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SANITATION CONDITIONS AND WATER AND SOCIO-ENVIRONMENTAL QUALITY OF THE LAGOON IN PITUAÇU METROPOLITAN PARK, SALVADOR, BAHIA, BRAZIL

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Abstract: The socio-ecological and environmental conservation of inland lakes and reservoirs ensures the multiple uses of these freshwater ecosystems, such as water supply, education, scientific research, fishing, and recreation. This research aims to investigate the variability of water quality in Pituaçu Lagoon (2014 to 2016), associated with the remnants of the Atlantic Forest, in the environmental context of Pituaçu Metropolitan Park, Salvador, Bahia, Brazil, through geochemical, microbiological, and multivariate analyses. Cluster analysis was applied to assess the variability of geochemical variables (pH, turbidity, TDS, DO, BOD_5, SO_4^{2-}, Cl-) and nutrients (Total P, N-NH-, N-NO^3-) of thermotolerant coliforms in water samples from Pituaçu Lagoon. Multivariate analysis allowed the identification of ecological groups based on these geochemical and microbiological variables, revealing that the greatest loss of water quality occurred in samples collected at the point of contact between the lagoon and the Pituaçu River, identifying one of the sources of pollution. In addition, the relationships between water quality loss, land use, and basic sanitation failures in the Rio das Pedras-Pituaçu River Basin, Salvador, Bahia, were highlighted.
Keywords: Ethics and Fundamental Rights; Land Use and Nature Conservation; Water Quality; Atlantic Forest; Multivariate Analysis.

INTRODUCTION

Socio-spatial inequalities in access to fundamental rights to drinking water, a healthy and ecologically balanced environment, education, adequate sanitation, and health have dominated the political agenda of the socio-environmental movement in Latin America in recent decades. This is because 40 million people do not have access to drinking water and are fighting for their rights to drinking water and basic sanitation in Latin America (Heller; Castro, 2007).

In Brazil, socio-spatial inequalities in access to basic sanitation services persist. The provision of quality services is concentrated in the South and Southeast regions, in affluent areas (Rezende; Heller, 2000). The North and Northeast regions still face profound inequalities in access, under public policies that reproduce social exclusion.

Gonçalves *et al.* (2022a) studied socio-spatial inequalities among municipalities in the Metropolitan Region of Salvador (RMS), in Bahia, whose adequate sanitation coverage rates varied between 24% and 93%, according to data from the IBGE (2010). They demonstrated the existence of relationships between basic sanitation failures, loss of water quality, hospitalizations for diarrhea per thousand inhabitants, and the infant mortality rate.

Álvares, Borja, and Moraes (2005) and Porciúncula, Alencar, and Gonçalves (2021) point out that 15% of the residents of Salvador, the metropolis of the RMS, do not have access to sanitary sewage, and that residents of the periphery live with intermittent public water supply, deterioration of socio-environmental quality, restrictions on water use, and health threats.

Scientific studies conducted by Porciúncula (2011; 2017), Ramos Junior (2017), Gonçalves *et al.* (2021), Silva *et al.* (2020), and Porciúncula and Alencar (2021) reveal that disorderly urbanization, land use, and metropolization have degraded aquatic ecosystems and produced tensions over water use and socio-spatial asymmetries in access to fundamental rights to health, a healthy environment, and sanitation in the RMS, Bahia.

Álvares *et al.* (2010), Jesus *et al.* (2011), Moraes *et al.* (2012), Alves *et al.* (2016), Silva *et al.* (2017), Moretto (2018), Alves *et al.* (2019), Silva *et al.* (2021b) and Viscard and Campos (2022), Gonçalves *et al.* (2025) relate land use and the discharge of *raw* liquid effluents into water bodies to the loss of environmental quality in rivers, lagoons, and lakes in the hydrographic basins, natural drainage systems, and aquifers of Salvador and other municipalities in the RMS.

Coelho, Borja, and Santos (2019) highlight that the urbanization of Brazilian metropolises has resulted in an informal city model, which has produced socio-spatial asymmetries in access to public services, judging by the provision of sanitation services. This civic model has generated hostility against social subjects, whether the popular classes, workers, and their territories, in addition to producing socio-ecological, environmental, and health threats.

It is also important to characterize the impacts on water quality resulting from the discharge of *raw* liquid effluents and eutrophication on the ecology of aquatic ecosystems and the conservation of aquatic biota (Li *et al.*, 2015; Chen *et al.*, 2016; Oliveira *et al.*, 2017). Knowledge about the ecology and conservation of aquatic ecosystems is fundamental for water use management (Tundisi; Tundisi, 2008; Esteves, 2011). In this sense, it is understood that lakes and lagoons are strategic freshwater reserves for the conservation of aquatic life, research, fishing, and water security in Salvador and the RMS. Lakes and lagoons are among the ecosystems with the highest primary productivity on the planet, and therefore should be promptly protected, studied, and conserved (Lawson, 2011). Thus, this research aims to investigate the water quality of Pituaçu Lagoon (2014-2016), in the Pituaçu Metropolitan Park, in the RMS, Bahia, with the aid of geochemical, microbiological, and multivariate analyses.

This highlights the importance of monitoring and evaluating water quality for conservation and nature use and territorial management in the RMS.

STUDY AREA

The study area includes Pituaçu Lagoon, which is part of Pituaçu Metropolitan Park (PMP), in the municipality of Salvador, in the RMS, Bahia (Figure 1). The PMP was established by Decree No. 23,666/77, which became a wildlife refuge and a conservation area for remnants of the Atlantic Forest Biome. This ecological complex encompasses the PMP and Pituaçu Lagoon and is part of the Rio da Pedras/Pituaçu River Basin.

