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Mapping environmental fragility and maintenance of ecosystem services in an Atlantic Forest region in Pontal do Paranapanema – SP.

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Mapeamento da fragilidade ambiental e a manutenção dos serviços ecossistêmicos em uma região de Mata-Atlântica no Pontal do Paranapanema - SP

RESUMO

Os serviços ecossistêmicos (SE) são vitais para o bem-estar e a sobrevivência da humanidade, abrangendo uma variedade de benefícios fornecidos pela natureza, como formação de solos, controle de erosão, regulação do clima, armazenamento de carbono, ciclagem de nutrientes, provisão de água, manutenção do ciclo de chuvas, proteção da biodiversidade e muito mais. Teodoro Sampaio, situado entre os rios Paraná e Paranapanema, abriga um extenso trecho de Mata Atlântica, servindo como refúgio para espécies ameaçadas. A região, no entanto, enfrenta desafios ambientais significativos devido às atividades econômicas, como hidrelétricas, agropecuária extensiva e o crescimento do agronegócio com influência estrangeira. O estudo buscou avaliar a fragilidade ambiental dessas áreas produtoras de SE, combinando a fragilidade potencial com o uso da terra. Foram considerados fatores como geomorfologia, clima, pedologia e uso do solo. Cada variável recebeu uma classificação de fragilidade (fraca, média ou forte), e esses dados foram combinados no software QGIS com peso igual para produzir um mapa de fragilidade ambiental. Esse mapa identificou níveis que variam de Muito Fraco a Muito Forte em termos de erosão linear e, consequentemente, na capacidade dos ecossistemas de fornecer serviços essenciais para o desenvolvimento da região.

PALAVRAS-CHAVE: Fragilidade ambiental. Serviços ecossistêmicos. Desenvolvimento sustentável.

Mapping environmental fragility and maintenance of ecosystem services in an Atlantic Forest region in Pontal do Paranapanema – SP.

SUMMARY

Ecosystem services (ES) are vital to the well-being and survival of humanity, encompassing a variety of benefits provided by nature, such as soil formation, erosion control, climate regulation, carbon storage, nutrient cycling, water provision, rainfall cycle maintenance, biodiversity protection, and more. Teodoro Sampaio, located between the Paraná and Paranapanema rivers, is home to an extensive stretch of Atlantic Forest, serving as a refuge for endangered species. The region, however, faces significant environmental challenges due to economic activities such as hydroelectric dams, extensive farming, and the growth of foreign-influenced agribusiness. The study sought to assess the environmental fragility of these SE-producing areas, combining potential fragility with land use. Factors such as geomorphology, climate, pedology, and land use were considered. Each variable received a frailty rating (weak, medium, or strong), and these data were combined in the QGIS software with equal weight to produce a map of environmental fragility. This map identified levels ranging from Very Weak to Very Strong in terms of linear erosion and, consequently, in the ability of ecosystems to provide essential services for the region's development.

KEYWORDS: Environmental fragility. Ecosystem services. Sustainable development.

Mapeo de la fragilidad ambiental y el mantenimiento de los servicios ecosistémicos en una región de Mata Atlántica en el Pontal del Paranapanema - SP

RESUMEN

Los servicios ecosistémicos (SE) son vitales para el bienestar y la supervivencia de la humanidad, abarcando una variedad de beneficios proporcionados por la naturaleza, como la formación de suelos, el control de la erosión, la regulación del clima, el almacenamiento de carbono, el ciclo de nutrientes, la provisión de agua, el mantenimiento del ciclo de lluvias, la protección de la biodiversidad y mucho más. Teodoro Sampaio, ubicado entre los ríos Paraná y Paranapanema, alberga un extenso tramo de Mata Atlántica, sirviendo como refugio para especies amenazadas. Sin embargo, la región enfrenta importantes desafíos ambientales debido a actividades económicas como centrales hidroeléctricas, ganadería extensiva y el crecimiento del agronegocio con influencia extranjera. El estudio buscó evaluar la fragilidad ambiental de estas áreas productoras de SE, combinando la fragilidad potencial con el uso de la tierra. Se consideraron factores como geomorfología, clima, edafología y uso del suelo. Cada variable recibió una clasificación de fragilidad (débil, media o fuerte), y estos datos se combinaron en el software QGIS con un peso igual para producir un mapa de fragilidad ambiental. Este mapa identificó niveles que varían desde Muy Débil hasta Muy

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Fuerte en términos de erosión lineal y, en consecuencia, en la capacidad de los ecosistemas para proporcionar servicios esenciales para el desarrollo de la región.

