Analysis of the physico-chemical relationship between losses of water, soil and soil nutrients in the water of the Farinha River – MA

Análise da relação fisico-química das perdas de água, solo e nutrientes do solo na água do rio Farinha – MA

Análisis de la relación físico-química entre las pérdidas de agua, suelo y nutrientes del suelo en el agua del río Farinha – MA

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ABSTRACT
Brazil has a vast reserve of water resources, but pollution from various sources and the effects of climate change have triggered a crisis in this sector. The assessment of water quality indices plays a crucial role in monitoring and understanding this issue, and the country has established its own standards and monitoring requirements to guarantee water quality. In addition, the physical-chemical relationship plays a fundamental role in the conservation of both soil and water. In this context, a study was carried out in the Farinha river basin, located in Maranhão, in the Cerrado biome, over an area of 55,338.12 hecta-res. Data was collected at ten different points along the river during the rainy and dry seasons. A Van Dorn bottle was used to collect water samples at vari-ous depths, which were analysed for pH, dissolved oxygen, electrical conducti-vity and temperature. Nutrients such as potassium, calcium, magnesium, sodi-um, silicon, nitrate and total phosphorus were quantified using filtration and spectroscopy techniques. The data obtained was tabulated and subjected to analysis of variance, with the means analysed using the Tukey test. This study reveals significant seasonal variations in the physico-chemical parameters of the water in the Farinha River in Maranhão, impacting aquatic life and water quality. This highlights the importance of continuous monitoring and manage-ment of these resources.

Keywords: Water Quality. Environmental Monitoring. Water Resources. Cerrado Maranhense.

RESUMO
O Brasil possui uma vasta reserva de recursos hídricos, porém, a poluição de diversas fontes e os efeitos das mudanças climáticas têm desencadeado uma crise nesse setor. A avaliação dos índices de qualidade da água desempenha um papel crucial no monitoramento e compreensão dessa questão, sendo que o país estabeleceu seus próprios padrões e requisitos de monitoramento para

garantir a qualidade da água. Além disso, a relação físico-química desempenha um papel fundamental na conservação tanto do solo quanto da água. Nesse contexto, realizou-se um estudo na bacia do rio Farinha, localizada no Mara-nhão, bioma Cerrado, em uma área de 55.338,12 hectares. A coleta de dados foi realizada em dez pontos diferentes ao longo do rio durante as estações chuvosa e seca. Utilizou-se a garrafa Van Dorn para coletar amostras de água em várias profundidades, as quais foram analisadas quanto a pH, oxigênio dis-solvido, condutividade elétrica e temperatura. A quantificação de nutrientes como potássio, cálcio, magnésio, sódio, silício, nitrato e fósforo total foi realiza-da utilizando técnicas de filtração e espectroscopia. Os dados obtidos foram tabulados e submetidos à análise de variância, sendo as médias analisadas pelo teste de Tukey. Este estudo revela variações sazonais significativas nos parâmetros físico-químicos da água no rio Farinha, no Maranhão, impactando a vida aquática e a qualidade da água. Assim, destaca-se a importância do monitoramento e gerenciamento contínuos desses recursos.

Palavras-chave: Qualidade da Água. Monitoramento Ambiental. Recursos Hídricos. Cerrado Maranhense.

RESUMEN

Brasil posee una vasta reserva de recursos hídricos, pero la contaminación de diversas fuentes y los efectos del cambio climático han desencadenado una crisis en este sector. La evaluación de los índices de calidad del agua desem-peña un papel crucial en el seguimiento y la comprensión de esta cuestión, y el país ha establecido sus propias normas y requisitos de seguimiento para ga-rantizar la calidad del agua. Además, la relación físico-química desempeña un papel fundamental en la conservación tanto del suelo como del agua. En este contexto, se realizó un estudio en la cuenca del río Farinha, situada en Mara-nhão, en el bioma del Cerrado, sobre una superficie de 55.338,12 hectáreas. Los datos se recogieron en diez puntos diferentes a lo largo del río durante las estaciones lluviosa y seca. Se utilizó una botella Van Dorn para recoger mues-tras de agua a distintas profundidades, que se analizaron para determinar el pH, el oxígeno disuelto, la conductividad eléctrica y la temperatura. Los nutrien-tes como potasio, calcio, magnesio, sodio, silicio, nitrato y fósforo total se cuan-tificaron mediante técnicas de filtración y espectroscopia. Los datos obtenidos se tabularon y se sometieron a análisis de varianza, analizándose las medias mediante la prueba de Tukey. Este estudio revela variaciones estacionales sig-nificativas en los parámetros físico-químicos del agua del río Farinha, en Mara-nhão, que afectan a la vida acuática y a la calidad del agua. Esto subraya la importancia de la monitorización y gestión continuas de estos recursos.