Figure 1 - Map showing the location and situation of Lagoa de Pituaçu in the municipality of Salvador (BA).

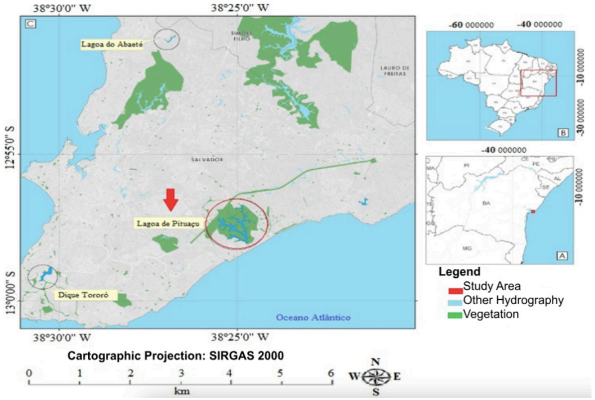

Figure 1 - Map showing the location and situation, and spatial distribution of sampling points (E1-E10) in the Tinharé-Boipeba Environmental Protection Area, Southern Bahia (stone reefs in gray).

Source: Prepared by the authors (2025).

Salvador falls within the Af tropical climate domain, according to Köppen and Geiger. It has average annual temperatures of 25 °C, 22.^{2}°C, and 28.^{2}°C, respectively. In addition, Salvador's rainfall index is ± 2000 mm/year, with rains distributed over four months plus rainy (April to July) and two less rainy (August to November; December to March) and an average annual relative humidity of 81%.

The Pituaçu Lagoon has a water surface area of ± 758,000 m^2, a capacity of 2,473,000 m^3, and an average depth of 4.5 m, bordered by 3,920,000 m² (392 ha) of remnants of the Atlantic Forest Biome. This reservoir was built by damming the Pituaçu River by engineer Teodoro Sampaio in 1906, during the administration of Gomes Carneiro da Rocha, in the vicinity of Luís Viana Filho Avenue (known as Avenida Paralela).

It should be noted that the Pituaçu River Microbasin, with a drainage area of 27.05 km², is the main tributary of the Rio das Pedras in Salvador. In this BH, the Rio das Pedras and Pituaçu rivers form the Rio das Pedras/Pituaçu Basin, where the Rio das Pedras emerges from the confluence of the Cascão, Saboeiro, and Cachoeirinha rivers (right bank) and the Pituaçu River (left bank). These rivers, which are located in the vicinity of the Pituaçu Lagoon, converge in the Rio das Pedras, which flows to its mouth at Boca do Rio Beach.

MATERIALS AND METHODS

GEOCHEMICAL, MICROBIOLOGICAL, AND NUTRIENT VARIABLES

The investigation of the water quality of Lagoa de Pituaçu is based on the statistical treatment and analysis of monitoring data (2014 to 2016) provided by Empresa Baiana de Águas e Saneamento S.A. (EMBASA).

The database of nutrient variables (Total P, $N\text{-}NH_3$-), variables total available solids - TDS , dissolved oxygen - DO, biochemical oxygen demand - BOD_5, turbi- dity, sulfate - SO_4^{2-}, chloride - Cl- and thermotolerant coliforms, based on APHA (2012) recommendations.

STATISTICAL APPROACH

The statistical approach covers descriptive analyses, with the aid of normality tests (*Shapiro-Wilk*) and multiple comparisons used for parametric (ANOVA) or non-parametric (*Kruskal-Wallis*) data, with a confidence level of 95%, and Cluster Analysis. In addition, Euclidean distance, a measure of similarity between points, and *Ward's* method for linking groups in multivariate analysis were chosen.

RESULTS AND DISCUSSION

Sanitation and Water Quality in the Salvador River Basins It appears that organized civil society and public authorities have directed efforts to expand the provision of sanitation to permanent private households located in the area of the Salvador Watersheds (Table 1). In addition, there has been a general improvement in basic sanitation between 2000 and 2010, and a trend toward universal provision. However, there is still a sociopolitical demand to overcome socio-spatial inequalities and expand access to adequate sewage systems, especially in the socio-environmental contexts of Ilha de Maré and Ilha dos Frades, in the RMS.

An improvement in sanitation was observed between 2000 and 2010, particularly due to the increase in the number of permanent private households connected to the system of sewage sanitation of Salvador, however There are still shortcomings in this service (Table 1). The benefits associated with the provision of and access to basic sanitation services in Salvador, in the RMS, do not reflect an improvement in the quality of the services provided (Moraes *et al*., 2012). It was found that the levels of the variables DO, $BOD_{5,}$total P, and the quantification of thermotolerant coliforms were not in accordance with the limits set forth in CONAMA Resolution No. 357/05 (Table 2). Thermotolerant coliforms indicate water contamination by human fecal material or other endotherms (Mendes; Oliveira, 2004; Leão *et al*., 2018).

The influence of liquid effluent ("sewage") discharges *in natura* in the environment on the water quality of the Salvador river basins.

Silva *et al*. (2021a) revealed the existence of eutrophication processes and the loss of water quality in the Tororó Dam, Abaeté Lagoon, Paixão Lagoon, and Pituaçu Lagoon in Salvador, in the RMS. This environmental degradation of water bodies was attributed, in particular, to land use and failures in basic sanitation, which are related to persistent socio-spatial inequalities in access to sewage systems.