PALABRAS CLAVE: Fragilidad ambiental. Servicios ecosistémicos. Desarrollo sostenible

1 INTRODUCTION

Brazil is recognized worldwide for its large territorial extension and the exuberant natural beauty of its rich mosaic of landscapes, resulting from the complex interaction between the different ecosystems. From a historical point of view, Brazil's economic structure was closely linked to transformations in land use, and, consequently, to the exploitation of natural resources (e.g., FURTADO, 1974, PRADO JR, 1998), highlighting the predatory nature of resources it would become one of the most striking characteristics of the economic development models adopted by Brazil over time. Due to its spatial magnitude, the country can contain a complete showcase of the main landscapes and ecologies of the tropical world (AB´SABER, 2003). It is estimated that between 15 and 20% of the 1.5 million species cataloged on planet Earth can be found in our ecosystems, a condition that elevates us to the position of the main country among the planet's mega diversity holders (LEWINSOHN & PRADO, 2000). According to Alho (2012, p151), “in countries considered to have high biodiversity and large territorial extension, such as Brazil, the issue of biodiversity has enormous relevance, strategic importance and political prominence in the global context”; since ecosystems and all-natural capital are productive assets shared by the entire human society, which presupposes the need for efficient, rational and sustainable management of this natural portfolio (ANDRADE & ROMEIRO, 2009).

Among the standards for recognizing a country's level of development, Ab´Saber (2003, p10) highlights “the ability of its people to preserve resources, the level of demand and respect for the zoning of activities, as well as the search for models capable of adequately valuing and renewing natural resources”. This large reserve of natural resources gives Brazil comparative and competitive advantages in the economic context, however, Brazil's strong insertion in international trade and the growing global concern with environmental problems challenge the country to build an integration policy between the productive sector and the environment. Concerning underdeveloped countries, Wu et al., (2020) understand that the contradiction and conflict between ecological conservation and livelihood development are particularly prominent. The author's main argument is “that most conservation areas are located in poor regions where resource use is limited by ecological conservation practices” (WU et al., 2020; p1). On the other hand, the growing global demand for goods and services highlights an increase in pressure on environmental resources and, consequently, the risk of negative economic and social impacts (DNI, 2021; WWF, 2020; FAO, 2019; TEEB, 2010; MEA, 2005).

With the advancement of environmental issues, society has become increasingly less tolerant of negative externalities and, for this reason, consumer decisions are beginning to favor more sustainable businesses and products. According to Leff (2015, p15), “ecological sustainability appears as a normative criterion for the reconstruction of the economic order, as a condition for human survival”. Furthermore, there are stricter environmental requirements for certain products, mainly in international markets, such as the European Union, and this restriction falls mainly on exporting countries (GVces, 2017).

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Brazil, one of the world's most important food producers, faces a major challenge of maintaining the growth of agricultural production and, at the same time, reducing the impacts of this production on natural resources. The maintenance of biodiversity and associated 'ES' gives the country an enormous opportunity to promote socioeconomic prosperity and include the country in a global agenda for the agricultural sector that is aligned with sustainable development. In this sense, the Ministry of the Environment aims to promote, in addition to conservation, the recovery of degraded areas, with emphasis on Permanent Preservation Areas (PPAs) and Legal Reserves (LRs), through research and instruments for environmental adaptation and regularization of rural properties, based on Law nº. 12.651, of May 25, 2012. To this end, the following actions stand out: i) implement new Reference Centers for the Recovery of Degraded Areas (RCDAs) in Brazilian biomes; ii) establish methods for recovering degraded areas for biomes; iii) establish the *National Native Vegetation Recovery Plan (Planaveg)*, whose objective is to expand and strengthen public policies, financial incentives, markets, good agricultural practices and other measures necessary for the recovery of at least 12 million native vegetation of hectares by 2030, mainly in permanent preservation areas (PPA) and legal reserves (LR), but also in degraded areas with low productivity.

