Reforest or perish: ecosystem services provided by riparian vegetation to improve water quality in an urban reservoir (São Paulo, Brazil)

Refloreste ou pereça: serviços ecossistêmicos providos pela vegetação ripária para melhorar a qualidade da água em um reservatório urbano (São Paulo, Brasil)

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ABSTRACT

We estimated the economic value of ecosystem services provided by the legally protected vegetation in riparian zones (RPA- riparian protected areas) of watercourses of the Guarapiranga Reservoir watershed (São Paulo, Brazil), considering two scenarios: (i) the value of ecosystem services provided if the RPA recovery complies with the applicable environmental legislation; and (ii) the year 2030, maintaining the urbanization rate and the loss of vegetation cover in the watershed observed between 1986 and

2010. Accomplishing the first scenario demands reforesting 5,917.5 ha of the RPA, which may reduce the annual expenses with chemicals for water treatment and save USD 181.774 per 1000 m3 of treated water. For 2030, we estimated a loss of 6,220 ha of vegetation cover in the RPA (1986 as the initial reference). The loss of ecosystem services provided by RPA would result in an accumulated increase of about USD 318 million in water treatment costs between 2011 and 2030.

Keywords: Riparian conservation. Water quality. Water supply. Natural resources management. Environmental valuation. Reforestation.

RESUMO

Estimamos o valor econômico dos serviços ecossistêmicos providos pela vegetação ripária protegida (RPA) das margens e afluentes da Represa Guarapiranga (São Paulo, Brasil), considerando dois cenários: (i) o valor dos serviços ecossistêmicos providos se a RPA for recuperada consoante a legislação ambiental aplicável; e (ii) o ano de 2030, mantido o ritmo de urbanização e perda de cobertura vegetal na bacia observados entre 1986 e 2010. O cumprimento do primeiro cenário demanda reflorestar 5917,5 ha da zona ripária, o que deve reduzir o gasto anual com reagentes e economizar USD 181,774 por 1000 m3 de água tratada. Para 2030, estima-se a perda de 6.220 ha de cobertura vegetal na zona ripária (1986 como ano inicial de referência). A perda de serviços ecossistêmicos providos pela RPA resultaria em um aumento acumulado de USD 318 milhões em custos de tratamento de água bruta entre 2011 e 2030.

Palavras-Chave: Conservação de zonas ripárias. Qualidade da água. Abastecimento público. Manejo de recursos naturais. Reflorestamento.

1 INTRODUCTION

Ecosystem services arise from the links between natural capital and human well-being, direct and indirect benefits generated by the complex interactions between the components of natural capital (COSTANZA et al., 1997). Despite their importance for the maintenance of life on the planet, most of these goods and services are not incorporated in traditional markets and economic transactions, which does not favor their conservation (COSTANZA et al., 2017; DE GROOT et al., 2012).

Variations in water quality as a consequence of land use and coverage changes are mainly due to surface runoff of organic matter and other substances from the activities developed (residences, industries, and others) and the discharge of effluents collected or not, which flow to the associated water bodies (FIQUEPRON et al., 2013; MOKONDOKO et al., 2016).

The decrease in water quality is also related to the reduction of vegetated areas, especially in riparian zones, that perform a series of ecosystem services, such as maintenance of water production, filtering of substances and organic matter, erosion control, nutrient cycling, biological control, and food production (CELENTANO et al., 2017; GUNDERSEN et al., 2010; MELLO et al., 2018; SWEENEY et al., 2004). Studies report an inverse relationship between the presence of vegetation in watersheds and the number of chemicals applied for raw water treatment and the respective financial costs, that is, the higher vegetation covers the better water quality (BRITO et al., 2018; BROGNA et al., 2017; ERNST et al., 2004; FIQUEPRON et al., 2013).

The types of eco-hydrological functions carried out by native vegetation vary according to their position in the relief so that it must be present in all relief types of the watershed to provide all the associated ecosystem services (TAMBOSI et al., 2015). Although usually occupying a fairly strict landscape area, riparian zones play a relevant role in the chemical and physical quality of water as it is a component of interchange between contiguous lands and the aquatic body (CHASE et al. 2016; MOKONDOKO et al., 2016).

The action of the riparian zone in the protection of water resources can vary according to the density of the vegetation bands, the ecological succession stage, the season, and conservation status and the type of vegetation and preserved bandwidth (BROGNA et al., 2017; LOVELL & SULLIVAN, 2006). Much of the ecosystem services provided by forests are related to regulatory functions, such as erosion prevention, pollution control, and water purification (BROGNA et al., 2018; GONZÁLEZ et al., 2017). Ecosystem management by the maintenance of these water services is generally more cost-effective in comparison to the implementation of artificial technologies or mitigation measures (GONZÁLEZ ET AL., 2017; GROLLEAU & MCCANN, 2012).

Taking this into account, this article presents an economic valuation to estimate losses of ecosystem services associated to water quality regulation due to the loss of vegetation cover in riparian zones in the Guarapiranga Reservoir watershed, responsible for the water supply of about 20% of the population of São Paulo Metropolitan Region (SPMR).

Considering the scenario of degradation of the Guarapiranga reservoir, which has eutrophic waters since the 1980s (FONTANA et al., 2014), and its importance for the metropolitan public supply system, it is crucial that the ecosystem services provided by the vegetation cover are better understood, especially regarding the water quality regulation, as well as the importance of recovering riparian areas to guarantee public supply.

Hence, the general objective of this work was to estimate the direct use value of ecosystem services associated with water quality regulation provided by the vegetation cover under legal protection in the riparian zones of the watershed (RPA, riparian protected area). To do so, based on previous assessment estimates, we worked with two hypothetical scenarios: (i) the value of the ecosystem services provided if the arboreal cover of RPAs in the watercourses were restored; and (ii) the estimation of the value of ecosystem services provided by RPAs in the year of 2030, maintaining the rate of urbanization and loss of vegetated areas in the watershed observed from 1986 to 2010.