Palabras clave: Calidad del Agua. Monitoreo Ambiental. Recursos Hídricos. Cerrado Maranhense.

1 INTRODUCTION

Brazil, which holds 53% of South America's freshwater and 12% of the world's river flow, faces significant water pollution challenges. In urban areas, rivers and water bodies are contaminated by toxic substances and waste, impacting wildlife and human health (Hirata *et al.*, 2009; Silva Neto, 2022). Rural areas also suffer from water quality problems due to domestic and industrial sewage, solid waste, and agricultural fertilizers, which can make water unfit for consumption (Silva, Araújo, 2003; Daneluz, Tessaro, 2015).

Climate change is exacerbating Brazil's water crisis through increased flooding, extreme precipitation, droughts, and deteriorating water quality (Tundisi; Matsumura-Tundisi, 2015; Barbado; Leal, 2021). Assessing water availability requires assessing physical, chemical and biological properties, as well as the impacts of land use (Medeiros *et al.*, 2018; Rodrigues; Bueno, 2019; França *et al.*, 2019). Water quality indices, such as the Water Quality Index (WQI), are crucial for monitoring and understanding water quality, converting several parameters into a single number (Almeida and Schrwarzbold, 2003; Carvalho *et al.*, 2011; Silva; Cunha; Lopes, 2019).

The Water Quality Index (WQI) was adapted from the USA and is today the main measure of water quality in Brazil (Aguiar; Balduíno, 2021). Brazilian water quality standards are defined by Resolution 357 of the National Environmental Council (CONAMA), which establishes guidelines for the classification and discharge of effluents (Brazil, 2005; Alves *et al.*, 2008; Pimenta, Peña and Gomes, 2009). Understanding these factors is crucial to address the water crisis caused by climate change and human activities. Therefore, the objective of this study is to evaluate the impact of the physical-chemical relationship on the loss of soil, water and soil nutrients in the Farinha River channel, in Maranhão.

2 MATERIAL AND METHODS

The study was carried out in the Farinha - MA river basin, located in the

Tocantins - MA river basin, covering 55,338.12 ha in the Cerrado biome (Da Silva; Pereira, 2024). Ten points were selected along the river for data collection, starting near the Chapada das Mesas National Park and ending near the mouth of the Farinha River, where it meets the Tocantins River. Data collection took place during the rainy season (April) and the dry season (September). The level and characteristics of the waters of the Farinha River - MA vary due to the influence of the Estreito Hydroelectric Power Station, which alters the level and condition of the waters in the different seasons.

The following procedures were used to collect and analyse the water: samples were collected at two depths (1 metre and 2 metres) with a Van Dorn bottle and stored in sterile plastic bottles, cooled with ice. On-site analysis included measuring pH, dissolved oxygen, electrical conductivity and temperature with an AK88 multiparameter probe. The samples were filtered and prepared for nutrient analysis, including potassium, calcium, magnesium, sodium and silicon, using a multipoint emission plasma spectrometer (ICP-AES). Nitrates and total phosphorus were quantified using spectrophotometric methods, measuring absorbance at 415 nm and 885 nm, respectively.

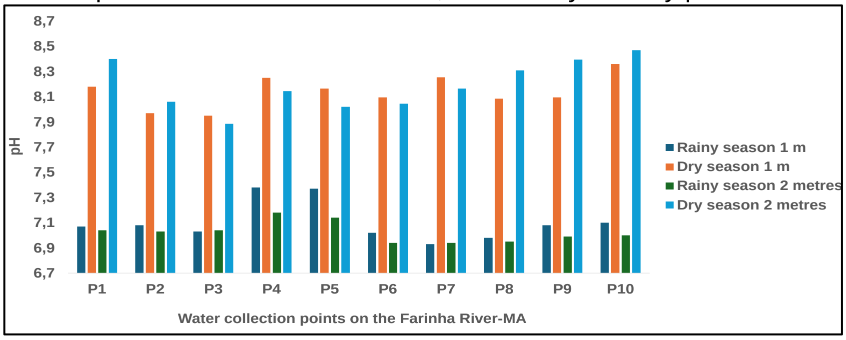
The data obtained was tabulated and statistically analysed. The means were subjected to analysis of variance and the Tukey test was applied at 5% probability, using Past 4.03 software for statistical analysis.

