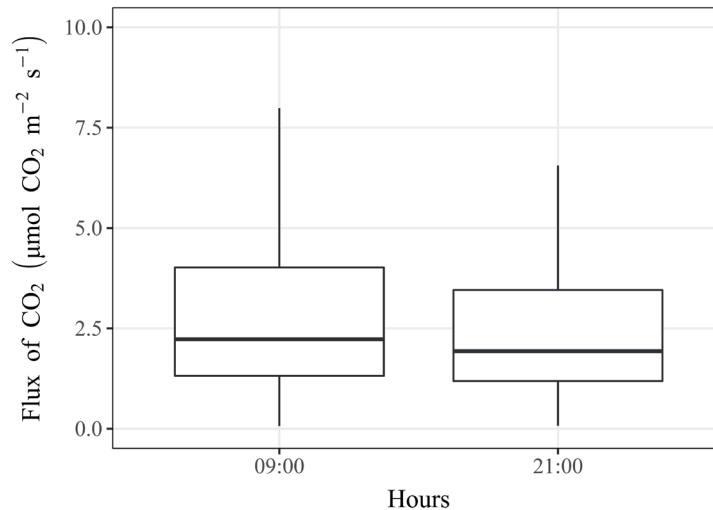
**Figure 3** | (a) shows the CO<sub>2</sub> flux of each treatment, (b) shows the daily precipitation, (c) shows the average soil temperature and (d) shows the soil moisture. Whiskers represent standard deviation.

Source: Field experiment data.

### 3.2. NIGHT AND DAY FLUX OF CO<sub>2</sub>

Figure 4 shows the results of the CO<sub>2</sub> flux for the day and night periods in the first five days of the experiment. The median of daytime and nighttime flux is 1.63 and 1.62  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ , respectively. The daytime period showed a maximum flux of 13.76  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ , while the maximum nighttime flux was only 10.89  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ . The minimum flux, on the other hand, show close values between the daytime and nighttime periods (Figure 4).

There was no significant difference between daytime and nighttime flux ( $p = 0.4791$  - Wilcox test), and the difference in the median between daytime and nighttime flux is small as shown in figure 4.

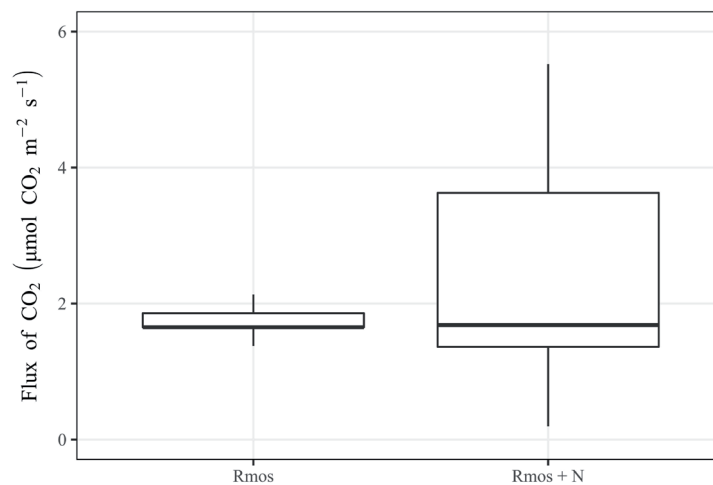


**Figure 4** | Boxplot of comparison between daytime and nighttime CO<sub>2</sub> flux.

*Source: Field experiment data.*

### 3.3 EFFECT OF NITROGEN ADDITION ON ORGANIC SOIL MATTER RESPIRATION (RSOM)

Figure 5 shows the results of adding N to R<sub>som</sub>. The results show that the addition of nitrogen increased the maximum CO<sub>2</sub> flux of R<sub>som</sub> by 3  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ , from 2.52 to 5.52  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ , that is, when there was the addition of nitrogen the maximum CO<sub>2</sub> flux has increased considerably. However, the same trend was not followed by the minimum flux (Figure 5). The results show that there was no significant difference ( $p = 0.2624$  - Wilcox test) between R<sub>som</sub> and R<sub>som+N</sub> treatments, indicating a small effect of nitrogen on R<sub>som</sub> respiration.



**Figure 5** - Boxplot of comparison between R<sub>som</sub> and R<sub>som + N</sub> flux of CO<sub>2</sub>.

*Source: Field experiment data.*

### 3.4 EFFECT OF ADDING NITROGEN ON HETEROTROPHIC RESPIRATION (RH)

Figure 6 shows the results of adding nitrogen to Rh. The results show that the median of treatments without and with nitrogen addition are 5.00 and 2.54  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ , respectively, indicating that the addition of nitrogen decreased the performance of heterotrophic decomposers. In addition, a decrease in the minimum flux after the addition of nitrogen can also be observed, going from 2.34 to 0.93  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  (Figure 6). The results show a negative significant effect of nitrogen addition ( $p < 0.0001$  Wilcox test) as show in Figure 6.

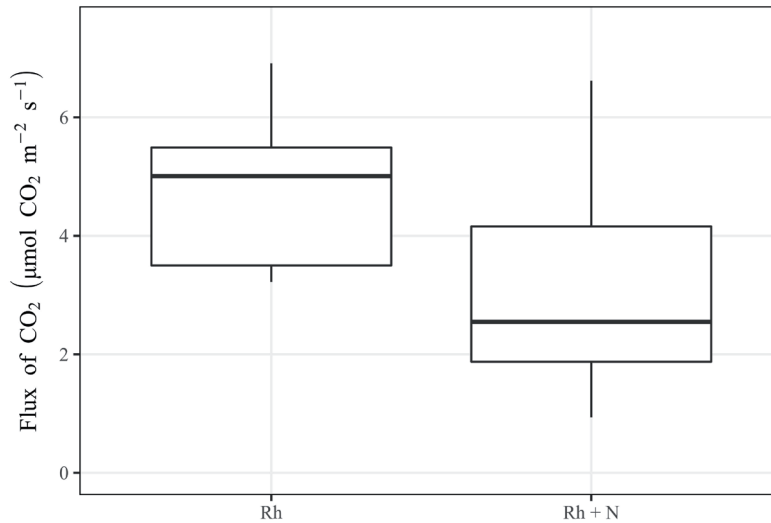


Figure 6 | Boxplot of comparison between Rh and Rh + N flux of CO<sub>2</sub>.

Source: Field experiment data

### 3.5 EFFECT OF NITROGEN ON AUTOTROPHIC RESPIRATION

Figure 7 shows the effect of adding nitrogen on Ra. The results show that the median decreased after the addition of nitrogen, from 1.21 to 1.06  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  (Figure 7). However, there is a drop in the maximum flux achieved, going from 2.22 to 2.16  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$  after the addition of nitrogen (Figure 7). The results indicate that there is no effect ( $p = 0.2091$  - Wilcox test) of the addition of nitrogen in Ra respiration.

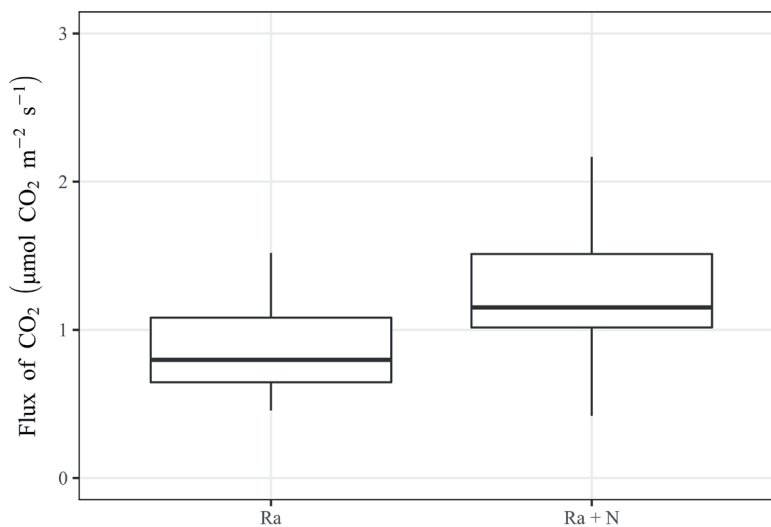


Figure 7 | Boxplot of comparison between Ra and Ra + N flux of CO<sub>2</sub>.

Source: Field experiment data

### 3.6 COMPARISON BETWEEN AUTOTROPHIC (RA) AND HETEROTROPHIC (RH) RESPIRATION

Figure 8 shows the comparison between Ra and Rh without the addition of nitrogen. The results show that the difference between the medians of Ra and Rh is greater than 200%, going from 1.21 to 5.00  $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ , respectively. Additionally, the maximum flux of Rh is approximately 6 times greater than that of Ra (Figure 8). Figure 8 shows that the treatments differ statistically after the addition of nitrogen ( $p < 0.0001$  - Wilcox test).

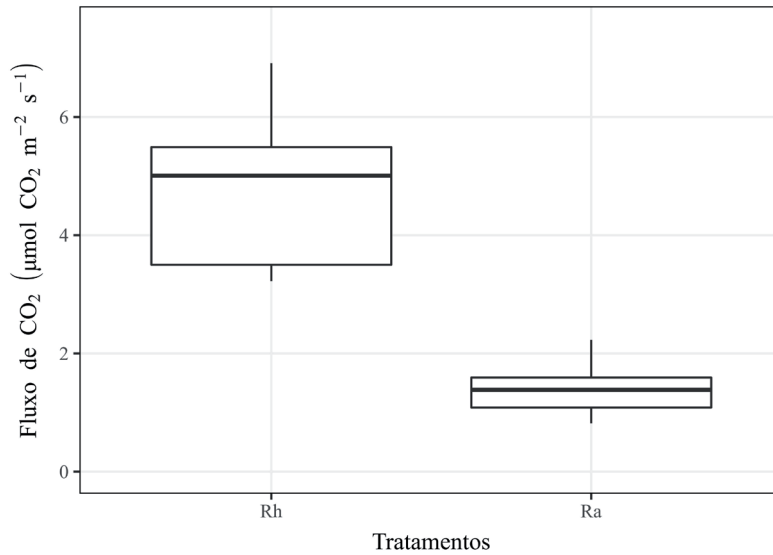


Figure 8 | Boxplot of comparison between autotrophic and heterotrophic respiration.

Source: Field experiment data

## 4. DISCUSSION

### 4.1 SOIL RESPIRATION AND ABIOTIC CLIMATIC ASSOCIATION.

Soil temperature and humidity might control respiration. Therefore, we correlate changes in soil temperature, humidity, and rainfall with CO2 flux measurements. In our results, no positive correlations were found between the variations and the treatments analyzed. However, we found a negative correlation between rainfall with R<sub>soil</sub> and Rh (Figure 9). Some root traits are already known to be correlated to root recalcitrance (POIRIER; ROUMET; MUNSON, 2018), and these traits favor short term stabilization by slowing decomposition. Poirier et al., (2018) already show that root depth distribution is the most crucial trait to control root C storage, and therefore CO2 emissions.

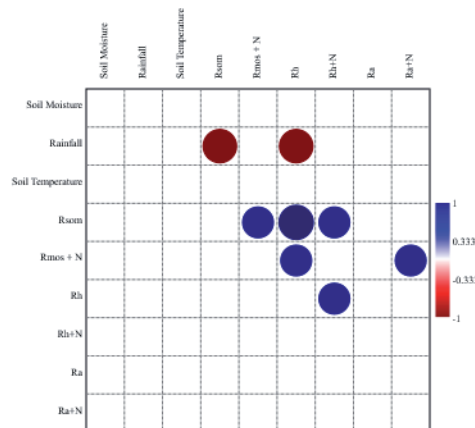


Figure 9 | Correlation between CO2 flux compartments and abiotic variables.

Source: Field experiment data.

## 4.2 DIFFERENCES BETWEEN DAY AND NIGHT CO<sub>2</sub> RESPIRATION

In our study, there was no significant difference ( $p = 0.4791$  - Wilcox test) between day and night CO<sub>2</sub> fluxes (Figure 4), indicating that day and night abiotic factors might be acting with the same intensity on decomposition and autotrophic respiration. The average CO<sub>2</sub> flux occurred during the day, a similar result was found by Hu et al., (2016) who found fluxes ranging between 4.15 and 0.20  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  in the daytime and 3.04 and 0, 13  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  at night in a subalpine forest in Tibet.

On the other hand, Grahammer et al., (1991), in a prairie in Northeast Kansas, found a 20% greater CO<sub>2</sub> flux during the day. However, in a study carried out in a pasture area on Caatinga vegetation in Brazil, Renata et al., (2018) found no difference. Previous studies indicate that the daytime and nighttime variability of the CO<sub>2</sub> flux can be affected by the biological growth of plants, photosynthesis, microbial activity (KUZUYAKOV; CHENG, 2001; TANEVA, 2011; VARGAS et al., 2011), but in Tijuca forest we did not find differences between day and night fluxes, indicating a possible, stable vegetation growth along the entire day.

## 4.3 RESPONSES OF HETEROTROPHIC RESPIRATION BY NITROGEN ADDITION.

On average, the addition of nitrogen decreases Rh by 34% (Figure 6). However, in a meta-analysis study Janssens et al., (2010) points to a 15% increase in Rh in forest environments. There is a great variation range between the results suggesting that in highly productive sites the deposition of nitrogen causes stronger negative effects. According to Zhou et al., (2014) the nitrogen addition stimulates negative responses in most Biomes, except in forest biomes. The addition of nitrogen can lead to a decrease in the rates of "microbial mining", which has an effect on some microbes during the decomposition process of organic matter (CRAINE et al., 2007; FONTAINE et al., 2003; MICHEL & MATZNER, 2003)

## 4.4 RESPONSES OF AUTOTROPHIC RESPIRATION BY NITROGEN ADDITION

We did not find a significant difference in Ra after adding nitrogen (Figure 7). In a study carried out in a temperate steppe area Yan et al., (2010) shows that Ra increased due to the increase in plant productivity. Zeng et al., (2018) in a study carried out in a non-degraded pasture area showed an increase in Ra after the addition of nitrogen. In a meta-analysis study in different biomes Zhou et al., (2014) points out that the addition of nitrogen did not significantly affect Ra in forest environments. According to Xu and Shang., (2016) Ra is strongly influenced by the carbohydrates of photosynthesis and can thus increase as the productivity of plants increases.

## 5 CONCLUSION

The data show that in the analyzed period there was no significant difference between the flows of the day and the night. The addition of nitrogen did not affect R<sub>soil</sub> and Ra, however, it reduced the average flux of Rh causing a significant difference. The data show that in our area of analysis, in a short period, the addition of nitrogen may have inhibited the action of microbial biomass, thus causing a reduction in Rh.

## REFERENCES

- A. DE SOUZA, P. et al. Atmospheric Wet, Dry and Bulk Deposition of Inorganic Nitrogen in the Rio de Janeiro State. **Revista Virtual de Química**, v. 9, n. 5, p. 2052–2066, 2017.
- BOND-LAMBERTY, B.; WANG, C.; GOWER, S. T. A global relationship between the heterotrophic and autotrophic components of soil respiration? **Global Change Biology**, v. 10, n. 10, p. 1756–1766, 2004.
- CCN, 1966, Floresta da Tijuca. Centro de Conservação da Natureza, Rio de Janeiro, 152p.
- CHEN, Z. et al. Soil autotrophic and heterotrophic respiration in response to different N fertilization and environmental conditions from a cropland in Northeast China. **Soil Biology and Biochemistry**, v. 110, p. 103–115, 2017.
- COELHO NETTO, A. L. 1992. O geoeossistema da Floresta da Tijuca. In: Natureza e Sociedade no Rio de Janeiro. Abreu, M. A. (Org.). Prefeitura do Rio de Janeiro: Secretaria Municipal de Cultura, Turismo e Esporte. **Coleção Biblioteca Carioca**, vol. 21, pp.104-142.
- CRAINE, JOSEPH M; MORROW, CARL; FIERER, N. Microbial Nitrogen Limitation Increases Decomposition. **Ecology**, v. 88, n. 8, p. 2105–2113, 2007.
- DAVIDSON, E. A. et al. Effects of soil water content on soil respiration in forests and cattle pastures of eastern Amazonia. **Biogeochemistry**, v. 48, n. 1, p. 53–69, 2000.
- DAVIDSON, E. A. to atmospheric nitrous oxide since 1860. **Nature Geoscience**, v. 2, n. 9, p. 659–662, 2009.
- DE ARAGÃO R. RODRIGUES, R. et al. Nitrogen Dynamics in Tropical Agricultural and Forest Systems and their Impact on Climate Change. **Revista Virtual de Química**, v. 9, n. 5, p. 1868–1886, 2017.
- FERNANDES, M. DO C.; AVELAR, A. DE S.; NETTO, A. L. C. Domínios geo-hidroecológicos do maciço da Tijuca, RJ: Subsídios ao entendimento dos processos hidrológicos e erosivos. **Anuario do Instituto de Geociências**, v. 29, n. 2, p. 122–148, 2006.
- FONTAINE, SÉBASTIEN; MARIOTTI, A. A. L. The priming effect of organic matter : a question of microbial competition ? **Soil Biology & Biochemistry**, v. 35, p. 837–843, 2003.
- GAO, Q. et al. Short-term response of soil respiration to nitrogen fertilization in a subtropical evergreen forest. **Soil Biology and Biochemistry**, v. 76, n. May, p. 297–300, 2014.
- GÓES, L. G. DE; QUINTELA, M. F. Florística e estrutura de um reflorestamento no Maciço da Tijuca, Rio de Janeiro, RJ, Brasil. **Revista Internacional de Ciências**, v. 5, n. 1, p. 106–126, 2015
- GRAHAMMER, K, JAWSON. M. D, S. J. Day and night soil respiration from a grassland. **Soil Biology and Biochemistry**, v. 23, n. 1, p. 77–81, 1991.
- JANSSENS, I. A. et al. Reduction of forest soil respiration in response to nitrogen deposition. **Nature Geoscience**, v. 3, n. 5, p. 315–322, 2010.
- JIA, S. et al. N fertilization affects on soil respiration, microbial biomass and root respiration in Larix gmelinii and Fraxinus mandshurica plantations in China. **Plant and Soil**, v. 333, n. 1, p. 325–336, 2010.
- KUZYAKOV, Y.; CHENG, W. Photosynthesis controls of rhizosphere respiration and organic matter decomposition. **Soil Biology & Biochemistry**, v. 33, p. 1915–1925, 2001.
- KUZYAKOV, Y.; GAVRICHKOVA, O. REVIEW: Time lag between photosynthesis and carbon dioxide efflux from soil: A review of mechanisms and controls. **Global Change Biology**, v. 16, n. 12, p. 3386–3406, 2010.
- LIU, L.; GREAVER, T. L. A global perspective on belowground carbon dynamics under nitrogen enrichment. **Ecology Letters**, v. 13, n. 7, p. 819–828, 2010.

- LIU, Q. et al. Nitrogen additions stimulate litter humification in a subtropical forest, southwestern China. **Scientific Reports**, v. 8, n. 1, p. 17525, 2018.
- LIU, X. et al. **Response of soil CO<sub>2</sub> efflux to water manipulation in a tallgrass prairie ecosystem**.pdf. p. 213–223, 2002.
- LU, M. et al. Minor stimulation of soil carbon storage by nitrogen addition: A meta-analysis. **Agriculture, Ecosystems and Environment**, v. 140, n. 1–2, p. 234–244, 2011.
- MAGNANI, F. et al. **The human footprint in the carbon cycle of temperate and boreal forests**. v. 447, n. June, 2007.
- MARTHEWS, TR.; RIUTTA, T.; OLIVERAS MENOR, I; URRUTIA, R.; Moore S, Metcalfe D, Malhi Y, Phillips O, Huaraca Huasco W, Ruiz Jaén M, Girardin C, Butt N, Cain R and colleagues from the RAINFOR and GEM networks (2014). Measuring Tropical Forest Carbon Allocation and Cycling: A RAINFOR-GEM Field Manual for Intensive Census Plots (v3.0). Manual, **Global Ecosystems Monitoring network**, <http://gem.tropicalforests.ox.ac.uk/>.
- MICHEL, K.; MATZNER, E. Response of enzyme activities to nitrogen addition in forest floors of different C-to-N ratios. **Biol Fertil Soils**, v. 38, p. 102–109, 2003.
- MO, J. et al. Nitrogen addition reduces soil respiration in a mature tropical forest in southern China. **Global Change Biology**, v. 14, n. 2, p. 403–412, 2007.
- OLSSON, P. et al. Fertilization of boreal forest reduces both autotrophic and heterotrophic soil respiration. **Global Change Biology**, v. 11, n. 10, p. 1745–1753, 2005.
- RAICH, J.; SCHLESINGER, W. **The global carbon dioxide flux in soil respiration**. *Tellus*, v. 44 B, n. 2, p. 81–99, 1992.
- RAICH, J. W.; POTTER, C. S.; BHAGAWATI, D. Interannual variability in global soil respiration, 1980-94. **Global Change Biology**, v. 8, n. 8, p. 800–812, 2002.
- RENATA, C. et al. Soil CO<sub>2</sub> Efflux Measurements by Alkali Absorption and Infrared Gas Analyzer in the Brazilian Semiarid Region. **Revista Brasileira de Ciência do Solo**, p. 1–10, 2018.
- RIZZINI, C. T. **Tratado de fitogeografia do Brasil: aspectos sociológicos e florísticos**. São Paulo: Hucitec, 1979. v. 2
- RUSTAD, L. E. et al. A meta-analysis of the response of soil respiration, net nitrogen mineralization, and aboveground plant growth to experimental ecosystem warming. **Oecologia**, v. 126, n. 4, p. 543–562, 2001.
- Secretaria de Meio Ambiente da Prefeitura do Rio de Janeiro; SMAC-RJ 2000. **Espécies Ameaçadas no Município do Rio de Janeiro: Flora e Fauna**. Editora PCRJ/SMAC, Rio do Janeiro. 68p.
- SERVIÇO FLORESTAL BRASILEIRO. **Inventário Florestal Nacional: Rio de Janeiro: principais resultados**. Brasília, DF: MMA, 2018. 111 p. (Série Relatórios Técnicos - IFN). Disponível em: Acesso em: 16/04/2019.
- SHAO, R. et al. Nitrogen fertilization increase soil carbon dioxide efflux of winter wheat field: A case study in Northwest China. *Soil and Tillage Research*, v. 143, p. 164–171, 2014.
- SUBKE, J. A.; INGLIMA, I.; COTRUFO, M. F. Trends and methodological impacts in soil CO<sub>2</sub> efflux partitioning: A metaanalytical review. **Global Change Biology**, v. 12, n. 6, p. 921–943, 2006.
- TANEVA, L. Distinct patterns in the diurnal and seasonal variability in four components of soil respiration in a temperate forest under free-air CO<sub>2</sub> enrichment. **Biogeosciences**, p. 3077–3092, 2011.
- VARGAS, R. et al. On the multi-temporal correlation between photosynthesis and soil CO<sub>2</sub> efflux : reconciling lags and observations. **New Phytologist**, p. 1006–1017, 2011.
- VITOUSEK, P.M., ABER, J.D., HOWARTH, R.W., LIKENS, G.E., MATSON, P.A., SCHINDLER, D.W., SCHLESINGER, W.H. AND TILMAN, D. Human Alteration of the Global Nitrogen Cycle: Sources and Consequences. **Ecological Applications**, v. 7, n. 2, p. 737–750, 1997.
- XU, M.; SHANG, H. Contribution of soil respiration to the global carbon equation. **Journal of Plant Physiology**, 2016.



YAN, LIMING; CHEN, SHIPING; HUANG, JIANHUI; LIN, G. Differential responses of auto- and heterotrophic soil respiration to water and nitrogen addition in a semiarid temperate steppe. **Global Change Biology**, v. 16, p. 2345–2357, 2010.

YAN, W.-D. et al. Response of Soil Respiration to Nitrogen Addition in Two Subtropical Forest Types \*1. **Pedosphere**, v. 0160, n. 2017, 2017.

ZENG, W. et al. Soil respiration and its autotrophic and heterotrophic components in response to nitrogen addition among different degraded temperate grasslands. **Soil Biology and Biochemistry**, v. 124, n. 2, p. 255–265, 2018.

ZHOU, X.; WAN, S.; LUO, Y. Source components and interannual variability of soil CO<sub>2</sub> efflux under experimental warming and clipping in a grassland ecosystem. **Global Change Biology**, v. 13, n. 4, p. 761–775, 2007.

ZHOU, L. et al. Different responses of soil respiration and its components to nitrogen addition among biomes: A meta-analysis. **Global Change Biology**, v. 20, n. 7, p. 2332–2343, 2014.

# Emergency funding public policy for disaster response in Brazil from 2013 to 2017

*Política pública de auxílio financeiro para resposta a desastres no Brasil no período 2013-2017*

Victor Marchezini<sup>a</sup>

Adriano Mota Ferreira<sup>b</sup>

Glauston Roberto Teixeira de Lima<sup>c</sup>

Demerval Aparecido Gonçalves<sup>d</sup>

<sup>a</sup>PhD in Sociology, researcher at Cemaden, São José dos Campos, SP, Brazil  
E-mail: victor.marchezini@cemaden.gov.br

<sup>b</sup>PhD student of the Disaster Postgraduate Program, Institute of Science and Technology, São Paulo State University, São José dos Campos, SP, Brazil  
E-mail: adriano.mota@unesp.br

<sup>c</sup>PhD in Electronic and Computer Engineering, researcher at Cemaden, São José dos Campos, SP, Brazil  
E-mail: glauston.lima@cemaden.gov.br

<sup>d</sup>Master in Aeronautical Infrastructure Engineering, researcher at Cemaden, São José dos Campos, SP, Brazil  
E-mail: demerval.goncalves@cemaden.gov.br

doi:10.18472/SustDeb.v11n2.2020.31268

Received: 30/04/2020  
Accepted: 22/07/2020

ARTICLE - VARIA

## ABSTRACT

Public financial aid policies for disaster response actions are a poorly studied topic. This article analyzed information extracted from the databases of the State of Emergency and State of Public Calamity decrees and the costs of disaster relief and response in Brazil, in the period 2013-2017, based on its spatial-temporal distributions. Disaster relief and response costs are also used in a cross-analysis with municipal indicators such as the Human Development Index (HDI) and the per capita Gross Domestic Product (GDP). It was identified that spending exceeded R\$ 800 million. State civil defences accounted for most of the resources used (76.4%). In a universe of 564 municipalities that used financial assistance via the Civil Defense Payment Card, a concentration of 40% of resources was found in 30 municipal civil defences, some of which in municipalities with high HDI and GDP per capita.

**Keywords:** Disasters. Civil defense. Public spending. Development.

## RESUMO

*As políticas públicas de auxílio financeiro para ações de resposta a desastres são um tema pouco estudado. Neste artigo analisaram-se informações extraídas das bases de dados dos decretos de*

*Situação de Emergência e Estado de Calamidade Pública e dos custos de socorro e resposta a desastres no Brasil, no período 2013-2017, a partir de suas distribuições espaço-temporal. Os custos de socorro e resposta a desastres são também utilizados em uma análise cruzada com indicadores municipais, como o Índice de Desenvolvimento Humano (IDHM) e o Produto Interno Bruto (PIB) per capita. Identificou-se que os gastos excederam R\$ 800 milhões. As defesas civis estaduais responderam pela maior parte dos recursos utilizados (76,4%). Em um universo de 564 municípios que utilizaram o auxílio financeiro via Cartão de Pagamento de Defesa Civil, constatou-se a concentração de 40% dos recursos em 30 defesas civis municipais, algumas das quais em municípios com alto IDHM e PIB per capita.*

**Palavras-chave:** Desastres. Defesa civil. Gastos públicos. Desenvolvimento.

## 1 INTRODUCTION

Economic damage in disasters that occurred in the 1998-2017 period was estimated at US\$ 2.9 billion, 68% higher than the losses reported in the 1978-1997 period (WALLEMACQ & HOUSE, 2018). These disaster impacts have led to serious obstacles to economic growth, which is measured by the percentage change in economic activity measured through the Gross Domestic product (GDP). Some countries experienced annual losses that represented a significant percentage of GDP, such as Haiti (17.5%), Honduras (7%), El Salvador (4.2%) (WALLEMACQ & HOUSE, 2018).

In addition to the impacts on economic growth – on GDP –, disasters have effects on development policies. The concept of development is broader than that of economic growth because it considers the way in which wealth is socially distributed, how citizenship is exercised, how life and dignity conditions and access to a healthy environment are assured (CARVALHO, 2002). A development indicator is the Human Development Index (HDI), which includes education, health and income. The HDI offers a counterpoint to the Gross Domestic Product (GDP) per capita, which considers only the economic dimension of development (PNUD, 2020).

There is a growing recognition on the part of multilateral organizations that disasters have caused losses not only to economic growth, but also to development. The *Human Development Report 2019* points out that developing countries have suffered, on average, a higher HDI reduction percentage than developed countries when facing disasters (UNDP, 2019). The report also points out that developing countries have less resources to prevent and respond to disasters, as well as to implement public policies for mitigation and/or reduction of disaster risks, whether they be of a structural nature – construction and maintenance of infrastructure, urban planning – or non-structural – development of contingency plans, educational actions, evacuation drills etc.

The *Global Assessment Report 2015* points out the need to not only recognize that disasters are obstacles to development, but also stresses that it is necessary to understand disasters as poorly resolved development problems (UNISDR, 2015). That is, it is necessary to incorporate disaster risk management as a fundamental component of the development models to be adopted. Disaster risk is a product that results from the combination of hazard (s), vulnerability, capacity and larger-scale risk mitigation policies (WISNER et al., 2012).

Hazards are phenomena that can contribute to triggering probable harm. Vulnerability is conceptualized as the potential to suffer losses and damages in the face of the hazard(s) and to recover after its occurrence. In addition to economic poverty, vulnerability considers other dimensions of deprivation, such as lack of physical capacity, insecurity, social isolation, lack of political power (CHAMBERS, 1989), and has several types, such as institutional vulnerability, which is characterized by obsolescence and rigidity of institutions, prevalence of political decisions on technical-scientific criteria etc. (WILCHES-CHAUX, 1993).

The capacities against these hazards and the risk mitigation policies – as exemplified previously – are important components for reducing impacts, that is, for disaster risk reduction (DRR). With the increasing impacts of disasters, different countries have adopted disaster risk governance arrangements. Governance in the context of risks and disasters means the process of defining competences and coordinating organizations, public and private actors, laws, regulations and standards in order to reduce the risks of disasters and their impacts (TIERNEY, 2012).

One of the important components of governance is the financing policies for Disaster Risk Management (DRM). When examining the DRM financing programs, Kellet and collaborators (2014) identified very heterogeneous approaches and stressed that the problem is not only the lack of financial resources, but the lack of coordination between the different levels of government, mechanisms for funding by municipalities, transparency and accountability.

Scientific analyzes of DRM financing policies are still scarce in the scientific literature, especially in the Latin American context (KELLETT et al., 2014). Among Latin American and Caribbean countries, Brazil has a history of recent disasters with significant impacts, such as the disaster related to floods and landslides in November 2008, in Santa Catarina, with losses and damages estimated at R\$ 5.32 billion (BANCO MUNDIAL, 2012a); the June 2010 floods in Pernambuco, with losses and damages of around R\$ 3.4 billion (BANCO MUNDIAL, 2012b); and the catastrophe in the mountainous region of Rio de Janeiro, when more than 900 people died in floods and landslides in January 2011 and about R\$ 4.78 billion in losses were accounted for (BANCO MUNDIAL, 2012c).

These disasters catalyzed investments by the Brazilian government. Marchezini et al. (2017) consider that the trend of increasing the percentage of national GDP invested in DRM follows the global logic. In 2006, the percentage of GDP invested was only 0.0009%. In 2009, a year after the disaster in Santa Catarina, the percentage increased to 0.02% of GDP.

In 2010, the percentage increased to 0.04% of GDP, the highest level in the period analyzed. With the catastrophe in Rio de Janeiro in 2011, the percentage of GDP invested in DRM increased successively in the following two years (0.015% of GDP in 2012; 0.023% of GDP in 2013), decreasing again in 2014 (0.011% of GDP).

The scope of financial resources in DRM also includes those for disaster response, a topic with few scientific analyzes (KELLETT et al., 2014). This article aims to analyze the public policy of financial assistance for disaster response actions in the period 2013 to 2017, when the Civil Defense Payment Card (CPDC) is implemented. CPDC is a way of transferring resources within the scope of the National System for Civil Defense and Protection (SINPDEC).

The organization of SINPDEC is presented briefly in the second section of this article, highlighting the main management instruments related to financial assistance for response actions: i) the Brazilian Disaster Codification; ii) the Disaster Information Form; iii) the declaration of State of Emergency (SE) and the State of Public Calamity (SPC); and, iv) the Civil Defense Payment Card (CPDC). Of these four elements, two will be analyzed: a) the SE and SPC statements; and, b) the financial aid expenses for response actions through the CPDC. After this characterization, the third section describes the method and data used.

Then, in the fourth section, basic statistics and spatial-temporal distributions of disasters and use of CPDC by states and municipalities in the period 2013-2017 are presented. Still in the fourth section, based on a sample of the 30 municipalities that spent more than R\$ 1 million on the CPDC, a correlation analysis is made between the CPDC spending profile of these municipalities and other municipal indicators: the MHDI – as an indicator of development – and GDP per capita – as an indicator of economic growth. These results of the Brazilian case are discussed, in the fifth section, based on scientific studies that have addressed funding and financial assistance policies in disaster response actions in other countries. Finally, in the conclusions and recommendations, suggestions for improving public policy are presented based on the data presented in the analysis.

## 2 THE NATIONAL SYSTEM FOR CIVIL DEFENSE AND PROTECTION

The National Department for Civil Defense (SEDEC) (CASTRO et al., 2004) considers civil defense activities as a “set of preventive and relief actions designed to avoid or minimize disasters, preserve the morale of the population and restore social normality”.

According to this federal management body (BRASIL, 2017), preventive actions refer to measures for planning the occupation of geographical space and the execution of works and services in areas considered at risk. The response actions include rescue activities, restoration of essential services and assistance to those affected, that is, emergency measures aimed at serving the population (BRASIL, 2017).

Finally, recovery and reconstruction actions are defined as the activities developed “after disaster response operations and aimed at recovering the infrastructure and restoring, in its entirety, public services, the economy of the area, social morality and the well-being of the population” (CASTRO et al., 2004).

Civil defense actions are organized in the form of a National System for Civil Defense and Protection (SINPDEC), composed of: consultative body (National Council for Civil Defense and Protection); central body (SEDEC), state bodies and the Federal District, and, sometimes, regional coordinators in those states; municipal civil defense agencies; and, finally, sectoral bodies, from the three spheres of government. It should also be noted that SINPDEC is responsible for implementing the National Policy on Civil Defense and Protection - PNPDEC and that it can mobilize civil society to act in a disaster situation, coordinating logistical support for the development of civil defense and protection actions (BRASIL, 2017).

One of the guiding elements of civil defense activities is the typology of hazards and disasters. With the 2011 catastrophe and the adoption of PNPDEC, SEDEC adopts the Brazilian Classification and Codification of Disasters (COBRADE) which is “corresponding to the classification of disasters in the International Disaster Database (EM-DAT)” (BRASIL, 2017, p.30). COBRADE has two broad categories of hazards: 1) natural; and, 2) technological.

The natural category covers five groups of hazards, some divided into subgroups (BRAZIL, 2017): i) geological (earthquake, volcanic emanation, erosion, mass movement such as landslides); ii) hydrological (river floods, flash floods, surface water floods); iii) meteorological (cyclones, heat waves, etc.); iv) climatological (drought); and, v) biological (epidemics and infestations/pests).

The technological category includes five other groups of hazards: i) disasters related to radioactive substances; ii) disasters related to dangerous products; iii) disasters related to urban fires; iv) disasters related to civil works; and, v) disasters related to the transportation of passengers and non-dangerous cargo (BRASIL, 2017).

Faced with a disaster in the municipality, the civil defense must choose a single type of hazard/disaster at COBRADE and complete the Disaster Information Form (FIDE) to assess the damage in that disaster.

FIDE filling out is guided by manuals (BRASIL, 2017) and must take place online through the Integrated Disaster Information System (S2ID), one of the requirements for the request for recognition of a State of Emergency (SE) or State of Public Calamity (SPC).

### 2.1 PROCEDURES FOR DECLARING SE AND SPC

In Brazil, one of the mechanisms of disaster management is the declaration of SE or SPC. SE is the “recognition (legal) by the public authorities of an abnormal situation, caused by disasters, causing surmountable (bearable) damage by the affected community”. The SPC, on the other hand, is the “recognition (legal) by the public authorities of an abnormal situation, provoked by disasters, causing serious damage to the affected community, including the safety or the lives of its members” (BRASIL, 2007, p.8).

In the legal framework, the term of validity of the SE or SPC decree “varies between 30, 60 and 90 days, which may be extended to 180 days” (BRASIL, 2007, p.24).

The SE or SPC decree process by municipalities, states and the Federal District is governed by procedures and criteria established in Normative Instruction nº 02, of December 20, 2016 (BRASIL, 2016). This Normative Instruction establishes some concepts to guide the operationalization of the policy, such as the definitions of damage, loss, disaster, response and resources:

- **DAMAGE:** result of human, material or environmental losses inflicted on people, communities, institutions, facilities and ecosystems, as a result of a disaster.
- **LOSS:** extent of loss related to the economic, social and patrimonial value of a given asset, in circumstances of disaster.
- **DISASTER:** result of adverse events, natural, technological or of anthropic origin, on a vulnerable scenario exposed to the hazard, causing human, material or environmental damages and consequent economic and social damages.
- **RESPONSE:** emergency measures, carried out during or after the disaster, aimed at the relief and assistance of the affected population and the return of essential services.
- **RESOURCES:** set of material, human, institutional and financial assets that can be used in case of disaster and are necessary to restore normalcy.

The main criterion for the decree is the intensity of the disaster. The normative instruction establishes that “disasters of level I and II give rise to the decree of SE, while disasters of level III to SPC” (BRASIL, 2016). Table 1 compiles the definitions of these three levels that guide the decree.

**Table 1 | Disaster intensity levels, defined by SINPDEC.**

| <i>Disaster intensity</i> | <i>Definition</i>   |
|---------------------------|---|
| LEVEL I                   | Level I disasters are those in which there is only considerable human losses and that the situation of normality can be reestablished with the resources mobilized at the local level or reinforced by the contribution of state and federal resources. (Art. 2nd § 1st)                          |
| LEVEL II                  | Characterized by the occurrence of at least two types of losses, one of them being obligatory human losses that have an impact on the public economic loss or in the private economic loss that affect the capacity of the local government to respond and manage the installed crisis. (Art.3rd) |
| LEVEL III                 | Characterized by the concomitant existence of deaths, isolation of the population, interruption of essential services, interdiction or destruction of housing units, damage or destruction of public facilities providing essential services and public infrastructure works (Art.4th)            |

Source: Brazil (2016).

