

Participatory Geographic Information System: citizen science approach in Potiguara Indigenous Land of Paraíba- Brazil

*Sistema de Informação Geográfica participativo:
abordagem em ciência cidadã em Terra Indígena
Potiguara da Paraíba - Brasil*

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ABSTRACT

Indigenous culture and ancestry have been historically threatened in the Potiguara Indigenous Territory in Paraíba, generating conflicts within its territory. The Territorial and Environmental Management Plan (PGTA) is a fundamental tool for addressing these conflicts. This article integrated a citizen science approach with a social cartographic map in a participatory Geographic Information System (PGIS) to identify the social-environmental impacts observed by the Potiguara, in defence of indigenous and traditional territories. PGIS workshop, along with guided tours and drone overflights, mapped together 29 Potiguara indigenous aspects of cultural, social, environmental, and political themes, identifying: 68 places related to cultural aspects; and 27 points of potential/threats. The citizen science approach connected with PGIS was essential for the territorial claim of the Potiguara, highlighting five key elements for its applicability: (1) creating a trustful environment; (2) recognizing local and traditional knowledge; (3) analyzing conflicts across temporal and spatial scales; (4) promoting empowerment in the use of geotechnologies; and (5) including Potiguara intergenerational participation in the identification and monitoring of social-environmental impacts.

Keywords: Environmental and Territorial Management Plan. Citizen science. Social cartography. Potiguara Indigenous Land.

RESUMO

A cultura e a ancestralidade indígena têm sido ameaçadas historicamente na Terra Indígena Potiguara na Paraíba, gerando conflitos em seu território. O Plano de Gestão Territorial e Ambiental (PGTA) é um dos instrumentos fundamentais para lidar com esses conflitos. Este artigo integrou uma abordagem em ciência cidadã com mapas de cartografia social em um Sistema de Informação Geográfica participativo (SIGp), para identificar os impactos socioambientais observados pelos Potiguara em defesa de territórios de povos e comunidades tradicionais. Oficinas de SIGp com visitas guiadas e sobrevoos de drone mapearam com aproximadamente 29 indígenas temas culturais, sociais, ambientais e políticos, identificando: 68 lugares relacionados com aspectos culturais e 27 pontos de potencialidades/ameaças. A abordagem em ciência cidadã acoplada com o SIGp foi importante para a reivindicação do território Potiguara, destacando-se cinco elementos-chave para sua aplicabilidade: (1) criar ambiente de confiança; (2) reconhecer o conhecimento local e tradicional; (3) analisar conflitos em escalas temporais e espaciais; (4) promover o empoderamento no uso de geotecnologias; (5) incluir a intergeracionalidade Potiguara na identificação e no monitoramento de impactos socioambientais.

Palavras-chave: Plano de Gestão Territorial Ambiental. Ciência cidadã. Cartografia Social. Terra Indígena Potiguara.

1 INTRODUCTION

The planetary crisis has been characterised by the overpass of multiple ecological boundaries essential to the functioning of the Earth System, alongside the “triple crisis” – climate change, biodiversity loss, and pollution (Richardson *et al.*, 2023; Rockström *et al.*, 2009; Sakschewski *et al.*, 2025; Steffen *et al.*, 2015). These processes unfold within the context of the Anthropocene (Brondizio *et al.*, 2016; Whyte, 2017), reflecting both increasing pressures from human activities and reduced ecosystem resilience, while also exacerbating social inequalities that disproportionately affect indigenous and traditional/local communities.

In many territories, environmental degradation has also affected traditional human well-being, cosmologies, and ancestral practices that have historically sustained reciprocal relations between humans and nature. Indigenous and traditional authors have emphasised the need to restore this reciprocity and expand intercultural dialogue to integrate multiple knowledge systems (Kopenawa, 2015; Krenak, 2022; Rezende, 2021; Santos, 2023) in addressing the planetary crisis. Within this debate, the creation of intercultural spaces for dialogue – where scientific and traditional knowledge can complement one another horizontally – has become increasingly relevant (Albert *et al.*, 2023; Alonso-Yanez *et al.*, 2019; David-Chavez *et al.*, 2024; Tengö *et al.*, 2017, 2021).

This context demands more open, collaborative, and inclusive scientific approaches that can integrate indigenous, traditional, and scientific knowledge into decision-making processes. The integration of multiple knowledge systems thus becomes essential for effective territorial governance. Principles such as legitimacy, relevance, and reciprocity (Moallemi *et al.*, 2023; Norström *et al.*, 2020) guide approaches that strengthen local capacities and enhance cognitive justice (Appadurai, 2006; Fraisl *et al.*, 2025; Haklay *et al.*, 2021; Tengö *et al.*, 2021).

Citizen science has emerged as one such strategy, expanding public participation in research. It is considered part of a broader “movement of movements” within open science and has demonstrated potential to democratize knowledge production by involving citizens in data collection, analysis, and interpretation (Albagli *et al.*, 2015; Albagli; Iwama, 2022; Albert *et al.*, 2023; Haklay *et al.*, 2021; Shirk *et al.*, 2012). Since the 1990s, two major components have influenced the conceptualization of citizen science: (1) volunteer-based bird-monitoring projects developed by the Cornell Lab of Ornithology in the United States, from the Rick Bonney’s research group (Bonney *et al.*, 2009); and (2) citizen science conceptualization in Europe by Alan Irwin’s research group as a critical and reflexive practice addressing science-society relations (Irwin, 1995).

From the 1990s to the present (Bonney *et al.*, 2009; Irwin, 1995, 2002), citizen science has demonstrated substantial potential for transdisciplinary approaches (Albert *et al.*, 2023; RBCC, 2025). This allows communities to contribute beyond the data production, but above all to decision-making and local action (Albert *et al.*, 2023; Chari *et al.*, 2019; Queiroz-Souza *et al.*, 2023; Reyes-García, 2023).

