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IMPACT OF ANTHROPOGENIC ACTIVITIES AND LAND USE ON WATER QUALITY: AN ANALYSIS IN MICROBASINS IN RIO GRANDE DO SUL, BRAZIL

IMPACTO DAS ATIVIDADES ANTRÓPICAS E DO USO DA TERRA NA QUALIDADE DA ÁGUA: UMA ANÁLISE EM MICROBACIAS DO RIO GRANDE DO SUL, BRASIL

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ABSTRACT

In the dynamic interface of human activities and natural ecosystems, understanding the impact of anthropogenic interventions on water quality is of paramount importance. This research investigates the interplay between land use patterns and water quality in three microbasins of the Lajeado Três Passos River, located in Rio Grande do Sul, Brazil, which have intensive land use that can generate an impact on water quality. For this purpose, a land use and occupation study was conducted using Sentinel-2 imagery classification with a supervised method. Additionally, water samples were collected from the main channel and the three microbasins for the analysis of physicochemical and microbiological parameters following standardized methods, and the Trophic State Index was calculated. The results indicate a connection between urban coverage and elevated total solids, pH, nitrogen species, coliforms, and *Escherichia coli content*, along with hypereutrophic characteristics throughout the studied region. Our findings emphasize the importance of identifying and controlling pollution sources that may be affecting this aquatic system.

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Keywords: Water pollution. Land use. Eutrophication. Sustainable development. Ecosystem health.

RESUMO

Na interface dinâmica entre atividades humanas e ecossistemas naturais, compreender o impacto das intervenções antropogênicas na qualidade da água é de suma importância. Esta pesquisa investiga a interação entre os padrões de uso do solo e a qualidade da água em três microbacias do Rio Lajeado Três Passos, localizadas no Rio Grande do Sul, Brasil, que possuem um uso intensivo do solo capaz de gerar impactos na qualidade da água. Para isso, foi realizado um estudo de uso e ocupação da terra utilizando a classificação de imagens do Sentinel-2 com um método supervisionado. Além disso, foram coletadas amostras de água do canal principal e das três microbacias para a análise de parâmetros físico-químicos e microbiológicos seguindo métodos padronizados, e o Índice de Estado Trófico foi calculado. Os resultados indicam uma ligação entre a cobertura urbana e os elevados níveis sólidos totais, pH, espécies de nitrogênio, coliformes e conteúdo de *Escherichia coli*, juntamente com características hipereutróficas em toda a região estudada. Nossas descobertas destacam a importância de identificar e controlar as fontes de poluição que podem estar afetando este sistema aquático.

Palavras-chave: Poluição da água. Uso do solo. Eutrofização. Desenvolvimento sustentável. Saúde do ecossistema.

INTRODUCTION

Water is vital for sustaining life and plays a pivotal role in a variety of human activities. Rivers, in particular, provide diverse services such as drinking water, construction materials, and food (ZINGRAFF-HAMED et al., 2021). In addition, the rivers serve as a sanctuary for numerous plant and animal species and they are considered reservoirs of freshwater (RASHID; ROMSHOO, 2013). However, the quality of water resources has deteriorated in numerous countries and regions worldwide because of processes of population growth, unplanned urbanization, agricultural expansion, and industrialization, which have increased the demand for water resources, leading to their deterioration (LIU et al., 2014; LI et al., 2020). As pointed out in the United Nations World Water Development Report (UNESCO, 2019), water demand has grown at an annual rate of 1% since the 1980s, reflecting the pressure exerted on this resource. Additionally, out of every 10 people, 3 lack access to safe drinking water, and 6 do not have sanitation services, reflecting issues of access and distribution of this crucial resource experienced by the population. Alternatively, the water quantity on Earth remains constant through temporal and spatial changes that affect water quality (KITHIIA, 2007; NGATIA et al., 2023).

The absence of spatial planning coupled with the lack of treatment of urban and industrial effluents, and effective public policies contribute significantly to the decline of water resources quality (SIMONETTI et al., 2019). Although river water pollution is prevalent in both developing and developed countries, it is the economically disadvantaged areas worldwide that experience the impact of insufficient water supply meeting established standards (NGATIA et al., 2023).

Land use is generally defined as practices on land implemented by individuals to derive benefits from its resources. It is associated with the services provided by the land and is not tied to surface cover. In essence, it reflects how people manage and utilize the terrain (GIRI; QIU, 2016). The relationship between water quality, land use, and land cover has been assessed in various regions around the world (RAO et al., 2022; GANI et al., 2023; YAO et al., 2023; GBEDZI et al., 2023). Alterations in land use and land cover (LULC) play a crucial role in degrading water quality, with distinct LULC types exerting varying degrees of influence on water quality. Generally, the types of land use dictate the kind of pollutants generated on land and carried through runoff into water bodies.

The conversion of natural environments, e.g., grassland and forests, which have the function of reducing surface runoff, and soil erosion, into agricultural and urban areas is propelled by growing anthropogenic resource demands, leading to enrichment in nutrient concentration and sedimentation in freshwater ecosystems (NAMUGIZE et al., 2018; XU et al., 2019; SHEN et al., 2021). The nitrogen and phosphorus released from cultivated land have the potential to raise their concentrations in water. Simultaneously, organic pollution may result from the discharge of industrial and domestic wastewater originating from activities in developed areas (SHEN et al., 2014). Water quality parameters are strongly correlated with the configuration and proportion of land uses within various areas (SHEHAB et al., 2021).

In Brazil, a vast and ecologically diverse country, plays a pivotal role in discussions surrounding land use practices and water quality. The intricacies of Brazil's land use patterns significantly influence the generation of pollutants that find their way into water bodies through runoff. The lack of treatment of domestic sewage in Brazil is a significant challenge to the quality of water resources. Many regions of the country are still lacking adequate treatment systems or even sewage collection networks (DOS SANTOS et al., 2018). Likewise, agricultural activities make up a considerable part of this problem, due to the excessive application of fertilizers and other pesticides in rural areas, being nitrate a remarkable indicator of water contamination that along with other parameters, causes eutrophication of water bodies, if it is present in abundance in the waters (LOURENÇO et al., 2022).

