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Article

Assessment of Water Quality and Microplastic Contamination in Urban Lakes in Guarulhos, São Paulo, Brazil

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ABSTRACT

Urban lakes are important providers of cultural ecosystem services, promoting integration between nature and urban centers. However, these environments are subject to various anthropogenic impacts, especially pollution from domestic sewage and improper disposal of solid waste. In this context, environmental diagnosis and monitoring are essential tools for protecting public health and environmental quality. The present study aimed to characterize the spatial-horizontal distribution of water quality and the presence of microplastics (MPs) in three recreational areas located in the municipality of Guarulhos, Metropolitan Region of São Paulo. Samples were collected during the rainy season (February to March 2022) and dry season (August to October 2022) at sites with varying degrees of anthropogenic influence. Physical-chemical and microbiological variables related to the presence of MPs were analyzed, and the Trophic State Index was calculated. The lakes studied presented turbidity and concentrations of total phosphorus, *chlorophyll-a*, and *Escherichia coli* above the limits established by CONAMA Resolution No. 357/2005, and were classified from oligotrophic to hypereutrophic, indicating wide heterogeneity in the trophic status of the lakes. Microplastics were detected in all areas studied, with densities of up to 1,654 MP L^{-1}. The results highlight the process of environmental degradation in the urban lakes evaluated, strongly influenced by human activities in the surrounding area and conditions of access and public use. The presence of MPs, in particular, stands out as an emerging indicator of diffuse pollution. In view of this, it is recommended that environmental monitoring of these ecosystems be intensified, with the systematic inclusion of MP analysis, as well as the implementation of ecological restoration actions and environmental education programs. Such measures should be promoted by *stakeholders*, aiming at the protection of water resources and the safety of the population that enjoys these urban leisure spaces.

Keywords: environmental diagnosis; water resources; eutrophication; microplastics; São Paulo metropolitan region.

RESUMO

Lagos urbanos constituem importantes prestadores de serviços ecossistêmicos culturais, promovendo a integração entre a natureza e os centros urbanos. Contudo, esses ambientes estão sujeitos a diversos impactos antrópicos, especialmente a poluição decorrente do lançamento de esgotos domésticos e o descarte inadequado de resíduos sólidos. Neste contexto, o diagnóstico e o monitoramento ambiental são ferramentas essenciais para a proteção da saúde pública e da qualidade ambiental. O presente estudo teve por objetivo caracterizar a distribuição espaço-horizontal da qualidade da água e da presença de microplásticos (MPs) em três áreas de lazer localizadas no município de Guarulhos, Região Metropolitana de São Paulo. Coletas foram realizadas durante o período chuvoso (fevereiro a março de 2022) e seco (agosto a outubro de 2022), em locais com diferentes graus de influência antrópica. Foram

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analisadas variáveis físico-químicas, microbiológicas e relacionadas à presença de MPs, além do cálculo do Índice de Estado Trófico. Os lagos estudados apresentaram turbidez e concentrações de fósforo total, clorofila-*a* e *Escherichia coli* superiores aos limites estabelecidos pela Resolução CONAMA nº 357/2005, e foram classificados desde oligotrófico a hipereutrófico, indicando ampla heterogeneidade na trofia dos lagos. Microplásticos foram detectados em todas as áreas estudadas, com densidades de até 1.654 MP L^{-1}. Os resultados evidenciam o processo de degradação ambiental nos lagos urbanos avaliados, fortemente influenciado pelas atividades humanas no entorno e condições de acesso e uso público. A presença de MPs, em especial, destaca-se como um indicador emergente de poluição difusa. Diante disso, recomenda-se a intensificação do monitoramento ambiental desses ecossistemas, com a inclusão sistemática da análise de MPs, bem como a implementação de ações de restauração ecológica e programas de educação ambiental. Tais medidas devem ser promovidas por *stakeholders*, visando à proteção dos recursos hídricos e à segurança da população que usufrui desses espaços de lazer urbano.
Palavras-chave: diagnóstico ambiental; recurso hídrico; eutrofização; microplástico; região metropolitana de São Paulo.

Introduction

Urban green spaces, such as parks and lakes, often located in metropolitan regions or in contiguous areas with easy access to the population, are characterized by the presence of native or exotic vegetation and infrastructure geared toward recreation, culture, sports, education, and art. These spaces are part of the urban landscape and stand out for providing ecosystem services, such as flood control during heavy rainfall events and mitigation of the "heat island" effect (Tucci 2010; Chen et al. 2020; Costa et al. 2021; Régis et al. 2023).

In addition, urban green spaces play an important role in promoting the physical and mental health of populations, contributing to stress reduction, improved overall well-being, and decreased levels of anxiety and depression (Régis et al. 2023; Capucho & Neves 2025). However, these environments are subject to intense anthropogenic pressures, which lead to the loss of habitat and microhabitat diversity, in addition to favoring the process of artificial eutrophication of urban lakes (Goular & Castilo 2003; Régis et al. 2023).

Given their socio-environmental and landscape relevance, urban lakes must maintain their ecological and aesthetic integrity, and continuous monitoring of water quality is essential to ensure their safe use by the population (Silva et al. 2017). Despite this, these environments still receive little scientific attention, with most studies on freshwater systems focusing on natural, semi-natural environments (Moldoveanu et al. 2025; Oliveira & Bortolini 2025) or those intended for public supply (Soares & Calijuri 2021; Peixoto-Chamizo et al. 2025).

The municipality of Guarulhos, located in the state of São Paulo and with approximately 1.3 million inhabitants (IBGE 2023), is the second largest in the state, behind only the capital. Like other large metropolises, it has a deficit of green areas in urbanized regions, which reinforces the importance of preserving and maintaining local parks and green areas.

The urbanization of Guarulhos intensified in the 1960s, amid a period of high migratory flow in Brazil. Since then, population growth has been rapid and disorderly, without proper urban infrastructure planning, resulting in serious environmental problems, especially related to water quality management, with untreated domestic and industrial effluents being discharged into rivers and streams (Guarulhos [n.d.]).

The municipality's hydrography consists of five main river basins: Baquirivu-Guaçu, Central, Cabuçu de Cima, Tietê-Sena, and Jaguari (Andrade 2009). Environmental studies on these lotic environments were conducted by Oliveira et al. (2018), Silva et al. (2019), Vargas et al. (2017; 2018; 2019), and Pelisson et al. (2024), which highlighted the impacts of land use and occupation and the effects of urbanization on water quality. In particular, Oliveira et al. (2018), Vargas et al. (2019), and Pelisson et al. (2024) investigated the Cachoeirinha-Invernada sub-basin; Silva et al. (2019) studied the Cabuçu sub-basin; and Vargas et al. (2018) analyzed the Ribeirão Guaraçau basin . The results converge toward a scenario of environmental degradation, marked by the irregular occupation of riparian forest areas and the precariousness or absence of basic sanitation.

