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SPATIO-TEMPORAL VARIABILITY OF DISSOLVED OXYGEN IN A LARGE TROPICAL SEMI-ARID RESERVOIR

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Abstract

The monitoring of dammed waters is important for the management of watersheds, mainly in the semi-arid region due to the meteorological regime in the region. The goal of this research is to analyze the spatio-temporal variability of dissolved oxygen (DO) in the Castanhão reservoir, Brazil, highlighting its impact on fish farming. The data used refer to six sampling stations provided by the Ceará State Company of Water Resources Management. Hydrogen potential (pH), sality (S), temperature (T), and depth (z) of the water column profile of the reservoir between January 2016, and June 2021 were analyzed. The Kruskal-Wallis test with Post-Hoc analysis and the Mann-Kendall trend test were used. In the spatial analysis on the water surface, most of the DO values observed were above 4.0 mg.L^{-1}*, corresponding to the recommended standards for creating Nile romis niloticus). Spatial analysis at the bottom of the reservoir showed that the deeper stations have a lower concentration of DO. It was possible to group the analyzed stations into two groups in the surface analysis (CTN-20 and CTNs) and three groups in the bottom analysis (group A: CTN-20, CTN-24, and CTN-08, group B: CTN-23 and CTN-03, and group C: CTN-16). The seasonal analysis at the bottom showed lower DO availability in the rainy season. In the interannual analysis, cluster A deteriorated over the years concerning DO concentration.*

Keywords: aquaculture, dissolved oxygen, tropical semi-arid, water quality.

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Introduction

Arid and semi-arid regions represent 45% of the earth's surface (Li *et al*., 2014). These regions are subject to a marked lack of water resources due to low precipitation, high rainfall variability, and high evaporation (Yanfen *et al*., 2019). In semi-arid northeastern Brazil, prolonged periods of drought directly impact economic development and pose risks to the region's water, energy, and food security (Marengo *et al*., 2017). The construction of reservoirs through the damming of non-perennial rivers is a common activity in this region to supply the lack of water during drought (Mamede *et al*., 2012; Paulino and Teixeira, 2012; Costa *et al*., 2021; Rabelo *et al*., 2021).

Dissolved oxygen (DO) concentration in reservoirs is paramount for water quality management. Dammed waters are subject to deterioration of their quality due to high average temperatures, longer water residence time Freire *et al*. (2009) and Bezerra *et al*.(2014), high evaporation, nutrient input from agriculture and domestic sewage Liu *et al*.(2011) and Pimenta *et al*.(2012) and volume reduction resulting from long periods of drought Freire *et al*.(2009) and Wiegand *et al*.(2021).

Due to the high seasonal and interannual variation of the inflow of water (Costa *et al*., 2021), tropical semi-arid reservoirs generally have large variations in water level and, consequently, are more prone to the release and resuspension of phosphorus from bottom sediments (Santos *et al*., 2016; Farias Mesquita *et al*., 2020; Rocha & Lima Neto, 2022). In China, the environmental factors that favored the release of phosphorus in a reservoir in the arid region followed the following ascending order: hydrodynamics > DO > pH > T (Lu *et al*., 2021). The DO threshold to trigger anaerobic phosphorus release is normally around 1.5 mg L^{-1} (Chapra & Canale, 1991). A high phosphorus concentration in the water column can lead to algal blooms, making the system more vulnerable to eutrophication (Lins *et al*., 2017; Lacerda *et al*., 2018).

Nile tilapia (*Oreochromis niloticus*) has great economic and social potential due to its easy reproduction, rapid growth, low production costs, and physiological ability to adapt to different environments and production systems (Vicente & Fonseca-Alves, 2013). The ideal DO range for Nile tilapia cultivation should be between 4.0 to 5.0 mg.L^{-1} in tropical reservoirs. Although tilapia is a species that supports a wide range of DO, this species is susceptible to diseases when frequently exposed to low concentrations of oxygen (Silva *et al*., 2015).

Thus, this research aims to analyze the spatio-temporal variability of DO at the surface and the bottom of Castanhão reservoir, the largest reservoir in the Brazilian semi-arid. The specific objectives are: (1) to statistically evaluate the spatial distribution of DO; (2) to analyze the interannual and seasonal variability of DO; and (3) to relate the DO with the conditions for rearing Nile tilapia on the surface of the reservoir.

Methodology

Study area

The study was carried out in the Castanhão reservoir (Latitude 5.50º S; Longitude 38.47º W) in the Hydrographic Region of the Middle Jaguaribe River, located in the semi-arid region of the State of Ceará, Northeastern Brazil (Figure 1). The Castanhão reservoir has a total storage capacity of 6.7 billion m³, with a normal operating capacity of 4.45 billion m³ (DNOCS, 2017).

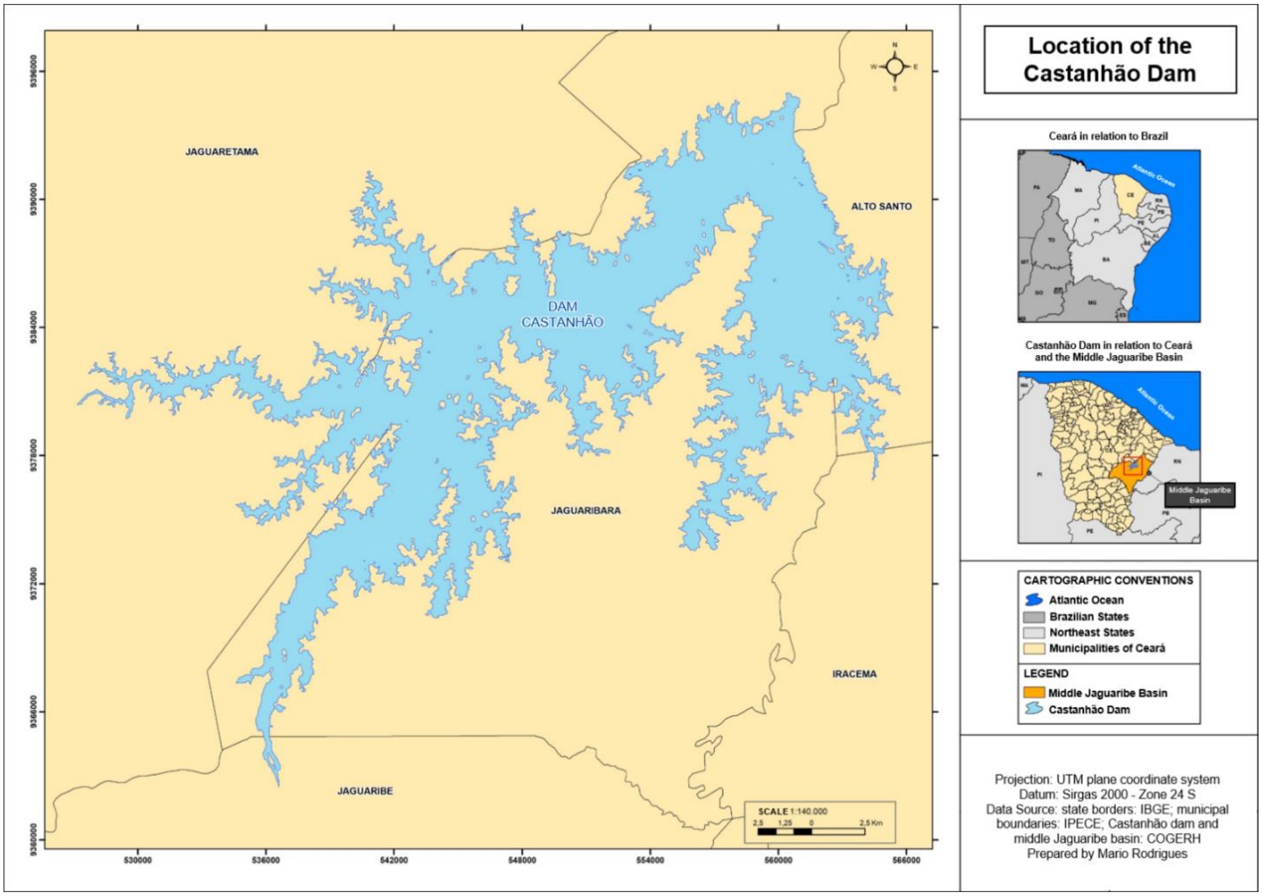

Figure 1. Location of the Castanhão Dam, Ceará, Brazil. *Fuente: Matos-Batista, 2021*

