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Trophic state in Brazilian semiarid reservoirs after reflooding

Estado trófico em reservatórios da região semiárida do Brasil após reinundação

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ABSTRACT

Prolonged drought extreme events can intensify eutrophication symptoms. This study aimed to analyze the trophic state of two semiarid reservoirs (Cruzeta and Dourado) that experience regular periods of drying and reflooding, verifying limnological changes. Two distinct periods were defined: Period I - before water depletion and Period II – after water renewal. To assess the changes in the limnological variables and the trophic state following the reflooding was conducted Wilcoxon test, Pearson's Correlation, and cluster analysis. Despite similar hydro-meteorological conditions, the reservoirs exhibited different outcomes in limnological variables. Due to the prolonged drought, Cruzeta maintained the eutrophic state in both periods, with the reservoir retaining only 2% of its water volume. In the Dourado reservoir, the trophic state change was observed, shifting from mesotrophic to eutrophic. The acceleration of eutrophication may have occurred due to the existence of organic matter in the sediment, coming from plantations inside the reservoir in addition to phosphorus carried from the drainage basin and by internal loading. Thus, reflooding did not improve water quality conditions and may intensify eutrophication. Therefore, it is recommended that effective reservoir and drainage basin management practices be implemented to mitigate eutrophication and aim for improvements in water quality.

Keywords: Eutrophication; Extreme drought; Nutrients; Water renewal.

RESUMO

Eventos extremos de seca prolongada podem intensificar os sintomas de eutrofização. O objetivo deste estudo foi analisar o estado trófico de dois reservatórios semiáridos (Cruzeta e Dourado) que sofrem constantes períodos de seca e reinundação, verificando as mudanças limnológicas. Dois períodos foram definidos: Período I - antes do esgotamento da água e Período II - após a renovação da água. Para verificar as alterações das variáveis limnológicas e do estado trófico após a reinundação foi realizado teste de Wilcoxon, Correlação de Pearson e análise de cluster. Os reservatórios apresentaram resultados diferentes nas variáveis limnológicas, apesar de cenários hidrometeorológicos semelhantes. Cruzeta manteve o estado eutrófico em ambos os períodos, devido ao efeito da seca prolongada, o reservatório se encontrava com apenas 2% do seu volume. Dourado passou de mesotrófico para eutrófico. A aceleração da eutrofização pode ter ocorrido devido à existência de matéria orgânica no sedimento, proveniente de plantios no interior do reservatório, além de fósforo carreado da bacia de drenagem e por carregamento interno. A reinundação não melhorou as condições de qualidade da água e pode intensificar a eutrofização. Portanto, recomendamos práticas eficazes de gestão de reservatórios e bacias de drenagem para mitigar a eutrofização, visando melhorias na qualidade da água.

Palavras-chave: Eutrofização; Seca extrema; Nutrientes; Renovação da água.

INTRODUCTION

Eutrophication is a natural or anthropogenic process characterized by an increase in primary productivity, primarily caused by elevated nutrient levels such as phosphorus (P) and nitrogen (N), particularly P (Le Moal et al., 2019; Schindler, 2012). This process leads to the proliferation of cyanobacterial species, resulting in heightened algal biomass, oxygen depletion, fish mortality, increased turbidity, and decreased biodiversity (Schindler, 2012).

The increase in nutrient concentrations in water bodies can originate from internal and external sources, the external can be diffuse or punctual (Carpenter et al., 1998). The internal source occurs directly in the water body, with the release of phosphorus stored in the sediment to the water column and nutrient cycling (Cooke et al., 1993). This process, identified as internal loading, is extremely important, as it enhances eutrophication, increasing the concentration of nutrients in the water column (Sondergaard et al., 2001).

Projections suggest that climate change will lead to an increased frequency of extreme events, including intense rainfall and prolonged droughts (Painel Intergovernamental sobre Mudanças Climáticas, 2014). As a result, the greater occurrence of dry periods, the increase in intense rainfall in a short period, and the increase in temperature (Marengo et al., 2016; Painel Intergovernamental sobre Mudanças Climáticas, 2019) make these events more likely to change eutrophication conditions (Moss, 2011). During heavy rainfall, nutrients are carried into water bodies (Stockwell et al., 2020), whereas drought intensification reduces reservoir volumes, leading to higher nutrient concentrations (Rocha Junior et al., 2018). These events alter aquatic ecosystems and cause damage to the region's population (Moss, 2011; Roland et al., 2012), as is the case in the semiarid region.

The semiarid region encompasses approximately 40% of the Earth's surface (Espejo et al., 2012) and naturally experiences periods of drought. In Brazil, the semiarid region covers 11% of the country's territory and possesses distinct characteristics compared to other semiarid regions. These characteristics include high spatial and temporal variability of precipitation, high temperatures, shallow and poorly structured soils, deciduous vegetation cover (Caatinga), drainage basins composed of intermittent rivers and streams, and a high potential for evapotranspiration. As a result, the region faces a water deficit for at least nine months of the year (Barbosa et al., 2012). These factors contribute to the natural vulnerability of the northeastern semiarid region to eutrophication. When combined with the increased occurrence of dry periods, they can lead to changes in the trophic states of water bodies (Braga & Becker, 2020; Rocha Junior et al., 2018; Figueiredo & Becker, 2018).