The integration of citizen science with social cartography and Participatory Geographic Information Systems (PGIS) – including Volunteered Geographic Information (VGI) – has proven valuable for collecting local data and strengthening the agency and autonomy of Indigenous and traditional communities in their territories (Connors *et al.*, 2012; Goodchild, 2007; Haklay, 2013; Malakar; Roy, 2024; McCall; Dunn, 2012; See *et al.*, 2016).

In the Potiguara Indigenous Land, on the northern coast of Paraíba – Brazil, there are multiple conflicts and threats, including the expansion of sugarcane plantations, deforestation of riparian vegetation,

and mangrove degradation. These processes intensify social vulnerabilities, affecting food security and cultural practices as spirituality (Cardoso *et al.*, 2017; Costa *et al.*, 2020; Gonçalves, 2020; Moonen, 2008; Palitot; Torres, 2022).

To support the identification of these impacts and conflicts, social cartography has been used as a key tool for enhancing community participation in sketch mapping production (Acselrad, 2013, 2022; Almeida, 2018; Davalos *et al.*, 2024; Ferreira *et al.*, 2021; Silva; Gonçalves, 2019). In this context, social cartography, combined with geotechnologies and PGIS, offers significant potential to inform and support the Potiguara Territorial and Environmental Management Plan (PGTA, in Portuguese), particularly given the multiple socio-environmental conflicts in the territory.

This article aims to identify the socio-environmental impacts observed by the Potiguara Indigenous community in Paraíba, based on a citizen science approach coupled with social cartography and PGIS, to support the development of the Territorial and Environmental Management Plan (PGTA) and to update and systematise cultural and historical information about their territory.

2 METHODS

The study area is located within the Potiguara Indigenous Land (TI), on the northern coast of the state of Paraíba, including three lands: TI Jacaré de São Domingos, TI Potiguara, and TI Potiguara de Montemor (Figure 1). TI Potiguara comprises 32 indigenous villages, and in this study, we focus on three: Alto do Tambá, Camurupim, and Tramataia.

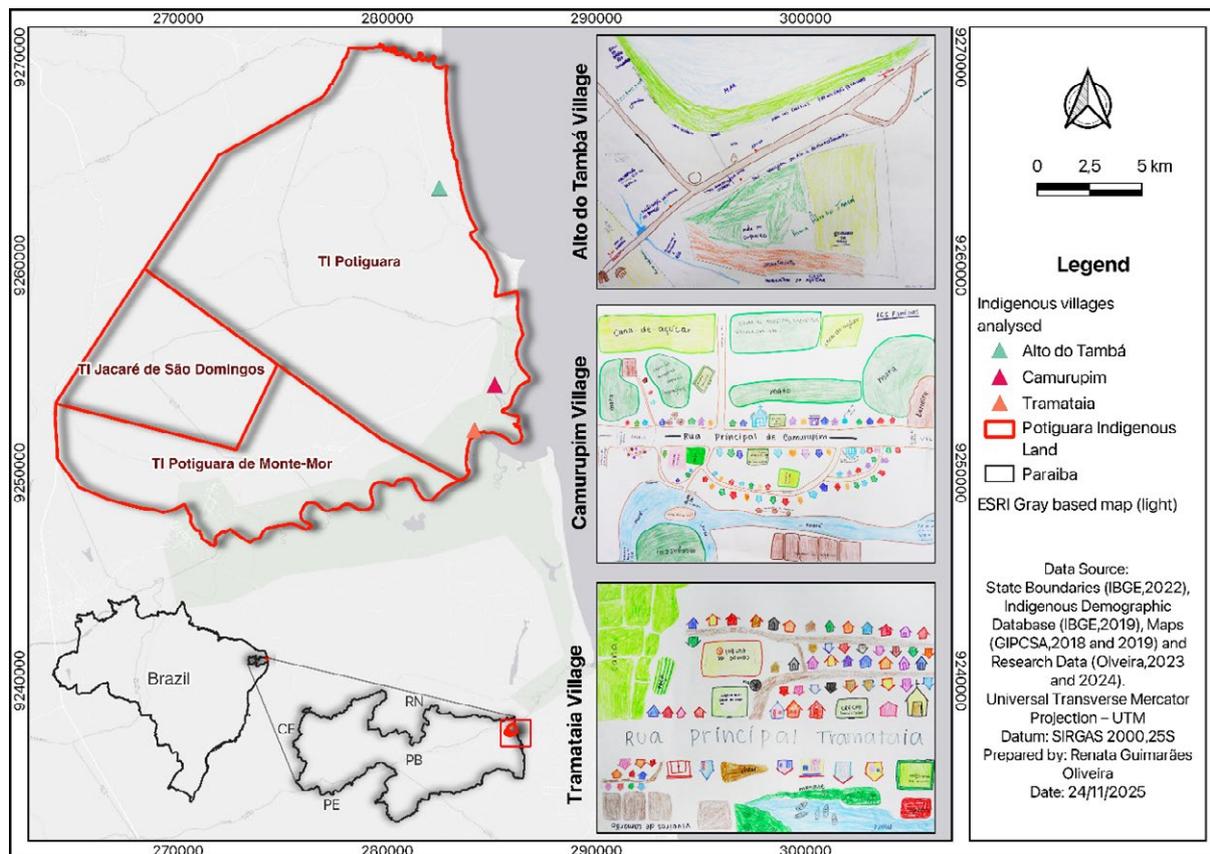


Figure 1 – Location map of the Potiguara Indigenous Land highlighting the villages selected for this study and their respective social maps developed in 2018 and 2019 by GIPCSA.

