Acta Limnologica Brasiliensia

Publication of the Brazilian Association of Limnology

Original Article
Acta Limnologica Brasiliensia, 2023, vol. 35, e35
https://doi.org/10.1590/S2179-975X3723
ISSN 2179-975X on-line version

Seasonal precipitation and anthropogenic pressure affect the water quality of reservoirs in the highland humid forest enclaves

A precipitação sazonal e a pressão antrópica afetam a qualidade da água dos reservatórios no Brejo de Altitude

Luciana Gomes Barbosa[1], Kalline de Almeida Alves Carneiro[2], Letícia Moro[2]*, João Paulo de Oliveira Santos[3] and Rodrigo Santana Macedo[4]

[1]Universidade Federal da Paraíba – UFPB, PB-079, Km 12, 58397-000, Areia, PB, Brasil

[2]Instituto Nacional do Semiárido – INSA, Av. Francisco Lopes de Almeida, 4000, 58434-700, Campina Grande, PB, Brasil

[3]Instituto Federal do Tocantins – IFTO, Rua 02, Lote 01, Quadra 05-A, 77493-000, Lagoa da Confusão, TO, Brasil

[4]Universidade Estadual da Paraíba – UEPB, Rua Baraúnas, 351, 58429-500, Campina Grande, PB, Brasil

*e-mail: leticia.moro@insa.gov.br

Cite as: Barbosa, L.G. et al. Seasonal precipitation and anthropogenic pressure affect the water quality of reservoirs in the highland humid forest enclaves. *Acta Limnologica Brasiliensia*, 2023, vol. 35, e35.

Abstract: Aim: Humid forest enclaves are areas with privileged rainfall patterns compared to the surrounding regions, which favours their use for human settlement and agricultural activities, actions that promote severe transformations of the landscape and can contribute to the degradation of local water resources. From this perspective, given the great importance of water reservoirs for this region and the high demand for water, this study aimed to analyse the conservation status of water quality in reservoirs subjected to different anthropic disturbance in a humid forest enclave in the State of Paraíba, Brazil. **Methods:** Sampling campaigns were carried out for one year in six reservoirs: Mazagão I, Mazagão II, Vaca Brava, Saulo Maia, Rio do Canto and Lagoa do Paó, to measure the physic-chemical variables of the water. **Results:** The influence of annual rainfall patterns on the capacity of these ecosystems to respond to anthropic pressures, indicating the effects of seasonality in the Lagoa do Paó reservoir. For the Vaca Brava, the low accumulated water volumes turned out to be more critical for changes in water quality than the use and occupation of the margins of this reservoir. Furthermore, the Mazagão I and II reservoirs showed low electrical conductivity. The Saulo Maia reservoir exhibit clear waters with low phosphorus content and can be used as a reference for a preserved environment for a highland humid forest enclave. **Conclusions:** The conservation of the reservoir environment in the highland humid forest enclave is not sufficient to guarantee the water quality, as it is concentrated an affected at a certain time of the year. These aquatic ecosystems are under great pressure and the lack of decisions based on technical criteria makes them vulnerable to eutrophication.

Keywords: human activities impacts; eutrophication; phosphorus content; reservoir management; land use and occupation.

Resumo: Objetivo: Os Brejos de Altitude são áreas com regime pluviométrico privilegiado em relação ao seu entorno, o que favorece seu uso para ocupação humana e atividades agrícolas, ações que promovem severas transformações na paisagem e podem contribuir para a degradação dos recursos hídricos locais. Nessa perspectiva, dada a grande importância dos reservatórios de água para essa região e a alta demanda hídrica, este estudo teve como objetivo analisar o estado de conservação da qualidade da água em reservatórios submetidos a diferentes níveis de perturbação antrópica no Brejo de Altitude do Estado da Paraíba, Brasil. **Métodos:** Campanhas de amostragem foram realizadas durante um ano em seis reservatórios: Mazagão I, Mazagão II, Vaca Brava, Saulo Maia, Rio do Canto e Lagoa do Paó, para medir as variáveis físico-químicas da água. **Resultados:** Há influência dos padrões pluviométricos anuais sobre a capacidade desses ecossistemas de responder às pressões antrópicas, indicando os efeitos da sazonalidade no reservatório Lagoa do Paó. Para Vaca Brava, os baixos volumes de água acumulados revelaram-se mais críticos para mudanças na qualidade da água do que o uso e ocupação das margens desse reservatório. Além disso, os reservatórios Mazagão I e II apresentaram baixa condutividade elétrica. O reservatório Saulo Maia apresentou águas límpidas com baixo teor de fósforo e pode ser utilizado como referência de ambiente conservado para Brejos de Altitude. **Conclusões:** A conservação do entorno dos reservatórios no Brejo de Altitude não é suficiente para garantir a qualidade da água, pois, a precipitação elevada concentrada em determinada época do ano a afeta negativamente. Esses ecossistemas aquáticos estão sob grande pressão, e a ausência de decisões baseadas em critérios técnicos os torna vulneráveis à eutrofização.

Palavras-chave: impacto das atividades humanas; eutrofização; teor de fósforo; gestão de reservatórios; uso e ocupação da terra.

1. Introduction

Human settlements in arid regions often arise in locations with relatively higher levels of air humidity and rainfall. However, the growing human occupancy in these areas has resulted in an escalation of soil and water degradation due to activities such as agriculture, livestock rearing, construction, and surface paving, among others (Oliveira et al., 2021).

The Northeastern region of Brazil primarily comprises areas affected by water scarcity and conflicts related to water accessibility (Gunkel et al., 2018). However, certain regions such as the moist forest enclaves (Brejos de Altitude) in the Caatinga display ditinct rainfall patterns in contrast to their surrounding areas, which is influenced by orographic effects leading to precipitation escalation and temperature decrease, thus developing areas with varying microclimates (Medeiros et al., 2016) and augmented water availability (Cabral et al., 2004).

River damming is a prevalent practice across the world the purpose of freshwater storage ensuring a dependable supply of water supply year-round. This process transforms reservoirs into significant water sources and crucial spaces for water security in many regions (Tundisi, 2018).

Reservoirs are susceptible to water deterioration because of the accumulation and sedimentation of potentially contaminating materials (Woldeab et al., 2018) as well as anthropogenic activities on their shores, such as land use and occupation, and the discharge of domestic and industrial effluents (Kimengich et al., 2019).

Eutrophication is a significant concern linked to human-induced disruption aquatic ecosystems (Dalu & Wasserman, 2018). This phenomenon, which involves the heightened levels of nutrients in water sources, is prevalent globally and has adverse impacts on water quality in both lentic and lotic ecosystems, ultimately limiting their suitability for various purposes such as public water supply (Rietzler et al., 2018), irrigation, industrial use, animal watering, and the conservation of aquatic ecosystems (Barbosa et al., 2019). Furthermore, environmental factors, such as seasonality, can exacerbate the effects of eutrophication in reservoirs in addition to anthropic actions (Sharip et al., 2019).