Proof of the occurrence of these criteria is requested through forms, among which FIDE stands out, technical documents and audiovisual records that assist in the understanding of the damage (BRASIL, 2017). The set of this documentation is electronically sent via the S2ID. After the occurrence of an event that causes damage within the intensity levels explained in Table 1, it will be up to the municipality, or the State, to send the information by S2ID within the period stipulated by the normative instruction, in general, from 15 to 20 days, a period that varies according to the type of disaster (“sudden, gradual or chronic evolution”).

After analyzing the documentation, the federal entity – SEDEC – may or may not recognize the SE and SPC decree request. The homologation of the federal recognition will allow the municipality to request federal resources for the execution of response and recovery actions. The use of these resources for response will take place through the civil defense payment card.

## 2.2 THE CIVIL DEFENSE PAYMENT CARD

CPDC is a specific means for implementing federal resources for response actions, assistance to those affected and reestablishment of essential services (BRASIL, 2017). It was designed to fulfill two main objectives: i) “accelerate the transfer of resources to municipalities and states (...)”; and, ii) “provide transparency and social control in the use of these resources” (BRASIL, 2017, p.68). CPDC is a form of payment based on legal instruments (BRASIL, 2017) that require, on the part of civil defense agencies, technical, legal and tax knowledge.

In order to use the resources, civil defense agencies need to acquire CPDC from Bank of Brasil (Banco do Brasil) before declaring SE or SPC. Without joining the CPDC, even if the SE or SPC is recognized, the entity will not be able to receive federal funds for response actions, assistance to the victims and reestablishment of essential services (BRASIL, 2017).

An important issue of these disaster management mechanisms refers to definitions of what response, assistance and the restoration of essential services consist of. The definitions are important guidelines for the use of CPDC. Federal decree n° 7.257, of August 4, 2010 establishes these definitions:

**RESPONSE ACTIONS:** they are “immediate actions to respond to disasters with the objective of helping the affected population, including search and rescue, first aid, pre-hospital care and emergency medical and surgical care (...)”.

**ACTIONS TO ASSIST VICTIMS:** “Immediate actions aimed at guaranteeing conditions of safety and citizenship to those affected, including the supply of drinking water, the provision and means of preparing food, the supply of shelter, clothing, cleaning and personal hygiene, the installation of laundries, bathrooms, logistical support for the teams committed to the development of these actions, comprehensive health care, handling the dead (...)”

**ACTIONS FOR THE ESTABLISHMENT OF ESSENTIAL SERVICES:** “emergency actions aimed at restoring safety and habitability conditions in the area affected by the disaster, including the dismantling of buildings and works of art with compromised structures, the supply and distribution of electricity, drinking water, sewage, urban cleaning, rainwater drainage, public transportation, traffic, communications, drinking water supply and clearing and debris removal (...)”.

The request for these resources through CPDC requires technical preparation of civil defense agencies - municipal or state - not only to know these definitions, but also to formulate a Detailed Response Plan (PDR) and submit it to SEDEC.

The PDR requires municipalities or states to add information on the number of human losses, the response actions in progress by the municipality, the items that are needed, the quantity requested, the unit value, justifying the need for each of the requested resources, among other information that requires technical capacity to be properly elaborated, while the municipal teams need to respond to the disaster.

Based on this contextualization about SINPDEC with regard to response actions and some of its main management instruments – the decree of SE or SPC and the CPDC –, the next section describes the method used to obtain the spatial-temporal distributions of the SE/SPC and CPDC costs and, based on distributions, analyze these two types of data.

### 3 METHOD

In this article, the years 2013 to 2017 were considered for analysis, because it is in this period that the two databases are available: i) the SE and SPC statements; and, ii) data from the Civil Defense Payment Card (CPDC).

The data referring to SE and SPC statements were obtained from the S2ID website (<https://s2id.mi.gov.br/paginas/>) and contain information such as the name of the municipality, the type of hazard according to COBRADE typology, the date of the SE or SPC decree and the date of publication of the ordinance in the Federal Official Gazette (Table 2). CPDC data were extracted from the Transparency Portal of the Federal Government. Table 2 presents the attributes of the data obtained from the two different portals consulted, as mentioned.

**Table 2 | Attributes of the data obtained from the S2ID and the Transparency Portal**

| <i>Attributes</i>                                  |                                   |                         |
|--|-----------------------------------|-------------------------|
| <i>Declarations of SE or SPC (S2ID)</i>            | <i>CPDC (Transparency Portal)</i> |                         |
| FU   | Code superior body                | Executor expense        |
| Geocode  | Name superior body                | Number agreement        |
| Municipality                                       | Code body                         | Code contracting party  |
| Decree   | Nome body                         | Name contracting party* |
| datadec (decree date)                              | Code managing unit                | Transfer                |
| Disaster   | Name managing unit                | Transaction             |
| SE or SPC  | Year statement                    | Date transaction        |
| Ordinance  | Month statement                   | Value transaction       |
| DOU (Official Gazette of the Union)                | CPF holder                        |                         |
| NDOU (number of the Official Gazette of the Union) | Holder name                       |                         |
| DtDOU (Date of the Official Gazette of the Union)  | CNPJ or CPF of the beneficiary**  |                         |
| Rite   | Name of the beneficiary           |                         |

\* It is the beneficiary of CPDC, the municipal or state agency.

\*\* It is the product supplier or service provider who will receive payment.

*Source: Elaborated by the authors*

In the S2ID data, two types of errors were found and adjusted: one in which the attribute “geocode” did not match the name of the municipality and another in which the name of the municipality was not spelled according to what appears in the IBGE database.

In addition, the disaster typology (disaster attribute) does not specify exactly the event and, in many cases, groups them, in addition to not adopting standardized terminology and referring to the same typology using different expressions. Regarding the Transparency Portal, two limitations are mentioned in the records: i) a large part of the agreement is the State and not the municipalities, thus making the delimitation of the area which has suffered disasters unfeasible; and, ii) the Transparency Portal does not describe the type of disaster or any details about the cause that culminated in the need to use CPDC resources.

After making the necessary adjustments, the data were included in a Geographic Information System environment in order to perform the spatial distribution of data regarding the SE and SPC declarations, considering the following criteria:

1. the number of reporting municipalities per year, which indicates the number of municipalities with disasters recognized by SEDEC;



2. the number of SE or SPC per year, which indicates the number of disasters recognized by SEDEC;
3. the frequency of declarations by municipality, that is, the frequency of disasters by municipality;
4. the number of SE or SPC by type of event, that is, by type of disaster according to COBRADE typology.

The next step consisted of a selection in the database regarding the use of the CPDC. At this stage, the data were analyzed in order to obtain:

1. the distribution of total expenses with the CPDC per year, which explain the federal financial aid for disaster relief and response actions;
2. The total value over the entire period and also per year of CPDC resources that the States used for response actions in the municipalities
3. the number of municipalities that used CPDC;
4. a ranking of the 30 municipalities with the highest use of CPDC whose data were correlated with other municipal indicators that express their level of development (Municipal Human Development Index-MHDI), obtained in PNUD (2013) and economic (Gross Domestic Product per- capita), obtained from IBGE (2017).

Since the databases for SE and SPC declarations and CPDC spending were not associated, it was not possible to discriminate CPDC spending by the types of disasters contained in the declarations.

## 4 RESULTS

In this section are presented, for the period 2013-2017, some statistics and maps of the spatial-temporal distributions derived from the SE and SPC declarations and CPDC spending databases described in section 3.

### 4.1 STATISTICS RELATING TO SE AND SPC DECLARATIONS

Of the 5570 municipalities in Brazil, 3057 municipalities (54.88%) declared, at least once, SE or SPC due to disasters in the period 2013-2017 – an average of 1746 municipalities per year (31.34% of those existing in Brazil).

There were 13894 disasters recognized by SEDEC, an average of 2778 per year. In the period, 51 disasters were considered as SPC, that is, classified as the maximum intensity category - level III.

Dry spells and droughts account for 81.78% of these records and have been frequent, mainly in the Northeast Region. River floods, flash floods and surface water floods are the second with the highest percentage of records (9.37%) and are distributed in the South (58.91%), North (19.05%) and Southeast (11.9%) regions. Table 3 shows a summary of statistics on the SE and SPC declarations in the analyzed period.

**Table 3 | Statistics of spatial-temporal distributions of SE-SPC declarations**

| <i>Nº of municipalities that declared SE or SPC at least once</i>                |   | <i>3057*</i>                                  |                       |                                       |                                  |                   |
|--|---|---|-----------------------|---------------------------------------|----------------------------------|-------------------|
| <i>Nº total of declarations</i>  |   | <i>Nº of declarations of SE</i>               |                       |                                       | <i>Nº of declarations of SPC</i> |                   |
| 13894  |   | 13843   |                       |                                       | 51                               |                   |
| <i>Number of declarations and reporting municipalities per year</i>              |   |   |                       |                                       |                                  |                   |
| <i>Year</i>  | <i>Nº of declarations</i>                             |   |                       | <i>Nº of reporting municipalities</i> |                                  |                   |
| 2013   | 3747  |   |                       | 1938                                  |                                  |                   |
| 2014   | 2666  |   |                       | 1886                                  |                                  |                   |
| 2015   | 2511  |   |                       | 1592                                  |                                  |                   |
| 2016   | 2072  |   |                       | 1450                                  |                                  |                   |
| 2017   | 2898  |   |                       | 1864                                  |                                  |                   |
| <i>Percentage distribution of total declarations by region</i>                   |   |   |                       |                                       |                                  |                   |
| <i>North (N)</i>   | <i>Northeast (NE)</i>                                 | <i>Central-west (CW)</i>                      | <i>Southeast (SE)</i> | <i>South (S)</i>                      |                                  |                   |
| 2.41%  | 73.16%  | 1.38%   | 11.35%                | 11.69%                                |                                  |                   |
| <i>Percentage distribution of frequency of declarations</i>                      |   |   |                       |                                       |                                  |                   |
| <i>Frequency ranges</i>  | <i>Percentage of the total of 3057 municipalities</i> | <i>Percentage of municipalities by region</i> |                       |                                       |                                  |                   |
|  |   | <i>N</i>                                      | <i>NE</i>             | <i>CW</i>                             | <i>SE</i>                        | <i>S</i>          |
| 1 to 4   | 58.62%  | 8.15%   | 21.60%                | 7.31%                                 | 19.03%                           | 43.92%            |
| 5 to 7   | 12.82%  | 2.80%   | 71.94%                | 0.00%                                 | 18.37%                           | 6.89%             |
| 8 to 10  | 22.44%  | 0.00%   | 90.23%                | 0.00%                                 | 9.62%                            | 0.15%             |
| 11 to 12   | 6.12%   | 0.00%   | 98.93%                | 0.00%                                 | 1.07%                            | 0.00%             |
| <i>Percentage distribution of total declarations by type of hazard</i>           |   |   |                       |                                       |                                  |                   |
| <i>Type of hazard</i>  |   |   |                       |                                       |                                  | <i>Percentage</i> |
| Dry spells and droughts (DSD)  |   |   |                       |                                       |                                  | 81.78%            |
| River floods, flash floods and surface water floods (RFFFSWF)                    |   |   |                       |                                       |                                  | 9.37%             |
| Local convective storms and heavy rains (LCTHR)                                  |   |   |                       |                                       |                                  | 5.30%             |
| Mass landslides (DM)   |   |   |                       |                                       |                                  | 0.17%             |
| Other**  |   |   |                       |                                       |                                  | 3.38%             |
| <i>Percentage distribution of total declarations by type of hazard by region</i> |   |   |                       |                                       |                                  |                   |
| <i>Hazard</i>  | <i>Percentage of declarations by region</i>           |   |                       |                                       |                                  |                   |
|  | <i>N</i>  | <i>NE</i>                                     | <i>CW</i>             | <i>SE</i>                             | <i>S</i>                         |                   |
| DSD  | 0.54%   | 88.40%  | 0.10%                 | 10.49%                                | 0.47%                            |                   |
| RFFFSWF  | 19.05%  | 7.14%   | 3.00%                 | 11.90%                                | 58.91%                           |                   |
| LCTHR  | 0.81%   | 1.49%   | 16.96%                | 16.83%                                | 63.91%                           |                   |
| DM   | 4.16%   | 16.67%  | 0.00%                 | 41.67%                                | 37.50%                           |                   |
| OTHER  | 21.66%  | 2.12%   | 3.61%                 | 64.12%                                | 8.49%                            |                   |

\* corresponding to 54.88% of the total of 5570 municipalities in Brazil.

\*\* technological, biological disasters, tornadoes, cyclones, hail, fires, erosions, debris flow.

Source: Elaborated by the authors, based on data from S2ID.

## 4.2 – SPATIAL-TEMPORAL DISTRIBUTIONS OF SE AND SPC DECLARATIONS

In the period covered, Brazil recorded several disasters, such as the river floods of 2012, 2014 and 2015 in Acre (AC); droughts in the Amazon in 2015-2016; river floods, flashfloods and landslides in the Southeast, especially in the states of MG, ES, RJ in 2013; the catastrophe associated with the rupture of the dam in Mariana-MG in 2015; drought in the semiarid region from 2012 to 2017.

Figure 1 shows the spatial-temporal distribution of disaster statements. The Northeast Region accounts for 73.16% of disasters in the period. Dry spells and droughts account for more than half of the annual

average, being more than 1500 municipal notifications per year, especially in the Northeast Region and in the North of the State of MG (Southeast Region). In 2013, there were 13 municipalities that declared SE four times, all located in the Northeast Region.

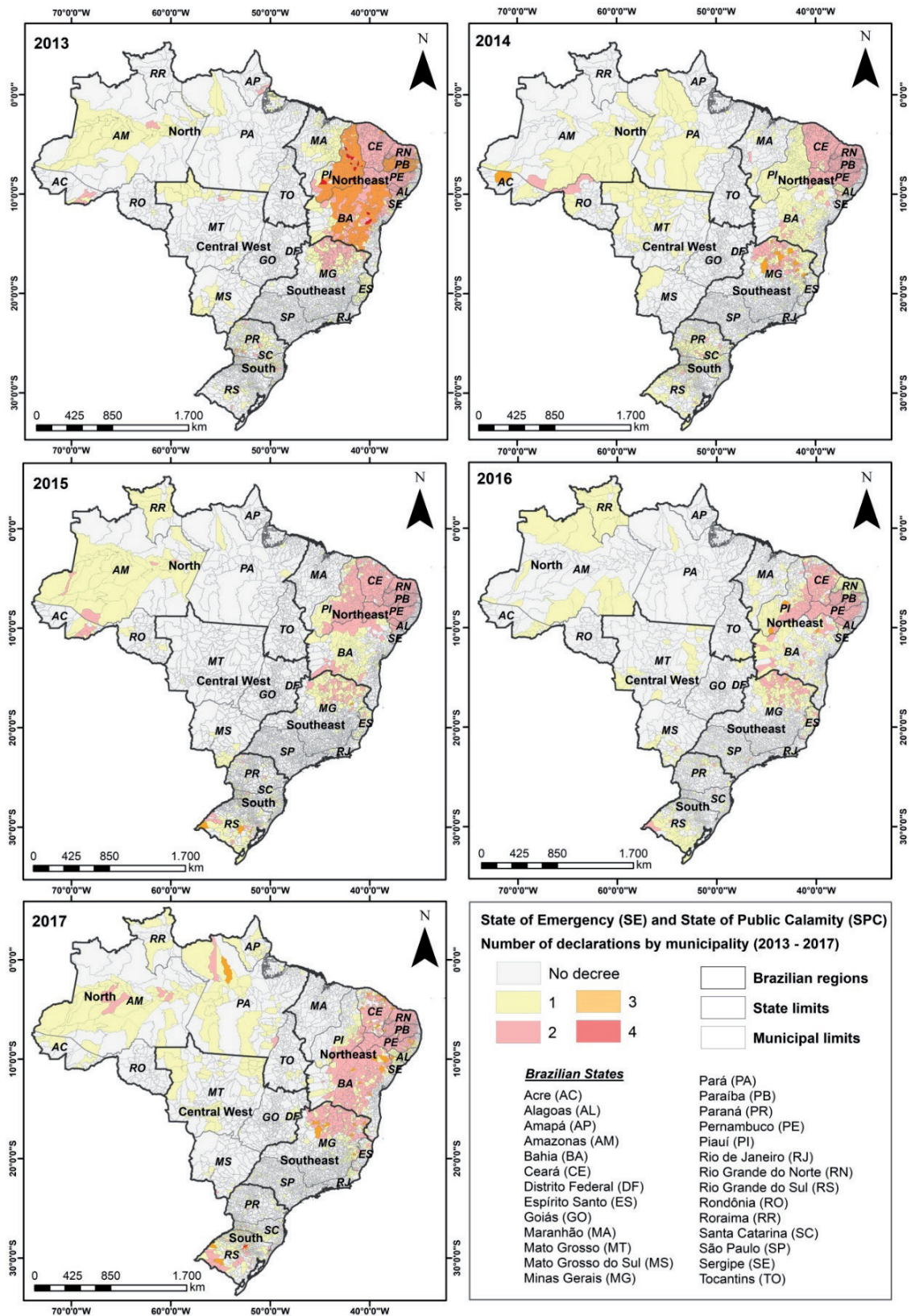
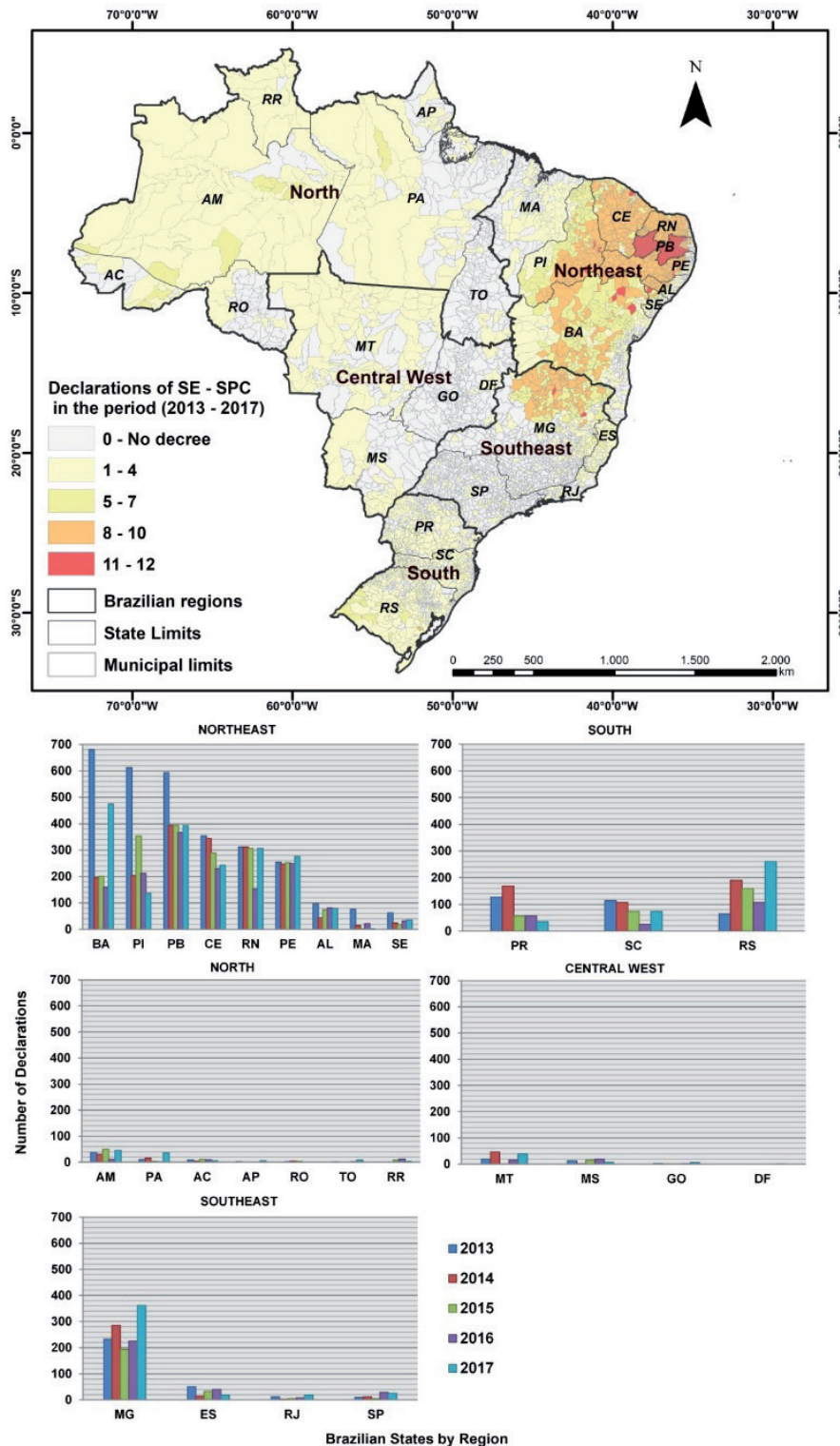


Figure 1 | Spatial-temporal distribution of SE-SPC declarations in Brazil, 2013-2017 period.

Source: Elaborated by the authors, based on data from S2ID.

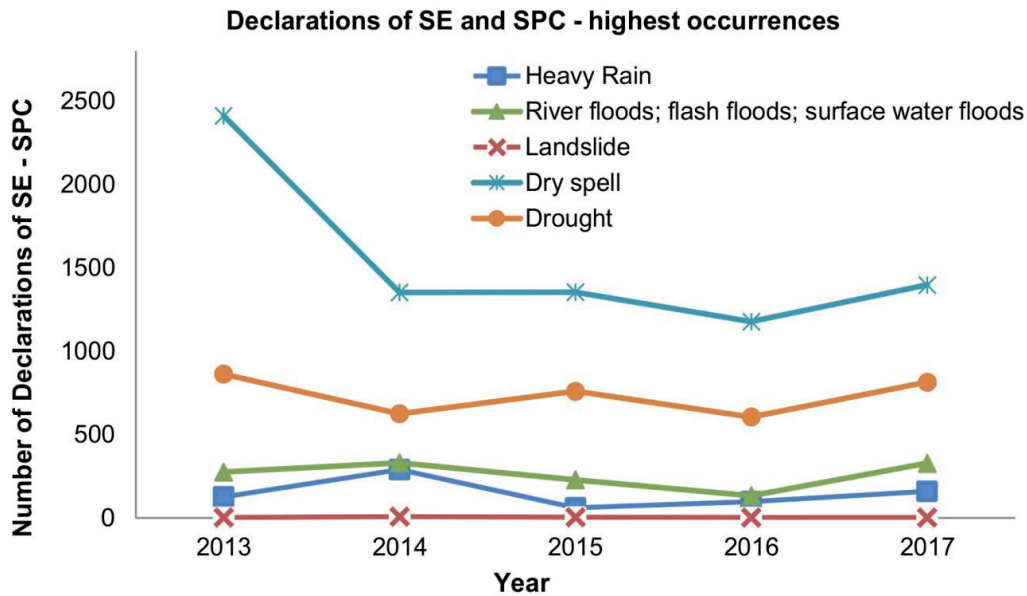
Figure 2 presents the map of the spatial distribution of the frequency of declarations for the analyzed period and also a graph indicating the total declarations made by each State in each year. In 185 municipalities in the Northeast Region (which corresponds to 10.31% of the municipalities in the Region), the frequency of declarations reached the range between 11 and 12 records, an average of more than two declarations per year. The highest occurrence was in the State of Paraíba (PB) with 170 municipalities, with emphasis on São José de Piranhas, with 12 declarations.



**Figure 2 |** Spatial-temporal distribution of the frequency of declarations of SE-SPC in Brazil, period 2013-2017, and bar chart with the total of declarations of States in each year.

Source: Elaborated by the authors, based on data from S2ID.

Most municipalities that declared SE-SPC due to river floods, flash floods and/or surface water floods did so more than once a year, especially in the South and North Regions. There is also the scenario in which municipalities experienced multiple hazards in the same year or over the period, such as the municipality of Rio Branco – AC, which in 2013 declared SE for both drought and river flood. Or the municipalities of Brasília and Eptaciolândia, both in the AC, which declared SE due to drought and also due to viral infectious diseases. Figure 3 illustrates the temporal distribution of SE – SPC by hazard type.



**Figure 3 |** Temporal distribution of SE-SPC declarations by type of threat in the period 2013-2017.  
 Source: Elaborated by the authors, based on data from S2ID.

One aspect that draws attention is the low amount of SE-SPC registration due to landslides, forest fires, technological and biological disasters. Technological disasters totaled 15 declarations, with the highest occurrence in 2015, associated with the rupture of dams in the State of MG. Biological disasters were concentrated in 2017 with 68 declarations, 62 in municipalities in MG, due to viral infectious diseases.

### 4.3 STATISTICS RELATING TO CPDC EXPENSES

States and municipalities that enact SE and SPC can use the CPDC. In cases of disasters that affect more than one municipality – such as those related to dry spells and droughts –, state civil defenses themselves can make use of the CPDC in favor of the municipalities that have been approved by SE and SPC. However, through the data available on the Transparency Portal, it is not possible to discriminate in favor of which municipalities these spending were made.

Of the total expenses with CPDC in the period – approximately R\$ 807.7 million – 76.45% (R\$ 617.9 million) were used with the intermediation of 21 Brazilian states and 23.55% (R\$ 189.7 million) directly by 564 municipalities (Table 4). Among the 21 States, the first nine positions were occupied by those in the Northeast region, with emphasis on CE, PE, PI and AL, which accounted for just over half of the resources used by the States.

Table 4 shows the expenses with the CPDC made with the intermediation of the States and the municipalities that are part of it, together with the number of declarations of SE and SPC in the analyzed period. It is ranked from highest to lowest total expenses on CPDC in order to facilitate the perception that the magnitude of these expenses is not directly related to the number of SE and SPC declarations

made by the State and its municipalities. The State of Paraíba (PB), for example, recorded the largest number of SE and SPC declarations in the period (2142) and had total spending with the CPDC that were lower than the State of Ceará (CE). CE registered almost the same number of declarations as PI and its total spending on CPDC was 2.36 times higher.

**Table 4 | CPDC expenses and total declarations between 2013 and 2017**

| <i>FU</i> | <i>CPDC Expenses by State</i> | <i>CPDC Expenses by Municipalities</i> | <i>Total CPDC Expenses</i> | <i>Number of declarations SE + SPC</i> |
|-----------|-------------------------------|--|----------------------------|--|
| CE        | 148.552.394,50                | 481.772,88                             | 149.034.167,38             | 1461                                   |
| PB        | 49.917.265,79                 | 54.198.609,20                          | 104.115.874,99             | 2142                                   |
| PE        | 78.943.909,35                 | 2.091.464,87                           | 81.035.374,22              | 1279                                   |
| PI        | 63.033.887,45                 | 44.595,44                              | 63.078.482,89              | 1518                                   |
| AL        | 57.074.976,28                 | 1.285.363,18                           | 58.360.339,46              | 374                                    |
| RN        | 48.963.360,96                 | 8.716.256,73                           | 57.679.617,69              | 1389                                   |
| BA        | 25.303.051,71                 | 17.385.328,13                          | 42.688.379,84              | 1711                                   |
| MG        | 21.949.506,59                 | 19.289.286,60                          | 41.238.793,19              | 1299                                   |
| AM        | 9.751.670,98                  | 22.943.570,20                          | 32.695.241,18              | 174                                    |
| MA        | 30.781.129,27                 | 0,00                                   | 30.781.129,27              | 117                                    |
| AC        | 14.731.789,83                 | 9.353.631,03                           | 24.085.420,86              | 40                                     |
| RJ        | 7.656.660,01                  | 15.345.344,73                          | 23.002.004,74              | 44                                     |
| RS        | 13.835.699,28                 | 6.338.159,53                           | 20.173.858,81              | 783                                    |
| SE        | 19.606.816,26                 | 0,00                                   | 19.606.816,26              | 172                                    |
| SC        | 5.231.898,86                  | 12.830.828,75                          | 18.062.727,61              | 395                                    |
| RO        | 13.390.024,26                 | 0,00                                   | 13.390.024,26              | 13                                     |
| PR        | 6.616.198,20                  | 4.303.357,67                           | 10.919.555,87              | 446                                    |
| SP        | 0,00                          | 5.880.513,93                           | 5.880.513,93               | 79                                     |
| PA        | 860.642,00                    | 2.735.692,49                           | 3.596.334,49               | 67                                     |
| AP        | 237.116,97                    | 2.956.682,00                           | 3.193.798,97               | 8                                      |
| GO        | 0,00                          | 1.881.862,47                           | 1.881.862,47               | 13                                     |
| MT        | 1.168.500,00                  | 97.575,80                              | 1.266.075,80               | 121                                    |
| ES        | 0,00                          | 960.806,00                             | 960.806,00                 | 155                                    |
| MS        | 0,00                          | 627.324,63                             | 627.324,63                 | 57                                     |
| RR        | 357.886,00                    | 0,00                                   | 357.886,00                 | 25                                     |
| DF        | 0,00                          | 0,00                                   | 0,00                       | 1                                      |
| TO        | 0,00                          | 0,00                                   | 0,00                       | 11                                     |
| Total     | 617.964.384,55                | 189.748.026,26                         | 807.712.410,81             | 13894                                  |

*Source: Elaborated by the authors, based on data from the Transparency Portal and S2ID.*

Average expenses on the CPDC per year was approximately R\$ 161.5 million, with an emphasis on 2014, with R\$ 270 million.

It is possible to identify that in the Northeast Region, States tend to be intermediaries in the use of CPDC resources to be applied in the municipalities in SE and SPC – with the exception of PB, where the use of CPDC resources directly by the municipalities and with the intermediation of the State were proportional in terms of the amount used over the period. In the South and Southeast Regions – with the exception of the States of MG and RS –, an opposite scenario is identified, with municipalities directly accessing financial resources via CPDC.

#### 4.4 EXPENSES ON CPDC BY MUNICIPALITY

Of the 3057 municipalities that enacted SE or SPC, 18.45% of them (564) made use of CPDC resources on their own.

Of these 564 municipalities, 54.61% (308) are concentrated in the Northeast Region, mainly in PB (184 municipalities) and BA (118 municipalities). The South Region is the second in number of municipalities (133) using the CPDC, 70 of which (61.95%) are from SC. The Southeast Region has 60 municipalities using CPDC, the majority (70%) in MG. In the North Region, AM registered 36 of the 59 municipalities. Figure 4 shows the spatial-temporal distribution of spending with CPDC in the period, by municipal civil defenses.

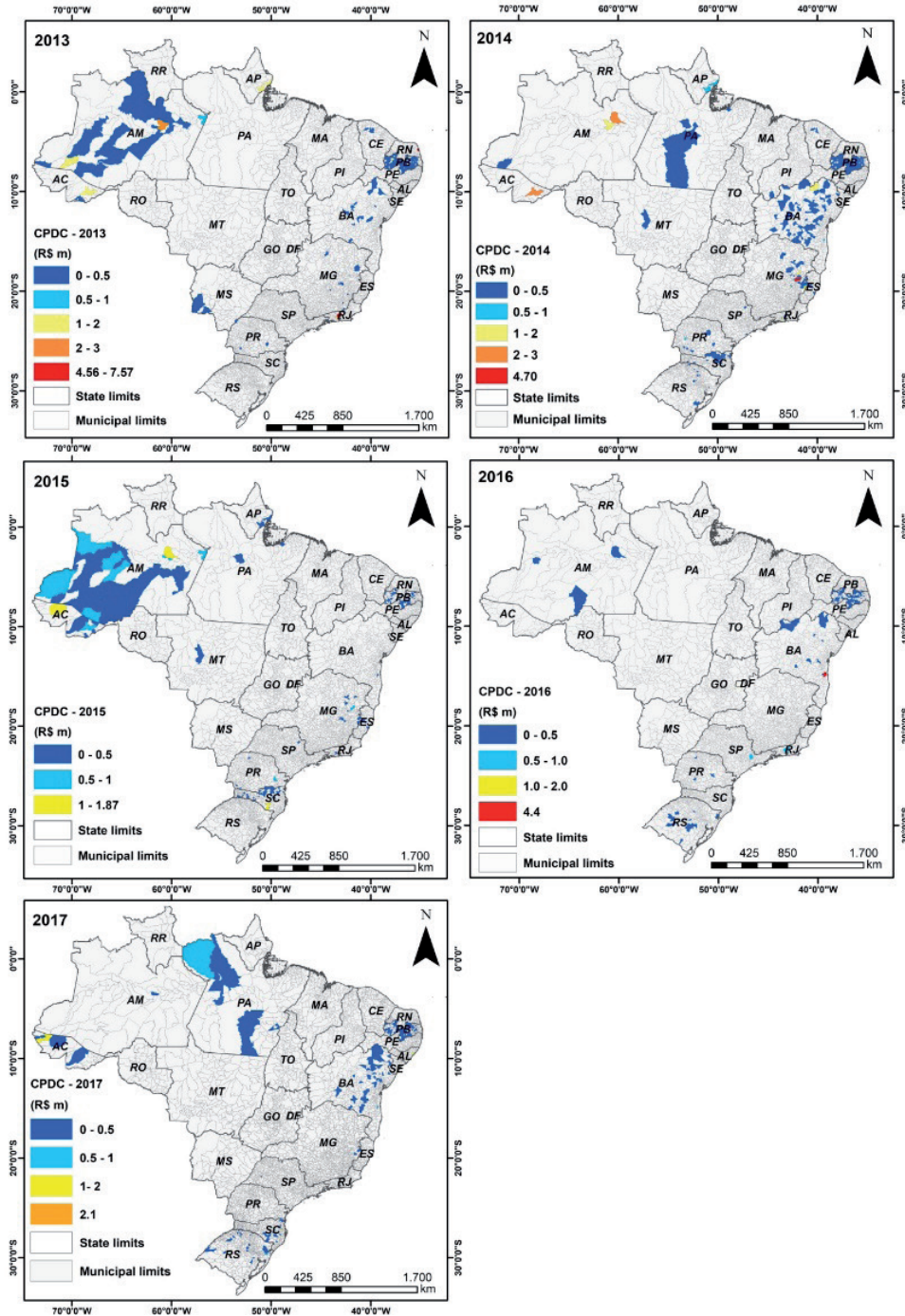


Figure 4 | Distribution of expenses with CPDC in the period 2013 - 2017, by the municipalities.

Source: Elaborated by the authors, based on data from the Transparency Portal.

Of the R\$ 189.7 million used by 564 municipalities, 41% (R\$ 77.7 million) were spent by 30 of them. More than half of these municipalities (19) have a high MHDl (above 0.700) (Figure 5). Of this sample, only one municipality had low development (MHDl less than 0.550), that is, a large part of the CPDC's resources has not been used by municipalities with lower MHDl values. All municipalities that had expenses with CPDC greater than R\$ 4 million in the 2013-2017 period had an MHDl greater than 0.700 (Figure 5).

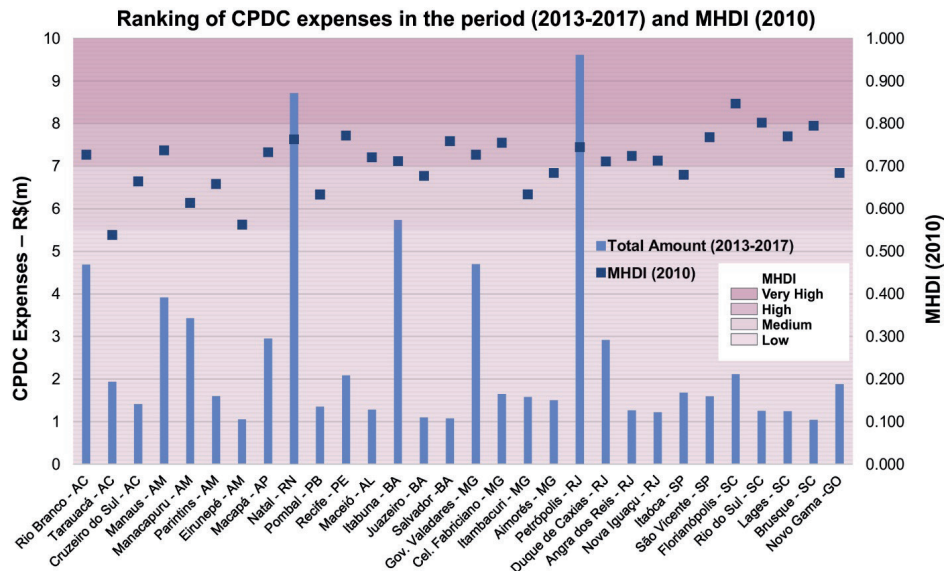
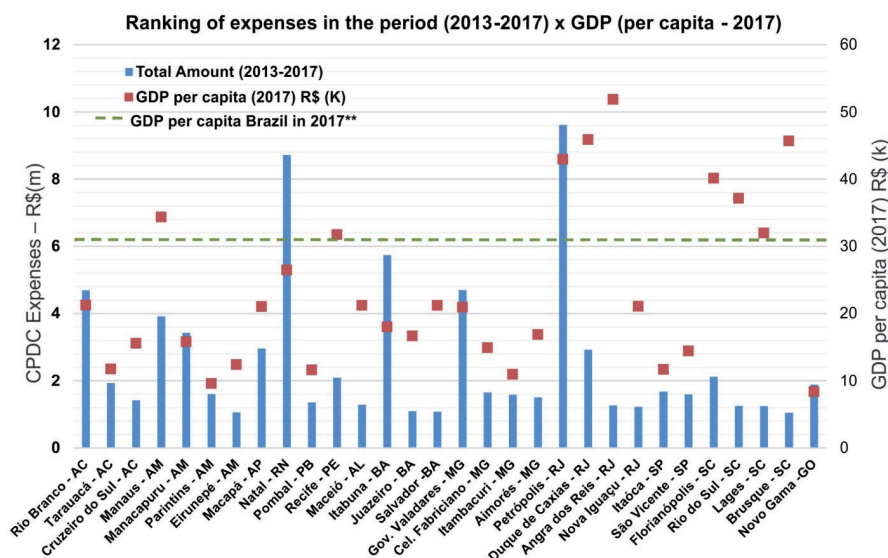


Figure 5 | CPDC values R\$ (m) and MHDl of the 30 municipalities with the highest expenses in the period.