Source: Research data, 2024

Starting the first contact in 2022 with indigenous leaders – and building upon an already established dialogue between groups within the Potiguara Indigenous Land and the Interdisciplinary Research Group on Culture, Society, and Environment (GIPCSA, in Portuguese) at Federal University of Paraíba (UFPB) – formal authorisation for the research was obtained through a Letter of Consent from the General Potiguara Chief. From that point onward, field activities were organised, including training processes with Indigenous participants/collaborators. Local Indigenous leaders supported the suggestion of participants, based on the following inclusion criteria: belonging to the Potiguara ethnic group; being over 18 years old; residing in the Indigenous Land; and agreeing to participate through signing the Free and Informed Consent Form (TCLE, in Portuguese), approved by the Research Ethics Committee (protocol 6.017.120/2022). Individuals with health conditions that could hinder communication or comprehension were not included.

Exploratory fields were conducted in 2022 as part of the extension project “Participatory Geographic Information System (PGIS) and Potiguara Social Maps” at the Federal University of Paraíba (UFPB). These initial visits, followed in the villages of Alto do Tambá and Tramataia, enabled closer engagement with local leaders and the establishment of a relationship of mutual trust. Based on these initial interactions, leaders identified participants to support data collection, recognising their knowledge of local social organisation and appropriate approaches for community engagement. Fieldwork planning followed the recommendations of indigenous representatives, ensuring respect for local routines and cultural practices.

Social cartography was updated to improve understanding of recent changes within the Potiguara land, based on social maps produced between 2018 and 2019 with support from GIPCSA (Cardoso *et al.*, 2017; Cardoso; Guimarães, 2012; Gonçalves, 2020, 2023; Gonçalves *et al.*, 2024).

These map-updating activities were carried out within the extension project between 2022 and 2023 using Wikiloc and KoboToolBox – the mobile georeferencing applications. Points, lines, and polygons were mapped using the open-source software Quantum GIS (QGIS). Guided fieldwork was conducted with an indigenous chief and influential leader from Alto do Tambá, who identified relevant and conflict-related locations within the Potiguara land, as well as places of historical and cultural significance.

The research group GIPCSA produced 43 social cartographies previously. Across eight Potiguara villages – Três Rios, Camurupim, Lagoa do Mato, Benfica, Alto do Tambá, Jacaré de São Domingos, Tramataia, and Coqueirinho do Norte – 13 social maps corresponding to the villages of Alto do Tambá, Camurupim, and Tramataia were selected and updated. The criteria used to select the social cartography were based on features referenced in the grounded data, such as houses, schools, public squares, artisan houses, ceremonial spaces, and other elements with sufficient resolution or recognisable features that allowed for vectorisation in QGIS.

Following this preparation and the updated social cartography, workshops were conducted in the three selected villages – Alto do Tambá, Tramataia, and Camurupim (Figure 1) – chosen among the eight villages with previously developed social maps by GIPCSA. Selection was based on the richness of detail in these maps, which facilitated the systematisation of features illustrated by the Potiguara and served as the foundation for the workshops and for guiding a participatory GIS approach.

Figure 2 presents the stages of the social cartography and Participatory GIS workshops conducted with the working groups formed in each selected village: Camurupim (workshop in November 2023); Tramataia (November 2023); Alto do Tambá (January 2024). Each workshop consisted of the following steps:

1st Step. Citizen science and PGIS project presentation, including GIPCSA/UFPB participants and the Potiguara community;

2nd Step. Presentation of previously produced social cartography, along with satellite imagery of the villages, to identify territorial changes, environmental transformations, and climate-change-related impacts;

3th Step. Identification of major territorial changes on the maps;

4th Step. Citizen science–based data collection, involving research interviews using georeferenced forms (KoboCollect/KoboToolBox) at locations indicated by workshop participants. Potiguara volunteers also used KoboToolBox to continue mapping data during and after the workshops;

5th Step. Systematisation of mapped points into QGIS;

6th Step. Presentation and validation of results with participants and other stakeholders.

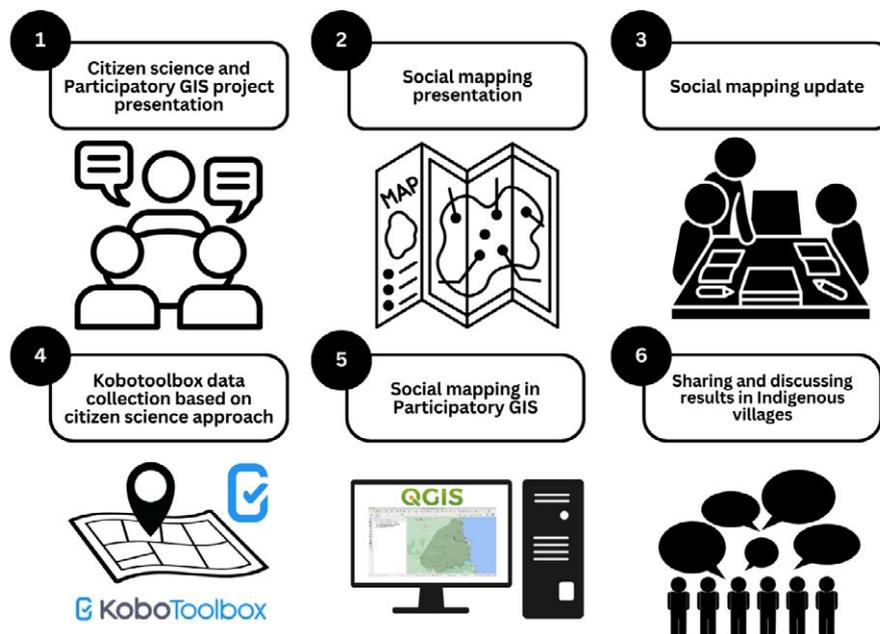


Figure 2 – Flowchart of the social cartography and participatory GIS steps in Potiguara land.