For instance, Rocha et al. (2019) graphically correlated limnological variables in the contributing basin of the Dr. João Penido reservoir, in Juiz de Fora, state of Minas Gerais, Brazil, determining the influence of organic matter (of natural and anthropogenic origin, resulting from pasture runoff and wastewater) on water quality parameters, especially in nitrogen and phosphorus, consumed oxygen, chemical oxygen demand, turbidity, and total suspended solids. Similarly, Schaefer Martins et al. (2023), compared two river basins in southern Brazil - the urban Antas River subbasin and the agricultural Faxinalzinho Stream Basin. They assessed the LULC across the entire basin and collected aquatic macroinvertebrates. Both basins showed a significant presence of vegetation, with a mix of urban and rural areas in the Antas River and predominantly rural areas in the Faxinalzinho Stream, indicating overall good water quality. However, the study highlights the necessity for proper management of the Pinus-associated stream to sustain its quality, and urgent recovery efforts are essential for the urban river despite its favorable conditions.

Moreover, studies have been conducted that relate land use and soil type to drive soil functions with water recharge potential (SANTANA et al., 2023), that determine the quality of surface waters in rural communities linked to land occupation and land use (MORAIS et al., 2023). There are temporal studies on land use change (KRAESKI et al., 2023) and its influence on soil biodiversity (BUSTAMANTE et al., 2023). Other researches evaluating the impact of land use and cultivation on soil erosion (ALVES et al., 2023) or highlighting concerns about the impact on river flows due to land use and climate changes (SALMONA et al., 2023).

The comprehensive assessment of water quality, involving the determination of physical, chemical, and biological parameters, is important for the identification of potential sources of pollution in watersheds (DA SILVA ANJINHO et al., 2020) and for guaranteeing the proper utilization and environmental safeguarding of river ecosystems (ISLAM et al., 2021). In Brazil, legislative policies play a crucial role in regulating water resources and ensuring water quality standards. For instance, Law No. 9,433 outlines the national policy concerning water resources, including the classification of water bodies based on their primary uses. The overarching goal is to safeguard water quality in alignment with its intended purposes, thereby minimizing the expenses associated with the remediation of contaminated water bodies (BRASIL, 1997).

Furthermore, Resolution No. 357/2005 by the National Council for the Environment establishes a classification system for bodies of water, providing reference standards and parameters for water quality monitoring. This classification scheme for freshwater encompasses various categories: (a)

Special Class, a designation that denotes the highest water quality, suitable for human consumption following disinfection, as well as for maintaining the natural balance of aquatic ecosystems. These waters are typically found within conservation units under integral protection; (b) Class 1, designated for human consumption (with simplified treatment), safeguarding aquatic ecosystems, primary contact recreation, irrigation of raw vegetable crops, and fruits grown close to the ground, along with the protection of aquatic environments in Indigenous Lands; (c) Class 2, reserved for human consumption (after conventional treatment), protection of aquatic communities, primary contact recreation, irrigation of vegetable crops, fruit plants, parks, and others, as well as for aquaculture or fishing activities; (d) Class 3, intended for human consumption (after conventional or advanced treatment), irrigation of arboreal, cereal, and fodder crops, amateur fishing, secondary contact recreation, animal watering, among other uses, and (e) Class 4, represents the lowest water quality level, suitable for navigation and aesthetic purposes in the landscape (BRASIL, 2005).

The sub-basin of Lajeado Três Passos is part of the Hydrographic Basin of the Turvo – Santa Rosa – Santo Cristo Rivers in the Hydrographic Region of the Uruguay River. Its sources are predominantly located within an urbanized area, subjecting them to rigorous impact due to the influence of urbanization. The tributaries derived from these springs have also been intensely affected, predominantly rectified, drained, or channeled. Lajeado Três Passos is characterized by receiving water from stormwater galleries and a substantial load of effluents from the city, including domestic and industrial effluents from various sources. Part of these effluents is discharged into the watercourse after a simplified treatment, while another part is discharged without treatment or with ineffective treatment. However, precise data on the exact number and/or type of effluents discharged into the Lajeado River are not available. The main objective of this research is to analyze water quality parameters in a local system composed of three microbasins tributary to the Lajeado Três Passos River, assessing their relationship with land use and occupation. This investigation seeks to contribute to the understanding of the impact of urbanization on water quality in river ecosystems, specifically within the Brazilian context. It aims to provide new insights into river water quality and the degradation caused by urban growth in Brazil. This approach is intended to generate valuable information for the sustainable management of water resources and the preservation of river ecosystems.