Given the scenario that has been projected for the next two decades about economic activities linked to the consumption and use of resources, one of the biggest challenges within the environmental and management theme that presents itself to the academic community and all spheres of governance concerns the nexuses involving the triad of water, energy, and food (TURETTA, 2019; OECD, 2012; FAO, 2011; MARSH & GROSA, 2005). Due to rapid population and economic growth in combination with accelerated urbanization and changing lifestyles, the demand for water, energy, and food (WEF) tends to continue to increase. On the other hand, natural resources are finite goods, which further increases the challenge that governments and decision-makers will have in guaranteeing water, energy, and food security equally in different regions, whether at a regional, national, or global level. Furthermore, growing demand will make some natural resources rare and increasingly strategic, increasing the dispute for control over their extraction and processing. As Martinez Alier (2018, p9) analyzed, “the greatest tension arises from the expansion of production on a material base that does not expand and is distributed across the planet according to natural processes”. In this sense, the first step towards adopting policies for sustainable ecosystem management must be to increase human knowledge about ecological dynamics and the complexities involving ecosystems (BENNET et al., 2005). This knowledge is essential since the quality of life, economic activities and the cohesion of human societies are deeply and irremediably dependent on the services generated by ecosystems, a fact that justifies the study of the dynamics of ES generation and their interactions with the variables humanities (ANDRADE & ROMEIRO, 2009).

From the last quarter of the 20th century, Latin American countries experimented with a model of exploitation of primary resources that Herrera & Torrent (2015) classified as *neoextractivism*[1]. After World War II, neoliberal policies in the 1970s and 1980s promoted the

[1] The concept of neoextractivism refers to an economic strategy adopted by some countries, especially in Latin America, that combines elements of traditional extractivism (the intensive exploitation of natural resources, such as oil, minerals and large-scale agriculture) with neoliberal economic policies. This approach emerged as a response to the economic policies prevailing in the 1970s and 1980s in many countries in the region. This scenario sets the stage

opening of markets and economic deregulation, facilitating the entry of multinational companies into the natural resources sector, often at the expense of strict environmental and social regulations. In the Brazilian case, neoliberal policies in the 70s and 80s played an important role in promoting the exploitation of natural resources for economic development. However, "this structural condition has generated important social dissent, focusing its discourse on 'growth' and "efficiency", but without an ideological debate that goes beyond the margins of the economy" (HERRERA & TORRENT, 2015, P441).

1.1Justification and Objectives

Teodoro Sampaio is part of the group of thirty-two municipalities that make up the Pontal do Paranapanema region (PP from now on) and will serve as the background for this investigation. Located at the confluence of the Paraná and Paranapanema rivers, in the west of the state of São Paulo, bordering the states of Mato Grosso do Sul (MS) and Paraná (PR), the place is the cradle of social movements fighting for agrarian reform in Brazil. Its occupation was late (MONBEIG, 1984), characterized by the irregular appropriation of public lands (LEITE, 1981), and marked by a series of violent socio-territorial conflicts (SAMPAIO, 1890) and significant environmental impacts (BOIN, 2020) that put the regional development (SANTOS & COCA, 2017). Although the western region of the state of SP was occupied late with the central-eastern portion, the area underwent rapid and severe changes to the natural landscapes as a result of the introduction of crops. "*Le grand marché*", as defined by Monbeig (1984) in the mid-1940s, was characterized as an achievement throughout the process; where man, the subject of this march, emerges as a true invader. As Sampaio (1890, p106) reported, "these people go like this, invading the hinterland and incessantly dislodging the buggy". According to Leite (1998), until the mid-19th century, the region was an indigenous territory inhabited by people of the Xavante, Kaingang, and Kaiowá ethnicities.

With a population of 22,173 inhabitants and an area of 2750 km², it is considered the largest municipality in São Paulo (SP) in terms of territorial extension (IBGE, 2022), responsible for housing the *Morro do Diabo State Park (MDSP)*, the largest fragment of Atlantic Forest in the interior of SP, which serves as a refuge for several animal and plant species threatened with extinction, such as the *black lion tamarin* and the *pink peroba*. All this natural wealth gives the municipality fundamental importance in providing and maintaining ES, and for maintaining the ecological balance in the region. Previous studies have demonstrated that the entire site of the study area is environmentally quite fragile, due to the physiographic characteristics, associated with the economic activities carried out at the site, such as hydroelectric production, extensive agriculture, and the expansion of agro-hydro business through large business groups both of national and international capital (e.g., BARRETO & THOMAZ JR, 2014). Like most municipalities in the PP region, Teodoro Sampaio experienced a developmental cycle during the 1970s and

for an extensive and intensive eco-territorial expropriation, under the premise of "growth for development", resulting in a structural marginalization of large sectors of the population to the detriment of financial, corporate and business interests. In addition to the dimensions of the transformations, which in many cases involve only monetary speculation and rent-seeking, and as the new productive position (...) it is important to observe how the actions and relationships of actors such as the State, private initiative and social organizations are expressed in territorial terms, as this structural condition has generated important social dissent, focusing its discourse on "growth" and "efficiency", but without an ideological debate that goes beyond the margins of the economy (HERRERA & TORRENT, 2015, P441).

