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SCIENTIFIC ARTICLE

Relation between trophic state index and land use in permanent preservation areas of the Paraíba do Sul River

Relação entre índice de estado trófico e o uso do solo em áreas de preservação permanente no Rio Paraíba do Sul

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ABSTRACT: The present study aimed to correlate the variables that could influence the water quality of Paraíba do Sul River (PSR), such as vegetation cover in the permanent protection areas (PPA), rainfall, and the Trophic State Index (TSI). The riparian zones were classified according to the vegetation cover from satellite images, as follows: Tree plant cover (TPC), Permeable area (PER), and Impermeable area (IMP). The total phosphorus (TP) and chlorophyll-a (CL) concentrations in the collected water were used to determine the TSI. A multivariate correlation analysis (Principal Component Analysis (PCA)) was carried out using the TSI values, rainfall, and vegetation cover. We observed a higher occurrence of IMP and PER in the riparian zones of the PSR. The TP and CL concentrations increased during rainy periods, mainly in PER. The multivariate analysis demonstrated that the terrestrial areas influenced significantly the PSR parameters. PER contributed to the impairment of the water quality from the PSR, particularly in the rainy period. Our results reinforce the need to preserve and promote the restoration of the riparian areas in basins, mainly in the PSR.

Keywords: Riparian Zones; Eutrophication; Water Scarcity; Water Quality.

RESUMO: O presente estudo teve como objetivo correlacionar as variáveis que poderiam influenciar na qualidade da água do Rio Paraíba do Sul (PSR), como cobertura vegetal em áreas de preservação permanente (PPA), pluviosidade e índice de estado trófico (TSI). As zonas ripárias foram classificadas de acordo com a cobertura vegetal através de imagens de satélite: Cobertura vegetal arbórea (TPC), Área Permeável (PER) e Área Impermeável (IMP). As concentrações de fósforo total (TP) e clorofila-a (CL) foram utilizadas para determinar o TSI do PSR. Uma análise de correlação multivariada (Análise dos Componentes Principais (PCA)) foi realizada usando os valores de TSI, a precipitação e o tipo de cobertura vegetal. Observou-se uma maior ocorrência de áreas sem cobertura vegetal arbórea. As concentrações de TP e CL aumentaram durante o período chuvoso, principalmente em PER. A análise multivariada demonstrou que as áreas terrestres influenciaram significativamente os parâmetros do PSR. PER contribuíram para o comprometimento da qualidade da água do PSR, principalmente no período chuvoso. Os resultados obtidos reforçam a necessidade de preservar e promover a restauração das matas ciliares das bacias hidrográficas, principalmente no PSR.

Palavras-chave: Zonas Ripárias; Eutrofização; Escassez Hídrica; Qualidade da Água.

INTRODUCTION

Riparian areas consist of an interface between aquatic and terrestrial ecosystems. The preservation of these areas is essential for diminishing the negative impacts of land-use practices on water bodies. The vegetation present in the riparian zone provides important ecosystem functions for

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the maintenance of water quality and offers shelter for numerous species of animals and plants (Forio et al., 2017; Lind et al., 2019). Some studies have already demonstrated that this vegetation helps to maintain the diversity and richness of aquatic organisms, such as fish (Wilkinson et al., 2018) and macroinvertebrates (Fierro et al., 2017; Peralta et al., 2020). Also, the riparian vegetation reduces riverbank erosion and decreases the nutrients input in the water body (Botero-Acosta et al., 2017). The nutrient increase in the water column can result in the eutrophication of the aquatic environment (Bruno et al., 2014; Alemu et al., 2017; Mello et al., 2018a).

The artificial eutrophication process occurs as a consequence of the excessive abundance of nutrients, mainly phosphorus, and nitrogen, in an aquatic ecosystem. This process can be triggered by runoff during rainfall or even the release of untreated effluents (Hilton et al., 2006; Ortiz-Reyes & Anex, 2018; Nguyen et al., 2019). Several methods seek to assess the eutrophication process in aquatic ecosystems. Trophic State Index (TSI) is used in limnological studies to evaluate the trophic grade in water bodies. This index uses the total phosphorus and chlorophyll-a concentrations present in the water column to classify the water bodies from ultraoligotrophic to hypereutrophic (Cunha et al., 2013; Silva et al., 2018).