Source: Elaborated by the authors, based on data from the Transparency Portal and PNUD (2013).

Sometimes municipalities have similar values for MHDl, but are unequal in relation to GDP per capita - an indicator of economic growth. The municipalities of Macapá - AP and Duque de Caxias - RJ have similar MHDl and expenses on CPDC was also similar, but Duque de Caxias-RJ has GDP per capita about twice as high as the GDP per capita of Macapá-AP.

It is important to highlight that among the 30 municipalities in this sample, the municipalities in the states of SC and RJ have GDP per capita higher than the national average, while a large part of the municipalities in the North and Northeast regions of the country are located below it (Figure 6).



\*\* GDP per capita in 2017: R\$ 31.833,50.

Figure 6 | Values of CPDC R\$ (m) and per capita income of the 30 municipalities with the highest expenses in the period.

Source: Prepared by the authors, based on data from the Transparency Portal and the IBGE (2017)



## 5 DISCUSSION

In the context of institutional vulnerability to disasters, Valencio (2014) proposed to analyze the decrees of SE and SPC as expressions of a chronic crisis in Brazil. When analyzing 19,441 SE and SPC decrees in the period 2004-2013, the author considers that the country is experiencing a kind of disaster pandemic (VALENCIO, 2014), with an annual average of 25% of municipalities in SE or SPC. When analyzing the 2013-2017 period, we found an increase in this average: almost 32% of Brazilian municipalities in SE or SPC per year.

In addition to analyzing the spatial-temporal distribution of the SE and SPC declarations (Figure 1), it is also important to identify the consequences that federal recognition implies, such as, for example, requesting access to financial aid for disaster response actions.

When analyzing the spatial-temporal distribution of spending with CPDC by the States and municipalities, in the period 2013-2017, it was possible to identify that in most of the States of the Northeast Region and in the States of MG and RS, the state entity is usually an intermediary in the use of CPDC (Table 4). Is this intermediation by the State entity justified by the disaster affecting more than one municipality and/or the affected municipality not having a municipal civil defense agency?

Future studies need to analyze these dimensions of governance and management within the scope of SINPDEC. In this regard, it is “relevant to emphasize the fact that the duty imposed on the Federal Government to transfer amounts in the event of disasters covers, even as beneficiaries, municipalities that have not fulfilled their respective legal duties to map risk areas, considering such studies in its master plans (...) and preventive actions (CARVALHO, 2020, p.151). It would also be relevant to consider whether municipalities have civil defense with sufficient staff and budget to carry out these actions in the context of disaster prevention, response and recovery.

Furthermore, it is important to analyze whether indicators could be used to prioritize CPDC resources for those municipalities with lower MHDl and per capita income, understanding these two indicators among the set of factors that may represent human development and economic wealth present in the municipalities. In our analysis for the 30 municipalities that most used CPDC in the period, we identified that a large part of them (19) have high MHDl – mainly those located in the South Region of the country. Although the MHDl can be used as one of the parameters for prioritizing CPDC resources, it is important to consider the limitations of the MHDl and other indicators.

Vieira and collaborators (2020), for example, identified an improvement in the MHDl values between 2000 and 2010 for municipalities in the Brazilian semiarid region. However, when analyzing the components that contributed to this change, they identified that health and education indicators generally improved over the years, while socioeconomic indicators remain low in some sets of municipalities, explaining intra-regional inequalities. In other words, in relation to droughts in the Brazilian semiarid region, it would be important to guide public policies not by the climate variable itself, but by the conditions of environmental susceptibility and social, economic and institutional vulnerabilities present in the municipalities (VIEIRA et al., 2020).

CPDC is considered a form of access to a complementary resource (BRASIL, 2017). Should the proportions of complementarity of the resource be the same, regardless of the conditions of development (MHDl) and economic wealth (GDP per capita) of the municipalities? Has the assessment for the release of CPDC resources been guided by the amount of damage and losses reported by the municipalities when they register disasters or by the financial and management capacity they have to provide relief, assistance and restoration services? The results of this article do not allow answering these questions, but the exploratory analysis on a topic that has been little studied in the country – public financial aid policy in response to disasters – has given rise to some of these questions that may have implications on the forms of governance and disaster risk management.

The exploratory analysis of this public policy allows other questions. In disasters with high visibility in the media, it is common for campaigns to collect donations and cash donations, as occurred in the disaster in the Vale do Itajaí/SC in 2008, when approximately R\$ 35 million were donated in favor of homeless. In Ilhota/SC, people questioned how the financial resources donated to them were being used by public agencies, given that the survivors had not been consulted about how the money donations, deposited in the state entity's bank account, should be used (MARCHEZINI, 2014).

From this example, one could ask: what criteria to adopt when the complementary use of CPDC resources is granted by SEDEC and, in the course of the emergency response, other sources of resources – such as cash donations – are directed to the same States and municipalities?

Spending transparency in response to disasters has been identified as one of the main strengths of CPDC (BRASIL, 2017). Transparency, accountability, lack of coordination between levels of government and local capacity for investment are among the main challenges identified by studies that analyzed funding policies for DRM (KELLETT et al., 2014).

Kellet and collaborators (2014) emphasized that the biggest problem is not always the lack of financial resources. To this element of institutional vulnerability we can add another: i) the high concentration of resources at the national level; ii) the lack of allocation of funds to the local level; iii) local capacity to implement DRM actions; iv) coordination mechanisms between levels of government; v) clarity in the legislation; vi) clarity in the roles and responsibilities of each of the government agencies; vii) knowledge of administrative procedures in order to access financing and financial assistance programs; and, viii) availability of data about the funds allocated to which DRM activities.

In the face of these challenges, Kellett and collaborators (2014) recommend improving clarity and sometimes simplifying legislation, as well as focusing on decentralizing resources to promote DRM at the local level. In Brazil, the public financial assistance policy for disaster response actions, via the CPDC, has procedures that require technical and legal capacity on the part of municipal civil defenses.

This is supplemented by the budgetary and financial reality of civil protection and defense in Brazilian municipalities, which, as acknowledged by SEDEC itself (BRASIL, 2017, p.37), in most cases “does not have its own resources (budget line), especially municipalities with a small number of inhabitants and those that do not register a significant frequency of disasters. There are also those who have minimal resources and are unable to execute them”.

In view of this reality, it may be important to use CPDC resources to reduce, even if occasionally, the institutional vulnerabilities of these municipalities, especially those with lower MHD and GDP per capita. Future studies can analyze these dimensions, identifying how municipal civil defense agencies finance their activities, and what effects the lack of financing and institutional capacity can generate on DRM activities.

## **6 CONCLUSIONS AND RECOMMENDATIONS**

The analysis of the spatial-temporal distributions of the SE and SPC and of the expenses with the CPDC in the 2013-2017 period allows to identify some conclusions that may be important for the planning of public financial aid policies for disaster response actions.

First, the SE declaration is being treated as something ordinary. More than half of the Brazilian municipalities declared SE in a period of five years. The frequency of declarations is another aspect that draws attention. In 187 Brazilian municipalities, the government deals with SE almost 200 days a year.

Most of the SE declarations are related to dry spells and droughts, especially in the Northeast Region. Other hazards, such as geological and biological hazards, have few records in the S2ID database.

The declaration of SE or SPC is a step to claim financial aid for response actions, via CPDC. States used most of the CPDC's resources (76.45%). Four states in the Northeast Region, which have frequent SE records due to dry spells and droughts, account for just over half of all spending. Although SE declarations have the municipality as the disaster site, many seem to depend on the State as an intermediate federative entity for the use of CPDC resources, mainly in the Northeast Region – with the exception of the States of PB and BA – and in the States of MG and RS.

Of the set of 564 municipalities that used CPDC, 54.61% are concentrated in the Northeast (mainly in PB and BA), South (23.58%), Southeast (10.64%), North (10.46%) and, finally, the Central-West (0.71%). Of the R\$ 189.7 million directly used by the municipalities, 41% of the total (R\$ 77.7 million) went to 30 municipalities.

It is interesting to highlight that all the municipalities that had spending with CPDC higher than R\$ 4 million in the period 2013-2017 had High MHDH (higher than 0.700) – especially in the South and Southeast regions of the country. In other words, municipalities with higher HDI and higher GDP per capita – indicators that, in theory, represent better conditions for development – also have more extraordinary resources from the federal government through CPDC, considered a type of complementary aid. Future analyzes will be able to verify if this trend of reproduction of inequality in assistance in disasters is replicated. To what extent have municipalities with lower MHDH values been affected by disasters and have not had access to CPDC resources?

As a way of improving the transparency of the CPDC and making it more appropriate for DRM analyzes, it is recommended that the beneficiary municipalities be detailed when resources are requested by the States, and also that the typology of hazards and disasters be informed on the Transparency Portal. Another important aspect may be to establish criteria for prioritizing CPDC resources based on the history of municipalities in disaster risk reduction.

## ACKNOWLEDGMENTS

VM thanks the São Paulo Research Foundation-Fapesp (Grant number 2018/06093-4). AMF thanks CAPES for the PhD scholarship. DAM thanks CNPq for the EXP-A scholarship.

## REFERENCES

BANCO MUNDIAL. **Avaliação de Perdas e Danos: inundações bruscas em Santa Catarina** – novembro de 2008. Brasília: Banco Mundial, 2012a.

BANCO MUNDIAL. **Avaliação de Perdas e Danos: inundações bruscas em Pernambuco** – junho de 2010. Brasília: Banco Mundial, 2012b.

BANCO MUNDIAL. **Avaliação de Perdas e Danos: inundações e deslizamentos na Região Serrana do Rio de Janeiro** – janeiro de 2011. Brasília: Banco Mundial, 2012c.

BRASIL. **Instrução Normativa nº 02, de 20 de dezembro de 2016**. 2016. Disponível em: <<https://www.mdr.gov.br/images/stories/ArquivosDefesaCivil/ArquivosPDF/legislacao/Anexo-VI---Conceitos.pdf>>. Acesso em: 17 jan. 2019.

BRASIL. Ministério da Integração Nacional. **Módulo de formação: resposta, gestão de desastres, decretação e reconhecimento federal e gestão de recursos federais em proteção e defesa civil para resposta**. Apostila do instrutor. Brasília-DF, 2017. Disponível em: <<https://www.mdr.gov.br/images/stories/ArquivosDefesaCivil/ArquivosPDF/publicacoes/II---Resposta---Livre-Base.pdf>>. Acesso em: 17 jan. 2019.

BRASIL. **Política Nacional de Defesa Civil**. Brasília: Sedec, 2007.

CARVALHO, D. W. **Desastres ambientais e sua regulação jurídica: deveres de prevenção, resposta e compensação ambiental**. 2. ed. São Paulo: Thomson Reuters, 2020.

- CARVALHO, J. M. **Cidadania no Brasil: o longo caminho**. Rio de Janeiro: Civilização Brasileira, 2002.
- CASTRO, A. L. C. **Glossário de Defesa Civil: estudos de riscos e medicina de desastres**. 5. ed. Brasília: Sedec, 2004.
- CHAMBERS, R. Vulnerability, coping and policy. **IDS bulletin**, v. 20, n. 2, p. 1-7, 1989.
- INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **PIB per capita [2017]**. IBGE Cidades. 2017. Disponível em: <<https://cidades.ibge.gov.br/>>. Acesso em: 17 jan. 2019.
- KELLETT, J.; CARAVANI, A.; PICHON, F. **Financing Disaster Risk Reduction: towards a coherent and comprehensive approach**. 2014. Disponível em: <<https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9027.pdf>>. Acesso em: 07 jul. 2019.
- MARCHEZINI, V. **Campos de desabrigados: a continuidade do desastre**. São Carlos: RiMa, 2014.
- MARCHEZINI, V.; SARTORI, J.; GONÇALVES, J. C. Desenvolvimento, Desastres e Reconstrução: o caso de São Luiz do Paraitinga/SP, Brasil. **Revista Brasileira de Gestão e Desenvolvimento Regional**, v. 13, p. 202-226, 2017.
- PROGRAMA DAS NAÇÕES UNIDAS PARA O DESENVOLVIMENTO. **Atlas do Desenvolvimento Humano no Brasil 2013**. Disponível em: <<https://www.br.undp.org/content/brazil/pt/home/idh0/rankings/idhm-municipios-2010.html>>. Acesso em: 15 jan. 2019.
- PROGRAMA DAS NAÇÕES UNIDAS PARA O DESENVOLVIMENTO. **O que é o IDH**. Brasília: Pnud, 2020. Disponível em: <<https://www.br.undp.org/content/brazil/pt/home/idh0/conceitos/o-que-e-o-idh.html>>. Acesso em: 10 jul. 2020.
- TIERNEY, K. Disaster governance: social, political, and economic dimensions. **Annual Review of Environment and Resources**, v. 37, p. 341-363. 2012.
- UNITED NATIONS DEVELOPMENT PROGRAM. **Human Development Report 2019**. Beyond income, beyond averages, beyond today: inequalities in human development in the 21st century. New York: UNDP, 2019. Disponível em: <<http://hdr.undp.org/sites/default/files/hdr2019.pdf>>. Acesso em: 05 jul. 2020.
- UNITED NATIONS INTERNATIONAL STRATEGY FOR DISASTER REDUCTION. **Global Assessment Report on Disaster Risk Reduction: making development sustainable**. The Future of Disaster Risk Reduction, UN, New York, 2015.
- VALENCIO, N. F. L. S. Desastres no Brasil: a face hídrica do antidesenvolvimento. In: VALENCIO, N. F. L. S.; SIENA, M. **Sociologia dos Desastres: construção, interfaces e perspectivas**. Volume IV. São Carlos: Rima Editora, 2014. p. 109-148.
- VIEIRA, R. M. S. P. et al. Characterizing spatio-temporal patterns of social vulnerability to droughts, degradation and desertification in the Brazilian northeast. **Environmental and Sustainability Indicators**, 2020.
- WALLEMACQ, P.; HOUSE, R. **Economic Losses, Poverty & Disasters**. 2018. Disponível em: <[https://www.preventionweb.net/files/61119\\_credeconomiclosses.pdf](https://www.preventionweb.net/files/61119_credeconomiclosses.pdf)>. Acesso em: 1 ago. 2019.
- WILCHES-CHAUX, G. La vulnerabilidad global. In: MASKREY, A. (Org.). **Los desastres no son naturales**, 1993, p. 11-41. LA RED: Panamá.
- WISNER, B.; GAILLARD, J. C.; KELMAN, I. Framing disaster: theories and stories seeking to understand hazards, vulnerability and risk. In: \_\_\_\_\_. **The Routledge handbook of hazards and disaster risk reduction**. p.18-34. London: Routledge, 2012.

# Política pública de auxílio financeiro para resposta a desastres no Brasil no período 2013-2017

*Emergency funding policy for disaster response in Brazil from 2013 to 2017*

Victor Marchezini<sup>a</sup>

Adriano Mota Ferreira<sup>b</sup>

Glauston Roberto Teixeira de Lima<sup>c</sup>

Demerval Aparecido Gonçalves<sup>d</sup>

<sup>a</sup>*Doutor em Sociologia, pesquisador no Cemaden, São José dos Campos, SP, Brasil  
End. Eletrônico: victor.marchezini@cemaden.gov.br*

<sup>b</sup>*Doutorando do Programa de Pós-Graduação em Desastres, Instituto de Ciência e Tecnologia,  
Universidade Estadual Paulista, São José dos Campos, SP, Brasil  
End. Eletrônico: adriano.mota@unesp.br*

<sup>c</sup>*Doutor em Engenharia Eletrônica e Computação, pesquisador no Cemaden,  
São José dos Campos, SP, Brasil  
End. Eletrônico: glauston.lima@cemaden.gov.br*

<sup>d</sup>*Mestre em Engenharia de Infraestrutura Aeronáutica, pesquisador no Cemaden,  
São José dos Campos, SP, Brasil  
End. Eletrônico: demerval.goncalves@cemaden.gov.br*

doi:10.18472/SustDeb.v11n2.2020.31268

Received: 30/04/2020  
Accepted: 22/07/2020

ARTICLE- VARIA

## RESUMO

As políticas públicas de auxílio financeiro para ações de resposta a desastres são um tema pouco estudado. Neste artigo analisaram-se informações extraídas das bases de dados dos decretos de Situação de Emergência e Estado de Calamidade Pública e dos custos de socorro e resposta a desastres no Brasil, no período 2013-2017, a partir de suas distribuições espaço-temporal. Os custos de socorro e resposta a desastres são também utilizados em uma análise cruzada com indicadores municipais, como o Índice de Desenvolvimento Humano (IDHM) e o Produto Interno Bruto (PIB) *per capita*. Identificou-se que os gastos excederam R\$ 800 milhões. As defesas civis estaduais responderam pela maior parte dos recursos utilizados (76,4%). Em um universo de 564 municípios que utilizaram o auxílio financeiro via Cartão de Pagamento de Defesa Civil, constatou-se a concentração de 40% dos recursos em 30 defesas civis municipais, algumas das quais em municípios com alto IDHM e PIB *per capita*.

**Palavras-chave:** Desastres. Defesa civil. Gastos públicos. Desenvolvimento.

## ABSTRACT

Public financial aid policies for disaster response actions are a poorly studied topic. This article analyzed information extracted from the databases of the State of Emergency and State of Public Calamity decrees and the costs of disaster relief and response in Brazil, in the period 2013-2017, based on its spatial-temporal distributions. Disaster relief and response costs are also used in a cross-analysis with municipal indicators such as the Human Development Index (HDI) and the per capita Gross Domestic Product (GDP). It was identified that spending exceeded R\$ 800 million. State civil defenses accounted for most of the resources used (76.4%). In a universe of 564 municipalities that used financial assistance via the Civil Defense Payment Card, a concentration of 40% of resources was found in 30 municipal civil defenses, some of which in municipalities with high HDI and GDP per capita.

**Keywords:** Disasters. Civil defense. Public spending. Development.

## 1 INTRODUÇÃO

Os danos econômicos em desastres ocorridos no período 1998-2017 foram estimados em US\$ 2,9 bilhões, 68% maior que as perdas reportadas no período 1978-1997 (WALLEMACQ; HOUSE, 2018). Esses impactos de desastres acarretaram sérios obstáculos ao crescimento econômico, que é mensurado pela mudança percentual na atividade econômica medida por meio do Produto Interno Bruto (PIB). Alguns países tiveram perdas anuais que representaram uma porcentagem significativa do PIB, como Haiti (17,5%), Honduras (7%) e El Salvador (4,2%) (WALLEMACQ; HOUSE, 2018). Além dos impactos no crescimento econômico (no PIB), os desastres acarretam efeitos nas políticas de desenvolvimento. O conceito de desenvolvimento é mais amplo que o de crescimento econômico, pois considera a forma como a riqueza está distribuída socialmente, como a cidadania é exercida, como as condições de vida e dignidade e o acesso a um ambiente sadio são garantidos (CARVALHO, 2002). Um indicador de desenvolvimento é o Índice de Desenvolvimento Humano (IDH), que congrega educação, saúde e renda. O IDH oferece um contraponto ao PIB *per capita*, que considera apenas a dimensão econômica do desenvolvimento (PNUD, 2020).

Há um crescente reconhecimento por parte dos organismos multilaterais que os desastres têm acarretado perdas não só ao crescimento econômico, como também ao desenvolvimento. O *Human Development Report 2019* aponta que os países em desenvolvimento têm sofrido, em média, um percentual de redução do IDH maior que os países desenvolvidos ao enfrentarem situações de desastres (UNDP, 2019). O referido relatório também aponta que países em desenvolvimento têm menos recursos para prevenir e responder a desastres, bem como para implementar políticas públicas de mitigação e/ou redução de riscos de desastres, sejam elas de natureza estrutural – construção e manutenção de infraestruturas, planejamento urbano – e não estrutural – desenvolvimento de planos de contingência, ações educativas, realização de simulados, etc.

O *Global Assessment Report 2015* aponta a necessidade de não somente reconhecer que desastres são obstáculos ao desenvolvimento, como também salienta que é preciso compreender os desastres como problemas mal resolvidos de desenvolvimento (UNISDR, 2015). Isto é, torna-se necessário incorporar a gestão de risco de desastre como um componente fundamental dos modelos de desenvolvimento a serem adotados. O risco de desastre é um produto que decorre da combinação entre ameaça(s), vulnerabilidade, capacidade de proteção e políticas públicas de mitigação (WISNER et al., 2012).

As ameaças são os fenômenos que podem contribuir para deflagrar um provável dano. A vulnerabilidade é conceituada como o potencial de sofrer perdas e danos diante da(s) ameaça(s) e de se recuperar após sua ocorrência. Para além da pobreza econômica, a vulnerabilidade considera outras dimensões de privação, como falta de capacidade física, insegurança, isolamento social e falta de poder político (CHAMBERS, 1989), e possui várias tipologias, como a vulnerabilidade institucional, que se caracteriza pela obsolescência e rigidez das instituições, e prevalência de decisões políticas sobre critérios técnico-científicos, etc. (WILCHES-CHAUX, 1993).

As capacidades de proteção diante dessas ameaças e as políticas públicas de mitigação, como exemplificadas anteriormente, são importantes componentes para diminuição de impactos, isto é, para reduzir os riscos de desastres. Com os impactos crescentes de desastres, diferentes países têm adotado arranjos de governança de riscos de desastres. Por governança no contexto de riscos e desastres se compreende o processo de definição de competências e coordenação de organizações, de atores públicos e privados, leis, regulamentos e normas com objetivo de reduzir os riscos de desastres e seus impactos (TIERNEY, 2012).

Um dos importantes componentes da governança são as políticas de financiamento para gestão de riscos de desastres (GRD). Ao examinarem os programas de financiamento para GRD, Kellet, Caravani e Pichon (2014) identificaram abordagens bem heterogêneas e ressaltaram que nem sempre o maior problema é a falta de recursos financeiros, mas, sim, a falta de coordenação entre os diferentes níveis de governo, de mecanismos para financiamento por parte dos municípios, de transparência e prestação de contas.

As análises científicas sobre as políticas de financiamento em GRD ainda são escassas na literatura científica, sobretudo no contexto latino-americano (KELLET; CARAVANI; PICHON, 2014). Entre os países da América Latina e Caribe, o Brasil apresenta um histórico de desastres recentes com impactos significativos, como o desastre relacionado a inundações e deslizamentos em novembro de 2008, em Santa Catarina, com perdas e danos estimados em R\$ 5.32 bilhões (BANCO MUNDIAL, 2012a); as inundações de junho de 2010 em Pernambuco, com perdas e danos da ordem de R\$ 3.4 bilhões (BANCO MUNDIAL, 2012b); e a catástrofe na Região Serrana do Rio de Janeiro, quando mais de 900 pessoas faleceram em inundações e deslizamentos ocorridos em janeiro de 2011 e cerca de R\$ 4.78 bilhões de prejuízos foram contabilizados (BANCO MUNDIAL, 2012c).

Esses desastres catalisaram investimentos por parte do governo brasileiro. Marchezini et al. (2017) consideram que a tendência de aumento da porcentagem do PIB nacional investido em GRD acompanha a lógica mundial. Em 2006, a porcentagem do PIB investida era de somente 0,0009%. Em 2009, um ano após o desastre em Santa Catarina, a porcentagem aumentou para 0,02% do PIB.

Em 2010, a porcentagem aumentou para 0,04% do PIB, o maior nível do período analisado. Com a catástrofe no Rio de Janeiro em 2011, a porcentagem do PIB investida em GRD sofreu aumentos sucessivos nos dois anos subsequentes (0,015% do PIB em 2012 e 0,023% do PIB em 2013), reduzindo-se novamente no ano de 2014 (0,011% do PIB).

No âmbito de recursos financeiros em GRD também se incluem aqueles para resposta a desastres, um tópico com poucas análises científicas (KELLET; CARAVANI; PICHON, 2014). Este artigo objetiva analisar a política pública de auxílio-financeiro para ações de resposta a desastres no período de 2013 a 2017, quando se implementa o Cartão de Pagamento de Defesa Civil (CPDC). O CPDC é uma forma de transferência de recursos no âmbito do Sistema Nacional de Proteção e Defesa Civil (Sinpdec).

A organização do Sinpdec é apresentada brevemente na segunda seção deste artigo, destacando os principais instrumentos de gestão que se relacionam ao auxílio-financeiro para ações de resposta: i) a Codificação Brasileira de Desastres; ii) o Formulário de Informações sobre Desastres; iii) a declaração de Situação de Emergência (SE) e o Estado de Calamidade Pública (ECP); e iv) o Cartão de Pagamento da Defesa Civil (CPDC). Desses quatro elementos, serão analisados dois: a) as declarações de SE e ECP; e b) os gastos do auxílio-financeiro para ações de resposta por meio do CPDC. Após essa caracterização, na terceira seção descrevem-se o método e os dados utilizados.

Em seguida, na quarta seção, apresentam-se estatísticas básicas e a distribuição espaço-temporal dos desastres e da utilização do CPDC pelos estados e municípios no período 2013-2017. Ainda na quarta seção, a partir de uma amostra dos 30 municípios que tiveram gastos superiores a R\$ 1 milhão no CPDC, faz-se uma análise de correlação entre o perfil de gastos com o CPDC desses municípios e outros indicadores municipais: o IDHM – como um indicador de desenvolvimento – e o PIB *per capita* – como um indicador de crescimento econômico. Esses resultados do caso brasileiro são discutidos, na quinta seção, tendo-se por base trabalhos científicos que abordaram políticas de financiamento

e auxílio-financeiro em ações de resposta a desastres em outros países. Por fim, nas conclusões e recomendações, apresentam-se sugestões de aperfeiçoamento da política pública a partir dos dados apresentados na análise.

## 2 O SISTEMA NACIONAL DE PROTEÇÃO E DEFESA CIVIL

A Secretaria Nacional de Defesa Civil – Sedec (CASTRO et al., 2004) considera as atividades de defesa civil como um “conjunto de ações preventivas, de socorro, assistenciais e reconstrutivas destinadas a evitar ou minimizar os desastres, preservar o moral da população e restabelecer a normalidade social”.

De acordo com esse órgão gestor federal (BRASIL, 2017), as ações de prevenção se referem a medidas de planejamento da ocupação do espaço geográfico e à execução de obras e serviços em áreas consideradas de risco. Já as ações de resposta compreendem atividades de socorro, restabelecimento de serviços essenciais e assistência aos atingidos, isto é, medidas emergenciais que objetivam o atendimento à população (BRASIL, 2017).

Por fim, as ações de recuperação e reconstrução são definidas como as atividades desenvolvidas “após as operações de resposta ao desastre e destinadas a recuperar a infraestrutura e a restabelecer, em sua plenitude, os serviços públicos, a economia da área, o moral social e o bem-estar da população” (CASTRO et al., 2004).

As ações de defesa civil se organizam sob a forma de um Sistema Nacional de Proteção e Defesa Civil (Sinpdec), composto por: órgão consultivo (Conselho Nacional de Proteção e Defesa Civil); órgão central (Sedec), órgãos estaduais e do Distrito Federal e, por vezes, coordenadorias regionais nesses estados; órgãos municipais de proteção e defesa civil; e, por fim, órgãos setoriais, dos três âmbitos de governo. Destaca-se ainda que compete ao Sinpdec a implementação da Política Nacional de Proteção e Defesa Civil – PNPDEC e que ele poderá mobilizar a sociedade civil para atuar em situação de desastre, coordenando o apoio logístico para o desenvolvimento das ações de proteção e defesa civil (BRASIL, 2017).

Um dos elementos orientadores das atividades de defesa civil é a tipologia de ameaças e desastres. Com a catástrofe de 2011 e a adoção da PNPDEC, a Sedec adota a Classificação Brasileira de Desastres (Cobrade) que é “correspondente à classificação dos desastres constante do Banco de Dados Internacional de Desastres (EM-DAT)” (BRASIL, 2017, p. 30). A Cobrade possui duas amplas categorias de ameaças: 1) natural; e 2) tecnológica.

A categoria natural abrange cinco grupos de ameaças, alguns divididos em subgrupos (BRASIL, 2017): i) geológico (terremoto, emanção vulcânica, erosão e movimento de massa, tais como deslizamentos); ii) hidrológico (inundações, enxurradas e alagamentos); iii) meteorológico (ciclones, ondas de calor, etc.); iv) climatológico (seca); e v) biológico (epidemias e infestações/pragas).

A categoria tecnológica contempla outros cinco grupos de ameaças: i) desastres relacionados a substâncias radioativas; ii) desastres relacionados a produtos perigosos; iii) desastres relacionados a incêndios urbanos; iv) desastres relacionados a obras civis; e v) desastres relacionados a transporte de passageiros e cargas não perigosas (BRASIL, 2017).

Diante de um desastre ocorrido no município, a Defesa Civil deve escolher um único tipo de desastre na Cobrade e preencher o Formulário de Informações sobre Desastres (Fide) para avaliar os danos.

O preenchimento do Fide é orientado por manuais (BRASIL, 2017) e deve ocorrer de forma *on-line* por meio do Sistema Integrado de Informações sobre Desastres (S2ID), um dos requisitos para o pedido de reconhecimento de Situação de Emergência (SE) ou Estado de Calamidade Pública (ECP).



## 2.1 OS PROCEDIMENTOS DE DECRETAÇÃO DE SE E ECP

No Brasil, um dos mecanismos de gestão de desastres é a declaração de SE ou ECP. SE é o “reconhecimento (legal) pelo poder público de situação anormal, provocada por desastres, causando danos superáveis (suportáveis) pela comunidade afetada”. Já o ECP é o “reconhecimento (legal) pelo poder público de situação anormal, provocada por desastres, causando sérios danos à comunidade afetada, inclusive à incolumidade ou à vida de seus integrantes” (BRASIL, 2007, p. 8).

No arcabouço jurídico, o prazo de vigência do decreto de SE ou ECP “varia entre 30, 60 e 90 dias, o qual poderá ser prorrogado até completar 180 dias” (BRASIL, 2007, p. 24).

O processo de decretação de SE ou ECP pelos municípios, estados e pelo Distrito Federal é regido por procedimentos e critérios estabelecidos na Instrução Normativa nº 02, de 20 de dezembro de 2016 (BRASIL, 2016). Essa Instrução Normativa estabelece alguns conceitos para orientar a operacionalização da política, como as definições de dano, prejuízo, desastre, resposta e recursos:

- **DANO:** resultado das perdas humanas, materiais ou ambientais infligidas às pessoas, comunidades, instituições, instalações e aos ecossistemas, como consequência de um desastre.
- **PREJUÍZO:** medida de perda relacionada com o valor econômico, social e patrimonial de um determinado bem, em circunstâncias de desastre.
- **DESASTRE:** resultado de eventos adversos, naturais, tecnológicos ou de origem antrópica, sobre um cenário vulnerável exposto a ameaça, causando danos humanos, materiais ou ambientais e consequentes prejuízos econômicos e sociais.
- **RESPOSTA:** medidas emergenciais, realizadas durante ou após o desastre, que visam ao socorro e à assistência da população atingida e ao retorno dos serviços essenciais.
- **RECURSOS:** conjunto de bens materiais, humanos, institucionais e financeiros utilizáveis em caso de desastre e necessários para o restabelecimento da normalidade.

O critério principal para a decretação é a intensidade do desastre. A Instrução Normativa estabelece que “desastres de nível I e II ensejam a decretação de SE, enquanto os desastres de nível III a de ECP” (BRASIL, 2016). A Tabela 1 compila as definições desses três níveis que orientam a decretação.

**Tabela 1 | Níveis de intensidade de desastre definidos pelo Sinpdec.**

| <i>Intensidade do desastre</i> | <i>Definição</i>   |
|--------------------------------|--|
| NÍVEL I                        | São desastres de nível I aqueles em que há somente danos humanos consideráveis e que a situação de normalidade pode ser restabelecida com os recursos mobilizados em nível local ou complementados com o aporte de recursos estaduais e federais (Art. 2º § 1º)  |
| NÍVEL II                       | Caracterizados pela ocorrência de ao menos dois danos, sendo um deles obrigatoriamente danos humanos que importem no prejuízo econômico público ou no prejuízo econômico privado que afetem a capacidade do poder público local em responder e gerenciar a crise instalada (Art. 3º)                         |
| NÍVEL III                      | Caracterizados pela concomitância na existência de óbitos, isolamento de população, interrupção de serviços essenciais, interdição ou destruição de unidades habitacionais, danificação ou destruição de instalações públicas prestadoras de serviços essenciais e obras de infraestrutura pública (Art. 4º) |

*Fonte: Brasil (2016).*

A comprovação da ocorrência desses critérios é solicitada mediante formulários, entre os quais se destaca o Fide, documentos técnicos e registros audiovisuais que auxiliem na compreensão dos danos (BRASIL, 2017). O conjunto dessa documentação é enviado eletronicamente através do S2ID. Registrada

a ocorrência de um evento que provoque danos enquadrados nos níveis de intensidade explicitados na Tabela 1, caberá ao município, ou ao estado, enviar as informações pelo S2ID no prazo estipulado pela Instrução Normativa, em geral, de 15 a 20 dias, período que varia conforme o tipo de desastre (“súbitos, graduais ou de evolução crônica”).

Após a análise da documentação, o ente federal – a Sedec – poderá reconhecer ou não o pedido de decretação de SE e ECP. A homologação do reconhecimento federal permitirá ao município solicitar recursos federais para a execução de ações de resposta e recuperação. A utilização desses recursos para resposta se dará mediante o Cartão de Pagamento de Defesa Civil.

## 2.2 CARTÃO DE PAGAMENTO DA DEFESA CIVIL

O CPDC é o meio exclusivo para a execução dos recursos federais para ações de socorro, assistência aos atingidos e restabelecimento de serviços essenciais (BRASIL, 2017). Foi concebido para cumprir dois principais objetivos: i) “acelerar o repasse de recursos a municípios e estados [...]”; e ii) “conferir transparência e controle social na utilização desses recursos” (BRASIL, 2017, p.68). O CPDC é uma forma de pagamento que se ampara em instrumentos legais (BRASIL, 2017) que exigem, por parte das Defesas Civas, conhecimento técnico, jurídico e tributário.

Para utilizar os recursos, as Defesas Civas precisam adquirir o CPDC, no Banco do Brasil, antes da declaração de SE ou ECP. Sem a adesão ao CPDC, mesmo com a SE ou ECP reconhecido, o ente não estará apto a receber recursos federais para ações de socorro, assistência às vítimas e restabelecimento de serviços essenciais (BRASIL, 2017).

Uma questão importante sobre mecanismos de gestão de desastres refere-se às definições sobre o que consistem as ações de socorro, assistência e restabelecimento de serviços essenciais. As definições são importantes diretrizes para o uso do CPDC. O Decreto Federal nº 7.257, de 4 de agosto de 2010, estabelece essas definições:

**AÇÕES DE SOCORRO:** são “ações imediatas de resposta aos desastres com o objetivo de socorrer a população atingida, incluindo a busca e o salvamento, os primeiros socorros, o atendimento pré-hospitalar e o atendimento médico e cirúrgico de urgência [...]”.

**AÇÕES DE ASSISTÊNCIA ÀS VÍTIMAS:** “ações imediatas destinadas a garantir condições de incolumidade e cidadania aos atingidos, incluindo o fornecimento de água potável, a provisão e meios de preparação de alimentos, o suprimento de material de abrigo, de vestuário, de limpeza e de higiene pessoal, a instalação de lavanderias, banheiros, o apoio logístico às equipes empenhadas no desenvolvimento dessas ações, à atenção integral à saúde, ao manejo de mortos [...]”

**AÇÕES DE RESTABELECIMENTO DE SERVIÇOS ESSENCIAIS:** “ações de caráter emergencial destinadas ao restabelecimento das condições de segurança e habitabilidade da área atingida pelo desastre, incluindo a desmontagem de edificações e de obras de arte com estruturas comprometidas, o suprimento e distribuição de energia elétrica, água potável, esgotamento sanitário, limpeza urbana, drenagem das águas pluviais, transporte coletivo, trafegabilidade, comunicações, abastecimento de água potável e desobstrução e remoção de escombros [...]”.

A solicitação desses recursos por meio do CPDC demanda preparo técnico das Defesas Civas – municipais ou estaduais – não só para conhecer essas definições, como também para formular um Plano Detalhado de Resposta (PDR) e submetê-lo à Sedec.

O PDR exige que municípios ou estados adicionem informações sobre o número de danos humanos, as ações de resposta em andamento por parte do município, os itens que são necessários, quantidade

requisitada, valor unitário, justificativa da necessidade de cada um dos recursos solicitados, entre outras informações que demandam capacidade técnica para serem repassadas de forma consistente, ao mesmo tempo em que as equipes municipais precisam responder ao desastre.

A partir dessa contextualização sobre o Sinpdec no tocante a ações de resposta e alguns de seus principais instrumentos de gestão – a decretação de SE ou ECP e o CPDC –, detalhar-se-á o método utilizado para se obter as distribuições espaço-temporais das SE/ECP e dos custos com o CPDC e, a partir das distribuições, analisar esses dois tipos de dados.

### 3 MÉTODO

Neste artigo foram considerados para análise os anos de 2013 a 2017, pois é nesse período que estão disponíveis as duas bases de dados: i) as declarações de SE e ECP; e ii) os dados do Cartão de Pagamento da Defesa Civil (CPDC).

Os dados referentes a declarações de SE e ECP foram obtidos no site do S2ID (<https://s2id.mi.gov.br/paginas/>) e contém informações como o nome do município, o tipo de ameaça segundo a tipologia da Cobrade, a data do decreto de SE ou ECP e a data da publicação da portaria no Diário Oficial da União. Os dados do CPDC foram extraídos do Portal da Transparência do Governo Federal.

De forma resumida, a Tabela 2 apresenta os atributos dos dados obtidos dos dois diferentes portais consultados, como mencionado.

**Tabela 2 | Atributos dos dados obtidos no S2ID e no Portal da Transparência**

| Atributos                                |                                |                      |
|--|--------------------------------|----------------------|
| Declarações de SE ou ECP (S2ID)          | CPDC (Portal da Transparência) |                      |
| UF                                       | Código órgão superior          | Executor despesa     |
| Geocódigo                                | Nome órgão superior            | Número convênio      |
| Município                                | Código órgão                   | Código conveniente   |
| Decreto                                  | Nome do órgão                  | Nome do conveniente* |
| Datadec (data do decreto)                | Código unidade gestora         | Repasse              |
| Desastre                                 | Nome unidade gestora           | Transação            |
| SE ou ECP                                | Ano do extrato                 | Data da transação    |
| Portaria                                 | Mês do extrato                 | Valor da transação   |
| Diário Oficial da União (DOU)            | CPF do portador                |                      |
| Número no Diário Oficial da União (NDOU) | Nome do portador               |                      |
| Data do Diário Oficial da União (DtDOU)  | CNPJ ou CPF do favorecido**    |                      |
| Rito                                     | Nome do favorecido             |                      |

\*É o beneficiário do CPDC, o órgão municipal ou estadual.