In this way, it was possible to compare the legal compliance scenario (i) with the recent scenario (2012) and the trend scenario (2030) and prospect if no conservation intervention is put into practice. We expect that evaluating economic costs for possible losses and gains of ecosystem services may assist in the land use planning and management for water public policies.

2 MATERIAL AND METHODS

2.1 STUDY AREA

The Guarapiranga watershed is located in the southwest portion of the São Paulo Metropolitan Region (SPMR), Brazil (Figure 1). The watershed has a drainage area of 611.3 km2, equivalent to 8% of the SPMR territory.

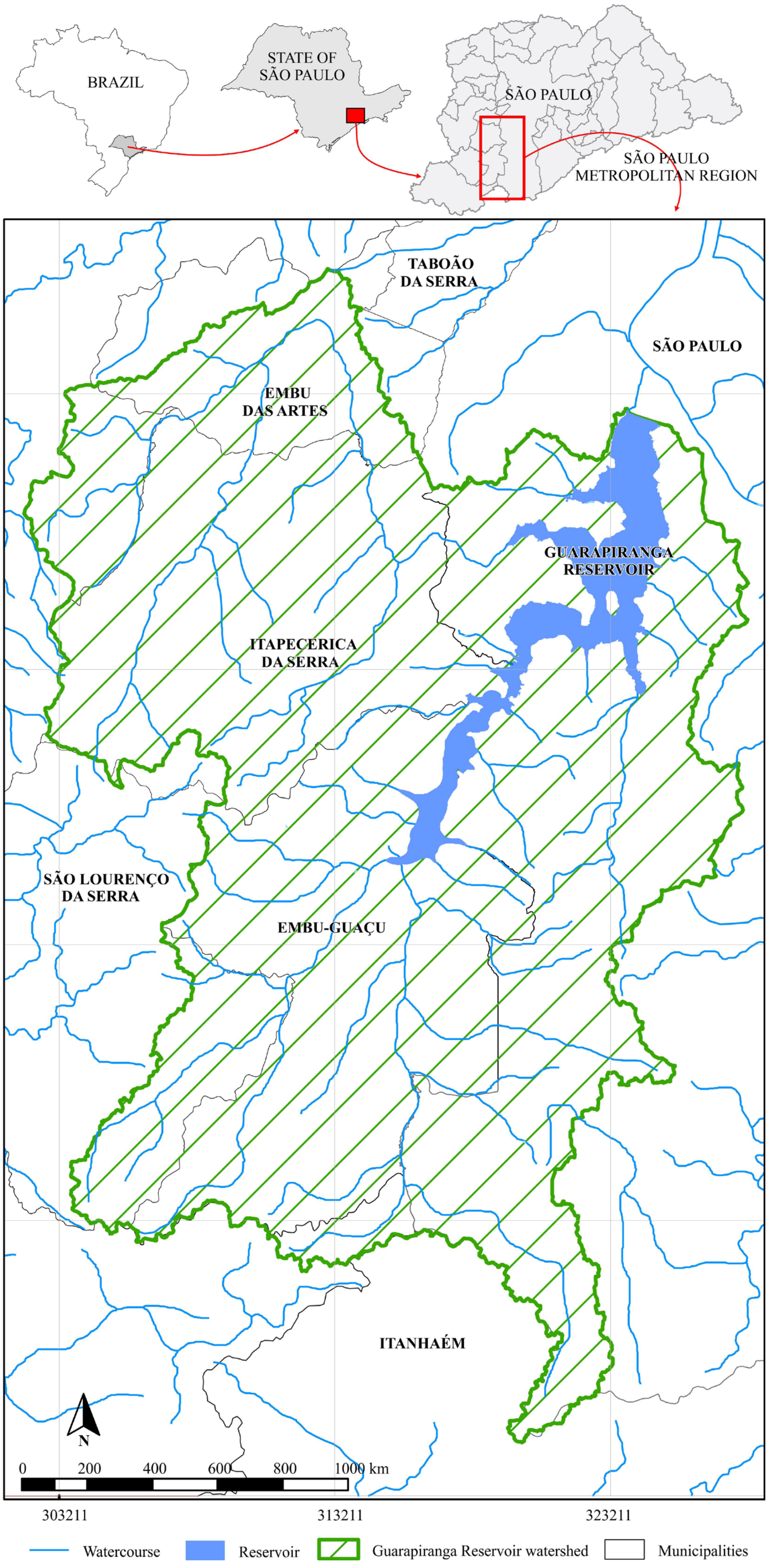

Figure 1 | Guarapiranga Reservoir watershed (green area) and municipalities in the SPMR, Brazil.

Source: Own elaboration by treating data from the cartographic base of the Hydrography of the São Paulo Metropolitan Region and Baixada Santista (IGC/SP).

The Guarapiranga Supply System (GSS) is the second-largest producer of water for the SPMR, with a flow of 14 m3/s, usually supplying 3.8 million inhabitants (20% of the SPMR population). In March 2015, during a hydrological crisis in São Paulo, the GSS supplied 5.2 million inhabitants and became the largest water producer temporarily (SABESP, 2015).

The dam was built around 1906, initially intended to regulate the flow of the Tietê River during the dry season and to complement the power generation (ARAÚJO, 2017). The reservoir became a source for public supply only in 1928 when the surrounded areas started gradually to demand more water for residential and recreational buildings, such as holiday clubs with marinas. The irregular urban settlements, quite populous, started forming in 1970 without sanitary infrastructure, leading to the current scenario, characterized by environmental impacts and social conflicts (ANDRADE et al., 2015; ARAÚJO, 2017).

The watershed landscape is a transitional territory of heavily urbanized northern and western areas of the SPMR, especially around the reservoir, and Atlantic Forest preserved areas, which include the headwaters of the Embu-Guaçu and Santa Rita rivers on the cliffs of Serra do Mar. There are also floodplains partially preserved in the southern and western portions (ANDRADE et al., 2015; SÃO PAULO, 2011).