Most of the information about the impacts of human activities on aquatic systems is only based on the changes in physicochemical and biological characteristics of water. These studies disregard, e.g., the role of riparian vegetation in the protection of the aquatic ecosystem. Particularly, in South America, the knowledge about how land use can affect the riparian zone and the balance of water bodies is still limited, as highlighted by Fierro et al. (2017). This lack of information can be observed in Brazil, where there is little information about its main rivers. For example, Paraíba do Sul river is an important river of Southeastern Brazil, but few studies have aimed to understand how land use in the riparian zone can impact this water body in particular (Andrade et al., 2016; Corrêa & Silva, 2017).

Paraíba do Sul basin is in a region with high populational density. There are many economic activities, as industries, agricultural areas, and hydroelectric plants in this basin. Also, part of the water from Paraíba do Sul River (PSR) is diverted to the Guandu river to supply the metropolitan region of Rio de Janeiro, which is the second largest in Brazil (Andrade et al., 2016). This scenario of intense anthropogenic activity impacts negatively the water quality of the PSR and its affluents. The impacts are mainly related to land use in the riparian zone and hydric pollution (Andrade & Ribeiro, 2020). Recently, the Southeast of Brazil faced a scenario of water scarcity considered the worst in 80 years (Targa & Batista, 2015). From 2011 was observed a gradual reduction of rainfall in this region, which reached the lowest annual values in 2014. This scenario affected water quality, storage, and public supply in the main cities in the Brazilian Southeast (Agência Nacional de Águas, 2014; Cavalcanti & Marques, 2016; Neves & Vilanova, 2021).

To give new insights into the influence of riparian vegetation in the maintenance of the water quality of Paraíba do Sul River, the present study investigates variables that may contribute to the alteration of the water characteristics and related ecosystem services. We investigated the correlation of the cover vegetation in the riparian zone, rainfall, and the eutrophication process in the Paraíba do Sul River. Apart from having an intense anthropogenic activity, which makes it an excellent case of study, the PSR region lacks correlative studies in the field. Particularly, the study was carried out during a period of water scarcity in the Paraíba do Sul basin.

MATERIAL AND METHODS

Study area and field sampling

The Paraíba do Sul River (PSR) basin is in the Brazilian Southeast region and covers an area of 62,074 Km^2 in the states of São Paulo, Minas Gerais, and Rio de Janeiro. The channel of the PSR has a length of approximately 1200 km (Ovalle et al., 2013; Cavalcanti & Marques, 2016). This lotic water body is used for public supply, irrigation, fishing, recreation and to protect aquatic communities.

Vegetation cover in the PSR basin is approximately 70% pastures, 27% agriculture and reforestation, and only 3% of the native Atlantic Forest (Ovalle et al., 2013). In the São Paulo stretch, the urbanized area and pastures represent 9.25% and 32.85%, respectively, as observed in Annex 1.

The present study was carried out during a period with low rainfall indexes in the PSR basin, between 2013 and 2014. The decrease in rainfall from 2011 to 2014 is shown in Figure 1A for comparison. The plot data indicated a linear gradual reduction ($r^2 = 0.975$) in annual rainfall from 2011 with a constant rate of 234 $mm.year^{-1}$.

Considering the sampling periods evaluated in the present study, it was observed that the highest average of rainfall was registered on November/13 (199.65 mm). Differently, August/13, the first sampling event, obtained the lowest average (2.1 mm) (Figure 1B). The sampling consisted of four field campaigns and was carried out in August 2013 (winter - dry season), November 2013 (spring - rainy season), February 2014 (summer - rainy season), and May 2014 (autumn - dry season). We used the rainfall data obtained from two rainfall stations of the Department of Water and Electricity (DAEE) to characterize the dry and rainy periods. The DAEE stations 1 (D2-076) and 2 (D2-035) are located along the stretch evaluated in the present study (Figure 2).

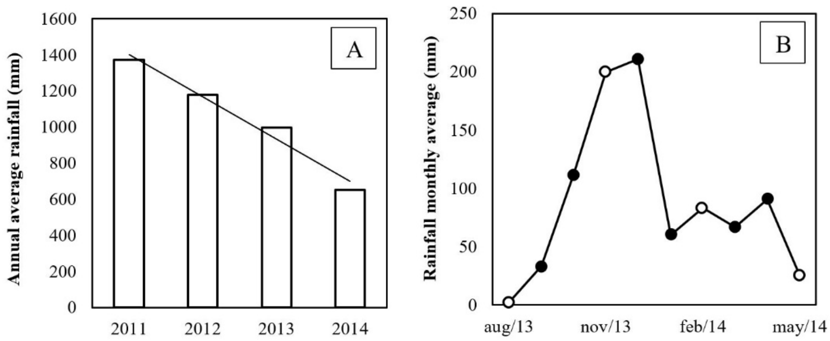

Figure 1. (A) Annual average rainfall (mm) in the evaluated stretch of the Paraíba do Sul River. Linear regression model is y = -234.02x + 1634.7. (B) Rainfall monthly average (mm) in the evaluated stretch of the Paraíba do Sul River. White circles indicate the sampling periods adopted in the present study.