METHODS

Study area

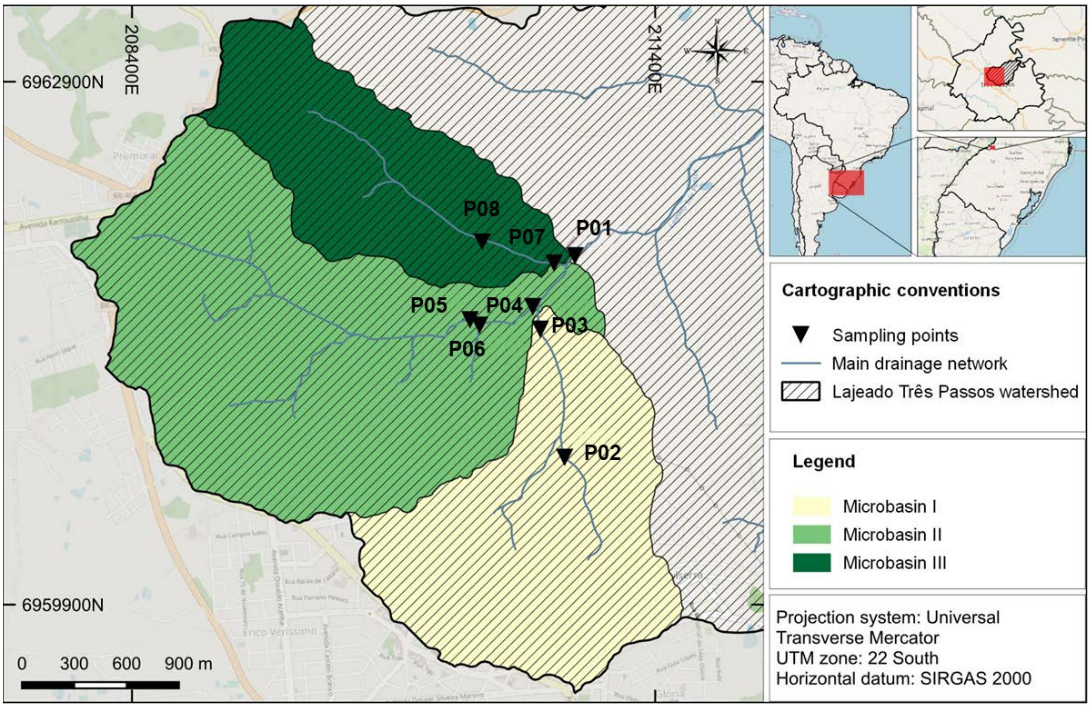
The study area encompasses three tributary microbasins of the Lajeado Três Passos River, located in the municipality of Três Passos, in the northwestern region of the state of Rio Grande do Sul, Brazil. The Lajeado Três Passos River is part of the Turvo-Santa Rosa-Santo Cristo River Basin, which is part of the Uruguay River Hydrographic Region. The river is characterized by receiving stormwater runoff and a considerable volume of effluents, including domestic and industrial waste from a variety of sources. These microbasins were chosen based on their distinct land use and occupancy characteristics, and are referred to as Microbasin I, Microbasin II, and Microbasin III, as illustrated in Figure 1.

Microbasins I and II, initially have extensive areas with remnants of forests; however, a significant portion of their areas has an intense urban occupation. In the former, for instance, a hospital, a Fridge, and a prison are located, constituting potential sources of water resource contamination due to the discharge of untreated effluents, as the city lacks proper wastewater treatment. Additionally, they also feature a substantial area of intensive agricultural use, which can be a source of pollution due to the use of pesticides and fertilizers.On the other hand, microbasin III stands out for having the largest coverage of areas with forest remnants and silvicultural cultivation. Despite the presence of extensive areas with temporary crop farming and urban occupation, this microbasin exhibits the lowest level of degradation among the areas analyzed. These particularities of the microbasins were established during a previous visit.

Land use and land cover characterization

The land use and land cover characterization for each analyzed watershed was conducted through the classification of Sentinel-2 imagery using a supervised method. The algorithm's training was based on samples corresponding to the observed land cover, determined through a prior temporal analysis of high-resolution images available in the Google Earth Pro image visualization software, version 7.3.6.9345. Consequently, six land use and land cover classes were considered, encompassing urban areas, forested areas, temporary crops, agriculture-pasture mosaic, pasture, and silviculture. The agriculture-pasture mosaic class pertains to areas where rotation practices are implemented, as identified using data from the MapBiomas project (SOUZA et al., 2020).

Figure 1 – Map of the microbasins considered in this research and sampling design for water sample analysis



Source: The authors.

The watershed boundaries were established based on altimetric measurements derived from the Shuttle Radar Topography Mission (SRTM) digital elevation model (Farr et al., 2007), acquired through the Application for Extracting and Exploring Analysis Ready Samples (AppEEARS) data distribution platform provided by NASA's Earth Observing Data and Information System (EOSDIS) Land Processes Distributed Active Archive Center (LP DAAC) at the following website: https://lpdaacsvc.cr.usgs.

Water quality analysis

Two sampling campaigns were carried out in September and November of 2022. The water quality analysis was conducted by collecting water samples at key points within each watershed, based on: distinct land use, land cover characteristics, proximity to urban, industrial, and agricultural areas, as well as the presence of riparian buffer zones along watercourses (Figure 1). Point P01 corresponds to the confluence of all tributaries from the three study watersheds (main channel). Sampling points P02 and P03 (Microbasin I) were situated near urban areas located approximately six hundred meters away from an effluent discharge point. Sampling points P04, P05, and P06 within Microbasin II, were directly influenced by urban areas and received contributions from domestic effluents and stormwater runoff. Finally, sampling points P07 and P08 within Microbasin III were situated farther from urban influence and had a greater presence of vegetation (Figure 1).

At each point, 1 L of water was collected. The samples were stored in clean, autoclaved Nalgon® polyethylene bottles, properly labeled, and subsequently transported to the Laboratório de Recursos Hídricos of the Universidade Federal de Santa Maria (Campus Frederico Westphalen) in insulated coolers. Once in the laboratory, they were preserved at 4°C and shielded from light. Physicochemical analyses included pH, temperature, dissolved oxygen, biochemical oxygen demand, total solids, turbidity, nitrate, nitrite, ammoniacal nitrogen, total phosphorus, and microbiological analyses consisted of total coliforms and thermotolerant coliforms (represented by *Escherichia coli* (*E. coli*) were carried out using standardized methods (APHA, 2012). Specifically, for the quantification of nitrate, nitrite, total nitrogen, and total phosphorus, the N- (1-Naphthyl) ethylenediamine, Alphanaphthylamine, Indophenol, and Ascorbic acid methods were employed respectively.

With the concentration of total phosphorus, the trophic State Index (TSI) described by Lamparelli (2004) was calculated, and each microbasin was classified based on its degree of eutrophication, considering six classes: ultraoligotrophic (≤47), oligotrophic (47<TSI ≤52), mesotrophic (52<TSI≤59), eutrophic (59<TSI≤63), supereutrophic (63<TSI≤67), and hypereutrophic (>67).