In early 2000 more than half of the areas around the reservoir were altered by intense anthropic activity and the population was just over 755,000 inhabitants; most of it concentrated northwest and east of the reservoir, where population densities ranged from 94.2 to 100.4 inhabitants/ha (IKEMATSU, 2014; OTOMO et al., 2015; SÃO PAULO, 2011). The historical process of territorial occupation over the last decades and the growing resident population mark the conflict between the environmental function of the watershed, as a producer of water for the public supply of the SPMR, and the potential residential expansion function, because it represents one of the few remaining areas available for human occupation in the metropolitan region (IKEMATSU, 2014).

WATER QUALITY

Previous studies show that the water quality of the Guarapiranga Reservoir is directly related to the characteristics of land use and cover, as well as the availability of sanitary infrastructure and operational efficiency (FONTANA et al., 2014; LEAL et al., 2017; SEMENSATTO & ASAMI, 2017). In 2000, 88% of the households in the watershed had water supply but only 53% were connected to the sewerage system (SÃO PAULO, 2011). The loads from domestic sewage in urban areas accounted for 93.6% of the estimated total phosphorus input generated in the watershed (SÃO PAULO, 2011).

More than half of the Guarapiranga Reservoir area presents significant changes caused by anthropic impacts (LEAL et al., 2017), mainly caused by the flow of untreated sewage to the reservoir that became eutrophicated (FONTANA et al., 2014). The situation is worse in the rainfall season when water quality declines due to more intense urban runoff (SEMENSATTO & ASAMI, 2017). Consequently, the water quality varies spatially and seasonally throughout the reservoir. The region closest to the catchment for supply presents better quality, which is the consequence of the natural depuration of the body of water, whereas the regions with higher population density and where tributaries and transposition that reach the reservoir present higher concentrations of pollutants (SÃO PAULO, 2011; SEMENSATTO & ASAMI, 2017).

2.2. DATA SOURCE AND CONCEPTUAL PREMISES

We used the land use and vegetation cover data elaborated by Andrade et al. (2015) for the Water Quality Assessment of Guarapiranga Reservoir (Aquased Project). This database was chosen because it presents a temporal and spatial resolution compatible with our study, besides being used by Brito et al. (2018) in the valuation of ecosystem services, which in turn served here as the reference for the local ecosystem services valuation. Andrade et al. (2015) analyzed territorial changes of the watershed by mapping land use and cover types for the years 1986, 1996, 2010, at the regional scale 1:100,000, using an automatic classification of Landsat® images. For a more detailed analysis, they also used multispectral images Ikonos® (05/28/2012), on the scale of 1:10,000 for urban regions and 1:20,000 for other areas.

This study is based on the following conceptual assumptions regarding the analysis of results:

- The valuation of ecosystem services can be overestimated or underestimated because it is virtually impossible to describe all valuable ecosystem relationships and functions adequately;
- The rate of future changes in land use and cover was calculated considering the same trend will continue over the years prospected, based on the rate of loss of vegetation cover observed from 1986 to 2010 by Andrade et al. (2015);
- In the quantification of arboreal vegetation cover in the riparian zones we did not consider the differences among the types of vegetation, their successional stage, as well as their variation in terms of ecological functions;
- The estimation of the valuation of ecosystem services in riparian zones considered only the vegetation cover area (fields, forests, and reforestation);
- The regression model used in inferences considered only the variable “area of vegetation cover” and did not consider the effect of other factors, such as a change in population growth rate, implementation/extinction of management programs, or change in legislation;
- The water treatment technologies employed, and the public policies related to environmental conservation were considered constant over the years.

2.3. HYPOTHETICAL SCENARIOS

SCENARIO I: RIPARIAN ZONES WITH VEGETATION COVER FULLY RECOVERED

We delimited the waterbodies’ RPAs using the cartographic base of the Hydrography of the São Paulo Metropolitan Region and Baixada Santista (IGC/SP), at the scale of 1:25,000. Due to the lack of data, it is important to mention that the tributary springs were not considered in this study. Using ArcGIS 10.5 software (ESRI)® the RPAs were delimited according to the definitions of the Federal Law 12.651/2012 (buffer between 30-50 m depending on the river width) and the margin of the Guarapiranga Reservoir according to the São Paulo State Law 12.233/2006 and State Decree 51.686/2007 (50 m measured in horizontal projection from the contour line corresponding to the maximum level of the reservoir of 737 m in altitude, which equals to 171.2 hm3 stored.

This scenario presupposes full compliance with the corresponding environmental legislation. It indicates that the whole RPAs are covered by vegetation and there is no other type of current use. From this, it was possible to compare the situation of land use and cover (updated map from 2012) with the hypothetical scenario of legal compliance to estimate the value of ecosystem services that are lost in the real scenario and that could be gained in case of full recovery.

The vegetation cover forming riparian zones on the margins of the watercourse, such as forests, mosaics of vegetation and naturally flooded areas, play a critical role in protecting water resources by maintaining water quality in good conditions and by supplying and replenishing groundwater, such as aquatic sheets and aquifers (GONZÁLEZ et al., 2017). Deforestation debilitates virtually all ecosystem services. Thus, preservation of these areas is fundamental for the regulation of both the hydrological cycle and the biogeochemical cycles (SWEENEY et al., 2004; TAMBOSI et al., 2015).