In contrast, the municipality's lentic environments have been less explored scientifically. Noteworthy are the works of Azevedo et al. (2016), Souza et al. (2019), Pontes et al. (2020), Osti et al. (2022), and Silva et al.

(2024), in addition to some monographs. The studies by Souza et al. (2019) and Pontes et al. (2020) evaluated the phytoplankton community of urban lakes in Guarulhos, and Silva et al. (2024) describe a new species of diatom for a municipal conservation unit, where only Azevedo et al. (2016) have deepened the discussions on the physical-chemical and microbiological characteristics of the water, bringing considerations on the sanitary aspects of Água Azul Lake. These studies point to a relationship between the urbanization process, population growth around the lakes, and the intensification of the eutrophication process.

Thus, conducting systematic environmental diagnoses in these ecosystems, integrating the collection and interpretation of physical, chemical, and biological data, is fundamental for the efficient management of urban water resources, as it allows for the identification of sources of contamination, changes in ecological patterns, and the impacts of urbanization. Additionally, these factors are modulated by seasonality, mainly due to climatic and hydrological variations, morphological characteristics of lakes, and anthropogenic interference, which influence the annual availability of nutrients (Zheng et al. 2024). As argued by these authors, the cumulative effect of climate change cannot be overlooked, as it is accentuated in regions with a high degree of urban sealing and densification.

Water quality monitoring in urban lakes can be performed by analyzing physical, chemical, and microbiological variables. Among the most commonly used microbiological indicators is the presence of *Escherichia coli*, a microorganism that is part of the intestinal microbiota of humans and other homeothermic animals (Barbosa et al. 2009). The detection of *E. coli* in freshwater aquatic ecosystems is widely used as an indicator of fecal contamination, given its strong correlation with the presence of other pathogens of enteric origin (bacteria, viruses, and protozoa). Thus, its occurrence signals risks to public health, since ingestion of this water or primary contact can cause various diseases, such as gastrointestinal infections, fever, vomiting, and, in more severe cases, meningitis or septicemia (Nataro 1998; Croxen et al. 2013; Frias et al. 2020; ANA 2023).

Another emerging factor of environmental concern is water pollution by plastics. The high daily generation of this waste, combined with improper disposal, contributes to its presence in water bodies, affecting the entire food chain (Montagner et al. 2021). Microplastics (MPs), originating from the degradation of plastic materials through physical, chemical, and biological processes, are present in reservoirs, lakes, rivers, and seas (Aliabad et al. 2019; Badea et al. 2023). According to ISO/TR 21960:2020, MPs are defined as water-insoluble solid particles with dimensions between 1 and 1,000 μm. Particles between 1,000 and 5,000 μm are classified as "large microplastics," and above that as "macroplastics" (Montagner et al. 2021). The main risks associated with MPs include their environmental persistence, ability to adsorb persistent organic pollutants, ingestion by aquatic biota, and transfer along the food web (Badea et al. 2023).

Considering the importance of urban lakes and the lack of data on microplastics in such systems, this study aimed to analyze the spatial-horizontal dynamics and temporal variation of physical, chemical, and microbiological variables (*E. coli*) and the occurrence of microplastics. The research was conducted in three urban environments with lakes in the municipality of Guarulhos/SP, aiming to understand the implications of these factors for the predominant uses of these ecosystems.

Materials and Methods

Study area

The municipality of Guarulhos is located in the northeastern portion of the São Paulo Metropolitan Region (RMSP). In hydrographic terms, the territory is part of the Alto Tietê (UGRHI-06) and Paraíba do Sul (UGRHI-02) Water Resource Management Units (UGRHIs), subdivided into five main basins: Baquirivu-Guaçu, Central, Cabuçu de Cima, Tietê-Sena, and Jaguari. The region's climate is humid subtropical, classified as Cwb (warm temperate) according to the Köppen system (Alvares et al. 2013). The average annual temperature is between 18ºC and 19ºC, with the average for the coldest month below 15ºC and in the hottest months (summer) the average varies between 23ºC and 24ºC. The rainfall index is between 1,250 and 1,500 mm/year (Andrade et al. 2008).

The municipality of Guarulhos borders Arujá (east), Itaquaquecetuba (southeast), Mairiporã (northwest), Nazaré Paulista (north), São Paulo (south, southwest, and west), and Santa Isabel (northeast). The areas with the highest population density are concentrated in the central region and its surroundings, where the three limnic systems selected for this study are located (Figure 1):

Lago dos Patos (LP): Located in the Vila Galvão neighborhood, it is one of the most traditional bodies of water in the municipality. It has an area of approximately 20,500 m² (Guarulhos, [n.d.]) and is undergoing an advanced process of silting, with a depth rarely exceeding 1 m. Because it is located in an intensely urbanized environment and surrounded by paved roads, the water body is subject to continuous input of solid waste and urban surface runoff.

Bosque Maia Municipal Park (BM): Located in the central region of Guarulhos, it is considered the largest urban park in the municipality, covering 120,000 m² (Guarulhos, [n.d.]). Its lakes are used predominantly for contemplative purposes and passive recreation, protected by the local tree vegetation.

Guarulhos Municipal Zoo (ZOO): The lakes are formed by the damming of the Ana Rita stream and their dynamics are influenced by the activities carried out on site and in the surrounding urban area (Souza et al. 2019).

Together, these ecosystems represent important leisure spaces for the local population, while also acting as centers for urban biodiversity conservation.