3 RESULTS AND DISCUSSIONS

The results obtained in the field at the collection points using the multi-parameter probe, at depths of 1 metre and 2 metres, during the rainy season and the dry season, show that there is a seasonal difference in the pH, Electrical Conductivity (µS.cm-^{1}) and Dissolved Oxygen (%) parameters, and a uniformity in the Temperature (ºC) data. The possible reasons for the difference in these parameters will be discussed below.

The pH values in the rainy season are lower, ranging from 6.9 to 7.4, and the pH values in the dry season were higher, ranging from 7.9 to 8.5. These low pH values in the rainy season may be due to the lower concentration of organic matter in the river water, unlike the dry season (Figure 1). This increase in pH during the dry period can be attributed to changes in environmental characteristics, because with the closure of the floodgates, the Farinha River has a more lentic behaviour and this condition favours the growth of phytoplanktonic microalgae, responsible for primary production that consumes CO_2 and can result in an increase in pH (Boyd, 1979; Lucena, 2022).

Figure 1: pH values of the water in the Farinha River -MA at the ten water collection points at depths of 1 metre and 2 metres, in the rainy and dry periods.

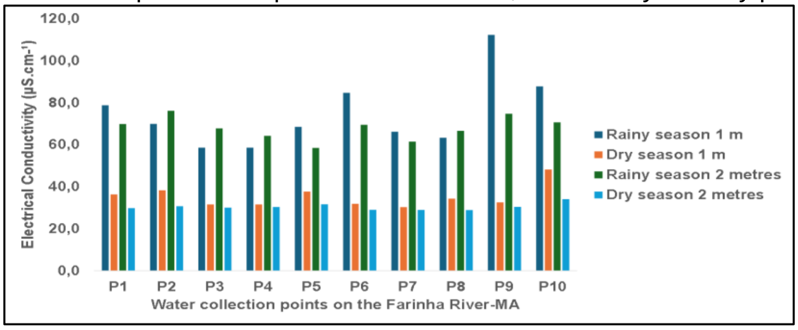


Source: Prepared by the authors (2024).

The presence of fulvic and humic acids from the degradation of organic matter can increase the acidity of river water, especially in areas with native vegetation (Bueno *et al.*, 2005; Souza, 2006; Lopes; Magalhães Jr, 2010). However, a study of the Catolé Grande river basin showed a small range of pH values between 6.23 and 7.16, contradicting the findings of this study (Barreto *et al.*, 2013). The pH is a measure of the acidity or alkalinity of water, being neutral at 7, alkaline above 7 and acidic below 7 (CETESB, 2024). The Farinha River was considered slightly acidic at points 6 and 7, while the other points varied between alkaline and neutral. During the dry season, the Farinha River had alkaline water. The pH levels observed in this study are within the range considered adequate for the protection of aquatic life in freshwater rivers, according to CONAMA Resolution 357/2005, which ranges from 6.0 to 9.0 for all freshwater quality classes (Barreto *et al.*, 2013).

Electrical conductivity in the Farinha River - MA varied more in the rainy season at both depths, ranging from 58.6 to 112.3 $\mu S.cm^{-1}$ at the 1 metre depth and from 58.5 to 76.1 $\mu S.cm^{-1}$ at the 2 metre depth. In the dry season and at a depth of 1 metre, electrical conductivity varied from 30.3 to 48.2 µS.cm-¹ and at a depth of 2 metres from 29.0 to 34.1 µS.cm-¹ (Figure 2).

Figure 2: Electrical conductivity values (µS.cm-¹) of the water in the Farinha River -MA at the ten water collection points at depths of 1 m and 2 m, in the rainy and dry periods.