The RPAs map was then superimposed over the map of land use and vegetation cover from 2012 elaborated by Andrade et al. (2015) to identify the type of land use present in riparian zones. This made it possible to define the arboreal cover deficit in the riparian zone observing the compliance with the legislation (Equation 1). Although the vegetation cover with exotic species (reforestation) is not in compliance with the current legislation for RPAs, we included this type of cover since the ecosystem functions and services for water regulation are somewhat similar to native forests (BROCKERHOFF et al., 2013; FERRAZ et al., 2013). Moreover, the presence of old commercial planting with the regeneration of native vegetation in the understory is a common structure for the reservoirs of SPMR (ROMERO et al., 2018). Even so, we cannot ignore concerns about the potential effects of forestry activities on water quality or the economic implications of limiting some chemical substances reaching lakes and streams (ERIKSSON et al., 2011).

$$ACD_{RB(YEAR)} = TA_{RB} - AC_{RB(YEAR)} \qquad (1)$$

$ACD_{RB(YEAR)}$: Arboreal Cover Deficit in the riparian zone in a given year

TA_{RB}: Total Area of the riparian zone

$AC_{RB(YEAR)}$: Arboreal Cover of the riparian zone in a given year

Scenario II: Keep Losing Vegetation Cover in the Riparian Zones until 2030

The year 2030 was chosen because it is the target year for meeting the Sustainable Development Goals (SDGs) of the 2030 Agenda established by the United Nations (UN), which includes the protection and restoration of ecosystems related to water quality, especially SDGs 6.3 and 15.1, which respectively state “By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally”, and “By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains, and drylands, in line with obligations under international agreements” (UNITED NATIONS, 2015). Moreover, it is equivalent to at least five federal government mandates in Brazil, which would be, in principle, enough time for the consolidation and execution of a public policy of environmental resources conservation necessary to meet the UN agenda.

We projected the vegetation cover in 2030, based on the rate of loss of vegetation in the watershed previously observed between 1986, 1996 and 2010. For that, we fitted a logarithmic curve between the years and the area of the vegetation cover computed by Andrade et al. (2015). Although we did not consider the increase of built-up areas, it is directly related to the reduction of the vegetation cover areas (BRITO et al., 2018).

2.4 VALUATING ECOSYSTEM SERVICES

We transferred the value of the ecosystem services calculated by Brito et al. (2018) to estimate the value of the ecosystem services related to water quality regulation provided by the vegetation cover identified in the watershed. This technique is widely used in the field of economic valuation of environmental resources when data is absent and it is acceptable when it is done between sites that present physical similarities and of the same valuation specificities (TROY & WILSON, 2006).

Brito et al. (2018) evaluated the ecosystem service of water quality in the Guarapiranga watershed through the Avoided Costs Method, which estimates the value of the use of natural resources that would be incurred in substitute goods in order not to alter the productivity since these services represent the production of a good that is not observable in the market. The estimate of the ecosystem service value was calculated utilizing the expenses needed to mitigate environmental degradation, namely the treatment of raw water for public supply. The authors estimated the value of the perfect substitute based on the data of average chemicals dosage utilized to treat raw water in the years of 1996 and 2010 obtained in consultation with the Brazilian National Sanitation Information System (SNIS), as well as expenditure on these chemicals.

The results obtained by Brito et al. (2018) showed that the loss of vegetation cover has a direct and negative correlation with the average dosage of reagents used in the treatment of raw water. The authors estimated the economic value of environmental resources for the ecosystem service of the water supply of the Guarapiranga reservoir for the years 1996 and 2010 at USD 927,536.25 and USD 6,624,543.78, respectively. Thus, the monetary value of the loss of vegetation cover is at least the value of the costs incurred in maintaining water quality (water treatment costs), and therefore the increase in the cost of treatment can be considered as a substitute for the evaluation of ecosystem services of good quality water supply. Using this approach and data, we rated the Value of the Ecosystem Service (VES) for the hypothetical scenarios by inferring the value of the increase in water treatment costs (WTCIha) to treat 1,000 m³ of raw water for each hectare of vegetation cover suppressed (Equation 2).

$$WTCI_{ha} = \frac{RCT_{2010} - RCT_{1996}}{VC_{1996} - VC_{2010}} \qquad (2)$$

$WTCI_{ha}$: Water Treatment Cost Increase for each hectare of vegetation suppressed (USD/ha)

RCT_{year}: Relative Cost of Treatment of raw water (1,000 m3) in a given year (USD)

VC_{year}: Vegetation cover in a given year (ha)

The VES was calculated through the monetary expenditure data with chemicals used to treat water and the area of vegetal cover for the period from 1996 to 2010. Based on this value and the vegetation cover inferred using the logarithmic model (fields, forests, and reforestation), it was possible to assess the relative cost in 2030 (RCT2030) (Equation 3) and the VES for the year 2030 (Equation 4).

$$RCT_{2030} = WTCI_{ha} \cdot (VC_{2030} - VC_{1996}) \qquad (3)$$

$$VES_{2030} = WP_{2030} \cdot RTC_{2030} \qquad (4)$$

VES_{year}: Value of the Ecosystem Service in a given year (USD)

WP_{year}: Water Production for public supply in a given year (1,000 m3)

Having established this estimate and the inference of the vegetation cover in 2030, we estimated the value associated with the loss of ecosystem services. We applied the same rationale by using the same value resulting from Equation 2 to calculate the VES of the deficit area of vegetation cover in the RPA. The reference currency was the US dollar to maintain compatibility with the data of Brito et al. (2018) and to allow comparability with other studies.

3 RESULTS AND DISCUSSION

3.1 SCENARIO I: FULL RECOVERY OF THE VEGETATION COVER IN RIPARIAN ZONES

The Guarapiranga watershed has 17,307.91 ha legally protected as RPAs (watercourses + reservoir), which is equivalent to 28% of the total area; 97% of RPAs are located at watercourse riparian zones (Table 1). In the present scenario (2012), the vegetation cover of RPAs represented equal rates to watercourses and reservoir, 77.4% and 75.2%, respectively. The difference was for arboreal cover (forest and reforestation), with 66.5% in the watercourses and 39.0% in the reservoir.

Moreover, the RPA of the reservoir proportionally concentrates more anthropized areas such as roads, residential areas, commerce and services, and other urban installations, than the RPAs of the watercourses in the entire watershed (Table 1, Figure 2). These differences indicate that the reservoir management did not have efficient control of the occupation and use of margins. Furthermore, they suggest that the legal definitions and the general guidelines of best practices of management to ensure better water quality is not being met.