Reservoirs are essential in the northeastern semiarid region, particularly due to prolonged periods of water scarcity (Barbosa et al., 2012). Therefore, these water bodies frequently experience drying events, sometimes even reaching complete depletion. This decreases water availability and negatively impacts public water supply and irrigation. From 2012 to 2019, the Brazilian northeast faced one of the most severe droughts on record (Cunha et al., 2019; Marengo et al., 2016). Drought events result in decreased reservoir water levels and alter the physical-chemical conditions of the water. This can lead to consequences such as reduced water transparency, increased turbidity due to sediment resuspension, elevated nutrient concentrations, and higher phytoplankton biomass. These factors influence the trophic state of reservoirs and contribute to the intensification of eutrophication (Braga & Becker, 2020; Rocha Junior et al., 2018; Figueiredo & Becker, 2018).

After periods of drought, reservoirs undergo reflooding, which refers to the accumulation of water in the reservoir following intense rainfall. Reflooding can have both positive and negative effects on water quality and trophic state. The reflooding of reservoirs after a period of water depletion can also result in improvements in water quality and is considered a restoration measure, particularly for reducing potentially harmful cyanobacterial blooms in water bodies (Teferi et al., 2014). A positive relation can occur between the increased volume of water bodies and the decreased nutrient concentrations in reservoirs, as a function of water dilution (Costa et al., 2008; Leite & Becker, 2019).

However, a scientometric analysis showed that extreme events related to rainfall, such as heavy rain, floods and severe droughts, predominantly have adverse effects on water quality, leading to increased concentrations of suspended solids and nutrients, thus favoring eutrophication (Moreira et al., 2023). Intense and short-term rainfall during reflooding can cause significant soil erosion, leading to the transport of sediment particles into the reservoir and directly impacting water quality (Figueiredo & Becker, 2018). This transport of nutrients into the reservoir may prevent an improvement in the trophic state after reinundation, which may have the opposite effect and worsen the trophic state of the reservoir (Cortez et al., 2022).The aim of this study is to analyze the trophic state of two Brazilian semiarid reservoirs that experience regular periods of drying and reflooding, verifying limnological changes, including shifts in trophic state.

MATERIAL AND METHODS

Study area

For this study, Cruzeta and Dourado reservoirs were selected, located in the semiarid region of the Brazilian Northeast and part of the Piancó-Piranhas-Açu basin (Figure 1), Seridó sub-basin. The semiarid region of Brazil has a BS'h' (steppe-like) tropical climate (Alvares et al., 2014) and has an annual rainfall of around 446 mm, a rainy season between February and April, and average annual temperatures of 27.5°C, with a maximum of 33°C, in addition to having an average annual relative humidity of 64% (Agência Nacional de Águas, 2016).

The Piancó-Piranhas-Açu basin has a drainage area of 43,683 km^2, partially inserted in the states of Paraíba (60%) and Rio Grande do Norte (40%) of which 69% are in urban centers and 31% in rural areas (Agência Nacional de Águas, 2016). The basin is cover predominantly by the caatinga biome. The predominant types of soil are the chromic luvisol and the litholic neosol, being properly developed soils and saturated by bases (Agência Nacional de Águas, 2016). The land use and occupation in the seridó sub-basin is mostly formed by sparse caatinga (Rocha Junior et al., 2023).

The Cruzeta reservoir covers a total area of 6.16 km^2 and has a maximum capacity of 23 hm^3, while Dourado covers a total area of 4.69 km^2, and has a maximum capacity of 10 hm^3.

The maximum depth of Cruzeta and Dourado are 15 m and 10 m respectively. Cruzeta reservoir was built in 1929, while Dourado Reservoir was built in 1982. Both reservoirs are used for water supply, animal watering, irrigation, fishing, and recreation (Agência Nacional de Águas, 2016).

Meteorological and volumetric data

The monthly rainfall was provided by the Empresa de Pesquisa Agropecuária do Estado do Rio Grande do Norte (EMPARN). To show the variations in the volume of the reservoir during the study, the Agência Nacional de Águas (ANA) was consulted through the Reservoir Monitoring System - RMS, and the values were converted into percentages.Sampling and water quality analysis

Water samples were collected monthly at the only sampling point, located near the dam, which is also the deepest point in the reservoirs, near the water intake for domestic supply. The collected water were samples composed of the integrated epilimium and a single point in each of the reservoirs. For each of the reservoirs, two periods of analysis were established, before a complete drying (water depletion) (Period I) and after drying with water renewal. (Period II). For Cruzeta: Period I – May to October 2016; Period II - March to August 2017. For Dourado: Period I - April 2016 to March 2017; Period II - May 2019 to March 2020.

Temperature and dissolved oxygen were measured in situ using an oximeter (Lutron DO-5519). The maximum depth was measured in the field using the depth gauge. The pH was measured with a portable pH meter. Electrical conductivity and measured using a conductivity meter (Tec-4MP), while turbidity was with a turbidimeter (PoliControl AP2000), respectively. For water transparency (Secchi) the Secchi disk was used. To analyze the total and fixed suspended solids, the water samples were filtered through glass fiber membranes with a porosity of 1.2 µm. Total suspended solids (TSS) and inorganic suspended solids (ISS) were defined by gravimetry, thus, due to the difference between TSS and ISS, organic suspended solids (OSS) are obtained (American Public Health Association, 2012).

The ascorbic acid method after oxidation with potassium persulfate (Valderrama, 1981; Murphy & Riley, 1962) was used to analyze total phosphorus (TP). Reactive soluble phosphorus was also determined by spectrophotometry, the samples were filtered through glass fiber (porosity of 1.2 µm) (Murphy & Riley, 1962). Chlorophyll-a was defined by extraction with 95% ethanol (Jespersen & Christoffersen, 1988).