\*\*É o fornecedor do produto ou prestador de serviço que receberá o pagamento.

*Fonte: Elaborada pelos autores*

Nos dados do S2ID, foram encontrados e corrigidos dois tipos de erros: um em que o atributo “geocódigo” não condizia com o nome do município e outro em que o nome do município não era grafado conforme o que consta na base do IBGE.

Além disso, a tipologia do desastre (atributo desastre) não especifica exatamente o evento e, em muitos casos, os agrupa, não adota uma terminologia padronizada e refere-se à mesma tipologia utilizando diferentes expressões. Em relação ao Portal da Transparência, citam-se duas limitações nos registros:

primeiramente, grande parte do conveniente é o estado e não os municípios, tornando-se assim inviável a delimitação da área a qual sofreu desastres; no Portal da Transparência não está descrita a tipologia do desastre, ou quaisquer detalhamentos em torno da causa que culminou na necessidade de utilização dos recursos do CPDC.

Realizados os ajustes necessários, os dados foram incluídos em ambiente SIG (Sistema de Informação Geográfica) com o intuito de realizar a distribuição espacial dos dados referentes às declarações de SE e ECP, considerando-se os seguintes critérios:

1. o número de municípios declarantes por ano, que indica o número de municípios com desastres reconhecidos pela Sedec;
2. o número de SE ou ECP por ano, que indica o número de desastres reconhecidos pela Sedec;
3. a frequência de declarações por município, ou seja, a frequência de desastres por município;
4. o número de SE ou ECP por tipo de evento, isto é, por tipo de desastre segundo a tipologia da Cobrade.

O passo seguinte consistiu em uma prospecção na base de dados referente à utilização do CPDC. Nessa etapa, os dados foram analisados visando-se obter:

1. a distribuição dos gastos totais com o CPDC por ano, que explicitam os auxílios-financeiros federais para ações de socorro e resposta a desastres;
2. o valor total em todo o período e também por ano dos recursos do CPDC que os estados utilizaram para ações de resposta nos municípios;
3. o número de municípios que utilizaram o CPDC;
4. um *ranking* dos 30 municípios com maior utilização de CPDC cujos dados foram correlacionados com outros indicadores municipais que expressam seu nível de desenvolvimento (Índice de Desenvolvimento Humano Municipal – IDHM), obtido em Pnud (2013) e econômico (Produto Interno Bruto *per capita*), obtido em IBGE (2017).

Uma vez que as bases de dados das declarações de SE e ECP e dos gastos com CPDC não estavam associados, não foi possível discriminar os gastos do CPDC pelos tipos de eventos que constam nas declarações.

## 4 RESULTADOS

Nesta seção são apresentadas, para o período 2013-2017, algumas estatísticas e os mapas das distribuições espaço-temporais derivadas das bases de dados de declarações de SE e ECP e de gastos com o CPDC descritos na seção 3.

### 4.1 ESTATÍSTICAS REFERENTES ÀS DECLARAÇÕES DE SE E ECP

Dos 5.570 municípios existentes no Brasil, 3.057 municípios (54,88%) declararam, ao menos uma vez, SE ou ECP em virtude de desastres no período 2013-2017 – uma média de 1.746 municípios ao ano (31,34% dos existentes no Brasil).

Foram 13.894 desastres reconhecidos pela Sedec, uma média de 2.778 ao ano. No período foram 51 desastres considerados como ECP, ou seja, classificados como a categoria máxima de intensidade – nível III.

As estiagens e secas respondem por 81,78% desses registros e têm sido frequentes, principalmente na Região Nordeste. Inundações, enxurradas e alagamentos são o segundo em maior porcentagem de registros (9,37%) e distribuem-se nas regiões Sul (58,91%), Norte (19,05%) e Sudeste (11,9%). A Tabela 3 mostra um sumário de estatísticas sobre as declarações de SE e ECP no período analisado.

**Tabela 3 | Estatísticas das distribuições espaço-temporais das declarações SE-ECP**

| <i>Nº de municípios que declararam SE ou ECP pelo menos uma vez</i>                  |   | 3057*                                      |                     |                                     |                |                   |
|--|---|--|---------------------|-------------------------------------|----------------|-------------------|
| <i>Nº total de declarações</i>   |   | <i>Nº de declarações de SE</i>             |                     | <i>Nº de declarações de ECP</i>     |                |                   |
| 13894  |   | 13843                                      |                     | 51                                  |                |                   |
| <i>Nº de declarações e de municípios declarantes por ano</i>                         |   |  |                     |                                     |                |                   |
| <i>Ano</i>   | <i>Nº de declarações</i>                      |  |                     | <i>Nº de municípios declarantes</i> |                |                   |
| 2013   | 3747  |  |                     | 1938                                |                |                   |
| 2014   | 2666  |  |                     | 1886                                |                |                   |
| 2015   | 2511  |  |                     | 1592                                |                |                   |
| 2016   | 2072  |  |                     | 1450                                |                |                   |
| 2017   | 2898  |  |                     | 1864                                |                |                   |
| <i>Distribuição percentual do total de declarações por região</i>                    |   |  |                     |                                     |                |                   |
| <i>Norte (N)</i>   | <i>Nordeste (NE)</i>                          | <i>Centro-Oeste (CO)</i>                   | <i>Sudeste (SE)</i> |                                     | <i>Sul (S)</i> |                   |
| 2,41%  | 73,16%  | 1,38%                                      | 11,35%              |                                     | 11,69%         |                   |
| <i>Distribuição percentual da frequência de declarações</i>                          |   |  |                     |                                     |                |                   |
| <i>Faixas de Frequência</i>  | <i>Percentual do total de 3057 municípios</i> | <i>Percentual de municípios por região</i> |                     |                                     |                |                   |
|  |   | <i>N</i>                                   | <i>NE</i>           | <i>CO</i>                           | <i>SE</i>      | <i>S</i>          |
| 1 a 4  | 58,62%  | 8.15%                                      | 21.60%              | 7.31%                               | 19.03%         | 43.92%            |
| 5 a 7  | 12,82%  | 2.80%                                      | 71.94%              | 0.00%                               | 18.37%         | 6.89%             |
| 8 a 10   | 22,44%  | 0.00%                                      | 90.23%              | 0.00%                               | 9.62%          | 0.15%             |
| 11 a 12  | 6,12%   | 0.00%                                      | 98.93%              | 0.00%                               | 1.07%          | 0.00%             |
| <i>Distribuição percentual do total de declarações por tipo de ameaça</i>            |   |  |                     |                                     |                |                   |
| <i>Tipo de ameaça</i>  |   |  |                     |                                     |                | <i>Percentual</i> |
| Estiagens e secas (ES)   |   |  |                     |                                     |                | 81.78%            |
| Inundações, enxurradas e alagamentos (IEA)   |   |  |                     |                                     |                | 9.37%             |
| Tempestades locais convectivas e chuvas intensas (TLCCI)                             |   |  |                     |                                     |                | 5.30%             |
| Deslizamentos de massa (DM)  |   |  |                     |                                     |                | 0.17%             |
| Outros**   |   |  |                     |                                     |                | 3.38%             |
| <i>Distribuição percentual do total de declarações por tipo de ameaça por região</i> |   |  |                     |                                     |                |                   |
| <i>Ameaça</i>  | <i>Percentual de declarações por região</i>   |  |                     |                                     |                |                   |
|  | <i>N</i>                                      | <i>NE</i>                                  | <i>CO</i>           | <i>SE</i>                           | <i>S</i>       |                   |
| ES   | 0.54%   | 88.40%                                     | 0.10%               | 10.49%                              | 0.47%          |                   |
| IEA  | 19.05%  | 7.14%                                      | 3.00%               | 11.90%                              | 58.91%         |                   |
| TLCCI  | 0.81%   | 1.49%                                      | 16.96%              | 16.83%                              | 63.91%         |                   |
| DM   | 4.16%   | 16.67%                                     | 0.00%               | 41.67%                              | 37.50%         |                   |
| OUTROS   | 21.66%  | 2.12%                                      | 3.61%               | 64.12%                              | 8.49%          |                   |

\* Correspondente a 54,88% do total de 5.570 municípios no Brasil.

\*\* Desastres tecnológicos, biológicos, vendavais, tornados, ciclones, granizo, incêndios, erosões e corridas de massa.

*Fonte: Elaborada pelos autores, com base em dados do S2ID.*

## 4.2 DISTRIBUIÇÕES ESPAÇO-TEMPORAIS DAS DECLARAÇÕES DE SE E ECP

No período abordado, o Brasil registrou diversos desastres, como as inundações de 2012, 2014 e 2015 no Acre (AC); secas na Amazônia em 2015-2016; inundações e deslizamentos de terra na Região Sudeste, em especial nos estados de MG, ES, RJ em 2013; a catástrofe associada ao rompimento da barragem em Mariana-MG e a seca na região semiárida de 2012 a 2017.

A Figura 1 apresenta a distribuição espaço-temporal das declarações de desastres. A Região Nordeste responde por 73,16% dos desastres no período. Secas e estiagens respondem por mais da metade da média anual, sendo superiores a 1.500 notificações municipais por ano, especialmente na Região Nordeste e no norte do Estado de MG (Região Sudeste). Em 2013, houve 13 municípios que declararam SE quatro vezes, todos situados na Região Nordeste.

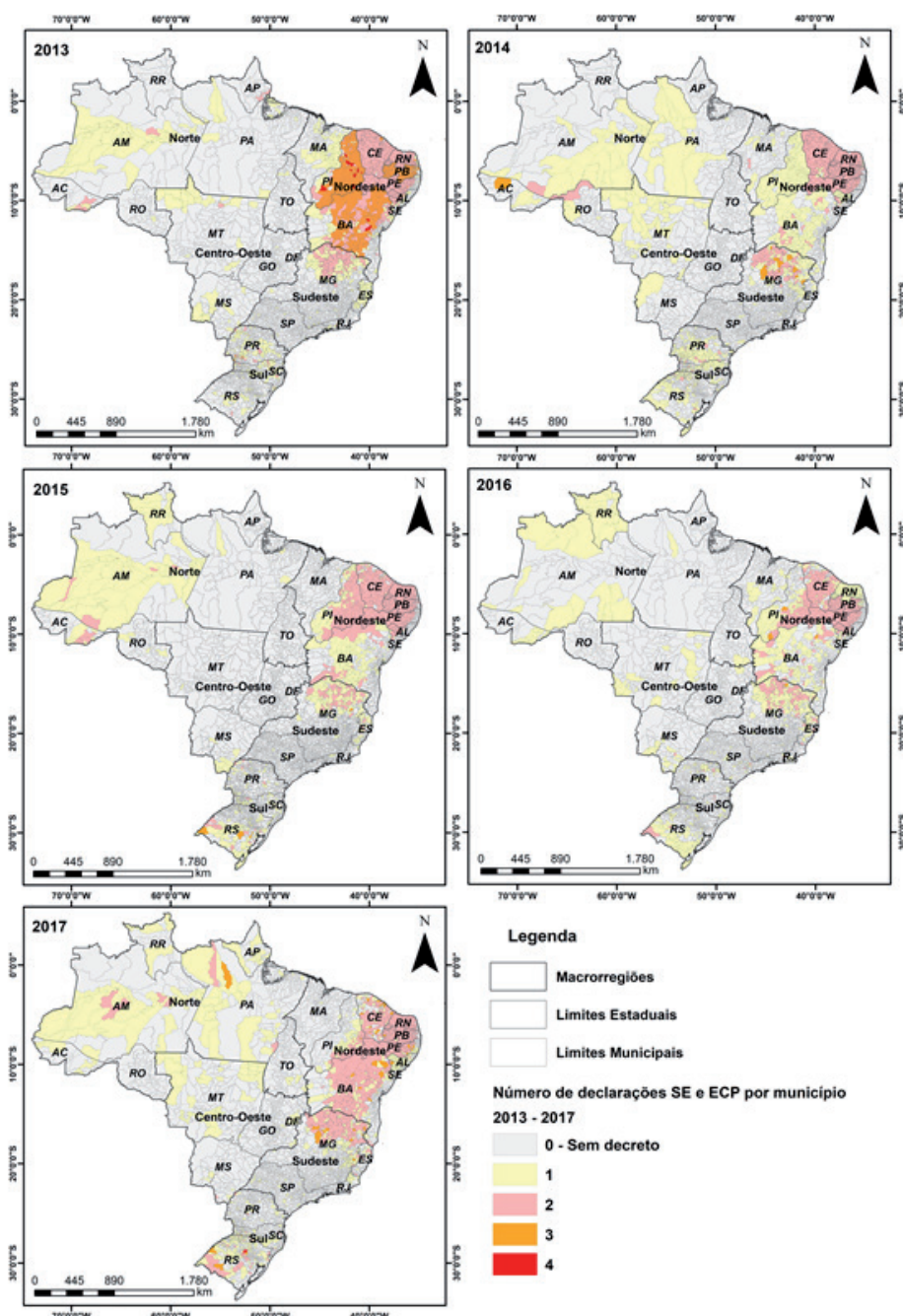


Figura 1 | Distribuição espaço-temporal de declarações SE-ECP no Brasil, período 2013-2017.

Fonte: Elaborada pelos autores, com base em dados do S2ID.

A Figura 2 apresenta o mapa da distribuição espacial da frequência de declarações para o período analisado e também um gráfico indicando o total de declarações feitas por cada estado em cada ano. Em 185 municípios da Região Nordeste (o que corresponde a 10,31% dos municípios da região), a frequência de declarações alcançou o intervalo entre 11 e 12 registros, uma média superior a duas declarações por ano.

A maior ocorrência foi no estado da Paraíba (PB), com 170 municípios, com destaque para São José de Piranhas, com 12 declarações.

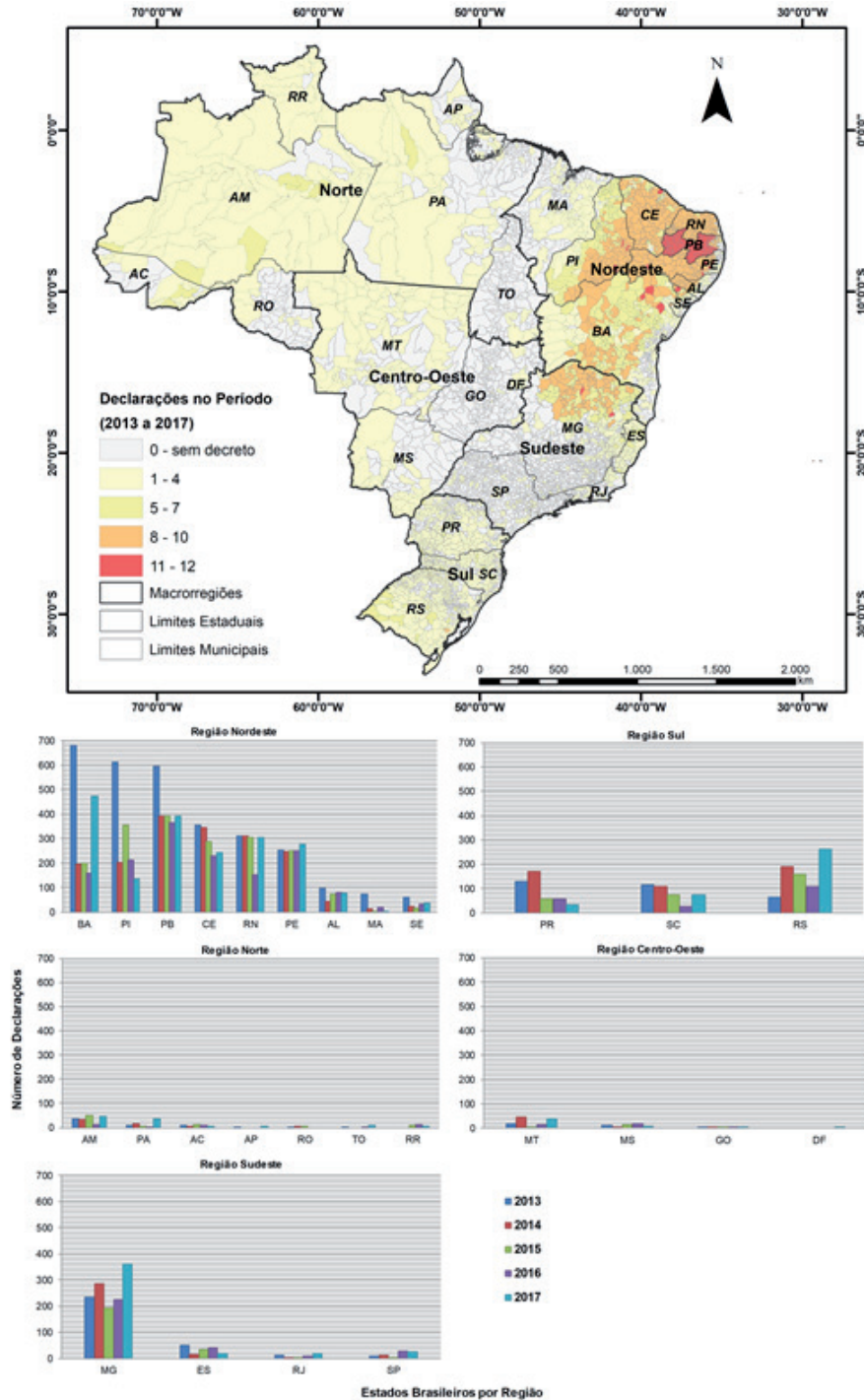


Figura 2 | Distribuição espaço-temporal da frequência de declarações de SE-ECP no Brasil, período 2013-2017, e gráfico de barras com o total de declarações dos estados em cada ano.

Fonte: Elaborada pelos autores, com base em dados do S2ID.

A maioria dos municípios que declararam SE-ECP em razão de inundações, enxurradas e/ou alagamentos o fez mais de uma vez ao ano, especialmente nas regiões Sul e Norte. Também há o cenário em que municípios vivenciaram múltiplas ameaças em um mesmo ano ou no decorrer do período, como o município de Rio Branco – AC, que no ano de 2013 declarou SE tanto por estiagem quanto por inundação. Ou ainda os municípios de Brasília e Etitaciolândia, ambos no AC, que declararam SE por estiagem e também por doenças infecciosas virais. A Figura 3 ilustra a distribuição temporal de SE e ECP por tipologia de ameaça.

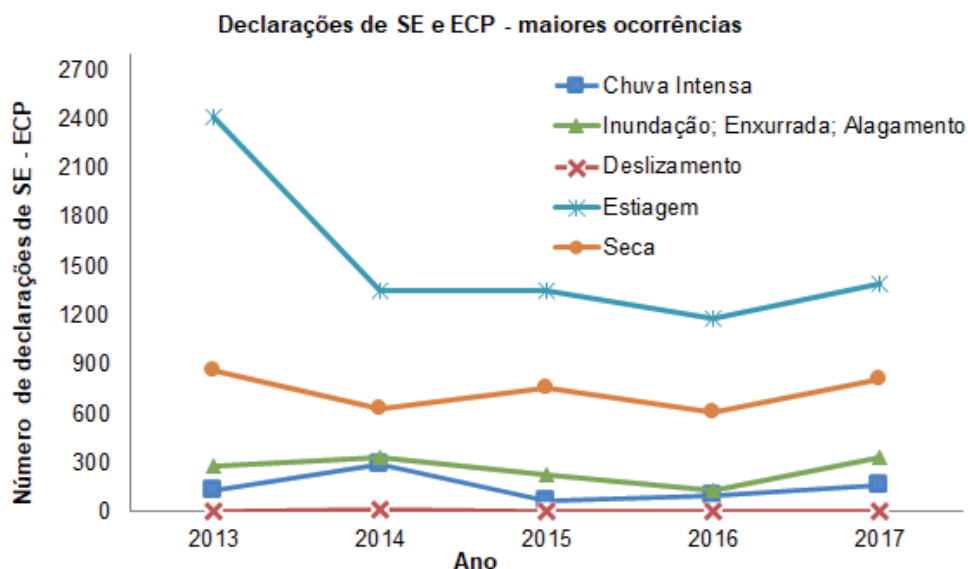


Figura 3 | Distribuição temporal de declarações SE-ECP por tipologia de ameaça no período 2013-2017.

Fonte: Elaborada pelos autores com base em dados do S2ID.

Um aspecto que chama atenção é a baixa quantidade de registro de SE e ECP em razão de deslizamentos, incêndios florestais, desastres tecnológicos e biológicos. Os desastres tecnológicos totalizaram 15 declarações, com maior ocorrência no ano de 2015, associados ao rompimento de barragens no estado de MG. Os desastres biológicos se concentraram em 2017 com 68 declarações, sendo 62 em municípios de MG, devido a doenças infecciosas virais.

#### 4.3 ESTATÍSTICAS REFERENTES AOS GASTOS COM O CPDC

Estados e municípios que decretam SE e ECP podem usar o CPDC. Em casos de desastres que atingem mais de um município – como é o caso daqueles relacionados às estiagens e secas –, as próprias Defesas Civis estaduais podem fazer uso do CPDC em prol dos municípios que tiveram a homologação de SE e ECP. Entretanto, por meio dos dados disponíveis no Portal da Transparência, não é possível discriminar em prol de quais municípios esses gastos foram realizados.

Do total de gastos com CPDC no período – aproximadamente R\$ 807,7 milhões –, 76,45% (R\$ 617,9 milhões) foram utilizados com a intermediação de 21 estados brasileiros e 23,55% (R\$189,7 milhões) diretamente por 564 municípios (Tabela 4). Entre os 21 estados, as nove primeiras posições foram ocupadas por aqueles da região Nordeste, com destaque para CE, PE, PI e AL, que responderam por pouco mais da metade dos recursos utilizados pelos estados.



A Tabela 4 mostra os gastos com o CPDC feitos com a intermediação dos estados e pelos municípios que dele fazem parte, juntamente com a quantidade de declarações de SE e ECP no período analisado. Ela está ordenada do maior para o menor gasto total com o CPDC no intuito de facilitar a percepção de que a magnitude desses gastos não tem uma relação direta com quantidade de declarações feitas pelo estado e seus municípios. O estado da Paraíba (PB), por exemplo, registrou o maior número de declarações de SE e ECP no período (2.142) e teve gastos totais com o CPDC que foram inferiores ao estado do Ceará (CE). Este registrou quase o mesmo número de declarações que PI, e seu gasto total com o CPDC foi 2,36 vezes maior.

**Tabela 4 | Gastos com o CPDC e total de declarações entre 2013 e 2017**

| UF     | Gastos CPDC pelo Estado | Gastos CPDC pelos Municípios | Gastos CPDC Total | Número de declarações SE + ECP |
|--------|-------------------------|------------------------------|-------------------|--------------------------------|
| CE     | 148.552.394,50          | 481.772,88                   | 149.034.167,38    | 1461                           |
| PB     | 49.917.265,79           | 54.198.609,20                | 104.115.874,99    | 2142                           |
| PE     | 78.943.909,35           | 2.091.464,87                 | 81.035.374,22     | 1279                           |
| PI     | 63.033.887,45           | 44.595,44                    | 63.078.482,89     | 1518                           |
| AL     | 57.074.976,28           | 1.285.363,18                 | 58.360.339,46     | 374                            |
| RN     | 48.963.360,96           | 8.716.256,73                 | 57.679.617,69     | 1389                           |
| BA     | 25.303.051,71           | 17.385.328,13                | 42.688.379,84     | 1711                           |
| MG     | 21.949.506,59           | 19.289.286,60                | 41.238.793,19     | 1299                           |
| AM     | 9.751.670,98            | 22.943.570,20                | 32.695.241,18     | 174                            |
| MA     | 30.781.129,27           | 0,00                         | 30.781.129,27     | 117                            |
| AC     | 14.731.789,83           | 9.353.631,03                 | 24.085.420,86     | 40                             |
| RJ     | 7.656.660,01            | 15.345.344,73                | 23.002.004,74     | 44                             |
| RS     | 13.835.699,28           | 6.338.159,53                 | 20.173.858,81     | 783                            |
| SE     | 19.606.816,26           | 0,00                         | 19.606.816,26     | 172                            |
| SC     | 5.231.898,86            | 12.830.828,75                | 18.062.727,61     | 395                            |
| RO     | 13.390.024,26           | 0,00                         | 13.390.024,26     | 13                             |
| PR     | 6.616.198,20            | 4.303.357,67                 | 10.919.555,87     | 446                            |
| SP     | 0,00                    | 5.880.513,93                 | 5.880.513,93      | 79                             |
| PA     | 860.642,00              | 2.735.692,49                 | 3.596.334,49      | 67                             |
| AP     | 237.116,97              | 2.956.682,00                 | 3.193.798,97      | 8                              |
| GO     | 0,00                    | 1.881.862,47                 | 1.881.862,47      | 13                             |
| MT     | 1.168.500,00            | 97.575,80                    | 1.266.075,80      | 121                            |
| ES     | 0,00                    | 960.806,00                   | 960.806,00        | 155                            |
| MS     | 0,00                    | 627.324,63                   | 627.324,63        | 57                             |
| RR     | 357.886,00              | 0,00                         | 357.886,00        | 25                             |
| DF     | 0,00                    | 0,00                         | 0,00              | 1                              |
| TO     | 0,00                    | 0,00                         | 0,00              | 11                             |
| TOTAIS | 617.964.384,55          | 189.748.026,26               | 807.712.410,81    | 13894                          |

Fonte: Elaborada pelos autores, com base em dados do Portal da Transparência e do S2ID.

A média de gastos com o CPDC por ano foi de aproximadamente R\$ 161,5 milhões, com destaque para o ano de 2014, com R\$ 270 milhões. É possível identificar que, na Região Nordeste, os estados costumam ser intermediadores no uso dos recursos do CPDC a serem aplicados nos municípios em SE e ECP – com exceção da PB, onde a utilização dos recursos do CPDC diretamente pelos municípios e com a intermediação do estado foi proporcional em termos da quantidade usada ao longo do período. Nas regiões Sul e Sudeste – com exceção dos estados de MG e RS –, identifica-se um cenário oposto, com os municípios acessando diretamente os recursos financeiros via CPDC.

#### 4.4 GASTOS COM O CPDC POR MUNICÍPIO

Dos 3.057 municípios que decretaram SE ou ECP, 18,45% deles (564) fizeram uso por si próprios dos recursos do CPDC.

Desses 564 municípios, 54,61% (308) concentram-se na Região Nordeste, principalmente na PB (184 municípios) e BA (118 municípios). A Região Sul é a segunda em número de municípios (133) utilizando o CPDC, sendo que 70 (61,95%) são de SC. A Região Sudeste tem 60 municípios utilizando o CPDC, a maioria (70%) em MG. Na Região Norte, o AM registrou 36 dos 59 municípios. A Figura 4 apresenta a distribuição espaço-temporal dos gastos com CPDC no período, por parte das Defesas Civas municipais.

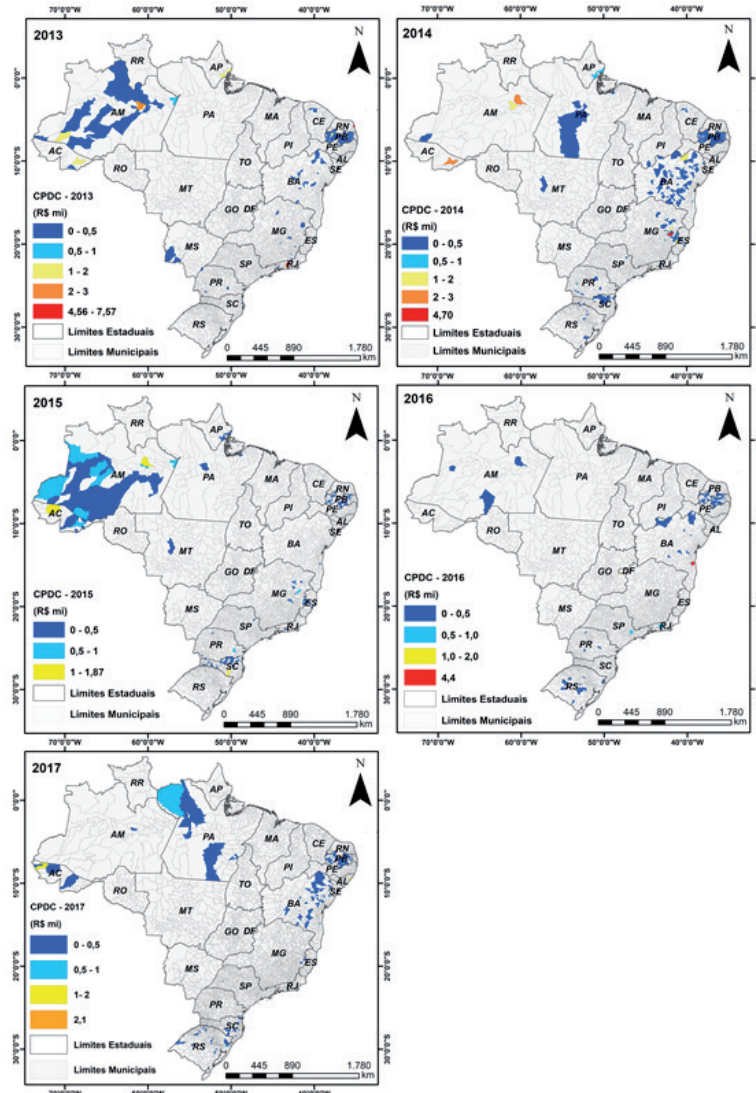


Figura 4 | Distribuição dos gastos com CPDC no período 2013 – 2017, por parte dos municípios.

Fonte: Elaborada pelos autores, com base nos dados do Portal da Transparência.

Dos R\$ 189,7 milhões utilizados pelos 564 municípios, 41% (R\$ 77,7 milhões) foram gastos por 30 deles. Mais da metade desses municípios (19) possuem IDHM Alto (acima de 0,700) (Figura 5). Dessa amostra, somente um município possuía baixo desenvolvimento (IDHM menor que 0,550), ou seja, grande parte dos recursos do CPDC não tem sido utilizada pelos municípios com valores mais baixos de IDHM. Todos os municípios que tiveram gastos com CPDC superiores a R\$ 4 milhões no período 2013-2017 possuíam IDHM superior a 0,700 (Figura 5).

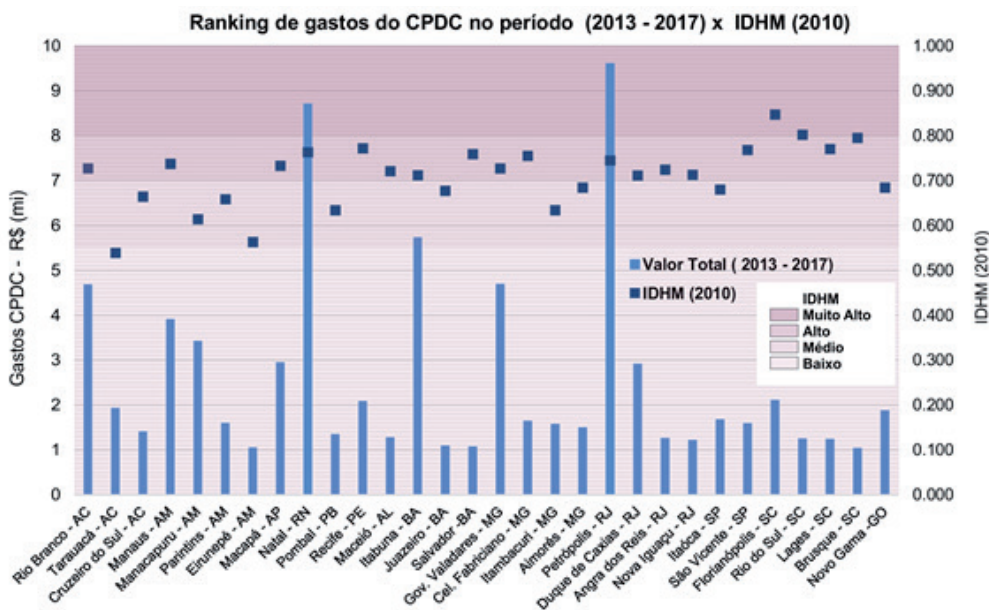
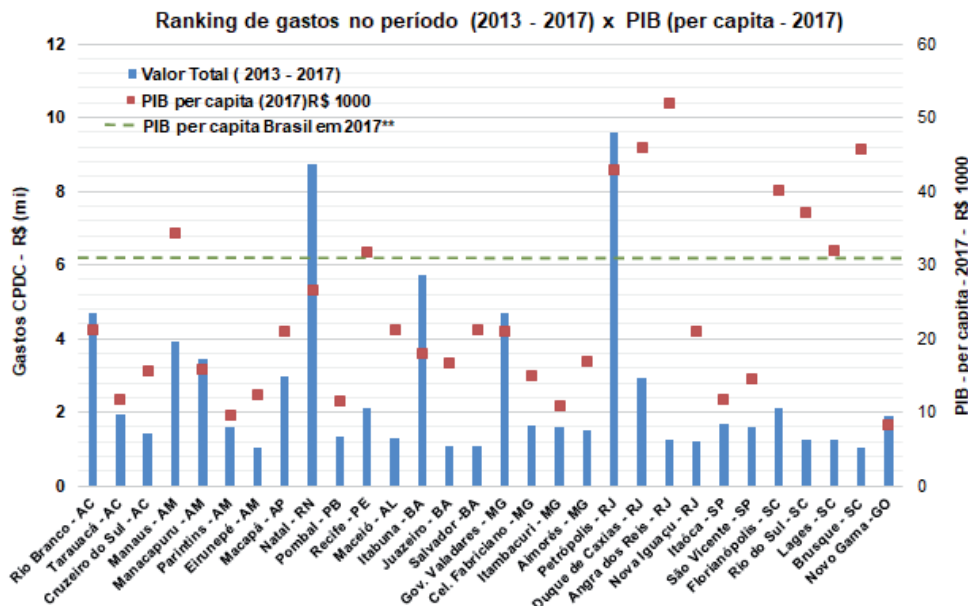


Figura 5 | Valores de CPDC R\$ (mi) e IDHM dos 30 municípios com maiores gastos no período.

Fonte: Elaborada pelos autores, com base em dados do Portal da Transparência e do Pnud (2013).

Por vezes, municípios apresentam valores semelhantes de IDHM, porém são desiguais em relação ao PIB *per capita* – um indicador de crescimento econômico. Os municípios de Macapá – AP e Duque de Caxias – RJ têm IDHM semelhantes, e os gastos com CPDC também foram similares, porém Duque de Caxias-RJ apresenta PIB *per capita* cerca de duas vezes maior que o PIB *per capita* de Macapá – AP.

Importante destacar que entre os 30 municípios dessa amostra, os dos estados de SC e RJ possuem PIB *per capita* maior que a média nacional, enquanto grande parte dos municípios das regiões Norte e Nordeste do País situam-se abaixo dela (Figura 6).



\*\* Valor do PIB *per capita* em 2017: R\$ 31.833,50.

Figura 6 | Valores de CPDC R\$ (mi) e renda *per capita* dos 30 municípios com maiores gastos no período.

Fonte: Elaborada pelos autores, com base em dados do Portal da Transparência e do IBGE (2017)

## 5 DISCUSSÃO

No âmbito da vulnerabilidade institucional a desastres, Valencio (2014) propôs analisar as decretações de SE e ECP como expressões de uma crise crônica no Brasil. Ao analisar 19.441 decretações de SE e ECP no período 2004-2013, a autora considera que o País vive uma espécie de pandemia de desastres (VALENCIO, 2014), com uma média anual de 25% de municípios em SE ou ECP. Ao analisarmos o período 2013-2017, encontramos um aumento nessa média: quase 32% dos municípios brasileiros em SE ou ECP por ano.

Para além da análise da distribuição espaço-temporal das declarações de SE e ECP (Figura 1), também é importante identificar os desdobramentos que o reconhecimento federal implica, como, por exemplo, solicitar acesso a auxílios-financeiros para ações de resposta a desastres.

Ao analisar a distribuição espaço-temporal dos gastos com o CPDC por parte dos estados e municípios, no período 2013-2017, foi possível identificar que na maioria dos estados da Região Nordeste e nos estados de MG e RS, o ente estadual costuma ser intermediador no uso do CPDC (Tabela 4). Essa intermediação do ente estadual se justifica pelo desastre atingir mais de um município e/ou pelo município atingido não possuir coordenadoria municipal de proteção e defesa civil?

Futuros estudos precisam analisar essas dimensões de governança e gestão no âmbito do Sinpdec. Sobre esse aspecto, é

relevante ressaltar o fato de que o dever imposto à União no sentido de repassar valores em casos de desastres abrange, inclusive, como beneficiários, os municípios que não cumpriram seus respectivos deveres legais de mapear áreas de risco, considerando tais estudos em seus planos diretores [...] e ações preventivas (CARVALHO, 2020, p.151).

Seria relevante também considerar em que medida os municípios dispõem de Defesa Civil com equipes e orçamento suficientes para realizar essas ações no âmbito da prevenção, resposta e recuperação ante os desastres.

Ademais, é importante analisar se indicadores poderiam ser utilizados para priorizar recursos do CPDC para aqueles municípios com menores IDHM e renda *per capita*, entendendo esses dois indicadores entre o conjunto de fatores que podem representar o desenvolvimento humano e riqueza econômica presentes nos municípios. Em nossa análise para os 30 municípios que mais utilizaram o CPDC no período, identificamos que grande parte deles (19) possui alto IDHM – principalmente aqueles situados na Região Sul do País. Ainda que o IDHM possa ser utilizado como um dos parâmetros para priorização de recursos do CPDC, é importante considerar as limitações do IDHM e de outros indicadores.

Vieira et al. (2020), por exemplo, identificaram uma melhoria nos valores do IDHM entre 2000 e 2010 para os municípios da região do semiárido brasileiro. Entretanto, ao analisarem os componentes que contribuíram para essa mudança, identificaram que os indicadores de saúde e educação geralmente apresentaram uma melhoria ao longo dos anos, enquanto os indicadores socioeconômicos permanecem baixos em alguns conjuntos de municípios, explicitando desigualdades intrarregionais, ou seja, em relação às secas na região do semiárido brasileiro, seria importante orientar as políticas públicas não pela variável climática em si, mas pelas condições de suscetibilidade ambiental e de vulnerabilidade social, econômica e institucional presentes nos municípios (VIEIRA et al., 2020).