The proportion of arboreal vegetation at 66.5% is a result of susceptibility of the RPAs to the historical process of the progressive anthropization of the watershed (ARAÚJO, 2017; FONTANA et al., 2014) represented by settlements (legal and illegal) and the construction of holiday clubs, marinas, restaurants, commerce and services linked to water sports (east) and small farms (west). As expected, the arboreal cover in the watercourses was concentrated mainly in areas of higher elevations in the western and southern regions of the watershed (Figure 2). On the other hand, the areas to the east and northwest of the reservoir, which present a higher population density (SÃO PAULO, 2011), are those with the lowest presence of arboreal cover. Although low-productivity or abandoned grasslands (here referred to “fields”) do not induce water degradation (that is one reason we included them in the vegetation cover), the forest cover should always be stimulated as a priority in riparian zones because of its strong and positive correlation with water quality (MELLO et al., 2018).

Table 1 | Land use and land cover in the RPAs of the Guarapiranga watershed (SP, Brazil) in 2012.

Land use and land cover	*Riparian Preservation Areas (RPAs)*			
	Watercourses (ha)	*%*	*Reservoir (ha)*	*%*
FIELDS	1,845.21	10.9	156.71	36.2
CULTIVATED LANDS	250.40	1.5	0.28	0.1
URBAN GREEN SPACES	44.45	0.3	-	-
UNBUILT LOTS	11.47	0.1	-	-
FORESTS	10,241.18	60.7	158.81	36.7
REFORESTATION	980.23	5.8	10.16	2.3
HOUSES/COMMERCE/SERVICES/OTHER URBAN INSTALLATIONS	3,422.49	20.3	104.31	24.1
ROADS	61.54	0.4	2.57	0.6
EXPOSED SOILS	17.88	0.1	0.19	0.04
TOTAL	**16,874.88**	**100**	**433.03**	**100**

Source: Own elaboration by treating data published by Andrade et al. (2015).

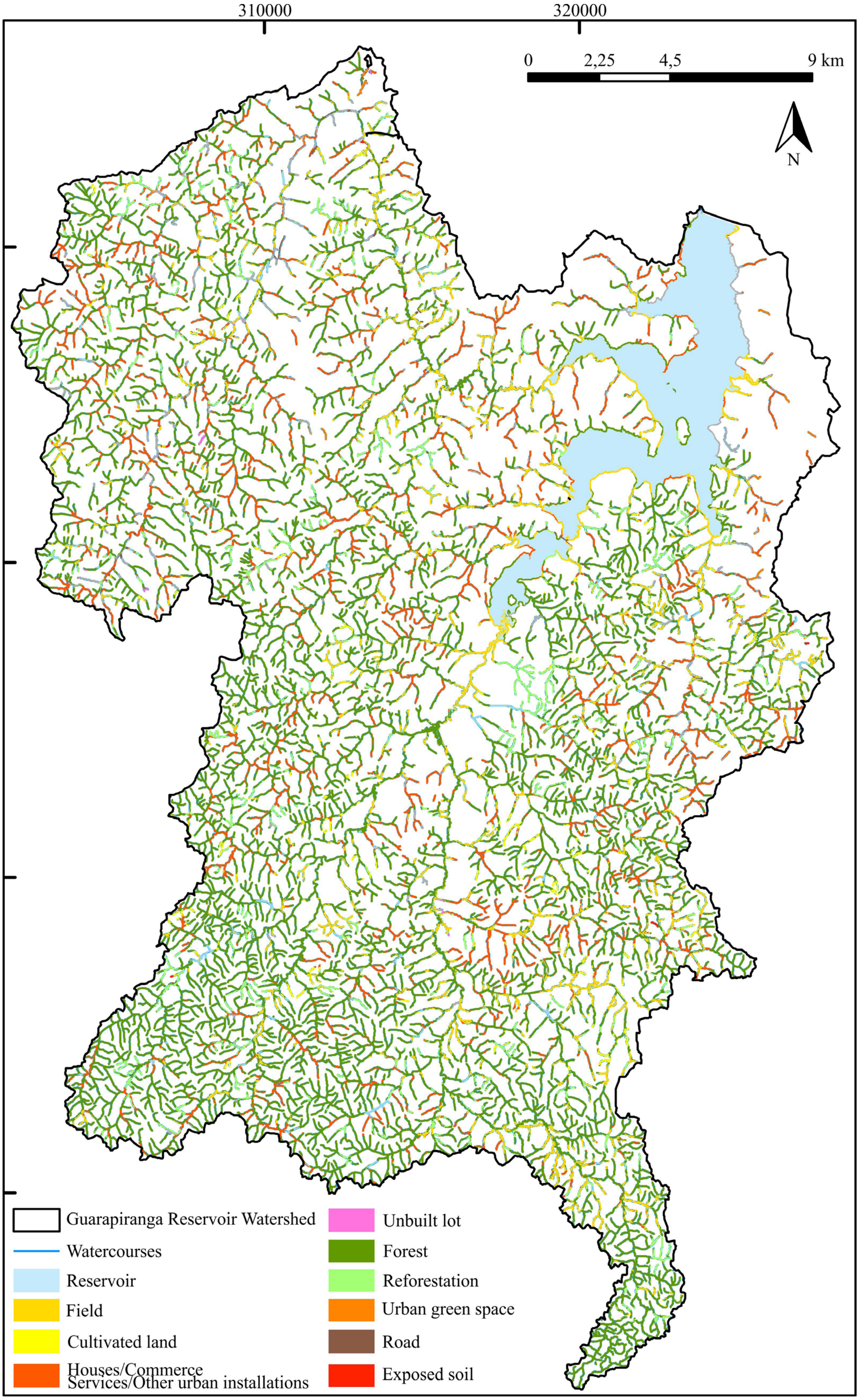

Figure 2 | Land use and cover of the RPAs of the Guarapiranga watershed (SP, Brazil) in 2012.

Source: Own elaboration by extracting and treating data published by Andrade et al. (2015) and the cartographic base of the Hydrography of the São Paulo Metropolitan Region and Baixada Santista (IGC/SP).