Various studies conducted on reservoirs under different climatic conditions suggest that the primary cause of eutrophication is the high concentration of nitrogen (N) and phosphorus (P) in the water (Wei et al., 2022). Additionally, there have been reports of contamination with black carbon, total organic carbon, chlorophyll-a, and salts (Brasil et al., 2016; Rocha Junior et al., 2018; Njagi et al., 2022). The reduction in the water volume responding to prolonged water deficit conditions has exacerbated the trophic status, salinization, and cyanobacterial blooms in reservoirs (Brasil et al., 2016; Rocha Junior et al., 2018). These environmental problems have been worsened by limited water supply. The physical, chemical, and biological makeup of these bodies of water undergo considerable changes as consequence (Barbosa et al., 2020; Hafuka et al., 2021), leading to food and water insecurity in areas dependent on this resource.

Assessing water quality in aquatic ecosystems is a core component integrated management of water resource management in any region.

Determining the conservations status of these environments requires the crucial stage monitoring environmental parameters (Pavlidis et al., 2018). Generating of reliable information about water quality in ecosystems is essential for sustainable management and controlling water pollution (Woldeab et al., 2018).

From this perspective, and considering the significant importance of water reservoirs for moist forest enclaves as well as the high water demand of these areas, this study aimed to analyze the conservation status of water in reservoirs of this region subjected to different anthropic disturbance levels.

2. Material and Methods

2.1. Study area

The research sites are situated in the Paraíba state, a location in the northeast region of Brazil. The climate of the area is tropical, with high temperatures and humidity (As), with an annual average temperature of 24.0 °C and rainfall amounting to 1,400 mm (Alvares et al., 2013). The area is part of the biogeographic unit of the northeastern 'Brejo de Altitude'. It features high altitude Atlantic Forest islands, which are subject to varying weather conditions and different use and occupation than the surrounding semiarid area (Caatinga). This leads to changes in soil use and occupation patterns and an increased the demand for water resources.

The study area is located in the upper course of the Mamanguape Watershed. The river flows through the Planalto da Borborema, rising in Cariri, passing through Brejo de Altitude, and descending towards Agreste via the Serra da Borborema (Barbosa et al., 2006). The physiographic characteristics of the basin indicate a low likehood of flood formation. These traits include a form factor (F) of 0.25, a compactness index (FC) of 1.62, a conformation index (KC) of 0.14, an average slope of 48%, an average height of 338.5 meters, a stream slope of 2.81%, a basin order of 4, stream density of 0.0099 km km^{-2} and drainage density of 0.145 km km^{-2} (Pessôa et al., 2019).

The soils of area are identified as Acrisols, Ferralsols, or Luvisols (IUSS Working Group WRB, 2022), resulting from the transformation of orthogneisses and granodiorite migmatites.

For this research, we identified six aquatic ecosystems in various municipalities that corresponded to the following reservoirs: Mazagão I, Mazagão II, Vaca Brava, Saulo Maia, Rio do Canto, and Lagoa do Paó (Tables 1 and 2; Figure 1).

The Mazagão I, Mazagão II, and Rio do Canto reservoirs are shallow (Zmax ≤ 5 m), run-of-the-river reservoirs with a small area. In recent decades, Rio do Canto was responsible for fulfiling all the water demands of the population of Areia, however, it was deactivated due to siltation, while upstream deforestation compromised the watershed and waste and garbage from rainwater polluted it. Currently, Mazagão supplies a portion of the city's water needs, but its storage capacity is low, meeting less than 20% of the daily water demand. Reservoirs Mazagão I and II exhibit remnants of the high-altitude Atlantic Forest, while the Rio do Canto reservoir is situated near to the urban area of the municipality and receives a significant amount of domestic sewage. The presence of floating macrophytes should be visually verified.

The Vaca Brava reservoir can hold up to 3,783,556 m^3 of water. This reservoir has a high rate of water withdrawal, as it fulfils the drinking water requirements for around 80,000 residents in the towns of Esperança, Remígio, and the districts of Cepilho, Lagoa do Mato and São Miguel, The aquatic ecosystem is located within a high-altitude forest reserve (State Park Mata do Pau Ferro), that safeguards the catchment area of the reservoir and is the only forest reserve of its kind in the Agreste region of Paraíba.

The Saulo Maia reservoir has a storage capacity of 9,833,615 m^3. Although it was constructed with a large capacity, it did not supplying the municipality of Areia until 2016, following the implementation of the water distribution system. The reservoir also provides water to other municipalities such as Remígio, Esperança, Arara, and Lagoa de Roça, in addition to several municipalities in the state of Rio Grande do Norte. Water from the reservoir is supplied to other regional municipalities through water trucks, but the volume extracted is not measured. In addition,

Table 1. Geographical coordinates and altitude of monitored aquatic ecosystems, Highland humid forest enclave, Paraíba, Brazil.

Aquatic ecosystems	Geographical coordinate	Altitude
Mazagão I	7°00'06"S 35°42'23"W	350 m
Mazagão II	6°59'57"S 35°42'13"W	365 m
Vaca Brava	6°59'24"S 35°45'05"W	510 m
Saulo Maia	6°55'39"S 35°40'37"W	410 m
Rio do Canto	6°57'07"S 35°42'35"W	480 m
Lagoa do Paó	7°02'37"S 35°37'52"W	123 m

Table 2. Basic description of monitored aquatic ecosystems, Highland humid forest enclave, Paraíba, Brazil.

Reservoir	Ecosystem	Capacity	Depth	Use of water	Surroundings	Effluents
Mazagão I	Lentic	Low	Shallow	Supply the population	Degraded altitude Atlantic Forest and agricultural areas	Low load of untreated sewage
Mazagão II	Lentic	Low	Shallow	Supply the population in critical periods of drought	Degraded altitude Atlantic Forest and agricultural areas	Low load of untreated sewage
Vaca Brava	Lentic	Medium	Shallow	Supply the population in rainy periods and leisure	Preserved altitude Atlantic Forest	Very low load of untreated sewage
Saulo Maia	Lotic (most of the year)	High	Deep	Supply the population including tanker trucks, fishing, fish farming, and leisure	Residential area built with preserved riparian forest	Low load of untreated sewage and waste from rainwater
Rio do Canto	Lentic	Low	Shallow	Animal watering	Degraded altitude Atlantic Forest and agricultural areas	Medium load of untreated sewage and waste from rainwater
Lagoa do Paó	Lentic	Medium	Shallow	Leisure and fishing	Built-up urban areas, agricultural areas with no riparian forest	High load of untreated sewage and waste from rainwater