Data analysis

The trophic state classification used in this study was based on Thornton & Rast (1993), because this classification was carried out specifically for the evaluation of eutrophication in semi-arid artificial lakes. To compare and identify statistically significant changes in the limnological variables, the Wilcoxon Test was performed. This test compared each variable studied between the different periods. Additionally, Pearson's Correlation analysis was conducted to determine whether there was a positive or negative linear relationship between all the variables studied in the two periods. These statistical analyses were performed using the R program version 4.0.4 (2023). To group the variables based on their behavior during the study periods, a cluster analysis was conductedusing the PC-ORD® v.6 program.

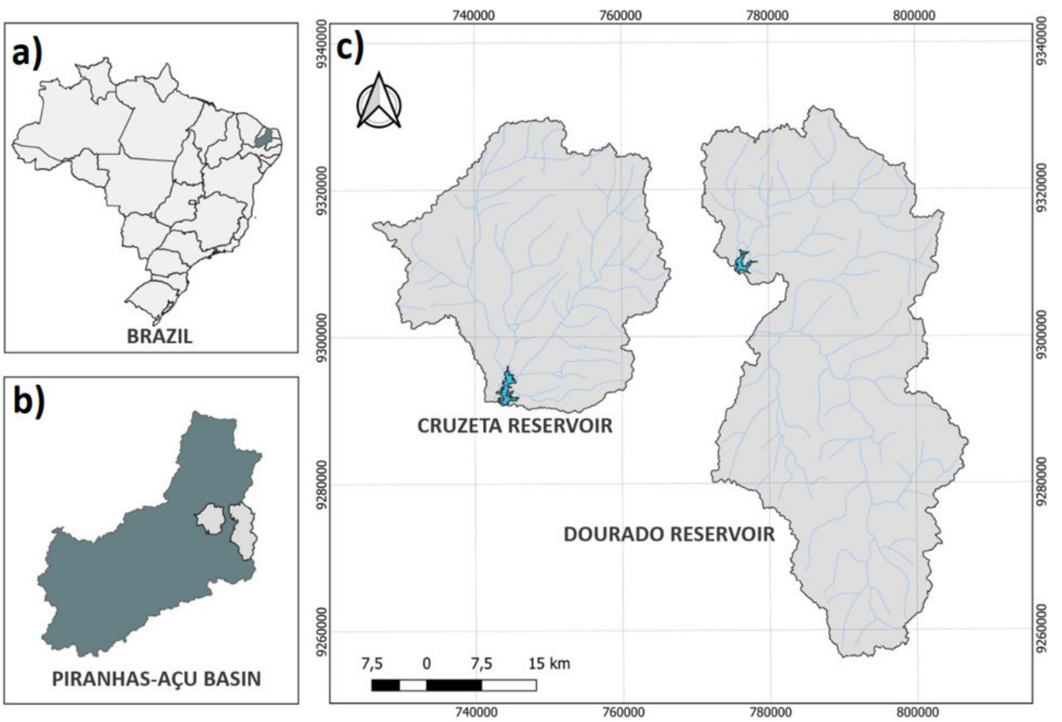

Figure 1. Geographiclocation map of the Cruzeta and Dourado reservoirs. Datum SIRGAS 2000, 24S zone. a) Study country: Brazil; b) Study basin: Piranhas-Açu; c) Cruzeta and Dourado reservoirs and their drainage basins.

RESULTS

Hydrological and meteorological scenario

The precipitation levels recorded in the reservoirs during the study periods were generally lower than the historical averages (Figure 2). As a result, the reservoir volumes decreased progressively, eventually reaching complete depletion. In Cruzeta, Period I had the highest accumulated volume value of the study, 2.3%, which corresponded to the beginning of Period I (May/2016), after which there was the period of water depletion, which corresponded to November/2016 to February/2017. The intense rains of February and March 2017 caused the reservoir to once again have a positive balance of accumulated volume (Period II), also having small volumes, with its maximum at 2.0%.

At the beginning of Period I (April/2016) the Dourado reservoir accumulated 58.8% of the total volume of water, being its maximum in this period; however, at the end of Period I (March/2017), the reservoir had 10.7% of its total capacity. In January 2018, the reservoir completely dried up, remaining so for 15 months. At the beginning of period II (May/2019), the reservoir accumulated water again, with a capacity of 27.6% of the total volume; at the end of period II (March/2020), the Dourado reservoir reached its maximum capacity.

Limnological scenario

The studied reservoirs showed different behaviors in the limnological scenario. In the Cruzeta reservoir, the volume values (Figure 3a) and all the physical variables (Turbidity, Secchi, ISS, and OSS) between the periods were similar and therefore showed no statistical difference (Figure 3). The maximum depth (Figure 3b) and water transparency (Secchi) (Figure 3c) averaged 1.2 ± 0.6m in Period I and 1.0 ± 0.4m in Period II, and, an average of 0.3 ± 0.1m in Period I and also 0.3 ± 0.2m in Period II, respectively. Regarding the chemical variables, only the electrical conductivity (EC) and dissolved oxygen (DO) data decreased statistically, comparing the two periods. EC obtained mean values of 914.7 ± 409.8 $\mu S.cm^{-1}$ in Period I and 339.0 ± 208.1 $\mu S.cm^{-1}$ in Period II ($p = 0.01$; Figure 3h). The DO presented means of 8.2 ± 3.0 mg L^{-1} in Period I and 4.8 ± 1.4 mg L^{-1} in Period II ($p = 0.03$; Figure 3i). The mean total phosphorus (TP) concentrations were 479.3 ± 229.1 µg L^{-1} in Period I and 712.3 ± 329.7 µg L^{-1} in Period II (Figure 3k). The mean values of the variable soluble reactive phosphorus (SRP) were 151.8 ± 69.9 µg L^{-1} in Period I and 208.6 ± 152.2 µg L^{-1} in Period II (Figure 3l). Chlorophyll-a showed mean values of 264.1 ± 464.7 µg L^{-1} in Period I and 41.26 ± 41.15 7 µg L^{-1} in Period II (Figure 3m). The trophic state of the reservoir remained eutrophic in both periods.