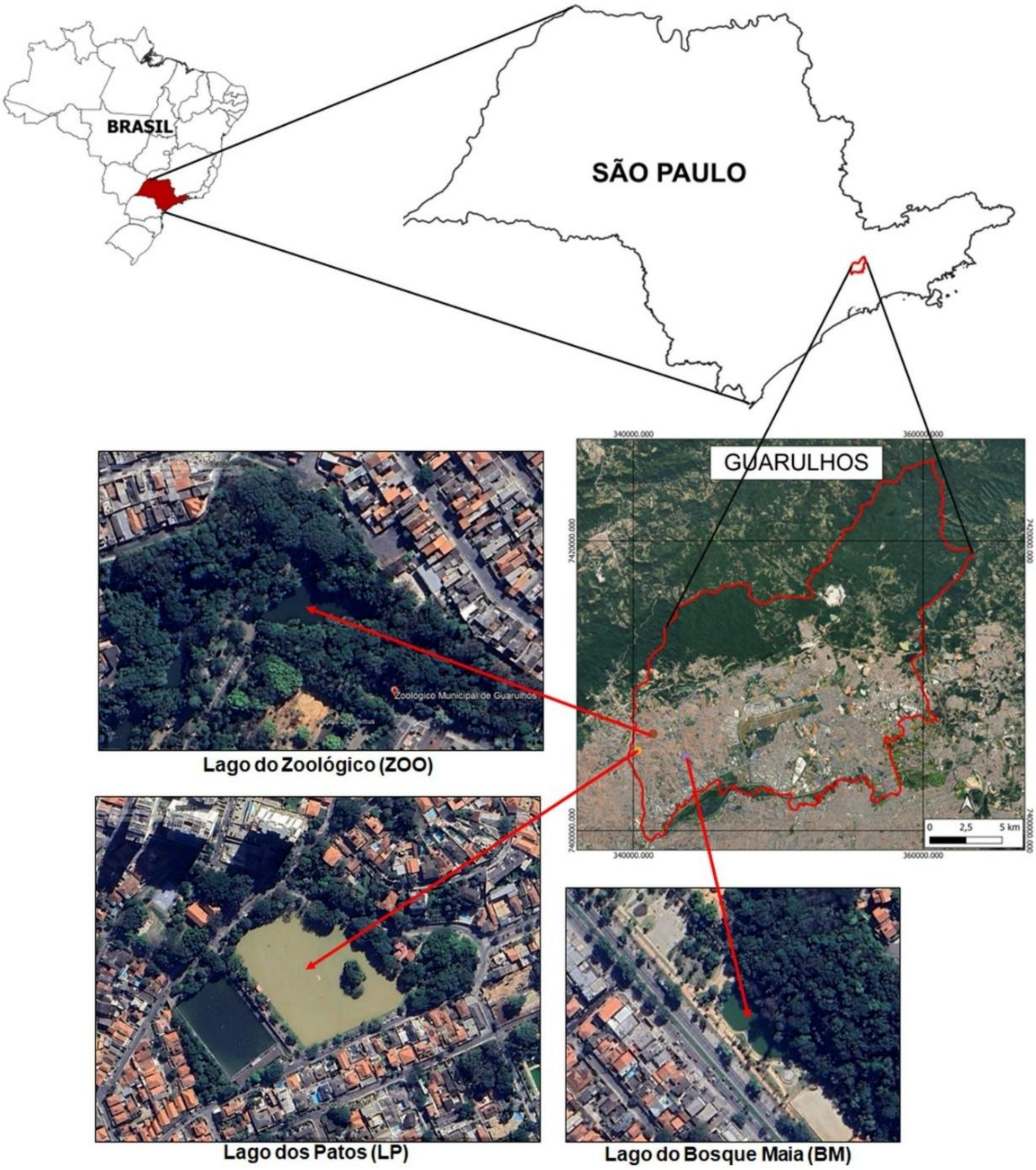

Figure 1. Location of the lakes studied in the municipality of Guarulhos. Images taken from Google Earth (flight date: 02/21/2022). Organization: F. Bau Dalmas, 2026. Source: Authors (2026).

Sampling design

Samples were collected from the subsurface layer of the water column in the three selected environments. The sampling design (Figure 1; Table 1) was structured as follows: 1) Lago dos Patos (LP): three sampling stations, one at the water inlet (comprising drainage and spring) and two located on the lake's shoreline. 2) Bosque Maia Park (BM): five sampling stations. The first is located in a lake formed upstream by a spring; two are in lakes arranged sequentially to this one, and the other two are located in lakes formed by the damming of storm drainage and springs. 3) Guarulhos Municipal Zoo (ZOO): six stations distributed in a system of sequential lakes, starting at a water body located downstream from a spring and following the flow of the subsequent lakes. Two sampling campaigns were carried out in 2022: one during the rainy season (February and March) and another during the dry season (July and August). For the specific analysis of microplastics, only the sampling campai ng to the dry season was considered, aiming to assess the concentration of these contaminants in a scenario of lower rain dilution. Additionally, we sought to characterize the occurrence of synthetic microparticles in these ecosystems, establishing a database that can guide and support future studies on the dynamics of this contaminant in urban environments.

Table 1. Code of sampling stations, geographic coordinates, and characteristics of the surroundings of three urban lakes located in the municipality of Guarulhos/SP.

Site	Geographic coordinates	Surrounding Characteristics
Lago dos Patos – LP1	23º27'8.95"S, 46º33'44.47"W	Drainage water
Lago dos Patos – LP2	23º27'6.81"S, 46º33'47.38"W	Lake without access*
Lago dos Patos – LP3	23º27'8.98"S, 46º33'50.30"W	Lake without access*
Maia Forest – BM1	23º27'20.00"S, 46º31'50.33"W	Lake near the spring
Maia Forest – BM2	23º27'22.96"S, 46º31'51.92"W	Lake with access
Maia Forest – BM3	23º27'25.47"S, 46º31'48.87"W	Lake with access
Bosque Maia – BM4	23º27'37.58"S, 46º31'39.98"W	Lake near the spring
Maia Forest – BM5	23º27'41.19"S, 46º31'37.42"W	Lake near the spring
Zoo – ZOO1	23º26'33.36"S, 46º33'6.67"W	Lake near the spring
Zoo – ZOO2	23º26'31.75"S, 46º33'11.66"W	Lake without access
Zoo – ZOO3	23º26'30.74"S, 46º33'12.96"W	Lake without access
Zoo – ZOO4	23º26'32.87"S, 46º33'14.10"W	Lake without access
Zoo – ZOO5	23º26'35.19"S, 46º33'15.89"W	Lake without access
Zoo – ZOO6	23º26'36.89"S, 46º33'17.28"W	Lake without access

* Pedal boat rides on weekends. Source: Authors (2025).

Physical-chemical and microbiological analyses of the water

Water samples were collected from the subsurface of the water column using a metal bucket, transported, and stored in appropriate bottles following the procedures outlined in the National Guide for Sample Collection and Preservation, provided by the São Paulo State Environmental Company and the National Water and Basic Sanitation Agency (CETESB; ANA 2023). The following variables were analyzed *in situ*: water temperature (T; °C) and dissolved oxygen (DO; mg L^{-1}) (Hanna HI 9146 Oximeter), pH (Digimed DM-2 pH meter), electrical conductivity (EC; µS cm^{-1}) (Digimed DM-3 Conductivity Meter), and turbidity (Tur; NTU) (Quimis Q279P Turbidimeter).