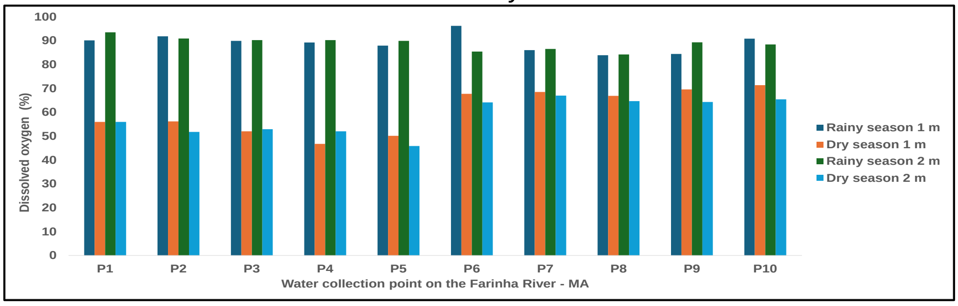
Source: Prepared by the authors (2024).

Water conductivity in tropical regions is influenced by the geochemical characteristics of the area, climatic conditions and land use (Von Sperling,2007; Esteves,2011; Piratoba *et al.*,2017). In the case of the Farinha River, higher conductivity values were observed during the rainy season at certain points, especially those close to ranches, farms and the river mouth. These values indicate greater weathering and leaching of ions into the water. This finding contrasts with the general expectation that conductivity would be lower during rainy seasons due to increased ion dilution. The anthropogenic effect of the Estreito HPP, which keeps the dam gates open during the rainy season, leads to a decrease in river levels and affects conductivity (Siqueira, 2018). On the other hand, during the dry season, when the dam gates are closed, conductivity decreases due to the increase in river levels and the dilution of ions. It is important to note that there are no official reference values for conductivity in Brazil, but previous studies suggest that natural water can vary from 10 to 100 µS.cm-¹, while polluted environments can reach up to 1000 µS.cm-¹ (Von Sperling,2007; Siqueira,2018).

Dissolved oxygen (DO) is essential for aerobic organisms and its quantity in water varies with temperature and altitude. Low DO levels indicate the presence of organic matter, the decomposition of which by aerobic bacteria further reduces DO. In streams with low self-depuration capacity, DO levels can be so low that they eliminate aerobic organisms (UFV, 2015). Temperature, dissolved oxygen and water contamination are interrelated, as an increase in temperature raises the metabolic rate of organisms, leading to greater energy expenditure, oxygen consumption and therefore greater sensitivity to pollutants (CETESB,2024b).

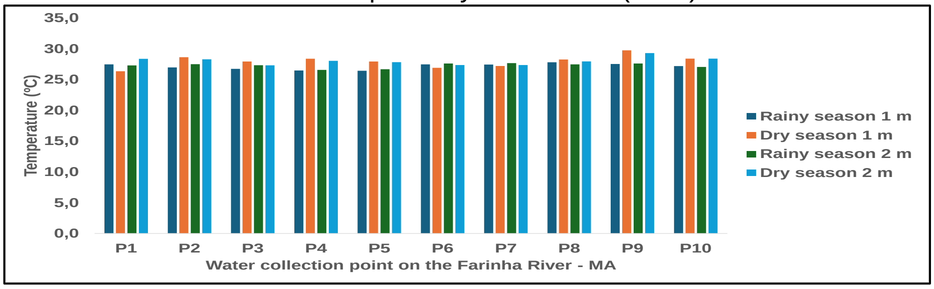
The dissolved oxygen results (%) (Figure 3) and the temperature results (ºC) (Figure 4) obtained in the field in the Farinha river are presented here, as well as the reference values contained in Embrapa's (2011) General Guide for the Interpretation of Oxygen Values (Table 1) for the percentage of dissolved oxygen saturation (%), which will be used to discuss the dissolved oxygen results of the water in the Farinha river - MA.

Figure 3: Values for the percentage of dissolved oxygen saturation (%) in the water of the Farinha River - MA at the ten water collection points at depths of 1 m and 2 m, during the rainy season and the dry season.



Source: Prepared by the authors (2024).

Figure 4: Temperature values (ºC) of the water in the Farinha River -MA at the ten water collection points at depths of 1 m and 2 m, during the rainy season and the dry season. Source: Prepared by the authors (2024).