Source: Elaborated by authors using CANVA software

The snowball sampling method (Goodman, 1961; Neuman, 2014) was used to reach key participants for discussions on climate change and adaptation strategies – after alignment meetings with local leaders and GIPCSA members. Communication with participants occurred through a WhatsApp group, where workshop schedules and details were shared.

Workshops in Alto do Tambá, Tramataia, and Camurupim took place on dates agreed upon with the local Potiguara Chiefs, with adjustments made to accommodate village agendas. Workshop locations and participant numbers (n) were as follows: Tramataia – Cacique Iniguaçu Municipal School (n=9); Camurupim – Teodolino Indigenous Municipal Early Childhood School (n=8); Alto do Tambá – Headquarters of the Águas Potiguara Project (n=12)

Each workshop lasted between 3 and 4 hours and was divided into two parts. The first consisted of presenting the social map; the second involved presenting a printed A0 satellite map to identify cultural, social, environmental, and political features within the community.

The second part of each workshop involved a guided visit and drone overflight of the points indicated by the Potiguara, enabling features previously viewed only on maps to be located and validated in

the territory. A DJI Mini 2 drone was used to document relevant areas pointed out by the leaders. KoboToolBox training sessions were conducted in each village, during which goals were established with leaders and community members to continue collecting data on threats, opportunities, and critical or culturally significant points for the Potiguara across the three villages.

Kernel Density Estimation (KDE) was applied to assess spatial distribution patterns of field-collected points in the three Potiguara villages. This spatial analysis technique produces density surfaces and is particularly suited for individual point locations (Câmara & Carvalho, 2004). The method estimates intensity $\lambda(s)$, where s represents any location within region R , and s_1, \dots, s_n are the coordinates of the n observed events:

$$\lambda(s) = \frac{1}{\delta(s)} \sum_{i=1}^n \frac{1}{\tau^2} k\left(\frac{(s - s_i)}{\tau}\right)$$

where k is the selected bivariate kernel density function and τ is the radius of influence.

To spatialize field data, tests were performed using different distances, and a minimum radius of 1 kilometre ($\tau = 1$ km) was adopted to generate the spatial density surface of the points.

3 RESULTS

3.1 SOCIAL CARTOGRAPHY IN A GIS ENVIRONMENT: PARTICIPATORY GIS (PGIS) IN THE POTIGUARA INDIGENOUS LAND, PARAÍBA

A total of **68 points** were identified for mapping features of the Potiguara land: 25 points in Tramataia, 28 in Camurupim, and 15 in Alto do Tambá. **Figure 3** shows the spatial location and Kernel density of the collected points. Although participants from Camurupim identified the highest number of points (28), the points from Tramataia were more concentrated in the central area of the village, giving it slightly more representation on the density map.

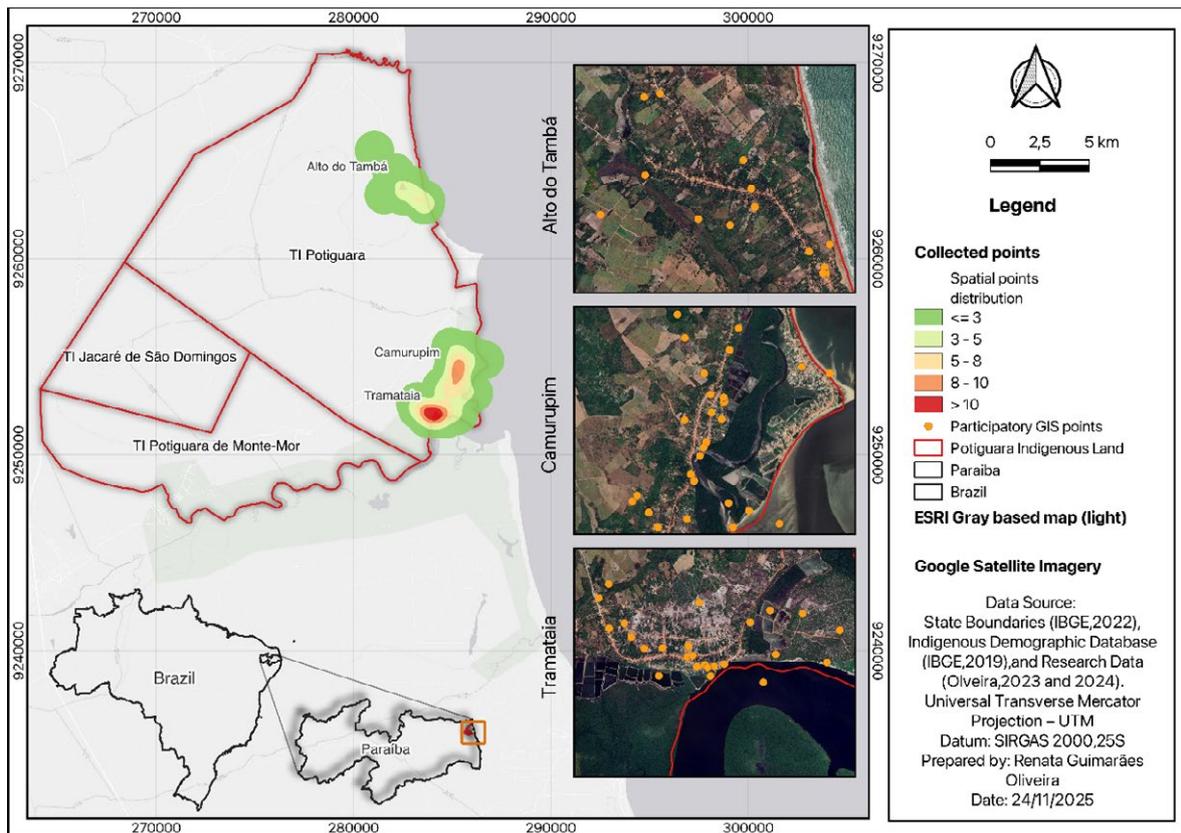


Figure 3 – Kernel density distribution map for points identified by the Potiguara during the social cartography workshops in Tramataia, Camurupim, and Alto do Tambá (2023–2024).