In the laboratory, total phosphorus (TP; µg L^{-1}) was analyzed using the methodology proposed by Valderrama (1981). Total solids (TS; mg L^{-1}) were analyzed following the methodology described in APHA (2012). For the analysis of *chlorophyll-a* (Cla; µg L^{-1}), 47 mm diameter glass microfiber filters (AP 20) were used. After filtration, the filters were wrapped in aluminum foil and stored in a freezer until analysis in the laboratory. Extraction using ethanol as a solvent, as well as analysis, followed the technique proposed by Marker et al. (1980) and Santory and Grobellar (1984). For the quantification of *E. coli*, the membrane filtration technique was used, according to the methodology described in APHA (2012). The results were expressed in CFU/100 mL, following the recommendations of CETESB (2013). It should be noted that, although CONAMA Resolution No. 357/2005 establishes limits in NMP/100 mL, the technical literature and regulatory agencies (APHA, 2012; CETESB, 2023) consider CFU and NMP units to be numerically equivalent for comparison with environmental standards, ensuring that the results comply with current legislation.

Trophic State Index

The Trophic State Index (TSI) classifies water bodies according to their degree of trophic status, assessed in terms of nutrient enrichment (total phosphorus variable) and its effect on primary production, i.e., its effect related to excessive phytoplankton growth (*chlorophyll-a* variable).

Based on the results for total phosphorus and *chlorophyll-a,* Carlson's (1977) Trophic State Index (TSI) was calculated, as adapted by Lamparelli (2004) for tropical lentic environments. This index is recommended by the National Water Agency (ANA 2023) and used by the São Paulo State Environmental Company (CETESB) to assess the trophic status of water bodies in the state of São Paulo (CETESB 2023), according to Equations 1, 2, and 3.

Equation 1. $\text{TSI (Chl } a) = 10\text{x}\left[6 - \left(\frac{0{,}92 - 0{,}34\text{x} \ln \text{Chl a}}{\ln 2}\right)\right]$

Equation 2. $\text{TSI (TP)} = 10\text{x}\left[6 - \left(\frac{1{,}77 - 0{,}42x \ln \text{TP}}{\ln 2}\right)\right]$

Equation 3. $\text{TSIm} = \left(\frac{TSI(Chl\ a) + TSI(TP)}{2}\right)$

Where: Chl a = *chlorophyll-a* concentration, in µg L^{-1};
TP = total phosphorus concentration, in µg L^{-1}.

The TSI result was considered to be the simple arithmetic mean (TSIm – equation 3) of the indices for total phosphorus and *chlorophyll-a*. The trophic status classification used was: ultraoligotrophic TSI ≤ 47; oligotrophic 47 < TSI ≤ 52; mesotrophic 52 < TSI ≤ 59; eutrophic 59 < TSI ≤ 63; supereutrophic 63 < TSI ≤ 67 and hypereutrophic TSI > 67.

Microplastic analysis

The methodology for collecting, filtering, removing organic matter, and counting microplastics followed the methodology proposed by the US government agency National Oceanic and Atmospheric Administration (NOAA 2015) and the protocol described in León-Muez et al. (2020). Water samples were collected from the subsurface of the water column using a metal bucket and stored in 0.6 L glass bottles without reducing the volume *in situ* (Hidalgo-Ruz et al. 2012). In the laboratory, with the aid of a glass filtration system, the samples were filtered with a glass microfiber filter (AP20) with a mesh opening of 0.7 µm and a diameter of 47 mm. The filtered volume varied between 100 and 300 mL, considering filter clogging.

After filtration, the samples were stored in desiccators until dry and then individually stored in Petri dishes until counting. To remove organic matter, the samples were added to a bath with hydrogen peroxide (H_2O_2), waiting between 1 and 24 hours to remove the organic matter present, given the high turbidity in some samples (Prata et al. 2019).

Finally, the filters were counted and identified using an Olympus BX51 optical microscope at 20x to 100x magnification. The microplastics were counted and divided into two categories, fragments and fibers. The results were expressed in microplastics per liter (MP L^{-1}), according to Equation 4.

Equation 4. Microplastic (MP) L = $\frac{N*1000}{Vol.\ filtrado}$

Where N is the number of microplastics and vol. filtered is the volume filtered per sample. Thus, the amount of MP of all samples in liters was maintained.

Statistical analysis of data

The results of the physical, chemical, and microbiological variables were analyzed using descriptive statistics, using the arithmetic mean as a measure of central tendency and standard deviation as a measure of the degree of absolute dispersion of the data.

In accordance with State Decree 10.755/77 (São Paulo 1977), the lakes studied are located in the Cabuçu de Cima (Lago dos Patos and Guarulhos Zoo) and Central (Bosque Maia) river basins and classified as Class 3 and 4, respectively. For standardization purposes, the results of the physical, chemical, and microbiological variables were compared to the limit values established by CONAMA Resolution 357/2005 for Class 3 water bodies (Brazil 2005), as it is more restrictive in terms of dissolved oxygen concentration and predominant use.

To assess possible differences in *E. coli* concentrations between urban lakes in Guarulhos and between the dry and rainy seasons, the nonparametric Kruskal-Wallis independent test ($\alpha = 0.05$) was used (Corder & Foreman 2014). The analysis and graphical presentation in *box plots* was performed using Past 4.01 statistical software.

To analyze the environmental variability of limnological variables in relation to the presence of *E. coli*, principal component analysis (PCA) was performed using the correlation matrix between limnological variables and the presence of *E. coli* in the urban lakes of Guarulhos during the dry and rainy seasons. The PC-ORD version 6.0 program for Windows (McCune & Mefford 2011) was used for this analysis. Variables with a significant correlation were considered to be those with $r > 0.5$ with axes 1 and 2 of the ordination. The data were transformed by applying [log(x+1)], except for pH.

Results and Discussion

The results of the physical, chemical, and microbiological variables monitored in the urban lakes of Guarulhos (Bosque Maia, Lago dos Patos, and Zoológico) are compiled in Table 2. The data obtained during the dry and rainy seasons were compared with the limits established by CONAMA Resolution No. 357/2005 for Class 3 waters. According to this standard, water bodies in this category are intended for domestic supply after conventional treatment, preservation of biota, and animal watering. For comparative purposes, Class 4 encompasses waters intended only for less demanding uses, such as landscape harmony, navigation, and industrial supply after advanced treatment (Brazil 2005).

The physical, chemical, and microbiological conditions of Patos and Zoológico were above water quality standards for total phosphorus, *chlorophyll-a*, turbidity, and *E. coli*, both in the dry and rainy seasons. These values were more pronounced for turbidity, with 93% of samples exceeding 100 NTU, and *E. coli*, which among the lakes studied, only two stations (or 7%) were in accordance with the limit established in CONAMA 357/05 legislation (up to 2.5 CFU 100 $mL^{-1} * 10^{+4}$).