The study area and the sampling points are shown in Figure 2. The samplings were carried out upstream and downstream of the urban perimeter of four municipalities in São Paulo State. P1 is located upstream of the stretch evaluated. River channel length from P1 to P8 is approximately 52 Km.

Figure 2. Sampling points (blue) and rainfall stations (yellow) in the Paraíba do Sul River (PSR).

In each campaign, the samples were collected in the superficial layer of the water column from the river bank. Water samples were conditioned in glass bottles, taken to the laboratory, and stored at 4°C.

Land cover classification

The evaluation of the riparian zones in the PSR was carried out considering the Brazilian Federal Law 12651/12 (Brasil, 2012) that defines them as Permanent Protection Areas (PPA). According to this regulation, the PPA is a protected area covered by vegetation with the function of preserving the water body and its biodiversity. In rivers with channel width from 10 to 50 m, e.g., a 50 m strip should be preserved to safeguard the protection of the aquatic environment (Brasil, 2012).

Map processing and spatial analysis were performed using Google Earth. Based on the satellite images, the forms of land use in the PPA were determined in a 50 meters radius from the sampling point. The vegetation was classified into three types of cover using the classification proposed by Anderson & Hardy (1979): Tree plant cover (TPC) – Dense forest formation; Permeable cover (PER) –

Fields, pasture, and exposed soil; and Impermeable cover (IMP) – Urbanized area with impermeable soil. The delimited area was calculated in m^2.

Trophic state index

Trophic State Index (TSI) is a tool commonly used to evaluate water quality. The method is based on the analysis of the trophic degree using total phosphorus (TP) and chlorophyll-a (CL) concentrations present in the water column. This index represents external nutrients inputs, like wastewater, industrial, and agricultural effluents. TSI is an essential support for the planning of eutrophication control and the use of the water body (Cunha et al., 2013; Silva et al., 2018).

The determination of TP concentrations was performed with 50 mL of the collected water sample, which was digested in a water bath (1 h at 90°C) with 1 mL of H_2SO_4 and 5 mL of HNO_3. The measurement was performed in a UV-VIS spectrophotometer (UV-visible Dynamica Halo DB-20) at 880 nm (American Public Health Association, 1999). CL concentration was obtained from the spectrophotometric analysis, after pigment extraction in acetone 90%, at wavelengths 630, 645, 665, and 750 nm (Parsons & Strickland, 1963).

TP and CL concentrations were used to calculate their respective trophic state indexes (TSI_{TP} and TSI_{CL}) following the equations proposed by Lamparelli (2004):

$$TSI\,TP = 10x\left(6-\left(\frac{0.42-0.36x\left(lnTP\right)}{ln2}\right)\right)-20$$

$$TSI\,CL = 10x\left(6-\left(\frac{-0.7-0.6x\left(lnCL\right)}{ln2}\right)\right)-20$$

Carlson's Trophic State Index (CTSI) was calculated from the simple arithmetic mean of the TSI_{PT} and TSI_{CL}.

$$CTSI = \frac{TSI\,TP + TSI\,CL}{2}$$

Established limits for the different trophic classes for rivers and reservoirs, according to Carlson's method modified, are described in Table 1. The CTSI was determined and shown as monthly and annual mean values.

Table 1. Classification of rivers according to Carlson's Trophic State Index (CTSI) modified (Lamparelli, 2004).