VARIABILITY IN WATER QUALITY AT LAGOA DE PITUAÇU

Statistical analysis of geochemical variables and nutrients helped in assessing the water quality of Lagoa de Pituaçu (Table 3). In addition, the medians showed significant seasonal differences between each other for the variables pH, DO, BOD_5, Total P, and N-NH_3-(< 0.001) and turbidity (p=0.001), as indicated by the results of the Kruskal-Wallis test (Figure 2).

The medians of the variables DO (> 5.0 mg.L-1), BOD_5 (< 5.0 mg.L-1) and Total P (0.003 mg.L^{-1}) were found to be in disagreement with the provisions of National Environment Council (CONAMA) Resolution No. 357/05, applied to Freshwater - Class 2 (Figure 2). However, medians were observed in accordance with the water quality standards for the BOD_5 in the samples from 2015.1 (1st semester of 2015) and 2015.2 (2nd semester of 2015) and the DO variable in 2015.1 (1st semester of 2015) (Table 3). Extreme values and *outliers* were observed for the variables turbidity, BOD_5, Total P, and N-NH_3- which represented violations of water quality stan- dards.

Samples from points P3 and P4, located at the water intake of the Pituaçu River, revealed the greatest loss of water quality (Figures 3 and 4). The measurements of turbidity, total P, and N-NH_3- were not in accordance with CONAMA Resolution No. 357/05 for *Freshwater - Class 2*.

Watershed	With Water Supply by Network (%)		With sewage collection by network (%)		With solid waste collection (%)	
	2000	2010	2000	2010	2000	2010
Rio das Pedras/Pituaçu	95.10	99.30	69.60	94.70	59.8	95.80
Jaguaripe River	93.90	99.00	54.60	77.80	53.20	95.80
Copper River	93.90	97.20	42.40	81.80	55.20	95.60
Camarajipe River	97.10	99.30	85.30	96.50	68.50	97.00
Lucaia River	97.60	99.50	93.60	98.20	70.20	98.10
Maré Island	91.90	92.80	0.00	5.30	27.10	90.60
Ilha dos Frades	0.00	97.30	0.00	2.70	95.70	99.10
Barra/Centenário/Seixas	97.40	98.70	98.70	98.80	89.10	98.20
Ipitanga River	89.80	95.50	45.90	71.20	52.10	96.80
Suburb (Paraguari)	94.70	98.10	50.70	84.6	28.9	95.70
Sample Estimators	**2000**	**2010**	**2000**	**2010**	**2000**	**2010**
Minimum	0.00	92.80	0.00	2.70	27.10	90.60
Maximum	97.60	99.50	98.70	98.80	95.70	99.10
Average	85.14	98.40	54.08	71.16	59.98	96.27
Median	94.30	97.67	52.65	83.20	57.50	96.30
Standard Deviation	30.02	2.12	34.69	36.60	22.31	2.34
Standard Error	9.49	0.67	10.97	11.57	7.05	0.74
Coefficient of Variation (%)	35.26	2.17	64.15	51.43	37.19	2.43
SW (*p-value*)	<0.0001[B]	0.03[B]	0.334[B]	0.002[B]	0.625[A]	0.044[B]

[A] Gaussian distribution; [B] Non-Gaussian distribution; SW: Shapiro-Wilk (*p-value*).

Table 1 - Basic sanitation conditions of permanent private households, based on the hydrographic basins located in the municipality of Salvador, Bahia, Brazil (2000-2010).

Source: Prepared by the authors (2025), based on a summary of IBGE data (2000, 2010).

a) Water samples from the Rio das Pedras/Pituaçu River Basin (2007 to 2009).

Sample Estimators	Thermotolerant Coliforms (NMP.100 ml^{-1})	BDO_5 ($mg.L^{-1}$)	DO ($mg.L^{-1}$)	Total P ($mg.L^{-1}$)
Samples with restrictions (N)	22	22	18	14
Minimum	87.50	87.50	75.00	87.50
Maximum	100.00	88.00	100.00	88.00
Average	91.67	87.67	91.67	87.50
Median	87.50	87.50	100.00	87.50

b) Water samples from the Jaguaribe, Cobre, Camarajipe, Lucaia, Ilhas de Maré and Frades, Barra/Centenário/Rio dos Seixos, Rio Ipitanga, Subúrbio (Paraguari) rivers (2007 to 2009).

Sample Estimators	Thermotolerant coliforms (NMP.100 ml^{-1})	BDO_5 ($mg.L^{-1}$)	DO($mg.L^{-1}$)	Total P ($mg.L^{-1}$)
Samples with restrictions (N)	112	100	111	127
Minimum	0.00	0.00	40.00	0.00
Maximum	100.00	100.00	100.00	100.00
Average	77.78	88.30	84.31	79.45
Median	100.00	72.92	100.00	96.70
	%		%	

Table 2 - Number and percentage of water samples from the Rio das Pedras/Pituaçu River Basin (2007 to 2009) that did not comply with water quality standards, as set forth in Conama Resolution 357/05 (Brazil, 2005).

Source: Prepared by the authors (2025), based on data from Moraes *et al.* (2012).