The Dourado reservoir showed a higher accumulated volume in Period I, being significantly different from Period II ($p = 0.02$) (Figure 3a). The maximum depth was greater in Period II, (average value of 4.8m ± 1.8m), being significantly different from Period I ($p = 0.0005$), with 1.2m ± 0.2m as an average value (Figure 3b). Water transparency (Secchi) and temperature did not show significant variation between periods (Figure 3c and 3d). Turbidity in period II (average 8.4 ± 4.6 NTU) was significantly different from period I (average 41.0 ± 74.5 NTU; Figure 3e). Inorganic and organic suspended solids did not vary significantly between the periods (Figure 3f; 3g).

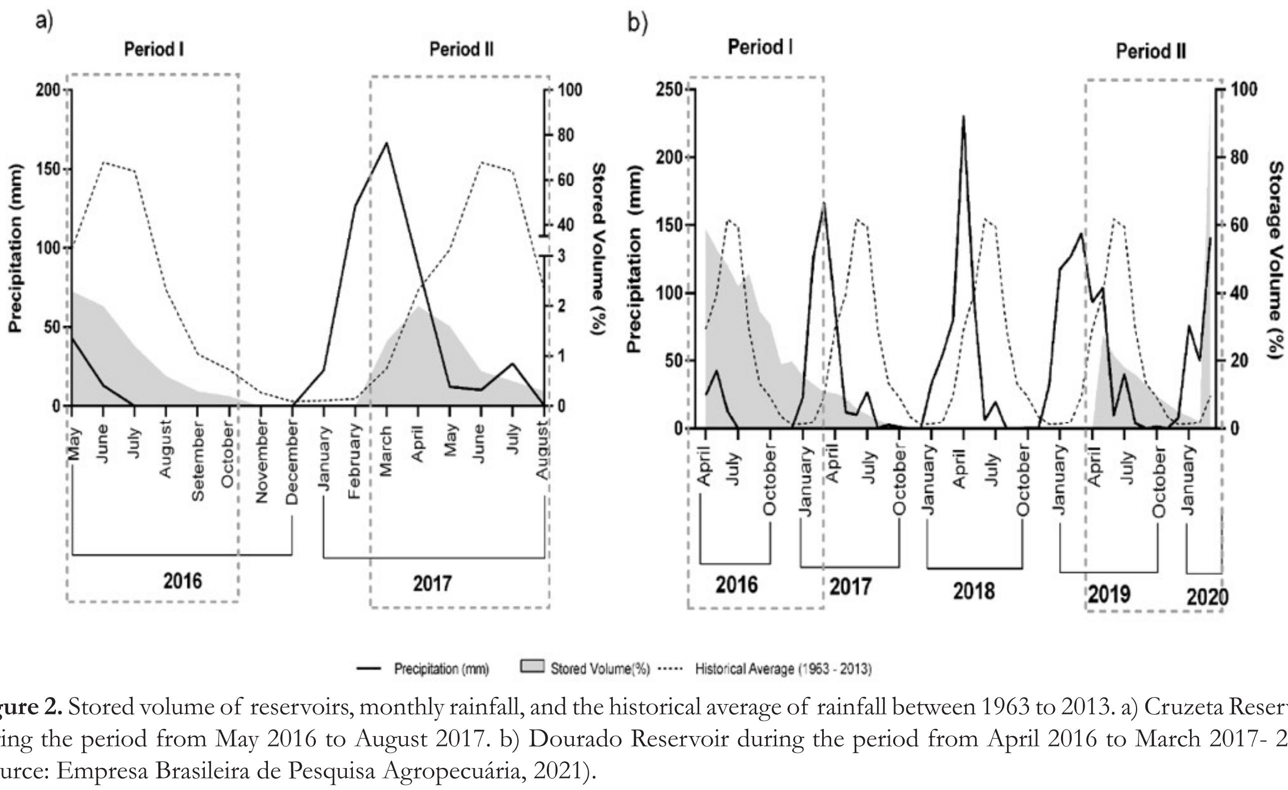

Figure 2. Stored volume of reservoirs, monthly rainfall, and the historical average of rainfall between 1963 to 2013. a) Cruzeta Reservoir during the period from May 2016 to August 2017. b) Dourado Reservoir during the period from April 2016 to March 2017- 2020 (Source: Empresa Brasileira de Pesquisa Agropecuária, 2021).

In the Dourado reservoir, the EC in Period I (average 284.3 ± 130.1 $\mu S.cm^{-1}$) was significantly different from Period II (average of 171.0 ± 81.3 μS.cm-1; Figure 3h). The pH presented higher values in period I, with an average of 7.6 ± 0.5, while in period II, the reservoir exhibited an average of 7.0 ± 0.8, and significantly different ($p = 0.04$; Figure 3i). DO did not vary significantly between Period I and II ($p = 0.83$; Figure 3j).