Source: Prepared by the authors (2024)

Table 1 - Reference values contained in Embrapa's general guide for interpreting oxygen values (2011) for the percentage of dissolved oxygen saturation (%)

Dissolved Oxygen saturation percentage (%)	Interpretation of Dissolved Oxygen values
< 60%	Poor; Water may be too hot; Bacteria may be consuming dissolved oxygen
60% -79%	Acceptable for most species
80% - 125%	Excellent for most species
125% or more	Very high Can be dangerous for fish

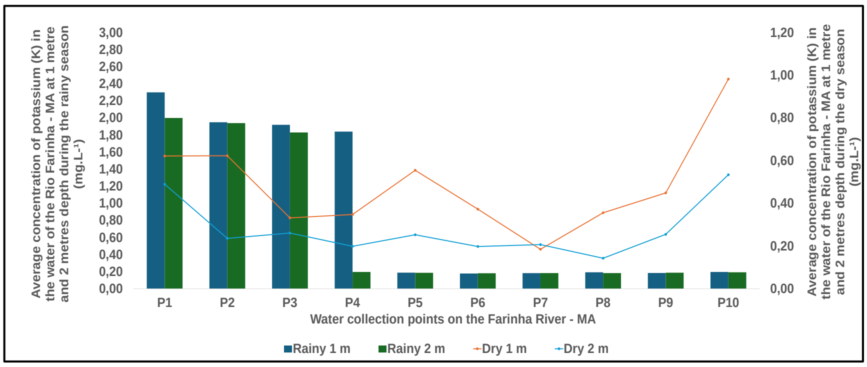
Source: Embrapa (2011).

The oxygen saturation rate in Brazil's Rio Farinha varies throughout the year. During the rainy season, oxygen saturation is high, with levels considered excellent for most species. However, during the dry season, the saturation rate drops significantly, due to factors such as the high water temperature and the consumption of oxygen by the bacteria present in the river. Maintaining adequate oxygen levels is important for aquatic life and for self-depuration processes in natural aquatic systems and sewage treatment plants (CETESB, 2024a). The abundance of organic matter can lead to oxygen depletion, negatively impacting animal life (Mendonça; Gonçalves e Rigue, 2020). In addition, human activity has affected the water dynamics of the Farinha River, highlighting the importance of preservation, control and efficient use of water to tackle the problems of contamination and water scarcity. To assess the anthropogenic effects on the water of the Farinha River, the levels of the nutrients potassium, calcium, magnesium, sodium and silicon were analysed.

Potassium is found in low concentrations in natural waters as it has low mobility in rocks and soils and is retained in most of these materials. The most common form of entry into the freshwater system is through industrial discharges and fertiliser leaching on agricultural land (Machado *et al.*, 2018). CONAMA Resolution 357/05 and Ministry of Health Ordinance 518/04 do not refer to this parameter. For human consumption, the maximum permissible value, according to the WHO (1985), is 20mg.L^{-1} (Sobral de Farias *et al.*, 2012). According to Esteves (2011), average potassium concentrations in South American rivers are 2 mg L^{-1}. According to Ayres and Westecot (1991), potassium concentrations ranging from 0 to 78 mg.L^{-1} are normal in irrigation water.

The results of this study showed that potassium concentrations in the rainy season were higher than in the dry season. The highest concentration in the rainy season was found at point 1 (2.30 mg.L^{-1} at a depth of 1m) and the lowest in the dry season at point 8 (0.14 mg.L^{-1} at a depth of 2m) (Figure 5), which are close to or below the values recommended in the literature.

Figure 5: Potassium (K) concentration values in mg.L-^{1} in the water of the Farinha River -MA at the ten water collection points at depths of 1 m and 2 m, during the rainy season and the dry season.

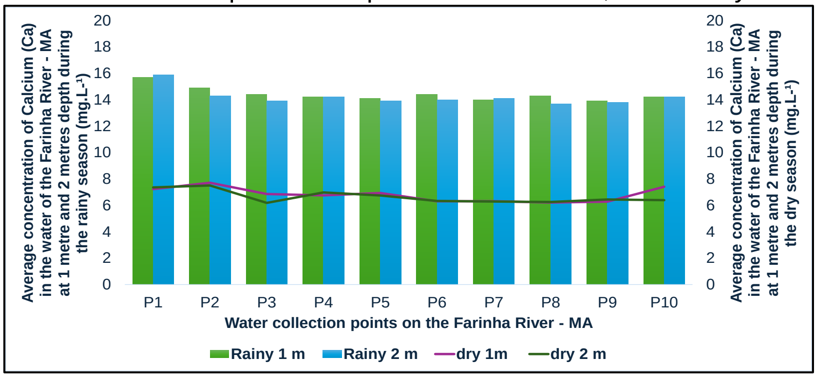


Source: Prepared by the authors (2024).