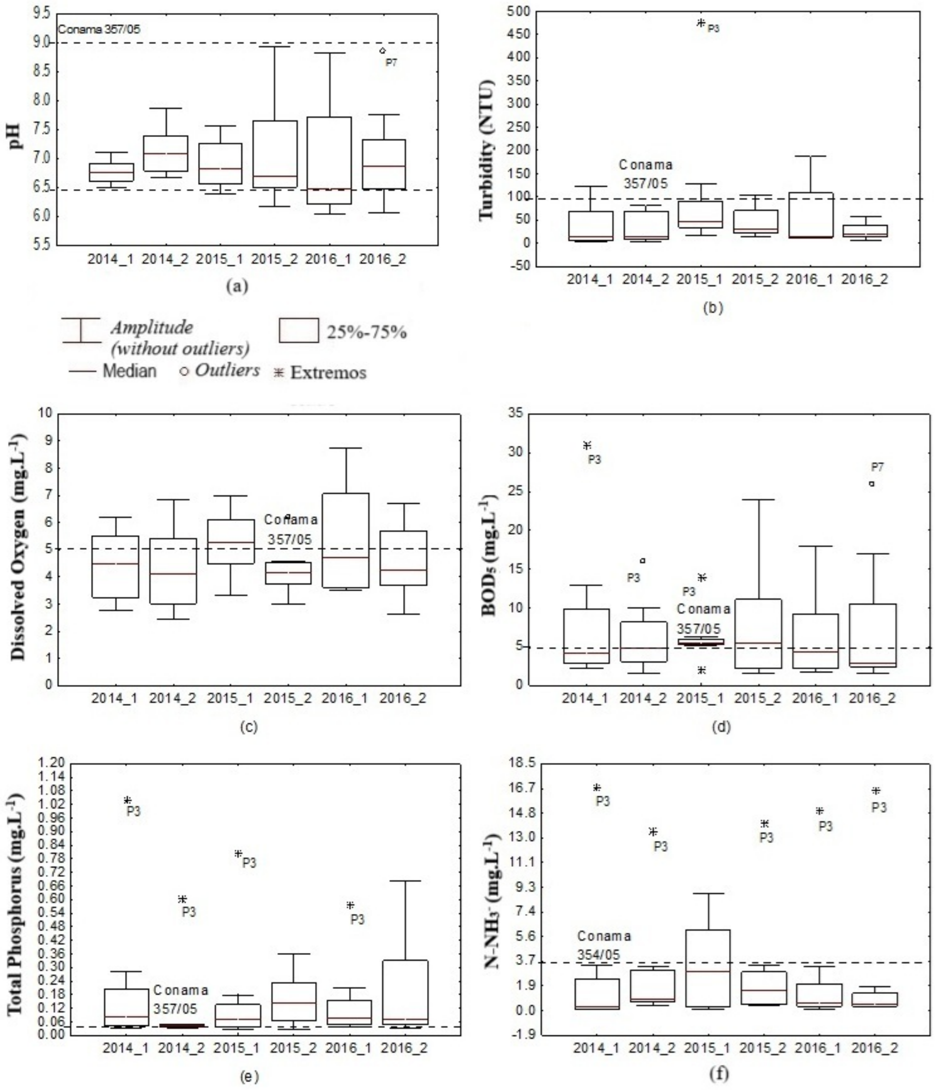

Figure 2 - *Box plot* diagrams showing the dispersion of geochemical and nutrient values in Pituaçu Lagoon, Salvador, in the Metropolitan Region of Salvador, Bahia.

Source: Prepared by the authors (2025), based on monitoring by EMBASA (2014-2016).

a) Samples from the 2014.1 campaign, during the rainiest four-month period (n= 8).

Sample estimators	NTU		mg.L^{-1}						
	Turb.	pH	DO	BOD_5	Total P	$N\text{-}NH_3$	TDS	Cl^-	SO_4^{2-}
Minimum	2.78	6.51	2.76	2.20	0.03	0.13	136.00	12.80	7.18
Maximum	123.0	7.11	6.22	31.0	1.04	16.80	249.00	40.30	28.76
Average	37.92	6.78	4.44	8.36	0.22	2.80	172.50	26.20	12.40
Median	14.65	6.76	4.48	4.20	0.09	0.32	153.50	24.60	9.42
Standard Deviation	47.92	0.21	1.31	9.80	0.34	5.76	40.63	8.49	7.32
Standard Error	16.90	0.10	0.50	3.50	0.10	2.00	14.40	3.00	2.60
SW (*p value*)	0.011^{B}	0.74^{A}	0.49^{A}	0.009^{B}	0.008^{B}	0.007^{B}	0.114^{A}	0.98^{A}	0.01^{B}

b) Samples from the 2014.2 campaign, within the least rainy four-month periods (n= 8).

Sample estimators	NTU		mg.L^{-1}						
	Turb.	pH	DO	BOD_5	Total P	$N\text{-}NH_3$	TDS	Cl^-	SO_4^{2-}
Minimum	3.04	6.68	2.45	1.60	0.03	0.39	154.00	17.80	5.64
Maximum	82.50	7.87	6.85	16.00	0.60	13.50	235.00	68.60	28.76
Average	33.7	7.14	4.30	6.21	0.11	2.90	172.38	44.05	11.38
Median	15.00	7.09	4.12	4.80	0.04	0.90	162.50	41.95	9.58
Standard Deviation	33.89	0.41	1.52	4.77	0.20	4.42	26.61	20.04	7.18
Standard Error	11.98	0.20	0.50	1.70	0.10	1.60	9.40	7.00	2.50
SW (*p value*)	0.035^{B}	0.53^{A}	0.696^{A}	0.11^{A}	0.006^{B}	0.008^{B}	0.009^{B}	0.35^{A}	0.008^{B}

c) Samples from the 2015.1 campaign, during the rainiest four-month period (n= 8).