Total phosphorus showed high values in both periods, but there was no significant difference between them ($p = 0.74$; Figure 3k). SRP showed higher values in the period I, with an average of 84.31 ± 57.6 $\mu g.\ L^{-1}$, being significantly different from period II ($p = 0.01$), which presented an average of 39.78 ± 20.8 $\mu g.\ L^{-1}$ (Figure 3l). Chlorophyll-a, on the other hand, showed higher values in period II, with an average of 44.8 ± 24.0 $\mu g.\ L^{-1}$, being significantly different from period I ($p = 0.0003$), with a mean of 12.6 ± 5.5 $\mu g.\ L^{-1}$ (Figure 3m). the Dourado reservoir was classified as mesotrophic in Period I, while in Period II it was considered eutrophic.

The limnological variables of the Cruzeta reservoir were positively correlated (Figure 4a). Maximum depth and water transparency were positively correlated (0.67). EC was positively correlated with OD (0.92), OSS (0.74), ISS (0.78), chlorophyll-a (0.78), and turbidity (0.75). This variable was also correlated with ISS (0.99), OSS (0.99), and chlorophyll-a (0.99). SRP correlated with temperature (0.65) and total phosphorus (0.87), and chlorophyll-a, in addition to the variables already mentioned, showed a positive correlation with organic (0.99) and inorganic (0.99) suspended solids.

In the Dourado reservoir (Figure 4b), the volume showed a positive correlation (0.53) with total phosphorus, while the maximum depth was positively correlated with chlorophyll-a (0.64), and the water temperature was negatively correlated with the transparency of water (-0.45). The pH showed a positive correlation with electrical conductivity (0.74) and dissolved oxygen (0.45). OD also showed a positive correlation with electrical conductivity (0.44). As for turbidity, inorganic and organic suspended solids were negatively correlated with values of -0.50, -0.45, and -0.48, respectively, with water transparency.