The climate in the region is considered hot semi-arid according to the Köppen climate classification (BSh'w'), with an average annual temperature of 27°C and an average annual rainfall of 757 mm during the last 80 years (COGERH, 2011). Between 2016 and 2018, and 2021, the annual precipitation observed in the Castanhão reservoir was below the historical average and around the average in 2019 and 2020 (Figure 2).

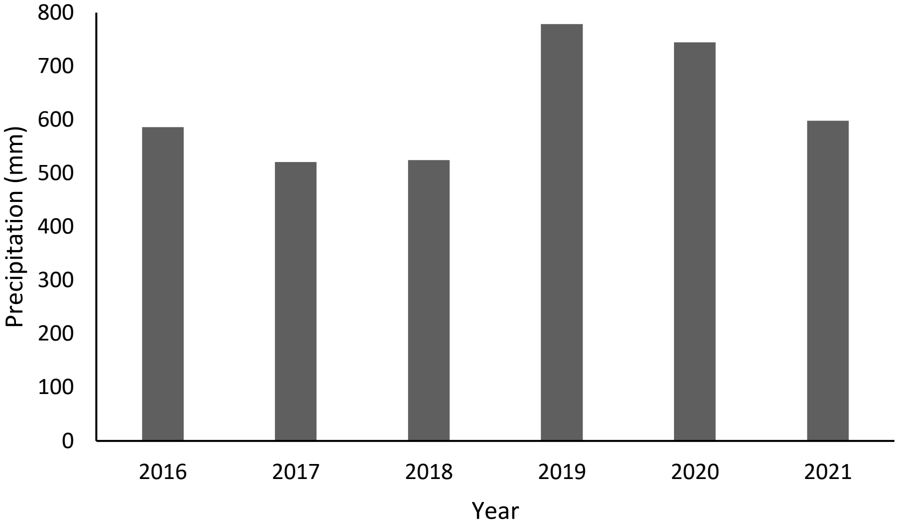

Figure 2. Annual Precipitation in the Castanhão reservoir between 2016-2021.

The region's rainy season is from January to Juny (Figure 3), with maximum values in March and April. The dry season lasts from July to December (Figure 3), with less rainfall occurring in September and October (Santos *et al*., 2016). Eastern Wave are responsible for the post-rainy season rains in the state of Ceará, as observed in July relatively high rainfall for the period (Ferreira & Mello, 2005). Figure 4 shows that the reservoir's lowest water levels were observed in 2016-2021, with around 7% of the total capacity (minimum: 2%, maximum: 16%) due to the intense drought and seasonal precipitation variation. Ceará went through a long period of drought between 2012 and 2017, resulting in a decrease in the volume of water in the state's reservoirs (Pereira *et al*., 2023).

The Castanhão reservoir is an important water reserve mainly intended for human supply in the Metropolitan Region of Fortaleza, capital of the State of Ceará, and in several municipalities downstream of the Jaguaribe River Valley, for drinking animals, irrigation, fish farming, and the regulation of the flow of the Jaguaribe River (COGERH, 2011).

Nutrient emissions to the Castanhão reservoir are due to natural and anthropic sources. The main anthropogenic sources are irrigated agriculture, livestock, fish farming, urban runoff, and solid waste disposal (Lacerda *et al*., 2018). They present themselves as potential contributors of nutrients to the hydrographic region of the Middle Jaguaribe River, contributing to the environmental imbalance and the increase in human exposure to contaminants (COGERH, 2011).

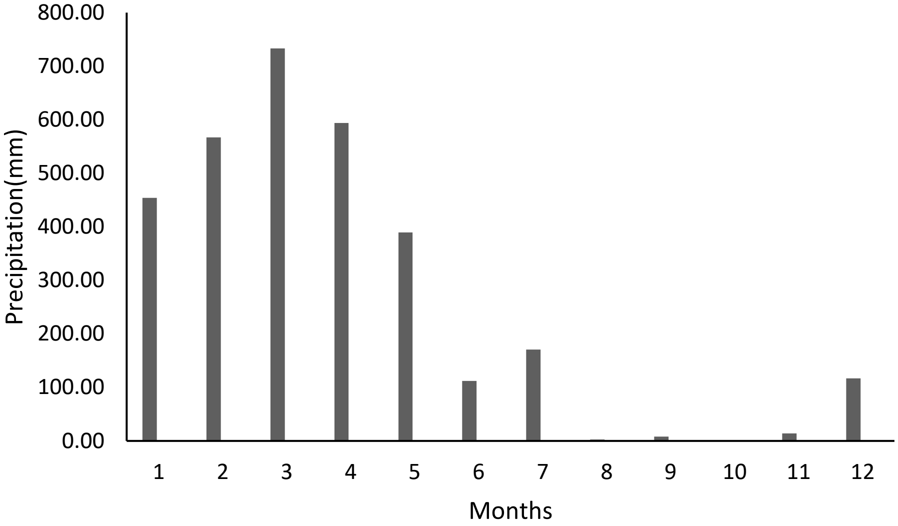

Figure 3. Precipitation seasonality in the Castanhão reservoir.

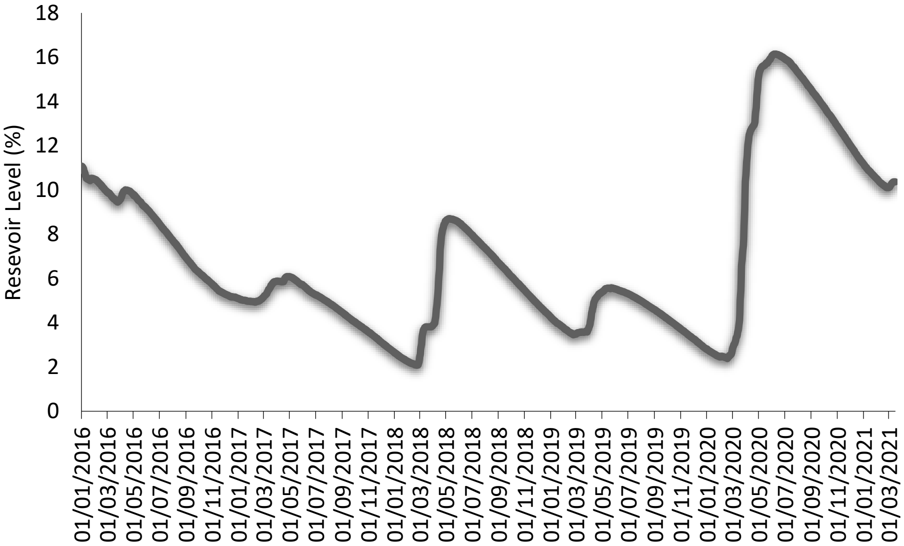

Figure 4. Variation in the volume of the Castanhão reservoir between 2016 and 2021.