Sample estimators	NTU		mg.L^{-1}						
	Turb.	pH	DO	BOD_5	Total P	$N\text{-}NH_3$	TDS	Cl^-	SO_4^{2-}
Minimum	16.70	6.39	3.34	1.80	0.03	0.11	101.00	19.80	8.81
Maximum	477.00	7.57	6.99	14.00	0.81	8.74	175.00	60.00	89.10
Average	99.30	6.90	5.00	5.30	0.20	2.82	147.25	38.59	30.13
Median	34.20	6.84	4.73	5.25	0.07	0.52	153.00	41.30	17.40
Standard Deviation	156.62	0.43	1.32	3.91	0.27	3.51	21.78	14.85	28.13
Standard Error	55.40	0.20	0.50	1.40	1.20	1.20	7.70	5.30	9.90
SW (*p value*)	0.008^{B}	0.55^{A}	0.46^{A}	0.035^{B}	0.008^{B}	0.014^{A}	0.23^{A}	0.46^{A}	0.013^{B}

d) Samples from the 2015.2 campaign, within the least rainy four-month periods (n= 8).

Sample estimators	NTU		mg.L^{-1}						
	Turb.	pH	DO	BOD_5	Total P	$N\text{-}NH_3$	TDS	Cl^-	SO_4^{2-}
Minimum	15.30	6.18	2.99	1.60	0.03	0.35	152.00	24.40	6.78
Maximum	103.08	8.94	6.20	24.00	0.36	14.00	235.00	80.20	29.90
Average	44.90	7.10	4.30	7.90	0.20	2.99	204.10	50.30	14.30
Median	29.10	6.69	4.18	5.50	0.14	1.48	218.00	52.50	9.81
Standard Deviation	35.71	1.00	0.93	7.97	0.11	4.59	32.50	16.64	9.63
Standard Error	12.60	0.40	0.30	2.80	0.04	1.60	11.50	5.90	3.40
SW (*p value*)	0.01^{B}	0.04^{B}	0.35^{A}	0.03^{B}	0.52^{A}	0.01^{B}	0.02^{B}	0.64^{A}	0.01^{B}

e) Samples from the 2016.1 campaign, during the rainiest four-month period (n= 8).

Sample estimators	NTU	mg.L^{-1}							
	Turb.	pH	**DO**	BOD_5	Total P	N-NH_3	TDS	Cl^-	SO_4^{2-}
Minimum	11.50	6.04	3.50	1.80	0.04	0.14	136.00	5.64	7.00
Maximum	188.00	8.83	8.76	18.00	0.58	15.00	270.00	41.30	61.70
Mean ± SD	59.10	6.96	5.4 0	6.40	0.15	2.60	190.00	16.90	37.10
Median	15.30	6.48	4.70	4.25	0.08	0.58	184.00	9.38	41.45
Standard Deviation	73.56	1.16	2.13	5.93	0.18	5.11	45.04	13.46	18.04
Standard Error	26.00	0.40	0.80	2.10	0.10	1.80	15.90	4.80	26.00
SW (p value)	0.009 ^{B}	0.01 ^{B}	0.052 ^{A}	0.026 ^{B}	0.009 ^{B}	0.007 ^{B}	0.68 ^{A}	0.041 ^{B}	0.80 ^{A}

f) Samples from the 2016.2 campaign, within the less rainy four-month periods (n= 8).

Sample estimators	NTU	mg.L^{-1}							
	Turb.	pH	**DO**	BOD_5	Total P	N-NH_3	TDS	Cl^-	SO_4^{2-}
Minimum	5.81	6.07	2.65	1.55	0.03	0.25	110.00	5.33	5.33
Maximum	56.70	8.85	6.69	26.00	0.69	16.50	249.00	52.30	39.80
Average	26.10	7.04	4.60	7.40	0.20	2.60	182.80	19.20	13.30
Median	20.25	6.86	4.25	2.80	0.07	0.49	173.50	7.83	6.65
Standard Deviation	17.46	0.88	1.41	9.07	0.26	5.63	47.27	18.61	13.31
Standard Error	6.20	0.30	0.50	3.20	0.10	1.99	16.70	6.60	4.70
SW (p value)	0.47^{A}	0.18 ^{A}	0.53 ^{A}	0.009 ^{B}	0.009 ^{B}	0.007 ^{B}	0.64 ^{A}	0.019 ^{B}	0.009 ^{B}

CV: coefficient of variation; ^{A}Gaussian distribution; ^{B}non-Gaussian distribution; SW: Shapiro-Wilk.

Table 3 - Measurements of geochemical, nutrient, and microbiological variables in Pituaçu Lagoon.

Source: Prepared by the authors (2023), based on monitoring by EMBASA (2014-2016).