The Farinha river basin in Maranhão has seasonal variations in potassium concentration and water levels. During the rainy season, potassium concentrations increase and water levels decrease due to the opening of the floodgates. In the dry season, potassium concentrations are lower and water levels higher, which favours the dissolution of potassium in the river water. This pattern was also observed in Barcarena, Pará. The mineralogical composition of the Farinha river basin, with plateaus, mesas and pediplain surfaces, may contribute to the high concentration of potassium in certain areas close to the boundary of the Chapada das Mesas National Park. In addition, the concentration of potassium varies in the rocks, with different rock types having different average potassium contents. Intensified leaching during the rainy season and the opening of floodgates also contribute to higher concentrations of potassium and other elements in the Farinha river basin. In groundwater, calcium ions from the dissolution of sedimentary rocks can precipitate as calcium carbonate (Santiago *et al.*, 2007). Although there are no limits set for magnesium in the CONAMA resolution, its concentrations in natural waters can also vary (EMBRAPA, 2011a; Ostrowski, 2020).

In this study, calcium concentrations were higher in the rainy season than in the dry season, with the highest value found at point 1 (15.90 mg L^{-1} at 2 m depth) during the rainy season, and the lowest value at point 3 (6.18 mg L^{-1} at 2 m depth) during the dry season, being within the limits recommended in the literature during the rainy season and below the recommended values in the dry season (Figure 6).

Figure 6: Average calcium (Ca) concentration values in mg.L^{-1} in the water of the Farinha River - MA at the ten water collection points at depths of 1 m and 2 m, in the rainy and dry periods.



Source: Prepared by the authors (2024).

With regard to the average sodium concentration at the water collection points, the results showed that these were higher in the rainy season than in the dry season (Figure 7). The highest concentration in the rainy season was found at point 1 (8.54 mg.L^{-1} at 1m depth), which is above the average concentration recommended for freshwater rivers. In the dry period, the lowest value was found at point 8 (0.31 mg.L^{-1} at 2 m depth).

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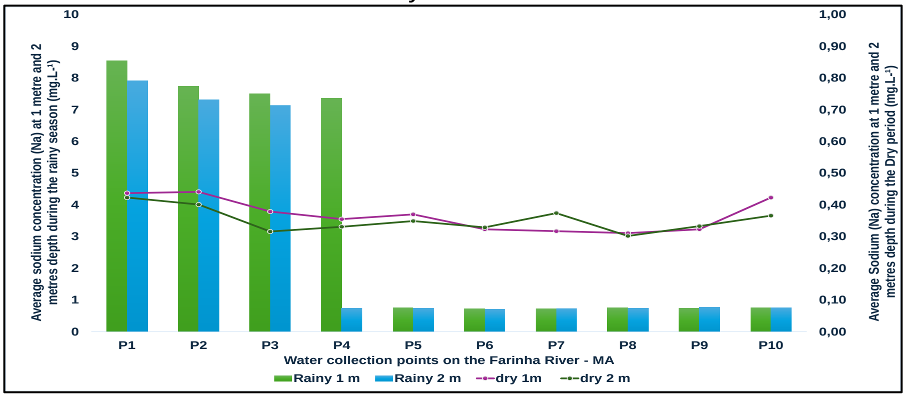
Figure 7: Average sodium (Na) concentration values in mg.L^{-1} in the water of the Farinha River - MA at the ten water collection points at depths of 1 m and 2 m, during the rainy season and the dry season.



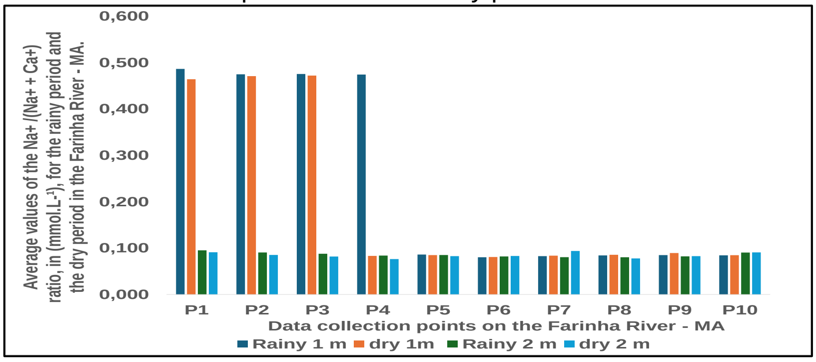
Source: Prepared by the authors (2024).