1980s, which reached its peak in the construction of hydroelectric plants on the Paraná and Paranapanema rivers. These plants played an important role in regional dynamics, especially during their construction, with the creation of jobs and an increase in population in the municipalities involved (SOUZA, 2002). On the other hand, the same projects caused social and environmental impacts that resulted in the departure of riverside and island populations, who practiced subsistence and commercial agriculture, and fishing, among other activities (MENDES, 2005). Furthermore, in the mid-1970s, the municipalities of Teodoro Sampaio, Santo Anastácio, Narandiba, Caiuá, Regente Feijó, and Caiabu received the first sugarcane units in the region, when large landowners in the region – attracted by fiscal and financial incentives from the federal government for through the *National Alcohol Program (PROALCOOL)* – saw an opportunity to increase the value of their land (BARRETO & THOMAS JR, 2014; p288-289).

Recently, on January 8, 2021, the state government presented the Development *Program for the Pontal do Paranapanema Region (Pontal 2030)*[2], to align public policies to improve the social, economic, and environmental indicators of the thirty-two municipalities of the 10th Administrative Region (Presidente Prudente). With the collaboration of city halls, civil society, universities, and private partnerships, the project proposes some state interventions aimed mainly at providing infrastructures and services to support the development of production chains, giving a strong sectoral orientation to the Program, as well as human development actions to ensure a plan to improve municipal indicators for the second region with the lowest Human Development Index (HDI) in the state.

After analyzing the area of study, Santos & Coca (2017; p64) concluded that "the great dilemmas of today's society can be understood by the absence of integrated studies and actions that encompass all aspects of reality, whether environmental, social, economic, or political." According to the authors, economic and political aspects are generally privileged to the detriment of social and environmental aspects in the context of the capitalist system. From a territorial planning perspective, the evaluation of ES provides an overview, detailing the costs and benefits of several different policies and highlighting the best local strategy to improve human well-being and economic sustainability. In addition, "this approach also helps to combat poverty, as it highlights the distribution of scarce and essential resources and also the services on which people depend" (TEEB, 2010; p4).

Based on the hypothesis that the regional development projects based on the neoliberal model that has been employed in the area of studies are acting in dissonance with the natural and human capital, the present work aims to map the environmental fragility of the ecosystem support and provision services in the municipality of Teodoro Sampaio to contribute to actions related to environmental planning, preservation of environmental protection areas and management of natural resources.

2 METHODOLOGY

2.1 Mapping the environmental fragility of ecosystem support and provision services

[2] https://pontal2030.sdr.sp.gov.br/

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The search for information on the distribution of natural resources was essential for the development of society. With technological advances, geoprocessing becomes a valuable tool for the treatment of geographic information, improving the analysis of environmental data that impacts decisions in various areas of the natural sciences and geosciences. According to Ross (ROSS, 1994; p64), "integrated studies of a given territory presuppose the understanding of the dynamics of the functioning of the natural environment with or without human actions". The diagnosis of environmental fragility, in turn, is a fundamental theme for environmental planning, as it indicates the reactions of a given environment and subsidizes the choice of actions for the preservation or environmental improvement of the area in focus (TROMBETA et al., 2014). Therefore, for the proposed objectives to be satisfactorily contemplated, the methodology used in the study involved the evaluation of the environmental fragility of the areas that produce ecosystem support and provision services within the study area. To this end, the following procedures were followed:

1. *Selection of Variables:* Based on the methodology proposed by Ross (1994), relevant geographic variables were chosen, including geomorphology, climate, pedology, and land use and occupation, which play a key role in assessing environmental fragility. This, in turn, is evaluated according to vulnerability to erosion, where the empirical analysis of this fragility is the result of the integrated analysis of relief characteristics (genesis, morphology, morphometry, and morphodynamics), soil types, lithology, vegetation cover, land use, and rainfall, and can be expressed through the following equation:

$$FP = \frac{G + R + S + Vg + C}{5}$$

FP = Potential fragility; G = Geomorphology; R = Geology; S = Soils; Vg = Vegetation; C = Climate

2. *Assignment of Fragility Values:* Each of the selected variables received a fragility classification, with assigned values of 1, 2, or 3, indicating degrees of weak, medium, or strong, which were crossed to identify the degree of potential and emerging fragility of the relief. The emerging or environmental fragility maps are a little more complex, resulting from the combination of the potential fragility map and the land use and occupation map. The Use and Occupation Map was prepared based on the classification of images in raster format from the Landsat 8 satellite, whose image has a passage date of 08/31/2020, having been obtained through the *Earth Observing System* website[3]. As part of the process of preparing this map, after processing the image and cropping the study area, different forms of use and occupation present within the municipal limits were identified, from which eighteen sampling points were subsequently selected to carry out the supervised classification. These points were chosen based on the potential fragility chart, where

[3] Disponível em <www.eos.com>, acessado em 05/11/2020.