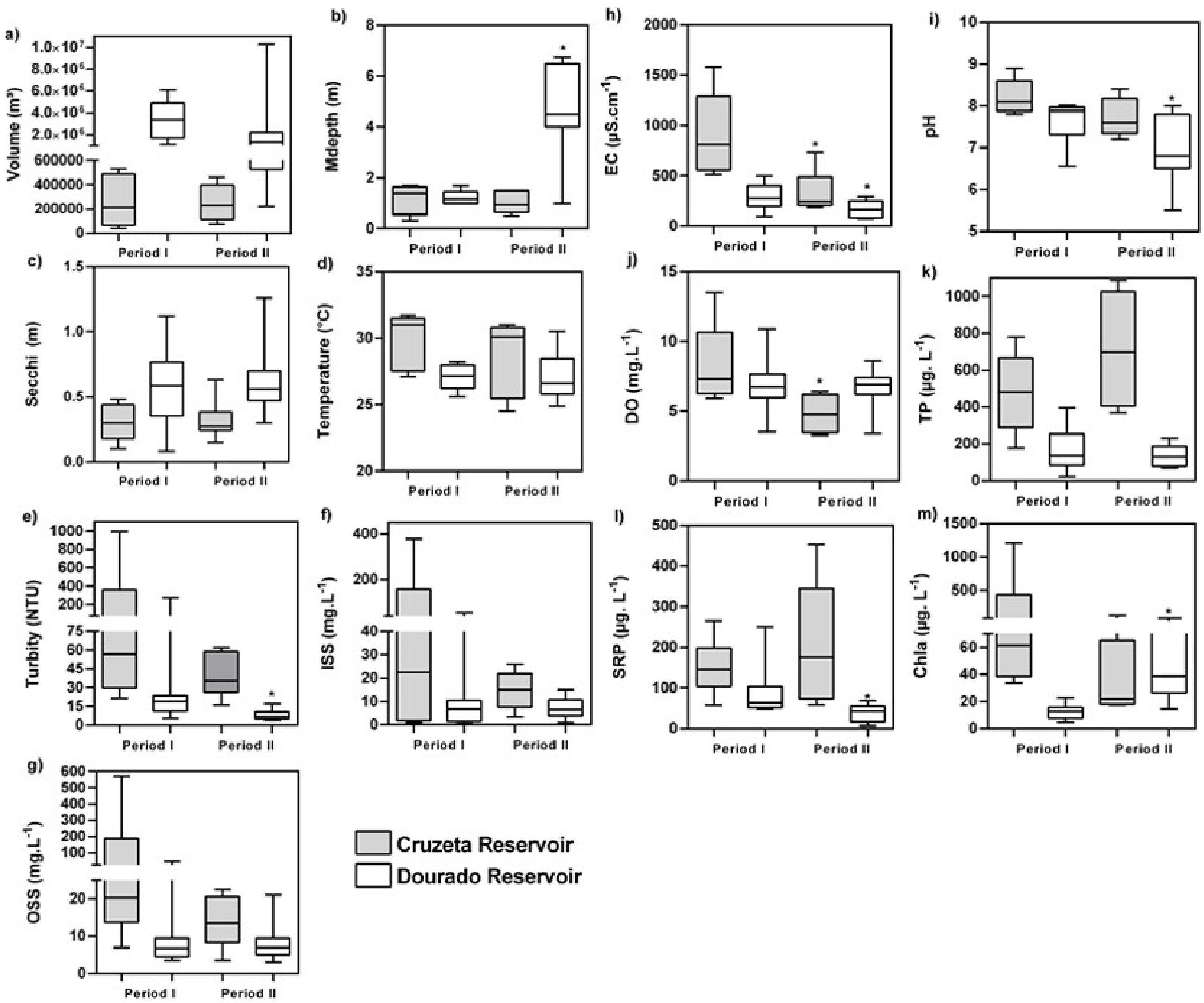

Figure 3. Boxplots for Periods I and II of the hydrological, physical, and chemical variables of the Cruzeta and Dourado reservoirs: a) Water Volume; b) Maximum Depth (Mdepth); c) Secchi transparency (Secchi); d) Water Temperature; e) Turbidity; f) Suspended Inorganic Solids (ISS); g) Organic Suspended Solids (OSS); h) Electrical Conductivity; i) pH; j) Dissolved Oxygen; k) Total Phosphorus; l) Soluble Reactive Phosphorus and m) Chlorophyll-a. *Significantly different from the period I ($p < 0.05$).

However, they were positively correlated with each other: turbidity with ISS (0.87) and OSS (0.85), and organic with inorganic suspended solids (0.92). Total phosphorus showed a negative correlation with water transparency (-0.42), a positive correlation with turbidity (0.52), SSO (0.42), and soluble reactive phosphorus (0.68).

Two-way Cluster analysis shows the similarity between environmental variables and monthly sampling for each reservoir (Figure 5). In the Cruzeta reservoir (Figure 5a) there was no evident separation between the sampled periods. However, two large groups were formed in the Dourado reservoir (Figure 5b), separating the studied periods. The first group contains samples from Period I, marked by the highest values of pH, turbidity, and SRP concentrations. The second group contains samples from Period II, having the highest values of maximum depth and chlorophyll-a.

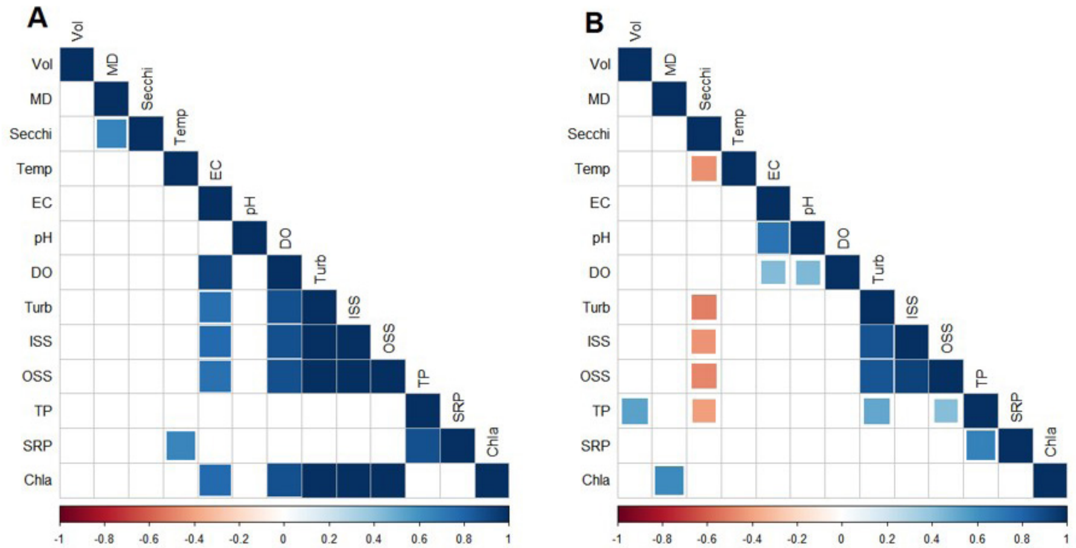

Figure 4. Pearson's correlation of the thirteen variables of the two periods in Cruzeta Reservoir (A) and Dourado Reservoir (B). Water Volume (Vol); Maximum Depth (MD); Secchi transparency (Secchi); Water temperature (T. water); Electrical Conductivity (EC); pH; Dissolved Oxygen (DO); Turbidity (Turb); Inorganic Suspended Solids (ISS); Organic Suspended Solids (OSS); Total Phosphorus (TP); Soluble Reactive Phosphorus (SRP) and Chlorophyll-a (Chla).