Source: Research data, 2024

About land cover-use changes in the territory, participants from two of the three villages reported that population growth has increasingly inducing the urban settlements in flooding risks areas. The increase in urban settlements has contributed to land-use changes, including vegetation loss, intensifying soil erosion. In addition, the occupations of wetlands have amplified exposure to flooding, as reported for the “campina” area in Tramataia. In Alto do Tambá, this specific concern was not raised; however, participants discussed territorial expansion, debating whether newly occupied spaces were traditional family extensions or areas subject to irregular occupation.

Deforestation appeared as one of the most recurrent themes across all workshops. Participants associated it with the expansion of sugarcane plantations into village areas and with the loss of fruit-bearing trees – such as *Mangabeira* – which hold cultural and historical significance for the community. Only in Tramataia did participants highlight areas currently undergoing reforestation efforts.

Several **cultural elements** were mapped, including the *Casa de Farinha*, which participants emphasised as essential to rebuilding to strengthen food security and protect Potiguara cultural heritage. The site historically served as a space for intergenerational knowledge exchange. The location of **Ocas** (traditional houses in indigenous land), where cultural activities and rituals are carried out, was also identified in two villages (Tramataia and Camurupim).

Additional features varied according to village-specific characteristics. In Alto do Tambá, participants highlighted *Angelina’s beiju*, a traditional preparation of cultural and touristic importance, as well as the *Pátio de Gado*, where horse/cattle rodeo events (*Vaquejadas*) take place. In Camurupim, the **Port** was identified as key infrastructure for community-based tourism, while **Cacimbas** – shallow wells near rivers or springs – remained important for recreation (bathing) and drinking water.

In Tramataia, participants noted similar features identified in other villages but emphasised the health post and a kiosk, the latter considered a tourist asset despite community concerns about pollution.



Photo (a) – Threat: Increased sugarcane-related deforestation near the Camurupim village (2023)



Photo (b) – Threat: Settlements in flooding risk area in the Tramataia village (2023)



Photo (c) – Potential: School with Indigenous education and an Oca as a Potiguara cultural space in the Tramataia village (2023)



Photo (d) – Restoration of the riverbanks by the Águas Potiguara project in the Alto do Tambá village (2023)

Figure 4 – Drone overflights for identifying historical-cultural locations and environmental threats indicated by Potiguara participants during guided visits.

Source: Research data, 2024

3.2 POTENTIALITIES AND THREATS IN THE POTIGUARA VILLAGES

During the workshops, after identifying important locations on the maps, participants classified sites as **potential (n=10)** or **threat/risks (n=17)** – Figure 5.

In **Alto do Tambá**, participants identified **3 potential elements**, including the spring of the Baixo/Badalo River, selected as the site for field validation during the guided visit. Five threats were identified, all related to environmental degradation, associated with deforestation.

In **Camurupim**, **5 potential elements** were identified, such as the preservation of native vegetation and experiential tourism. Participants also mapped **9 threats/risks**, notably shrimp farms, which, despite being an important source of income for some families, exert strong pressure on local coastal ecosystems.

Tramataia identified the fewest points, with **2 potentialities**: the Indigenous school, which provides employment and leads environmental education initiatives such as mangrove and river cleanups, and another community asset. Conversely, threats identified in Tramataia relate mainly to increasing areas at risk of flooding due to unplanned settlement expansion and to pollution.