O CPDC é considerado uma forma de acesso a um recurso complementar (BRASIL, 2017). As proporções de complementaridade do recurso deveriam ser as mesmas, independentemente das condições de desenvolvimento (IDHM) e de riqueza econômica (PIB *per capita*) dos municípios? A avaliação para liberação de recursos do CPDC tem sido balizada pela quantidade de danos e perdas reportada pelos municípios quando registram desastres ou pela capacidade financeira e de gestão que possuem para prover ações de socorro, assistência e restabelecimento de serviços? Os resultados deste artigo não permitem responder a essas perguntas, mas a análise exploratória sobre um tema pouco estudado no

País – a política pública de auxílio-financeiro em ações de resposta a desastres – ensejou algumas dessas perguntas que podem ter implicações sobre as formas de governança e de gestão de riscos de desastres.

A análise exploratória sobre essa política pública permite outros questionamentos. Em desastres com grande visibilidade nos meios de comunicação é comum que sejam feitas campanhas para arrecadação de doativos e de doações em dinheiro, como ocorrido no desastre no Vale do Itajaí/SC em 2008, quando cerca de R\$ 35 milhões foram doados em prol dos desabrigados. Em Ilhota/SC, as pessoas questionavam como os recursos financeiros doados para eles estavam sendo utilizados pelos órgãos públicos, tendo em vista que os sobreviventes não haviam sido consultados sobre como as doações em dinheiro, depositadas na conta bancária do ente estadual, deveriam ser utilizadas (MARCHEZINI, 2014).

A partir desse exemplo, poderia indagar-se: quais critérios adotar quando o uso complementar dos recursos do CPDC é concedido pela Sedec e, no decorrer da resposta à emergência, outras fontes de recursos – como doações em dinheiro – são direcionadas para os mesmos estados e municípios?

A transparência dos gastos em resposta a desastres tem sido identificada como um dos principais pontos positivos do CPDC (BRASIL, 2017). A transparência, a prestação de contas e a falta de articulação entre os níveis de governo e de capacidade local para investimento estão entre os principais desafios apontados por estudos que analisaram as políticas de financiamento para a GRD (KELLET; CARAVANI; PICHON, 2014).

Kellet, Caravani e Pichon (2014) ressaltaram que nem sempre o maior problema é a falta de recursos financeiros. A esse elemento de vulnerabilidade institucional se somam: i) a alta concentração de recursos no nível nacional; ii) a falta de alocação de fundos para o nível local; iii) de capacidade local para implementar ações de GRD; iv) de mecanismos de coordenação entre níveis de governo; v) de clareza na legislação; vi) de clareza nos papéis e responsabilidades de cada um dos órgãos governamentais; vii) de conhecimento sobre os procedimentos administrativos a fim de acessar os programas de financiamento e auxílio-financeiro; e viii) de dados sobre as atividades de GRD para as quais os fundos são alocados.

Diante desses desafios, Kellet, Caravani e Pichon (2014) recomendam melhorar a clareza e, por vezes, simplificar a legislação, bem como dar enfoque à descentralização de recursos para fomentar a GRD em âmbito local. No Brasil, a política pública de auxílio-financeiro para ações de resposta a desastres, via CPDC, possui procedimentos que demandam capacidade técnica e jurídica por parte das Defesas Civis municipais.

A isso se adiciona a realidade orçamentária e financeira de proteção e defesa civil nos municípios brasileiros, a qual, segundo reconhece a própria Sedec (BRASIL, 2017, p. 37), na maioria das vezes, “não possui recursos próprios (rubrica orçamentária), sobretudo os municípios de pequeno número de habitantes e os que não registram uma frequência significativa de desastres. Há, ainda, os que possuem recursos mínimos e não conseguem executá-los”.

Diante dessa realidade, talvez seja importante utilizar os recursos do CPDC para reduzir, ainda que pontualmente, as vulnerabilidades institucionais desses municípios, sobretudo aqueles que possuem menores IDHM e PIB *per capita*. Futuros estudos podem analisar essas dimensões, identificando como os órgãos municipais de Defesa Civil financiam suas atividades e quais efeitos a falta de financiamento e de capacidade institucional podem gerar nas atividades de GRD.

## 6 CONCLUSÕES E RECOMENDAÇÕES

A análise das distribuições espaço-temporais das SE e ECP e dos gastos com o CPDC no período 2013-2017 permite chegar a algumas conclusões que podem ser importantes para o planejamento das políticas públicas de auxílio-financeiro para ações de resposta a desastres.

Em primeiro lugar, a declaração de SE está sendo tratada como algo corriqueiro. Mais da metade dos municípios brasileiros declarou SE em um período de cinco anos. A frequência de declarações é outro aspecto que chama atenção. Em 187 municípios brasileiros governa-se quase 200 dias por ano em SE.

A maioria das declarações de SE está relacionada a estiagens e secas, sobretudo na Região Nordeste. Outras ameaças, como as geológicas e biológicas, têm poucos registros na base de dados do S2ID.

A declaração de SE ou ECP é uma etapa para pleitear auxílio-financeiro para ações de resposta, via CPDC. Os estados utilizaram a maior parte dos recursos (76,45%) do CPDC. Quatro estados da Região Nordeste, que tem registros frequentes de SE em virtude de estiagens e secas, respondem por pouco mais da metade de todos os gastos. Embora as declarações de SE tenham o município como o local do desastre, muitos parecem depender do estado como um ente federativo intermediário para uso dos recursos do CPDC, principalmente na Região Nordeste – com exceção dos estados da PB e BA – e nos estados de MG e RS.

Do conjunto de 564 municípios que utilizaram o CPDC, 54,61% se concentram nas regiões Nordeste (principalmente na PB e BA), Sul (23,58%), Sudeste (10,64%), Norte (10,46%) e, por fim, Centro-Oeste (0,71%). Dos R\$ 189,7 milhões diretamente utilizados pelos municípios, 41% do total (R\$ 77,7 milhões) foi destinado a 30 municípios.

Interessante destacar que todos os municípios que tiveram gastos com CPDC superiores a R\$ 4 milhões, no período 2013-2017, possuíam IDHM Alto (superior a 0,700), sobretudo nas regiões Sul e Sudeste do País, ou seja, municípios com maior IDH e com maior PIB per capita – indicadores que, em teoria, representam melhores condições de desenvolvimento – também possuem mais recursos extraordinários do governo federal por meio do CPDC, considerado um tipo de auxílio complementar. Análises futuras poderão verificar se essa tendência de reprodução da desigualdade assistencial em desastres se replica. Em que medida municípios com menores valores de IDHM têm sido afetados por desastres e não têm tido acesso aos recursos do CPDC?

Como forma de melhorar a transparência do CPDC e torná-la mais apropriada às análises de GRD, recomenda-se que sejam detalhados os municípios beneficiários quando da utilização pelos estados e, também, seja feita a associação da tipologia de ameaças e desastres no Portal da Transparência. Outro aspecto importante talvez seja estabelecer critérios de priorização dos recursos do CPDC baseados no histórico dos municípios na redução de risco de desastres.

## AGRADECIMENTOS

VM agradece à Fapesp (Processo nº 2018/06093-4). AMF agradece à Capes pela bolsa de nível doutorado. DAM agradece ao CNPq a bolsa EXP-A.

## REFERÊNCIAS

BANCO MUNDIAL. **Avaliação de Perdas e Danos:** inundações bruscas em Santa Catarina – novembro de 2008. Brasília: Banco Mundial, 2012a.

BANCO MUNDIAL. **Avaliação de Perdas e Danos:** inundações bruscas em Pernambuco – junho de 2010. Brasília: Banco Mundial, 2012b.

BANCO MUNDIAL. **Avaliação de Perdas e Danos:** inundações e deslizamentos na Região Serrana do Rio de Janeiro – janeiro de 2011. Brasília: Banco Mundial, 2012c.

BRASIL. **Instrução Normativa nº 02, de 20 de dezembro de 2016.** 2016. Disponível em: <<https://www.mdr.gov.br/images/stories/ArquivosDefesaCivil/ArquivosPDF/legislacao/Anexo-VI---Conceitos.pdf>>. Acesso em: 17 jan. 2019.

BRASIL. Ministério da Integração Nacional. **Módulo de formação: resposta, gestão de desastres, decretação e reconhecimento federal e gestão de recursos federais em proteção e defesa civil para resposta.** Apostila do instrutor. Brasília-DF, 2017. Disponível em: <<https://www.mdr.gov.br/images/stories/ArquivosDefesaCivil/ArquivosPDF/publicacoes/II---Resposta---Livro-Base.pdf>>. Acesso em: 17 jan. 2019.

BRASIL. **Política Nacional de Defesa Civil.** Brasília: Sedec, 2007.

CARVALHO, D. W. **Desastres ambientais e sua regulação jurídica: deveres de prevenção, resposta e compensação ambiental.** 2. ed. São Paulo: Thomson Reuters, 2020.

CARVALHO, J. M. **Cidadania no Brasil: o longo caminho.** Rio de Janeiro: Civilização Brasileira, 2002.

CASTRO, A. L. C. **Glossário de Defesa Civil: estudos de riscos e medicina de desastres.** 5. ed. Brasília: Sedec, 2004.

CHAMBERS, R. Vulnerability, coping and policy. **IDS bulletin**, v. 20, n. 2, p. 1-7, 1989.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **PIB per capita [2017].** IBGE Cidades. 2017. Disponível em: <<https://cidades.ibge.gov.br/>>. Acesso em: 17 jan. 2019.

KELLETT, J.; CARAVANI, A.; PICHON, F. **Financing Disaster Risk Reduction: towards a coherent and comprehensive approach.** 2014. Disponível em: <<https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9027.pdf>>. Acesso em: 07 jul. 2019.

MARCHEZINI, V. **Campos de desabrigados: a continuidade do desastre.** São Carlos: RiMa, 2014.

MARCHEZINI, V.; SARTORI, J.; GONÇALVES, J. C. Desenvolvimento, Desastres e Reconstrução: o caso de São Luiz do Paraitinga/SP, Brasil. **Revista Brasileira de Gestão e Desenvolvimento Regional**, v. 13, p. 202-226, 2017.

PROGRAMA DAS NAÇÕES UNIDAS PARA O DESENVOLVIMENTO. **Atlas do Desenvolvimento Humano no Brasil 2013.** Disponível em: <<https://www.br.undp.org/content/brazil/pt/home/idh0/rankings/idhm-municipios-2010.html>>. Acesso em: 15 jan. 2019.

PROGRAMA DAS NAÇÕES UNIDAS PARA O DESENVOLVIMENTO. **O que é o IDH.** Brasília: Pnud, 2020. Disponível em: <<https://www.br.undp.org/content/brazil/pt/home/idh0/conceitos/o-que-e-o-idh.html>>. Acesso em: 10 jul. 2020.

TIERNEY, K. Disaster governance: social, political, and economic dimensions. **Annual Review of Environment and Resources**, v. 37, p. 341-363. 2012.

UNITED NATIONS DEVELOPMENT PROGRAM. **Human Development Report 2019.** Beyond income, beyond averages, beyond today: inequalities in human development in the 21st century. New York: UNDP, 2019. Disponível em: <<http://hdr.undp.org/sites/default/files/hdr2019.pdf>>. Acesso em: 05 jul. 2020.

UNITED NATIONS INTERNATIONAL STRATEGY FOR DISASTER REDUCTION. **Global Assessment Report on Disaster Risk Reduction: making development sustainable.** The Future of Disaster Risk Reduction, UN, New York, 2015.

VALENCIO, N. F. L. S. Desastres no Brasil: a face hídrica do antidesenvolvimento. In: VALENCIO, N. F. L. S.; SIENA, M. **Sociologia dos Desastres: construção, interfaces e perspectivas.** Volume IV. São Carlos: Rima Editora, 2014. p. 109-148.

VIEIRA, R. M. S. P. et al. Characterizing spatio-temporal patterns of social vulnerability to droughts, degradation and desertification in the Brazilian northeast. **Environmental and Sustainability Indicators**, 2020.

WALLEMACQ, P.; HOUSE, R. **Economic Losses, Poverty & Disasters.** 2018. Disponível em: <[https://www.preventionweb.net/files/61119\\_credeconomiclosses.pdf](https://www.preventionweb.net/files/61119_credeconomiclosses.pdf)>. Acesso em: 1 ago. 2019.

WILCHES-CHAUX, G. La vulnerabilidad global. In: MASKREY, A. (Org.). **Los desastres no son naturales**, 1993, p. 11-41. LA RED: Panamá.

WISNER, B.; GAILLARD, J. C.; KELMAN, I. Framing disaster: theories and stories seeking to understand hazards, vulnerability and risk. In: \_\_\_\_\_. **The Routledge handbook of hazards and disaster risk reduction.** p.18-34. London: Routledge, 2012.

# Climate change and the unsustainable urbanism in the municipality of João Pessoa, PB, Brazil

*Mudanças climáticas e o urbanismo insustentável no município de João Pessoa, Paraíba, Brasil*

Letícia Palazzi Perez<sup>a</sup>

Andréa Leandra Porto Sales<sup>b</sup>

José Augusto Ribeiro da Silveira<sup>c</sup>

<sup>a</sup>Doutora, Professora Visitante no Departamento e no Programa de Pós Graduação em Arquitetura e Urbanismo da Universidade Federal da Paraíba, João Pessoa, PB, Brasil  
E-mail: leticia.palazzi@gmail.com

<sup>b</sup>Doutora, Professora Adjunta no Departamento de Geografia da Universidade Federal da Paraíba, João Pessoa, PB, Brasil  
E-mail: andreaportosales@gmail.com

<sup>c</sup>Doutor, Professor no Departamento e no Programa de Pós Graduação em Arquitetura e Urbanismo da Universidade Federal da Paraíba, Vice Coordenador do Programa de Pós Graduação em Arquitetura e Urbanismo da Universidade Federal da Paraíba, João Pessoa, PB, Brasil  
E-mail: ctlaurre@gmail.com

doi:10.18472/SustDeb.v11n2.2020.32330

Received: 02/07/2020  
Accepted: 19/08/2020

ARTICLE- VARIA

## ABSTRACT

In the scope of urban space production, Brazilian urban policy, despite pointing out in its guidelines the struggle for the right to the city, seems indifferent to the impacts of real estate speculation on ecosystems. Given the context of the climate emergency, there is an urgent need to align urban and environmental policy for planning cities adapted to climate change. This work presents, based on spatial data from the recent deforestation of the city of João Pessoa, the legal and socioenvironmental characteristics of the urban expansion of the city and how the municipal urban and environmental policy has catalyzed processes of socioenvironmental injustice. It appears that planning and management are limited to following the trends signaled by the real estate market and that pressure ecosystems, especially in the southern portion of the municipality, and also that democratic arrangements are forged to make society's role in defending ecosystems unfeasible.

**Keywords:** Urban Policy. Environmental Policy. Urban Sprawl. Climate Change.

## RESUMO

*No âmbito da produção do espaço urbano, a política urbana brasileira apesar de assinalar em suas diretrizes a luta pelo direito à cidade, parece indiferente aos impactos da especulação imobiliária sobre os ecossistemas. Dado o contexto da emergência climática, é urgente alinhar a política urbana e*



*ambiental para o planejamento de cidades adaptadas às mudanças do clima. Este trabalho apresenta, a partir de dados espaciais do desflorestamento recente da cidade de João Pessoa, as características jurídicas e socioambientais da expansão urbana da cidade e como a política urbana e ambiental municipal têm catalisado processos de injustiça socioambiental. Constatou-se que o planejamento e a gestão se limitam a acompanhar as tendências sinalizadas pelo mercado imobiliário e que pressionam os ecossistemas, principalmente na porção sul do município, e também que os arranjos democráticos são forçados para inviabilizar a atuação da sociedade na defesa dos ecossistemas.*

*Palavras-chave:* Política Urbana. Política Ambiental. Espreadimento Urbano. Mudanças Climáticas.

## 1 INTRODUCTION

The Anthropogenic action on ecosystems has advanced at an astounding rate since the Industrial Revolution, creating the geological era of Anthropocene (CRUTZEN, 2006, p.14), from processes of socioeconomic production that result in global warming. The new forms of global socioeconomic organization, represented by urban population growth, mobility and unbridled consumption, imply the intensive use of natural resources (BAI et.al, 2016), amplifying, in a vicious circle, the causes and impacts of changes from global to local scale.

In the surroundings of cities, deforestation is the main indicator of anthropogenic pressure on ecosystems. The horizontal urban expansion, as the maximum transformation of the local scale, has not only suppressed forests, but also pressured rivers and modified the soil.

Cities exist and have existed in history because men have found more advantageous and efficient ways to manage their social, economic and power relations in a spatially concentrated manner (CAMAGNI, 2005, p. 21). In the course of history, as Santos (1997) reports, the relations of economic production and social reproduction that support capitalism situated, in the urban structure, in a different way, in time and in the territories under specific technical and political conditions, ways of obtaining profit through advantages provided by the concentration of people and things.

Thus, the locational advantage of the urban structure placed in the background, ironically, in the urban planning, the socially elaborated anthropological needs in the city; to live in the city, neglecting ecosystems.

According to Lefebvre (2001), the need for the meeting, the organization of work, the game, communication, and a quality of life were forged by technocratic urbanism and sales promoters, materialized in collective, commercial and real estate products that fragmented the city, generating spatial segregation and “new” urban problems, such as those of an environmental nature: water scarcity, natural disasters, heat waves are examples of these problems.

In their efforts to optimize the organization of economic activities and social reproduction and to minimize the socio-environmental chaos, generated and arising from past plans, supranational entities, multilateral agencies and the government have idealized diverse agendas and plans, whose guidelines and goals aim to achieve “urban sustainability” (LEFF, 2007). At first sight, the paradigm break brings important reflections on the political strength of local urban agents in decision-making processes and inevitable concerns about the overload of urban society on planet Earth.

However, it is urgent to point out the contradictions that exist in the interface of urban and environmental planning, that catalyze the evolution of land use and occupation conflicts, which in turn accentuate environmental problems. And, mainly, to highlight the appropriation and instrumentalization of the discourse of environmental protection for real estate speculation purposes.

When the Theory of Value from Adam Smith (1776 [1996]) denies the priority of agricultural production in generating wealth, nature is purposefully pointed out as an obstacle to economic development in

classical economic theories, who attributed to work a fundamental role in the generation of wealth<sup>1</sup>. Neil Smith (1988), reflecting on the complex process of production of nature under the capitalist logic of space production, highlights that the devaluation of nature in theory was accompanied by its devaluation in reality for its appropriation as a means of production.

In the course of urbanization, here understood as a multi-dimensional process catalyzed by industrialization, the supposed domination of nature was convenient in theory and in practice until the crisis of scarcity of resources or its most immediate effects (SMITH, 1988), such as climate change. Floods, landslides, different kinds of pollutions and other pressures on ecosystems are some of the most immediate and perceived effects on the scale of the city. They result from planning oriented to market trends and real estate speculation. In other words, they are not the result of an environmental crisis, but of the contradiction of the urban space production process itself, which expresses its development limits by assigning value to natural resources such as water, vegetation and fertile soil.

A claim of nature is being materialized in government policies, plans, programs and projects. It is an indirect advertisement to escape not only the tendency of a deteriorated, fragmented and dispersed city but, above all, as argued by Leff (2007, p.67), it is an appeal to “the construction of another productive rationality, founded on the potentials of nature”. The adoption of this perspective would demand a readjustment of the planning, of the guidelines of the territorial ordering and of the forms of regulation of the public spaces and the environmental protection areas in the city, but, above all, a readjustment in the forms and spectrum of the urban governance (SOUZA, 2001).

The decentralization of administrative competences and the participation of society in urban planning have been pointed out as democratic ways capable of mitigating socio-environmental problems (UN, 2016; JACOBI & SULAIMAN, 2016). However, this overestimation of local power in decision-making processes, as an instigator of social justice and environmental protection, contained in international guidelines, only works when citizens truly contribute to the implementation and, mainly, to the monitoring of public policies. Otherwise, as Souza (2001) argues, there is a risk of instrumentalizing the discourse of popular participation in planning and environmental protection to forge interests of capital productivity over urban space, unfortunately, as argued by Campbell (1996, p.196).

Controls over land use and urban development in Third World cities have been weak, and most of the instruments and techniques adopted in developed countries - land use planning and master plans, zoning, permits to use of land and to build, in addition to the territorial tax - it is emasculated in developing countries by the power of demand, administration difficulties, special interests and corruption (CAMPBELL, 1992, p.196).

In this regard, this article aims to present, from the recent deforestation in the municipality of João Pessoa, the main areas of urban expansion and their legal and socio-environmental characteristics to discuss how urban and environmental municipal policy have subsidized the process of urban expansion at the expense of environmental preservation .

## 1.1 URBAN SPREADING VERSUS SUSTAINABLE URBANISM

More than 50% of the world's population lives in urban areas that occupy less than 1% of the earth's surface (IPCC, 2019). In addition to increasing Greenhouse gas emissions (GHG), motorized transport, civil construction, energy expenditure in maintaining and operating cities (SCHAEFFERA et. Al, 2012; BORBA, 2012), the world's urban population generates about 25% of the total global emissions of carbon, through the use of energy (IPCC, 2014).

The pressure of urbanization on ecosystems and the degradation of forested areas, inside and outside the urban environment, tend to increase, either due to the need for housing production or the consumption of food and other goods, mostly produced miles away from large cities.

Among the main impacts of climate change in Brazil are the increase in temperature, the change in the rainfall regime and the increase in the occurrence of extreme weather, with special emphasis on rainy extremes, increased occurrence of droughts, in addition to elevation of the sea level (MARENGO, 2014).

Disorganized and exploited by the desire for immediate profit urbanization (HARVEY, 2001) has consequences in increasing the climatic risk to the population. In the rainy extremes, the lack of urban infrastructure such as rainwater drainage and environmental sanitation, as well as occupation of floodplains and slopes, intensify the impact of rains in urban areas (TUCCI, 2008), mainly, but not exclusively, in precarious settlements, where the poorest and most vulnerable population resides to the impacts of these events (HARDOY & PANDIELLA 2009).

The Assessment Report 5 (AR5) from IPCC (2014) points out that the most socioeconomically vulnerable populations are also the most vulnerable to the impacts of climate change: the intrinsic relations of income, social class, gender, ethnicity, age and special needs are conditioning factors of adaptive capacity and risk exposure.

If socioeconomic vulnerability is one of the main conditioning factors of the intensity of the impact of climate change on populations (OJIMA, 2009; BARCELLOS AND HACON, 2007), the processes to reduce the impacts of climate change in cities pass, necessarily, to new perspectives of governance, based on the democratic and participatory processes laid down by the legislation (JACOBI and SULAIMAN, 2016), on the popular knowledge of traditional communities and also on the reduction of socioeconomic inequality.

The reduction of social inequality is a priority issue for the adaptation of the Brazilian population to the impacts of climate change. The IPCC (2014) emphasizes the importance of income transfer policies, including mention of the Bolsa Família program in AR5. In Brazil, 75% of the 5,570 municipalities are exempt from elaborating Master Plans because they have less than 20 thousand inhabitants.

Despite the Statute of the City (2001) and Reurb (2017) establishing essential legal instruments to improve the quality of urban infrastructure, especially in precarious or informal settlements, the low institutional capacity of many Brazilian municipalities (ALMEIDA et al, 2017), linked to the pressures of power of capital over urban dynamics make the application of such instruments difficult. These facts compromise urban development and, consequently, sustainable urban planning. The vulnerability is also intensified due to the difficulty in organizing preventive actions of the civil defense, which still acts in the relief and not in the prevention<sup>2</sup> (NOGUEIRA E CANIL, 2018).

If it is essential to promote sustainable urban planning as adaptation to climate change, to encourage urban agriculture, afforestation and the permeability of cities, as well as to promote the suitable densification of cities, inhibiting the spreading and, consequently, the reduction of pressure from urban areas on ecosystems and rural areas, smart urban density and the implementation of green and digitalized infrastructures are elements of urban development that favor non-polluting mobility with lower energy expenditure (COHEN, 2017).

For Nakano (2018), are the well applied urban instruments that can determine the “optimal density point”, from a socio-environmental perspective. In this sense, the municipality of João Pessoa is in the opposite direction of promoting a city adapted to the climate crisis, accommodating urban sprawl, especially over the last Atlantic Forest reserves and water supply courses in the municipality, so important for mitigating the impacts of climate change in the occurrence of diseases, heat waves, in water security, in addition to disasters related to occupations on the banks of rivers.

## 1.2 URBAN SPRAWL IN JOÃO PESSOA

João Pessoa, capital of the State of Paraíba, Northeast Brazil, has approximately 800,000 inhabitants, with 214 km<sup>2</sup>, 64 neighborhoods and 120 subnormal agglomerations (IBGE, 2010). Only 20% of the population has completed higher education and 15% of the population is between poor and extremely poor, with an income below 1 minimum wage (IBGE, 2010).

In the municipality of João Pessoa, there are four Conservation Units, registered in the National System of Conservation Units (SNUC), namely the National Forest Restinga de Cabedelo - FLONA (2004), the “Parque Nacional Cuiá” (Municipal Natural Park) (2012), “Reserva da Vida Silvestre Mata do Buraquinho” (Remnant of Atlantic Forest) (2014) and “the Parque Estadual das Trilhas” (State Park) (2017), as shown in Figure 1.

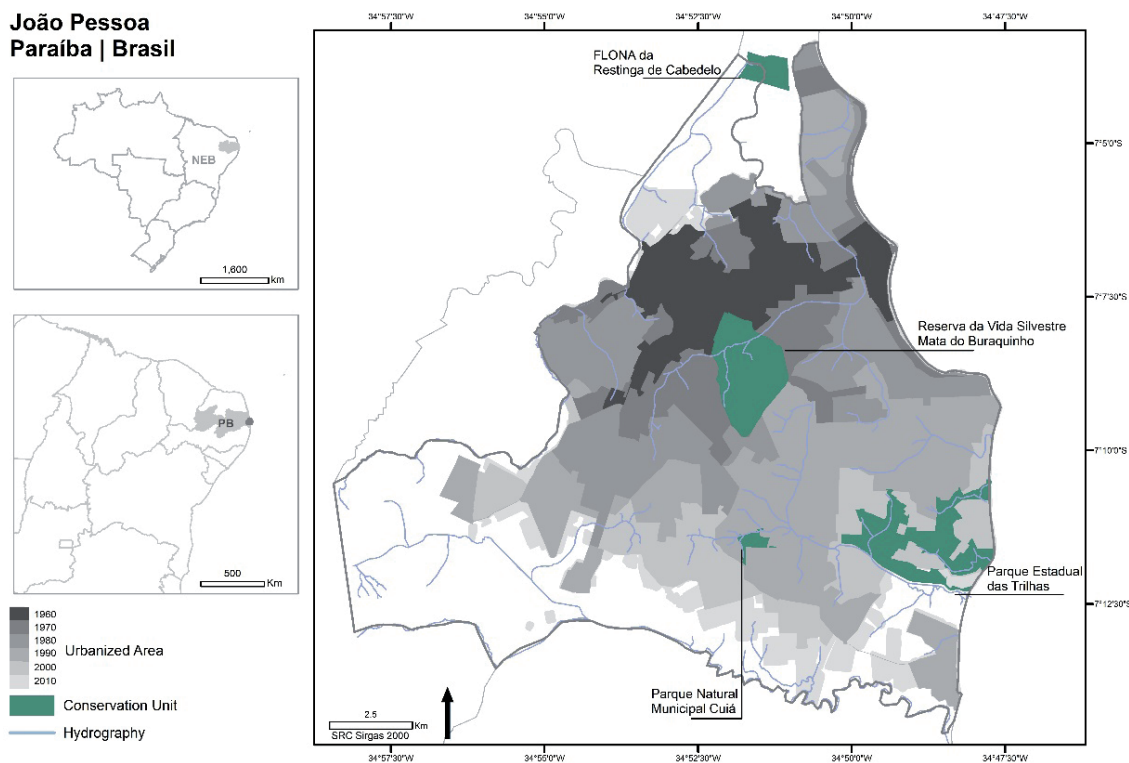


Figure 1 | Location map of João Pessoa: protected areas, green areas and urbanized area.

Source: MMA, 2019; IBGE, 2010. Elaborated by the authors.

The 1960s is a milestone in the urban expansion of the city, fostered by private initiative, with the consonance and intervention of the public authorities. The development of motorized and private transport allowed access to more distant places from the central area, which added to the opening of important avenues such as Epitácio Pessoa and Pedro II, and the transposition of the courses of the city's rivers, especially the Jaguaribe, Mandacaru, Tambaí and small tributaries, enabled the growth of the urban structure for the north-northeast region (SILVEIRA et al., 2015).

Currently, this logic of production of urban space is guided by the logic of the real estate market which directs the growth of the urban structure to the southern part of the city, where there is no consolidated urban infrastructure and remnants of the Atlantic Forest are systematically suppressed to allocate, mainly, tourist enterprises of the municipal and state governments, and vertical residential real estate products, for a low income in the south-southwest portion, and for high income in the south-southeast portion of the municipality, constituting a fragmented city (HARVEY, 2001).

## 2 METHODOLOGY

Spatial and socio-environmental data were used and correlated in spatial analysis techniques for building maps that allowed us to outline the reality of urban expansion. The survey of the legal provisions that regulate the use and occupation of the city's land, as well as the democratic records of hearings and municipal councils served to identify and characterize the dynamics and political arrangements existing in the city.

To understand the issue, an alignment of the urban and environmental debate was sought by selecting a conceptual repertoire capable of providing an understanding of the social nature of the city and the ecological processes that occur in urban structures.

The concepts were divided into three main types: a) those indispensable for thinking about the problem, such as "space production" and "climate change"; b) those that are in the acceptance phase within the scope of the philosophical validation system that use the former, although necessary, as "sustainability"; c) and those that are not recurring, but that in this work were fundamental to align the dimensions of analysis, such as the "scales policy".

In this sense, the bibliographic survey consisted of the search for classic works, theoretical reviews and the state of the art via official documents (minutes, plans, maps and reports) and legal provisions, which in turn indicated the socio-economic and spatial data indispensable to spatial analysis.

The geostatistics were elaborated from data derived from the Global Forest Change project (HANSEN et al., 2013), data from IBGE (2010, 2017), from the Municipal Master Plan (Law 054/2009) and Ministry of the Environment (2019), in a georeferenced information system.

Deforestation data (HANSEN et al., 2013) in raster format indicate the date of forest loss each year, in a historical series from 2000 to 2018, based on Landsat images. These data were vectorized and later transformed into patches of concentration of occurrence of vegetation loss, based on the density of lines of each vector.

These patches of concentration of occurrence of vegetation loss indicated, in mesoscale, which areas are most affected by deforestation, since the aim is to observe the production process of urban space, from the point of view of the loss of green areas and pressure on ecosystems.

Understanding that deforestation occurs through urban expansion over ecosystems, vegetation loss spots were plotted on Conservation Units and hydrography. On the other hand, to understand the socio-environmental characteristics of urban sprawl, these spots were also plotted on the classification of IBGE's Intra-urban Typologies (2017), which points, from data on environmental sanitation, income, education, access to goods and services, the living conditions of the population.

On a more detailed scale, maps of vegetation loss patches were plotted with Macro zoning, so that it was possible to observe the production of urban space based on the urban governance strategies of the law in force. Finally, in conjunction with these cartograms, images from the Google Earth platform were added, allowing the observation of anthropic actions that cause deforestation.

From the generated cartograms, analyzes of the production of the urban space were made, observing the different socio-environmental and legal aspects of the urban expansion of the municipality of João Pessoa.

## 3 RESULTS AND DISCUSSION

The first Master Plan of João Pessoa was prepared in 1992 and officially published in 1994, through Complementary Law 03/1994 (PMJP, 1994). It is the result of the Brazilian urban reform, but it does not represent the first territorial ordering and zoning of the municipality. However, as a basic

instrument of Brazilian urban policy, it presented guidelines, rules and restrictions for the use and occupation of the city's land. The plan's possible urban expansion design, as shown in Figure 2, describes the environmental impacts by marking it as permanent protection areas and as municipal and state conservation units.



Figure 2 | Master Plan of João Pessoa, 1992.

Source: Scanned from analogical originals.

When analyzing past zoning and the recent use and occupation of the soil, it is possible to verify an undisguised political-ideological content in its elaboration, by promoting land stock for tourist real estate enterprises in the coastal strip of the city (HARVEY, 2001, p. 166-170 and p. 221). The zones of additional restrictions, outlined in Figure 3, and characterized as areas of “social interest for the preservation of environmental, landscape, historical and cultural characteristics” were gradually being neglected in the name of private interests and sanctioned by city governments on behalf of “urban development”, contradicting Leff’s (2007) expectations that interinstitutional arrangements and legal instruments could direct urban policy towards sustainability.

The inexistence of a Brazilian urban planning system articulated with the legal provisions that sanction the urban parameters of land use and occupation with other public policies that affect the urban, such as the environmental, allows maneuvers based on less visible speculative interests to be performed without adequate supervision or control by the government.

For example, the construction in progress of a hypermarket, whose architectural project highlights the construction of 12,000 m<sup>2</sup> in the Environmental Amenization Sector (SAA) and the Permanent Preservation Area (APP). The environmental installation license was granted by the Municipal Environment Secretariat and unanimously canceled by the Municipal Environment Council (COMAM).

The opinion of the counselor of the Federal University of Paraíba, to case nº 2018/068932 and 2018/066994 of the Secretariat of the Environment, was unequivocal in pointing out several aspects by which the work should be interrupted, among them: i) the incongruity in the typification of the enterprise between the Planning Secretariat (SEPLAN) and SEMAM; ii) the negligence of the body responsible for issuing the environmental license when allowing a lot occupancy rate double of that stipulated by law in the environmental softening sector; iii) by not preventing vegetation removal of fragments from the Atlantic Forest; iv) authorize the installation of a project that does not have a solid waste and effluent management plan, in an area without sanitation infrastructure; v) and do not present a neighborhood impact study for a project of this size. Despite the unanimous request for revocation of the license, the work continues in progress.

This fact is a clear example of how the production of urban space takes place in accordance with the interests of capital above the socio-environmental interests of the population, based on the consent and convenience of the public authorities.

These practices of municipal administrations not only demonstrate an imbalance between the scales policy of urban legislation and environmental legislation, which allows a non-compliance between one and the other, according to the interest of the agents who participate and operate the bureaucratic ritual, according to Campbell (1992).

The natural processes and flows that take place in the urban landscape are fundamental for a quality of everyday life in the city. It is not just a matter of environmental protection, but a right to the city. Contact with nature, sunbathing, breathing fresh air, walking to shop, having access to drinking water, meeting friends and working are individual needs that we collectively carry out in the city.

With the institutional setbacks in critical areas such as the environmental and the urban, the advance of the urban structure in the fragments of the Atlantic Forest has been allowed, not only in the municipality of João Pessoa, but also as it occurs in the north coast of the State of São Paulo (BORELLI, 2007), with the advance of fragmented urbanization, based on the tourist exploration of the region and which implies the loss of life quality in the city, or according to Barreto (2013), who has deeply studied the history of the occupation of the Northeast Atlantic Forest, since colonization to the present day.

Barreto (2013) also points out the need to promote connectivity between fragments of the Atlantic Forest in Northeast Brazil, a proposition that becomes unfeasible with urban sprawl and pressure on what remains of this biome. Despite having two large non-urbanized areas, one to the north and one to the south, the deforestation of the municipality of João Pessoa is concentrated in the southern portion of the municipality, as shown in Figure 3, where there are quilombola, indigenous and artisanal fishermen communities, such as Paratibe, Tabajaras and Jacarapé, none of them demarcated or regulated.

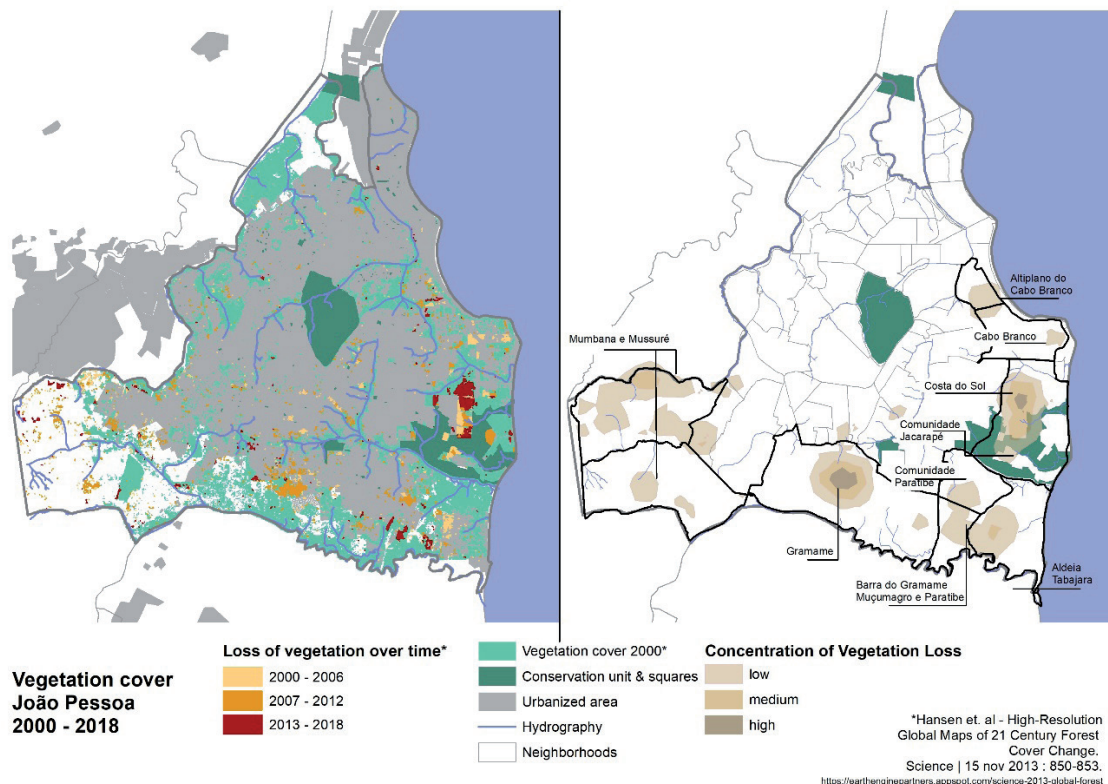


Figure 3 | Maps of vegetation cover and loss of vegetation in João Pessoa.

Source: Hansen et al. (2013), MMA (2019). Prepared by the authors.