The high turbidity values observed in Lago dos Patos (LP), with peaks exceeding 300 NTU (Table 2), are associated with the shallow depth of the water body, rarely exceeding 1 m, combined with the use of mechanical aerators. The operation of this equipment in shallow environments promotes the stirring of bottom sediment, suspending particles and reducing water transparency. This condition is harmful to the local ichthyofauna, as light attenuation limits the euphotic zone and, consequently, the primary productivity of phytoplankton (Tundisi & Tundisi 2008). In addition, the solid material suspended in the water can adhere to the gills of fish, compromising gas exchange and increasing vulnerability to pathogens (Moro et al. 2013).

Table 2. Mean values and standard deviations of environmental variables measured in three urban lake systems in the municipality of Guarulhos/SP. The data refer to the rainy (February to March 2022) and dry (August to October 2022) seasons. Lakes in Bosque Maia Park (n = 5); Lagos dos Patos (n = 3);

Lakes in the Guarulhos Municipal Zoo (n = 6). Note: Values in bold indicate concentrations that exceed the limits established by CONAMA Resolution No. 357/2005 for Class 3 freshwater in lentic environments. Abbreviations see Table 3.

	Lake Bosque Maia		**Lago dos Patos**		**Lake Zoo**		**CONAMA 357/05**
	Dry (07/04/2022)	**Rainy (03/10/2022)**	**Dry (08/18/2022)**	**Rainy (03/03/2022)**	**Dry (08/22/2022)**	**Rainy (02/05/2022)**	**Class 3**
Temp (°C)	19.2±0.6	24.8±1.0	23.1±1.5	30.2±2.15	17.8±0.75	22.3±2.3	n.a.
pH	7.0±1.0	5.1±1.4	7.8±0.5	7.7±0.7	7.2±0.8	6.2±0.9	6.0 to 9.0
Cond. (μS. cm^{-1})	177.6±25.1	182.3±16.4	151.6±13.5	174.4±55.1	156.4±17.1	154.5±6.2	n.a.
Turb. (NTU)	83.5±41.2	67.0±52.2	282.5±155.3	238.4±119.9	105.9±7.4	105.3±3.9	< 100 UNT
OD (mg. L^{-1})	7.4±1.5	4.9±1.8	5.4±2.0	6.2±1.5	8.9±0.2	7.6±0.2	> 2 mg L^{-1}
TP (μg. L^{-1})	28.7±24.2	66.5±98.4	30.9±4.0	24.4±3.2	74.3±28.4	54.2±20.3	< 50 μg L^{-1}
Cl *a* (μg. L^{-1})	44.1±58.0	20.5±22.1	77.4±55.1	66.8±56.6	94.0±63.7	84.4±65.1	< 60 μg L^{-1}
ST (mg. L^{-1})	0.2±0.0	0.1±0.1	0.4±0.5	0.2±0.0	0.3±0.1	0.2±0.2	< 500 mg L^{-1}
*E. coli**	2.1±1.3	1.1±0.8	1.8±0.3	0.4±0.2	1.7±0.6	1.4±0.5	< 2,500 NMP 100 mL^{-1}
TSI	56.2±7.5	56.2±5.3	61.9±4.4	58.8±5.1	64.1±3.4	61.6±5.9	---

* *E. coli* = CFU/100 * 10^{+4} ; CFU and NMP units were considered numerically equivalent. Source: Authors (2025).

In Bosque Maia, during the rainy season, the average pH value was 5.1, below the limit established by CONAMA Resolution 357/05 (pH between 6.0 and 9.0). This result may be associated with the higher rainfall index for the period, which promotes the transport of leaf litter and plant debris from adjacent areas into the lakes. The decomposition of this organic matter, often incomplete in lentic systems, results in the release of humic and fulvic acids, giving the water a dark color and acidity. Additionally, the process of microbial respiration increases carbon dioxide (CO_2) concentrations, which, when reacting with water, form carbonic acid (H_2CO_3), contributing to a reduction in pH (Buzelli & Cunha-Santino 2013).

For the variables total phosphorus and *chlorophyll-a,* it was recorded that 43% and 46%, respectively, of the urban lakes in Guarulhos were in disagreement with the limit established by law. These results highlight the process of eutrophication of the lakes, since the constant presence of nutrients (such as phosphorus) has the effect of excessively increasing algal biomass (*chlorophyll-a*), the consequences of this process being the formation of microalgae and cyanobacteria blooms (Boyd 2016).

The relationship between cause (P input) and effect (increased primary productivity) was evidenced by the Trophic State Index, where 64% of the lakes were classified as eutrophic (Table 2; Figure 2). The most critical trophic conditions were recorded in the lakes of the Zoo, with classifications ranging from eutrophic to hypereutrophic. The exception occurred at station ZOO1 (spring) during the rainy season, characterized as oligotrophic. At Lago dos Patos (LP), trophic conditions were more severe in the dry season compared to the rainy season. In the Bosque Maia (BM) lakes, a spatial-horizontal and temporal variation in trophic status was observed, ranging from sites characterized as ultra-oligotrophic to super-eutrophic, with these values being more pronounced in the dry season than in the rainy season.