Category	*TP (μg.L⁻¹)*	*CL (μg.L⁻¹)*	*Weighing*
Ultraoligotrophic (UOL)	TP ≤ 13	CL ≤ 0,74	CTSI ≤ 47
Oligotrophic (OLI)	13 < TP ≤ 35	0,74 < CL ≤ 1,31	47 < CTSI ≤ 52
Mesotrophic (MES)	35 < TP ≤ 137	1,31 < CL ≤ 2,96	52 < CTSI ≤ 59
Eutrophic (EUT)	137 < TP ≤ 296	2,96 < CL ≤ 4,70	59 < CTSI ≤ 63
Supereutrophic (SEU)	296 < TP ≤ 640	4,70 < CL ≤ 7,46	63 < CTSI ≤ 67
Hypereutrophic (HEU)	640 < TP	7,46 < CL	CTSI > 67

Statistical analysis

Rainfall, TSI_{TP}, TSI_{CL}, and vegetation covers (IMP, PER, and TPC) were subject to Principal Component Analysis (PCA). This analysis allowed us to identify the most relevant components in the spatial and seasonal patterns throughout the study. PCA reduces the dimensionality of multivariate data, making them clearer, and transforms the original data variables into several influencing variables by linear combinations. The two principal components (PCs) that showed a large variance interpretation rate were used as the coordinate axes to produce the PCA ordination diagram. This diagram allows us to understand the distribution of the characteristics, distances, and the correlation between the variables (Bartholomew, 2010). MINITAB software was used for this purpose.

RESULTS AND DISCUSSION

Land cover

In the present study, all the evaluated sampling points showed areas with low vegetation cover (PER) and/or building areas (IMP) in the PPA (Figure 3).

The analysis of satellite images for the sampling points P1, P2, and P3 located upstream of the evaluated stretch showed the highest occurrence of IMP, 48.8, 47.9, and 39.4%, respectively. PER was most representative in P7, occupying 100.0%. TPC predominated in the other points, P4 (79.8%), P5 (85.2%), P6 (84.6%), and P8 (77.8%) (Figure 3 and 4).