Water quality data

The parameters evaluated in this study were DO, temperature (T), hydrogen potential (pH), salinity (S) and depth (z) of water column profiles carried out monthly in the reservoir between June 2016 and June 2021. There was no profile data in April 2020 and from February to May 2021. The Ceará State Company of Water Resources Management (COGERH, in Portuguese) provided all data.

In addition to the water quality parameters described above, the water temperature gradient and the temperature difference between the surface and bottom of the reservoir were used. The temperature gradient was determined by the ratio between the difference in temperatures at the bottom and surface and the difference in depth of measurements (equation 1).

$$\frac{\Delta T}{\Delta Z} = \frac{T_f - T_S \blacksquare}{Z_f - Z_S} \qquad \text{Equation (1)}$$

In the equation:
ΔT temperature difference;
ΔZ depth difference of the measurements;
T_f temperature of the reservoir at the bottom;
T_s temperature at the surface;
Z_f depth at which the measurement was taken at the bottom;
Z_s depth at which the measurement was taken at the surface.

Figure 5 shows the measuring stations where the Ceará State Company of Water Resources Management (COGERH~~)~~ performed the "in situ" profiling. They are CTN-20 (near the dam), CTN-24 and CTN-23 (near fish farm areas), CTN-03, and CTN-08 (left and main arm for the supply of water and nutrients), and CTN-16 (right and secondary arm for the supply of water and nutrients). Data from the surface and bottom of the reservoir were used from profiling, corresponding to a depth of 0.30 m from the surface and 1.0 m from the bottom, respectively. Table 1 presents the depth variation range at which profiling occurred during the study period and the maximum depth of the reservoir at the water quality sampling station.

It is important to note that, due to the long dry period experienced by the Castanhão Reservoir, some of the reservoir's profiling was performed at a depth of approximately 2.0 meters, following the methodology adopted by COGERH. Therefore, the surface and bottom data were measured under virtually the same conditions during some periods between 2017 and 2020. These measurements correspond to stations CTN-03 and CTN-23.

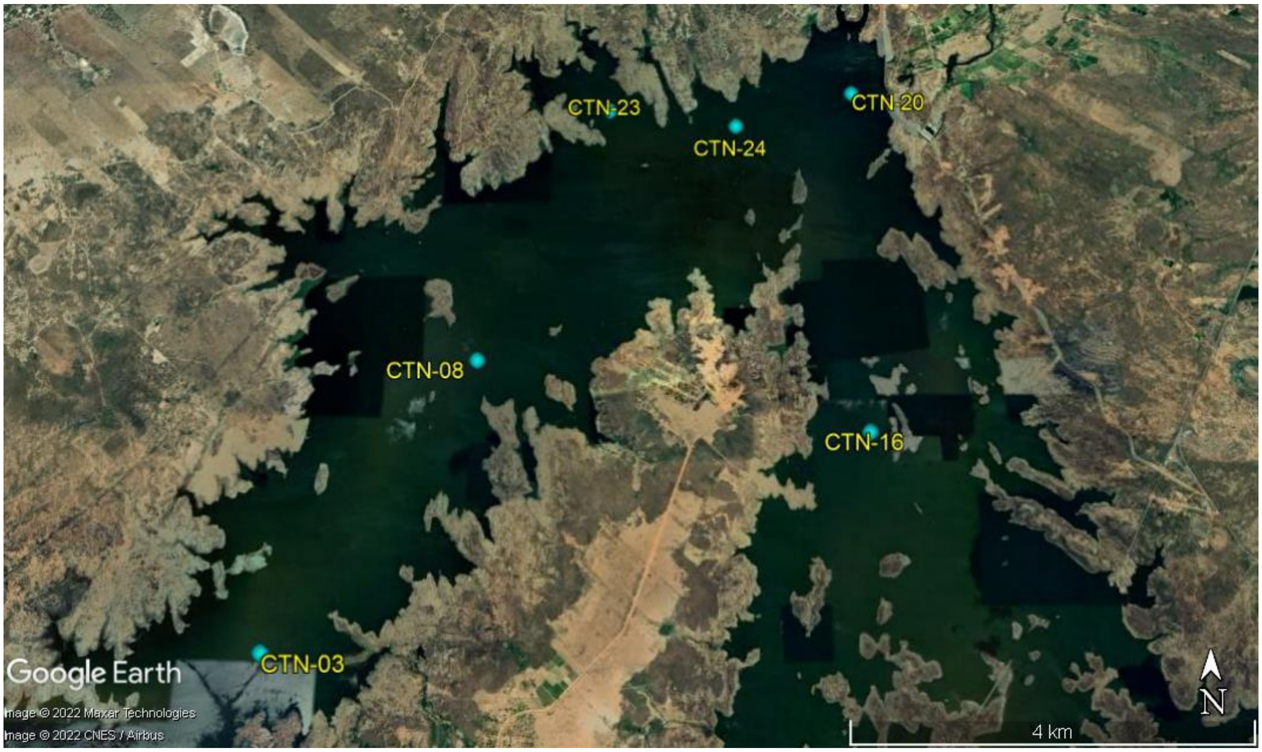

Figure 5. Spatial distribution of water quality measurement stations in the Castanhão reservoir (CTN-20, CTN-24, CTN-23, CTN-08, CTN-03, and CTN-16). *Fuente Google Earth, 2022*

Table 1. Depth range between 2016-2021 measurements and maximum depth for each sampling station.

Sampling stations	Measurement depth variation (m)	Maximum depth (m)
CTN-20	10.52 - 30.01	36.12
CTN-24	7.46 - 10.24	33.03
CTN-08	5.52 - 24.00	35.11
CTN-23	1.00 - 19.45	26.03
CTN-03	0.46 - 17.60	28.71
CTN-16	3.42 - 19.04	25.12

Spatial analysis

The spatial analysis included the measurement of DO, pH, T, S and z values. The difference in water temperature between the surface and bottom and the temperature gradient was also analyzed. The Shapiro-Wilk normality test (SW) was used to verify if the sample data from each monitoring station had a Gaussian distribution. Then, the Kruskal-Wallis test (KW) was applied to verify if the samples from the stations originated from the same distribution. If so, the Dwass-

Steel-Critchlow-Fligner test (DSCF) was used to assess whether there were significant differences between pairs of samples from each station. Clusters with statistical similarities were formed from non-significant ranks. A significance level of 1% was used in all analyzes. The free Jamovi software (https://www.jamovi.org/) was used to analyze the data collected.

Seasonal analysis

The seasonal analysis considered the DO variation between the rainy season, from January to June, and the dry season, from July to December. The same statistical procedure used in the spatial analysis, the application of SW, KW, and DSCF tests, was used to analyze the variation of DO between the rainy and dry seasons, both at the surface and at the bottom of the reservoir. However, this temporal analysis was based on a compartmentalized view of the Castanhão reservoir considering the DO spatial clusters.