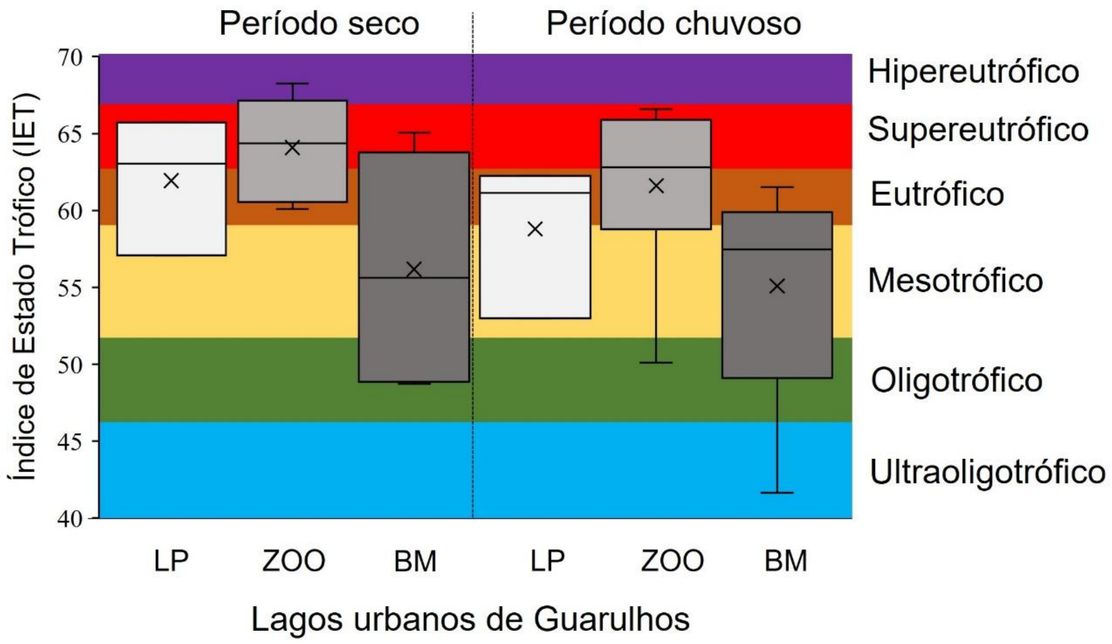

Figure 2. BoxPlot analysis of Trophic State Index (TSI) values according to the Carlson Index (1977) adapted by Lamparelli (2004) for lentic environments, in three locations with lakes in the municipality of Guarulhos, during the rainy season (February to March 2022) and dry season (August to October 2022). Legend: LP = Lago dos Patos; ZOO = Guarulhos Municipal Zoo; BM = Bosque Maia. The colors are merely illustrative and correspond to the trophic status categories. Source: Authors (2025).

The TSI is an important tool for diagnosing and monitoring aquatic ecosystems, as it can reflect the influence of anthropogenic activities on the trophic status of aquatic ecosystems (Cunha et al. 2013). The studies by Osti et al. (2022) used this metric to assess the trophic status of watercourses in a conservation unit (CU) in Guarulhos and concluded that the methodology was sensitive in indicating the eutrophication process in watercourses located in the buffer zone of this CU.

The intensification of trophic levels in urban lakes poses a threat to aquatic fauna. Eutrophication raises the biological demand for oxygen to levels that exceed the capacity for natural replenishment (atmospheric diffusion and daytime photosynthesis). During the night, the reversal of the gas balance, in which phytoplankton and other organisms (macrophytes, zooplankton, and fish) consume oxygen and release CO_2 through respiration, can result in critical deficits of dissolved oxygen. Under these conditions, fish fauna become vulnerable to disease or the risk of death by asphyxiation (Boyd 2016; Boyd et al. 2018).

The lack of oxygen associated with algae and cyanobacteria blooms due to the eutrophication process is one of the main factors leading to mass fish kills. Fish kills in the state of São Paulo are recorded by the São Paulo State Environmental Company (CETESB), , where we can see that lack of oxygen is an important factor in the causes of fish deaths. Taking as an example the records between 2020, 2021, 2022, and 2023, we can see that the percentage of fish deaths caused by lack of oxygen and/or associated with the eutrophication process leading to algae and cyanobacteria blooms corresponded to 40%, 46%, 50%, and 50%, respectively (Available at: https://cetesb.sp.gov.br/mortandade-peixes/).

The presence of phytoplankton that can potentially form blooms has already been documented in urban ecosystems in Guarulhos, including in water bodies evaluated in this study. Pontes et al. (2020), in a survey covering Lago dos Patos, Zoológico, Bosque Maia, among others, recorded cyanobacteria such as *Microcystis aeruginosa*, *Aphanocapsa annulata,* and *Radiocystis fernandoi*. These species, classified as very frequent, are known to produce toxins in eutrophicated environments, which gives them high ecological and sanitary importance. In addition, Souza et al. (2019) attribute the eutrophication of the lakes at the Guarulhos Zoo to both internal activities and anthropogenic pressures in the surrounding area, such as the disposal of domestic waste and the contribution of sewage from diffuse sources.

The urban lakes of Guarulhos presented *E. coli* levels above the recommended values for Class 3 environments, according to CONAMA Resolution 357/2005, with values ranging from 1,500 to 30,000 CFU 100 mL^{-1}(Figure 3). Among the three areas studied, the worst results were observed in the central lakes of Bosque Maia (Stations BM 2, 3, and 4) during the dry season. The lowest concentrations of *E. coli* were observed in Lago dos Patos during the rainy season, regardless of the sampling season.

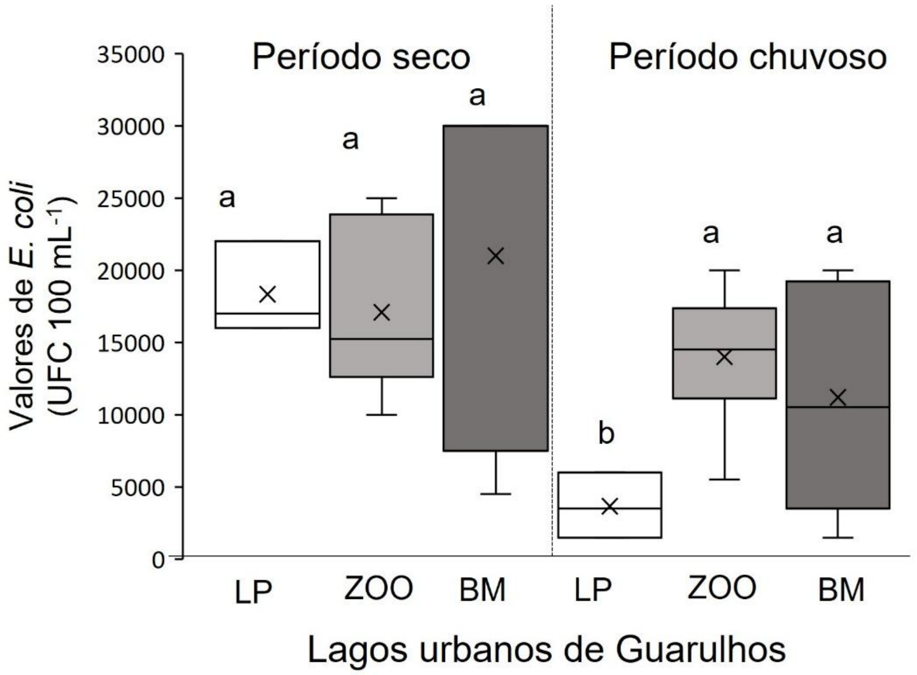

Figure 3. BoxPlot analysis between *E. coli* values at three locations with lakes in the municipality of Guarulhos during the rainy season (February to March 2022) and dry season (August to October 2022). Legend: LP = Lago dos Patos; ZOO = Guarulhos Municipal Zoo; BM = Bosque Maia. Groups (box) followed by different letters (a and b) indicate statistically significant differences according to the Kruskal-Wallis test (p < 0.05). Source: Authors (2025)

The high levels of *E. coli* recorded in urban lakes are a health concern, as these bacteria are indicators of fecal contaminants, and for this reason are frequently monitored in freshwater bodies to assess potential risks to human health due to contact with pathogens in recreational waters, as this increases the possibility of gastrointestinal diseases (Frias et al. 2020). It should be noted that *E. coli*, whose habitat is exclusive to the digestive tract of humans and homeothermic animals (Brazil 2005), may indicate contamination by domestic effluents, but also the presence of "warm-blooded" animals that have the bacteria in their intestines, a fact that can be attributed to the higher *E. coli* values observed in the lakes of the Guarulhos Zoo. According to Souza et al. (2019), the nutrient input from the internal areas of the Guarulhos Zoo is related to leftover feed and waste from confined animals.