Under the theoretical hypothesis of full compliance with environmental legislation (Federal Law 12651/2012 and State Law 12233/2006), in which the entire riparian zones should be covered with forests (arboreal vegetation considering the study's purposes), and applying Equation 1, it would be necessary to reforest 5,917.5 ha (Table 2). Applying reference data from Antoniazzi et al. (2016), the cost (only material and manpower) to reforest this area may vary from USD 1,571,392.00 (active natural regeneration) to USD 14,545,037.00 (planting native trees), considering non-economic use of the planted area in Atlantic Forest (São Paulo State, Brazil) using native seedling.

Nonetheless, the real costs require study of specific characteristics of the area that were not addressed here, such as physical characteristics of the landscape, phytosociological data, and analysis of possible expropriations of real estate and removals, which was not in the scope of this analysis. Despite the undoubted importance (ecological and economic) of the restoration of arboreal cover in riparian zones, the historical and current land use of riparian zones does not show signs of changes in this sense.

There is a heterogeneous distribution of land uses of riparian zones throughout the area, resulting from the advance of large urbanization axes with the replacement of vegetation cover by built-up areas (ANDRADE et al., 2015; IKEMATSU, 2014). This process was stimulated by both public and private projects of settlements with various social profiles including irregular occupations of more remote areas and less value from the real estate perspective (ARAÚJO, 2017).

Table 2 | Arboreal cover (forest and reforestation) of the riparian zones of Guarapiranga watershed (SP, Brazil) in the present situation (2012), in the scenario of full legal compliance and the deficit of compliance in 2012

Type of the RPA	*Present situation (2012)*		*Full legal compliance*		*Deficit of legal compliance in 2012*	
	Area (ha)	*%*	*Area (ha)*	*%*	*Area (ha)*	*%*
WATERCOURSES	11,221.4	66.5	16,874.9	100	-5,653.5	33.5
RESERVOIR	169.0	39.0	433.0	100	-264	61.0
TOTAL RPAS	11,390.4	65.8	17307.9	100	5,917.5	34.2

Source: Own elaboration by treating data published by Andrade et al. (2015).

3.2. SCENARIO II: VEGETATION COVER IN 2030

The logarithmic curve was traced to obtain its regression model and infer the vegetation cover in the whole watershed in 2030, considering the rate of regional loss inferred from data reported by Andrade et al. (2015) (Figure 3). The logarithmic model is the most appropriate conceptually because the substitution of vegetation cover by other types of use must occur until near an asymptotic minimum limit. The forecast is that by 2030 the area of vegetation cover (51,390 ha) is reduced by 6,220 ha, which represents a reduction of 10.8% having the year 1986 as the initial reference (Table 3). Riparian deforestation impacts negatively on many types of ecosystem services, such as preventing pollutants from entering water bodies and amortizing nonpoint and point source pollutants (CHASE et al., 2016; SWEENEY et al., 2004).

Thus, deforestation has the potential to affect other ecosystems and respective services by reverbing negative impacts through diverse links, which may increase the externalities to users of water supply. We know that water quality may decrease with riparian deforestation because it promotes disturbances in hydrological and physical aspects of water bodies (e.g., sediment transport, water velocity, channel roughness), increases transference of some pollutants to water bodies by leaching and superficial runoff (riparian vegetation plays a filtering role), and induces changes in biological aquatic activities linked to aquatic chemical transformations (BROGNA et al., 2017; FIQUEPRON et al., 2013; MELLO et al., 2018; SWEENEY et al., 2004).

If deforestation keeps the recent pace through the next years in the watershed, the SDGs 6.3 and 15.1 will never be accomplished. Although 10% of vegetation loss over two decades does not appear overly impressive, this scenario can be worse considering recent political tendencies. The main Brazilian law that regulates RPAs (Federal Law 12.651/2012 – Forest Code) has changed in the last years, becoming more flexible and allowing anthropic uses in consequence of changes in technical terms that define protected areas; creation of the consolidated area concept in rural landscapes (uses before 2008); and the reinforcement of public utility and social interest in urban areas (ISSII et al., 2019; SPAROVEK et al., 2011).

These are important changes that may weaken conservation efforts and the possible gains in ecosystem services (ALARCON et al., 2015), which may represent an extra obstacle to recover the riparian zones and restore their ecological functions. Another important challenge facing riparian zones is that some modifications in legislation can create contradictory guidance with non-specific laws applicable to those zones (GONZÁLEZ et al., 2017), such as the State Decrees that forbid the construction of sanitation infrastructure in RPAs with irregular settlements.

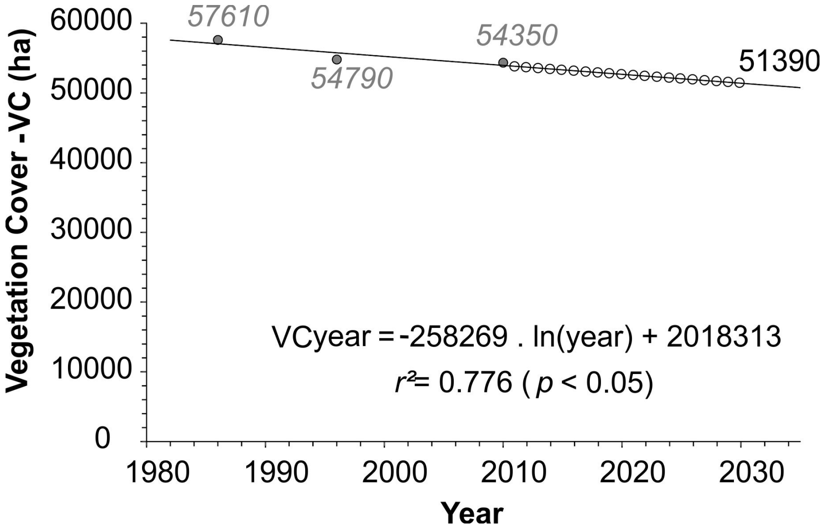

Figure 3 | Scatterplot with the logarithmic curve and respective model used to infer the vegetation cover throughout the years at the Guarapiranga watershed (SP, Brazil). The values in grey were observed by Andrade et al. (2015) and the white circles were computed from the logarithmic regression model.