Between 2007 and 2018, large areas of deforestation can be seen in the southeastern portion, close to “Parque Estadual das Trilhas”, a Conservation Unit enacted in 2017. The orange spot, in Figure 3, further east, is the Convention Center, inaugurated in 2012, and that is part of the development plan for a high standard tourism industrial district (GOVERNO DO ESTADO DA PARAÍBA, 2017).

In the northern portion of “Parque Estadual das Trilhas”, Costa do Sol neighborhood, Figure 4, the most recent deforestation can be observed under the logic of capital that spatially follows the entrepreneurship of urban public policy (HARVEY, 2001,) to occupy areas previously forested and that now have transportation infrastructure brought by the installation of the Convention Center. In the southeastern portion, in neighborhoods such as Barra do Gramame, Muçumagro and Paratibe, deforestation appears towards the neighboring municipality, Conde, which has beaches disputed by the tourism sector.

The patches of loss of vegetation in the central south and southwest areas, respectively in the Gramame neighborhood, followed by the Mussuré and Mumbaba neighborhoods, present themselves as the great frontier of expansion over ecosystems - from the Atlantic Forest areas to the Gramame River, which supplies the City. In Figure 4, it is possible to observe that, unlike the surroundings of “Parque Estadual das Trilhas”, in these areas there is a low living condition (IBGE, 2017).

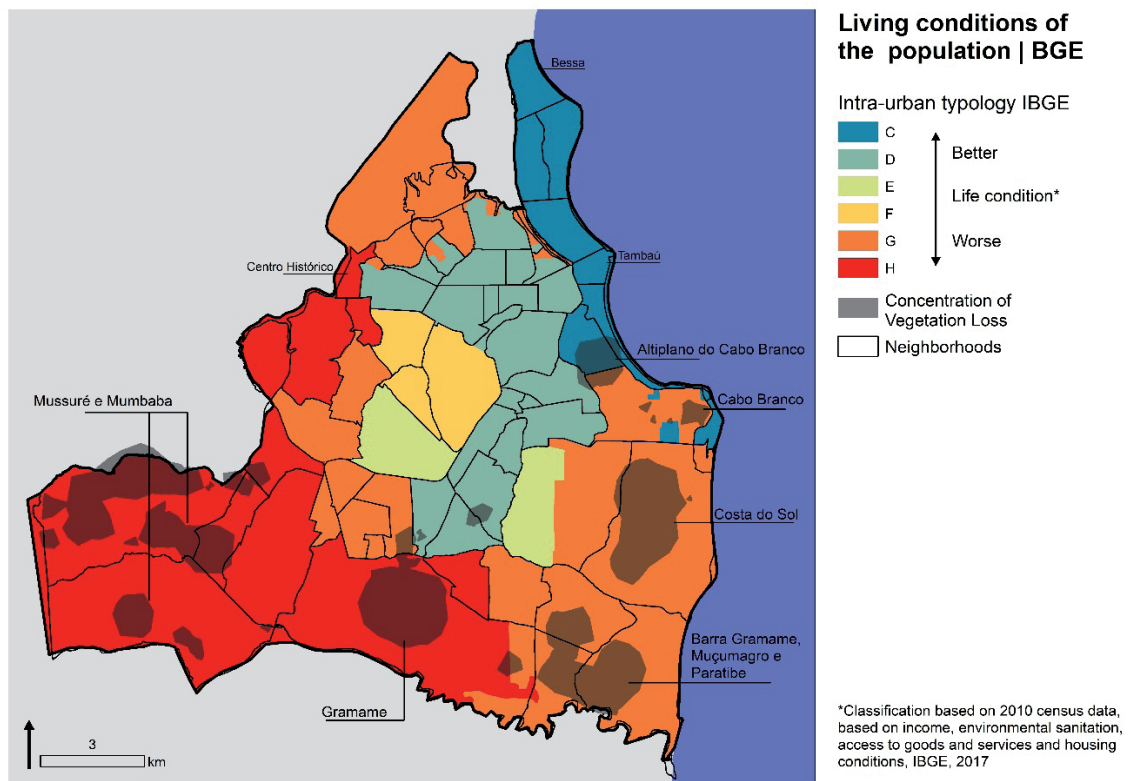


Figure 4 | Intra-urban typologies of João Pessoa.

Source: IBGE, 2017. Prepared by the authors.

With the calculation of the loss of vegetation, between 2012 and 2018, by macro-zone of the Master Plan, it is possible to observe that urban expansion occurs primarily (almost 90% of the total) over Non-Dense Areas, of Non-Priority Density, Environmental Amenization Sectors, Landscape Preservation and extremely close to the Environmental Protection Zones, often occurring on the margins of permanent preservation areas.

This finding points to a failure to comply with legislation and to the fragility of the municipal urban and environmental policy in the face of ecosystems, which should be valued in a city seen as touristic.

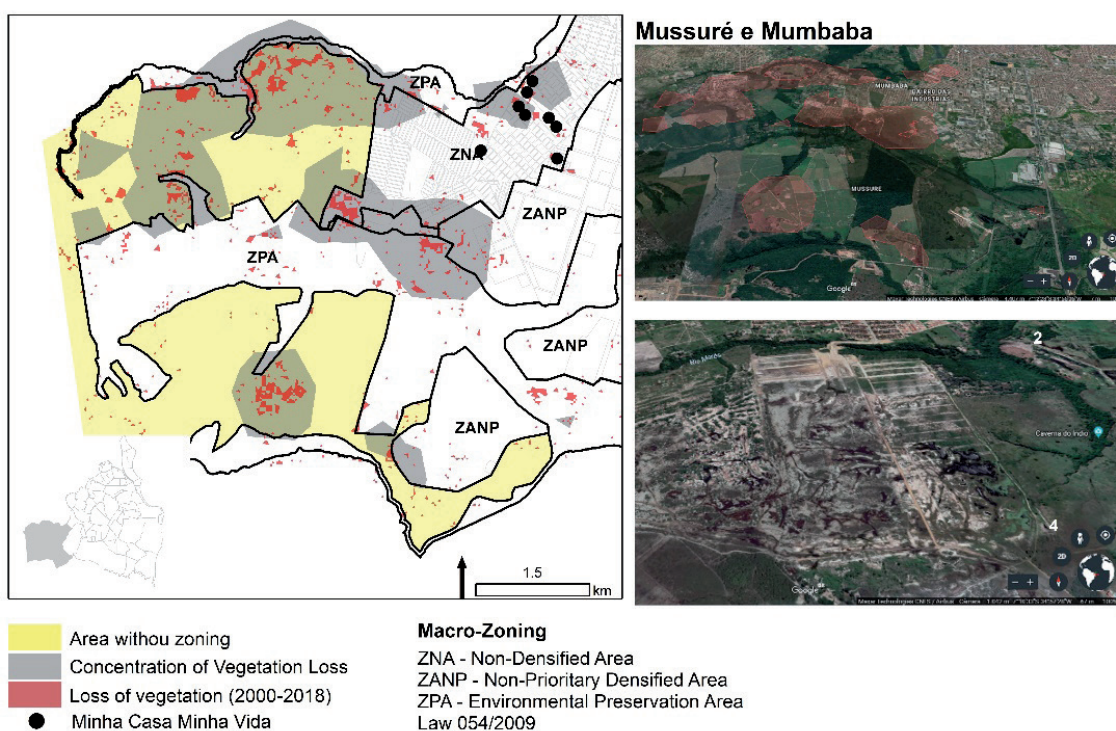


**Table 1 | Loss of vegetation (2012-2018) by Macro-zone of the Master Plan**

| Macro-zone                                      | Area (ha) | Percentual (%) |
|---|-----------|----------------|
| ENVIRONMENTAL PRESERVATION AREA - ZPA           | 157.1     | 53.1           |
| NON-DENSIFIED AREA - ZNA                        | 105.3     | 35.6           |
| WITHOUT ZONING                                  | 15.7      | 5.3            |
| NON-PRIORITARY DENSIFIED AREA - ZANP            | 12        | 4.1            |
| LANDSCAPE PROTECTION SECTOR - SPP               | 2.7       | 0.9            |
| MINERAL EXPLORATION SECTOR                      | 1.3       | 0.4            |
| PRIORITARY DENSIFIED AREA - ZAP                 | 1         | 0.3            |
| ENVIRONMENTAL MITIGATION SECTOR - SAA           | 0.5       | 0.2            |
| DEPOSITION AND TREATMENT OF LIQUID WASTE SECTOR | 0.3       | 0.1            |

Source: Prepared by the authors based on data of Hansen et al., 2013 and PMJP.

In the southwestern portion of João Pessoa there are large patches of deforestation resulting from two very different processes: mining and social and popular housing, as shown in Figure 5.



**Figure 5 | Detail of the loss of vegetation in the Costa do Sol neighborhood.**

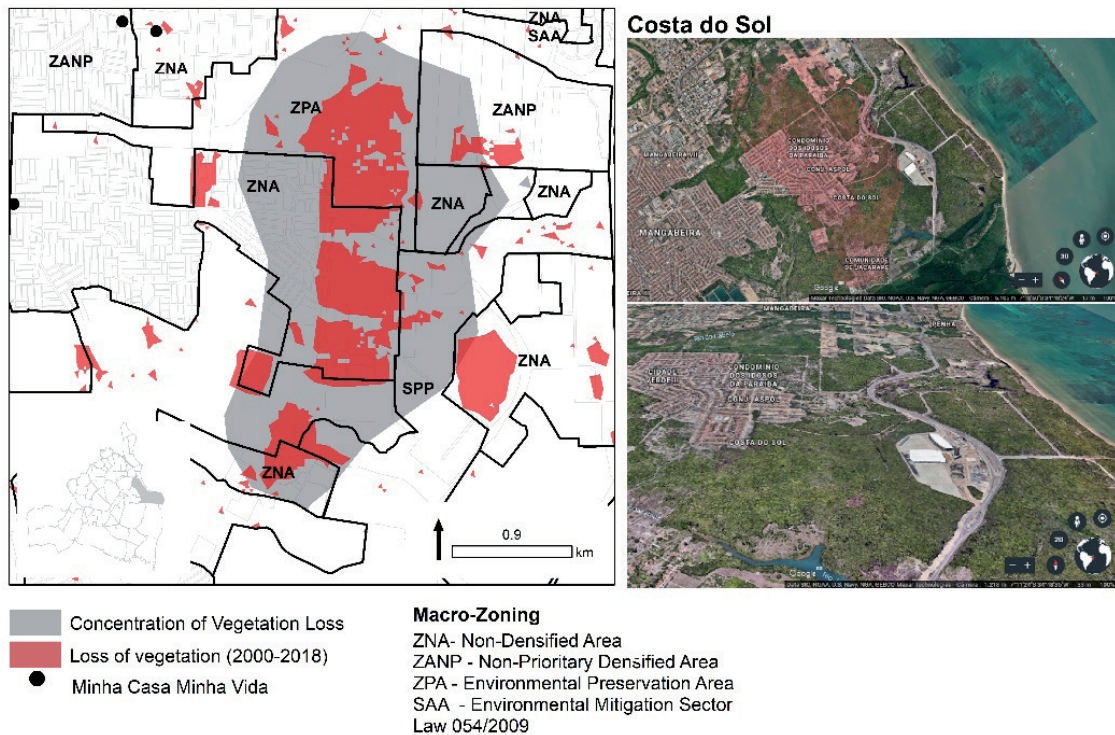
Source: Hansen et al. (2013), Law 054/2009, Google Earth Pro. Prepared by the authors.

In an area that does not have a macro-zone defined by the current law, mineral exploration (Figure 5) is perceived in the vicinity of Environmental Protection Zones.

According to Silva et al. (2016), urban expansion segregates the poorest from socio-environmental opportunities, since access to the city is through consumption and cost of land. In João Pessoa, and in other cities on the northeastern coast, the most distant areas from the “sea view” are the most excluded and Donegan (2019) has already discussed how the coastal urban infrastructure has an urban morphology that excludes the poorest portion of the population.

In the Cabo Branco and Altiplano do Cabo Branco neighborhoods, although the deforestation patches are smaller (Figure 3), it is important to observe the high living conditions (IBGE, 2017) of the population in these areas (Figure 4) in order to understand how the capitalist production of urban space occurs in the most tourist regions of João Pessoa.

In the Costa do Sol neighborhood it is possible to observe (Figure 6) that, according to the current legislation (MPJP Municipal Law 054/2009), the loss of vegetation occurred in non-densified or non-priority areas. These are subdivisions approved from the first decade of this century, with horizontal condominiums that, despite being identified by the 2010 IBGE census as low-income, are now being occupied by upper middle class population, an assumption that can only be confirmed in the IBGE 2021 census.

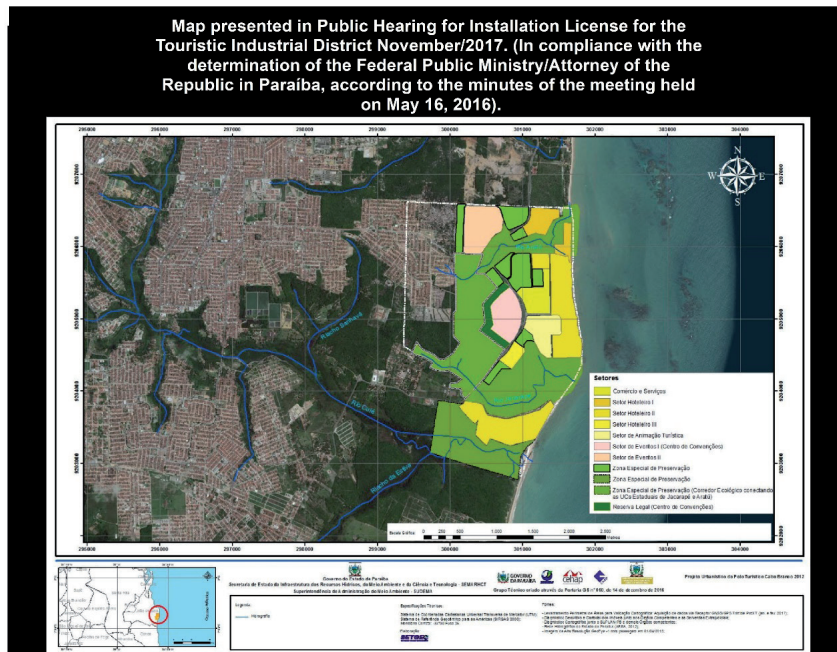


**Figure 6 |** Details of the loss of vegetation in the Costa do Sol neighborhood.

Source: Hansen et al. (2013), Law 054/2009, Google Earth Pro. Prepared by the authors.

The neighborhoods highlighted in Figure 6 follow the logic of segregation pointed out by Harvey (2001), in which a public-private partnership, not legalized, but agreed, serves urban infrastructure that does not exist outside the walls of closed condominiums, or that exists only in the vicinity of the high ones vertical condominiums, meeting the desires of the wealthiest class of the population.

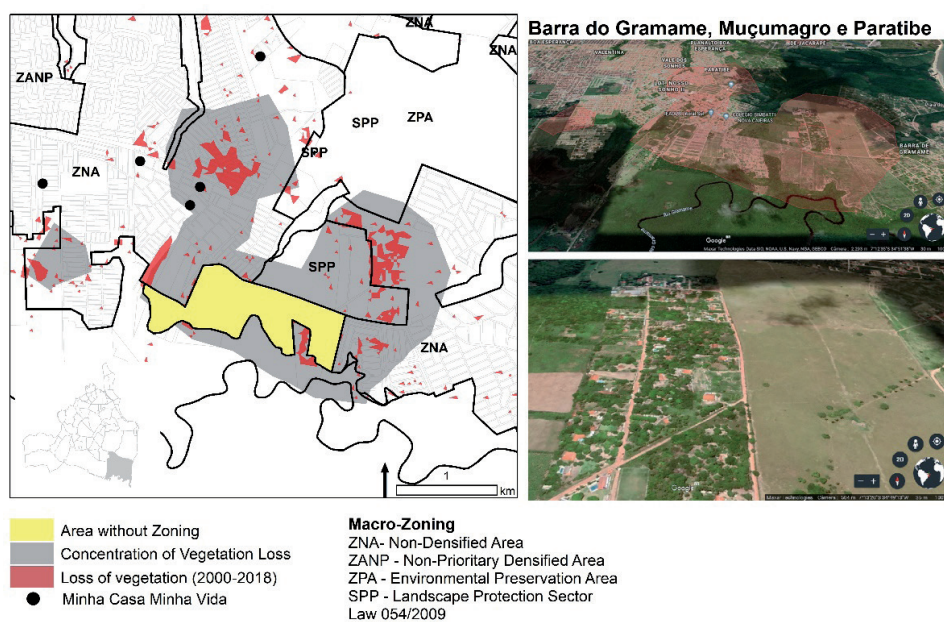
The Convention Center, in the satellite image at the bottom of Figure 6, shows that the road infrastructure brought by the construction of the equipment contributes to the advancement of the urban spot in the southern region of João Pessoa. In the same image, the easternmost portion of the same photo shows a large forested area that will eventually become the high standard tourism industrial district (Government of the State of Paraíba, 2017), as shown in Figure 7 below.



**Figure 7 |** Map of the urban development project for the Industrial Tourism District of João Pessoa.  
 Source: Paraíba State Government (2017).

It is in this same area that the Jacarapé Community is located, where artisanal fishermen live divided into two nuclei, one of which is by the waterfront (Figure 3). This community has undergone several removal attempts, to give way to tourist developments, materializing what the IPCC (2019) points out as land dispute and loss of livelihoods and subsistence of traditional communities.

The polygons of the conservation units surround the area of the tourist district forming a protective shield. The urban infrastructure destined to the tourist offer tends to have more burdens and to pressure the adjacent biodiversity more than the domestic demand. Ironically, much of the Atlantic Forest fragment that constitutes the main asset of the project will be removed to make room for the resorts that will be implemented. The economic and political rationality that guide these government projects and actions show an order based on market law, in which state entities act as urban entrepreneurs to attract investments (Harvey, 2001).



**Figure 8 |** Detail of the loss of vegetation in the neighborhoods Barra do Gramame, Muçumagro and Paratibe.  
 Source: Hansen et al. (2013), Law 054/2009, Google Earth Pro. Prepared by the authors.

In the southeastern portion of the municipality, deforestation is mainly due to the occupation of summer farms, as shown in Figure 8. Corroborating with Municipal Macrozoning, these are low-occupancy subdivisions. These settlements put pressure on the Gramame River and on traditional populations that are still struggling for recognition, such as the Paratibe community and the Tabajara indigenous people (QUARESMA, 2017), who must be evicted due to real estate speculation, the Paratibe community is threatened by the same removal logic of the Jacarapé community, also implying the loss of cultural ecosystem services, in addition to provision (IPCC, 2019).

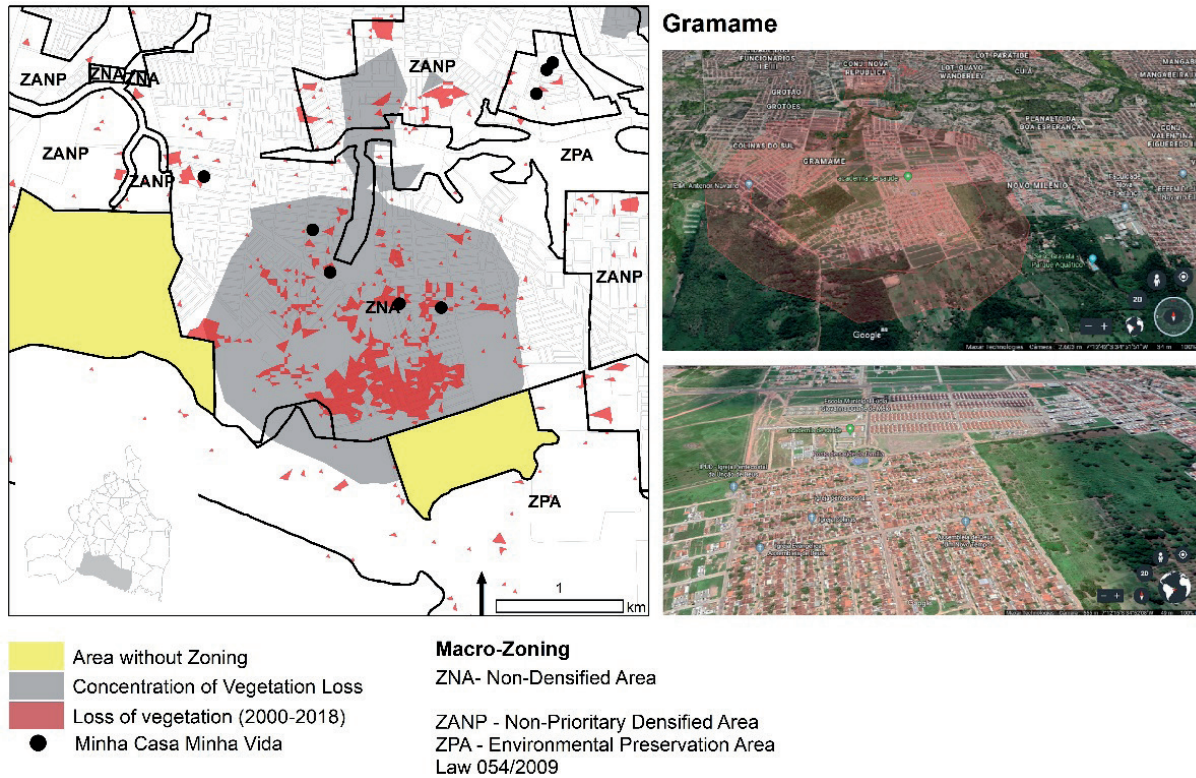
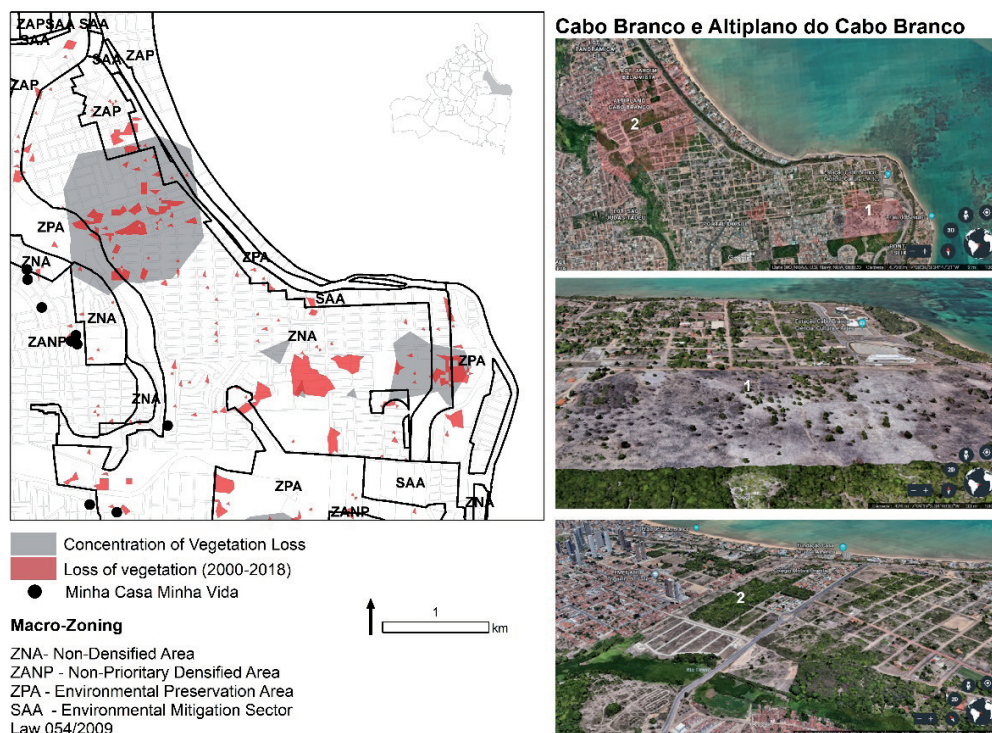


Figure 9 | Detail of the loss of vegetation in the Gramame neighborhood.

Source: Hansen et al. (2013), Law 054/2009, Google Earth Pro. Prepared by the authors.

In Gramame, the major vector of deforestation is the construction of low-income subdivisions, some subsidized by the Federal Government, with resources from the Minha Casa Minha Vida Program and others raised by small construction companies in the city. Despite being on a Non-Dense Area, the patch of loss of vegetation shows dense and continuous soil parceling.

They are small lots, with a high occupancy rate, as shown by the satellite images in Figure 10. Still on Figures 7 and 8, it is worth mentioning that the neighborhoods presented are very close to the Gramame River, a water course that supplies 70% of the city, which may (i) compromise the region's water availability in future scenarios of changes in rainfall regimes and (ii) put at risk of inundation or flooding the poor populations living near the river, with an increase in rainy extremes coupled with low infrastructure of environmental sanitation (HARDOY AND PANDIELLA, 2009).



**Figure 10 |** Detail of vegetation loss in the Altiplano do Cabo Branco and Cabo Branco neighborhoods.  
 Source: Hansen et al. (2013), Law 054/2009, Google Earth Pro. Prepared by the authors.

Located in a privileged location overlooking the sea, in the Cabo Branco and Altiplano do Cabo Branco neighborhoods, the region's deforestation occurred for the construction of horizontal high-income condominiums. In the Altiplano do Cabo Branco, Figure 10, satellite image in the middle, takes place around the extremely high-income vertical condominiums, approved by altering the template defined in the zoning, via decree, in 2008. In the Cabo Branco neighborhood are condominiums horizontal, also of very high income, with low occupancy rate. Both neighborhoods have low levels of environmental sanitation and the surrounding area does not have an urban drainage system (IBGE, 2010). These neighborhoods are located on the Barrier of Cabo Branco, of geological formation sensitive to landslides, located in the direction of the “Seixas” corals, which are threatened by the erosion of the cliff. For example, in June 2019, during a rainy extreme that lasted more than 72 hours, part of the barrier slid over the sea, affecting part of the corals. In this process of formalized occupation, legal from the point of view of urban policy, it subverts the idealization of a sustainable city of Leff (2007), strengthening the segregation of the elite in clusters of urban reality that does not exist outside the walls or perimeters of these neighborhoods.

The greatest losses of vegetated area occurred in a preservation area of the landscape, which is not densified, and in the area of the Master Plan that has no zoning whatsoever. This fact demonstrates that the establishment of laws to regulate the use and occupation of land does not align with the environmental policy, because, the reasonable flexibility existing within the scope of these regulatory devices opens space for the interests of the actors that compose the managements to redefine priorities in the name of urban entrepreneurship. Nevertheless, the popular participation forged within the ambit of the environment and urban development councils of the city of João Pessoa corroborates these advances that destroy the city's ecosystems.

In the context of climate change, land disputes within the power relations of capital tend to harm micro rural producers and traditional communities (IPCC, 2019) and may, in the near future, compromise the food security of the low-income population and traditional populations that persist in their rural subsistence characteristics, mainly in the southeastern portion of the municipality (Figure 3) where, as previously stated, riverside, indigenous and quilombola residents live.

Furthermore, ecosystem services related to the city's climatic-environmental regulation (CARVALHO E SZLAFSZTEIN, 2019 and VIEIRA ET AL., 2018) can be compromised with the loss of the Atlantic Forest, bringing consequences for water security in the city, mainly due to anthropic pressure on the Gramame River (Figure 8), in addition to contributing to the increase of heat islands (OKE et al., 2017 pp. 197), in future climatic scenarios.

Finally, according to Figures 5, 8 and 9, a large part of the deforestation has occurred in areas of low urban infrastructure, with the implantation of subdivisions for low income (Figure 4), imposing risk to these communities, which can experience direct and indirect effects of climate change (IPCC, 2019), mainly those associated with disasters, such as inundations, floods and runoffs, as a result of the increase in the intensity and frequency of rainy extremes combined with the low quality of environmental sanitation services (TUCCI, 2008), contrary to indications from the National Adaptation Plan - PNA (MMA, 2016), to promote urbanization of precarious settlements, and maintenance of populations in their original settlements, in the consolidated portion of the city.

#### **4 FINAL CONSIDERATIONS**

The urban space production process per se press the ecosystems, the pace and urban lifestyle demand the degradation of natural resources and the conformation of urban structures in Brazil were based on deforestation, soil waterproofing, contamination of water bodies and in the occupation of vulnerable areas.

In the Anthropocene, with the reality of the climatic emergency, an environmental rationality based on the idea that everything and everyone is part of interconnected and interdependent systems and subsystems has guided the production of institutional reports, policies, plans and governmental urban programs, but, but, although the guidelines and goals are from the perspective of sustainability, in practice, the executive projects arising from these documents do not correspond to multifunctional solutions that mitigate urban environmental problems.

What is perceived is that, across governments, there is a mismatch between planning and management. It is a marketing and deregulation agenda, characterized by the misunderstanding of nature and its cycles, which appropriates from it to raise funds and “plan projects” of special and dubious interests.

The unsustainable urbanism, wide open on maps, is the result of the supposed “democratic management of the city”, which grows and spreads according to profit and walls. With the consent of the public authorities for non-compliance with legislation, be it urban or environmental, the growth of the urban structure of the municipality of João Pessoa advances on important remnants of the Atlantic Forest.

This neglect of the public power is due both to the implementation of institutional projects for the settlement of low-income families, in areas lacking urban infrastructure, far from the commercial area and services of the city, as well as by the impetus for real estate and services aimed at elites and tourists with high purchasing power.

On the one hand, the vertical densification of areas already consolidated has been discarded by the upper social classes, who prefer the walls of closed horizontal condominiums or clusters of vertical condominiums, whose “view of nature” is the main asset of the projects; on the other, the provision of low-income housing, allocated in areas that are far from the city's tourist attractions, and demand the suppression of vegetation because they are close to the industrial and mining area, exposed to pollution and other risks associated with this proximity.

The adaptation of cities to the climate crisis involves sustainable densification, instead of urban sprawl, promoting the implementation of green infrastructure, sustainable transport and mobility: compact cities where internal mobility does not imply GHG emissions (MMA, 2016), and which can only be managed in a participatory manner, with socio-environmental justice for all inhabitants.

Climate threats do not affect the entire population in the same way, the lower income populations have less resilience than the more affluent classes but, on the other hand, with the recurrence of hydrometeorological disasters that affect these low-income or traditional communities, such as riverside communities, improve adaptation techniques that need to be taken into account when planning and implementing adaptation actions.

Adaptive measures must necessarily include the implementation of environmental sanitation services to reduce the risk of extreme events and the proliferation of waterborne and vector-borne diseases, especially in serving populations with less financial resources. These services must also be linked to the way of life of traditional populations and the ecosystem in which they will be inserted, based on alternatives for the collection of domestic sewage treatment and rainwater management that do not involve large infrastructure and concrete works, which may represent new environmental impacts.

Regarding traditional peoples and communities, the PNA (MMA, 2016) points out the need to maintain these populations in their traditional environments, promoting land regularization and agroextractive tools.

Deforestation, in addition to promoting the loss of GHG absorption capacity, compromises ecosystem services (i) of environmental regulation - the loss of vegetation and soil impermeability is directly related to heat islands, maintenance of water courses and its water capacity, increased energy consumption for environmental comfort, (ii) provision - by expelling riverside communities and small rural producers, in addition to (iii) culturally compromising the way of life of these populations.

As a future suggestion, it would be necessary to analyze the living conditions of the populations of the deforested areas with updated census data in 2021, as well as with data on environmental licenses and building permits granted throughout the historical data series of Hansen et al. (2013), to understand the impacts of urban expansion in the city of João Pessoa.

## NOTES

1 | The proposed reflection aims only to admit the naturalness of man and the historicity of nature, as discussing the conceptual dualism of the term is not the objective of this work.

2 | The Creation of Cemaden for risk monitoring and the creation of CENAD and the action structure of civil defenses in the three spheres of the federation are already important steps in the political, scientific and social organization of risk management actions in the country.

## REFERENCES

ALMEIDA, G. M. et al. A política nacional de regularização fundiária: capacidades institucionais dos municípios na implementação do Programa Federal Papel Passado e suas implicações na gestão do território. In: XVII Encontro Nacional da Associação Nacional de Pós-Graduação e Pesquisa em Planejamento Urbano e Regional - **Enanpur**, XVII, 2017. São Paulo, 2017.

BAI, X. et al. Plausible and desirable futures in the Anthropocene: A new research agenda. **Global Environmental Change**, v. 39, p. 351-362, 2016. <https://doi.org/10.1016/j.gloenvcha.2015.09.017>

BARCELLOS, C.; HACON, S. Velhos indicadores para novos problemas: a relação entre saneamento e saúde. **Revista Panamericana de Salud**, SciELO Public Health, v. 22, n. 3, 2007.

BARRETO, Cristiane Gomes. **Devastação e proteção da mata atlântica nordestina: formação da paisagem e políticas ambientais**. 294 f., il. Tese (Doutorado em Desenvolvimento Sustentável) - Universidade de Brasília, 2013.

BORBA, B.S.M.C. et al. Energy-related climate change mitigation in Brazil: Potential, abatement costs and associated policies. **Energy Policy**, v. 49, p. 430-441, 2012. <https://doi.org/10.1016/j.enpol.2012.06.040>

BORELLI, E. Urbanização e Qualidade Ambiental: o Processo de Produção do Espaço da Costa Brasileira. **INTERthesis**, v. 4, p. 1-27, Florianópolis, 2007. DOI: <https://doi.org/10.5007/%25x>

CAMAGNI, R. **Economía Urbana**. Barcelona, Espanha: Antoni Bosch Editor, 2005.

CAMPBELL, T. Desenvolvimento urbano no Terceiro Mundo: dilemas ambientais e pobres urbanos. In: LEONARD, H. Jeffrey (org.): **Meio ambiente e pobreza: Estratégias de desenvolvimento para uma agenda comum**. Rio de Janeiro: Ed. Jorge Zahar, 2002.

CARVALHO, R.M.; SZLAFSZTEIN, C.F. Urban vegetation loss and ecosystem services: The influence on climate regulation and noise and air pollution. *Environmental Pollution*, n. 245, p. 844-852, 2019. DOI: [doi.org/10.1016/j.envpol.2018.10.114](https://doi.org/10.1016/j.envpol.2018.10.114)

COHEN, D.A. **Climate Justice and the Right to the City**. USA: Penn University, 2018.

CRUTZEN, P.J. The Anthropocene. In: EHLERS E, KRAFF, T. (eds). **Earth System Science in the Anthropocene**. Berlin: Ed. Springer, 2006.

DONEGAN, L. **Qual é a sua praia?** Brasília: Ed. FRBH, 2019.

GOOGLE EARTH. **Satellite images**. Disponível em <https://earth.google.com/web/> . Acesso em Janeiro de 2020.

GOVERNO DO ESTADO DA PARAÍBA. Audiência Pública para Licença de Instalação para o Distrito Industrial do Turismo. Em atendimento à determinação do Ministério Público Federal/Procuradoria da República na Paraíba, conforme **Ata de Reunião realizada em 16 de maio de 2016**.

HACON, SS.; OLIVEIRA, BFA; SILVEIRA, I. Capítulo 4: Health Sector. NOBRE, C.A.; MARENGO, J.A., SOARES, W.R. (Org.): **Climate Change Risks in Brazil: A Review of the Health Sector Impacts of 4 °C or more Temperature Rise**. Ed. Springer, 2018.

HANSEN et. al. High-Resolution Global Maps of 21 Century Forest Cover Change. **Science**, v. 342, i. 6160, p. 850-853, 2013. DOI: [10.1126/science.1244693](https://doi.org/10.1126/science.1244693)

HARDOY, J. AND PANDIELLA, G. Urban poverty and vulnerability to climate change in Latin America. **Environment and Urbanization**, v. 21, n. 1, p. 203-224, 2009. <https://doi.org/10.1177/0956247809103019>

HARVEY, D. **A produção capitalista do espaço**. São Paulo: Ed. Anna Blume, 2001.

IBGE. **Censo demográfico 2010**. Disponível em [ibge.gov.br](http://ibge.gov.br) . Acesso em janeiro de 2020.

IBGE. **Tipologias Intraurbanas**. 2017. Disponível em [ibge.gov.br](http://ibge.gov.br) . Acesso em janeiro de 2020.

IPCC. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II. **Fifth Assessment Report of the IPCC**. Cambridge, UK and New York, NY, USA: Cambridge University Press. 2014.

IPCC. **Climate Change and Land Special Report**. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2019.

JACOBI, P., E SULAIMAN, S. Governança ambiental urbana em face das mudanças climáticas. **Revista USP**, v. 09, p.133-142, 2016. DOI: <https://doi.org/10.11606/issn.2316-9036.v0i109p133-142>

LEFEBVRE, H. **O Direito à Cidade**. São Paulo: Ed. Centauro, Reedição, 2011.

LEFF, E. **Saber Ambiental: sustentabilidade, racionalidade, complexidade e poder**. Petrópolis, RJ: Ed. Vozes, 2001.

MARENGO, J. O futuro do clima no Brasil. **Revista USP**, n. 103, p. 25-32. São Paulo. 2014. DOI: <https://doi.org/10.11606/issn.2316-9036.v0i103p25-32>

MINISTÉRIO DO MEIO AMBIENTE. **Plano Nacional de Adaptação**. Brasília, 2016.



MOURA, A. K. C.; GARCIA, L. G. Políticas públicas de turismo e sustentabilidade: o polo turístico Cabo Branco em análise. **CULTUR - Revista de Cultura e Turismo**, Ano 03, n. 03, p. 85-101, 2009.

NAKANO, A.K. A produção da “cidade oca” nos padrões recentes de verticalização e adensamento construtivo do município de São Paulo. **Revista Oculum Ensaios**. Campinas, 2018. DOI: <https://doi.org/10.24220/2318-0919v15n1a3373>

NOGUEIRA, F. AND CANIL, K. Reflexões sobre a gestão de risco: Avanços e limitações. In: SULAIMAN, S. E JACOBI, P. (org) **Olhares e saberes para a redução de risco de desastre**. São Paulo: IEE-USP, 2018.

OKE, T.R., MILLS, G.; CHRISTEN, A., VOOGT, J.A. **Urban Climates**. Cambridge: Cambridge University Press, Cambridge, 2017.

OJIMA, R. **Perspectivas para a Adaptação Frente às Mudanças Ambientais Globais no Contexto da Urbanização Brasileira: Cenários para os Estudos de População**. Campinas: NEPO - Unicamp, 2009.

ONU. **Urbanization and Development: emerging futures**. Nairobi, Kenya: United Nations Human Settlements Programme, 2016.

PMJP [Lei Municipal Complementar 03/1994] – **Lei do Plano Diretor da Cidade de João Pessoa**. João Pessoa, PB: Câmara de Vereadores, 1994.