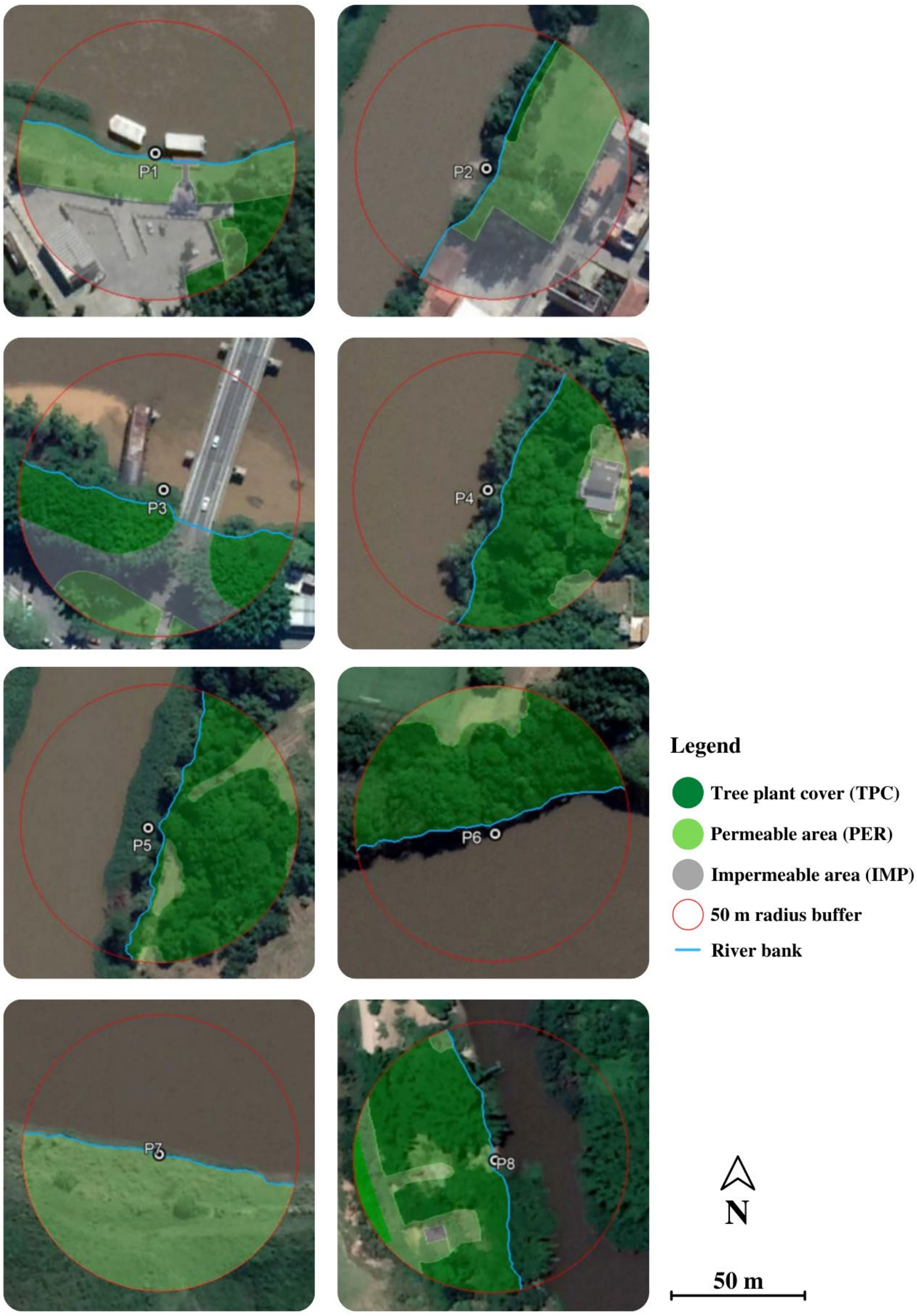

Figure 3. Areas for determination of land use categories in the sampling points of the Paraíba do Sul River. Red circles represent the 50 m radius buffer proposed by the present study.

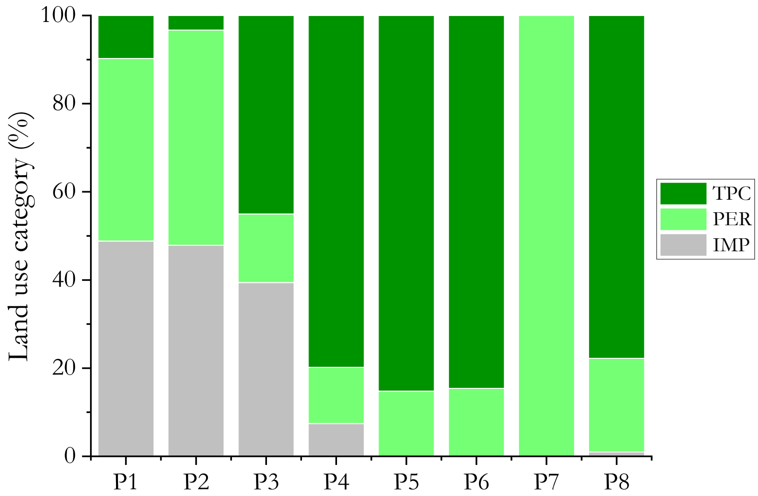

Figure 4. Land use category (%) in Permanent Preservation Areas (PPA) in each sampling point of Paraíba do Sul River. Impermeable Area (IMP), Permeable Area (PER), and Tree Plant Cover (TPC).

Failure to comply with PPA legislation could be observed in the evaluated areas of the present study. Corrêa & Silva (2017) also evaluated the land use of PPA in the middle stretch of the PSR in the three municipalities of the Rio de Janeiro State. In their case, the presence of areas of urban occupation and pasture prevailed. Only at the point located in the middle portion in the evaluated stretch was observed an area of 0.05 Km^2 of tree vegetation, equivalent to only 1.8% of the evaluated area.

Trophic State Index

During the present study, the TP concentrations showed values between 20.01 and 41.62 $\mu g.L^{-1}$ and the CL concentrations had a large variability ranging from 0.18 to 22.03 $\mu g.L^{-1}$. In the P7, the mean values for TP and CL were the highest ones, recording 31.84±6.64 $\mu g.L^{-1}$ and 8.36±8.41 $\mu g.L^{-1}$, respectively (Table 2).

Table 2. Total phosphorus (TP) and Chlorophyll-a (CL) concentrations in water samples collected in Paraíba do Sul River.

	Total Phosphorus ($\mu g.L^{-1}$)			Chlorophyll-a ($\mu g.L^{-1}$)		
Point	**Max**	**Min**	**Mean ± SD**	**Max**	**Min**	**Mean ± SD**
P1	28.96	20.01	25.48±3.35	5.29	0.34	2.23±1.84
P2	31.88	20.70	26.90±4.79	5.27	0.45	2.14±1.90
P3	28.77	20.35	24.86±3.08	8.32	0.42	3.92±3.49
P4	28.60	24.05	25.96±1.74	7.57	1.08	2.99±2.66
P5	28.44	22.59	24.86±2.24	7.76	0.34	3.06±2.81
P6	29.13	22.76	25.33±2.46	6.76	0.23	2.58±2.58
P7	41.62	23.02	31.84±6.64	22.03	0.18	8.36±8.41
P8	30.41	24.48	27.42±2.42	5.80	0.28	2.58±2.12
Category	**UOL**	**OLI**	**MES**	**EUT**	**SEU**	**HEU**

Subtitle: Ultraoligotrophic (UOL), Oligotrophic (OLI), Mesotrophic (MES), Eutrophic (EUT), Supereutrophic (SEU), and Hipereutrophic (HEU).