Interannual analysis

DO box diagrams were created for the interannual analysis, and the Mann-Kendall test (MK) was applied considering the period of 2016-2020. The compartmentalization into clusters was again considered in the comparative evaluation. The MK test was applied to verify the existence of a monotonous, positive, or negative trend in the series. Therefore, the normality of the series was verified, and the existence of serial correlation was tested by applying the autocorrelation function (ACF). The analyzed stations were CTN-20, CTN-24, CTN-08, and CTN-23. Stations CTN-03 and CTN-16 were excluded due to missing data. XLSTAT, an MS Excel data analysis add-on (https://www.xlstat.com), was used to run the MK test.

Results

Spatial analysis

The statistical analysis showed that the DO at the CTN-20 station differed statistically from the other five sampling stations on the reservoir surface. It is possible to group the surface stations into two spatial clusters: CTN-20 and CTNs. The CTN-20 station had the lowest DO values among the six stations (Figure 6). At least 50% of the DO values were above 5.0 mg.L^{-1} (the minimum value for Nile tilapia rearing is 4.0 mg.L^{-1}) (Silva *et al*., 2015).

Regarding the DO at the bottom of the reservoir, the result obtained from the statistical tests allowed the grouping of stations into three spatial clusters: cluster A (CTN-08, CTN-20, and CTN-24), cluster B (CTN-03 and CTN- 23), and cluster C (CTN-16). The analysis of the DO box diagrams in Figure 7 shows that cluster A (CTN-08, CTN-20, and CTN-24) presented the lowest DO concentrations. Considering that the DO limit for releasing phosphorus from the sediment in an anaerobic situation is 1.5 mg.L^{-1} (Chapra & Canale, 1991), phosphorus release in the reservoir may have occurred, mainly in the cluster A region.

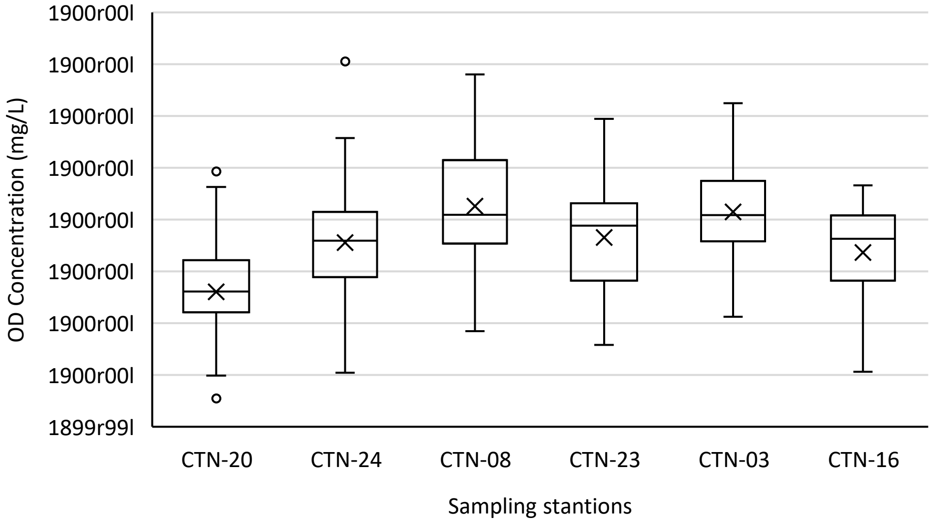

Figure 6. Box diagram for surface dissolved oxygen (DO) for each sampling station between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

Cluster A represents the stations with the greatest depth (Figure 8). The findings show a similar result to that found for DO at the bottom of the reservoir, except for the CTN-20 station, which was statistically different from the other five.

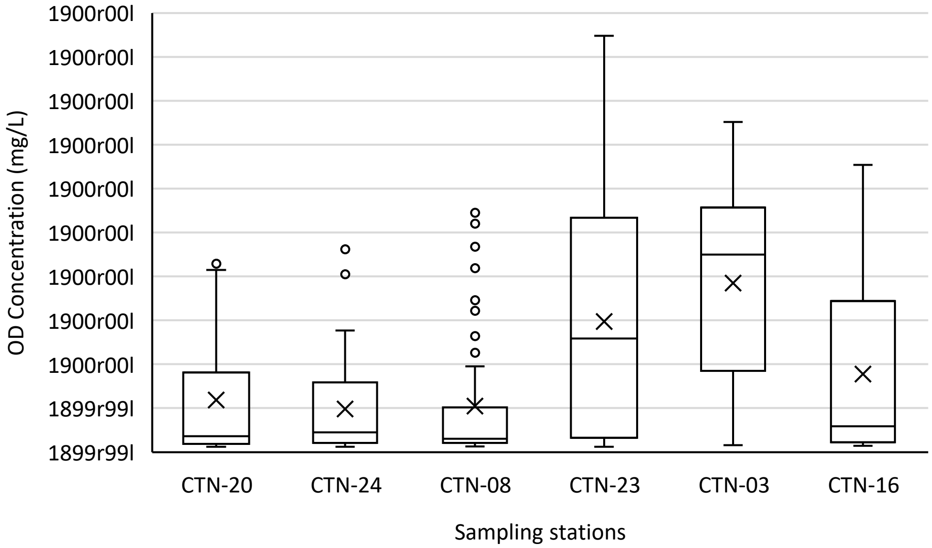

Figure 7. Box diagram for dissolved oxygen (DO) at the bottom for each sampling station between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

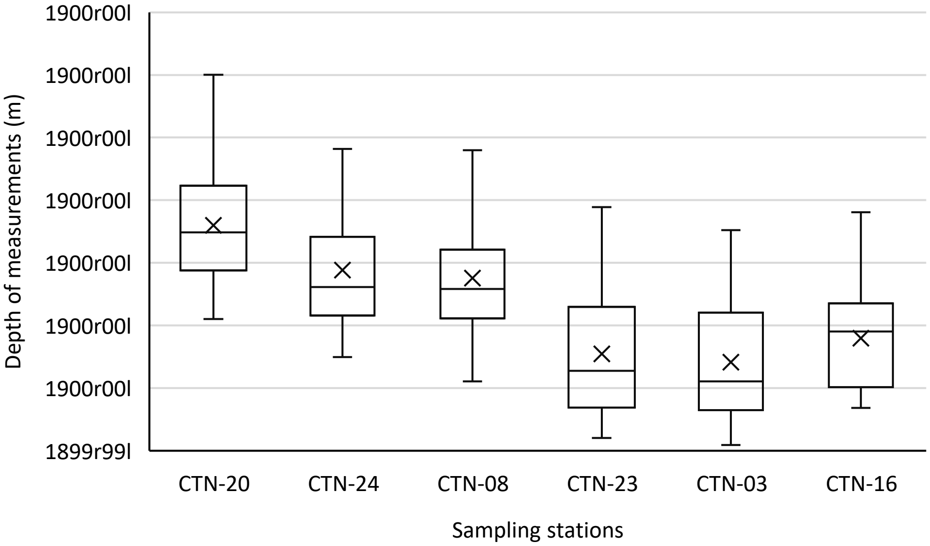

Figure 8. Box diagram for depth of bottom measurements for each sampling station between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

Stations CTN-03, CTN-08, CTN-20, and CTN-24 are positioned in the longitudinal profile of the reservoir that receives water from the Jaguaribe River, the main contributor of water and nutrients to the reservoir. However, station CTN-03 does not present low concentrations of DO, as observed in other stations. Possibly, the low concentrations of DO existing in cluster A are related to the reception of nutrients and organic matter from the Jaguaribe River that accumulates in the deepest regions of the reservoir. This environment provides greater DO consumption due to the decomposition of organic matter, which may cause to low DO concentrations in the bottom.

