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Water resource management, the environment, and challenges in the municipal territory: analysis of the municipality of Presidente Epitácio, São Paulo

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Gestão de recursos hídricos, ambiente e desafios no território municipal: análise do município de Presidente Epitácio, São Paulo

RESUMO

Objetivo - O objetivo desta pesquisa foi analisar a gestão de recursos hídricos, seus desafios e suas relações com o ambiente no município de Presidente Epitácio, estado de São Paulo, visando contribuir com subsídios para o planejamento ambiental.

Metodologia – A metodologia adotada consistiu em levantamento bibliográfico e revisão de literatura, mapeamentos, coleta de dados secundários, trabalho de campo e registros fotográficos.

Originalidade/relevância - A preocupação com a disponibilidade hídrica tem crescido, mesmo em áreas antes consideradas seguras. Isso destaca a importância de estudos sobre a gestão de recursos hídricos e planejamento ambiental de bacias hidrográficas, fundamentais para sua conservação e essenciais para processos ecológicos e preservação da biodiversidade. Estudos dessa natureza são incipientes no território municipal, embora o município esteja legalmente munido de autonomia administrativa.

Resultados - Os resultados revelaram que os cursos d'água do município estão significativamente assoreados e carecem de Áreas de Preservação Permanente (APP) de acordo com a legislação vigente, além de não possuírem vegetação adequada. Essa situação compromete a infiltração das águas pluviais e a recarga dos aquíferos, ocasionando alagamentos na área urbana. Além disso, observou-se que a utilização dos recursos hídricos é predominantemente impulsionada por atividades econômicas, e há uma falta de clareza e empoderamento na atuação municipal em relação à gestão das águas.

Contribuições teóricas/metodológicas – O estudo evidencia a necessidade de discutir e adotar estratégias de gestão ambiental, com foco nos recursos hídricos em âmbito municipal.

Contribuições sociais e ambientais – Os resultados da pesquisa ressaltam que o município desempenha um papel essencial na gestão de recursos hídricos e não pode mais delegar essa responsabilidade apenas ao Estado e à União.

PALAVRAS-CHAVE: Recursos hídricos. Gestão ambiental. Município.

Water resource management, the environment, and challenges in the municipal territory: analysis of the municipality of Presidente Epitácio, São Paulo

ABSTRACT

Objective - The objective of this research was to analyze water resource management, its challenges, and its relationship with the environment in the municipality of Presidente Epitácio, state of São Paulo, with the aim of contributing to environmental planning.

Methodology - The methodology adopted consisted of a bibliographic survey and literature review, mapping, secondary data collection, fieldwork, and photographic records.

Originality/relevance - Concern about water availability has grown, even in areas previously considered safe. This highlights the importance of studies on water resource management and environmental planning of river basins, which are fundamental for their conservation and essential for ecological processes and biodiversity preservation. Studies of this nature are incipient in the municipal territory, although the municipality is legally equipped with administrative autonomy.

Results - The results revealed that the municipality's watercourses are significantly silted up and lack Permanent Preservation Areas (APP) in accordance with current legislation, in addition to not having adequate vegetation. This situation compromises rainwater infiltration and aquifer recharge, causing flooding in the urban area. In addition, it was observed that the use of water resources is predominantly driven by economic activities, and there is a lack of clarity and empowerment in municipal action regarding water management.

Theoretical/methodological contributions - The study highlights the need to discuss and adopt environmental management strategies, focusing on water resources at the municipal level.

Social and environmental contributions – The research results emphasize that the municipality plays an essential role in water resource management and can no longer delegate this responsibility solely to the state and federal governments.

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KEYWORDS: Water resources. Environmental management. Municipality.

Gestión de los recursos hídricos, el medio ambiente y los retos en el territorio municipal: análisis del municipio de Presidente Epitácio, São Paulo

RESUMEN
Objetivo: El objetivo de esta investigación fue analizar la gestión de los recursos hídricos, sus retos y sus relaciones con el medio ambiente en el municipio de Presidente Epitácio, estado de São Paulo, con el fin de contribuir con datos para la planificación ambiental.
Metodología: la metodología adoptada consistió en una revisión bibliográfica y de la literatura, mapeos, recopilación de datos secundarios, trabajo de campo y registros fotográficos.
Originalidad/relevancia: la preocupación por la disponibilidad de agua ha aumentado, incluso en áreas que antes se consideraban seguras. Esto destaca la importancia de los estudios sobre la gestión de los recursos hídricos y la planificación ambiental de las cuencas hidrográficas, fundamentales para su conservación y esenciales para los procesos ecológicos y la preservación de la biodiversidad. Los estudios de esta naturaleza son incipientes en el territorio municipal, aunque el municipio cuenta legalmente con autonomía administrativa.
Resultados: los resultados revelaron que los cursos de agua del municipio están significativamente encenagados y carecen de Áreas de Preservación Permanente (APP) de acuerdo con la legislación vigente, además de no contar con la vegetación adecuada. Esta situación compromete la infiltración de las aguas pluviales y la recarga de los acuíferos, provocando inundaciones en el área urbana. Además, se observó que el uso de los recursos hídricos está impulsado predominantemente por actividades económicas, y que existe una falta de claridad y empoderamiento en la actuación municipal en relación con la gestión del agua.
Contribuciones teóricas/metodológicas: el estudio pone de manifiesto la necesidad de debatir y adoptar estrategias de gestión ambiental, centradas en los recursos hídricos a nivel municipal.
Contribuciones sociales y ambientales: los resultados de la investigación resaltan que el municipio desempeña un papel esencial en la gestión de los recursos hídricos y ya no puede delegar esta responsabilidad únicamente al Estado y a la Unión.

PALABRAS CLAVE: Recursos hídricos. Gestión ambiental. Municipio.

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1 INTRODUCTION

Concerns about water availability have intensified in recent decades, even reaching regions previously considered comfortable in terms of this resource. The gradual reduction in water supply is due to increased demand and consumption of natural resources, coupled with inefficient management practices, especially in developing countries (Ishaque; Mukhtar; Tanvir, 2023). In this scenario, the importance and urgency of studies focused on water resource management and environmental planning of river basins, capable of supporting strategies for their conservation and sustainable use, stand out.

Water is not only an essential resource for human survival, but also a vital strategic asset for the sustainable development of the economy and the environment (Liu *et al.*, 2022). There is a clear link between water, energy, and food, and a fragile balance between the three, which are essential elements for high-quality regional development (Wang *et al.*, 2023). Food security depends directly on the availability of water resources (Ju *et al.*, 2023), and a well-developed society is closely linked to the efficient management of these resources (Ahmed *et al.*, 2024).

The protection of water resources is intrinsically linked to the environmental conditions of river basins. Respect for the natural dynamics of these units is essential for maintaining fundamental ecological processes, as well as for preserving biodiversity, ecosystems, and surface and groundwater. In this sense, water resources are central elements of sustainable development, integrating economic, social, and environmental dimensions. In addition to ensuring human supply and meeting food and energy production demands, they play an indispensable role in supporting, maintaining, and restoring ecosystems (Porto; Porto, 2008; Brazilian Society for the Advancement of Science, 2012; Cerezini; Hanai, 2017; Lollo; Neves; Arantes; Lima; Lorandi, 2018; Santos; Piroli; Moroz-Caccia Gouveia, 2021; Piroli, 2022; Buryak *et al.*, 2022; Jin; Fang; Chen, 2023; Guo *et al.*, 2024).