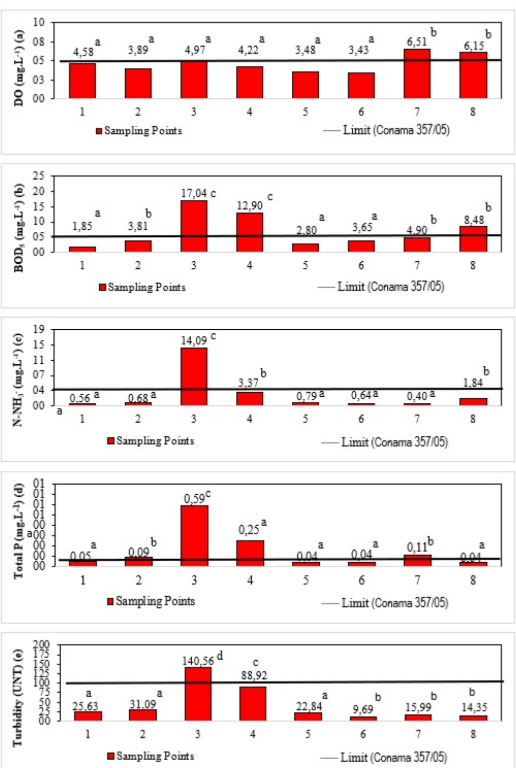

Figure 3 - Distribution of the means of geochemical variables and nutrients by sampling point.

Source: Prepared by the authors (2025), based on monitoring by EMBASA (2014-2016).

The analytical results of the geochemical variables, nutrients, and coliform quantification indicate that the samples from points P3 and P4 were the most influenced by the polluted waters of the Pituaçu River (Figures 3 and 4). The results of the quantification of thermotolerant coliforms revealed the existence of microbiological contamination of the waters of the Pituaçu Lagoon, which can be related, in general, to the discharge of *raw* liquid effluents into the water bodies in the BH of the Rio das Pedras/Pituaçu (Figure 4).

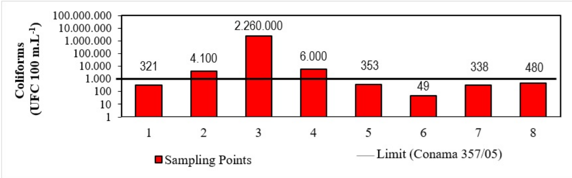

Figure 4 - Quantification of thermotolerant coliforms at sampling points in Pituaçu Lagoon.

Source: Prepared by the authors (2025), based on monitoring by EMBASA (2014-2016).

Integrated Analysis: Sanitation and Water Quality of Pituaçu Lagoon Land use and occupation, solid waste disposal, and

The discharge of *raw* liquid effluents into the soil and water bodies in the upper and middle reaches of the Pituaçu River partly explains the increase in BOD_5, the depletion of DO levels, and microbiological contamination of Pituaçu Lagoon (Figure 5). According to Silva *et al.* (2021a), Porciúncula *et al.* (2021), Gonçalves *et al.* (2021), and Gonçalves *et al.* (2022b).

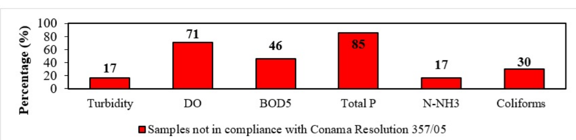

Figure 5 - Distribution of quantified coliform values by sampling points in Lagoa de Pituaçu, based on the synthesis of data provided by EMBASA (2014 to 2016).

Source: Prepared by the authors (2025), based on monitoring by EMBASA (2014-2016).

Figure 5 shows the percentages of samples in relation to the quality limits established by CONAMA Resolution No. 357/05, especially for the variables Total P, DO, and BOD_5 and thermotolerant coliforms, whose Total P and $N\text{-}NH^-$ levels reflect the influence of eutrophication.

Additionally, cluster analysis was applied to assist in the assessment of water quality on spatial and reflection scales of Pituaçu Lagoon (Figure 6). Multivariate analysis allowed the classification of samples into **Ecological-Environmental Groups** (**GE1**, **GE2**, and **GE3**), based on visual observation of the dendrogram. A cutoff point was adopted in the dendrogram at a distance of less than 60 in the analysis of similarity between the original variables, and less than 45 for the interpretation of the spatio-temporal variability of the variables indicating water quality in Pituaçu Lagoon.

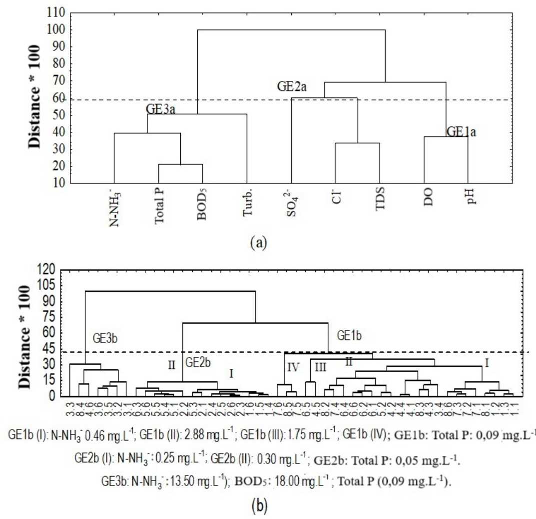

Figure 6 - Dendrogram and classification based on the results of the analyses of limnological variables and nutrients in water samples from Pituaçu Lagoon, in Salvador, Bahia (BR).

Source: Prepared by the authors (2025), based on monitoring by EMBASA (2014-2016).

Three **Ecological-Environmental Groups** (GE1, GE2, and GE3) were found, whose differences can be explained, in general, by the distribution of the values of the variables TDS, OD, BOD_5 , and nutrients (Table 4). There is greater impairment of water quality in **Subgroups GE3b and G1Eb** (II-III), which had the highest levels of BOD_5,total phosphorus, and $N\text{-}H_3$-. These subgroups concentrate water samples collected at points P3 and P4, located at the contact between the Pituaçu River and the lentikular system, revealing an important source of pollution in the Pituaçu Lagoon.