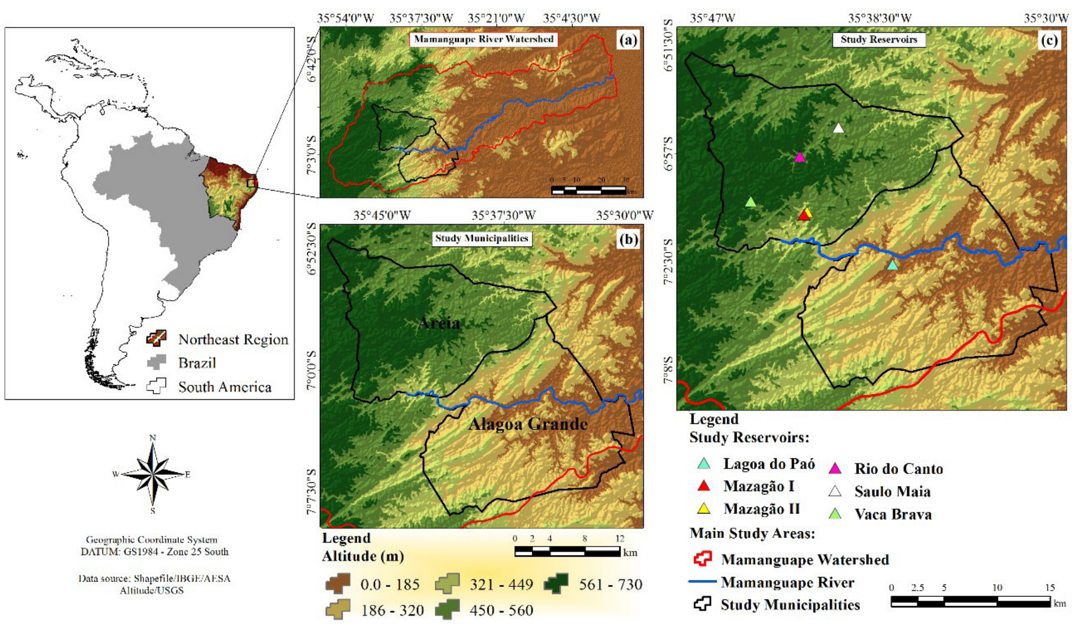

Figure 1. Location of monitored aquatic ecosystems, Highland humid forest enclave, Paraíba, Brazil.

human activities such as constructing condominiums on reservoir shores and cage fish farming, also have an impact on the quality of water.

The Lagoa do Paó reservoir is situated in the urban area of Alagoa Grande. It is a small and shallow urban pond (≤2.5 m) experiencing intensive anthropic impacts from urbanisation processes and the discharge of untreated sewage. The scarce riparian vegetation present contributes towards creating a eutrophic or hypereutrophic state, as established by Oliveira et al. (2020). Visually check for the presence of cyanobacteria.

2.2. Methodological procedures

Sampling occurred monthly from January through December 2015 at the reservoirs' deepest point. Except in October, when concentrated rainfall caused roads to become muddy and inaccessible, monthly campaigns were conducted.

The rainfall data for the study period were retrivied from the Agência Executiva de Gestão das Águas do Estado da Paraíba (AESA) (Figure 2). The current year experienced the El Niño phenomenon's impact on the region, leading to a negative effect on water bodies' water levels (Marengo et al., 2018).

Water samples for the analysis of phosphorus and orthophosphate were collected in high-density polyethylene vials that were pre-washed with diluted hydrochloric acid (10%) and re-washed three times before sampling water from the designated location. The subsurface of the water column was sampled, and samples were frozen to avoid any the degradation of targeted compounds. The total phosphorus and orthophosphate in the water were analysed using the methodology outlined by APHA (Bahobail et al., 2005).

The pH and electrical conductivity (EC) were measured *in situ* through the use of a multi-parameter probe, specifically the Hanna HI 8733. The water transparency (WT) in the reservoirs was measured by observing the visual reach of the Secchi disk.

The trophic state index for phosphorus (TSI) was determined by employing Carlson's index (1977), adapted for tropical environments by Toledo Júnior et al. (1983). The index utilised on the total phosphorus content (Equation 1) present in the water:

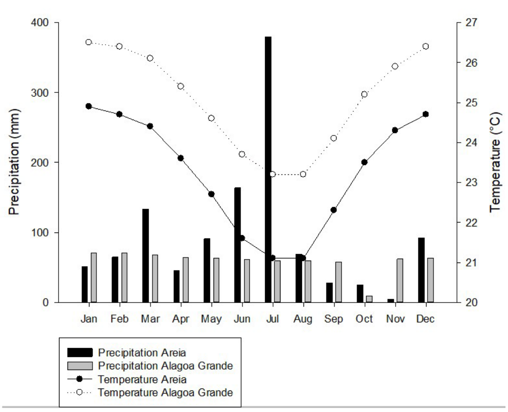

Figure 2. Average monthly precipitation and temperature data, ranging from January to December 2015, Highland humid forest enclave, Paraíba, Brazil. Source: AESA (2023) and Alvares et al. (2013).

$$TSI = 10\left\{6 - \left[\frac{\ln(80.32 / TP)}{ln2}\right]\right\} \quad (1)$$

where: TSI = trophic state index for phosphorus; TP = total phosphorus concentration, measured at the surface of the water (μg L^{-1}).

The values for the Carlson index ranged from 0 to 100, which permits the classification of the trophic state of ponds and reservoirs (Lamparelli, 2004).

2.3. Statistical analysis

The variables were examined via ANOVA). The Scott-Knott mean test was used when the F-test showed significance at a 5% level. Multivariate statistical techniques were employed to discover correlations and patterns between alterations in water quality and local rainfall patterns. Principal component analysis (PCA), hierarchical cluster analysis and a heat map were employed to examine the connection between the monitored variables and evaluate the factors that impact the water quality within the reservoirs. The analyses were conducted using the R software version 4.1.2 (R Core Team, 2023).

3. Results

Water transparency varied among the monitored environments, with Lagoa do Paó and Vaca Brava exhibiting more turbid waters, with transparency means of 0.1 and 0.2 meters, respectively (Table 3). In contrast, Saulo Maia reservoir presented clear waters, with a mean of 2.3 meters.

The water in these environments exhibited predominantly alkaline pH values throughout most months. Notably, Lagoa do Paó showed particularly strong alkalinity with an average pH of 8.6 (Table 3). On the other hand, the water pH in Saulo Maia and Rio do Canto was essentially neutral, averaging 7.7 and 7.3, respectively. In contrast, water in Vaca Brava, Mazagão I and Mazagão II was moderately alkaline, with mean values of 7.6, 7.2, and 7.8, respectively.

The EC levels in Mazagão I and II reservoirs were low, whereas the mean values of this parameter in Lagoa do Paó reservoir were high.

The Lagoa do Paó reservoir also indicated increased levels of phosphorus (P.total and P.orto). Despite being subjected to a significant polluting load, Rio do Canto exhibited lower levels of phosphorus than preserved environments such as Vaca Brava (Table 3).

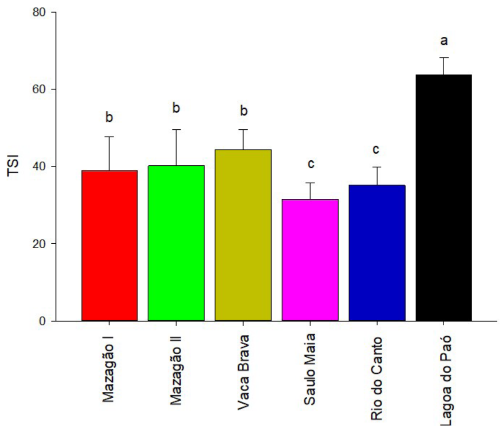

Figure 3. Average and SD values of the trophic state index for phosphorus (TSI) in water across six ecosystems monitored from January to December 2015 Highland humid forest enclave, Paraíba, Brazil. Bars with small letters indicate significant differences ($p < 0.05$) between the aquatic ecosystems via the Scott-Knott test.