For this reason, watersheds are considered the basic territorial unit for environmental studies, planning, and management, which should occur in an integrated manner, considering all the processes acting within them (World Meteorological Organization, 1992; Botelho; Silva, 2004; Porto; Porto, 2008; Tundisi; Matsumura-Tundisi, 2011; Di Mauro; Mageste; Lemes, 2017; Cerezini; Hanai, 2017; Buryak *et al.*, 2022; Supangat *et al.*, 2023; Jam; Mosaffaie, 2023). This premise was regulated in Brazil by Federal Law n. 9,433 of January 8, 1997, which established the National Water Resources Policy and created the National Water Resources Management System (Brazil, 1997).

Watersheds are fundamental units for water resource management, as their planning impacts environmental quality and the preservation of other natural resources. Delimited by watersheds, they are spaces of interaction between society and nature, where surface and groundwater converge into larger watercourses (Piroli, 2016; Tang; Adesina, 2022; Nugroho *et al.*, 2023). The growing pressure on freshwater, marked by increased demand, waste, and pollution, is one of the main challenges of the 21st century, requiring water management policies integrated with territorial and environmental planning, capable of reconciling social needs and ecological preservation (Leal, 2012).

The environmental consequences of unsustainable development in recent decades

demonstrate how the inappropriate relationship between society and nature threatens the integrity of watersheds around the world (Jam; Mosaffaie, 2023). Urban, industrial, and agricultural expansion and deforestation reinforce the need to monitor land cover and land use, an essential step for the sustainable management of natural resources in impacted areas (Simionatto *et al.*, 2024). In this context, changes in land use are among the greatest environmental concerns today (Kalfas *et al.*, 2023).

Effective watershed management requires the integration of the interests of different actors and consideration of diverse natural scenarios, with the aim of ensuring environmental sustainability, ecological balance, and productivity (Supangat *et al.*, 2023; Vargas *et al.*, 2023; Ding *et al.*, 2024). In this sense, integrated management corresponds to the planning and coordination of activities in the watershed environment, articulating social, economic, and environmental dimensions in interaction with human, institutional, and natural systems, always guided by sustainability (Tang; Adesina, 2022). The effectiveness of this process, however, depends not only on technical and scientific knowledge, but also on the appreciation of local knowledge and the active participation of the communities involved (Nugroho *et al.*, 2023). Thus, water resource management becomes more effective when it promotes integration between managers and the population (Kolahi; Davary; Khorasani, 2024).

The quantitative and qualitative depletion of water resources, both surface and groundwater, is directly related to the need to protect soils from degradation, rationalize land use, and regulate surface water runoff in the watershed (Buryak *et al.*, 2022; Wang *et al.*, 2023). Over-exploitation and inefficient use of these resources compromise the sustainable development of the economy, society, and the environment (Liu *et al.*, 2022). Thus, the quality and quantity of natural resources, as well as the guarantee of agricultural production and sustainability, depend on proper watershed management (Zehtabian *et al.*, 2023; Gatgash; Sadeghi, 2024).

Understanding the interactions between land use and occupation and the hydrological responses of watersheds is essential for the efficient management of water resources and for predicting critical future scenarios (Marra; Silva Júnior, 2023). Therefore, monitoring these dynamics is essential, particularly in areas that have been severely negatively impacted (Simionatto *et al.*, 2024).

Based on the scenario presented, environmental management is considered an appropriate tool to help reverse this water crisis (Santos, 2020; Piroli, 2022; Buryak *et al.*, 2022; Liu *et al.*, 2022), which is increasingly recurring in Brazil and in various parts of the world. This should be considered at various levels of analysis, particularly at the municipal level, the level of government closest to the population, which has had little impact on this process.

Water scarcity in São Paulo in recent years has increased concern about water availability among researchers, authorities, and society, given the importance of water for life. This scenario has generated growing interest in studies on water dynamics and its relationship with the environment. Events such as droughts and deforestation drive research in the affected areas, impacting the economy, agriculture, energy production, industry, and urban supply (Ramires; Manzione, 2019).

In general, watershed management aims to ensure water availability, improve soil use and productivity, and promote the socioeconomic development of the region (Supangat *et al.*,

2023). Watershed management has become a central priority, essential to ensuring the sustainability and well-being of current and future generations (Gatgash; Sadeghi, 2024).

According to Rodriguez and Silva (2013), environmental management is a comprehensive concept that encompasses the principles of environmental stewardship and management. Its objective is to ensure, based on planning guidelines and principles, the proper use of natural resources, both economic and sociocultural, within environmental systems. Thus, environmental planning, including projected scenarios, should support decisions about a given space in an environmental management system. In this view, the authors state that environmental management is a component of land management and should be developed in an integrated and harmonious manner.

Philippi Júnior and Bruna (2014, p. 752) define environmental management as the process of administering and regulating the natural and social ecosystems in which humans interact through their activities. The main objective is to establish, restore, or preserve the balance between nature and society. Regarding the purpose of environmental management, the authors emphasize that “the promotion of quality of life, which is the ultimate goal of environmental management, is closely linked to public health and territorial planning” [...].

Brazilian territorial management is centralized, but it also allows for decentralization through various laws, giving municipalities greater autonomy in local decisions. Environmental planning and municipal management should prioritize the needs of the population, avoiding favoring specific groups represented by agencies from other geographical scales (Santos, 2020).

Land use planning policies are the responsibility of municipalities, but there are still no clear legal definitions regarding their effects on water resource management, which creates uncertainty about the role of municipalities in this process. Watershed management, in turn, is intrinsically related to land use planning and sanitation policies, which highlights the need for effective integration between land use planning and water management (Faria, 2011). Furthermore, efficient environmental management requires the active involvement of the population, which depends on assertive, accessible, and high-quality communication of the content transmitted (Gong *et al*., 2022).

The Federal Constitution of 1946 redefined the ownership of water bodies, transferring control from the municipal and private levels to the states and the federal government, which authorize the use of water as a public good, which was maintained in the Federal Constitution of 1988 (BRAZIL, 1988). This change generated conflicts between urban management, which follows the logic of private property, and environmental management, which is guided by public interests. Urban management is the responsibility of municipalities, while water resource management is predominantly assigned to states and the federal government (Cirilo; Almeida, 2020).

Water management faces limitations due to the physical boundaries of river basins, which often do not coincide with municipal boundaries. This overlap makes the management of shared basins one of the greatest challenges for water management systems in the country. For its effective implementation, in-depth studies, political coordination, and cooperation between the different actors involved are necessary (Leal, 2012). On a global scale, similar challenges occur in transboundary watersheds, where issues of ownership, control, and controversial boundaries intensify management conflicts (Varady *et al*., 2023).

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It is from this perspective and this challenge that this study is inserted, seeking to investigate water resource management and its relationship with the environment in the municipality of Presidente Epitácio, in the west of the state of São Paulo, and, at the same time, to provide subsidies for the improvement of environmental conditions, constituting contributions to the environmental planning of river basins in its territory. Thus, the objective of this research was to analyze water resource management, its challenges, and its relationship with the environment in the municipality of Presidente Epitácio, state of São Paulo, with a view to contributing to environmental planning.