Additionally, a Kruskal-Wallis test was conducted using Statgraphics Centurion 18 to establish significant differences between the microbasins and the main channel (spatial variation). This allowed for the identification of patterns and relationships among the water quality parameters.

RESULTS AND DISCUSSIONS

Land Use and Land Occupation of microbasins

The analysis of land use and land cover in the studied catchment areas showed the same general use and cover in the areas but with different spatial coverage rates per class. Through the spatial distribution of land use patterns, as depicted in Figure 2 (map), it is possible to observe that Microbasins I and II exhibit significant urban occupation, which can potentially be associated with higher level of water streams pollution. In contrast, Microbasin III shows a lower rate of urban occupation and primarily featured by short cycle crops. Despite the present of native forest in river banks, the major agricultural and urban areas seem to contributing to water resource degradation. Also is important to note the most of spring are not completely protected by native vegetation.

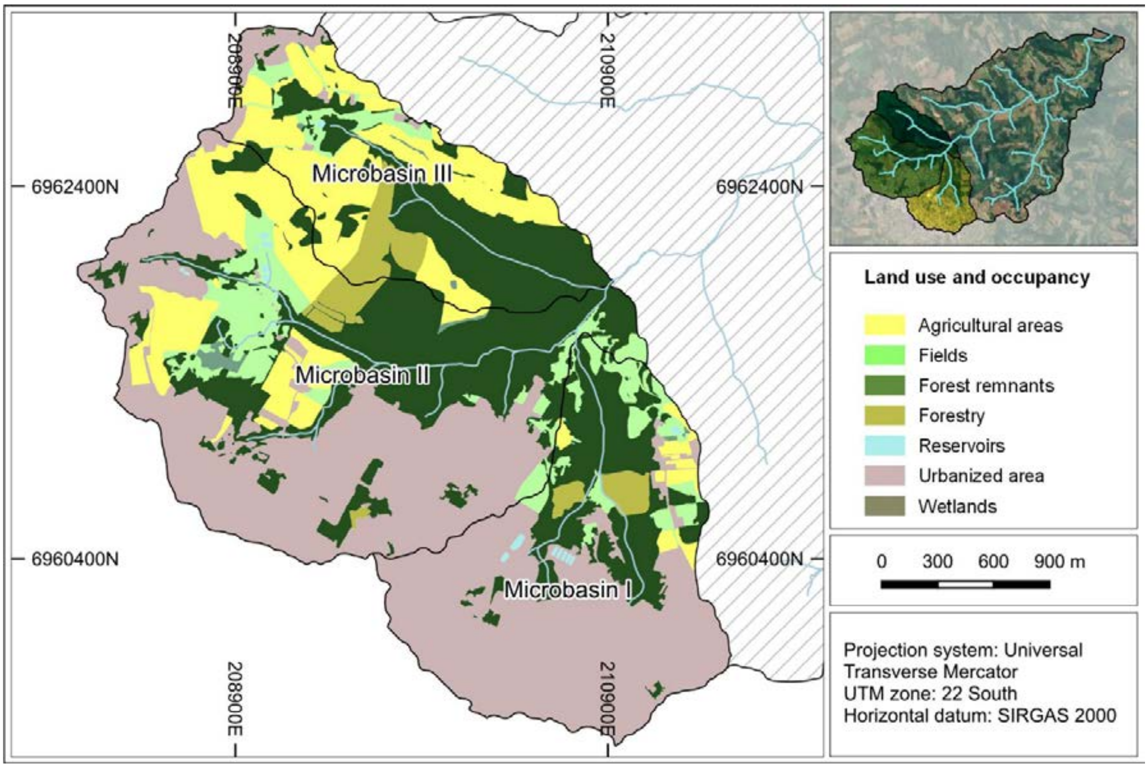
All three microbasins under analysis contain artificial water reservoirs, characterized by small extent, and low volume. These reservoirs serve specific purposes, including animal dessedentation, irrigation, and water storage. Notably, Microbasin I hosts a slaughterhouse where several reservoirs for storing treated and controlled wastewater were identified. However, only a portion of these reservoirs has some connection to the local drainage network.

The results demonstrate that, microbasin I consists of 2.3037 km², microbasin II of 3.7478 km², and microbasin III of 1.6177 km². Figure 3 reveals that Microbasin I is characterized by a predominant urban landscape, covering 62.82% of the total area. This highlights a high degree of urbanization in this locality, potentially contributing to an increased pollution load in the watercourses. Furthermore, the existence of designated agricultural areas (occupying 3.16% of the area) and forest remnants (covering 23.47% of the area) indicates the coexistence of diverse land uses, emphasizing the environmental complexity of the region. Studies evaluating the impact of forestry on water quality and flow showed that there are no significant differences when compared to native ones (PERRANDO et al., 2021). Urban areas also predominate in the Microbasin II, covering 43.77% of the total area. Nevertheless, this microbasin stands out for its significant representation of agricultural zones (13.96% of the area) and forest remnants (30.10% of the area). This landscape combination implies a coexistence between the urban landscape and elements of rural and natural surroundings, potentially resulting in diverse impacts on the water resources of the region. The presence of forest areas in river banks can significantly contribute to reducing sediment transport into the river, mainly associated with extreme rainfall events (BREUNIG et al., 2017), that tend to be even more frequent (PREIN et al., 2017).

Microbasin III presents notable differences compared to the previous ones, with a higher presence of agricultural areas, covering 41.41% of the total area. However, agricultural activity may have a significant impact on water quality and environmental sustainability in the region. In contrast to this, the significant presence of forest remnants (constituting 39.33% of the area) contributes positively to environmental conservation. The urbanized area is the smallest of the three microbasins, representing only 5.89% of the area, characterizing this microbasin as predominantly rural with a strong presence of natural resources.