According to Alpha (1999) and Soares (2019), natural surface waters, such as rivers, have an average sodium concentration of 6.3 mg.L^{-1}, one of the metals with the highest concentrations. These values are considered adequate for drinking water, as they are below the recommended limits of 20 mg.L^{-1} and a maximum of 200 mg.L^{-1} for sodium in drinking water (Brasil, 2005; Embrapa, 2011a).

The ratio Na+ / (Na^{+} + Ca^{2+}) was calculated to understand the effects of weathering on the Farinha River - MA. This ratio helps to compare the relative concentration of Na^{+} and Ca^{2+} ions in the water. A high ratio indicates a relatively higher concentration of Na^{+} compared to Ca^{2+}, while a low ratio indicates a relatively higher concentration of Ca^{2+} compared to Na^{+} (Andrews *et al.*, 2004). Drever (1997) classifies water samples with total dissolved solids (TDS) below 1,000 mg.L^{-1} as fresh waters, characterised by bicarbonate as the main anion and sodium and calcium as the main cations. This classification is supported by Gibbs (1970), who observed that calcium (Ca^{2+}) is the predominant cation in fresh waters, while sodium (Na^{+}) predominates in saline waters.

Therefore, when analysing the Na^{+} / (Na^{+} + Ca^{2+}) ratio in the Farinha River - MA (Figure 8), it was observed that during the rainy season, points 1, 2, 3 and 4 showed a higher concentration of the sodium ion (Na^{+}) than the other data collection points. In the dry season, all the points showed higher concentrations of calcium ion (Ca^{2+}). This result shows that there is a seasonal variation in the chemical composition of the water.

Figure 8: Average concentration values of the Na^+ / (Na^+ + Ca^{2+}) ratio, in (mmol.L-¹) in the water of the Farinha River -MA at the ten water collection points at depths of 1 m and 2 m, in the rainy period and in the dry period.

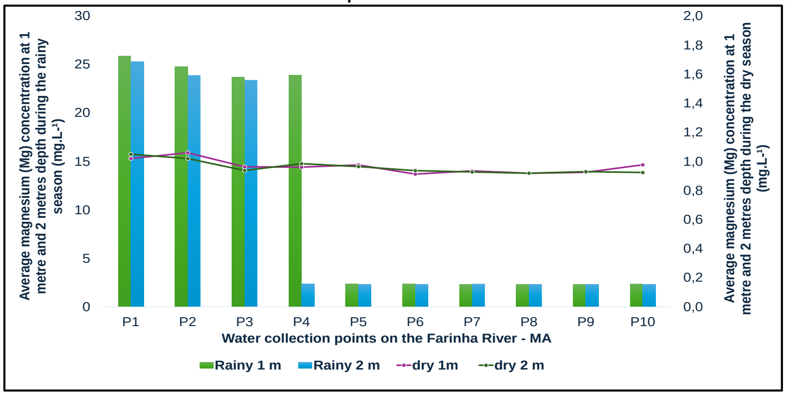


Source: Prepared by the authors (2024).

The Farinha - MA river follows its underground course for around 100 metres under the rocks before emerging again, which can contribute to natural weathering between the water and the rock. This can increase the concentration of sodium and calcium during the rainy and dry seasons, respectively. The higher concentration of sodium in the rainy season and the increase in calcium in the dry season may be related to the irregular residence time of the water and the intense interaction between water and rock. Zhang *et al.* (2018), Santos and Massaro (2000), Monteiro *et al.* (2021) and Monteiro *et al.* (2022) point out that these conditions can initiate the process of water salinisation, a common problem in the Brazilian Northeast. It is therefore essential to monitor these variations in order to prevent salinisation and implement appropriate management strategies.

The results showed that magnesium concentrations followed the same trend as calcium, being higher in the rainy season than in the dry season. The highest concentration in the rainy season was found at point 1 (25.90 mg.L^{-1} at 1m depth) and the lowest in the dry season was 0.9 mg.L-¹ at both 1m and 2m depth (Figure 9), which in the rainy season was above the limit set by the literature and in the dry season below the recommended values.

Figure 9: Average magnesium (Mg) concentration values in $mg.L^{-1}$ in the water of the Farinha River -MA at the ten water collection points at depths of 1 m and 2 m, in the rainy and dry periods.