Based on the mean CL concentrations observed in each period evaluated, the rainy months (Nov/13 and Feb/14) showed high values. In these periods, the respective PSR stretch was classified as supereutrophic ($4.70 < CL \leq 7.46$). Differently, May/14 was classified as oligotrophic ($0.74 < CL \leq 1.31$). Regarding the mean TP concentrations, all the evaluated periods were classified as oligotrophic ($13 < TP \leq 35$) (Table 3).

Table 3. Total phosphorus (TP) and chlorophyll-a (CL) mean concentrations in water samples collected in Paraíba do Sul River in different periods.

	Total Phosphorus (μg.L^{-1})			Chlorophyll-a (μg.L^{-1})		
Month	**Max**	**Min**	**Mean± SD**	**Max**	**Min**	**Mean± SD**
Aug/13	41.62	24.97	29.65±4.89	3.00	0.42	1.27±0.81
Nov/13	32.40	26.20	29.23±2.14	8.25	5.27	6.63±1.07
Feb/14	30.33	22.59	25.00±2.31	22.03	1.72	5.50±6.56
May/14	24.48	20.01	22.46±1.69	1.37	0.18	0.52±0.37
Category	**UOL**	**OLI**	**MES**	**EUT**	**SEU**	**HEU**

Subtitle: Ultraoligotrophic (UOL), Oligotrophic (OLI), Mesotrophic (MES), Eutrophic (EUT), Supereutrophic (SEU), and Hipereutrophic (HEU).

In some sampling periods, the CTSI reached trophic levels classified as eutrophic (59 < CTSI ≤ 63), mainly in rainy periods: Nov/13 (P6 and P7) and Feb/14 (P3 and P7). Only on May/14, all the points presented a trophic level classified as oligotrophic (47 < CTSI ≤ 52), showing a mean CTSI of 46.30 ± 2.88 (Table 4). From the mean CTSI values obtained, the sampling periods could be ordered as follows: Nov/13 > Feb/14 > Aug/13 > May/14.

Table 4. Carlson's Trophic State Index (CTSI) of water collected in the Paraíba do Sul River.

Sampling points	Aug/13	Nov/13	Feb/14	May/14	Annual TSI
P1	51.95	57.35	53.73	45.18	52.05 ± 5.10
P2	46.84	57.65	54.30	48.84	51.91 ± 4.96
P3	46.34	57.90	60.39	47.50	53.03 ± 7.15
P4	50.45	58.66	55.61	51.65	54.09 ± 3.76
P5	52.45	58.96	54.59	45.56	52.89 ± 5.59
P6	45.89	59.91	55.14	43.96	51.23 ± 7.57
P7	55.76	60.54	66.13	42.82	56.31 ± 9.94
P8	50.63	57.87	56.04	44.89	52.36±5.85
Monthly average	50.04±4.46	58.61±1.14	56.99±4.23	46.30±2.88	

Category	**UOL**	**OLI**	**MES**	**EUT**	**SEU**	**HEU**

Subtitle: Ultraoligotrophic (UOL), Oligotrophic (OLI), Mesotrophic (MES), Eutrophic (EUT), Supereutrophic (SEU), and Hipereutrophic (HEU).

Resolution 357/05 of the Environment National Council (CONAMA) determines TP and CL concentrations in class II lotic environments should remain below 10 μg.L^{-1} and 30 μg.L^{-1}, respectively (Brasil, 2005). In the present study, TP concentrations well above the limit established were observed. In P7, e.g., the TP concentration reached 41.62 μg.L^{-1} in the dry season (August/13). On the other hand, CL concentrations remained within that established by the resolution (Table 2).