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priority was given to choosing at least two points within each degree of fragility, in addition to territorial heterogeneity, so that the largest possible part of the worked area was covered. To improve the accuracy of the data obtained through remote sensing, on 10/28/2020 an incursion was carried out near the study area to carry out a test of the coherence of the points with the reality of the ground. Next, six use classes were defined, where each of them was assigned "degrees of protection", which vary according to the vegetation cover, as proposed by Ross (1994), the results of which can be seen in Table 1.

Table 1- Definition of land use classes in the municipality of Teodoro Sampaio, SP (2020).

Classes of Use	Definition	Degree of Protection
1. Native Vegetation	Area corresponding to fragments of Atlantic Forest; whether they are: natural, natural destined for the APP, or legal reserve and planted forests.).	Very High
2. Sugarcane field	Areas for sugarcane cultivation	Discharge
3. Grazing	Areas covered by forage species for cattle grazing. It includes natural areas, planted in good conditions and planted in poor conditions	Average
4. Urban	Area that comprises the urban fabric of Teodoro Sampaio and the district of Planalto do Sul.	Low
5. Exposed Soil	Areas with a deficit of vegetation cover and areas that present erosive processes (gullies and ravines).	Very low
6. Water	It is related to "bodies of water" such as lakes and ponds.	-

Source: Prepared by the authors, adapted from Ross (1994).

3. *Multicriteria Analysis:* Using the Weighted Sum Raster Overlay tool in the QGIS 3.4 software, the variable data was combined in raster format (.TIFF), with each variable having an assigned weight, which, in this case, was assigned an equal weight of 50 % for each of the thematic maps (potential fragility and land use and occupation). This feature allows you to perform multi-criteria analysis between qualitative (subjective) and quantitative (objective) data, representing an advance in the crossing of different layers. From Traficante (et al., 2017) point of view, its application in decision-making can be very useful, as it provides an appropriate tool for decision-makers in complex situations. Quantitative and qualitative criteria can be used to structure heterogeneous problems in the form of hierarchy, pairwise comparisons, and criteria weighting. As a result of this process, the Emerging Fragility Map (Environmental) was generated. The final result presented five levels of environmental fragility in the study area, being: very low, low, moderate, strong, and very strong, still following the methodology proposed by Ross (1994), referring to the empirical analysis of environmental fragility. natural and anthropized. This, in turn, used the approach based on studies of Ecodynamic Units, a concept developed

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by Tricart (1977), where the author systematizes a nominal hierarchy of fragility represented by values or weights: very weak (weight 0), weak (weight 1), medium (weight 2), strong (weight 4) and very strong (weight 5).

4. Definition of ecosystem services (ES): Based on previous knowledge of the area of study, socio-spatial data, and the work of Constanza (1997), MEA (2005), and Burkhard et al. (2012), the classification matrix of the levels of environmental fragility of ecosystem support and provision services was elaborated according to the types of land use referring to Teodoro Sampaio. In total, ten ES were identified, four in the Support category and another six Provision services, considered fundamental for the development of the economic and social activities of the site (Figure 1).

Figure 1 – Ecosystem Support and Provision services found in Teodoro Sampaio, SP.

Source: Genaro (2020).

Through the analysis of the Emergent Fragility Map, it was possible to select the points that presented the highest degree of fragility with natural characteristics plus human activities. With the help of the Land Use and Occupation Chart of the year 2020, it was observed which activity(s) was developed in that place and, in this way, it was possible to establish which social actors and/or economic activities are involved in the use of certain services provided by that fraction of natural space. Also with the help of these two maps, it was possible to establish the degree of environmental fragility (Very weak; Weak; Moderate; Strong, and Very Strong) presented by each 'SE' concerning the different types of land use presented in the municipality.