In fact, the depth of the reservoir has a great influence on the quality of the water. In these systems, transport processes occur preferentially along with the depth. Among the factors related to depth is the speed of heat transfer in the water mass, the energy of the winds that cannot be enough to mix the water column, and the process of thermal and chemical stratification (Cunha & Ferreira, 2013; Bezerra *et al*., 2014; Costa *et al*., 2016; Rocha and Lima Neto, 2022).

The existence of thermal stratification hinders the exchange of matter between the upper and lower water column, causing a prolonged anaerobic reduction state. This causes the nutrients from the sediment to continue to be released into the water column, causing the deterioration of water quality (Lima Neto *et al*., 2022). In a study carried out at the Castanhão reservoir, nutrient accumulation was found in deeper monitoring stations (Santos *et al*., 2016).

The comparison test result for water temperature on the reservoir's surface showed that CTN-20 was statistically different from CTN-08, CTN-03, and CTN-23. A similar finding was found concerning the bottom temperature, showing that CTN-20 differed from CTN-03 and CTN-23 and that CTN-03 and CTN-24 differed from each other. The surface T-box diagram (Figure 9) and the bottom T-box diagram (Figure 10) show that the water temperatures at the surface and bottom were similar.

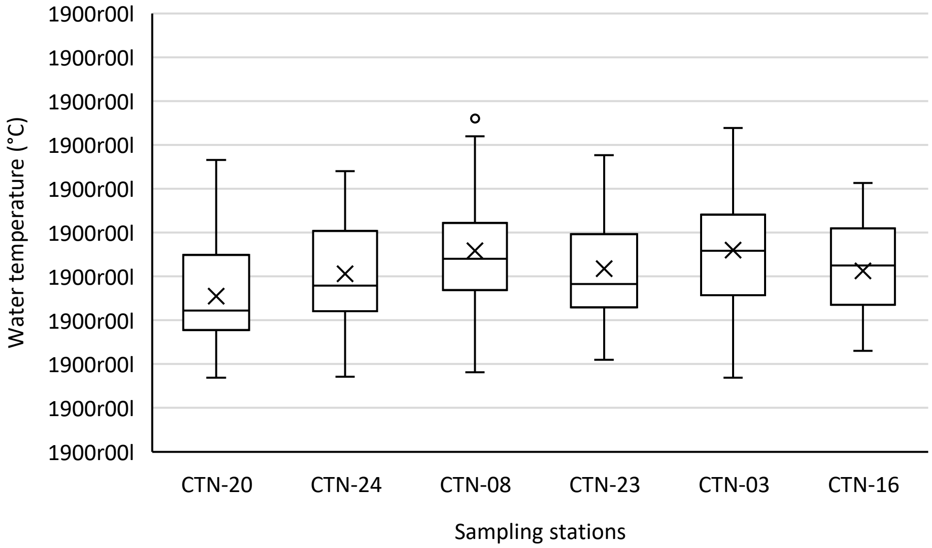

Figure 9. Box diagram for surface water temperature (T) for each sampling station between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

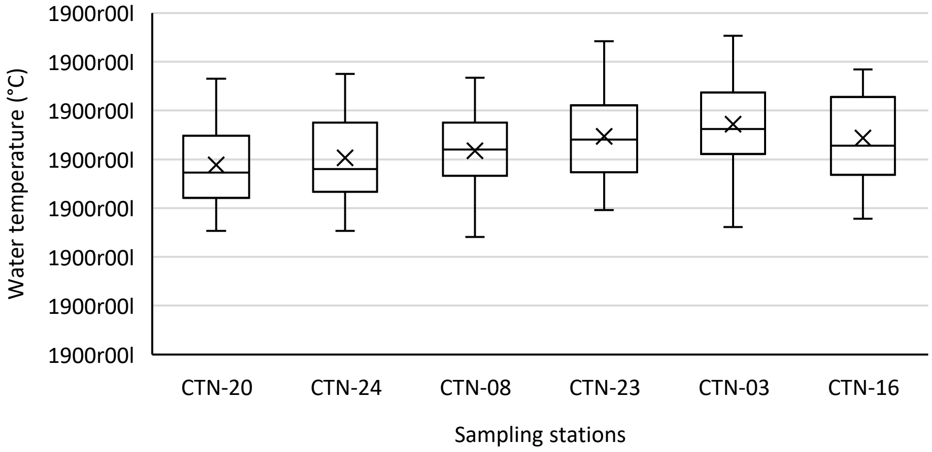

Figure 10. Box diagram for water temperature (T) at the bottom for each sampling station between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

It was impossible to explain the spatial variation of DO at the surface and the bottom of the reservoir through the statistical tests and box diagrams performed using water temperature data. The temperature gradient (Figure 11) and the temperature difference (Figure 12) were then analyzed to explain the spatial variation of DO at the bottom of the reservoir. The results showed different patterns from those found at the bottom of the reservoir. The low DO concentrations at the bottom of the reservoir in cluster A are possibly related to the greater depth found in the stations in this cluster, which allows the formation of a lower water mass in a prolonged anaerobic reduction state.

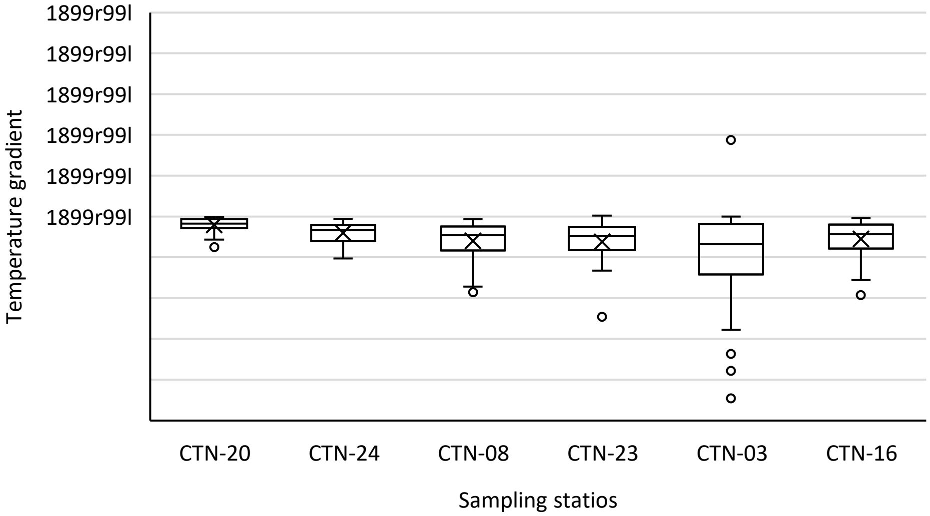

Figure 11. Box diagram for temperature gradient for each sampling station between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