The TSI values were found to be higher in the Lagoa do Paó reservoir (63.7), with Saulo Maia and Rio do Canto exhibiting lowest values averaging at of 33.3. Mazagão I, Mazagão II, and Rio do Canto were observed to have intermediate values with an average of 41.2 (Figure 3).

The initial two dimensions of analysis account for 76.45% of the total variability. Since this percentage is substantial, the first plane (Dim1 = 61.85% and Dim2 = 14.59%) plays a vital role in explaining the data's variability. This value is significantly greater than the reference value of 43.03%, making the variability explained by this plane highly significant. To ensure an appropriate interpretation of the axes, it is advisable to restrict the analysis to the description of the first axis (Dim1). Only this axis contains relevant data. Therefore, the description will be limited to this axis (Figure 4).

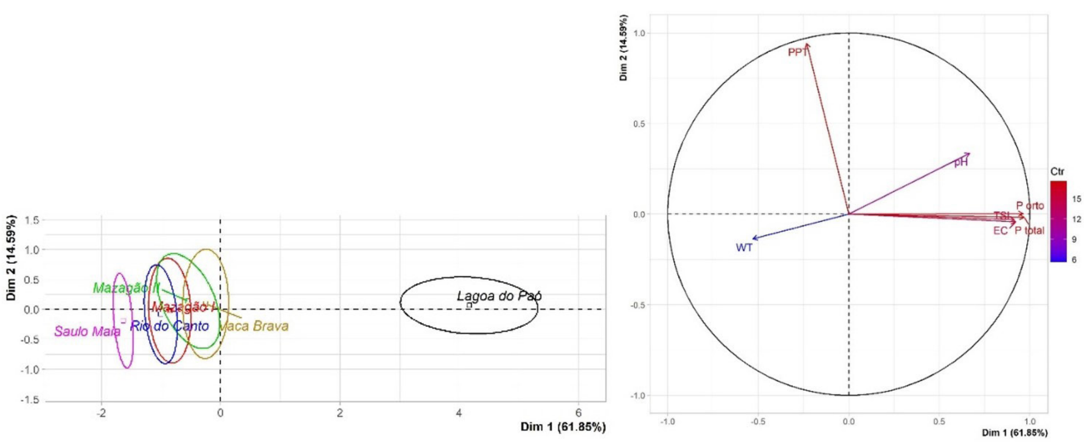

Figure 4. Order resulting from the Principal Components Analysis (Dim1 and Dim2), which summarized data on rainfall and limnological conditions for the six aquatic ecosystems under study. PPT: Rainfall; EC: Electrical conductivity; WT: Water transparency; pH: Hydrogenionic potential; P.orto: Orthophosphate; P.total: Total phosphorus.

Table 3. Average ± SD values of water transparency (WT), hydrogenionic potential (pH), electrical conductivity (EC), total phosphorus (P.total) and orthophosphate (P.orto) measured in six ecosystems monitored from January to December 2015 Highland humid forest enclave, Paraíba, Brazil.

Aquatic ecosystem	WT m	pH -	EC µs cm^{-1}	P.total µg L^{-1}	P.orto µg L^{-1}
Mazagão I	1.0 ± 0.3 b[1]	7.2 ± 0.7 b	216.0 ± 34.0 c	23.0 ± 20.0 b	7.3 ± 2.9 b
Mazagão II	0.4 ± 0.1 d	7.8 ± 0.7 b	182.0 ± 101.4 c	25.9 ± 24.3 b	7.8 ± 8.1 b
Vaca Brava	0.2 ± 0.2 e	7.5 ± 0.8 b	288.2 ± 70.1 b	28.8 ± 10.0 b	13.8 ± 10.6 b
Saulo Maia	2.3 ± 0.4 a	7.7 ± 0.3 b	349.1 ± 13.0 b	11.6 ± 3.6 b	3.9 ± 2.1 b
Rio do Canto	0.6 ± 0.2 c	7.3 ± 0.5 b	401.8 ± 88.0 b	15.1 ± 6.0 b	6.4 ± 3.0 b
Lagoa do Paó	0.1 ± 0.1 e	8.6 ± 0.4 a	1,556.4 ± 396.4 a	109.1 ± 36.4 a	94.9 ± 41.6 a

[1]Small letters in columns indicate a significant difference ($p < 0.05$) between aquatic ecosystems according to Scott-Knott test.

One group associated with Lagoa do Paó reservoir exhibits high values for the variables TSI, EC, P.total, P.orto, and pH, and low values for the variable WT. In contrast, the other group (Mazagão I, Mazagão II, Vaca Brava, Rio do Canto e Saulo Maia) demonstrates high values for the variable WT and low values for the variables TSI, pH, P.total, EC, and P.orto.

The variables P orto, P total, Lagoa do Paó, and Mazagão I exhibit a strong correlation with this dimension. Their respective correlations are 0.92, 0.94, 0.99, and 0.91. Hence, these variables could be considered as summary indicators for Dim1.

The hierarchical cluster analysis and heat map based on the physicochemical variables of water and rainfall indicate a group architecture with two clusters (Figure 5). One group includes the sampled months in Areia (Mazagão I, Mazagão II, Rio do Canto, Saulo Maia and Vaca Brava), while the other cluster contains the sampled months in Alagoa Grande (Lagoa do Paó).

4. Discussion

The conservation and vulnerability of water resources in moist forest enclaves are topics that are not fully explored in scientific literature. This is particularly concerning due to such areas often being regarded as having a more abundant water supply compared to the surrounding regions (Cabral et al., 2004).

However, the findings of this research reveal that, while enjoying above-average levels of rainfall in comparison to their semiarid surroundings, these ecosystems are susceptible to soil use and occupation, as well as the elevated demand for water in the area. Similar observations has made observed in other moist areas worldwide, such as the Lake Erie Basin in the United States of America (Sekaluvu et al., 2018), Xochimilco in Mexico (Pérez-Belmont et al., 2019), and Tharavai in southeastern India (Rameshkumar et al., 2019).

Within the same region and with geographic proximity (<20 km), differences in the climate norm, as observed for Areia (1,358.4 mm per year) and Alagoa Grande (950.0 mm per year), have led to environments subjected to similar environmental stressors displaying different patterns of water quality. Thus, the precise distribution and quantity rainfall play a crucial role in preserving the quality of this valuable resource within the region. This is particularly significant, given the growing capacity of water bodies to dilute the effects of pollutants (Lacerda et al., 2018; Junger et al., 2019).

The cluster analysis of Lagoa do Paó reservoir (Figure 5) clearly demonstrated the impact of seasonality on water quality, despite this parameter being unsatisfactory during the entire sampling period.

The large presence of macrophytes in Rio do Canto, which cover all this reservoir, functions as a nutrient sink, notably for phosphorus, thus mitigating the increase in the trophic level and enhancing water quality (Song et al., 2019; Zhang et al., 2019).

The Lagoa do Paó reservoir receives a similar effluent discharge to the Rio do Canto reservoir. However, it has a higher electrical conductivity that is amplified by this The Lagoa do Paó reservoir receives an effluent discharge similar to the Rio do Canto reservoir but shows a higher electrical conductivity, which is accentuated by this ecosystem's lower dilution capacity. As a consequence, the full development of macrophytes is hindered, further affected by salinity in lentic freshwater systems, in this case (Dodemaide et al., 2018).