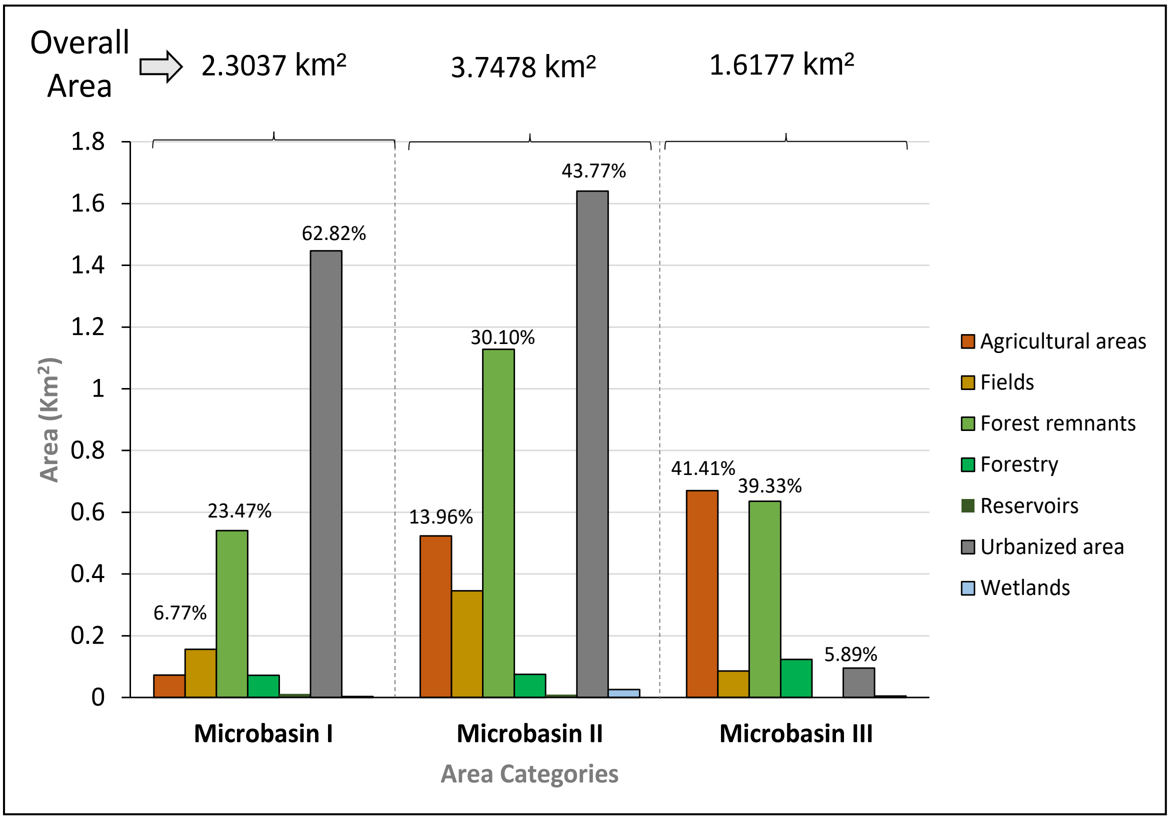
The predominance of urban and agricultural areas in Microbasins I and II implies significant risks in terms of potential watercourse contamination (Wang et al., 2020). Specifically, the high degree of urbanization is associated with the presence of urban pollution sources, both point and diffuse, domestic waste, and industrial waste, such as domestic sewage, industrial discharges, and atmospheric pollutants, making them particularly vulnerable to water pollution (Tania et al. 2023). Moreover, the substantial presence of agricultural areas in these microbasins increases the likelihood of introducing agrochemicals, fertilizers, and pesticides into watercourses, representing an additional source of contamination (GANI et al., 2023; MUHAMMED et al., 2022; WANG; ZHANG, 2018; WU et al., 2023).

Figure 2 – Map of land use and cover of the microbasins analyzed in the municipality of Três Passos



Source: The authors.

Figure 3 – Total area in km² of each microbasin with distribution of land use and land cover in percentage (%)



Source: The authors.

On the other hand, in Microbasin III, the predominance of agricultural areas is balanced by the considerable presence of forest remnants. Native areas are giving way to agriculture and, according to Curtis et al. (2018), 27%± 5% of global forest loss between 2001 and 2015 was caused by deforestation caused by commodities. These remnants play a crucial role in preserving water quality, acting as natural filters and water stabilizers. The forest vegetation contributes to sediment retention, pollutant absorption, and water quality improvement, thus reducing the potential for contamination. The combination of these factors makes it essential to implement stringent waste control and treatment measures, as well as promote sustainable agricultural practices to mitigate environmental impacts.

Water quality

The overall results obtained from physicochemical and bacteriological analyses, as well as the Trophic State Index for the main river channel and the three microbasins in the months of September and November, are shown in Table 1. The temperature remained quite stable throughout the study, with average values ranging between 17.9 and 19.3 °C. Turbidity in September showed values between 2 and 5 NTU, and during November, water samples showed no turbidity. Total solids presented values between 85 and 348 mg/L across the entire area considered, with Microbasin III showing the lowest values (less than 100 mg/L) and Microbasin I reporting higher values for both months (348 mg/L and 184 mg/L, respectively).