Aleluia *et al.* (2016) recorded DO levels ranging from 3.3 to 7.95 $mg.L^{-1}$ (median of 4.35 $mg.L^{-1}$), BOD_5 from 1.9 to 11.8 $mg.L^{-1}$o(median of 2.85 $mg.L^{-1}$), Total P from 0.02 to 0.35 $mg.L^{-1}$ and $N-NH_3$- from 0.42 to 3.9 $mg.L^{-1}$. They observed that some of the samples did not comply with the quality standards established by CONAMA Resolution No. 357/05 CONAMA No. 357/05 for the variables DO (92%), BOD_5(67%), Total P (17%) and $N-NH_3$- (8%), in addition to high quantification of thermotolerant coliforms (25%).

Thus, it should be noted that the input of nutrients from the discharge of *raw* liquid effluents contributes significantly to the eutrophication and deterioration of the socio-ecological conditions of Pituaçu Lagoon. Santos *et al.* (2018) emphasize that water quality management must consider that the pollution of water bodies caused by the discharge of *raw* liquid effluents, solid waste, and organic pollution poses a threat to the aquatic environment, public health, and the economy.

Silva *et al.* (2021a) associate eutrophication and the loss of environmental health in Pituaçu Lagoon and the Rio das Pedras/Pituaçu River Basin with the negative environmental impacts attributed to land use and poor sanitation. Eutrophication threatens aquatic life and restricts the use of water for public supply, the economy, and recreation (Silva *et al.*, 2018).

Considering the multiple spatial and analytical scales related to the issue of water use in the Pituaçu River, which is part of the Rio das Pedras/Pituaçu River Basin in Salvador, in the RMS, it can be observed that this lotic ecosystem runs, from upstream to downstream, the neighborhoods of Pau da Lima, Sussuarana, Nova Sussuarana, Bahia Administrative Center, and Pituaçu. In many of these neighborhoods, part of the population is deprived of fundamental rights to education, health, a healthy environment, and sanitation.

Given the above, it can be concluded that the results obtained in this study and in previous studies conducted by Moraes *et al.* (2012), Aleluia *et al.* (2016), Silva *et al.* (2017), Costa (2018), Silva *et al.* (2021a), Silva *et al.* (2021b), and Gonçalves *et al.* (2025) consolidate a scenario of water and environmental quality loss in the Pituaçu Lagoon and the Rio das Pedras/Pituaçu Hydrographic Basin, resulting from the permanence of pollution sources, sanitation failures, and socio-spatial inequalities.

In this context, the discharge of *raw* liquid effluents into water bodies represents an unsustainable social practice and culture, because it restricts water use, threatens the environment and human health, and violates the principle of human dignity. Therefore, it deserves the attention of environmental managers of Lagoa de Pituaçu and BH do Rio das Pedras/Pituaçu, in the RMS.

De Carvalho and Adolfo (2012) assume that access to basic sanitation represents a fundamental right related to the principles of minimum socio-environmental existence and human dignity. This is because socio-spatial failures and asymmetries in access to sanitation influence environmental quality and living conditions and interfere with the health--disease process.

CONCLUSIONS

A close relationship has been revealed between the existence of socio-spatial asymmetries, the deterioration of the chemical and microbiological quality of water, land use, and the persistence of basic sanitation failures in the area of influence of Pituaçu Lagoon and other aquatic ecosystems that make up the socio-ecological and environmental context of the Rio das Pedras-Pituaçu River Basin in Salvador, in the Metropolitan Region of Salvador, Brazil. The application of multivariate analysis allowed the identification of **Ecological-Environmental Groups** based on differences in