PMJP [Lei Municipal 054/2009] – **Plano Diretor da Cidade de João Pessoa**. João Pessoa, PB: Câmara de Vereadores, 2012.

QUARESMA, I.N. et al. **Efetividade De Gestão Do Parque Estadual Do Jacarapé-PB**. CONGRESSO BRASILEIRO DE GESTÃO AMBIENTAL E SUSTENTABILIDADE, v. 5. João Pessoa, PB. 2017. ISSN 2318-7603.

SANTOS, M. **A Natureza do Espaço**. São Paulo: Ed. Edusp, 4ª edição, 1997.

SCHAEFFERA, R A et al. Energy sector vulnerability to climate change: A review. **Energy**, v. 38, I.1, p. 1-12, 2012. DOI: 10.1016/j.energy.2011.11.056

SILVA, G. et al. **Lugares e suas interfaces: transformações urbanas e periferização**. João Pessoa: Ed. UFPB, 2016.

SILVEIRA, J.A.R. et al. **Dinâmica da cidade e bordas urbanas**. João Pessoa: Ed. UFPB, 2015.

SMITH, A. A Riqueza das Nações. Coleção Os Economistas. São Paulo: Editora Nova Cultura, [1776] 1996.

SMITH, N. **Desenvolvimento Desigual**. Rio de Janeiro: Ed. Bertrand, 1998.

SOUZA, M. L. **Mudar a Cidade: uma introdução crítica ao planejamento e à gestão urbanos**. São Paulo: Ed Bertrand Brasil, 2001.

TUCCI, C. Águas urbanas. **Revista Estudos Avançados** v. 22, n. 63. São Paulo. 2008. Disponível em <http://www.revistas.usp.br/eav/article/view/10295> . Acesso em janeiro de 2020.

VIEIRA, J. ET AL. Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks. **Environmental Research**, n. 160, p. 306-313, 2018. <http://dx.doi.org/10.1016/j.envres.2017.10.006>

# Mudanças climáticas e o urbanismo insustentável no município de João Pessoa, Paraíba, Brasil

*Climate change and the unsustainable urbanism in the municipality of Joao Pessoa, Paraíba, Brazil*

Letícia Palazzi Perez<sup>a</sup>

Andréa Leandra Porto Sales<sup>b</sup>

José Augusto Ribeiro da Silveira<sup>c</sup>

<sup>a</sup>Doutora, Professora Visitante no Departamento e no Programa de Pós Graduação em Arquitetura e Urbanismo da Universidade Federal da Paraíba, João Pessoa, PB, Brasil  
End. Eletrônico: leticia.palazzi@gmail.com

<sup>b</sup>Doutora, Professora Adjunta no Departamento de Geografia da Universidade Federal da Paraíba, João Pessoa, PB, Brasil  
End. Eletrônico: andreaportosales@gmail.com

<sup>c</sup>Doutor, Professor no Departamento e no Programa de Pós Graduação em Arquitetura e Urbanismo da Universidade Federal da Paraíba, Vice Coordenador do Programa de Pós Graduação em Arquitetura e Urbanismo da Universidade Federal da Paraíba, João Pessoa, PB, Brasil  
End. Eletrônico: ctlaurbe@gmail.com

doi:10.18472/SustDeb.v11n2.2020.32330

Received: 02/07/2020  
Accepted: 19/08/2020

ARTICLE- VARIA

## RESUMO

No âmbito da produção do espaço urbano, a política urbana brasileira apesar de assinalar em suas diretrizes a luta pelo direito à cidade, parece indiferente aos impactos da especulação imobiliária sobre os ecossistemas. Dado o contexto da emergência climática, é urgente alinhar a política urbana e ambiental para o planejamento de cidades adaptadas às mudanças do clima. Este trabalho apresenta, a partir de dados espaciais do desflorestamento recente da cidade de João Pessoa, as características jurídicas e socioambientais da expansão urbana da cidade e como a política urbana e ambiental municipal têm catalisado processos de injustiça socioambiental. Constata-se que o planejamento e a gestão se limitam a acompanhar as tendências sinalizadas pelo mercado imobiliário e que pressionam os ecossistemas, principalmente na porção sul do município, e também que os arranjos democráticos são forjados para inviabilizar a atuação da sociedade na defesa dos ecossistemas.

**Palavras-chave:** Política Urbana. Política Ambiental. Espreadimento Urbano. Mudanças Climáticas.

## ABSTRACT

*In the scope of urban space production, Brazilian urban policy, despite pointing out in its guidelines the struggle for the right to the city, seems indifferent to the impacts of real estate speculation on ecosystems. Given the context of the climate emergency, there is an urgent need to align urban and*

*environmental policy for planning cities adapted to climate change. This work presents, based on spatial data from the recent deforestation of João Pessoa, the legal and socio-environmental characteristics of the urban expansion of the city and how the urban and environmental policy of João Pessoa has catalyzed processes of socio-environmental injustice. . It appears that planning and management are limited to following the trends signaled by the market that pressure ecosystems, mainly in the southern portion of João Pessoa, and also that democratic arrangements are forged to make it impossible for society to act in defense of ecosystems.*

**Keywords:** Urban Policy. Environmental Policy. Urban Sprawl. Climate Change.

## 1 INTRODUÇÃO

A ação antrópica sobre os ecossistemas avançou de tal forma vertiginosa desde a Revolução Industrial, criando a era geológica do Antropoceno (CRUTZEN, 2006, p. 14), a partir de processos de produção socioeconômica que resultam no aquecimento global. As novas formas de organização socioeconômica mundial, representadas a partir do crescimento populacional urbano, da mobilidade e consumo desenfreado implicam no uso intensivo dos recursos naturais (BAI et.al, 2016), amplificando, num círculo vicioso, as causas e os impactos das mudanças climáticas, desde a escala global até a local.

No entorno das cidades, o desflorestamento é o principal indicativo da pressão antrópica sobre os ecossistemas. A expansão urbana horizontal como a máxima transformação de escala local tem não só suprimido florestas, mas pressionado os rios e modificado o solo.

As cidades existem e tem existido na história porque os homens encontraram meios mais vantajosos e eficientes para gerir suas relações sociais, econômicas e de poder de forma espacialmente concentrada (CAMAGNI, 2005, p. 21). No curso da história, conforme relata Santos (1997), as relações de produção econômica e de reprodução social que sustentam o capitalismo situaram na estrutura urbana de maneira diferenciada, no tempo e nos territórios sob condições técnicas e políticas específicas, formas de obter lucro através de vantagens proporcionadas pela concentração das pessoas e das coisas.

Assim, a vantagem locacional da estrutura urbana colocou em segundo plano, ironicamente, nos planos e planejamentos urbanos, as necessidades antropológicas socialmente elaboradas na cidade para se viver na cidade, negligenciando os ecossistemas.

Segundo Lefebvre (2001), a necessidade do encontro, da organização do trabalho, do jogo, de comunicação e de uma qualidade de vida foram forjadas pelo urbanismo tecnocrático e dos promotores de venda dos produtos imobiliários, materializadas em equipamentos coletivos, comerciais e produtos imobiliários que fragmentaram a cidade, gerando segregação espacial e “novos” problemas urbanos, como os de cunho ambiental: escassez de água, desastres naturais, ondas de calor são exemplos desses problemas.

Em seus esforços para otimizar a organização das atividades econômicas e reprodução social e minimizar o caos socioambiental, gerado e oriundo, dos planos e planejamentos pretéritos, as entidades supranacionais, agências multilaterais e o poder público têm idealizado agendas e planos diversos, cujas pautas, diretrizes e metas visam alcançar a “sustentabilidade urbana” (LEFF, 2007).

À primeira vista, a ruptura de paradigma traz reflexões importantes sobre a força política dos agentes urbanos locais nos processos decisórios e preocupações inevitáveis quanto a sobrecarga da sociedade urbana no planeta terra. Contudo, urge apontar as contradições existentes na interface do planejamento urbano e do planejamento ambiental, que catalisam a evolução dos conflitos de uso e ocupação do solo, que por sua vez acentuam os problemas ambientais. E, sobretudo, destacar a apropriação e instrumentalização do discurso da proteção ambiental para fins de especulação imobiliária.

Quando a teoria de formação de valor de Adam Smith (1776 [1996]) nega a prioridade da produção agrícola na geração de riqueza, a natureza é propositalmente apontada como um obstáculo ao desenvolvimento econômico nas teorias econômicas clássicas, que atribuíram ao trabalho papel fundamental na formação de riquezas<sup>1</sup>. Neil Smith (1988), ao refletir sobre o complexo processo de produção da natureza, sob a lógica capitalista de produção do espaço, destaca que a desvalorização da natureza na teoria foi acompanhada pela sua desvalorização na realidade para sua apropriação como meio de produção.

No percurso da urbanização, aqui, entendida como um processo de múltiplas dimensões catalisado pela industrialização, a suposta dominação da natureza foi conveniente na teoria e na prática até as crises de escassez de recursos ou seus efeitos mais imediatos (SMITH, 1988), como a mudança do clima. As inundações, alagamentos, deslizamentos de terra, poluições diversas e demais pressões sobre os ecossistemas são alguns dos efeitos mais imediatos e percebidos na escala da cidade. Eles resultam de um planejamento orientado para as tendências do mercado e da especulação imobiliária. Ou seja, não são oriundos de uma crise ambiental, mas da contradição do próprio processo de produção do espaço urbano que expressa seus limites de desenvolvimento ao atribuir valor aos recursos naturais como água, vegetação e solo fértil.

Uma reivindicação da natureza está sendo materializada nas políticas, planos, programas e projetos (supra)governamentais. Trata-se de um anúncio indireto para fugir não só da tendência de uma cidade deteriorada, fragmentada e dispersa, mas, sobretudo, como argumenta Leff (2007, p.67), trata-se de um apelo “a construção de outra racionalidade produtiva, fundada nos potenciais da natureza”.

A adoção desta perspectiva demandaria um reajuste do planejamento, das diretrizes do ordenamento territorial e das formas de regulação dos espaços públicos e das áreas proteção ambiental na cidade, mas, sobretudo, um reajuste nas formas e espectro da governança urbana (SOUZA, 2001).

A descentralização das competências administrativas e a participação da sociedade no planejamento urbano têm sido apontadas como caminhos democráticos capazes de mitigar problemas socioambientais (ONU, 2016; JACOBI & SULAIMAN, 2016). Contudo, essa superestimação do poder local nos processos decisórios, como instauradora da justiça social e da proteção ambiental, contida nas orientações internacionais, só funciona quando os cidadãos contribuem verdadeiramente na implementação e, principalmente, no monitoramento das políticas públicas. Do contrário, conforme argumenta Souza (2001), corre-se o risco de instrumentalizar o discurso da participação popular no planejamento e o da proteção ambiental para forjar interesses de produtividade do capital sobre o espaço urbano, lamentavelmente, como argumenta Campbell (1996, p.196):

Têm sido fracos os controles sobre o uso da terra e o desenvolvimento urbano nas cidades do Terceiro Mundo, e a maioria dos instrumentos e técnicas adotados nos países desenvolvidos – planejamento do uso da terra e planos diretores, zoneamentos, permissões para uso da terra e para construir, além do imposto territorial – é emasculada nos países em desenvolvimento pelo poder da demanda, as dificuldades de administração, os interesses especiais e a corrupção (CAMPBELL, 1992, p.196).

Neste sentido, este artigo objetiva apresentar, a partir do desflorestamento recente no município de João Pessoa, as principais áreas de expansão urbana e suas características legais e socioambientais para discutir como a política urbana e ambiental municipal têm subsidiado o processo de expansão urbana em detrimento da preservação ambiental.

## 1.1 ESPRAIAMENTO URBANO VERSUS URBANISMO SUSTENTÁVEL

Mais de 50% da população mundial vive em áreas urbanas que ocupam menos de 1% da superfície terrestre (IPCC, 2019). Além de aumentar as emissões de gases efeito estufa (GEE), o transporte motorizado, a construção civil, o gasto energético na manutenção e funcionamento das cidades

(SCHAEFFERA et. al, 2012; BORBA, 2012), a população urbana mundial gera cerca de 25% das emissões globais totais de carbono, através do uso de energia (IPCC, 2014). A pressão da urbanização sobre os ecossistemas e a degradação de áreas florestadas, dentro e fora do ambiente urbano, tende a aumentar, seja pela necessidade de produção habitacional ou pelo consumo de alimentos e outras mercadorias, em sua maioria produzidas à quilômetros de distância das grandes cidades.

Dentre os principais impactos das mudanças climáticas no Brasil estão o aumento de temperatura, a alteração no regime de chuvas e o aumento da ocorrência de extremos de clima, com especial destaque aos extremos chuvosos, aumento da ocorrência de secas, além das elevações e sobre-elevações do nível do mar (MARENGO, 2014).

A urbanização desordenada ou explorada pelos anseios de lucro imediato (HARVEY, 2001) tem consequências no aumento do risco climático à população. Nos extremos chuvosos, a falta de infraestrutura urbana como drenagem de águas pluviais e saneamento ambiental, bem como ocupação de várzeas e encostas, intensificam o impacto das chuvas nas áreas urbanas (TUCCI, 2008), principalmente, mas não exclusivamente, nos assentamentos precários, onde também reside a população mais pobre e vulnerável aos impactos destes eventos (HARDOY & PANDIELLA 2009).

O *Assessment Report 5* (AR5) do IPCC (2014) aponta que as populações mais vulneráveis socioeconomicamente são também as mais vulneráveis aos impactos das mudanças climáticas: as intrínsecas relações de renda, classe social, gênero, etnia, idade e necessidades especiais são fatores condicionantes da capacidade adaptativa e exposição ao risco.

Se a vulnerabilidade socioeconômica é um dos principais fatores condicionantes da intensidade do impacto das mudanças climáticas sobre as populações (OJIMA, 2009; BARCELLOS E HACON, 2007), os processos de redução dos impactos das mudanças climáticas nas cidades passa, necessariamente, por novas perspectivas de governança, pautadas nos processos democráticos e participativos previstos na legislação (JACOBI E SULAIMAN, 2016), no conhecimento popular das comunidades tradicionais e, também, na redução da desigualdade socioeconômica. A redução da desigualdade social é questão prioritária para a adaptação da população brasileira aos impactos das mudanças climáticas. O IPCC (2014) coloca a importância das políticas de transferência de renda, fazendo inclusive menção ao programa bolsa família, no AR5.

No Brasil, 75% dos 5.570 municípios estão isentos de elaborar Planos Diretores por terem menos de 20 mil habitantes. Apesar do Estatuto da Cidade (2001) e da Reurb (2017) estabelecerem instrumentos jurídicos essenciais para a melhoria da qualidade da infraestrutura urbana, principalmente em assentamentos precários ou informais, a baixa capacidade institucional de muitos municípios brasileiros (ALMEIDA et al, 2017), atrelada às pressões do poder do capital sobre a dinâmica urbana dificultam a aplicação de tais instrumentos. Esses fatos comprometem o ordenamento urbano e, conseqüentemente, o planejamento urbano sustentável. Intensifica-se ainda a vulnerabilidade pela dificuldade em organizar ações preventivas da defesa civil, que ainda atua no socorro e não na prevenção<sup>2</sup> (NOGUEIRA E CANIL, 2018).

Se é essencial promover o planejamento urbano sustentável como adaptação às mudanças do clima, incentivar a agricultura urbana, a arborização e permeabilidade das cidades, bem como promover o adensamento adequado das cidades, inibindo o espraiamento e, conseqüentemente, a diminuição da pressão das áreas urbanas sobre os ecossistemas e áreas rurais, o adensamento urbano inteligente e a execução das infraestruturas verdes e digitalizadas são elementos do desenvolvimento urbano que favorecem a mobilidade não poluente de menor gasto energético (COHEN, 2017). Para Nakano (2018) são os instrumentos urbanísticos bem aplicados que podem determinar o “ponto ótimo” de adensamento, sob a perspectiva socioambiental.

Nesse sentido, o município de João Pessoa está em direção oposta à promoção de uma cidade adaptada à crise climática, acomodando o espraiamento urbano, principalmente sobre as últimas reservas de

Mata Atlântica e cursos de abastecimento d'água do município, tão importantes para a mitigação dos impactos das mudanças climáticas na ocorrência de doenças, ondas de calor, na segurança hídrica, além dos desastres relacionados às ocupações das margens dos rios.

## 1.2 ESPRAIAMENTO URBANO DE JOÃO PESSOA

João Pessoa, capital do Estado da Paraíba, Nordeste do Brasil, tem aproximadamente 800.000 habitantes, com 214 km<sup>2</sup>, 64 bairros e 120 aglomerados subnormais (IBGE, 2010). Apenas 20% da população pessoense tem ensino superior completo e 15% da população está entre pobres e extremamente pobres, com renda menor que 1 salário mínimo (IBGE, 2010).

No município de João Pessoa, encontram-se quatro Unidades de Conservação, cadastradas no Sistema Nacional de Unidades de Conservação (SNUC), sendo elas Floresta Nacional da Restinga de Cabedelo (2004), o Parque Natural Municipal do Cuiá (2012), o Refúgio da Vida Silvestre da Mata do Buraquinho (2014) e o Parque Estadual das Trilhas (2017), conforme Figura 1.

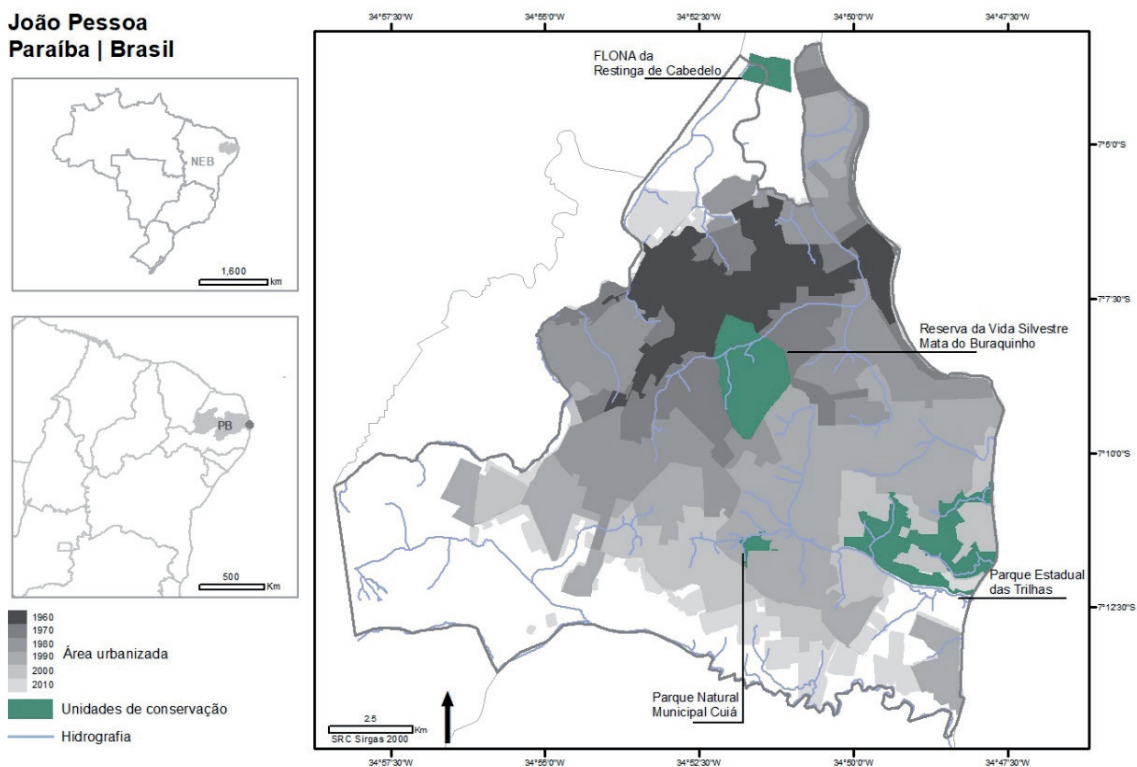


Figura 1 | Mapa de localização de João Pessoa: áreas protegidas, áreas verdes e área urbanizada.

Fonte: MMA (2019); IBGE (2010). Elaborado pelos autores.

A década de 1960 é um marco da expansão urbana da cidade, fomentada pela iniciativa privada, com a consonância e intervenção do poder público. O desenvolvimento dos transportes motorizados e particulares permitiram o acesso a lugares mais distantes da área central, que somados a abertura de avenidas importantes como a da Epitácio Pessoa e Pedro II, e a transposição dos cursos dos rios da cidade, em especial os dos rios Jaguaribe, Mandacaru, Tambiá e pequenos afluentes, possibilitaram o crescimento da estrutura urbana para a região norte-nordeste (SILVEIRA et al., 2015).

Atualmente, essa lógica de produção do espaço urbano é orientada pela lógica do mercado imobiliário, que direciona o crescimento da estrutura urbana para a porção sul da cidade, onde não há infraestrutura urbana consolidada e resquícios de Mata Atlântica são sistematicamente suprimidos para alocar,

principalmente, empreendimentos turísticos dos governos municipal e estadual, e produtos imobiliários residenciais verticais, para um baixo renda na porção sul-sudoeste, e para alta renda na porção sul-sudeste do município, constituindo uma cidade fragmentada (HARVEY, 2001).

## 2 METODOLOGIA

Dados espaciais e socioambientais foram utilizados e correlacionados em técnicas de análise espacial para construção de mapas que permitiram delinear a realidade da expansão urbana. O levantamento dos dispositivos jurídicos que regulam o uso e ocupação do solo da cidade, bem como dos registros democráticos de audiências e conselhos municipais serviram para identificar e caracterizar a dinâmica e arranjos políticos existentes na cidade.

Para compreensão do tema, buscou-se um alinhamento do debate urbano com o ambiental pela seleção de um repertório conceitual capaz de fornecer um entendimento sobre a natureza social da cidade e dos processos ecológicos que ocorrem em estruturas urbanas.

Os conceitos foram divididos em três grandes tipos: a) os indispensáveis para pensar a problemática, como “produção do espaço” e “mudança climática”; b) os que estão em fase de aceitação no âmbito do sistema filosófico de validação que utilizam os primeiros, apesar de necessários, como “sustentabilidade”; c) e aqueles não recorrentes, mas que neste trabalho foram fundamentais para alinhar as dimensões de análise, como o “política de escalas”.

Nesse sentido, o levantamento bibliográfico consistiu na busca por obras clássicas, revisões teóricas e do estado da arte via documentos oficiais (atas, planos, mapas e relatórios) e dispositivos jurídicos, que por sua vez indicaram os dados socioeconômicos e espaciais indispensáveis à análise espacial.

As geoestatísticas foram elaboradas a partir de dados derivados do projeto *Global Forest Change* (HANSEN et al., 2013), dados do IBGE (2010, 2017), do Plano Diretor Municipal (PMJP, Lei Municipal 054/2009) e Ministério do Meio Ambiente (2019), em um sistema de informação georreferenciado.

Os dados de desflorestamento (HANSEN et al., 2013) em formato *raster* indicam a data da perda de floresta a cada ano, em uma série histórica de 2000 até 2018, com base em imagens *Landsat*. Estes dados foram vetorizados e posteriormente transformados em manchas de concentração de ocorrência de perda de vegetação, a partir da densidade de linhas de cada vetor.

Estas manchas de concentração de ocorrência de perda de vegetação apontaram, em meso-escala, quais as áreas mais afetadas pelo desflorestamento, uma vez que o intuito é observar o processo de produção do espaço urbano, do ponto de vista da perda de áreas verdes e pressão sobre os ecossistemas.

Entendendo que o desflorestamento se dá quando da expansão urbana sobre os ecossistemas, as manchas de perda de vegetação foram plotadas sobre Unidades de Conservação e hidrografia. Por outro lado, para a compreensão das características socioambientais do espraiamento urbano, estas manchas foram também plotadas sobre a classificação de Tipologias Intraurbanas do IBGE (2017), que aponta, a partir de dados de saneamento ambiental, renda, escolaridade, acesso à bens e serviços, as condições de vida da população.

Em escala mais detalhada, foram plotados os mapas das manchas de perda de vegetação com o Macrozoneamento, para que fosse possível observar a produção do espaço urbano baseado nas estratégias de governança urbana da lei em vigor. Por fim, juntamente a estes cartogramas, foram adicionadas imagens da plataforma Google Earth, permitindo a observação das ações antrópicas que causam o desflorestamento.

A partir dos cartogramas gerados, foram feitas análises da produção do espaço urbano, observando os diversos aspectos socioambientais e jurídicos da expansão urbana do município de João Pessoa.

### 3 RESULTADOS E DISCUSSÃO

O primeiro Plano Diretor de João Pessoa foi elaborado em 1992 e publicado oficialmente em 1994, através da Lei Complementar 03/1994 (PMJP, 1994). É fruto da reforma urbanística brasileira, mas não representa o primeiro ordenamento territorial e zoneamento do município. Porém, como um instrumento básico da política urbana brasileira apresentou diretrizes, normas e restrições para o uso e ocupação do solo da cidade. O desenho da expansão urbana possível do plano, conforme Figura 2, esboçou preocupações ambientais ao assinalar as áreas de proteção permanente e as unidades de conservação municipais e estaduais.



Figura 2 | Plano Diretor de João Pessoa, 1992.

Fonte: Escaneado dos originais analógicos.

Ao analisar zoneamento pretérito e o uso e ocupação recente do solo, é possível constatar um indistigável conteúdo político-ideológico na sua elaboração, ao promover estoque de terras para empreendimentos turísticos na faixa litorânea da cidade (HARVEY, 2001, p. 166-170 e p. 221).

As zonas de restrições adicionais, delineadas na Figura 3, e caracterizadas como áreas da cidade de “interesse social de preservação de características ambientais, paisagísticas, históricas e culturais” foram, paulatinamente, sendo negligenciadas em nome de interesses particulares e sancionadas pelas gestões em nome do “desenvolvimento urbano”, contrariando as expectativas de Leff (2007) de que arranjos interinstitucionais e instrumentos legais poderiam direcionar a política urbana à sustentabilidade.

A inexistência de um sistema brasileiro de planejamento urbano articulado com os dispositivos jurídicos que sancionam os parâmetros urbanísticos de uso e ocupação do solo com outras políticas públicas que incidem sobre o urbano, como a ambiental, permite que manobras baseadas em interesses especulativos menos visíveis sejam executadas sem fiscalização ou controle adequado pelo poder público.

A exemplo, a construção em andamento de um hipermercado, cujo projeto arquitetônico assinala a edificação de 12.000 m<sup>2</sup> em Setor de Amenização Ambiental (SAA) e Área de Preservação Permanente (APP). A licença ambiental de instalação foi concedida pela Secretaria Municipal de Meio Ambiente e cassada por unanimidade pelo Conselho Municipal de Meio Ambiente (COMAM).

O parecer da conselheira da Universidade Federal da Paraíba, ao processo nº 2018/068932 e 2018/066994 da Secretaria de Meio Ambiente, foi contundente ao assinalar diversos aspectos pelos quais a obra deveria ser interrompida, entre eles: i) a incongruência na tipificação do empreendimento entre a Secretaria de Planejamento (SEPLAN) e a SEMAM<sup>3</sup>; ii) a negligência do órgão responsável pela emissão da licença ambiental ao permitir uma taxa de ocupação do lote em dobro da estipulada por lei no setor de



amenização ambiental; iii) ao não coibir a supressão vegetal de fragmentos da Mata Atlântica; iv) autorizar a instalação de um empreendimento que não apresenta um plano de gerenciamento dos resíduos sólidos e efluentes, em área sem infraestrutura de saneamento; v) e não apresentar um estudo de impacto de vizinhança para empreendimento deste porte. Apesar da unanimidade do pedido de cassação da licença, a obra continua em andamento. Tal fato, trata-se de um exemplo claro de como a produção do espaço urbano se dá de acordo com os interesses do capital acima dos interesses socioambientais da população, a partir da anuência e conveniência do poder público.

Essas práticas das gestões municipais não só demonstram um desequilíbrio entre a política de escalas da legislação urbana e da legislação ambiental, que possibilita um descumprimento entre uma e outra, conforme o interesse dos agentes que participam e operam o ritual burocrático, conforme Campbell (1992).

Os processos e fluxos naturais que se dão na paisagem urbana são fundamentais para uma qualidade de vida cotidiana na cidade. Não é só uma questão de proteção ambiental, mas um direito à cidade. O contato com a natureza, tomar sol, respirar ar puro, caminhar para fazer compras, ter acesso a água potável, encontrar amigos e trabalhar são necessidades individuais que realizamos de modo coletivo na cidade.

Com os retrocessos institucionais em áreas críticas como a ambiental e a urbana, têm-se permitido o avanço da estrutura urbana nos fragmentos de Mata Atlântica, não apenas no município de João Pessoa, mas também como ocorre no litoral norte do Estado de São Paulo (BORELLI, 2007), com o avanço da urbanização fragmentada, pautada na exploração turística da região e que implica na perda da qualidade de vida na cidade, ou conforme Barreto (2013), que estudou profundamente o histórico de ocupação da Mata Atlântica nordestina, desde a colonização aos dias atuais. Barreto (2013) aponta também a necessidade de promover conectividade entre os fragmentos de Mata Atlântica no Nordeste brasileiro, proposição esta que se torna inviável com o espraiamento urbano e pressão sobre o que resta deste bioma.

Apesar de possuir duas grandes áreas não urbanizadas, uma ao norte e outra ao sul, o desflorestamento do município de João Pessoa concentra-se na porção sul do município, conforme Figura 3, onde existem comunidades quilombolas, indígenas e pescadores artesanais, como Paratibe, Tabajaras e Jacarapé, nenhuma delas demarcadas ou regulamentadas.

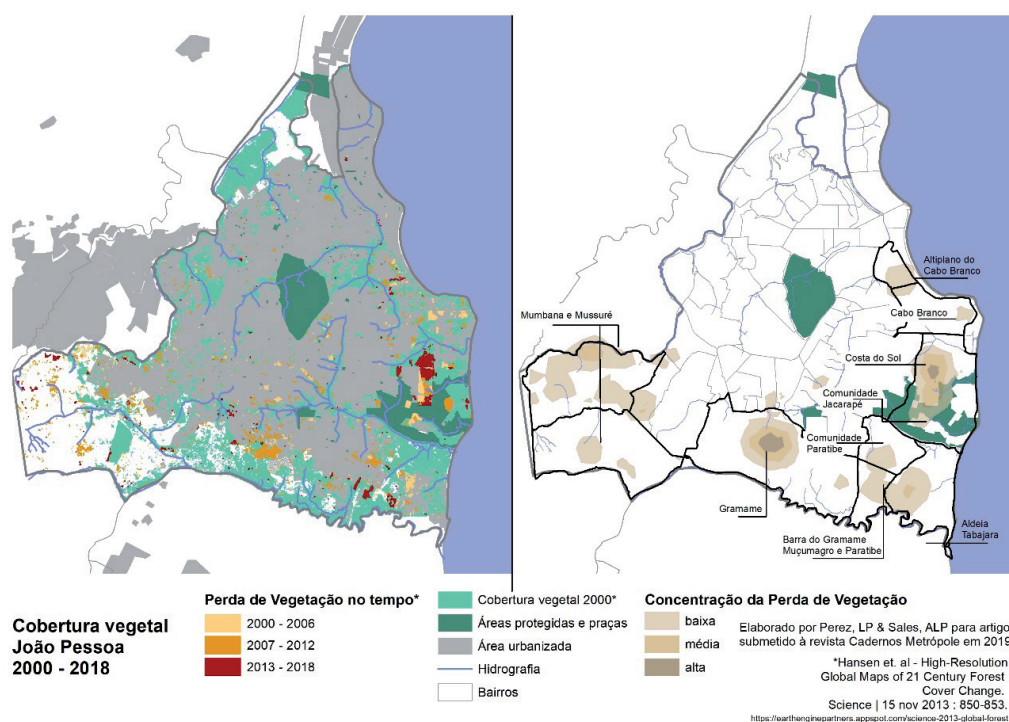


Figura 3 | Mapas da cobertura vegetal e perda de vegetação em João Pessoa.

Fonte: Hansen et al. (2013), MMA (2019). Elaborado pelos autores.

Entre 2007 e 2018, grandes áreas de desflorestamento podem ser observadas na porção sudeste, próximas ao Parque Estadual das Trilhas, Unidade de Conservação decretada em 2017. A mancha em laranja, na Figura 3, mais a leste, é o Centro de Convenções, inaugurado em 2012, e que é parte do plano de desenvolvimento de um distrito industrial de turismo de alto padrão (GOVERNO DO ESTADO DA PARAÍBA, 2017).

Na porção norte do Parque das Trilhas, bairro Costa do Sol, Figura 4, o desflorestamento mais recente pode ser observado sob a lógica do capital que segue, espacialmente, o empreendedorismo da política pública urbana (HARVEY, 2001) para ocupar áreas antes florestadas e que agora possuem infraestrutura de transporte trazidos pela instalação do Centro de Convenções. Na porção sudeste, em bairros como Barra do Gramame, Muçumagro e Paratibe, o desflorestamento aparece em direção ao município vizinho, o Conde, que possui praias disputadas pelo setor turístico.

As manchas de perda de vegetação das áreas centro sul e sudoeste, respectivamente do bairro Gramame, seguido dos bairros de Mussurê e Mumbaba, se apresentam como a grande fronteira de expansão sobre os ecossistemas - das áreas de Mata Atlântica ao rio Gramame, que abastece a cidade. Na Figura 4 é possível observar que, diferente do entorno do Parque das Trilhas, nessas áreas encontra-se baixa condição de vida (IBGE, 2017).

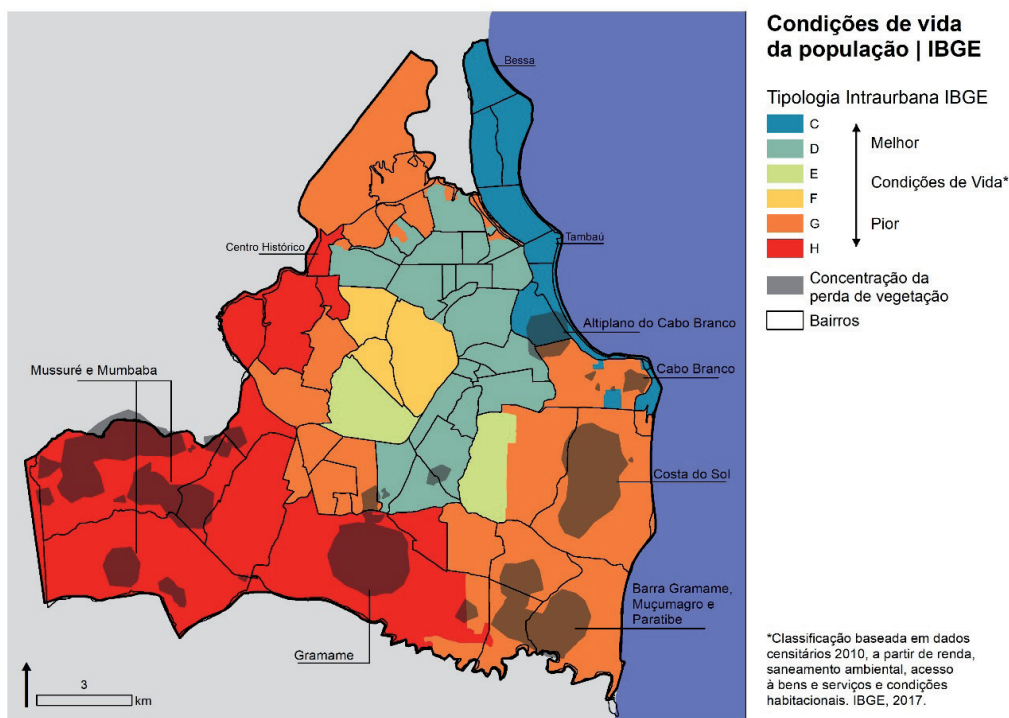


Figura 4 | Tipologias intraurbanas de João Pessoa.

Fonte: IBGE (2017). Elaborado pelos autores.

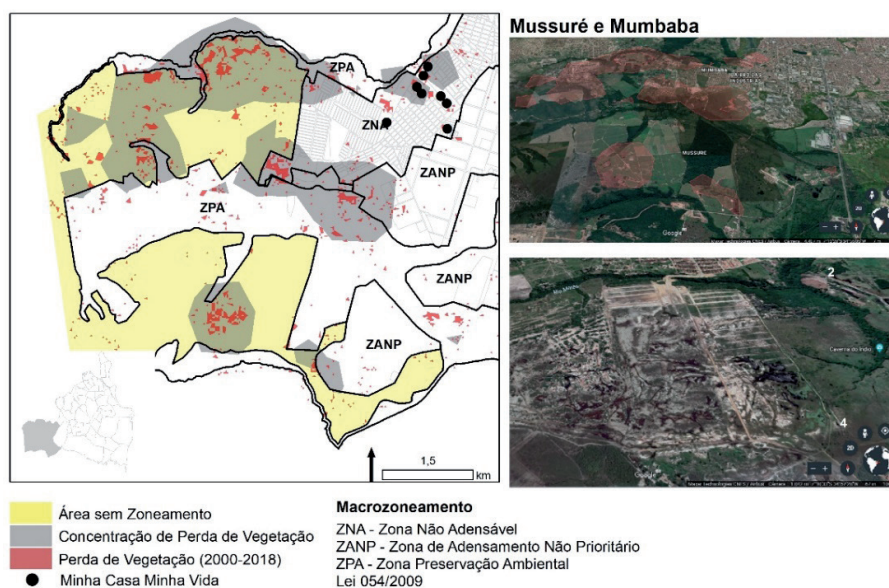
Com o cálculo de perda de vegetação, entre 2012 e 2018, por macrozona do Plano Diretor, é possível observar que a expansão urbana se dá prioritariamente (quase 90% do total) sobre Zonas Não Adensáveis, de Adensamento Não Prioritário, Setores de Amenização Ambiental, Preservação da Paisagem e extremamente próximos das Zonas de Proteção Ambiental, muitas vezes ocorrendo às margens de áreas de preservação permanente. Tal constatação, aponta um descumprimento da legislação e para a fragilidade da política urbana e ambiental municipal face aos ecossistemas, que deveriam ser valorados em uma cidade vista como turística.