Ovalle et al. (2013) reported the CL concentration of 3.4 ± 5.1 μg.L^{-1} collecting near the mouth of the PSR to determine the water quality in the municipality of Campos dos Goytacazes, but no relation between CL concentrations and rainfall was observed. Differently, in the present study, we found the highest CL concentrations in periods with high rainfall indexes (Nov/13 and Feb/14), mainly in areas with low vegetation cover in the evaluated stretch of PSR (Table 2).

Watanabe et al. (2018) evaluated CL concentrations in the Funil reservoir in 2012, which is also in the PSR basin. The determined concentrations ranged from 2.33 to 208.68 μg.L^{-1} in the dry period and 4.37 to 306.03 μg.L^{-1} during the rainy period. According to the authors, the eutrophication process in reservoirs can be more intense than in rivers due to water level control, increasing the residence time, and the high accumulation of nutrients.

We observed the highest TSI values during the rainy periods (Nov/13 and Feb/14). TSI values varied in most of the sampling points. P7, e. g., displayed high TSI values in Aug/13, Nov/13, and

Feb/14, but, in the last sampling (May/14), it displayed the lowest trophic index (TSI = 42.82) compared to the other sampling points of the same month (Table 4).

Areas with exposed soil, like our case, spotted in Figure 3, are vulnerable to erosion processes in rainfall events. The runoff promotes the transport of sediment and nutrients to the river. The seasonal variability influences significantly the trophic level of the tropical waters, developing in a more intense or limited way depending on the environmental and climatic conditions of the region (Mello et al., 2018a, 2018b).

Multivariate correlation analysis

We observed a positive correlation between the variables evaluated in the present study. Two axes formed by PCA analysis explained 71.1% of the data variation. In the first axis, we observed an overlap of effects between the variables that exhibited a positive correlation: rainfall (0.341), TSI_{TP} (0.429), TSI_{CL} (0.386), PER (0.398), and IMP (0.368). On the other hand, TPC (-0.506) displayed a negative correlation. PER and IMP parameters were responsible for variations along the second axis (Figure 5). Correlation values are presented in Table 5.

Our results demonstrated that in the rainy periods the nutrient concentrations increased in areas with low tree plant cover (IMP and PER) that could be verified by the positive correlation values observed (Table 5) and the arrangement formed by PCA (Figure 5).

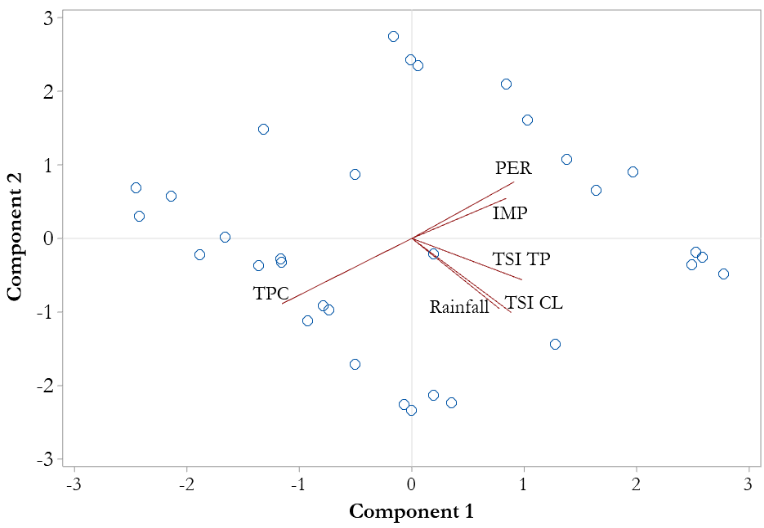

Figure 5. Principal Component Analysis (PCA) of variables evaluated in PSR: Rainfall, impermeable area (IMP), permeable area (PER), tree plant cover (TPC), chlorophyll-a (TSI_{CL}), and total phosphorus (TSI_{TP}).

Table 5. Correlation values of the PCA analysis using the environmental variables related to the water quality of the Paraíba do Sul River.

	Principal components	
Variables	1	2
Rainfall	0.341	-0.483
IMP	0.368	0.275
PER	0.398	0.388
TPC	-0.506	-0.449
TSI_{TP}	0.429	-0.284
TSI_{CL}	0.386	-0.508
Eigenvalue	2.285	1.978
% Variance	38.1	33.0
% Accumulated Variance	38.1	71.1

In the rainy period, the runoff can be an important pathway for nutrients to enter this ecosystem. The runoff promotes the intensification of diffuse pollution and the occurrence of the erosive process, which explains the nutrient increase in tropical freshwater ecosystems (Nobre et al., 2020).