A research carried out at Lago Paó reservoir highlighted the total absence of macrophytes over a year of evaluation, with the phytoplankton biomass being dominated by filamentous cyanobacteria (Barbosa et al., 2020). The authors identified a significant correlation between this reservoir and the light attenuation coefficient (lower transparency), the concentration of soluble reactive phosphorus, alkaline pH, nitrogen-fixing cyanobacteria, cyanobacteria typical of turbid environments, and cyanobacterial blooms in shallow and eutrophic lakes.

The elevated levels of orthophosphate in the Lagoa do Paó reservoir are likely attributed to the

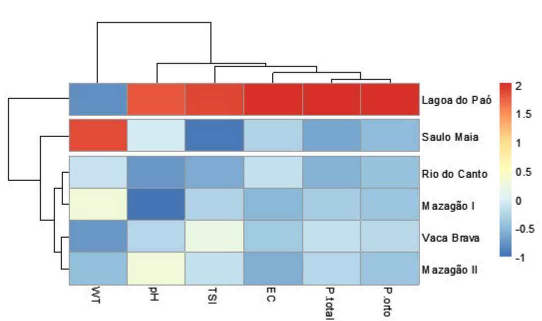

Figure 5. Hierarchical cluster analysis and heat map based on limnological variables evaluated in the six aquatic ecosystems. Red and blue colors represent importance, from highest to lowest, respectively. P.orto: Orthophosphate; P.total: Total Phosphorus; EC: Electrical conductivity; TSI: Trophic State Index; pH: Hydrogenionic potential; and WT: Water transparency.

high P contents present in the effluents discharged into this water body. Sewage effluents contain a high concentration of P, which plays a critical role in the eutrophication process of rivers and the formation of cyanobacterial blooms in lakes, especially in urbanized areas (Jarvie et al., 2006). However, phosphate fertilization near the reservoir should also be considered for agricultural purposes. Labile P forms (e.g., orthophosphate) have been credited to anthropic activities as the result of the eutrophication and pollution of water bodies (Barcellos et al., 2019).

The high P contents in Lagoa do Paó reservoir cause it to have the highest TSI value among the monitored reservoirs, resulting in its classification as a super-eutrophic reservoir, which makes it strongly affected by eutrophication linked with algal bloom episodes, compromising the use of water.

The evaluation of the impact of pH on the on P release in sediments has revealed that P-NaOH is discharged under alkaline conditions. Conversely, under acid conditions, P-HCl is released, but no P is released at neutral pH (Jin et al., 2006). This pattern also elucidates the higher orthophosphate levels observed in the Lagoa do Paó reservoir, which is the only location with alkaline conditions. In this environment, it is likely that the increase in hydroxyl ions due to the increase in pH probably increased the competition with orthophosphate ions for the protonated sites of oxides, increasing P release into the water column.

The expansion of urban areas and land use for agricultural purposes are related to the increased eutrophication of reservoirs worldwide (Cheng et al., 2022). In many of these environments, notably the shallow and eutrophic ones, phosphorus that is bound to iron oxides via inner sphere complexes potentially controls P release (Yuan et al., 2020).

From this perspective, area surrouding of the Lagoa do Paó reservoir show a predominance of Leptic Luvisols (Loamic, Differentic) (IUSS Working Group WRB, 2022) formed by orthogneiss and granodiorite migmatites, whose main characteristics are: i) high nutrient levels (eutrophic soils), with P contents that can reach 50 mg dm^{-3} (Santos et al., 2017); ii) soil horizons with a sandy and/or average texture over clayey layers (abrupt textural change), which decreases soil permeability and considerably increases the risk of erosion (Macedo et al., 2021); iii) a chromic character, due to the occurrence of primary iron oxides such as hematite and/or pedogenic iron oxides formed from the weathering of biotite in the melanocratic band of the gneiss parent material (Câmara et al., 2021); iv) temporary hydromorphy, with the common occurrence of features related to the reduction of Fe oxides.

The prevailing local geomorphology varying from slightly undulating to undulating, results in conducive the pedological conditions that facilitate the transportation of dissolved ions (e.g. Ca^{2+}, Mg^{2+}, K^+, P) and precipitated ions (e.g. P-Fe) into the reservoir. A biological reduction of these Fe oxides may occur during temporary anaerobiosis periods (Yuan et al., 2020), thus increasing P release into the water column. Therefore, these environmental characteristics, associated with the agricultural activities around the Lagoa do Paó reservoir, can account for the higher orthophosphate levels and alkalinity observed in this reservoir.

Vaca Brava revealed a considerable percentage of orthophosphate in the total phosphorus composition (48.9%) among the monitored reservoirs. As a result, since this fraction is the most readily available for the aquatic biota, this environment is also subject to the establishment of eutrophication (Ballah et al., 2019). Furthermore, the low water volume accumulated in this reservoir during the studied period leads to higher water temperatures close to the sediment, promoting phosphorus mineralization and orthophosphate availability (Beutel & Horne, 2018; Longyang, 2019).

The rise in turbidity levels in reservoirs located in Brazil's semiarid region corresponds directly to decreased water volume during periods of drought (Brasil et al., 2016; Rocha Junior et al., 2018). These assumptions are supported by our findings, despite our location within a conservation unit with less anthropic intervention, which heightened the concentration of suspended material and increased turbidity. Furthermore, these observations are supported by negative observed between rainfall and water transparency ($r = -0.46$).

This scenario arises due to the excessive withdrawal of water from this ecosystem for public use, reducing the water volume accumulated. Under these conditions, a deep environment is converted into a shallow one, implying greater exposure to wind and sediment resuspension, increasing the volume of material in suspension and consequently decreasing transparency (Shi et al., 2018; Ouni et al., 2019). Moreover, this process augments nutrient contents in the water column (Jalil et al., 2019).

The prevalence of high P concentrations in Lagoa do Paó reservoir led to limited light entry and as a result promoted cyanobacteria growth and restrict macrophyte growth. This caused a rise in increased water turbidity. According to Scheffer & Van Nes (2007), a comprehensive survey of shallow lakes worldwide revealed that water turbidity increased with eutrophication due to phytoplankton growth. From this perspective, the Lagoa do Paó reservoir exhibited a robust correlation between alkalinity, limited subaquatic light, water temperature, and high P concentrations with the flourishing of filamentous cyanobacteria (Barbosa et al., 2020).

The only reservoir in the analyzed set to feature strongly alkaline water was Lagoa do Paó. The PCA revealed that the water pH in this reservoir is strongly correlated to the electrical conductivity, the total P levels, and the orthophosphate content. Allied with the high turbidity resulting from the resuspension of sediments by the action of wind and/or the reduction in macrophyte coverage, these conditions favor phytoplankton development (Scheffer & Van Nes, 2007; Barbosa et al., 2020). In addition, the continuous cyanobacterial blooms probably increased the CO_2 demand for photosynthesis, decreasing the free levels of atmospheric CO_2 and consequently increasing the pH of the reservoir (Paerl & Huisman, 2009).

The majority of water quality metrics in this research were obtained in the Saulo Maia reservoir, characterized by a deep environment with a much higher stored volume than other reservoirs. In this ecosystem, the high transparency (>2.0 m) and low phosphorus content (<12 μg L^{-1}) highlight that, even under high water withdrawal rates for several intentions, the reservoir is operating within its carrying capacity (Silva-Lehmkuhl et al., 2019). This scenario was reflected in the lower TSI values, resulting in the classification of this reservoir as ultraoligotrophic, characterized by clean water and nutrient levels that are not harmful for use (Lamparelli, 2004).