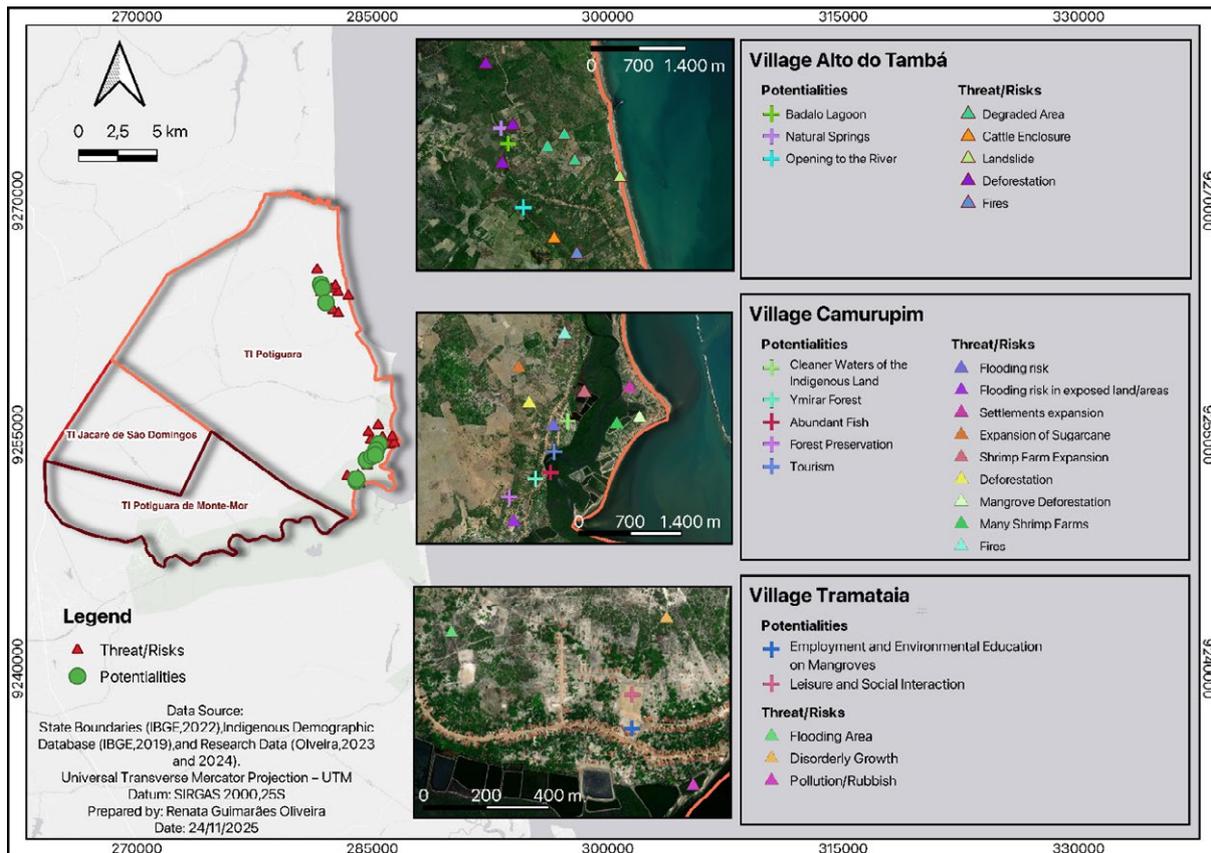


Figure 5 – Map of threats and potentialities identified by the Potiguara during the social cartography workshops in Tramataia, Camurupim, and Alto do Tambá.

Source: Research data, 2024

4 DISCUSSION

4.1 PGIS IN THE POTIGUARA INDIGENOUS LAND: KEY ELEMENTS FOR PARTICIPATORY MAPPING

The results highlight the Potiguara people’s knowledge of threats and potentialities in their territory, as well as the identification of locations that are essential to community life (such as *ocas*, the *casa de farinha* and the school). These results reinforce the findings from several studies on the Potiguara Indigenous (Cardoso *et al.*, 2017; Costa *et al.*, 2022; Gonçalves, 2020; Gonçalves *et al.*, 2024; Palitot; Torres, 2022), which indicate a close relationship between the Potiguara and the use and management of their territory.

At the same time, Potiguara knowledge and well-being (*Bem-Viver*) are historically shaped by socio-environmental conflicts linked to sugarcane cultivation in the territory, with recurrent reports of burning, deforestation, and contamination of soil and water by agrochemicals, as observed and reported by Potiguara participants in this research. These conflicts reinforce the need for demarcation and formal recognition (*Homologação*) as guarantees for the protection of their ancestral territory (Costa *et al.*, 2020; Moonen, 2008; Palitot; Torres, 2022).

In this context, social cartography, when represented in digital maps within a Geographic Information System in a participatory manner (Participatory GIS – PGIS), can serve as an important tool of struggle and resistance for the Potiguara, including in the formulation of public policies such as the Territorial and

Environmental Management Plan for Indigenous Lands (PGTA). The PGTA has been used as a planning instrument that formalises territorial management, integrating cultural, environmental, and economic dimensions.

Because it is a method designed to offer means and tools for communities to express themselves and claim their rights (Acselrad, 2013; Almeida, 2018; Davalos *et al.*, 2024; Silva; Gonçalves, 2019; Sombra *et al.*, 2022), social cartography in this study not only documented physical features in the territory but also captured territorial claims and cultural sites. The mapped elements express what it means to be Potiguara, particularly when participants highlight places such as the casa de farinha and ocas to describe traditional practices and uses.

Drawing on key elements for good governance of participation in spatial/territorial planning (McCall; Dunn, 2012), such as legitimacy, equity, respect, competence and responsibility, this research identifies several critical conditions for implementing PGIS in the Potiguara villages that can also be extended, with locally adapted designs, to other contexts in Latin America and the Caribbean and across the Global South (Auerbach *et al.*, 2019; Cunha *et al.*, 2017; Haklay *et al.*, 2021; Mikulewicz, 2020; Pereira *et al.*, 2023). These elements include:

(1) A trust-based environment – Pre-existing trust between the GIPCSA research group and Potiguara representatives was fundamental, since GIPCSA has been working with the community since 2018 in support of the PGTA in the Indigenous Territory. The PGTA initiative in the Potiguara land is among the few in the Northeastern region, and, beyond its importance for the community, it strengthens Indigenous peoples in this region, where there are relatively few state or non-state initiatives oriented toward protecting Indigenous territories or rights (Andrade, 2019; Sampaio; Andrade, 2018).

National and international studies emphasise that building trust is essential for research with local and traditional communities, especially in light of different levels of participation in research processes (Albagli; Iwama, 2022; David-Chavez *et al.*, 2024; David-Chavez; Gavin, 2018; Lam *et al.*, 2020; McCall; Dunn, 2012; Reyes-García *et al.*, 2019). In this study, the creation of trust bonds promoted respect and a sense of shared responsibility in field activities, including care in scheduling with community members and transparency regarding previously agreed procedures;

(2) Respect for and recognition of local and traditional knowledge in participatory mapping – A growing body of work highlights the need to reduce power asymmetries between multiple knowledge systems (Hill *et al.*, 2020; Tengö *et al.*, 2017, 2021). Respecting and recognising other forms of knowledge, such as Potiguara Indigenous knowledge, was a guiding principle to ensure that ancestral customs and land rights claims were appropriately represented in the social maps.