3 RESULTS AND DISCUSSION

As with most of the cities in PP, Teodoro Sampaio finds himself at a delicate inflection regarding the decisions that will define the near future of the municipality, since the development models implemented in the region prove to be unsustainable, associated with

issues of socio-territorial nature, turned the place into a socio-space of conflict[4]. Both hydroelectricity production and activities linked to the agricultural and sugar-alcohol sectors have become unviable from a socio-environmental point of view, as, in addition to being activities that consume natural resources excessively, they also use the majority of the territory and generate very little income for the local population due to the low number of jobs that the sectors offer (GENARO, 2020). On the other hand, the externalities resulting from the degradation of ecosystem services – considered the reduction in the capacity of an ecosystem to provide services – have fallen disproportionately on the poorest populations, which in this case are the agrarian reform settlers. This factor has contributed to the increase in inequalities and disparities between different groups of the population, sometimes being the main factor generating poverty and social conflicts. In addition to the historical socio-territorial conflicts over land, the study area has also presented some conflicts related to the appropriation and privatization of water resources (e.g., OLIVEIRA, 2008; OLIVEIRA & CARVALHAL, 2012), with the agribusiness sector as a vector (THOMAS Jr, 2010).

The watershed is a fundamental geographical unit for the management and planning of water and environmental resources, addressing complex issues related to water, the environment, society, and the economy on a scale that considers both natural and human interactions. In this sense, understanding the watershed as an essential part of the planning and management of natural resources reveals its complexity, which goes beyond a superficial analysis of the territory, enabling the identification of the interactions between the elements of the landscape and the processes of its formation, revealing the dynamic interconnection between nature and society (ARAÚJO & PINESE, 2004).

With a drainage area of approximately 12,395 km², the UGRH-22 (Pontal do Paranapanema) – of which Teodoro Sampaio is part – has four large hydroelectric plants (HPP): Engenheiro Sergio Mota, on the Paraná River; in addition to Taquaruçu, Rosana and Capivara, on the Paranapanema River, registering 25% of flooded areas, a value that corresponds to the highest percentage in the state of São Paulo (CBH-PP). Graph 1 below shows the demand for water according to the different economic sectors.

[4] "A sociospace of conflict is a field of forces formed by actors and the network of social relations that maintain among themselves, who dispute control of a conflict generated by the emergence of a socio-environmental problem" (ALEDO, 2018; p64). Still according to the author, a sociospace of conflict can be a set of relations of a new group, made up of different stakeholders who fight for control of the process decision-making process related to an environmental problem in dispute. In this sense, any problem socio-environmental conflict can turn into a social conflict as interested parties discuss and question the unequal distribution of the positive and negative effects that the problem generates.

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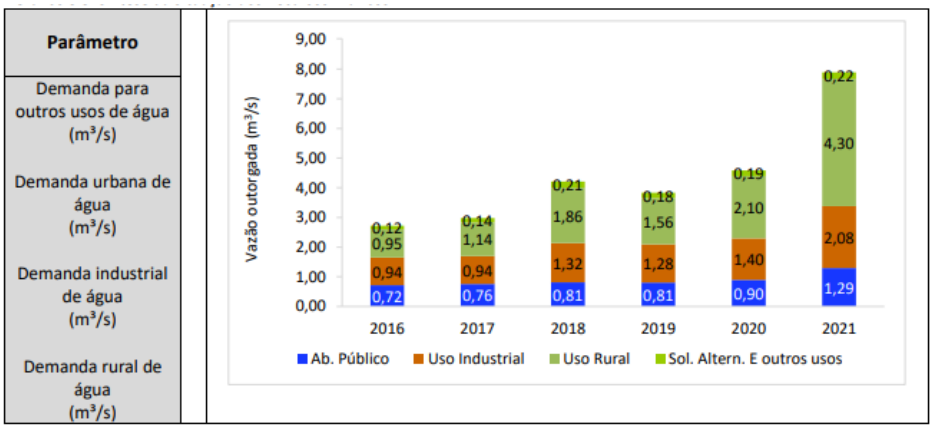
Graph 1. Water demand by economic sectors in Pontal do Paranapanema, SP.



Source: CBH-PP, 2022.

Several studies have shown that over the last two decades, the soils of the UGRH22 are highly compromised and susceptible to erosion processes (LEAL, 2000; BARONE et al., 2007; MOROZ, 2017). All these factors, added to the high degree of susceptibility to erosion presented in that area, put at risk the ecosystem's ability to support the promotion of the most important economic activities in the region.

> [...] The combination of factors related to the characteristics of the physical environment, combined with the aggressive occupation of the West of São Paulo, made this region become one of the areas with the largest number and greatest diversity of erosive processes in the state of São Paulo. The serious environmental problems that occur in the West of São Paulo, such as pollution of surface waters; groundwater compromise; soil exhaustion and erosion; silting of rivers; The extinction of flora, fauna, and ichthyofauna, caused by human activities, have never threatened the quality of life and the very survival of man in this geographical space (BOIN, 2000).