2 METHODOLOGY

2.1 Location of the study area

The municipality of Presidente Epitácio is located in the Paraná River basin, in western São Paulo State, bordering Mato Grosso do Sul State (Figure 1), a region known as Pontal do Paranapanema. In the municipality, the urban area consists of the city – the municipal seat – and the district of Campinal. The rural area includes Agrovilas I, II, IV, and V, in addition to several rural properties. In the northern portion, small and medium-sized properties predominate, while in the southern portion, medium and large properties stand out.

With the enactment of State Law No. 6,956 on July 20, 1990, the municipality was recognized as a Tourist Resort, highlighting its various natural attractions (SÃO PAULO, 1990). Starting in 1998, with the construction of the Engenheiro Sérgio Motta Hydroelectric Plant dam, part of the municipal territory was flooded, resulting in the loss of important natural features, such as fragments of vegetation and islands, as well as changes in the river plains and socioeconomic dynamics. However, these changes also opened up new opportunities that may favor local tourism, which is not yet considered the most important activity.

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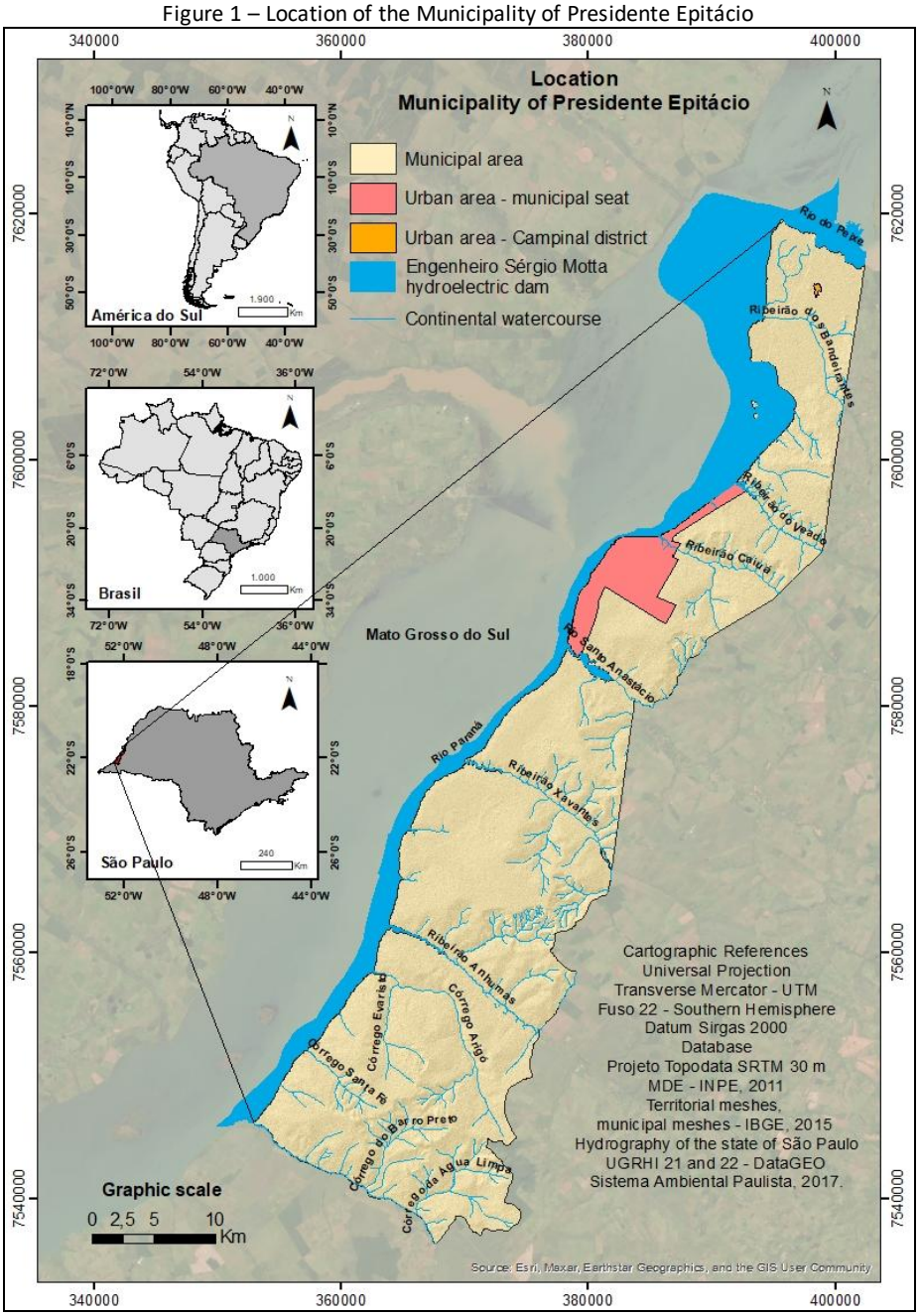
Figure 1 – Location of the Municipality of Presidente Epitácio



Prepared by Santos, 2020.

According to the Brazilian Institute of Geography and Statistics (IBGE), the municipality has a total area of approximately 1,260.28 km², making it one of the largest in the region. In 2022, it had a resident population of 39,505 inhabitants, with a population density of 31.35 inhabitants per km², with more than 90% of the population residing in urban areas.

2.2 Acquisition, data processing, and systematization

For the development of the research, a bibliographic survey and literature review on the subject were conducted to support discussions on water resource management,

environmental management, and the challenges identified at the municipal level, with a focus on the municipality of Presidente Epitácio. The maps were prepared using geoprocessing techniques with ArcGIS software, available at the São Paulo State University (Unesp), Faculty of Science and Technology in Presidente Prudente.

To analyze the issue presented in the study, a Map of Watersheds and Drainage Networks in the municipality of Presidente Epitácio was prepared based on the Digital Elevation Model (DEM) extracted from the Shuttle Radar Topography Mission (SRTM), with a resolution of 30 meters, from the SRTM 1S22W052V3 raster image (.tif), systematized and published in 2011 (http://www.dsr.inpe.br/topodata/), obtained through the National Institute for Space Research (INPE) from the Geomorphometric Database of Brazil – TOPODATA.

The image underwent processing to correct possible imperfections and improve its quality, with the raster being transformed from 32 bits to 16 bits. It was then redesigned for the Universal Transverse Mercator (UTM) plane coordinate system, the Sirgas 2000 geodetic system in force in Brazil, used in most of the research mapping, with the exception of some location maps prepared in the Geographic Coordinates system. The image was then cropped from the territorial boundary of Presidente Epitácio, where procedures were initiated to delimit the watersheds using the ArcGIS Spatial Analyst Tools – Hydrology – Fill tool to fill the raster surface, removing minor imperfections. Subsequently, the Flow Direction, Flow Accumulation (accumulated flow in each cell), and Stream Order (hierarchy of channels) tools were used, selecting channels of 4th order and above through the Arc Toolbox - Spatial Analyst Tools - Conditional - Con path. Finally, the Spatial Analyst Tool - Hydrology - Stream to Feature and Hydrology - Basin paths were used to delimit the watersheds, converting the raster to vector - Conversion tools - From raster - raster to polygon. The shaded relief was also generated using the path Arctoolbox - 3D analyst tools - raster surface - hillshade in ArcGIS (Moroz-Caccia Gouveia, 2015).