However, due to the growing water demand, real estate speculation, and fishing activities in this ecosystem, this scenario may change and lead to the degradation of its water, thus implying the need for constant monitoring strategies for the proper management of water and correct decision-making (Ziemińska-Stolarska et al., 2019).

Despite similar levels of environmental pollution, including P-rich effluent discharge, the Lagoa do Paó and Rio do Canto reservoirs exhibited varying water quality levels due to the dilution capacity and presence of floating macrophytes in Rio Canto. Furthermore, the considerable removal of water and the low volumes accumulated, as noted in the Vaca Brava reservoir, can increase the degree of water eutrophication regardless of the conservation around the ecosystem. Saulo Maia reservoir can serve as a reference ecosystem for the region under study. Nonetheless, the presence of human activity in the vicinity is capable of bringing about changes to the ecosystem's existing state.

Future researches should take into account the diverse applications and activities taking place in and around reservoirs, as well as the soil characteristics of these locations. This is important due to the potential impact of Fe oxides in adsorption/desorption processes and sediment, and the direct implications for the eutrophication process.

From this view point, the elevate water temperature in the Lago Paó reservoir (Barcellos et al., 2019), allied to its shallow depth and fluctuating oxidizing and reducing conditions, hinders the formation of highly-reactive Fe oxides with the potential to adsorb considerable contents of phosphate anions, thus releasing higher levels of P into the water column. Hence, to regulate eutrophication in the examined reservoirs, it is essential to maintain oxic conditions, decrease the P contents and dilute the salt inflow are crucial measures to.

5. Conclusions

The reservoirs exhibit a hierarchy of water quality conservation with Saulo Maia being the most conserved, followed by Rio do Canto, Mazagão I, Mazagão II, Vaca Brava, and Lagoa do Paó.

To conserve water quality, maintenance of native vegetation around the reservoirs alone is not sufficient. The Vaca Brava reservoir situated in a forest reserve exhibits a lower conservation degree compared to the aquatic ecosystems surrounded by forest remnants.

Annual precipitation is significant in determining water export and nutrient supply as variations in rainfall can affect electrical conductivity, transparency, pH, and the levels of P in water, which in turn directly impact water quality in reservoirs.

The aquatic ecosystems of the Highland humid forest enclave (Brejo de Altitude) are currently under severe pressure, and the lack of technical criteria-based decisions makes them vulnerable to eutrophication due to the region's climatic conditions.

Acknowledgements

This research was supported by the Universidade Federal da Paraíba – UFPB.

References

Agência Executiva de Gestão das Águas do Estado da Paraíba – AESA, 2023. Meteorologia - chuvas [online]. Retrieved in 2023, October, from http://www.aesa.pb.gov.br/aesa-website/meteorologia-chuvas/

Alvares, C.A., Stape, J.L., Sentelhas, P.C., Gonçalves, J.L.M. & Sparovek, G., 2013. Köppen's climate classification map for Brazil. Meteorol. Z. 22(6), 711-728. http://dx.doi.org/10.1127/0941-2948/2013/0507.

Bahobail, A., Gad El-Rab, S.M.F. & Amin, G.A., 2005. Standard methods for the examination of water and wastewater.Washington, DC: American Public Health Association.

Ballah, M., Bhoyroo, V. & Neetoo, H., 2019. Assessment of the physico-chemical quality and extent of algal proliferation in water from an impounding reservoir prone to eutrophication. J. Ecol. Environ. 43(1), 5. http://dx.doi.org/10.1186/s41610-018-0094-z.

Barbosa, J.D.S., Bellotto, V.R., Silva, D.B. & Lima, T.B., 2019. Nitrogen and phosphorus budget for a deep tropical reservoir of the Brazilian Savannah. Water 11(6), 1205. http://dx.doi.org/10.3390/w11061205.

Barbosa, J.E.L., Andrade, R.A., Lins, R.P. & Diniz, C.R., 2006. Diagnóstico do estado trófico e aspectos limnológicos de sistemas aquáticos da bacia hidrográfica do Rio Taperoá, trópico semiárido brasileiro. Rev. Biol. Ciênc. Terra 1, 81-89.

Barbosa, L.G., Alves, R.M.A., Santos, J.P.O., Araújo, M.C.S.P. & Dantas, Ê.W., 2020. Role of submerged macrophytes in sediment phosphorus stabilization in shallow lakes from the Brazilian semiarid region. Inland Waters 10(4), 505-515. http://dx.doi.org/10.1080/20442041.2020.1814090.

Barcellos, D., Queiroz, H.M., Nóbrega, G.N., Oliveira Filho, R.L., Santaella, S.T., Otero, X.L. & Ferreira, T.O., 2019. Phosphorus enriched effluents increase eutrophication risks for mangrove systems in northeastern Brazil. Mar. Pollut. Bull. 142, 58-63. PMid:31232342. http://dx.doi.org/10.1016/j.marpolbul.2019.03.031.

Beutel, M.W. & Horne, A.J., 2018. Nutrient fluxes from profundal sediment of ultra-oligotrophic Lake Tahoe, California/Nevada: implications for water quality and management in a changing climate. Water Resour. Res. 54(3), 1549-1559. http://dx.doi.org/10.1002/2017WR020907.

Brasil, J., Attayde, J.L., Vasconcelos, F.R., Dantas, D.D.F. & Huszar, V.L.M., 2016. Drought-induced water-level reduction favors cyanobacteria blooms in tropical shallow lakes. Hydrobiologia 770(1), 145-164. http://dx.doi.org/10.1007/s10750-015-2578-5.

Cabral, J.J.S.P., Braga, R.A.P., Montenegro, S.M.G.L., Campello, M.S.C. & Lopes-Filho, S., 2004. Recursos hídricos e os brejos de altitude. In: Pôrto, K.C., Cabral, J.J.P. & Tabarelli, M., orgs. Brejos de altitude em Pernambuco e Paraíba: história natural, ecologia e conservação. Brasília: Ministério do Meio Ambiente, 31-48.

Câmara, E.R.G., Santos, J.C.B., Araújo Filho, J.C., Shulze, S.M.B.B., Corrêa, M.M., Ferreia, T.O., Sousa, J.E.S. & Souza Júnior, V.S., 2021. Parent rock-pedogenesis relationship: how the weathering of metamorphic rocks influence the genesis of Planosols and Luvisols under a semiarid climate in NE Brazil. Geoderma 385, 114878. http://dx.doi.org/10.1016/j.geoderma.2020.114878.

Cheng, R., Hou, S., Wang, J., Zhu, H., Shutes, B. & Yan, B., 2022. Biochar-amended constructed wetlands for eutrophication control and microcystin (MC-LR) removal. Chemosphere 295, 133830. PMid:35149020. http://dx.doi.org/10.1016/j.chemosphere.2022.133830.

Dalu, T. & Wasserman, R.J., 2018. Cyanobacteria dynamics in a small tropical reservoir: understanding spatio-temporal variability and influence of environmental variables. Sci. Total Environ. 643, 835-841. PMid:29958171. http://dx.doi.org/10.1016/j.scitotenv.2018.06.256.