In the mapping of the municipality of Teodoro Sampaio, 5 classes of land use and land cover were identified, where it is possible to observe a predominance of agricultural activities in the municipality, which covers approximately 64% of the territory; Another 37% of this amount, which is equivalent to 60,000 ha, corresponds to pastures for agricultural activity. Activities aimed at the agri-hydro business sector occupy another 25% of the municipal territory. The area corresponding to the urban area is irrelevant compared to the rural area, covering a tiny 539.86 hectares, i.e. 0.35% of the total territorial area of Teodoro Sampaio. According to data from the Census of Agriculture (IBGE, 2017), permanent crops occupy a tiny portion of the territory and have a very low production value, which makes the activity less decisive for the local economy, whose main activity is agribusiness. Most of these permanent crops are located in the territory destined for agrarian reform settlements and another part in the southern portion of the municipality, on the banks of the Paranapanema River, where the traditional communities that already inhabited the area before the damming of the waters of the river for the construction of the Taquaruçu HPP, located 40 km upstream.

According to the 2019 Management Report, presented by China Tree Gorges (CTG-Brazil), the company that manages the concession of hydroelectric plants on the Paranapanema River, in recent years, hydroelectric plants have generated below their physical guarantees due

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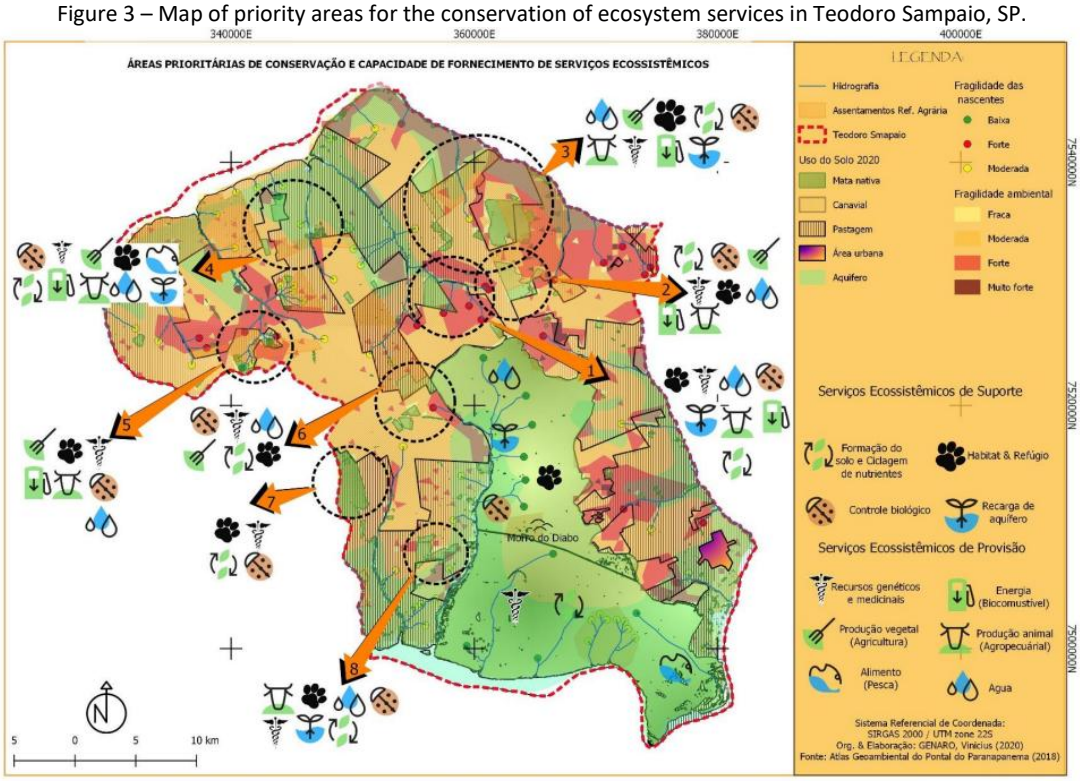
to periods of hydrology and increasingly prolonged and severe droughts. The situation is extremely worrying since in Brazil, more extreme climate scenarios are predicted, with droughts, floods, and more severe and frequent heat waves (PBMC, 2014). Furthermore, warming of the atmosphere can lead to changes in precipitation patterns, affecting the availability and temporal distribution of river flows. This possible scenario of water variability should be further pressured by the increase in demand for water, as a result of population growth and the country's development (ANA, 2010).