To prepare the Map of land use conflicts in Permanent Preservation Areas (APP) in the municipality of Presidente Epitácio, it was first necessary to prepare the Land cover and use map, based on the Landsat 8 satellite image (bands 6, 5, and 4). – Scene from July 6, 2017, with a resolution of 30 meters, obtained from the National Institute for Space Research (INPE) – Image catalog (http://www.dgi.inpe.br/CDSR/), associated with the false color R6G5B4 and subsequently merged with band 8 (panchromatic), which enabled an improvement in its quality, reaching 15 meters.

The selection of band and color combinations was made to optimize the visualization of spectral targets, aiming to distinguish classes such as urbanized areas, mining (clay extraction), sugarcane crops, temporary and permanent crops, pastures, forestry, forest vegetation, rural vegetation, uncovered areas, and wetlands. All land uses identified in the image were confirmed in the field.

The identification of land use conflicts in Permanent Preservation Areas (APP) was carried out using the ArcGIS Buffer tool, following the guidelines of current environmental legislation on preservation areas, in accordance with Federal Law n. 12,727, of October 17, 2012 (BRAZIL, 2012), which vary according to the width of watercourses and the presence of springs and dams. These data were then compared with the 2017 Land Cover and Use Map to identify possible incompatibilities. The criteria adopted were 30 meters for smaller watercourses

(tributaries of the Paraná River), 50 meters for springs, and 100 meters for the Paraná River, covering the area around the Engenheiro Sérgio Motta Hydroelectric Plant dam, which has sections with a width of about 12 km. Finally, the data were analyzed based on compiled maps, graphs, and tables.

To complete the analysis, some secondary data were obtained from the Department of Water and Electric Energy (DAEE) of the state of São Paulo regarding users, forms of use, and purposes of use of water resources (surface and underground) in Presidente Epitácio. This data was organized and systematized into graphs and tables to facilitate the visualization of information.

The municipal boundary, like the others, was extracted from the cartographic databases of the Brazilian Institute of Geography and Statistics (IBGE) – Municipal grids, territorial grids of 2020, while the drainage networks (dam and continental water body) come from the hydrography of the State of São Paulo, the Water Resource Management Units – UGRHI 21 and 22, and DataGEO – Spatial Environmental Data Infrastructure of the State of São Paulo (IDEA - SP). Fieldwork was carried out to confirm the mappings performed. In addition, photographic records were made to illustrate the environmental problems resulting from ineffective and inadequate environmental management.

3 RESULTS

Considering the structure of municipal public management and the legal instruments available, no significant actions have been identified in the municipality regarding the environmental management of water resources. In the municipality, it is noted that the environmental legislation applicable to water resources is consistent with the parameters established at the federal level. Although other departments interact with environmental issues, the environmental theme is directly linked to the Department of Economy, Planning, and Environment, through the Environment Directorate.

Water resource management initiatives are tenuous, mainly noted through sporadic actions by the state or federal government, especially those originating from river basin committees. Despite the water wealth of the Paraná River, the municipality faces challenges in conserving water resources, such as silting and erosion of a significant part of its watercourses, which requires care and effective monitoring.

The municipality of Presidente Epitácio, located on the banks of the Paraná River, receives water from several rivers, streams, and creeks that originate in other municipalities. These waters flow mainly westward, where the main tributary is located. The region has a considerable abundance of water, notably the Sérgio Motta Hydroelectric Plant reservoir, which floods large areas and has a significant impact on the municipality, which is the most affected in the state of São Paulo.

Among the main watercourses in the north are the Peixe River, which borders Panorama, the Bandeirantes stream near the Campinal district, and the Veado and Caiuá streams, which cross the urban area. To the south, the Santo Anastácio River, Ribeirão Xavantes, Jacutinga Stream, Ribeirão Anhumas, and other streams such as Arigó, Evaristo, Santa Fé, Barro Preto, and Ribeirão Água Sumida, which borders Teodoro Sampaio, stand out.

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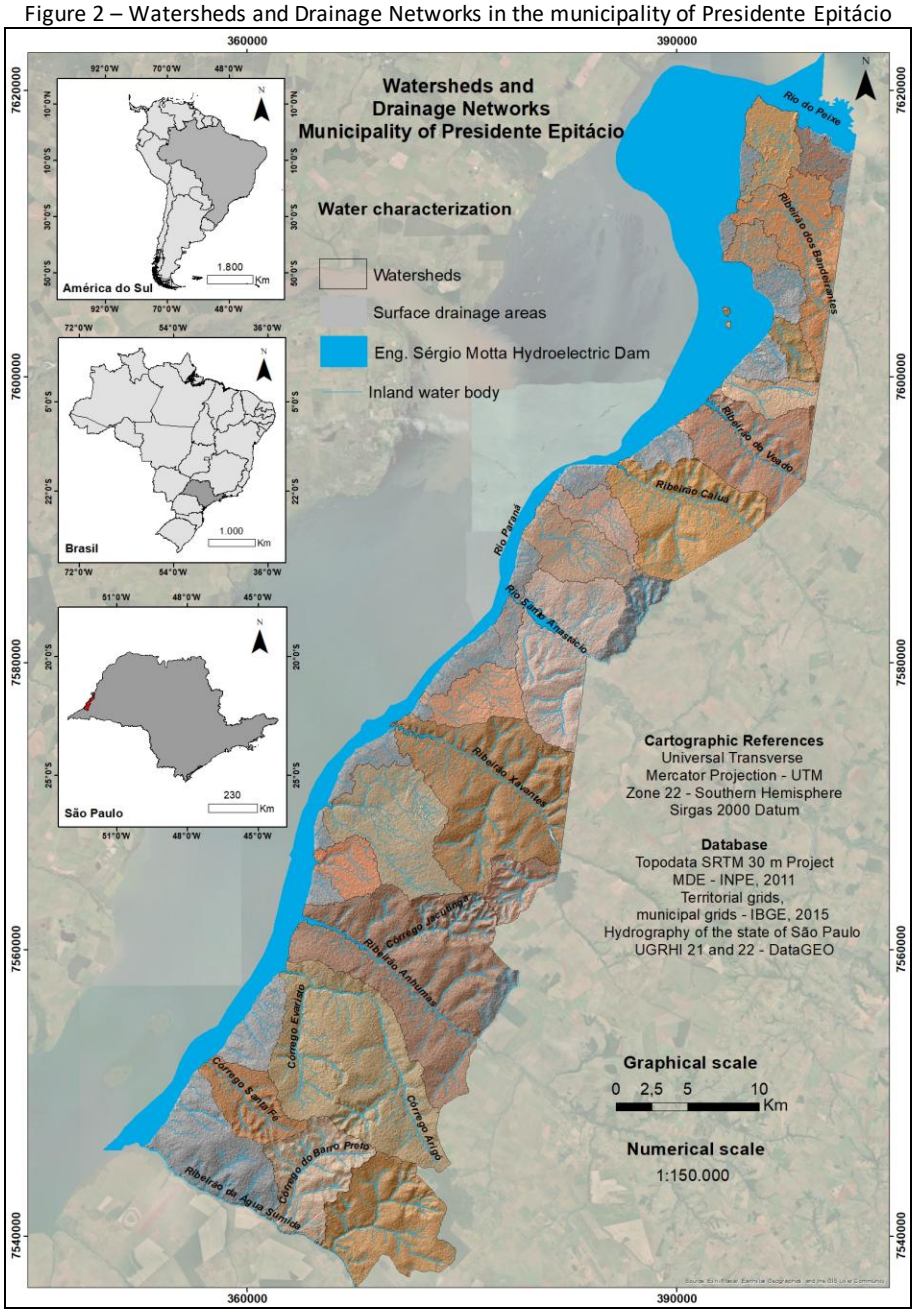
The municipality's drainage network was obtained from the Digital Elevation Model (DEM). Around twenty (20) watersheds were identified in the municipality, including several areas of surface drainage (intermittent or perennial). Few watercourses have their sources in the municipality (Figure 2).