The PSR basin has a high incidence of areas used for cultivation and agriculture close to the river channel (Ovalle et al., 2013). These activities commonly employ fertilizers on the soil to make it more fertile and improve production. These areas, here classified as permeable (PER), have an important contribution to the load of nutrients that reach the water body after a rainfall event (Ortiz-Reyes & Anex, 2018). Based on the pattern observed in the present study, mainly in P7, PER areas may have contributed to the increase in the trophic degree observed in the PSR during the evaluated period.

Additionally, in agricultural areas without riparian vegetation, there might be an intensification of pollution from pesticides, which might lead to ecosystem imbalance as it acts on different freshwater organisms (Queiroz et al., 2021).

The riparian vegetation helps to mitigate non-point pollution because it reduces the drag of nutrients and organic matter to the water body (Uriarte et al., 2011; Mori et al., 2015; Wang et al., 2018). Herein, we observed that the area with dense vegetation cover (TPC) displayed a negative correlation (-0.506) with the variables associated with the eutrophication process, TSI_{TP} (0.429), and TSI_{CL} (0.386) (Table 5). Besides, it was reported that the decrease of the forest cover in the PSR basin has intensified the drought and the minimum flows (Andrade & Ribeiro, 2020).

In the present study, the PCA indicated a positive correlation between rainfall, IMP, PER, and the trophic state index (TSI_{TP} and TSI_{CL}). The rainfall may have acted more intensively in the nutrient transport in PER and IMP compared to TPC.

It is important to highlight that our study was carried out in a period characterized by low rainfall rates compared to previous years in the PSR (Figure 1). Considering that the riparian zones in the PSR showed a low ratio of vegetal cover and the clear influence of the rainfall on the nutrient concentration, we suggest that in normal conditions of rainfall, the runoff could be more intense, and consequently, the trophic state could be even greater.

In this context, the maintenance of PPAs along the PSR would reduce the nutrient input during the rainy period, preventing the development of the eutrophication process near the margins. Thus, the restoration of riparian areas should be a high priority for PSR conservation.

According to Mello et al. (2017), restoration is an important strategy to improve water quality and to ensure the availability of this resource. But only this practice is not enough to restore all hydrological parameters associated with the water quality, such as total phosphorus, total nitrogen, and suspended sediments, or help the balance in the aquatic ecosystem. Sustainable human activities need to be encouraged to mitigate the impacts on the aquatic ecosystems (Ferreira et al., 2019), such as land management practices in agricultural and urban areas, improvement of the wastewater treatment, and preservation of the riparian vegetation (Hashemi et al., 2016).

The Integrated Plan for Water Resources of the Paraíba do Sul River Hydrographic Basin proposes priority areas for forest restoration along the PSR basin (Associação Pró-Gestão das Águas da Bacia Hidrográfica do Rio Paraíba do Sul, 2021). However, the projects of reforestation and the ampliation of the connections in the Atlantic rainforest proposed by the plan do not include the São Paulo stretch. The present study show pieces of evidence about the effects of the absence of vegetation in PPAs on the trophic state index of the PSR. Thus, our results highlight the necessity of more attention from regulatory committees to propose reforestation projects aiming to ensure the water quality in this river.

CONCLUSIONS

The rainfall regime influenced the variation of limnological parameters in the Paraíba do Sul River. The land use in the riparian zone influenced the parameters associated with the trophic state index of this river. The areas with tree plant cover contributed significantly to the improvement of the water quality from the Paraíba do Sul River.

Our results reinforce the need to preserve and promote the restoration of the riparian areas in basins. Also, the data can contribute to the development and implementation of public policies that aim at the monitoring of the TSI, considering the influence of the rainfall regime. Especially, the studies carried out in tropical basins that display well-defined rainy and dry seasons could be benefited. The seasonality proved to be a very important variable capable of significantly influencing the trophic degree in tropical freshwater. The absence of seasonality as a parameter in an analysis may make it difficult to compare the studies carried out in distinct periods. Thus, an integrated approach that uses representative environmental variables simultaneously can contribute to a better understanding of the functioning of these ecosystems. For this purpose, the Principal Component Analysis could be an important tool in the management and to guide decisions for conservation programs. The data obtained in the present study could help to promote the improvement of the evaluation and monitoring of tropical aquatic ecosystems and ensure the quality of water used in public supply.

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Annex 1. Land use classification of Paraíba do Sul Basin.