Dodemaide, D.T., Matthews, T.G., Iervasi, D. & Lester, R.E., 2018. Anthropogenic water bodies as drought refuge for aquatic macroinvertebrates and macrophytes. Sci. Total Environ. 616-617, 543-553. PMid:29128841. http://dx.doi.org/10.1016/j.scitotenv.2017.10.333.

Gunkel, G., Selge, F., Keitel, J., Lima, D., Calado, S., Sobral, M., Rodriguez, M., Matta, E., Hinkelmann, R., Casper, P. & Hupfer, M., 2018. Water management and aquatic ecosystem services of a tropical reservoir. Reg. Environ. Change 18(7), 1913-1925. http://dx.doi.org/10.1007/s10113-018-1324-8.

Hafuka, A., Tsubokawa, Y., Shinohara, R. & Kimura, K., 2021. Phosphorus compounds in the dissolved and particulate phases in urban rivers and a downstream eutrophic lake as analyzed using 31P NMR. Environ. Pollut. 288, 117732. PMid:34256284. http://dx.doi.org/10.1016/j.envpol.2021.117732.

IUSS Working Group WRB, 2022. World Reference Base for Soil Resources. International soil classification system for naming soils and creating legends for soil maps (4th ed.). Vienna: International Union of Soil Sciences, 236 p.

Jalil, A., Li, Y., Zhang, K., Gao, X., Wang, W., Khan, H.O.S., Pan, B., Ali, S. & Acharya, K., 2019. Wind-induced hydrodynamic changes impact on sediment resuspension for large, shallow Lake Taihu, China. Int. J. Sediment Res. 34(3), 205-215. http://dx.doi.org/10.1016/j.ijsrc.2018.11.003.

Jarvie, H.P., Neal, C. & Withers, P.J.A., 2006. Sewage-effluent phosphorus: a greater risk to river eutrophication than agricultural phosphorus? Sci.

Total Environ. 360(1-3), 246-253. PMid:16226299. http://dx.doi.org/10.1016/j.scitotenv.2005.08.038.

Jin, X., Wang, S., Pang, Y. & Wu, F.C., 2006. Phosphorus fractions and the effect of pH on the phosphorus release of the sediments from different trophic areas in Taihu Lake, China. Environ. Pollut. 139(2), 288-295. PMid:16061319. http://dx.doi.org/10.1016/j.envpol.2005.05.010.

Junger, P.C., Dantas, F.C.C., Nobre, R.L.G., Kosten, S., Venticinque, E.M., Araújo, F.C., Sarmento, H., Angelini, R., Terra, I., Gaudêncio, A., They, N.H., Becker, V., Cabral, C.R., Quesado, L., Carneiro, L.S., Caliman, A. & Amado, A.M., 2019. Effects of seasonality, trophic state and landscape properties on CO2 saturation in low-latitude lakes and reservoirs. Sci. Total Environ. 664, 283-295. PMid:30743122. http://dx.doi.org/10.1016/j.scitotenv.2019.01.273.

Kimengich, B.K., Takeuchi, J., Goto, K. & Fujihara, M., 2019. Temporal and spatial change in phosphate–phosphorus concentration and modeling with land-use variation in Sengari reservoir basin. Japan. Paddy Water Environ. 17(2), 131-139. http://dx.doi.org/10.1007/s10333-019-00705-6.

Lacerda, L.D., Santos, J.A., Marins, R.V. & Silva, F.A.D., 2018. Limnology of the largest multi-use artificial reservoir in NE Brazil: the Castanhão Reservoir, Ceará State. An. Acad. Bras. Cienc. 90(2, Suppl. 1), 2073-2096. PMid:30133571. http://dx.doi.org/10.1590/0001-3765201820180085.

Lamparelli, M.C., 2004. Grau de trofia em corpos d'água do estado de São Paulo: avaliação dos métodos de monitoramento [Doctoral dissertation in Sciences: Aquatic and Terrestrial Ecosystems]. São Paulo: Universidade de São Paulo.

Longyang, Q., 2019. Assessing the effects of climate change on water quality of plateau deep-water lake-a study case of Hongfeng Lake. Sci. Total Environ. 647, 1518-1530. PMid:30180357. http://dx.doi.org/10.1016/j.scitotenv.2018.08.031.

Macedo, R.S., Beirigo, R.M., Medeiros, B.M., Felix, V.J.L., Souza, R.F.S. & Bakker, A.P., 2021. Processos pedogenéticos e susceptibilidade dos solos à degradação no Semiárido brasileiro. Caminhos Geogr. 22(81), 176-195. http://dx.doi.org/10.14393/RCG228155397.

Marengo, J.Á., Alves, L.M., Alvala, R.C.S., Cunha, A.P., Brito, S. & Moraes, O.L.L., 2018. Climatic characteristics of the 2010–2016 drought in the semiarid northeast Brazil region. An. Acad. Bras. Cienc. 90(2, Suppl. 1), 1973-1985. PMid:28813107. http://dx.doi.org/10.1590/0001-3765201720170206.

Medeiros, R.L.S., Souza, V.C., Barbosa Neto, M.A., Araújo, L., Barbosa, A.S. & Medeiros, R.L.S., 2016. Estrutura da regeneração natural de *Anadenanthera colubrina* em fragmento de brejo de altitude em Bananeiras, PB. Pesqui. Florest. Bras. 36(86), 95-101. http://dx.doi.org/10.4336/2016.pfb.36.86.887.

Njagi, D.M., Routh, J., Odhiambo, M., Luo, C., Basapuram, L.G., Olago, D., Klump, V. & Stager, C., 2022. A century of human-induced environmental changes and the combided roles of nutrients and land use in Lake Victoria catchment on euthrophication. Sci. Total Environ. 835, 155425. PMid:35489498. http://dx.doi.org/10.1016/j.scitotenv.2022.155425.

Oliveira, A.F.N., Sousa, L.I.S., Costa, V.A.S., Andrade, J.V.T., Lima, L.A.L., Sales, P.A.F., Silva, D.F., Pereira, A.P.A. & Melo, V.M.M., 2021. Long-term effects of grazing on the biological, chemical, and physical soil properties of the Caatinga biome. Microbiol. Res. 253, 126893. PMid:34678684. http://dx.doi.org/10.1016/j.micres.2021.126893.

Oliveira, C.S.P., Fonseca, A.S., Diaz, C.A. & Santos, W.P., 2020. Reflexões sobre o desafio ambiental: níveis de eutrofização e floração de cianobactérias na Bacia Apodi-Mossoró. Rev. Ibero-Am. Cienc. Ambient. 11(5), 519-530. http://dx.doi.org/10.6008/CBPC2179-6858.2020.005.0047.

Ouni, H., Kawachi, A., Irie, M., M'Barek, N.B., Hariga-Tlatli, N. & Tarhouni, J., 2019. Development of water turbidity index (WTI) and seasonal characteristics of total suspended matter (TSM) spatial distribution in Ichkeul Lake, a shallow brackish wetland, Northern-East Tunisia. Environ. Earth Sci. 78(6), 228. http://dx.doi.org/10.1007/s12665-019-8126-2.