In participatory mapping processes, it is crucial to acknowledge that Indigenous communities have their own validation methods and rules governing who can determine what kind of knowledge, where and when it can be transmitted, and how it may be shared (David-Chavez *et al.*, 2024; Hill *et al.*, 2020; Hudson *et al.*, 2023; Souza de Lima *et al.*, 2024). This ongoing research sought to validate the maps collectively during plenary sessions at the workshops, where results were presented to the community. However, a key challenge was the establishment of a governance and data sovereignty protocol within the relatively short timeframe of a two-year master's degree. For that reason, the study anchored itself in medium – and long-term initiatives, such as CoAdapta | Litoral, to ensure continuity of co-construction of knowledge, validation processes and community autonomy (Albagli; Iwama, 2022; Iwama *et al.*, 2021, 2023; Pereira *et al.*, 2023);

(3) Dynamism and local spatio-temporal scale – In 2018, previously developed social maps produced by GIPCSA were revisited to assess changes in the territory. Analysing temporal scales was fundamental to detecting processes, such as increased deforestation driven by sugarcane expansion, in the Potiguara land. Using land-cover/land-use change analysis based on satellite imagery, Medeiros *et al.* (2023)

identified land-use conflicts in these areas, village and population growth, flooding issues, and threats such as the expansion of shrimp farms (Medeiros *et al.*, 2023).

(4) Empowerment through geotechnologies – McCall and Dunn (2012) emphasise that good governance and meaningful citizen involvement in participatory territorial planning require broad and continuous participation, where both the number and frequency of engagements and the types of involvement are crucial. The use of georeferenced KoboToolbox forms enabled faster data collection and improved data systematisation in post-collection spreadsheets. However, in this study, the use of these forms was largely confined to the main researcher and members of the field team, as it was difficult to extend their use to broader segments of the Potiguara community due to limited interest, lack of familiarity, or insufficient time for training.

Some important conditions for empowering communities in the use of such tools include: **(i) the existence of demands that are meaningful to the Indigenous community**, i.e. community legitimacy (David-Chavez *et al.*, 2024; Hill *et al.*, 2020; McCall; Dunn, 2012; Tengö *et al.*, 2021), such that research questions are connected to local priorities. Conflicts and land claims are central issues, and geotechnologies can support Potiguara mobilisation – the approval of the legal framework of the Potiguara de Monte-Mor Indigenous Territory in 2024 by Decree No. 12.288/2024 (Brasil, 2024), after years of struggle to secure legal recognition of ancestral rights; **(ii) medium- and long-term studies and adequate funding** for research implementation. Within the scope of a master's program, this study had a limited budget and conditions to expand training on geotechnologies, although such training was encouraged during specific workshops.

Building shared agendas with social movements such as the *Águas Potiguara* project (<https://www.instagram.com/aguaspotiguara/>), Anama initiative – *Fortalecendo juventude e lideranças Potiguara* (<https://www.instagram.com/anama.potiguara/>), and partnerships with schools together with the National Foundation for Indigenous Peoples (Funai, in Portuguese), could provide longer and more robust training processes on the use of mobile applications and geovisualization platforms. Such strategies are key to expanding spaces for greater autonomy and empowerment of the Potiguara using geotechnologies (David-Chavez *et al.*, 2024; Kohsaka; Rogel, 2019; McCall; Dunn, 2012; Silva; Gonçalves, 2019);

(5) Intergenerationality – The social cartography workshops and training in georeferenced applications (KoboToolbox) involved a youth movement of Potiguara leaders, as well as younger and older community leaders and elders. This intergenerational encounter facilitated exchanges in which younger participants learned about territorial uses through the stories and testimonies of elders. At the same time, young people also played a leading role in identifying threats and potential sites and in articulating narratives concerning autonomy and historical-cultural protection of the Potiguara.

Intergenerational encounters can foster knowledge exchange and strengthen community cohesion through participatory approaches such as oral histories, focus groups, or three-dimensional mapping models (Albagli; Iwama, 2022; Marchezini *et al.*, 2017; Trejo-Rangel *et al.*, 2021), while also creating opportunities for sharing and learning across different fields of knowledge.

4.2 CITIZEN SCIENCE AND PGIS IN THE POTIGUARA INDIGENOUS LAND: CHALLENGES AND OPPORTUNITIES FOR ENVIRONMENTAL MANAGEMENT PLANNING (PGTA)

Given the importance of implementing PGTA in Indigenous Lands for sustainable territorial planning, one key need to support the PGTA in this territory was to update the social maps previously developed with GIPCSA/UFPB, which existed only in analogue (paper) format. This need stems from the importance of cartographic representation of the territory based on community perspectives. Participatory GIS offered a pathway to update these analogue maps in a way that ensured active involvement of the

Potiguara through geotechnologies. In this sense, the approach of combining participatory GIS with citizen science, in close collaboration with Indigenous peoples, proved promising and showed potential to involve additional communities and villages.

A central challenge, however, has been maintaining social engagement over the medium- to long-term, with participants exercising greater autonomy and leadership in ongoing community monitoring. Although the master's research benefited from support from a graduate program for field activities and relied on research projects such as CoAdapta | Litoral (Albagli; Iwama, 2022; Iwama *et al.*, 2023; Pereira *et al.*, 2023), additional funding and a longer implementation period would have been necessary to expand workshops and field activities for training and capacity building in GIS and geotechnologies.