Table 1 – Average values of physicochemical and microbiological parameters, as well as the Trophic State Index, in the two months of sampling

Parameters	Main Channel		Microbasin I		Microbasin II		Microbasin III	
	Sep.	Nov.	Sep.	Nov.	Sep.	Nov.	Sep.	Nov.
Physicochemical parameters and trophic state index								
Temperature (°C)	18.0±0.1	19.2±0.1	18.7 ±0.3	19.3 ±0.7	17.9 ±0.3	18.2 ±0.1	18.5 ±0.8	18.6 ±0.1
Turbidity (NTU)	2 ±1	0	3 ± 3	0	2 ±1	0	5 ± 3	0
TS[a] (mg/L)	242±2	145±2	348 ± 226	184 ± 43	152 ± 33	121 ± 15	85 ± 1	100 ± 35
pH	8.0±0.2	8.1 ± 0.2	8.1 ± 0.3	8.3 ± 0.6	8.0 ± 0.2	7.5 ± 0.1	7.3 ± 0.7	7.4 ±0.4
DO[b,c] (mg/L)	7.9± 0.2	8.9 ± 0.2	7.6 ± 0.4	6.6 ± 0.1	8.0 ± 0.4	6.5 ± 0.7	7.4 ± 0.7	6.1 ± 0.7
BOD_5[d] (mg/L)	2.7±0.2	4.3 ± 0.2	2.4 ± 0.5	2.3 ± 0.3	2.6 ± 0.6	1.9 ± 0.6	2.3 ± 0.7	1.3 ± 0.2
Nitrite(mg/L)	0.05±0.01	0.04±0.01	0.11±0.05	0.10±0.04	0.06±0.03	0.10±0.06	0.04±0.01	0.05±0.02
Nitrate (mg/L)	19 ± 2	41 ± 2	32 ± 1	47 ± 12	26 ± 14	18 ± 10	3 ± 2	7 ± 4
Amonia (mg/L)	0.06±0.01	0	0.1 ± 0.1	0	0.01±0.02	0.03 ± 0.05	0	0.04±0.05
TP[e,f] (mg/L)	1.92±0.05	1.04±0.05	3.7 ± 0.02	1.12± 0.05	3 ± 2	0.8 ± 0.4	0.89±0.03	0.6 ± 0.2
TSI[g]	75 ± 1	72 ± 1	78.5 ± 0.3	72.2 ± 0.2	76 ± 4	70 ± 2	71.0 ± 0.2	69 ± 2
Microbiological parameters								
TC (CFU)	1090 ± 80	2880 ± 90	4020±2531	5285±120	990 ± 661	5273±7178	305 ± 149	425 ± 601
E. coli (NMP)	200 ± 50	630 ± 30	590 ± 552	1320 ± 523	703 ± 872	2133 ± 2820	0	0

[a] Total Solids; [b] Dissolved Oxygen; [c] Reported a statistically significant variation depending on the months of sampling with an E=5.84315 and P=0.0445; [d] biochemical oxygen demand of 5 days; [e] Total Phosphorus; [f] Reported a statistically significant variation depending on the months of sampling with an E=4.41176 and P=0.035686 e; [g] Trophic State Index calculated and interpreted according to Lamparelli (2004).
Source: The authors.

The pH values ranged between 7.3 and 8.3 units, indicating the slightly alkaline trend of this Microbasin system. Resolution 357 of the National Council for the Environment of Brazil (CONAMA, 2005), sets the maximum allowable values for pH and turbidity parameters. For freshwater class 1 (Intended for supply for human consumption after conventional treatment) and class 2 (Suitable for the protection of aquatic life and primary contact recreation), the pH levels should ideally range between 6.0 and 9.0. The values obtained in this study were within that range. Regarding turbidity, it should not exceed 5 UNT or 40 UNT respectively. It is noteworthy that the observed turbidity values are within the Maximum Permissible Values (VMP) outlined in the Resolution. The content of total solids is not considered in this resolution. Mendes (2020) notes that the concentration of solids in water sources is high when there is greater exposure of soil particles to the watershed, and the slope of the terrain can influence these concentrations, as there may be increased soil erosion when conservation practices are not adopted in these places. This aligns with the present study, as Microbasin I (P02) is situated at a higher altitude and consists of a pasture area (1.17%) with animal breeding in its surroundings, potentially facilitating erosion and the transport of particles to the water body.

The average dissolved oxygen (DO) values ranged from 6.6 to 8.9 mg/L, surpassing the established limits for classes 1 and 2 (greater than 5 mg/L for class 2 and greater than 6 mg/L for class 1), meeting the criteria for available oxygen in the water to support aquatic life as specified by regulations. The solubility of dissolved oxygen varies with altitude and temperature, with a saturation concentration in clean water of 9.2 mg/L. Concentrations above this value may indicate algae proliferation, while concentrations below may suggest the presence of organic matter in the water body, likely originating from sewage discharges, domestic effluents, or plant residues (TCHOBANOGLOUS et al., 2003; VON SPERLING, 2014; OLIVEIRA et al., 2021).

Additionally, the amount of oxygen required by microorganisms to decompose organic matter (OM) in the water over a five-day period (BOD_5) was determined to assess the presence of biodegradable OM (APHA, 2012), with values ranging from 1.9 mg/L to 4.3 mg/L, with the highest values reported in the main channel (2.7 mg/L in September and 4.3 mg/L in November). CONAMA resolution establishes, within the conditions of class 1 water quality, a value of up to 3 mg/L, and for class 2 water, up to 5 mg/L. Therefore, the levels do not exceed the established limits for these water classes.

On the other hand, nitrogen in its different forms is an indicator of contamination of water bodies. In urban areas, its presence in high concentrations indicates inadequate sanitary conditions whereas in rural areas, this parameter indicates that there may be contamination of water also by effluents of livestock activity, in addition to nitrogen compounds added for fertilization in agricultural areas (CADONÁ et al., 2018). The average nitrite values in this study ranged from 0.04 mg/L to 0.11 mg/L, with a higher concentration in microbasin I (around 0.10 mg/L in both months). Nitrate values ranged from 3 mg/L to 47 mg/L. The highest values were recorded in the main channel and microbasin I. In contrast, microbasin III recorded the lowest nitrate content values (between 3 and 7 mg/L). The ammonium species was absent in November for the main channel and microbasin I, and in September for microbasin III. The values for this species ranged between 0.01 and 0.1 mg/L.