Despite still having a high capacity to provide ES, the physical environment has become increasingly fragile as a result of human actions that advance on natural fragments. The city's largest source of natural capital, the Morro do Diabo State Park (MDEP), has been suffering intense pressure (Figure 3) – especially on the east, northeast, and northwest edges –, promoted by the expansion of agro-hydro business and agriculture.

Figure 3 – Map of priority areas for the conservation of ecosystem services in Teodoro Sampaio, SP.



Fonte: GENARO, 2020

The matrix of ecosystem services and economic activities involved in their exploitation appears as a complement to the cartographic material. Through this material, it is possible to associate which 'ES' the main activities are benefiting from. When analyzing it, it is clear that agriculture is the sector of society that most depends on ecosystem services within the study area, whether they are support or provision. Agroindustry, as well as agricultural activities, mainly use support services, while urban areas and the industrial sector are large consumers of ecosystem provisioning services. This phenomenon may be associated with the role that food agribusinesses located in the PP region play in the western region of the state of São Paulo. In the same way, freshwater, which is considered a 'provision service', was together with 'aquifer

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recharge' (support service) the only two 'ES' on which all activities directly depend. The urban environment and industries, in turn, stand out for their large consumption of 'ES' provision, while agriculture and agro-hydro businesses tend to make more use of support services (Table 2).

Table 2- Matrix of ecosystem services and economic activities in Teodoro Sampaio, SP.

Ecosystem Services	**Economic activities (Users of ecosystem services**						
	City	Indústry	Pasture	Agriculture	Fishing	Hydroelectric sector	Agro hydro business
Soil formation and nutrient cycling*			x	x			x
Habitat and refuge*			x	x			x
Aquifer replenishment*	x	x	x	x	x	x	x
Biological control*				x	x	x	x
Genetic resources**	x	x	x	x			x
Vegetal production (food)**	x	x		x			
Animal production (alimentos)**	x	x		x			
Alimento** (peixe)	x	x		x	x		
Bioenergy** (sugar-cane)	x	x		x			
Freshwater**	x	x	x	x	x	x	x

*Support services **Provision services

Source: Genaro (2020)

The paths indicate that the future of cities does not only depend on the will and effort on the part of public authorities but on the balance between political forces, the private sector, and civil society in the search for a more dignified future. Through the findings obtained through cartographic material, it is possible to observe the complex dynamics that exist between the different social sectors concerning the appropriation of the territory, which also involves the use of services and environmental resources diffusely spread across that same territory. For this reason, Teodoro Sampaio's geographic space becomes a “system”, as there is a set of components interconnected by “flows” of energy and functioning as a unit. From then on, the world of interconnectivity becomes the world of possibilities, as the joining of variables in a totalizing system can, by probability, generate countless responses, including unpredictable ones.

4 CONCLUSION

Given the complexity inherent to the dynamics addressed, the results discussed in this article converge on the pressing need for an integrated approach to analysis and management. It becomes evident that a new development model is imperative, a model that is, simultaneously, socially inclusive, ecologically viable, and economically fair.

From a technical point of view, the mixed methodology used, combining Environmental Fragility Maps and the 'ES' Matrix Method, proved to be highly effective, successfully meeting the objectives proposed in scientific research. The validation of this approach is supported by the recognition of the TEEB, which highlights the 'ES' Matrix as a powerful and simple tool for initial diagnosis in projects, integrating the ecosystem approach and the values of ecosystem services.

Given the conclusions drawn from this research, it is possible to affirm that Teodoro Sampaio has peculiarities that positively differentiate it from other municipalities in São Paulo, standing out for its significant natural heritage. Understanding the location and conservation of this natural capital not only guides rural and urban management but also informs spatial planning and management of protected areas.

The importance of ecosystem services transcends the environmental scope, offering solutions and strategies for the sustainable use of resources, monitoring environmental quality, and territorial planning. Furthermore, the focus on ecosystem services can result in economic and fiscal benefits, increasing municipal public revenue beyond the Ecological ICMS[5] and existing royalties. Furthermore, municipal managers play a fundamental role in maximizing the benefits of ecosystem services. Influencing modes of production, implementing government regulations, and creating market-based incentives are strategies that can enhance the flow and benefits of these services, contributing to sustainable and equitable development.

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[5] "Imposto sobre Circulação de Mercadorias e Serviços (ICMS)" is a Brazilian tax on the circulation of merchandise, electric power, rendering of interstate and intermunicipal transportation services, and communications.

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