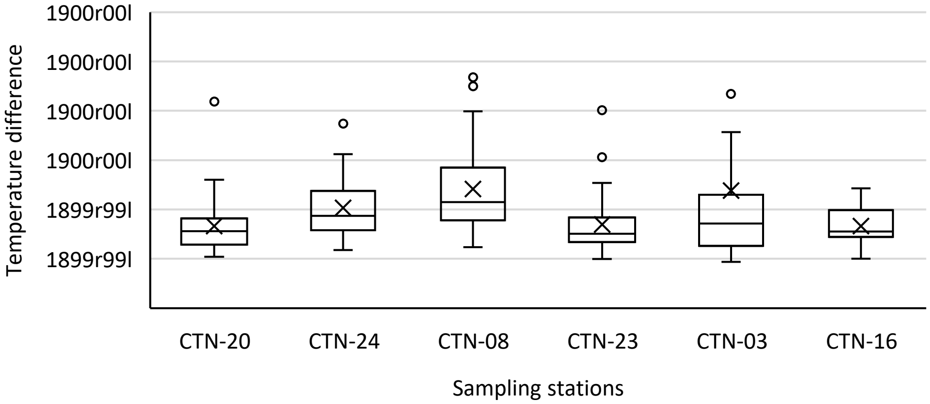

Figure 12. Box diagram for temperature difference (surface-bottom) for each sampling station between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

The results of the statistical tests for surface pH were similar to those found for surface DO, making it possible to divide the stations into two clusters: CTN-20 and other CTNs. The CTN-20 cluster had the lowest pH (Figure 13), and the lowest DO concentrations (Figure 6). Concerning the pH at the bottom of the reservoir, the statistical tests showed similar results to those found for DO at the bottom. The CTN-16 station did not show consistent results in the tests, being placed in a separate cluster. The pH box diagrams (Figure 14) show that all stations analyzed had pH values below 8.0, which characterizes an acidic to a neutral environment.

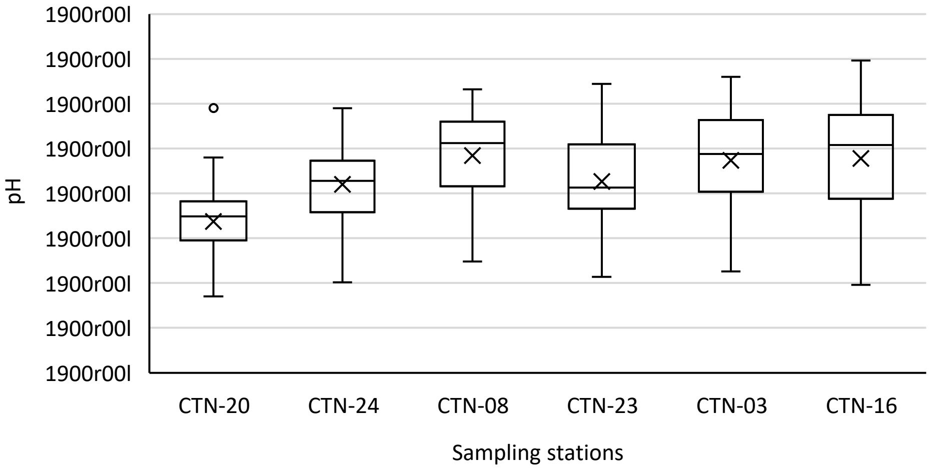

Figure 13. Box diagram for surface hydrogen potential (pH) for each sampling station between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

DO and pH values indicated a favorable environment of phosphorus release from the Castanhão reservoir sediment in cluster A (CTN-20, CTN-24, and CTN-08), mainly around CTN-08, which had the lowest DO value (below 1.0 mg.L^{-1}) (Figure 7). Further analysis involving temperature, pH and DO is required to confirm the release of phosphorus from the reservoir sediment. In another study carried out in a reservoir in the northeastern semi-arid region, it was found that phosphorus was released from the sediment in a range of 1.0 to 5.0 mg.L^{-1} associated with different T and pH conditions, equal to 6, 8, and 10. However, the greatest phosphorus release occurred in an anoxic environment (DO < 1.0 mg.L^{-1}), at pH=10 and T=32ºC (Cavalcante *et al*., 2021).

The statistical tests and box plots performed with salinity failed to explain the spatial variation in DO at the surface and bottom of the reservoir. Comparison tests for surface (Figure 15) and bottom (Figure 16) salinity data showed only station CTN-16 to be statistically different from stations CTN-20, CTN-24, and CTN-08. The box plot for salinity for the six stations analyzed presents a virtually homogeneous scenario for the entire reservoir, with salinity around 0.20°. In Brazil, CONAMA resolution 357/2005 considers water to be freshwater when it has a salinity greater than 0.05 ‰ and less than 30 ‰. In 2007, in a study on the sustainability of fish farming activities, a salinity of 0.30 ‰ was found in the Castanhão reservoir (Nascimento, 2007).

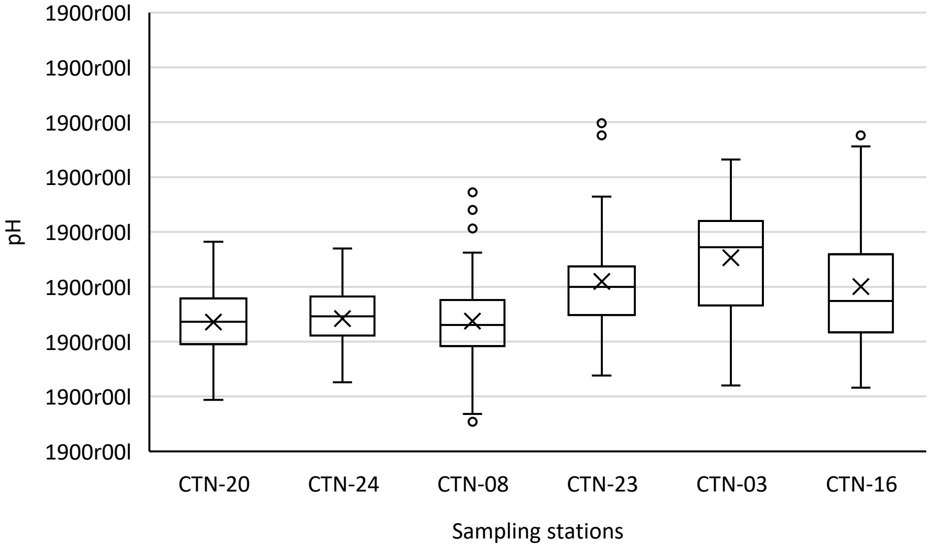

Figure 14. Box diagram for each sampling station's bottom's hydrogen potential (pH) between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

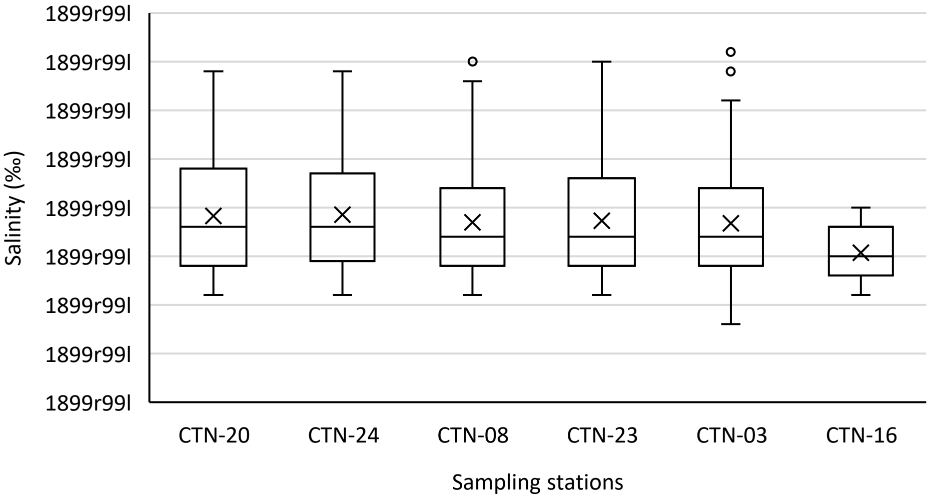

Figure 15. Box diagram for sufarce salinity (s) between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