The joint evaluation of the data, using Principal Component Analysis (PCA), summarized 57% of the total variability of the data in the first two ordination axes. These axes summarized the environmental gradients by explaining the spatial-horizontal dispersion of urban lakes and limnological variables, together with the variations observed throughout the seasonal period (Table 3; Figure 4).

The first axis was the most important because it explained the spatial-horizontal distribution of urban lakes and sampling stations based on limnological characteristics. On the negative side of this axis, the sampling stations referring to the Guarulhos Zoo (regardless of the seasonal period) and stations 2, 3, and 4 of Bosque Maia (dry period) were ordered, associated with the highest concentrations of dissolved oxygen, total phosphorus, chlorophyll *a*, and *E. coli*. In addition to the central area of Lago dos Patos (stations LP 2 and 3), associated with the highest values of pH, total solids, and turbidity, as well as the highest concentrations of *chlorophyll-a*. On the positive side of the axis, samples located near the springs (ZOO1-R; BM1-R and D; PL1-R and D) were grouped, in addition to samples collected in Bosque Maia Park (rainy season), associated with the lowest values of the limnological variables analyzed. Lago dos Patos is recorded on axis 2, associated with the highest water temperature values and the lowest concentrations of *E. coli*, regardless of the sampling period.

Table 3. Pearson correlation coefficient matrix, performed from the principal component analysis, between the environmental variables of urban lakes located in the municipality of Guarulhos.

	Abbreviations	**PC 1**	**PC 2**
Temperature (°C)	Temp	0.218	0.691
Hydrogen ion potential	pH	-0.673	0.425
Electrical Conductivity (µS cm^{-1})	Cond	0.519	-0.489
Turbidity (NTU)	Turb	-0.679	0.284
Dissolved oxygen	DO	-0.548	-0.505
Total phosphorus (µg L^{-1})	PT	-0.476	-0.502
Chlorophyll *a* (µg L^{-1})	Cl *a*	-0.882	0.096
Total solids (mg L^{-1})	TSS	-0.618	0.083
E. coli (CFU.100mL^{-1})	E. coli	-0.529	-0.622
	Explainability	35.52	21.82

Source: Authors (2025)

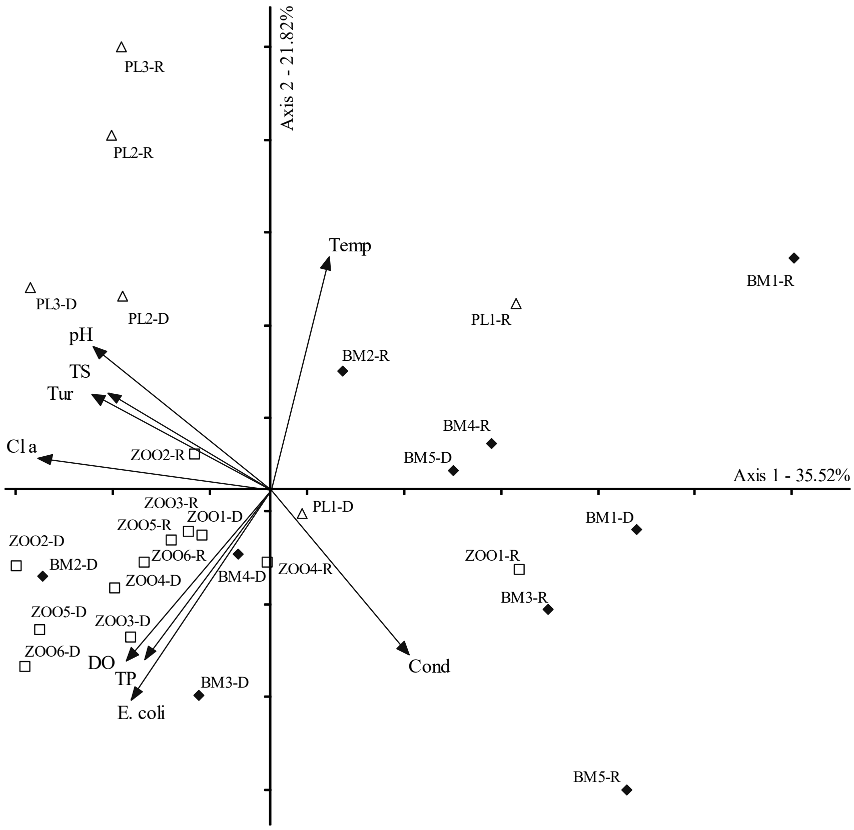

Figure 4. Biplot ordering for Principal Component Analysis (PCA) between the mean values of environmental variables for urban lakes located in the municipality of Guarulhos during the dry and rainy seasons. Being: Bosque Maia (♦), Lago dos Patos (▲) and Guarulhos Municipal Zoo (□); R = rainy season and D = dry season. For the correlations of the physical, chemical, and microbiological variables of the water with axes 1 and 2 of the ordering and the respective abbreviations and units, see Table 3. Source: Authors (2025).

The spatial-horizontal variation deserves special mention in this assessment of eutrophication in the urban lakes of Guarulhos. Through PCA, it was evident that the spring areas (BM1 and ZOO1) had the lowest nutrient concentrations and were characterized as oligo-mesotrophic. these values may be related to the greater protection of these areas, corresponding to less anthropized uses and with a predominance of vegetation, which sometimes have controlled or even restricted access to the public, as is the case with ZOO1. Unlike what was observed in the present study, the survey by Souza et al. (2019) classified the headwaters region of the Guarulhos Zoo lakes as super-eutrophic. This divergence in results may be associated not only with greater access control and preservation of the surrounding area, but also with optimization of the management of internal activities at the Zoo, such as waste management and control of effluents from the enclosures. Such management measures mitigate the excessive input of nutrients and organic matter, favoring the improvement of the trophic status of this lentic system over time.

On the other hand, the high concentrations of nutrients and *E. coli* recorded in the lakes may be related to human activities in the watersheds. According to Tundisi and Matsumura-Tundisi (2008), different anthropogenic pressures from land use and occupation promote changes in hydrological cycles, biogeochemical cycles, and the biodiversity of aquatic environments. The findings by Azevedo et al. (2016), Souza et al. (2019), and Pontes et al. (2020), who studied different urban lakes in Guarulhos, corroborate this statement.