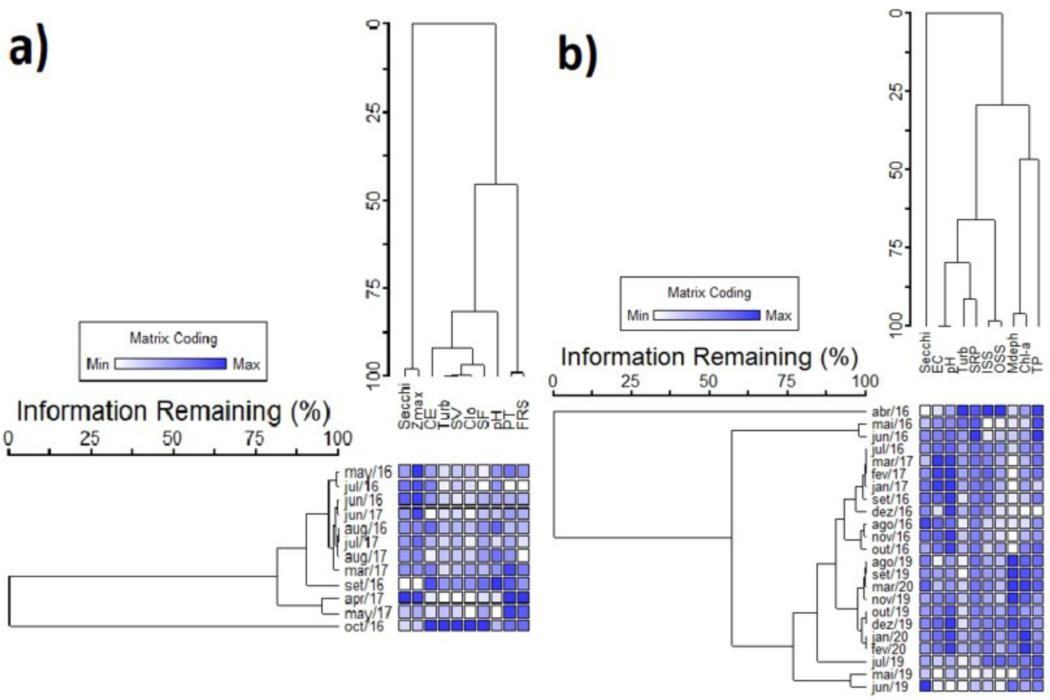

Figure 5. Cluster analysis of Cruzeta (A) and Dourado (B) reservoirs and limnological variables during periods I and II Variables: Secchi = water transparency; EC = electrical conductivity; SRP = Soluble Reactive Phosphorus; TURB = turbidity; OSS = organic suspended solids; ISS = inorganic suspended solids; TP = total phosphorus; Chl-a = chlorophyll-a; Mdepth = maximum depth.

DISCUSSION

The studied reservoirs exhibited different limnological resuts, despite experiencing similar hydro-meteorological conditions. Cruzeta reservoir maintained its eutrophic state consistently between the periods with high values levels of total phosphorus and chlorophyll-a. Dourado reservoir transitioned from mesotrophic to eutrophic, with higher values of chlorophyll-a in period II. These results suggest that reflooding may not effectively improve the symptoms of eutrophication.

Extreme events such as severe droughts and heavy rains directly impact the vulnerability of water bodies by altering their physical, chemical, and biological characteristics through fluctuations in water levels (Jeppesen et al., 2015; Moss, 2011; Santos et al., 2021; Wiegand et al., 2021; Moreira et al., 2023). These impacts have been observed in semiarid environments, leading to changes in the trophic state of water bodies (Brasil et al., 2016; Rocha Junior et al., 2018). The prolonged drought from 2012 to 2019, in the northeastern semi-arid region (Cunha et al., 2019), favored relevant changes in the water quality of the Cruzeta and Dourado reservoirs over the periods. Climate change projections indicate that such events will happen more frequently (Painel Intergovernamental sobre Mudanças Climáticas, 2014, 2019) and this can lead to a very high state of water degradation in these reservoirs (Marengo et al., 2009).

The prolonged drought event had a direct impact on the volume of the Cruzeta reservoir, which was very low in both periods. The decrease in rainfall, associated with high temperatures and the long water residence time in such systems contributes to the concentration of nutrients which in turn will maintain high algal biomass and higher values of electrical conductivity (Figueiredo & Becker, 2018; Santos et al., 2021). With the drought the reservoirs become highly susceptible to eutrophication and sedimentation, primarily due to the retention of nutrients (Barbosa et al., 2012; Jeppesen et al., 2015). This phenomenon explains the high concentrations of total phosphorus, electrical conductivity (EC), turbidity, solids and the higher values of chrolophyll-a observed in the Cruzeta reservoir.

During Period I in the Cruzeta reservoir, the water became increasingly concentrated with salts (as indicated by electrical conductivity - EC) and algal biomass (chlorophyll-a), as the volume gradually decreased due to the effects of the drought. The advanced stage of eutrophication was observed until after reflooding and was no improvement in the trophic state in the Cruzeta reservoir, which remained eutrophic. This corroborates our low DO values, which indicate the process of degradation of organic matter leads to the consumption of oxygen, and water bodies with advanced stages of eutrophication tend to have lower concentrations of dissolved oxygen (Cortez et al., 2022; Le Moal et al., 2019).

The maintenance of high phosphorus concentrations in the Cruzeta reservoir, despite the drougth, also can be attributed to intense rainfall events that lead to increased runoff, carrying nutrients into the water body (Mosley, 2015). Additionally, the internal load of phosphorus present in the sediment can contribute to the perpetuation of eutrophication. Under certain conditions of the aquatic system, such as high pH values and low dissolved oxygen levels, phosphorus can be released back into the water column from the sediment (Lima et al., 2022; Søndergaard et al., 2003). Although the accumulated volume was small (2%), another study in this reservoir shows that even with an increase in water volume of approximately 20%, there was no improvement, but an increase in the trophic state of the reservoir (Cortez et al., 2022). This was attributed to the entry of nutrients leached from the watershed by rainwater during the water renewal period. The shallow soils in the semiarid region are naturally prone to erosion processes, resulting in the loss of nutrients that eventually enter the reservoir with rainfall (Barbosa et al., 2012; Cortez et al., 2022).