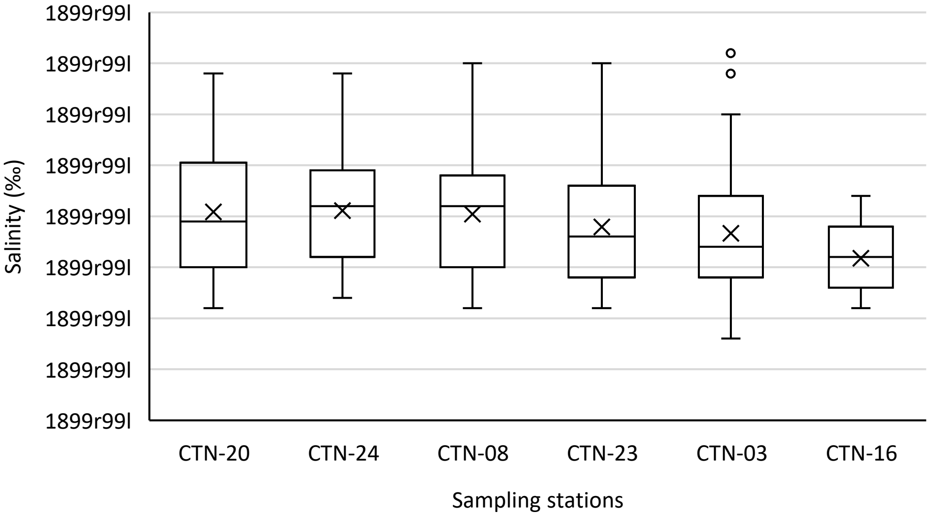

Figure 16. Box diagram for each sampling station's bottom's salinity (s) between 2016-2021. The location of the stations in the Castanhão reservoir is shown in Figure 5.

Seasonal analysis

The seasonal analysis was performed considering the compartmentalized reservoir in two surface clusters (CTN-20 and CTNs) and three bottom clusters: A (CTN-08, CTN-20, and CTN-24), B (CTN-23 and CTN- 03), and C (CTN-16). The KW test did not show significant differences between the wet and dry seasons at the surface, indicating a dominance of the spatial scale over the seasonal one (Figure 15). Consequently, it was not necessary to apply for the DSCF test. Similar results were found for the Castanhão reservoir, which presented DO concentrations in surface waters statistically equal across the seasons (Santos *et al*., 2016; Lacerda *et al*., 2018).

The lower DO concentrations in the rainy season may be related to the entry of organic matter brought by the rainwater. Aquatic ecosystems in the semi-arid northeast of Brazil tend to undergo severe physical and chemical changes during the rainy season. River inlets are responsible for most of the nutrients the reservoirs receive in the rainy season (Araújo *et al*., 2011; Paulino & Teixeira, 2012; Lu *et al*., 2021; Rocha and Lima Neto, 2022).

Clusters A, B, and C differed from each other between the rainy and dry seasons, which indicates equal importance of the spatial and seasonal scales for DO variation at the bottom. The DO values at the bottom were statistically lower in the rainy season, mainly in clusters A and C (Figure 18). Temperature and pH analyses are important to check phosphorus release. In tropical semiarid regions, other studies show phosphorus release during the rainy season

(Araújo *et al*., 2011; Santos *et al*., 2016; Lacerda *et al*., 2018; Lima Neto *et al*., 2022). Under anoxic conditions, phosphorus was released into the water column (Moura *et al*., 2020). In a reservoir in the semi-arid region of northeastern Brazil, a higher phosphorus concentration was observed during the rainy season, when the stratification environment and low concentrations of DO were more evident. This condition was related to the combination of external and internal loads (Lima Neto *et al*., 2022).

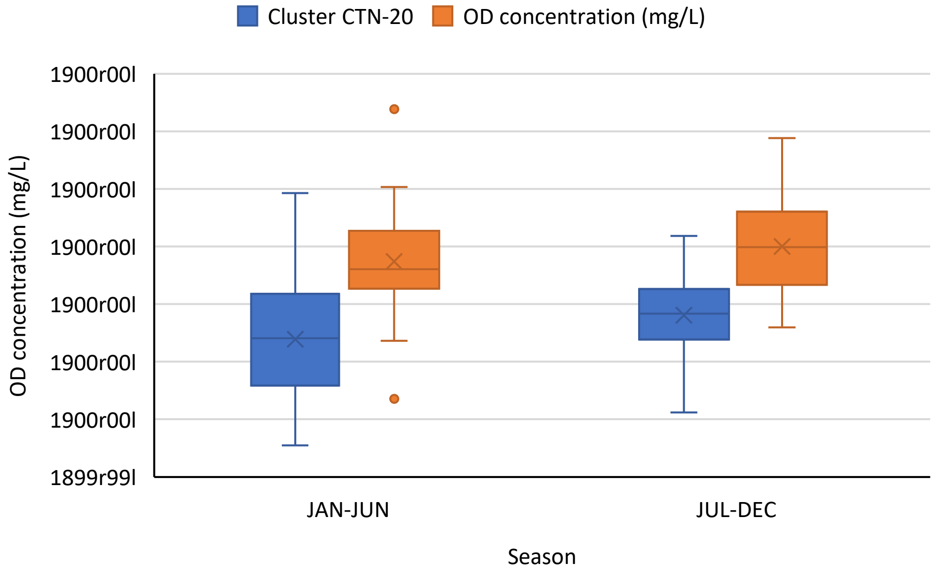

Figure 17. Box diagram for surface dissolved oxygen (DO) for CTN-20 and CTN clusters, between wet and dry seasons, 2016-2021.

This result may also be related to the thermal stratification of the reservoir. Low levels of hypolimnetic DO (hypoxia) were related to the thermal stratification of the water column in tropical reservoirs (Lima Neto *et al*., 2022). The vertical profile of the temperature in the reservoirs can vary by season (Santos *et al*., 2017; Lacerda *et al*., 2018) also due to the entry of colder waters (Meireles *et al*., 2007; Long *et al*., 2019). The rainwater, colder than the stored water, reaches the reservoir and quickly sinks to the bottom, thus generating a stratified environment due to the differences in water density caused by temperature (Araújo *et al*., 2011). The thermocline makes it difficult to oxygenate the water at the bottom of the reservoir because DO transport is compromised due to density difference and wind action (Meireles *et al*., 2007). This may explain the role of reservoir depth in the spatial variation of DO.