As for microplastics, a total of 1,654 MP L^{-1} were quantified in the urban lakes of Guarulhos, with 1,297 MP L^{-1}consisting of fibers and 357 MP L^{-1}consisting of MP fragments (Table 4; Figure 5). Bosque Maia was the location with the highest amount of MPs (956 MP L^{-1}), notably in Lake 2 (the park's central lake), where 646 MP L^{-1}particles were recorded.

Table 4. Quantification of microplastics in urban lakes in Guarulhos/SP, collected during the dry season. Date of collection: Lagos dos Patos – 08/18/2023; Bosque Maia – 07/04/2022; Guarulhos Municipal Zoo – 08/22/2022.

	Total MP densities L^{-1}		
	Fibers	**Fragments**	**Total**
Lago dos Patos - LP1	25	8	33
Lago dos Patos - LP2	96	0	96
Lago dos Patos - LP3	120	0	120
Maia Forest - P1	39	8	47
Maia Forest - P2	375	271	646
Maia Forest - P3	129	43	171
Maia Forest - P4	35	20	55
Maia Forest - P5	30	8	38
Zoo - P1	10	0	10
Zoo - P2	71	0	71
Zoo - P3	222	0	222
Zoo - P4	72	0	72
Zoo - P5	35	0	35
Zoo - P6	38	0	38

Source: Authors (2025).

The abundance and spatial-horizontal distribution values of microplastics in urban lakes in Guarulhos are shown in Figure 4. Lago dos Patos had a total of 15 MP $^{L^{-1}}$ between fibers and fragments, and a piece of fabric was also found. At the Guarulhos Municipal Zoo, in addition to many microalgae, a total of 38 fibers were found. Bosque Maia was the location with the highest amount of MP (81 MP L^{-1}), the highest result for waste, with fibers and fragments totaling 81 MPs. More fibers than fragments were found; for example, in the samples collected at the Guarulhos Zoo, no MPs in the form of fragments were recorded.

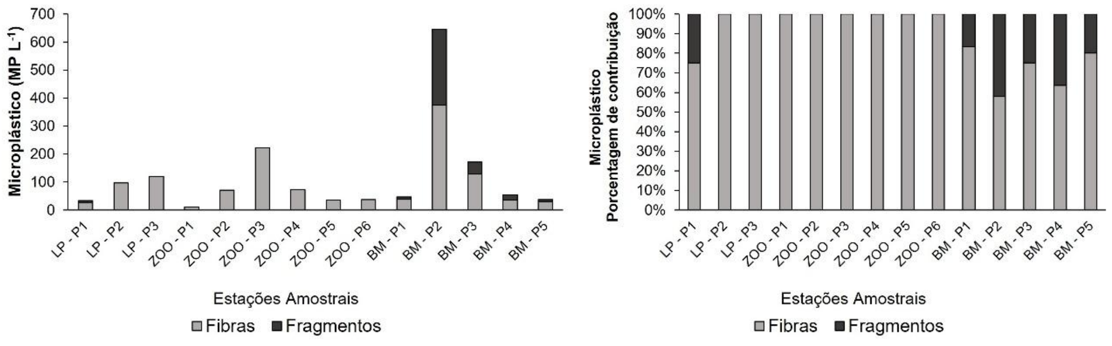

Figure 5. Abundance and distribution of microplastics in urban lakes in Guarulhos/SP during the dry season of 2022. Figure 2A – Microplastic density. Figure 2B – Percentage contribution between fibers and fragments. Legend: LP = Lago dos Patos; BM = Bosque Maia; ZOO = Guarulhos Zoo. Source: Authors (2025).

The urbanization process and the activities carried out around the lakes of Guarulhos promote an increase in the diffuse load of nutrients and contaminants, which are carried by the sub-basins to these bodies of water. This scenario is alarming in view of the UN projections (2019), which indicate that 70% of the world's population will live in urban areas by 2050. In this context, the preservation of urban lakes becomes strategic, as they provide essential ecosystem services, such as heat island mitigation, wildlife support, and flood protection (Maia et al. 2020; Régis et al. 2023; Granath et al. 2024).

However, the integrity of these services is threatened by diffuse pollution, especially by the irregular disposal of solid waste. The present study found that locations with free access to visitors had the highest concentrations of microplastics (MP), with fibers being the predominant form. This ubiquity of fibers may be directly related to the fragmentation of improperly disposed plastic waste, a process that reduces the buoyancy of particles and increases their bioavailability to aquatic biota (Saad & Alamin 2024).

The predominance of fibers is particularly concerning for the local ichthyofauna. As suggested by Saad and Alamin (2024), species such as tilapia, which is exotic but widely distributed in Brazil, show a preference for fiber-like particles during foraging. Thus, the abundance of this specific form of MP in the lakes of Guarulhos may increase accidental ingestion and bioaccumulation of contaminants.

The results of this study reinforce that microplastics are widely distributed pollutants in aquatic ecosystems, but that methodological standardization for collection and analysis in freshwater is still lacking. This study stands out for analyzing how spatial-horizontal and temporal variation and land use management directly influence ecological imbalance and the chemical and physical degradation of critical urban ecosystems.

Conclusion

This study conducted a spatial-horizontal and temporal analysis of water quality and the occurrence of microplastics (MP) in three urban lake systems in Guarulhos/SP, revealing a scenario of degradation accentuated by urbanization and influenced by seasonality. The results indicate that most of the monitored lakes (64%) are eutrophic or supereutrophic, with high turbidity (> 300 NTU) and conductivity (> 100 $\mu S\ cm^{-1}$) values, influenced by inadequate management and the transport of organic matter.

Microbiological analysis confirmed the influence of point and diffuse sources of pollution, with *E. coli* concentrations that place water bodies outside Class 3 (CONAMA 357/05) in several periods. At the same time, the ubiquitous detection of microplastics, with a predominance of fibers in areas freely accessible to the public, shows that the irregular disposal of solid waste is a persistent vector of contamination. Such pollutants not only compromise scenic beauty, but also pose ecological risks to local ichthyofauna and migratory fauna due to the potential for bioaccumulation and accidental ingestion.

Finally, the spatial-horizontal variation of environmental variables demonstrates that the management of these environments must transcend palliative monitoring. It is imperative that *stakeholders* implement ecological restoration strategies integrated with environmental education projects. Such actions should focus on raising awareness about the solid waste cycle and the invisible impacts of microplastics, aiming to ensure the maintenance of ecosystem services and the survival of fauna in these urban refuges.

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