Source: Own elaboration by treating data published by Andrade et al. (2015).

Table 3 | Estimates of vegetation cover loss in the Guarapiranga watershed (SP, Brazil) throughout the years. The values between 2011 and 2030 were inferred from the logarithmic model (Figure 3).

Year	*Vegetation cover area (ha)*	*Vegetation cover lost since 1986 (accumulated %)*	*Accumulated area of vegetation cover lost since 1986 (ha)*
1986	57.610	-	-
1996	54.790	4,89	-2.820
2010	54.350	5,66	-3.260
2011	53.819	6,58	-3.791
2012	53.691	6,80	-3.919
2013	53.562	7,03	-4.048
2014	53.434	7,25	-4.176
2015	53.306	7,47	-4.304
2016	53.178	7,69	-4.432
2017	53.050	7,92	-4.560
2018	52.921	8,14	-4.689

Year	*Vegetation cover area (ha)*	*Vegetation cover lost since 1986 (accumulated %)*	*Accumulated area of vegetation cover lost since 1986 (ha)*
2019	52.794	8,36	-4.816
2020	52.666	8,58	-4.944
2021	52.538	8,80	-5.072
2022	52.410	9,03	-5.200
2023	52.282	9,25	-5.328
2024	52.155	9,47	-5.455
2025	52.027	9,69	-5.583
2026	51.900	9,91	-5.710
2027	51.772	10,13	-5.838
2028	51.645	10,35	-5.965
2029	51.518	10,58	-6.092
2030	51.390	10,80	-6.220

Source: Own elaboration.

3.3. VALUE OF THE ECOSYSTEM SERVICE

According to Brito et al. (2018), Sabesp produced 357,462,595 m3 of treated water for public supply in the Guarapiranga System in 1996 and spent USD 927,536.25 on chemicals for water treatment. Thus, the estimated relative cost was USD 2.5948 per 1,000 m3 of treated water. In 2010, Sabesp produced 411,175,012 m3 of treated water, which represented an increase of 15% compared to 1996. However, a total expenditure with chemicals in 2010 reached USD 6,624,543.78, resulting in the relative cost of USD 16.1113 per 1,000 m3 of treated water. Although the production of the system increased by 15%, the relative cost of treatment increased dramatically by around 621%. This amount represents one of the dimensions of loss of value of ecosystem services in the watershed due to the replacement of vegetation cover (ecosystem service provider) by built-up areas (demand for ecosystem service), as explained by Brito et al. (2018).

Mello et al. (2018) reported a similar situation in other areas in Brazil (Sapuraí River watershed, State of São Paulo), where they found a significant and positive correlation between the forest cover and water quality and a significant and negative correlation between the urban cover and water quality. They reported that forest cover correlates strongly and positively with dissolved oxygen and correlates negatively with total phosphorous (TP), total nitrogen (TN) and fecal coliforms (FC). Indeed, these last three variables and the eutrophication process have increased throughout the last decades at Guarapiranga watershed as deforestation took place (FONTANA et al., 2014; SEMENSATTO & ASAMI, 2017).

Concerning the total expenditure with chemicals for water treatment between 1996 and 2010, there was a nominal increase of USD 13.5165 per 1,000 m3 of treated water, and during this period the RPA vegetation cover was reduced by 440 ha, from 54,790 to 54,350 ha (Table 3). Thus, the result of the application of Equation 2 is that the $WCTI_{ha}$ is equal to 0.030718 USD/ha per 1,000 m3 of treated water. As we mentioned earlier (item 3.2), maintaining a similar rate of land use and changes in land cover, by 2030 vegetation cover will be 51,390 ha, which represents a reduction of 2,960 ha since 2010 (Figure 3, Table 3). Therefore, based on this change and the assumptions of this work, the RCT_{2030} may reach USD 90,917 per 1,000 m3 of treated water. If the level of water production (*WP*) recorded between 2009 and 2013 is maintained, the reservoir may produce around 420,000 m3 in 2030. Thus, with the loss of vegetation and its respective ecosystem services the $WTCI_{ha}$, the total estimated cost of water treatment for public supply for the year 2030 will be USD 38,185,319.75, which here is recognized as equivalent to the *VES* (Table 4). When compared to 2010 costs, this will mean an increase of USD 31,560,775.97 or approximately 576% in expenses with chemicals. If we observe the inferred annual increase in the treatment cost compared to that spent in 2010, by 2030 USD 318,343,202.12 of VES would have been lost for 18 years.

It is an estimate of the loss of ecosystem services provided by the vegetation cover with the probable consequent externality to users of the public supply. At the same time, it also represents an estimate of the amount of investment in the water treatment system needed to replace the service provided by vegetation cover and amortize their respective loss over time, if the objective is to maintain the values of 2010. It should be noted that this scenario considers only the water quality maintenance service estimated for direct use, following the estimate of Brito et al. (2018). It does not consider the possible level of degradation of water quality in terms of impeding all the multiple uses and of restrictions in availability for public supply due to sanitary standards.

Table 4 | Inference of the VES estimated for the water quality maintenance by vegetation cover in the Guarapiranga Reservoir watershed (SP, Brazil).