Paerl, H.W. & Huisman, J., 2009. Climate change: a catalyst for global expansion of harmul cyanobacterial blooms. Environ. Microbiol. Rep. 1(1), 27-37. PMid:23765717. http://dx.doi.org/10.1111/j.1758-2229.2008.00004.x.

Pavlidis, G., Ploumistou, E., Karasali, H., Liapis, K., Anagnostopoulos, C., Charalampous, A., Alexakis, D., Gamvroula, D. & Tsihrintzis, V.A., 2018. Evaluation of the water quality status of two surface water reservoirs in a Mediterranean island. Environ. Monit. Assess. 190(10), 570. PMid:30187137. http://dx.doi.org/10.1007/s10661-018-6908-8.

Pérez-Belmont, P., Alvarado, J., Vázquez-Salvador, N., Rodríguez, E., Valiente, E. & Díaz, J., 2019. Water quality monitoring in the Xochimilco peri-urban wetland: experiences engaging in citizen science. Freshw. Sci. 38(2), 342-351. http://dx.doi.org/10.1086/703395.

Pessôa, G.C.M., Souza Neto, J.J., Silva, M.P.A., Soares, W.K.A., Lucena, F.T., Silva, Z.L., Cavalcanti, I.L.R., Moreira, A.R., Sousa, E.F., Silva, K.J.M. & Araújo, J.E.B., 2019. Estudo hidrológico da bacia hidrográfico do Rio Mamanguape. In: Zuffo, A.M., org. As regiões semiáridas e suas especificidades 2. Ponta Grossa: Atena Editora, 181-187. http://dx.doi.org/10.22533/at.ed.91619150321.

R Core Team, 2023. R: a language and environment for statistical computing [online]. Retrieved in 2023, October, from http://www.R-project.org/

Rameshkumar, S., Radhakrishnan, K., Aanand, S. & Rajaram, R., 2019. Influence of physicochemical water quality on aquatic macrophyte diversity in seasonal wetlands. Appl. Water Sci. 9(1), 12. http://dx.doi.org/10.1007/s13201-018-0888-2.

Rietzler, A.C., Botta, C.R., Ribeiro, M.M., Rocha, O. & Fonseca, A.L., 2018. Accelerated eutrophication and toxicity in tropical reservoir water and sediments: an ecotoxicological approach. Environ. Sci. Pollut. Res. Int. 25(14), 13292-13311. PMid:27761862. http://dx.doi.org/10.1007/s11356-016-7719-5.

Rocha Junior, C.A.N., Costa, M.R.A., Menezes, R.F., Attayde, J.L. & Becker, V., 2018. Water volume reduction increases eutrophication risk in tropical semi-arid reservoirs. Acta Limnol. Bras. 30, e106. https://doi.org/10.1590/S2179-975X2117.

Santos, J.C.B., Le Pera, E., Souza Júnior, V.S., Corrêa, M.M. & Azevedo, A.C., 2017. Gneiss saprolite weathering and soil genesis along an east-west regolith sequence (NE Brazil). Catena 150, 279-290. http://dx.doi.org/10.1016/j.catena.2016.11.031.

Scheffer, M. & Van Nes, E.H., 2007. Shallow lakes theory revisited: various alternative regimes driven by climate, nutrients, depth and lake size. Hydrobiologia 584(1), 455-466. http://dx.doi.org/10.1007/s10750-007-0616-7.

Sekaluvu, L., Zhang, L. & Gitau, M., 2018. Evaluation of constraints to water quality provements in the Western Lake Erie Basin. J. Environ. Manage. 205, 85-98. PMid:28968590. http://dx.doi.org/10.1016/j.jenvman.2017.09.063.

Sharip, Z., Yusoff, F.M. & Jamin, A., 2019. Seasonal water quality and trophic status of shallow lentic waters and their association with water levels. Int. J. Environ. Sci. Technol. 16(8), 4851-4862. http://dx.doi.org/10.1007/s13762-018-2172-2.

Shi, K., Zhang, Y., Zhu, G., Qin, B. & Pan, D., 2018. Deteriorating water clarity in shallow waters: evidence from long term MODIS and in-situ observations. Int. J. Appl. Earth Obs. Geoinf. 68, 287-297. http://dx.doi.org/10.1016/j.jag.2017.12.015.

Silva-Lehmkuhl, A.M.D., Tremarin, P.I., Vercellino, I.S. & Ludwig, T.A.V., 2019. Periphytic diatoms from an oligotrophic lentic system, Piraquara I reservoir, Paraná state, Brazil. Biota Neotrop. 19(2), e20180568. http://dx.doi.org/10.1590/1676-0611-bn-2018-0568.

Song, H., Meng, X., Wang, S., Zhou, W., Wang, X., Kako, T. & Ye, J., 2019. Direct and selective photocatalytic oxidation of CH4 to oxygenates with O2 on cocatalysts/ZnO at room temperature in water. J. Am. Chem. Soc. 141(51), 20507-20515. PMid:31834789. http://dx.doi.org/10.1021/jacs.9b11440.

Toledo Júnior, A.P., Talarico, M., Chinez, S.J. & Agudo, E.G., 1983. The application of simplified models for the evaluation of the process of eutrophication in tropical lakes and reservoirs. São Paulo: Cetesb.

Tundisi, J.G., 2018. Reservoirs: new challenges for ecosystem studies and environmental management. Water Secur. 4-5, 1-7. http://dx.doi.org/10.1016/j.wasec.2018.09.001.

Wei, Y., Cui, H., Hu, Q., Bai, Y., Qu, K., Sun, J. & Cui, Z., 2022. Eutrophication status assessment in the Laizhou Bay, Bohai Sea: further evidence for the ecosystem degradation. Mar. Pollut. Bull. 181, 113867. PMid:35780630. http://dx.doi.org/10.1016/j.marpolbul.2022.113867.

Woldeab, B., Beyene, A., Ambelu, A., Buffam, I. & Mereta, S.T., 2018. Seasonal and spatial variation of reservoir water quality in the southwest of Ethiopia. Environ. Monit. Assess. 190(3), 163. PMid:29470719. http://dx.doi.org/10.1007/s10661-018-6527-4.

Yuan, H., Tai, Z., Li, Q. & Liu, E., 2020. In-situ, high resolution evidence from water-sediment interface for significance role of iron bound phosphorus in eutrophic lake. Sci. Total Environ. 706, 136040. PMid:31864994. http://dx.doi.org/10.1016/j.scitotenv.2019.136040.

Zhang, Q., Liu, Y.P., Luo, F.L., Dong, B.C. & Yu, F.H., 2019. Does species richness affect the growth and water quality of submerged macrophyte assemblages? Aquat. Bot. 153, 51-57. http://dx.doi.org/10.1016/j.aquabot.2018.11.006.

Ziemińska-Stolarska, A., Imbierowicz, M., Jaskulski, M., Szmidt, A. & Zbiciński, I., 2019. Continuous and periodic monitoring system of surface water quality of an impounding reservoir: Sulejow Reservoir, Poland. Int. J. Environ. Res. Public Health 16(3), 301. PMid:30678078. http://dx.doi.org/10.3390/ijerph16030301.

Received: 20 April 2023
Accepted: 27 October 2023

Associate Editor: Andre Andrian Padial.