Developing co-financing strategies for continued training is both desirable and necessary to guarantee community access to high-quality learning opportunities—aligned with locally relevant interests and themes and with practical application—regarding the use of geotechnologies. Such training is crucial for integrating and complementing local knowledge, and for enabling communities to express and claim their territorial rights (Cardoso *et al.*, 2017). To advance research on citizen science with Indigenous peoples and traditional communities, several aspects are particularly important: (1) legitimacy and identity (David-Chavez *et al.*, 2024; Hill *et al.*, 2020; McCall; Dunn, 2012; Tengö *et al.*, 2021), as already discussed. Studies show that when local or Indigenous communities articulate their own demands and research practice is oriented toward addressing them, there is greater potential for sustained action over time and space; (2) continuity and proximity between researchers and communities, with transparency about agreements, research planning, and actions (Haklay *et al.*, 2021; Hill *et al.*, 2020; Reyes-García *et al.*, 2019), as well as concrete deliverables that respond to local demands—for example, booklets, guides, or videos about the Potiguara land.

One way to overcome or mitigate these challenges is to include a person or group within the territory to act as focal points of local knowledge – *knowledge-holders* (Orlove *et al.*, 2023; Reyes-García, 2023; Reyes-García *et al.*, 2019), to facilitate and multiply actions while helping to balance power asymmetries and social injustices (Acsehrad, 2013; Brugnach *et al.*, 2017; Chambers, 2006). This research sought to engage Potiguara leaders with decision-making authority in the villages, as well as elders and young leaders. However, the limited timeframe for fully incorporating their voices and perspectives suggests the need for medium- to long-term processes that go beyond the temporal scope of this master's project.

Empowerment in the use of geotechnologies can facilitate and expand participation in the development of citizen science research projects and foster autonomy in establishing partnerships and initiatives (Haklay, 2013; Haklay *et al.*, 2021; McCall; Dunn, 2012). The research was initially designed to build Potiguara capacity not only for data collection but also for GIS operation and map production, aiming to match higher levels of participation and involvement in citizen science projects, as outlined by Haklay (2013).

Working collaboratively with traditional communities requires time to build relationships between all those involved in research. Time spent in the field also helps to encourage and support traditional communities—in this case, the Potiguara Indigenous people—to undertake research on behalf of their “relatives” (parentes) and their territory. Co-participation and autonomy have been, and must continue to be, central themes in research involving traditional knowledge, particularly with regard to data sovereignty and governance over information collected with and/or about traditional communities, so that they can better benefit from the outcomes of research (Hill *et al.*, 2020; Reyes-García, 2023; Williamson *et al.*, 2023).

Despite the challenges, advancing along these paths to create new arrangements, mobilisations, and relationships for the co-construction of knowledge requires putting into practice the principle “nothing about us without us” (Albert *et al.*, 2023). Recognising participating groups as community researchers

and co-authors of outputs and materials is a sine qua non condition in citizen science projects with Indigenous peoples and traditional communities.

Another important mechanism for addressing the challenges identified in this research is the co-creation of Free, Prior and Informed Consent (FPIC) protocols –consistent with the International Labour Organisation’s Convention 169 – together with the communities involved. These protocols should provide guidance on data collection, storage, and use in ways that secure collective benefit, autonomy, ethics, and responsibility, and contribute to formalising data governance and sovereignty frameworks (Hudson *et al.*, 2023; Reyes-García *et al.*, 2022; Wilks *et al.*, 2018; Williamson *et al.*, 2023).

5 CONCLUSIONS

Despite challenges related to the quality of the social maps and the logistics of travelling between villages, the combined use of citizen science, social cartography, and participatory GIS demonstrated strong potential for identifying social, historical, cultural, and tourism-related elements in the Potiguara villages analysed. At the same time, the approach highlighted threats associated with population growth and the expansion of settlements and housing, which intensify problems linked to construction in flood-prone areas and the loss of vegetation.

The citizen science strategy, grounded in social cartography and participatory GIS, fostered integration between the research team and the Potiguara community involved in the study. By positioning communities as protagonists in mapping their territories, this approach enabled the systematisation of elements previously identified by the GIPCSA research group in 2018–2019 and the updating of historical-cultural aspects and environmental changes observed during workshops held in the villages between 2022 and 2023.

This research supported the systematisation of Potiguara observations regarding landscape changes, impacts, and cultural elements through a collaborative process involving researchers and the local community. The method demonstrated strong potential as a tool to support the development of the Territorial and Environmental Management Plan (PGTA) for the Potiguara Indigenous Territory, expanding the collection of territory-related data through active community participation.

Schools were identified as strategic spaces to strengthen Potiguara culture and to promote environmental education initiatives that should be expanded across the territory. All participating villages also emphasised the importance of protecting natural resources to ensure food security and local well-being, as well as the potential of community-based tourism. These initiatives represent opportunities for community strengthening, provided there is territorial governance capable of, for example, limiting “mass tourism” and supporting the Potiguara community’s self-management.

Despite the challenges posed by the limited duration of the research relative to the time required for community assimilation of geotechnologies, the application of a citizen science approach coupled with participatory methodologies shows considerable potential to expand data collection. However, it should be accompanied by protocols that guarantee data sovereignty for Indigenous peoples and traditional communities. Future projects and research on this topic will require the construction of shared agendas among all actors present in the territory, alongside partner schools, to promote training and capacity-building processes that support the Potiguara in their struggle and resistance for governance and management of their territory.

These directions constitute key elements for future research involving citizen science and Indigenous peoples and traditional communities, in line with contributions from scholars of Indigenous science and traditional knowledge.

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STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

The authors used ChatGPT version 5.1 (OpenAI) solely for language editing and stylistic polishing. All scientific content, analysis, and intellectual input were developed and verified by the authors; we take full responsibility for the accuracy and integrity of the manuscript.

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