In contrast to Cruzeta, Dourado exhibited different results as indicated by the cluster analysis. Period I was characterized by lower chlorophyll-a concentrations, high turbidity, and soluble reactive phosphorus (SRP) concentrations. The increase in volume during Period II resulted in a decrease in turbidity and pH, which can be attributed to dilution effects observed in previous studies, leading to a reduction in ion and solid concentrations (Braga & Becker, 2020; Cordeiro-Araújo et al., 2010; Fraga et al., 2012; Teferi et al., 2014). However, despite these changes, there was an acceleration of the eutrophication process in the second period, leading to a shift from a mesotrophic to eutrophic state. The acceleration of eutrophication in the Dourado reservoir can be comproved through the high TP concentrations ($>50 \mu g\ L^{-1}$), although they are not different between periods, and, mainly of high chlorophyll-a values (mean $> 40 \mu g\ L^{-1}$).

The contrasting patterns observed between soluble reactive phosphorus (SRP) and chlorophyll-a (Chla) in the Dourado reservoir can be attributed to the establishment of algal biomass in the water column. SRP is the easiest form of phosphorus assimilation for phytoplankton, and when nutrients are readily available, they can be rapidly captured by the algal community (Rangel et al., 2016; Reynolds 2006). Greater initial availability of nutrients can result in their rapid capture (Reynolds, 2006; Figueiredo & Becker, 2018). After water renewal, the gradual process of eutrophication is reflected in the high levels of soluble reactive phosphorus and chlorophyll-a. Similar behavior was observed in another reservoir within the same basin in the semi-arid region, where the trophic state deteriorated after water renewal (Cortez et al., 2022). However, a previous study on the Dourado reservoir (Leite & Becker, 2019) showed the opposite, indicating an improvement in water quality and trophic state after reflooding. It is important to note that these changes may be temporary if no mitigation and management actions are implemented in the reservoir and its basin.

Typically, rainy periods result in the dilution of nutrients in water bodies (Dantas et al., 2012), however in the Dourado reservoir, it is a common practice in the region to cultivate in moist soil when this reservoir dries up (Pinheiro et al., 2022). Furthermore, as it goes through long periods of drought, there is also natural growth of vegetation in addition to agricultural practices within the reservoir (Rocha Junior et al., 2023). Thus, with the arrival of new waters, all this vegetation is flooded and the process of degradation of this organic matter occurs, being able to increase the phosphorus present in the water.

In addition, studies show that the drying-flooding process of lake sediments may increase the potential release of phosphorus in the water body depending on environmental conditions (Dieter et al., 2015). Aeration and sediment flooding alter redox conditions, thus influencing phosphorus binding forms and its potential release from mobile forms (Dieter et al., 2015).

The greater the amount of mobile phosphorus, the greater the release of it into the water column, maintaining and worsening the symptoms of eutrophication (Kinsman-Costello et al., 2016).

Also, the precipitations can carry the phosphorus present in the soil to the reservoir (Cunha et al., 2022), so the rainy season can contribute to the transport of phosphorus to the water body. This process is exacerbated in the semi-arid region due to factors such as the presence of shallow soils and sparse vegetation, facilitating erosion processes and promoting diffuse pollution (Oliveira et al., 2021). The positive correlation between TP and turbidity, total suspended solids (OSS), and SRP can be attributed to the association of phosphorus with sediment particles that enter the reservoir through precipitation, thereby increasing turbidity levels (Medeiros et al., 2015; Santos et al., 2021).

Indeed, studies in semiarid regions have highlighted the impact of land use and anthropic activities in the riparian zones on the eutrophication process in aquatic ecosystems. Activities such as soil exposure and land use practices in these areas can lead to the accumulation of phosphorus (P) in the soil, increasing the risk of phosphorus transport to water bodies (Cunha et al., 2022; Cunha & Cunha, 2023). The combination of exposed soil in riparian zones with prolonged drought conditions further amplifies the vulnerability of reservoirs, potentially compromising their resilience upon the arrival of new waters.

Semiarid regions, such as the one in this study, require heightened attention to the water quality in reservoirs due to their crucial importance for the surrounding population. Therefore, effective reservoir and drainage basin management practices are necessary to mitigate the impacts of future extreme events such as prolonged droughts and intense rains, aiming for permanent improvements in water quality. Some examples of these practices are the protection of the riparian zone and sustainable practices in agriculture and livestock. In addition, as they go through constant periods of complete drying, a potential technique mitigation alternative could be the withdrawal of the exposed sediment.

It is important to emphasize the limitations of this study. The period of analysis differs between the two reservoirs due to varying durations of complete drying that each reservoir experienced. Consequently, our results refer only to single potential impacts and cannot allow a generalization to all reservoirs that experience flooding.

CONCLUSIONS

The results of the study indicate that reflooding did not lead to an improvement in the eutrophication symptoms of the studied reservoirs. In the case of Cruzeta reservoir, the trophic state remained eutrophic throughout the studies periods, with higher chrolophyll-a concentrations. This suggests that the reflooding process did not effectively mitigate the eutrophication processes in this period in Cruzeta reservoir. Nevertheless, it is crucial to emphasize that, despite the return of the rains, the reservoir's depth remained very low due to direct impact of the prolonged drought event on its water volume. Dourado reservoir, there was a significant change in the trophic state from mesotrophic to eutrophic after reflooding. The increase in algal biomass observed in period II indicates a deterioration of water quality and an acceleration of the eutrophication process. The presence of organic matter in the reservoir sediment, despite the practice to cultivate in moist soil and the and natural growth of vegetation, and the transport of phosphorus from the surrounding environment through precipitation are identified as potential factors contributing to the change in trophic state.

The findings emphasize the vulnerability of Cruzeta and Dourado reservoirs to prolonged drought and the potential loss of resilience upon the arrival of new waters. These results highlight the importance of implementing effective management strategies to mitigate eutrophication processes and protect water quality in semiarid regions.

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