Figure 2 – Watersheds and Drainage Networks in the municipality of Presidente Epitácio



Prepared by Santos, 2020.

These characteristics pose a challenge for water management at the municipal level, as the boundaries of watersheds diverge from political and administrative boundaries, and some problems, such as water pollution and silting, among others, can originate in the territory of other municipalities, directly affecting the rest. This scenario highlights the importance of

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dialogue between the various mayors in the region, especially through the watershed committees present throughout the state.

Inadequate management of anthropized watersheds causes water to run off superficially, preventing its infiltration. This situation has led to erosion, silting, flooding, and various other risk situations, as well as causing a decrease in water accumulated in the soil, groundwater recharge, and aquifers, negatively impacting plant development, decreasing air humidity, compromising the permanence of rivers, as well as maintaining their volumes during longer periods of drought (Piroli, 2016).

Among the environmental problems that Presidente Epitácio has faced, the following stand out, especially in rural areas: erosion, lack of vegetation cover, lack of Permanent Preservation Areas (APPs) in watercourses, which fall short of current legislation, and silting in several sections. Some of these problems can be seen in Figures 3, 4, 5, and 6.

Figure 3 - Erosion process occurring on the banks of the Paraná River and containment barrier

Figure 4 - Furrows and ravines in rural areas

Source: Santos, 2020

Figure 5 – Silting process in the Anhumas stream

Figure 6 – Santo Anastácio River without adequate APP

Source: Santos, 2020

In mapping carried out, the total area of the municipality was calculated to be 1,259.74 km², with 236.63 km² corresponding to hydrography (18.78%). As for the distribution of water resources, it was estimated that 235.29 km² correspond to the waters of the Paraná River, dammed by the Engenheiro Sérgio Motta Hydroelectric Plant, and 1.34 km² correspond to

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continental watercourses distributed over its surface.

It is observed that the municipality has a significant area that requires effective management of water resources and forest vegetation. This management becomes even more crucial due to factors that limit the agricultural and industrial use of the waters of the Paraná River, which can impact the operation of the Hydroelectric Plant located downstream, in the district of Primavera, in Rosana, São Paulo. In this context, it is essential to conserve surface waters, which are being affected by recurrent silting of watercourses, aggravated by the lack of adequate vegetation cover.

The mapping results were based on current legislation that provides for the protection of native vegetation recommended by Federal Law n. 12,727, of october 17, 2012 (Brazil, 2012). Although insufficient from a scientific point of view, they indicated that 37.62% of pastures are located in areas that should be classified as APP. Of these, 7.91% are occupied by temporary and permanent crops, 6.63% by uncovered areas, 5.64% by sugarcane cultivation, 2.99% by forestry, 0.92% by urbanized areas, and 0.21% by mining (Santos, 2020; Santos; Piroli; Moroz-Caccia Gouveia, 2021).

Only 27.26% of the municipality's water body APPs comply with standards, being covered by forest vegetation (5.39%) and grassland vegetation (21.87%), which is also considered protective of APPs. Wetlands, which represent 10.82%, are considered normal due to the increase in the water table caused by the Engenheiro Sérgio Motta hydroelectric dam on the Paraná River. Thus, these spaces should be occupied by native vegetation, preferably dense, corresponding to about 72.74% of the minimum areas established (Table 1), equivalent to approximately 34.03 km² or 3,403.00 hectares (Santos, 2020; Santos; Piroli; Moroz-Caccia Gouveia, 2021).

Table 1 - Land use classes and conflicts in Permanent Preservation Areas (APP)

Classes	Area (km²)	Percentage (%)
Urbanized area	0.43	0.92
Mining	0.10	0.21
Crops – sugarcane	2.64	5.64
Temporary and permanent crops	3.70	7.91
Pasture	17.60	37.62
Forestry	1.40	2.99
Open área	3.10	6.63
Forest vegetation	2.52	5.39
Countryside vegetation	10.23	21.87
Wetland	5.06	10.82
	46.78	100.00

Source: Santos, 2020.

Land use conflicts in APPs in the municipality of Presidente Epitácio are illustrated in Figure 5. This figure shows a breakdown of the areas occupied by activities such as sugarcane cultivation, temporary and permanent crops, as well as uncovered regions and some wetlands. In the municipality, it can be observed that many springs are without vegetation cover, indicating that most watercourses do not meet the minimum requirements of current legislation.