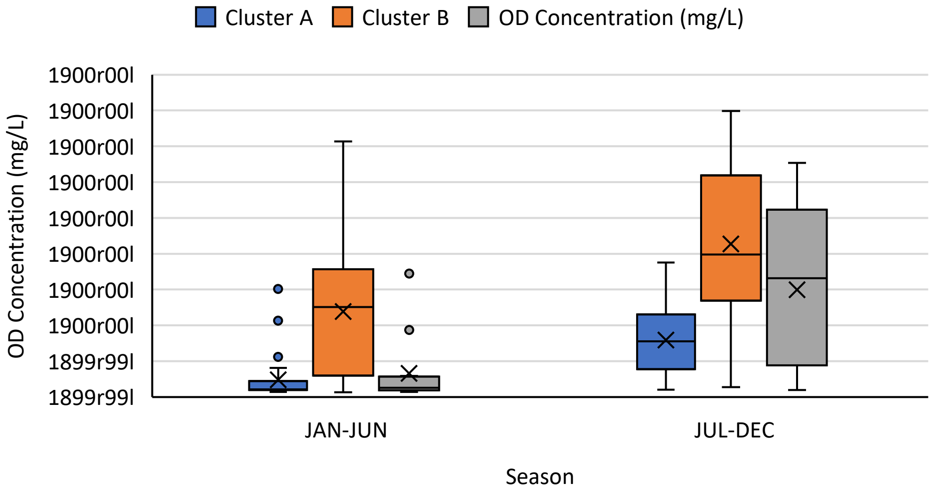

Figure 18. Box diagram for dissolved oxygen (DO) in the bottom for clusters A (CTN-08, CTN-20 and CTN-24), B (CTN-03 and CTN-23), and C (CTN-16) between the wet and dry seasons, 2016-2020.

Interannual analysis

The interannual analysis of the DO at the surface considered the CTN-20 and CTN clusters. The bottom of the reservoir was divided into three clusters: A (CTN-08, CTN-20 and CTN-24), B (CTN-03 and CTN-23), and C (CTN-16). The interannual analysis showed that, year after year, CTN-20 had the lowest oxygen levels (Figure 19).

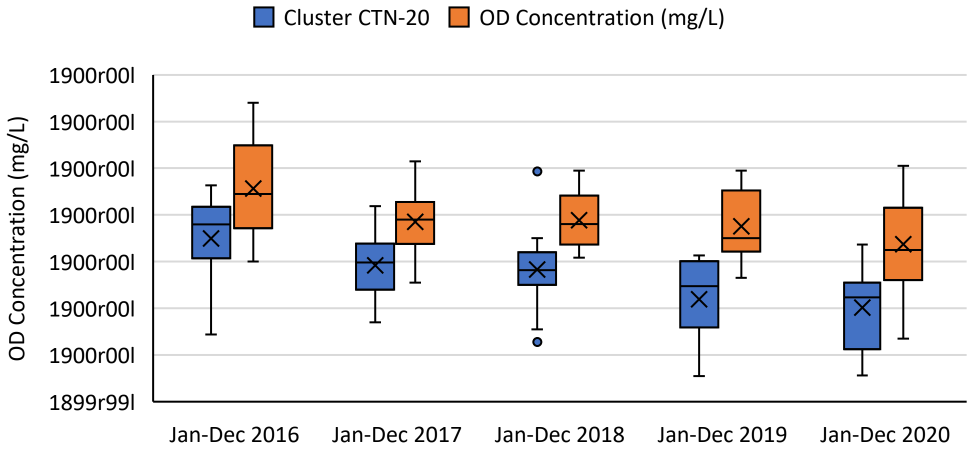

Figure 19. Box diagram for surface dissolved oxygen (DO) for CTN-20 and CTNS clusters between 2016-2020.

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It was possible to observe a decrease in the OD levels of both clusters (CNT-20 and CTNs), following the low level of the reservoir due to the prolonged hydrological drought (see Figure 3). Regarding the analysis at the bottom of the reservoir, cluster A (CTN-08, CTN-20, and CTN-24) presented the lowest DO concentrations, with most values below 1.5 mg.L^{-1} (Figure 20).

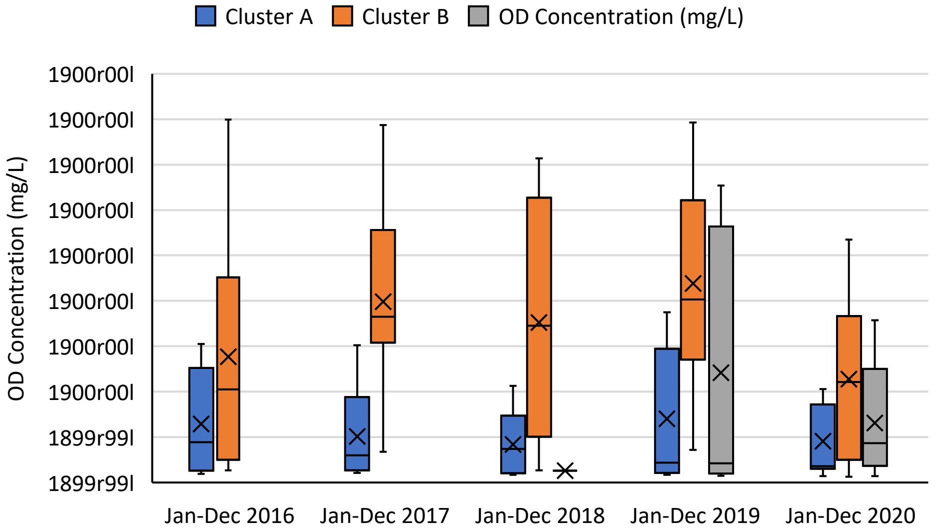

Figure 20. Box diagram for dissolved oxygen (OD) in the bottom for clusters A (CTN-08, CTN-20 and CTN-24), B (CTN-03 and CTN-23), and C (CTN-16) between 2016-2020.

The MK test indicated a negative trend (Kendall's: -0.520 and -0.366, respectively) of the DO concentrations in CTN-20 and CTNs . However, the two trends did not show statistical significance (p-value CTN-20 = 1,000, and p-value CTNs = 0.996 > α = 0.01).

The analyzes show a decline in DO levels in CTN-20, although the MK test showed a low significance. The tests demonstrate that the interannual variability is low concerning the spatial variation of DO at the surface and the bottom. Furthermore, seasonality is much more influential than the interannual DO variability. The MK test results for clusters A and B indicated a positive trend (Kendall's 0.003 and 0.182, respectively). However, there was no statistically significant trend in any of the clusters (p-value A = 0.500, p-value B = 0.102 > α = 0.01).

Conclusions

The analysis of DO variability in the Castanhão reservoir made it possible to divide the surface into two spatial clusters, the CTN-20 and the other CTNs. The CTN-20 cluster, closer to the weir dam, had the lowest DO concentration, although most values are within the ideal range for Nile tilapia rearing. Through the spatial analysis at the bottom of the reservoir, cluster A (CTN-08, CTN-20, and CTN-24) had the lowest DO concentration.

Based on the temperature and salinity values, it was not possible to relate these variables to the variation in the concentration of [DO]. Cluster A had the stations with the highest depth, this variable may be related to low DO concentrations. Additional analyses are essential to verify the release of phosphorus from the reservoir settling, especially in the region of cluster A. The spatial analysis indicated a dominance in relation the seasonal at the surface, as the statistical tests did not show significant differences between the rainy and dry seasons. The seasonal analysis at the bottom showed that the reservoir is more degraded in the rainy season.

The interannual analysis showed a marked decrease in DO concentrations on the reservoir's surface over the analyzed period. Regarding the data at the bottom of the reservoir, cluster A was the most deteriorated concerning the DO concentration. The findings are relevant for the public management of water resources, as it presents a methodological proposal that enables the grouping of sampling stations. Besides, it is possible to reduce time and costs using water quality data from the Castanhão reservoir, which can be replicated for other reservoirs in the semi-arid region.

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