Year	*Water Production (1,000 m3)*	*Relative Cost of Treatment – RCT (USD/1,000 m3)*	*VES (USD/year)*	*Increment of the Cost of Treatment from 2010 (USD)*	*Accumulated Increment of the Cost of Treatment from 2010 (USD)*
1996	357,463	2,595	927.536	-	-
2010	411,175	16,110	6.624.543,78	-	-
2011	420,000	16,313	6.851.563,98	227.020,20	-
2012	420,000	20,257	8.508.075,58	1.883.531,80	2.110.552,00
2013	420,000	24,199	10.163.764,06	3.539.220,28	5.649.772,28
2014	420,000	28,140	11.818.630,24	5.194.086,46	10.843.858,74
2015	420,000	32,078	13.472.674,95	6.848.131,17	17.691.989,92
2016	420,000	36,014	15.125.899,00	8.501.355,22	26.193.345,14
2017	420,000	39,948	16.778.303,20	10.153.759,42	36.347.104,56
2018	420,000	43,881	18.429.888,37	11.805.344,59	48.152.449,14
2019	420,000	47,811	20.080.655,30	13.456.111,52	61.608.560,67
2020	420,000	51,740	21.730.604,83	15.106.061,05	76.714.621,72
2021	420,000	55,666	23.379.737,75	16.755.193,97	93.469.815,69
2022	420,000	59,591	25.028.054,88	18.403.511,10	111.873.326,79
2023	420,000	63,513	26.675.557,01	20.051.013,23	131.924.340,02
2024	420,000	67,434	28.322.244,96	21.697.701,18	153.622.041,20
2025	420,000	71,353	29.968.119,53	23.343.575,75	176.965.616,95
2026	420,000	75,269	31.613.181,53	24.988.637,75	201.954.254,70
2027	420,000	79,184	33.257.431,74	26.632.887,96	228.587.142,66
2028	420,000	83,097	34.900.870,99	28.276.327,21	256.863.469,87
2029	420,000	87,008	36.543.500,06	29.918.956,28	286.782.426,15
2030	420,000	90,917	38.185.319,75	31.560.775,97	318.343.202,12

Source: Own elaboration.

Taking into account the scenario of legal compliance for this study, where the riparian zones would be completely recovered by arboreal vegetation, it is observed that the recovery of 5,917.5 ha (Table 2) using the same logic for the projections by 2030 would represent theoretical savings of USD 181,774 per 1,000 m³ of treated water (5,917.5 ha x USD 0.030718). Although this value gained in the ecosystem services (cost-of-treatment savings) would initially express a hypothetical cost below zero for water treatment, it is more appropriate to infer that the cost involved with reagents would potentially regress to the levels spent in 1996.

Our results point out that the value that would be generated in terms of ecosystem services if the vegetation cover deficit in riparian zones was eliminated would be higher than the amount spent for the water treatment. Fiquepron et al. (2013) estimated that an increase of 1% of forest cover would decrease by €0.0034/m3 (USD 0.0038/m3) of invoiced drinking water. If we compare their results with our estimates, an increase of 1% of vegetation cover at the Guarapiranga watershed would decrease treatment cost by €0.015/m3 (USD 0.0168/m3) which represents a more significant economic impact on water users. Certainly, it is necessary to consider that there are many other factors associated with the relationship between vegetation cover and water quality (BROGNA et al., 2017), especially in a complex watershed such as the Guarapiranga reservoir.

Furthermore, the installation of sanitation infrastructure for sewage collection and treatment, for example, should have an impact on the cost of water treatment as significant as the recovery of the vegetation cover. Despite these influences, in general, afforestation may produce many more benefits and improve other ecosystem services not included in our analysis (BROGNA et al., 2017). Buffin-Bélanger et al. (2015), for instance, predicted that riparian zones ecosystem services could reach CDN$ 958/ha/year (USD 691/ha/year) in Canadian watersheds by avoiding costs related to flood protection and improving wetlands ecosystem services.

3.4. LIMITS OF THE INFERENCES

Although the results showed an estimate of the value for the ecosystem services provided by the vegetation for water quality regulation, it is necessary to keep in mind that the methodology applied has some limitations. First, the projection of areas of vegetation cover for the future trend scenario in 2030 considered only the “vegetation cover area” as a variable. Other variables could influence changes in water quality, such as population growth, changes in current legislation, implementation of sanitation facilities or other measures that can reduce the input of organic matter and substances that alter water quality, as we have discussed above.

Furthermore, the practice of transferring values generally results in errors in the estimates due to the inherent differences among ecosystems and the lack of information. For this study, this was not a limitation, considering that the values transferred are specific for the studied site since both studies were carried out in the Guarapiranga watershed.

Variations in estimated values should be viewed with caution. The initial implicit idea is that variations in the values of ecosystem services reflect changes in their physical flows. However, the dynamics of ecosystem functions are not linear and require an in-depth knowledge of the relationships between ecosystem components to figure them out. Finally, considering the period proposed in the scenarios and that the scenario estimates are based on the variable “vegetation coverage area”, values of the ecosystem services coefficients cannot be considered static either, since the variation in the quantity of ecosystem services provided may change its monetary value due to interaction between demand and supply.

4 CONCLUSIONS

This work presents an example of the valuation of ecosystem services and projected scenarios due to the loss of vegetation cover in the Guarapiranga Reservoir watershed. This study was performed to demonstrate the importance of this methodological tool and to predict potential impacts for the public supply to subsidize environmental public policies. The results showed a negative impact on the value of the ecosystem service of water quality regulation, and therefore on the possible increase of externalities (e.g. water cost for users) with the loss of these services provided by the vegetation cover.

The conjectures derived from the projected scenarios presented here indicate that society faces two options concerning the Guarapiranga Reservoir: (i) to recover water sources and to conserve vegetation cover that protects water resources, thus saving financial resources due to ecosystem services provided by these natural areas, or (ii) to maintain the rate of land use and change in land cover, leading to progressive degradation of water resources and the need for larger financial contributions to maintain the quality of water in the SPMR. In the latter case, the support capacity of the watershed in terms of degradation must be considered, as once it reaches this level, the resources will become unavailable. Moreover, it will be impossible to accomplish SGDs 6.3 and 15.1.

Our results show that from simple data, such as historical land use and cover, we can infer the impact of change in land cover on water quality and calculate the financial damage in terms of water treatment costs. This projection analysis is quite simple and predicts the future without considering other socio-political-economic influences, and has the strength of simplicity and replicability of the model. The intention of this study is not to provide robust economic analysis, but to allow a simple prediction of the trend of future environmental changes (in water quality) to make this applicable in decision making on planning and management of water resources.

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