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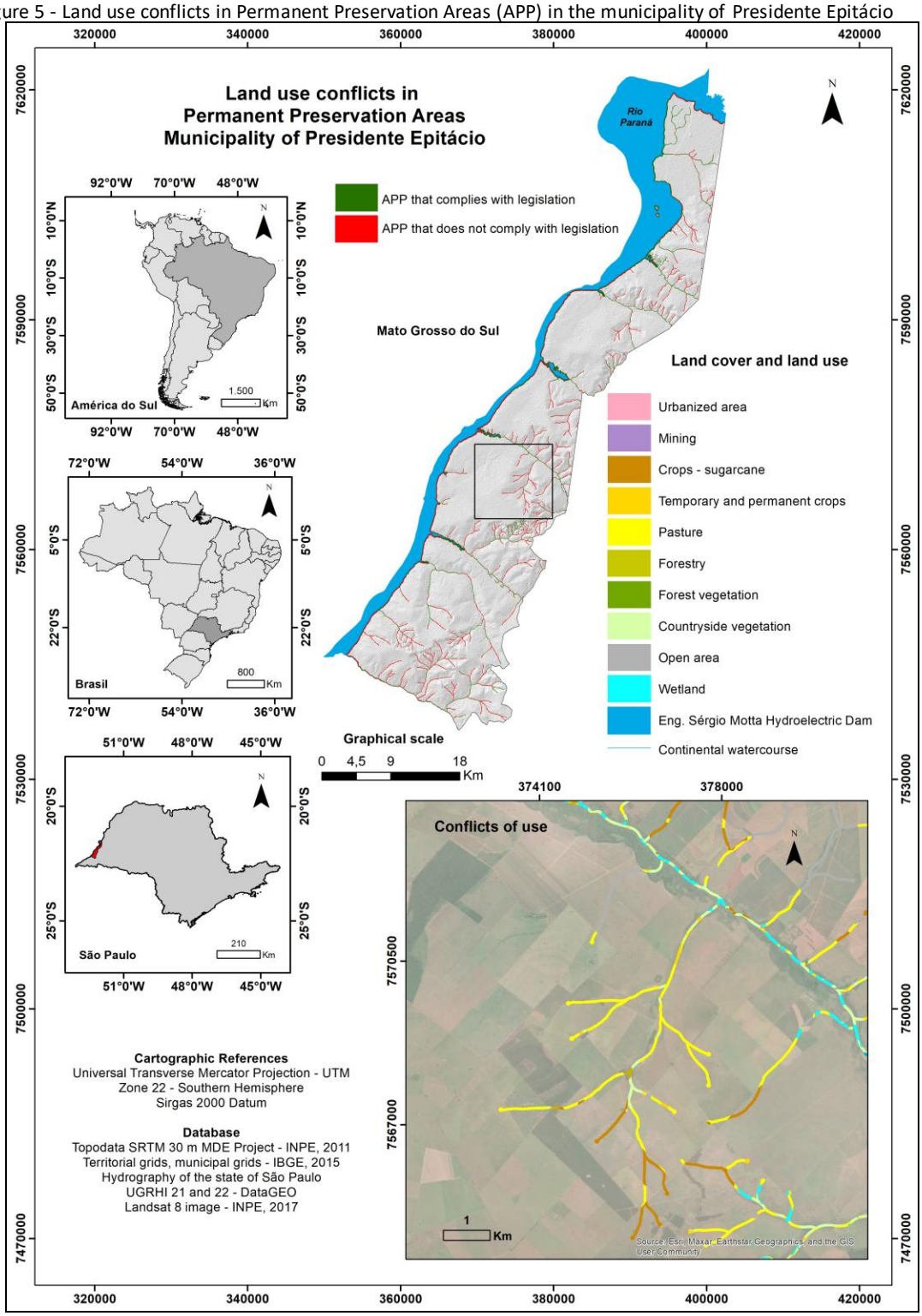
Figure 5 - Land use conflicts in Permanent Preservation Areas (APP) in the municipality of Presidente Epitácio



Source: Santos; Piroli; Moroz-Caccia Gouveia, 2021

Concerns about groundwater scarcity have increased, as its recharge depends on vegetation, which facilitates rainwater infiltration. In addition, the drilling of illegal wells without proper licensing poses a risk, as it can compromise water quality and lead to contamination. This practice undermines access to sufficient quantity and quality of water, exposing the population

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to health risks and affecting society as a whole.

In addition to the Paraná River, which faces erosion processes exacerbated by the construction of the Engenheiro Sérgio Motta Hydroelectric Plant dam, the Caiuá stream, located in the urban area, has also increased in width and water volume. In recent decades, this watercourse has been affected by the removal of riparian vegetation in certain sections, becoming a site for the illegal disposal of garbage, debris, and even dead animals, despite the fact that the city government's garbage collection service covers a large part of the urban area. In addition, some APPs have been occupied by dwellings, many of which were established before the dam was built, resulting in excessive humidity problems for residents. These families are gradually being removed from the area (Figures 6 and 7).

Figure 6 - Disposal of trash and debris near the Caiuá stream in an urbanized area

Figure 7 - Occupation in the Permanent Preservation Area of the Caiuá stream

Source: Santos, 2020.

Other problems are evidenced by frequent flooding in parts of the urban area, resulting from increasing soil sealing, lack of adequate tree cover, and the absence of effective mechanisms for rainwater drainage, especially after heavy rains. This situation may worsen in the future, making the search for solutions or mitigation measures for this issue increasingly complex.

In order to contribute to the analysis of water and water resource management in the municipality, some data related to users, forms of use, and purposes of water resource use (surface and underground) in Presidente Epitácio were systematized. Figure 8 shows the users who make the most use of this resource.

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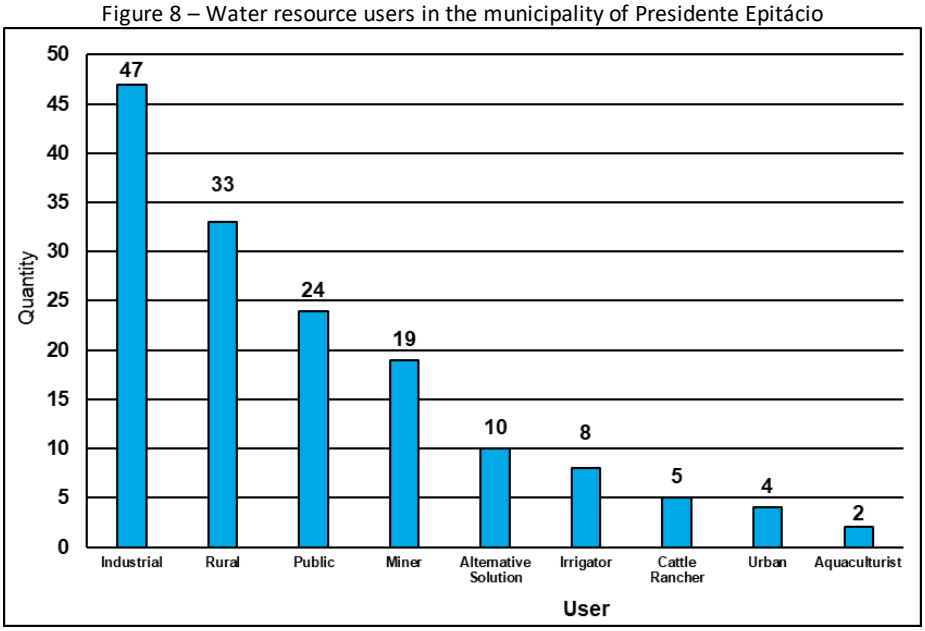
Figure 8 – Water resource users in the municipality of Presidente Epitácio



Source: Department of Water and Electric Power (DAEE) of the state of São Paulo, 2020.
Organized by Santos, 2020.

Figure 8 highlights that users who make use of water in the municipality include industry (30.92%); rural users (21.71%); the general public, normally for supply purposes (15.79%); and miners (12.50%). To a lesser extent, users seeking alternative solutions (6.58%); irrigators (5.26%); cattle ranchers (3.29%); and aquaculturists (1.32%) are also listed.

There is a scenario of loss of surface water resources in the municipality, leading many residents and landowners to use groundwater, often without authorization and in violation of the law. This practice can result in contamination of this resource and compromise the health of users. On the other hand, there is a growing trend toward using water from the Paraná River dam, which, however, will be restricted by the need for the hydroelectric plant to maintain a minimum level for its operation.

As for the forms of use, Figure 9 shows groundwater abstraction (49.34%); surface abstraction (14.47%); surface discharge (12.50%); discharge into the ground (8.55%); mineral extraction (5.92%); damming (2.66%); network discharge (2.63%); discharge into mining pits (1.97%); underground water extraction (1.32%); and desilting (0.66%). It is noteworthy that there is a considerable difference between surface and underground abstraction, considering the abundance of water, especially related to the Paraná River and its tributaries.