Point	pH	NTU				mg.L-1			
		Turbidity	TDS	DO	BDO_5	Total P	Ammoniacal Nitrogen	Sulfate	Chloride
Ecological Group 1b (I): EG1b (I)									
1.1	6.51	2.78	147.00	4.93	2.50	0.05	0.35	7.30	41.70
1.3	6.49	26.20	152.00	4.59	1.80	0.05	0.56	8.36	34.15
1.2	7.16	11.80	157.00	5.11	1.60	0.05	0.93	5.99	41.50
8.1	7.11	4.31	151.00	6.22	3.20	0.03	0.28	7.00	41.30
7.1	7.01	8.09	194.00	6.12	4.90	0.13	0.13	7.05	61.70
7.2	7.56	5.26	164.00	6.85	6.30	0.03	0.87	6.07	42.90
7.3	7.57	6.10	175.00	6.79	5.30	0.09	0.11	7.18	40.30
8.6	7.76	5.81	175.00	6.69	2.90	0.05	1.84	14.40	52.50
Median	**7.14**	**6.95**	**160.50**	**6.17**	**3.05**	**0.05**	**0.46**	**7.12**	**41.60**
Ecological Group 1b (II): EG1b (II)									
3.4	6.65	100.00	213.00	3.72	6.20	0.18	14.00	9.04	38.30
4.3	7.00	127.00	145.00	4.15	6.30	0.18	6.58	11.80	20.90
8.3	7.13	32.30	157.00	5.42	5.50	0.03	5.43	10.20	29.70
4.1	6.65	103.08	209.00	4.22	13.00	0.28	3.37	10.11	45.60
4.4	6.65	103.08	209.00	4.22	16.00	0.28	3.37	10.11	45.60
4.2	6.70	78.40	174.00	2.45	3.30	0.04	3.27	8.42	49.20
5.2	6.88	10.70	161.00	2.96	3.30	0.04	2.88	5.33	41.90
6.1	6.70	5.50	138.00	2.76	2.20	0.05	0.14	28.76	41.60
6.2	7.02	3.04	157.00	4.50	2.90	0.04	0.60	28.76	42.70
6.6	6.85	8.87	172.00	3.47	2.70	0.03	0.41	28.76	52.60
6.4	6.94	15.30	235.00	2.99	6.10	0.16	2.31	28.76	68.60
7.4	8.38	23.00	224.00	4.44	4.90	0.12	0.51	10.30	62.10
8.2	7.87	18.20	177.00	3.73	10.00	0.03	0.39	5.46	52.30
Median	**6.88**	**23.00**	**174.00**	**3.73**	**5.50**	**0.05**	**2.88**	**10.20**	**45.60**
Ecological Group 1b (III): EG1b (III)									
4.5	6.04	163.00	188.0	5.67	13.00	0.21	3.35	56.10	42.00
6.5	6.37	12.40	231.00	3.50	2.80	0.06	0.14	89.10	40.60
Median	6.21	87.70	209.50	4.59	7.90	0.14	1.75	72.60	41.30
Ecological Group 1b (IV): EG1b (IV)									
7.5	8.79	13.10	209.00	8.45	5.30	0.10	0.41	16.90	60.00
8.5	8.83	11.50	180.00	8.76	5.30	0.06	0.71	26.00	45.60
7.6	8.85	19.40	243.00	6.43	2.70	0.13	0.41	29.90	80.20
Median	**8.83**	**13.10**	**209.00**	**8.45**	**5.30**	**0.10**	**0.41**	**26.00**	**60.00**
Ecological Group 2b (I): GE2b (I)									
1.4	6.37	26.20	152.00	4.59	1.90	0.05	0.36	8.36	26.80
1.5	6.33	54.70	152.00	4.43	1.80	0.04	0.60	10.90	24.60
1.6	6.07	56.70	152.00	3.88	1.55	0.05	0.56	9.42	34.15
2.3	6.39	24.43	154.00	3.88	2.49	0.09	0.48	7.23	22.70
2.6	6.39	21.09	154.00	3.89	4.08	0.09	0.25	7.23	24.40
2.5	6.11	12.70	154.00	3.61	1.80	0.09	0.55	8.81	22.70
2.4	6.18	39.50	154.00	4.13	1.60	0.09	0.64	5.64	17.80
2.1	6.58	35.40	156.00	4.74	6.60	0.12	1.37	5.64	21.60
5.3	6.67	54.30	136.00	4.86	2.10	0.03	0.38	8.64	12.80
Median	**6.68**	**21.20**	**136.00**	**3.34**	**3.50**	**0.04**	**0.25**	**8.64**	**26.00**

Ecological Group 2b (II): GE2b (II)									
2.2	6.68	82.50	154.00	3.07	6.30	0.05	0.78	7.23	29.70
5.1	6.83	21.20	136.00	3.06	3.50	0.04	0.14	8.64	24.80
5.4	6.73	32.00	136.00	3.72	2.50	0.03	0.35	8.64	26.00
5.5	6.59	17.50	136.00	3.61	3.20	0.04	0.22	15.30	19.80
5.6	6.91	19.20	110.00	2.65	2.20	0.05	0.79	5.30	3.60
6.3	6.64	16.70	101.00	3.34	5.20	0.04	0.25	28.76	26.30
Median	**6.71**	**20.20**	**136.00**	**3.21**	**3.35**	**0.04**	**0.30**	**8.64**	**26.15**
Ecological Group 3b: EG3b									
3.1	6.81	123.00	249.00	3.45	31.00	1.04	16.80	26.70	53.40
3.2	7.23	59.40	235.00	5.72	16.00	0.60	13.50	39.80	36.50
3.5	6.64	188.00	270.00	4.97	18.00	0.58	15.00	17.90	53.40
3.6	6.58	33.50	249.00	4.97	17.04	0.53	16.50	6.78	46.70
4.6	6.87	43.90	205.00	4.60	26.00	0.69	0.26	7.27	59.50
8.4	8.94	20.30	223.00	6.20	24.00	0.36	2.41	10.20	67.20
3.3	7.38	477.00	158.00	6.99	14.00	0.81	8.74	16.60	22.90
Median	**6.87**	**59.4**	**235.00**	**4.97**	**18.00**	**0.60**	**13.50**	**16.60**	**53.40**

Table 4 - Classification of samples according to the similarity between the values of limnological variables and nutrients in ecological groups (EG1b-EG4b).

Source: Prepared by the authors (2025), based on data from EMBASA (2014 to 2016).

nutrient levels (P Total, N-NO_3-, N-NH_3-) in the variables TDS , DO, BOD_5 and microbiological quantification. Greater water quality impairment was observed in samples belonging to **Subgroups GE3b and G1Eb (**II-III), which are concentrated at points located near the mouth of the Pituaçu River in the Pituaçu Lagoon.

In this sense, it is clear that land use, socio-spatial asymmetries, and basic sanitation failures deserve urgent attention from sanitation, health, and water quality managers in both the Pituaçu Lagoon and the Rio das Pedras/Pituaçu River Basin. The socio-ecological and socio-environmental degradation of these aquatic ecosystems restricts the uses of nature and threatens human health in Salvador, RMS.

Therefore, there is an urgent need for public policies aimed at environmental protection, guaranteeing fundamental rights and the principles of human dignity and minimum sociocultural and environmental existence.

Such policies should promote the improvement of basic sanitation systems, as well as education and public and collective health in Salvador and the RMS.

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