**Tabela 1 | Perda de vegetação (2012-2018) por Macrozona do Plano Diretor.**

| Macrozona                                | Área (ha) | Percentual (%) |
|--|-----------|----------------|
| ZONA DE PRESERVAÇÃO AMBIENTAL - ZPA      | 157.1     | 53.1           |
| ZONA NÃO ADENSÁVEL - ZNA                 | 105.3     | 35.6           |
| SEM ZONEAMENTO                           | 15.7      | 5.3            |
| ZONA ADENSÁVEL NÃO PRIORITÁRIA - ZANP    | 12        | 4.1            |
| SETOR DE PROTEÇÃO DA PRAISAGEM - SPP     | 2.7       | 0.9            |
| SETOR DE EXPLORAÇÃO MINERAL              | 1.3       | 0.4            |
| ZONA ADENSÁVEL PRIORITÁRIA - ZAP         | 1         | 0.3            |
| SETOR DE AMENIZAÇÃO AMBIENTAL - SAA      | 0.5       | 0.2            |
| SETOR DE TRATAMENTO DE RESÍDUOS LÍQUIDOS | 0.3       | 0.1            |

Fonte: Elaborada pelos autores a partir de dados Hansen et al. (2013) e PMJP.

Na porção sudoeste de João Pessoa encontram-se grandes manchas de desmatamento provenientes de dois processos muito distintos: mineração e habitação social e popular, conforme Figura 5.



**Figura 5 | Detalhamento da perda de vegetação no bairro Costa do Sol.**

Fonte: Hansen et al. (2013), Lei 054/2009, Google Earth Pro. Elaborado pelos autores.

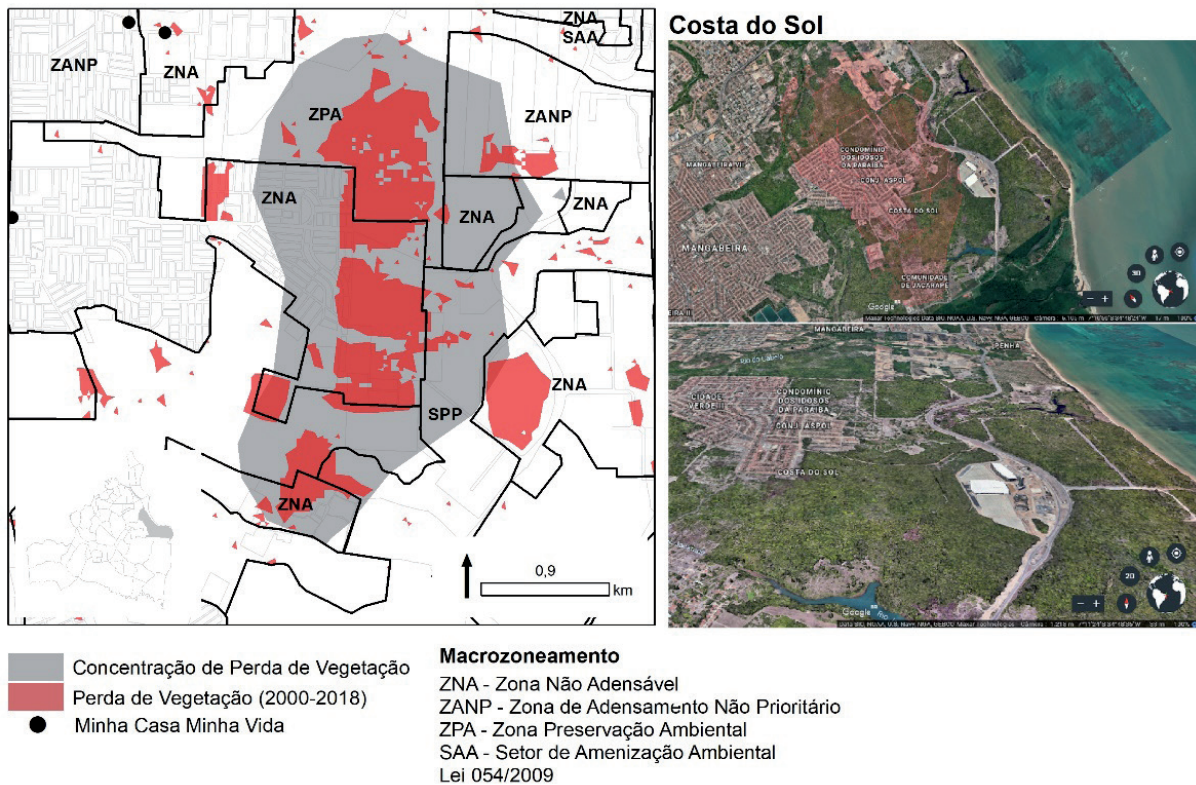
Em uma área que não tem macrozona definida pela lei vigente, percebe-se a exploração mineral (Figura 5) no entorno de Zonas de Proteção Ambiental.

Conforme Silva et al. (2016), a expansão urbana segrega os mais pobres de oportunidades socioambientais, uma vez que o acesso à cidade se dá pelo consumo e custo da terra. Em João Pessoa, e em outras cidades do litoral nordestino, as áreas mais distantes da “vista para o mar” são as mais excluídas e Donegan (2019) já discutiu como a infraestrutura urbana litorânea possui uma morfologia urbana que exclui a parcela mais pobre da população.

Nos bairros do Cabo Branco e Altiplano do Cabo Branco, embora as manchas de desflorestamento sejam menores (Figura 3), é importante observar a alta condição de vida (IBGE, 2017) da população

nestas áreas (Figura 4) para, a seguir, compreender como se dá a produção capitalista do espaço urbano nas regiões mais turísticas de João Pessoa.

No bairro Costa do Sol é possível observar (Figura 6) que, de acordo com a legislação vigente (PMJP, Lei Municipal 054/2009), a perda de vegetação se deu em zonas não adensáveis ou de adensamento não prioritário. Trata-se de loteamentos aprovados a partir da primeira década deste século, com condomínios horizontais que, apesar de serem apontados pelo censo IBGE de 2010 como de baixa renda, hoje estão sendo ocupados por população de classe média alta, suposição que poderá ser confirmada apenas no censo IBGE 2021.

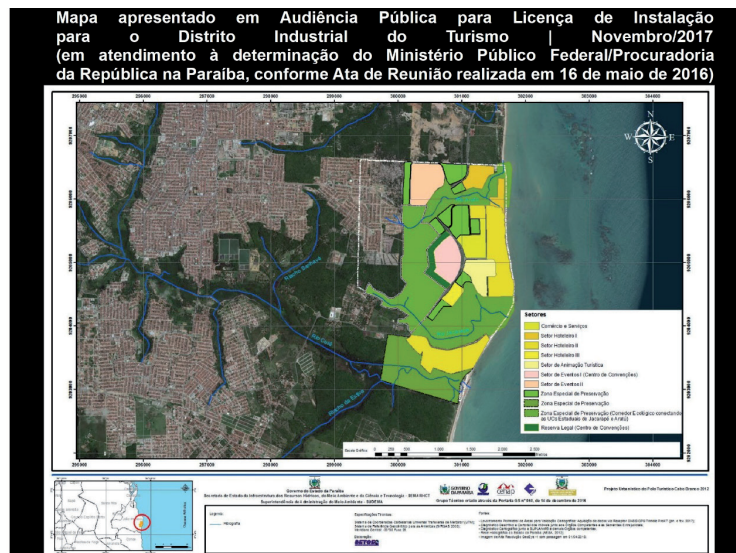


**Figura 6 |** Detalhamento da perda de vegetação no bairro Costa do Sol.

*Fonte: Hansen et al. (2013), Lei 054/2009, Google Earth Pro. Elaborado pelos autores.*

Os bairros destacados na Figura 6 seguem a lógica da segregação apontada por Harvey (2001), em que uma parceria público-privada, não legalizada, mas acordada, serve infraestrutura urbana inexistente fora dos muros dos condomínios fechados, ou existente apenas nos arredores dos altos condomínios verticais, atendendo aos anseios da classe mais abastada da população.

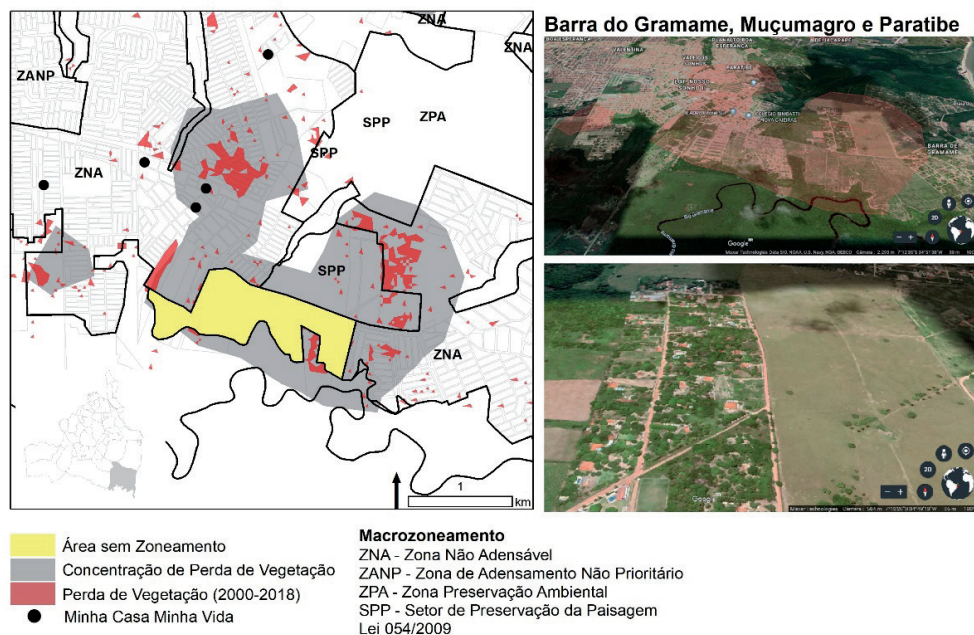
O Centro de Convenções, na imagem de satélite da parte inferior da Figura 6, mostra que a infraestrutura viária trazida pela construção do equipamento contribui para o avanço da mancha urbana na região sul de João Pessoa. Na mesma imagem, a porção mais a leste da mesma foto mostra uma grande área florestada que virá a se transformar no distrito industrial de turismo de alto padrão (Governo do Estado da Paraíba, 2017), conforme mostra a Figura 7 abaixo.



**Figura 7 |** Mapa do projeto de desenvolvimento urbano do Distrito Industrial de Turismo de João Pessoa.  
*Fonte: Governo do Estado da Paraíba (2017).*

É nesta mesma área que se localizam a Comunidade Jacarapé, em que vivem pescadores artesanais divididos em dois núcleos, sendo um deles à beira-mar (Figura 3). Esta comunidade tem sofrido diversas tentativas de remoção, para dar lugar aos empreendimentos turísticos, materializando o que o IPCC (2019) aponta como disputa de terra e perda de modos de vida e subsistência das comunidades tradicionais.

Os polígonos das unidades de conservação envolvem a área do distrito turístico formando um escudo protetor. A infraestrutura urbana destinada à oferta turística tende a ter mais sobrecarga e a pressionar a biodiversidade adjacente mais que a demanda doméstica. Ironicamente, boa parte do fragmento de Mata Atlântica que se constitui como o principal ativo do empreendimento será suprimido para dar espaço aos *resorts* que serão implementados. A racionalidade econômica e política que guiam esses projetos e ações do governo mostram uma ordem baseada na lei de mercado, na qual os entes do Estado agem como empreendedores urbano para atrair investimentos (Harvey, 2001).



**Figura 8 |** Detalhamento da perda de vegetação nos bairros Barra do Gramame, Muçumagro e Paratibe.  
*Fonte: Hansen et al. (2013), Lei 054/2009, Google Earth Pro. Elaborado pelos autores.*

Na porção sudeste do município, o desflorestamento se dá principalmente pela ocupação de chácaras de veraneio, como mostra a Figura 8. Corroborando com o Macrozoneamento Municipal, são loteamentos de baixo coeficiente de ocupação. Esses assentamentos fazem pressão sobre o rio Gramame e sobre populações tradicionais que ainda lutam por reconhecimento, como a comunidade do Paratibe e os indígenas Tabajara (QUARESMA, 2017), que devem sofrer processo de expulsão por influência da especulação imobiliária, sendo a comunidade Paratibe ameaçada pela mesma lógica da remoção da comunidade Jacarapé, implicando ainda na perda de serviços ecossistêmicos culturais, além de provisão (IPCC, 2019).

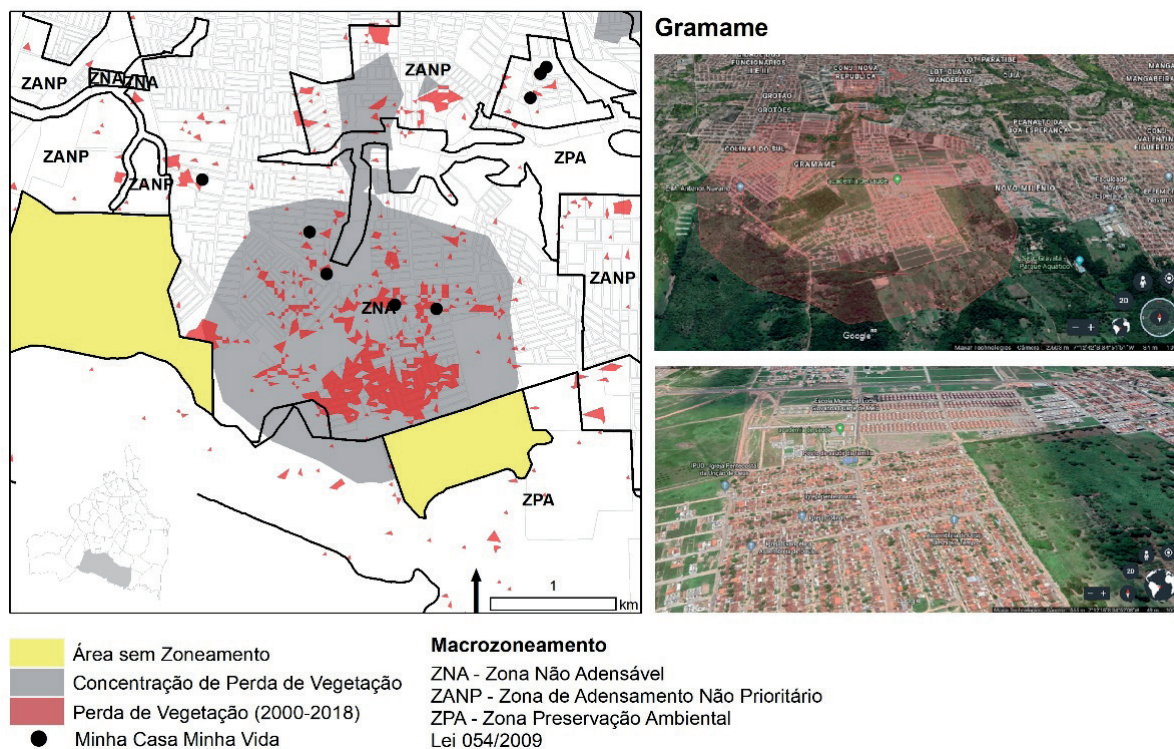
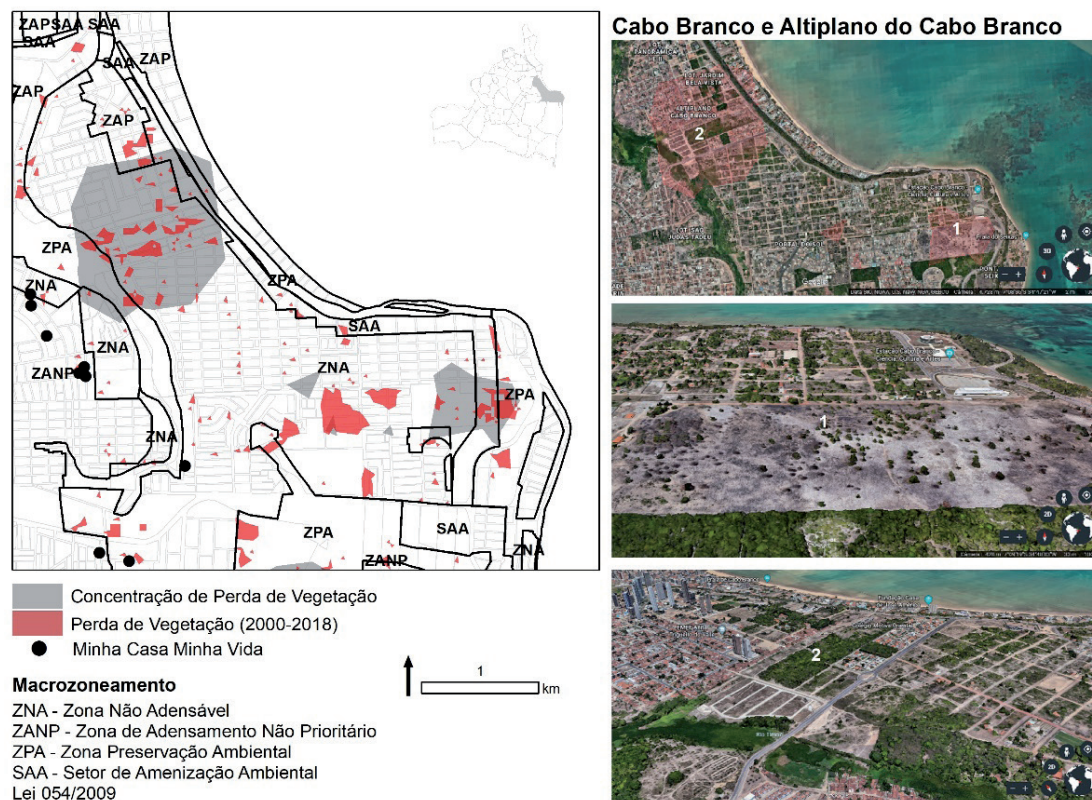


Figura 9 | Detalhamento da perda de vegetação no bairro Gramame.

Fonte: Hansen et al. (2013), Lei 054/2009, Google Earth Pro. Elaborado pelos autores.

No Gramame, o grande vetor de desflorestamento é a construção de loteamentos de baixa renda, alguns subsidiados pelo Governo Federal, com recursos do Programa Minha Casa Minha Vida e outros erguidos por pequenas construtoras da cidade. Apesar de estar sobre uma Zona Não Adensável, a mancha de perda de vegetação mostra parcelamento do solo denso e contínuo.

São lotes pequenos, de alta taxa de ocupação, conforme mostram as imagens de satélite na Figura 10. Ainda sobre as Figuras 7 e 8, vale colocar que os bairros apresentados se encontram muito próximos do rio Gramame, curso d'água que abastece 70% da cidade, podendo (i) comprometer a disponibilidade hídrica da região em cenários futuros de alteração nos regimes de chuva e (ii) colocar em risco de inundação ou enchentes as populações pobres residentes próximo ao rio, com o aumento de extremos chuvosos aliado à baixa infraestrutura de saneamento ambiental (HARDOY E PANDIELLA, 2009).



**Figura 10 |** Detalhamento da perda de vegetação nos bairros Altiplano do Cabo Branco e Cabo Branco.

*Fonte: Hansen et al. (2013), Lei 054/2009, Google Earth Pro. Elaborado pelos autores.*

Situados em localização de vista privilegiada para o mar, os bairros Cabo Branco e Altiplano do Cabo Branco, o desflorestamento da região se deu para a construção de condomínios horizontais de alta renda. No Altiplano do Cabo Branco, Figura 10, imagem de satélite do meio, se dá ao redor dos condomínios verticais de altíssima renda, aprovados por meio de alteração no gabarito definido no zoneamento, via decreto, em 2008. No bairro do Cabo Branco são condomínios horizontais, também de altíssima renda, com baixa taxa de ocupação. Ambos bairros têm baixos índices de saneamento ambiental e o entorno não possui sistema de drenagem de águas pluviais (IBGE, 2010).

Estes bairros estão assentados sobre a Barreira do Cabo Branco de formação geológica sensível ao deslizamento, situada na direção dos corais “do Seixas”, que estão ameaçados pela erosão da falésia. A exemplo, em junho de 2019, durante um extremo chuvoso que durou mais de 72 horas, parte da barreira deslizou sobre o mar, afetando parte dos corais. Neste processo de ocupação formalizada, legal do ponto de vista da política urbana, subverte a idealização de uma cidade sustentável de Leff (2007) fortalecendo a segregação da elite em *clusters* de realidade urbana inexistente fora dos muros ou perímetros desses bairros.

As maiores perdas de área vegetada se deram em zona de preservação, de preservação da paisagem, não adensáveis e na área do Plano Diretor que não tem zoneamento algum. Tal fato, demonstra que o estabelecimento de leis para regular o uso e ocupação do solo não se alinha com a política ambiental, pois, a razoável flexibilidade existente no âmbito desses dispositivos de regulação abre espaço para que os interesses dos atores que compõem as gestões redefinam as prioridades em nome do empreendedorismo urbano. Sem embargo, a participação popular forjada no âmbito dos conselhos de meio ambiente e de desenvolvimento urbano da cidade de João Pessoa corrobora com essas investidas que destroem os ecossistemas da cidade.

No contexto das mudanças climáticas, a disputa de terra dentro das relações de poder do capital tendem a prejudicar os micro produtores rurais e as comunidades tradicionais (IPCC, 2019) podendo, no futuro próximo, comprometer a segurança alimentar da população de baixa renda e das populações tradicionais que persistem em suas características rurais de subsistência, principalmente, na porção sudeste do município (Figura 3) onde, conforme colocado anteriormente, residem ribeirinhos, indígenas e quilombolas.

Além disso, os serviços ecossistêmicos relacionados à regulação climático-ambiental da cidade (CARVALHO E SZLAFSZTEIN, 2019 e VIEIRA ET AL., 2018) podem ser comprometidos com a perda de Mata Atlântica, trazendo consequências para a segurança hídrica na cidade, principalmente pela pressão antrópica sobre o rio Gramame (Figura 8), além de contribuir com o aumento de ilhas de calor (OKE et al., 2017 pp. 197), em cenários climáticos futuros.

Por fim, conforme Figuras 5, 8 e 9, boa parte do desflorestamento tem se dado em áreas de baixa infraestrutura urbana, com a implantação de loteamentos para baixa renda (Figura 4), imprimindo risco a estas comunidades, que podem experimentar impactos diretos e indiretos das mudanças climáticas (IPCC, 2019), principalmente aqueles associados aos desastres, como inundações, enchentes e enxurradas, fruto do aumento da intensidade e frequência de extremos chuvosos combinado à baixa qualidade dos serviços de saneamento ambiental (TUCCI, 2008), contrariando as indicações do Plano Nacional de Adaptação - PNA (MMA, 2016), de promover urbanização de assentamentos precários, e manutenção das populações em seus assentamentos originários, na porção consolidada da cidade.

#### 4 CONSIDERAÇÕES FINAIS

O processo de produção do espaço urbano *per se* pressiona os ecossistemas, o ritmo e estilo de vida urbana demandam a degradação de recursos naturais e a conformação das estruturas urbanas no Brasil foram baseadas no desflorestamento, na impermeabilização do solo, contaminação dos corpos d'água e na ocupação de áreas vulneráveis.

No Antropoceno, com a realidade da emergência climática, uma racionalidade ambiental pautada na ideia de que tudo e todos são parte de sistemas e subsistemas interconectados e interdependentes têm orientado a produção de relatórios institucionais, políticas, planos e programas urbanos governamentais mas, muito embora as diretrizes e metas versem pela perspectiva da sustentabilidade, na prática, os projetos executivos oriundos desses documentos não correspondem a soluções multifuncionais que mitiguem os problemas ambientais urbanos.

O que se percebe é que, atravessando governos, há um descompasso entre o planejamento e a gestão. Trata-se de uma agenda *mercadológica* e *desregulacionista*, caracterizada pela incompreensão da natureza e seus ciclos, que se apropria dela para levantar financiamentos e “planejar projetos” de interesses especiais e escusos.

O urbanismo insustentável, escancarado em mapas, é fruto da pretensa “gestão democrática da cidade”, que cresce e se espalha em função do lucro e dos muros. Com anuência do poder público pelo descumprimento da legislação, seja ela urbana ou ambiental, o crescimento da estrutura urbana do município de João Pessoa avança sobre resquícios importantes de Mata Atlântica.

Esta negligência do poder público se dá tanto pela concretização de projetos institucionais para o assentamento de famílias de baixa renda, em áreas desprovidas de infraestrutura urbana, distantes da zona comercial e serviços da cidade, como pelo impulsionamento por empreendimentos imobiliários e de serviços direcionado às elites e turistas de alto poder aquisitivo.

De um lado, o adensamento vertical das áreas já consolidadas têm sido descartado pelas altas classes sociais, que prefere os muros dos condomínios horizontais fechados ou *clusters* de condomínios verticais,



cuja “vista da natureza” é o principal ativo dos empreendimentos; do outro, a provisão habitacional de baixa renda, alocada em áreas distantes dos atrativos turísticos da cidade, e demandam a supressão da vegetação por estarem próximos da área industrial e de mineração, expostas à poluição e outros riscos associados a essa proximidade.

A adaptação das cidades à crise climática passa pelo adensamento sustentável, ao invés do espraiamento urbano, promovendo a implantação de infraestruturas verdes, de transporte e mobilidade sustentáveis: cidades compactas onde a mobilidade interna não implica em emissão de GEE (MMA, 2016), e que só pode ser gestada de maneira participativa, com justiça socioambiental para todos os habitantes.

As ameaças climáticas não afetam toda a população da mesma forma, as populações de mais baixa renda apresentam menos resiliência que as classes mais abastadas mas, por outro lado, com a reincidência de desastres hidrometeorológicos que afetam estas comunidades de baixa renda ou tradicionais, como ribeirinhos, aprimoram técnicas de adaptação que precisam ser levadas em consideração no planejamento e implantação de ações de adaptação.

Medidas adaptativas devem passar necessariamente pela implantação de serviços de saneamento ambiental para redução do risco aos eventos extremos e a proliferação de doenças de veiculação hídrica e das transmitidas por vetores, principalmente no atendimento às populações com menos recursos financeiros. Estes serviços devem estar também articulados com o modo de vida das populações tradicionais e com o ecossistema em que serão inseridos, a partir de alternativas de coleta de tratamento de esgoto doméstico e de manejo das águas pluviais que não impliquem em grandes obras de infraestrutura e concreto, que possam representar novos impactos ambientais.

Sobre os povos e comunidades tradicionais, o PNA (MMA, 2016) aponta a necessidade de manutenção destas populações em seus ambientes tradicionais, promovendo a regularização da terra e instrumentos de agroextrativistas.

O desflorestamento, além de promover a perda de capacidade de absorção de GEE, compromete os serviços ecossistêmicos (i) de regulação ambiental – a perda de vegetação e impermeabilização do solo tem relação direta com as ilhas de calor, manutenção dos cursos d’água e sua capacidade hídrica, aumento no consumo de energia para conforto ambiental, (ii) de provisão – ao expulsar comunidades ribeirinhas e de pequenos produtores rurais, além de (iii) comprometer culturalmente o modo de vida destas populações.

Como sugestão futura, caberia analisar as condições de vida das populações das áreas desflorestadas com dados censitários atualizados em 2021, bem como com dados sobre as licenças ambientais e os alvarás de construção concedidos ao longo da série histórica dos dados de Hansen et al. (2013), para a compreensão dos impactos da expansão urbana no município de João Pessoa.

## NOTES

1 | A reflexão proposta objetiva apenas admitir a naturalidade do homem e a historicidade da natureza, pois discutir o dualismo conceitual do termo não é o objetivo deste trabalho.

2 | A Criação do Cemaden para monitoramento de risco e a criação do CENAD e a estrutura de ação das defesas civis nas três esferas da federação já são passos importantes de organização política, científica e social de ações de gerenciamento de riscos no país.

3 | Segundo o decreto nº 5.363/2005 do COPAM estabelecimentos acima de 5.000 m<sup>2</sup> deve ser tipificados como CV4. No alvará da SEPLAN, o empreendimento é cadastrado como CV1, que corresponde a um mercadinho, apesar de indicar uma construção de 12.418,62 m<sup>2</sup> em um terreno de 8.497,50 m<sup>2</sup>. Enquanto a SEMAM, conforme o alvará de licença para construção (nº 2018/000150) classifica o empreendimento como médio porte. E de acordo com o decreto nº 6.499/2009, neste setor de amenização ambiental não pode ser instalado empreendimento tipificados em CV3 e CV4.

## REFERÊNCIAS

- ALMEIDA, G. M. et al. A política nacional de regularização fundiária: capacidades institucionais dos municípios na implementação do Programa Federal Papel Passado e suas implicações na gestão do território. In: XVII Encontro Nacional da Associação Nacional de Pós-Graduação e Pesquisa em Planejamento Urbano e Regional - **Enanpur**, XVII, 2017. São Paulo, 2017.
- BAI, X. et al. Plausible and desirable futures in the Anthropocene: A new research agenda. *Global Environmental Change*, v. 39, p. 351-362, 2016. <https://doi.org/10.1016/j.gloenvcha.2015.09.017>
- BARCELLOS, C.; HACON, S. Velhos indicadores para novos problemas: a relação entre saneamento e saúde. *Revista Panamericana de Salud*, SciELO Public Health, v. 22, n. 3, 2007.
- BARRETO, Cristiane Gomes. **Devastação e proteção da mata atlântica nordestina: formação da paisagem e políticas ambientais**. 294 f., il. Tese (Doutorado em Desenvolvimento Sustentável) - Universidade de Brasília, 2013.
- BORBA, B.S.M.C. et al. Energy-related climate change mitigation in Brazil: Potential, abatement costs and associated policies. *Energy Policy*, v. 49, p. 430-441, 2012. <https://doi.org/10.1016/j.enpol.2012.06.040>
- BORELLI, E. Urbanização e Qualidade Ambiental: o Processo de Produção do Espaço da Costa Brasileira. *INTERthesis*, v. 4, p. 1-27, Florianópolis, 2007. DOI: <https://doi.org/10.5007/%25x>
- CAMAGNI, R. **Economía Urbana**. Barcelona, Espanha: Antoni Bosch Editor, 2005.
- CAMPBELL, T. Desenvolvimento urbano no Terceiro Mundo: dilemas ambientais e pobres urbanos. In: LEONARD, H. Jeffrey (org.): **Meio ambiente e pobreza: Estratégias de desenvolvimento para uma agenda comum**. Rio de Janeiro: Ed. Jorge Zahar, 2002.
- CARVALHO, R.M.; SZLAFSZTEIN, C.F. Urban vegetation loss and ecosystem services: The influence on climate regulation and noise and air pollution. *Environmental Pollution*, n. 245, p. 844-852, 2019. DOI: [doi.org/10.1016/j.envpol.2018.10.114](https://doi.org/10.1016/j.envpol.2018.10.114)
- COHEN, D.A. **Climate Justice and the Right to the City**. USA: Penn University, 2018.
- CRUTZEN, P.J. The Anthropocene. In: EHLERS E, KRAFF, T. (eds). **Earth System Science in the Anthropocene**. Berlin: Ed. Springer, 2006.
- DONEGAN, L. **Qual é a sua praia?** Brasília: Ed. FRBH, 2019.
- GOOGLE EARTH. **Satellite images**. Disponível em <https://earth.google.com/web/> . Acesso em Janeiro de 2020.
- GOVERNO DO ESTADO DA PARAÍBA. Audiência Pública para Licença de Instalação para o Distrito Industrial do Turismo. Em atendimento à determinação do Ministério Público Federal/Procuradoria da República na Paraíba, conforme **Ata de Reunião realizada em 16 de maio de 2016**.
- HACON, SS.; OLIVEIRA, BFA; SILVEIRA, I. Capítulo 4: Health Sector. NOBRE, C.A.; MARENGO, J.A., SOARES, W.R. (Org.): **Climate Change Risks in Brazil: A Review of the Health Sector Impacts of 4 °C or more Temperature Rise**. Ed. Springer, 2018.
- HANSEN et. al. High-Resolution Global Maps of 21 Century Forest Cover Change. *Science*, v. 342, i. 6160, p. 850-853, 2013. DOI: [10.1126/science.1244693](https://doi.org/10.1126/science.1244693)
- HARDOY, J. AND PANDIELLA, G. Urban poverty and vulnerability to climate change in Latin America. *Environment and Urbanization*, v. 21, n. 1, p. 203-224, 2009. <https://doi.org/10.1177/0956247809103019>
- HARVEY, D. **A produção capitalista do espaço**. São Paulo: Ed. Anna Blume, 2001.
- IBGE. **Censo demográfico 2010**. Disponível em [ibge.gov.br](http://ibge.gov.br) . Acesso em janeiro de 2020.

IBGE. **Tipologias Intraurbanas**. 2017. Disponível em [ibge.gov.br](http://ibge.gov.br). Acesso em janeiro de 2020.

IPCC. **Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II. Fifth Assessment Report of the IPCC**. Cambridge, UK and New York, NY, USA: Cambridge University Press. 2014.

IPCC. **Climate Change and Land Special Report**. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press, 2019.

JACOBI, P., E SULAIMAN, S. Governança ambiental urbana em face das mudanças climáticas. **Revista USP**, v. 09, p.133-142, 2016. DOI: <https://doi.org/10.11606/issn.2316-9036.v0i109p133-142>

LEFEBVRE, H. **O Direito à Cidade**. São Paulo: Ed. Centauro, Reedição, 2011.

LEFF, E. **Saber Ambiental: sustentabilidade, racionalidade, complexidade e poder**. Petrópolis, RJ: Ed. Vozes, 2001.

MARENGO, J. O futuro do clima no Brasil. **Revista USP**, n. 103, p. 25-32. São Paulo. 2014. DOI: <https://doi.org/10.11606/issn.2316-9036.v0i103p25-32>

MINISTÉRIO DO MEIO AMBIENTE. **Plano Nacional de Adaptação**. Brasília, 2016.

MOURA, A. K. C.; GARCIA, L. G. Políticas públicas de turismo e sustentabilidade: o polo turístico Cabo Branco em análise. **CULTUR - Revista de Cultura e Turismo**, Ano 03, n. 03, p. 85-101, 2009.

NAKANO, A.K. A produção da “cidade oca” nos padrões recentes de verticalização e adensamento construtivo do município de São Paulo. **Revista Oculum Ensaios**. Campinas, 2018. DOI: <https://doi.org/10.24220/2318-0919v15n1a3373>

NOGUEIRA, F. AND CANIL, K. Reflexões sobre a gestão de risco: Avanços e limitações. In: SULAIMAN, S. E JACOBI, P. (org) **Olhares e saberes para a redução de risco de desastre**. São Paulo: IEE-USP, 2018.

OKE, T.R., MILLS, G.; CHRISTEN, A., VOOGT, J.A. **Urban Climates**. Cambridge: Cambridge University Press, Cambridge, 2017.

OJIMA, R. **Perspectivas para a Adaptação Frente às Mudanças Ambientais Globais no Contexto da Urbanização Brasileira: Cenários para os Estudos de População**. Campinas: NEPO - Unicamp, 2009.

ONU. **Urbanization and Development: emerging futures**. Nairobi, Kenya: United Nations Human Settlements Programme, 2016.

PMJP [Lei Municipal Complementar 03/1994] – **Lei do Plano Diretor da Cidade de João Pessoa**. João Pessoa, PB: Câmara de Vereadores, 1994.

PMJP [Lei Municipal 054/2009] – **Plano Diretor da Cidade de João Pessoa**. João Pessoa, PB: Câmara de Vereadores, 2012.

QUARESMA, I.N. et al. **Efetividade De Gestão Do Parque Estadual Do Jacarapé-PB**. CONGRESSO BRASILEIRO DE GESTÃO AMBIENTAL E SUSTENTABILIDADE, v. 5. João Pessoa, PB. 2017. ISSN 2318-7603.

SANTOS, M. **A Natureza do Espaço**. São Paulo: Ed. Edusp, 4ª edição, 1997.

SCHAEFFERA, R A et al. Energy sector vulnerability to climate change: A review. **Energy**, v. 38, I.1, p. 1-12, 2012. DOI: 10.1016/j.energy.2011.11.056

SILVA, G. et al. **Lugares e suas interfaces: transformações urbanas e periferização**. João Pessoa: Ed. UFPB, 2016.

SILVEIRA, J.A.R. et al. **Dinâmica da cidade e bordas urbanas**. João Pessoa: Ed. UFPB, 2015.

SMITH, A. **A Riqueza das Nações**. Coleção Os Economistas. São Paulo: Editora Nova Cultura, [1776] 1996.

SMITH, N. **Desenvolvimento Desigual**. Rio de Janeiro: Ed. Bertrand, 1998.

SOUZA, M. L. **Mudar a Cidade: uma introdução crítica ao planejamento e à gestão urbanos**. São Paulo: Ed Bertrand Brasil, 2001.

TUCCI, C. Águas urbanas. **Revista Estudos Avançados** v. 22, n. 63. São Paulo. 2008. Disponível em <http://www.revistas.usp.br/eav/article/view/10295> . Acesso em janeiro de 2020.

VIEIRA, J. ET AL. Green spaces are not all the same for the provision of air purification and climate regulation services: The case of urban parks. **Environmental Research**, n. 160, p. 306-313, 2018. <http://dx.doi.org/10.1016/j.envres.2017.10.006>



In its Editorial of this second edition of 2020, *Sustainability in Debate* warns about the need and urgency of responsible political action around preventive measures to combat Covid-19. Given the national and international scenario, never have the principles of responsibility, precaution, and prevention, so dear to sustainable development, been so current and imperative! In its Dossier “Environmental Systems Modelling and Landscape Management”, *SeD* presents nine articles. They deal with topics related to innovative methodologies in quantitative modelling and geoprocessing capable of promoting ways to improve management and territorial governance. Closing the edition, we have the *Varia* section with four articles, which address climate change, soil respiration and urbanization. We wish you a good read!

*Nesta segunda edição de 2020, Sustentabilidade em Debate, em seu Editorial, alerta sobre a necessidade e a urgência de uma ação política responsável em relação às medidas preventivas de combate ao Covid-19. Diante do cenário nacional e internacional, nunca os princípios da responsabilidade, da precaução e da prevenção, tão caros ao desenvolvimento sustentável, foram tão atuais e imperativos! Em seu Dossiê “Modelagem de Sistemas Ambientais e Gestão da Paisagem”, SeD apresenta nove artigos, que tratam de temas relacionados a metodologias inovadoras em modelagem quantitativa e geoprocessamento capazes de promover meios de aprimorar a gestão e a governança territorial. Fechando a edição, temos a seção Varia com quatro artigos, que abordam temas relacionados às mudanças climáticas, respiração do solo e urbanização. Desejamos uma boa leitura!*

Realização



CDS-UnB



LEA-UnB

Edição



Apoio