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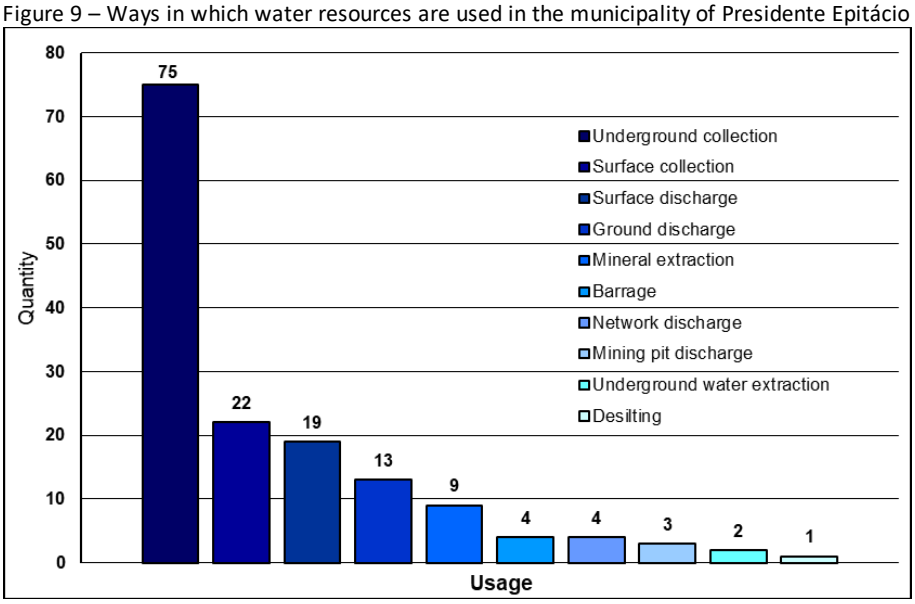
Figure 9 – Ways in which water resources are used in the municipality of Presidente Epitácio



Source: Department of Water and Electric Power (DAEE) of the state of São Paulo, 2020.
Organized by Santos, 2020.

To obtain more detailed information on water resource use in the municipality, data were collected to assess the purposes for which water is used. The results are presented in Table 2.

Table 2 - Purposes of water resource use in the municipality of Presidente Epitácio

Purpose of use	Quantity	Flow rate (m³/h)
Mining	26	3371.42
Industrial	13	2687.94
Irrigation	19	1173.81
Alternative Solution for Private/Industrial Supply	3	590.75
Public Supply	3	569.86
Sanitary/Industrial	7	551.78
Sanitary	54	512.58
Public Effluent	2	225.79
Rural	3	35
Not reported/Other	11	25.9
Desalination	4	22.3
Alternative Solution for Private Water Supply	2	15.74
Urban	1	15
Hydro-agricultural	1	4
Flow regulation	1	0
Level elevation	1	0
Desilting/cleaning	1	0

Source: Department of Water and Electric Power (DAEE) of the state of São Paulo, 2020.
Organized by Santos, 2020.

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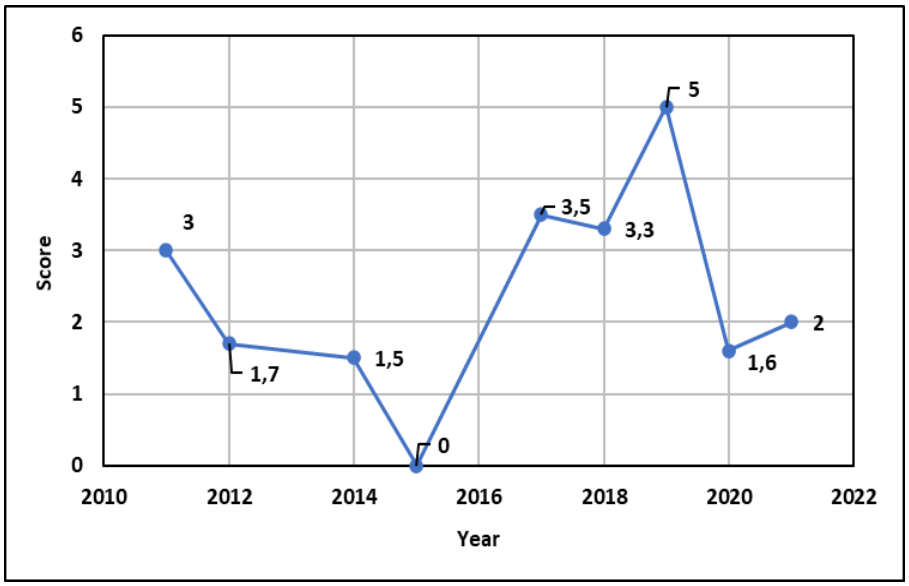
The main purposes for which water resources are used are related to economic activities such as mining (especially sand and clay extraction), industry (although the municipality mainly has small and medium-sized industries), and irrigation. Other purposes include public and private supply, public and sanitary effluents, as well as less frequent uses and some unknown or unreported purposes.

Water management is one of the indicators evaluated by the GreenBlue Municipality Program (PMVA), developed by the São Paulo State Secretariat for Infrastructure and the Environment and implemented since 2008. Each year, several parameters are considered, such as the environmental preservation and recovery of springs and their surroundings, water quality, treatment conditions, and environmental education actions related to the topic, which must be carried out by municipal management, summarized in a single score.

In the period considered, between 2011 and 2021, water management showed fluctuations in scores, with low results and an average of 2.4 out of a maximum of 10.00, ranking as one of the worst results, despite the municipality having good access to drinking water for the population (Figure 10). This mention is concomitant with the unsatisfactory assessments of urban tree planting, biodiversity, environmental council, air quality, and sustainable municipality.

Figure 10 – Water Management Assessment – GreenBlue Municipality Program (PMVA)



Source: São Paulo State Secretariat for Infrastructure and the Environment.
Organized by Santos, 2024.

Regarding the quality of water resources, a study conducted by Brito, Gomes, and Macena (2017), which collected water samples at different times in the O Figueiral Municipal Park in Presidente Epitácio, a recreational area on the banks of the Paraná River, found some worrying issues. The results were in line with the standards established by the São Paulo State Environmental Company (CETESB), which is the environmental regulatory agency, with the exception of coliform indicators, classified as unsuitable for recreational use, presenting 1000