When comparing with the water regulations, it is evident that the concentration of nitrite throughout the entire studied water system adhered to the maximum permissible value (1.0 mg/L). However, concerning nitrate levels, it was observed that in Microbasin I, Microbasin II, and the main channel, the reported values exceeded the established limits (10 mg/L) for waters of classes 1, 2, and even for class 3 (intended for human consumption after conventional or advanced treatment, irrigation, amateur fishing, secondary contact recreation, and other uses). Nitrate can originate from various localized sources, including the discharge of animal effluents, several industrial sectors, sludge from effluent treatment ponds, agricultural residues from pig farming activities, and the release of domestic effluents. Furthermore, soil leaching and the runoff of pesticides into water bodies can also contribute to nitrate pollution (Padilla et al., 2018). This finding is particularly relevant to the conditions of the evaluated system, as the sampled points receive substantial effluent loads, particularly from urban areas characterized by high population densities and a pig slaughter industry with a daily slaughter capacity of up to 2,600 pigs.

The concentration of total phosphorus in the analyzed waters varied between 0.6 mg/L and 3.7 mg/L, with lower concentrations in November and the highest value in Microbasins I. The CONAMA Resolution 357 (2005) establishes a maximum allowed value for total phosphorus in lotic environments, for freshwater classes 1 and 2, of 0.1 mg/L, and for class 3 (Waters that can be destined for navigation and landscape harmony) of 0.15 mg/L. All total phosphorus values obtained in this study exceeded those limits set by legislation, categorizing Lajeado as class 4 (suitable for navigation and aesthetic purposes in the landscape) when considering this parameter.

The application of mineral and organic fertilizers in the soil for fertility correction is a practice that contributes to the arrival of phosphorus in water bodies due to soil erosion, surface runoff, or leaching (GATIBONI et al., 2015). In a study on the impact of anthropization on water and soil quality in a watershed, Wroblescki et al. (2021) found similar results for phosphorus, where the highest values occurred in locations along the watercourse located near the urban area due to the release of domestic effluents in the riverbed. Microbasin II is composed of 31.44% temporary crops and 27.95% urbanized area, while Microbasin I has a coverage of 9.15% temporary tillage and 24.88% agricultural and pasture areas, in addition to being surrounded by urbanized areas, which could be contributing to the impact on this aquatic ecosystem. As Microbasin III is located in a region with the highest proportion of forest formation (64.79%), its tendency to lower phosphorus concentration values can be explained.

Phosphorus is one of the main parameters responsible for causing eutrophication in water sources and may have a natural origin, coming from rocks and particulate materials in the atmosphere, and anthropogenic, through domestic and industrial effluents and soil leaching (CETESB, 2014; QUINELATO et al., 2021). Eutrophication corresponds to the excessive growth of aquatic plants in watercourses, causing interference with the desired uses of the water body, with excess nutrients being one of the main factors for this occurrence (VON SPERLING, 2014), when present in greater quantities than the assimilative capacity of the watercourse (WROBLESCKI et al., 2021). In this

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regard, the Trophic State Index (TSI) obtained for each microbasin and the main channel reported values between 69 and 78.5, categorizing this aquatic system as Hypereutrophic. Gargiulo et al. (2022) found that TSI results alike the present study, when evaluating the water quality of the Taquacetuba Compartment, Billings Reservoir, in the state of São Paulo. This level in the aquatic environment indicates that the water body is significantly affected by high concentrations of OM and nutrients, leading to algal blooms and fish mortality, and impacting its various uses, including livestock activities practiced in riverside regions (CETESB, 2014; LAMPARELLI, 2004).

High nutrient levels can lead to excessive algae growth, which can deplete oxygen levels in the water when the algae die and decompose. Therefore, a high TSI often indicates poor ecosystem health, with reduced biodiversity and impaired ecological functioning. Also, a high TSI can lead to water quality issues such as taste and odor problems, increased turbidity, and the presence of harmful algal blooms, affecting water supplies for human consumption, recreational activities, and agriculture, posing risks to both ecosystem and human health, and having significant economic consequences, including the loss of revenue from tourism and recreational activities, decreased property values, and costs associated with treating contaminated water supplies or managing the impacts (SMITH, 2003; SCHINDLER, 2006; LOPES et al., 2019).