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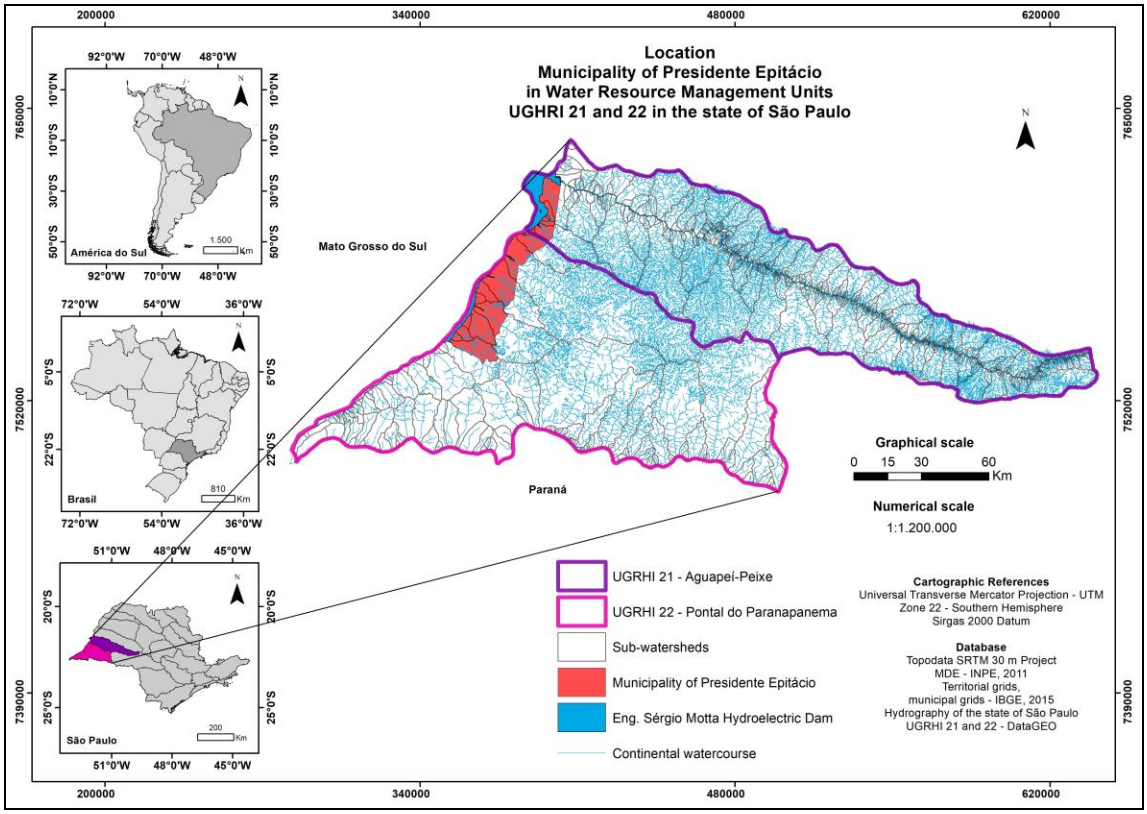
CFU/100 mL more than 20% of the time. This fact points to the need for constant water monitoring to ensure better conditions for those who use these environments, putting the health of visitors at risk.

Another issue that deserves attention is the size of the municipality of Presidente Epitácio, which belongs to two Water Resource Management Units: UGRHI 21, with the Aguapeí and Peixe River Basin Committee, and UGRHI 22, with the Pontal do Paranapanema Committee (Figure 11). Each municipality has representation and can participate in the dialogue on basin management and fundraising, such as the State Water Resources Fund (FEHIDRO). However, there is no specific plan for municipal water management, only a policy for the protection of water sources for public supply, which should be extended to all water sources.

Figure 11 - Location of the municipality of Presidente Epitácio in Water Resource Management Units (UGRHI) 21 and 22.



Prepared by Santos, 2020.

The participation of municipalities in river basin committees does not replace the need for specific actions within their territory. Municipal public management can implement legal mechanisms that complement state and federal legislation, in addition to developing initiatives that promote the sustainability of these important environmental systems, which are essential for life.

While the division into units facilitates action, it can also represent an obstacle to the work of representatives, particularly when a municipality is located in two distinct areas, as demonstrated. This fact, associated with municipal territorial boundaries and administrative

autonomy, needs to be increasingly considered in the process of environmental planning and management of river basins.

4 **CONCLUSION**

The current water crisis, marked by paradoxes of abundance and scarcity, results in droughts and floods, revealing the complexity of natural resource management today. This scenario can affect regions that were previously comfortable, as has been observed in recent years.

In the municipality of Presidente Epitácio, water abundance is represented by the Paraná River, which has been transformed into a vast reservoir due to the formation of the Engenheiro Sérgio Motta Hydroelectric Plant reservoir. This situation results in limitations on the uses of the river. Although there are legal regulations that promote the protection of water resources and other natural resources, this objective cannot be achieved without adequate enforcement, the application of penalties, and the commitment of society. In addition, responsibility for enforcement falls on the municipal level, even though Articles 20 and 26 of the 1988 Federal Constitution state that all rivers are public and belong to the Union or the states, not to the municipalities (Brazil, 1988). This issue requires a new discussion among all levels of government, with the active participation of society.

The scenario is alarming, with many watercourses lacking Permanent Preservation Areas (APP), according to current legislation, in addition to lacking dense and adequate vegetation. This situation compromises rainwater infiltration and aquifer recharge. Furthermore, the silting up of watercourses contributes to the reduction of surface water and impairs its quality, making these environments vulnerable to extreme events. Without the restoration of vegetation, there is no guarantee of surface and subsurface water. The inappropriate use of groundwater can lead to contamination and cause serious health problems for the population.

The frequent flooding identified in urban areas is caused by soil sealing, lack of trees, and the absence of adequate rainwater drainage mechanisms, especially after heavy rains. This situation is likely to worsen in the future, making it difficult to find solutions and mitigation measures.

In Presidente Epitácio, the use of water resources is predominantly associated with economic activities, especially sand and clay extraction, industry, and irrigation. In this context, claims that domestic consumption is primarily responsible for the water crisis are refuted, although the contribution and shared responsibility of this sector cannot be ignored.

With regard to water resource management, which is essential for various activities in society, the municipality plays an important role and can no longer delegate this responsibility solely to the state and federal governments. All actions that impact the environment directly affect the availability of water, both in quantity and quality, affecting all activities in society. Thus, this issue should be one of the main municipal priorities, integrated with other processes, such as legislation, urban tree management, solid waste disposal, basic sanitation, including stormwater drainage, and biodiversity protection in rural and urban areas. Land use planning should be based on the proper management of water resources, carefully assessing the limits and potential of the environment.

However, another challenge to be overcome is the need for clarity and empowerment of municipal action in relation to water management, in addition to overcoming limitations arising from territorial delimitation, which is not always consistent with the physical-natural outlines of river basins and with institutions legitimized by the State and society, such as water resource management units. These have the function of contributing, but can also constitute an obstacle when a municipality is located in two distinct areas, as is the case of Presidente Epitácio. Finally, it is necessary to ensure the presence of the population throughout the water resource management process, favoring and consolidating forms of action by society, combined with environmental awareness through Environmental Education.

Environmental education is recognized as an essential tool for environmental management. It should include a formative and participatory approach that involves different social actors in various issues. Therefore, it is crucial to ensure that the community has opportunities to express its opinions to managers. This participation is vital to overcome environmental conflicts and to actively participate in decision-making (Santos; Leal, 2016), and it is essential to establish effective communication between managers and water users (Kolahi; Davary; Khorasani, 2024).

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DECLARATION OF CONFLICTS OF INTEREST

We, Ricardo dos Santos and Edson Luís Piroli, declare that the manuscript entitled **"Water resource management, environment, and challenges in the municipal territory: analysis of the municipality of Presidente Epitácio, São Paulo":**

1. **Financial ties:** There are no financial ties that could influence the results or interpretation of the work because this work was not funded.
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