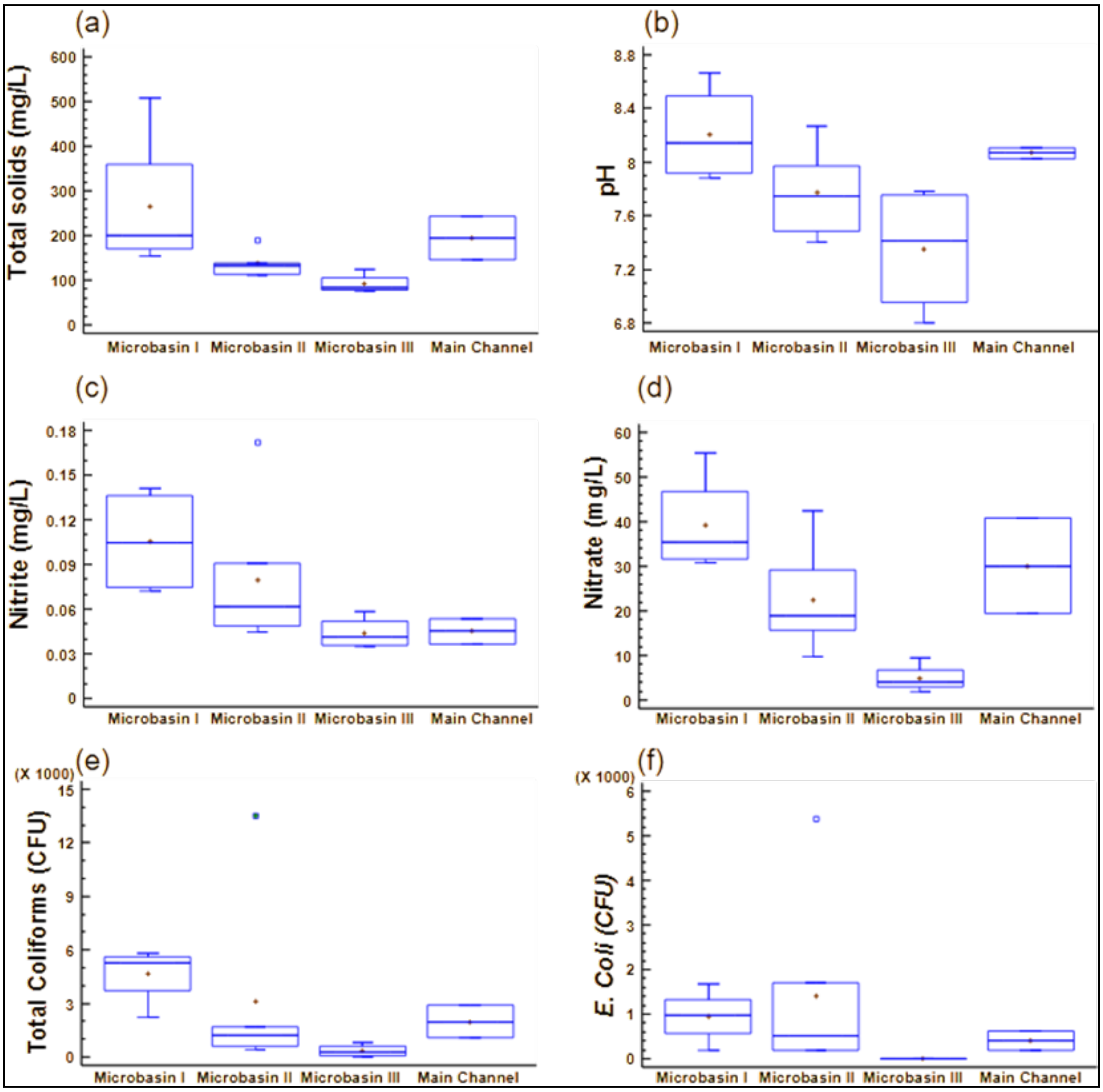
Total coliforms are a broad group of bacteria that can be present in water and soil, as well as in human and other warm-blooded animal feces. They serve as indicators of the presence of other free-living organisms, not just intestinal organisms (VON SPERLING, 2014). For this study, positive results for total coliforms were found in all areas and in both months considered, with values ranging from 305 CFU to 5285 CFU. Elevated values were recorded in microbasins I and II, which have a higher proportion of urbanized areas. Overall, total coliform values tended to increase in the second collection (November). Regarding *E. coli*, values between 200 and 2133 NMP/100 mL were reported, with higher values in microbasins I and II. According to CONAMA Resolution 357/2005, freshwater of class 2 should not exceed the limit of 1,000 thermotolerant coliforms (in this case, *E. coli*) per 100 mL in at least 80% of samples collected during one year. In this study, the limits of thermotolerant coliforms were exceeded in the second campaign for microbasins I and II. The presence of *E. coli* was negative in microbasin III.

On the other hand, to verify the spatial variation in water quality, a Kruskal-Wallis analysis was carried out (Figure 4), from which significant differences based on the studied areas (pre-established microbasins) in total solids content, pH, nitrite, nitrate, total coliforms, and *E. coli* were found. The following trend in water quality impact can be established: microbasin I > microbasin II > microbasin III, as revealed by the box and whisker plot for attributes that showed statistically significant variation (Figure 4).

This trend is related to the differences in land use, as water quality indicators show higher concentrations in microbasin I, which has a higher urban coverage. Microbasin III, with the lowest urban coverage equivalent to the coverage of remaining forests, exhibits better water quality. However, based on the results, treatment would be required for these waters to be suitable for consumption.

Existing gaps in raw water monitoring persist, manifesting themselves in several critical areas, such as specific contaminations and the geographic scope addressed, in addition to the notable lack of data integration, which rarely occurs. Research and scientific advancement play a crucial role in understanding the dynamics of water resources in river basins, and it is imperative to promote continuous updates in land use practices, as well as urban and agricultural occupation patterns.

Figure 4 – Box and whisker plots corresponding to the physicochemical and microbiological parameters showed statistically significant variation based on the location of water samples (spatial variation). (a) Total solids, (b) pH, (c) Nitrite, (d) Nitrate, (e) Total coliforms, and (f) *E. coli*



Source: The authors.

Furthermore, the development of research contributes significantly to the constant improvement and restructuring of current legislation related to water quality, which must consider the real conditions of water resources, to take conservation and remediation measures when necessary. Therefore, two aspects stand out: (I) Understanding the quality of raw water is essential to propose appropriate technologies for its treatment, guaranteeing a safe supply to the population; (II) Systemic management of water resources is crucial to guarantee the sustainability of the fauna and flora of the microbasins analyzed, contributing to the environmental balance of the region.

CONCLUSIONS

Based on the assessment of land use and occupation in the micro-watershed system studied in Lajeado Três Passos, it can be pointed out that this region has a significant urbanized area, pasturelands, and agricultural uses (including temporary crops) with a substantial presence of forest formation (forest remnants).

The results of the water quality analysis indicated that most of the values obtained comply with the maximum allowed for freshwater classes 1 and 2, according to CONAMA Resolution 357/2005. However, in the case of the nutrients nitrate and total phosphorus, the values were high, exceeding the established limits in legislation, indicating a hypereutrophic state and classifying Lajeado in class 4. The presence of *E. coli* is also noteworthy, with levels surpassing the established limits for class 2.

In this way, and relating the results to the land use and occupation in the selected microbasins system, its influence on water quality is inferred, which is more impacted in microbasins I and II. These microbasins have a greater release of domestic and industrial effluents and the potential transport of agricultural fertilizers to the watercourse. On the other hand, the forest cover present in microbasin III and its location at a greater distance from the urbanized area promotes a higher state of preservation.

This study highlights the importance of identifying and controlling pollution sources that may be affecting this aquatic system, considering its potential uses, and promoting sustainable soil management practices and the conservation of natural areas in regions susceptible to intensive agricultural activities.

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