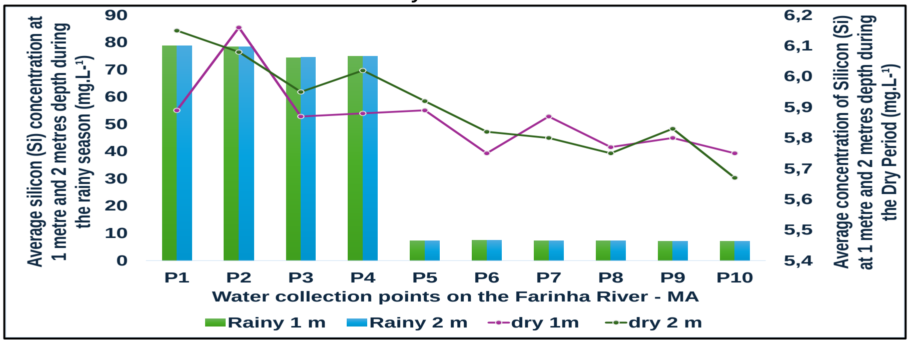


Source: Prepared by the authors (2024).

Gonçalves *et al.* (2005) observed high concentrations of calcium and magnesium increasing from the source to the mouth of the waters studied, with calcium ranging from 2.7 to 5.0 mg L^{-1} and magnesium from 1.4 to 3.5 mg L^{-1}. This increase was attributed to high erosion rates and the high availability of these nutrients in the soil, suggesting that the high concentration of these elements in the water is associated with excessive availability and inadequate soil management. Excess calcium in water resources can cause health problems, as calcium carbonate can precipitate, increasing the hardness of the water (Von Sperling, 2005; Simonetti; Silva; Rosa, 2022). Calcium is crucial for ion regulation in freshwater fish, influencing the permeability of biological membranes and preventing excessive ion loss. It is essential for biological processes such as bone formation, blood clotting and other cellular functions (Flik *et al.*, 1985; Scheuer, 2017).

Silicon is the second most abundant element in the Earth's crust, found in various forms such as sand, quartz, amethyst, feldspar, clays and micas (Loiola, 2022; Soares, 2023). In the Farinha - MA river basin, the average silicon concentration at the Farinha - MA river water collection points was higher in the rainy season (78.8 $mg.L^{-1}$) than in the dry season (5.7 $mg.L^{-1}$) (Figure 10).

Figure 10: Average silicon (Si) concentration values in mg.L^{-1} in the water of the Farinha River - MA at the ten water collection points at depths of 1 m and 2 m, during the rainy season and the dry season.



Source: Prepared by the authors (2024).

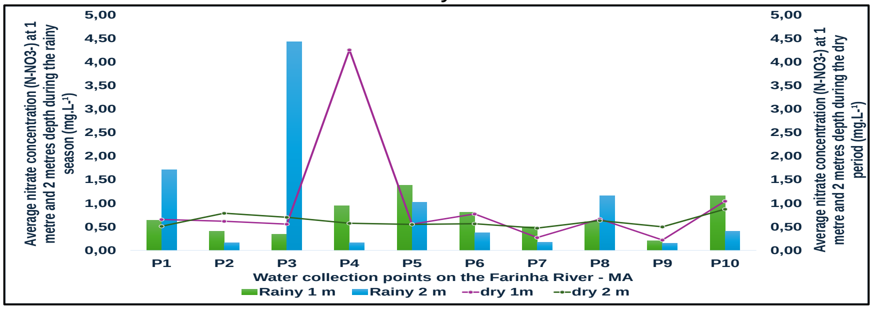
The high concentration of silica in the Farinha River can be explained by the presence of sandy soils in the river basin, such as QUARTZARENIC NEOSSOLS, formed by sandstone sediments due to the erosion of sandstones (Castro *et al.*, n.d.; ICMBio, 2019). It is estimated that 200 million tonnes of silicates move into lakes and seas every year, and that rivers transport around 4 billion tonnes of silica particles to the seas and oceans (Loiola, 2022). To analyse the anthropogenic effects on the water of the Farinha River, MA, the levels of Nitrate (N-NO_3-) and Total Phosphorus (Ptotal) were measured with the Shimadzu ICP-9000 Multipoint Emission Plasma Spectrometer (ICP-AES) (EPA 6010B) during the rainy and dry periods. The results show significant seasonal variations for these nutrients.

Human activities such as industry and agriculture have had a negative impact on water quality, releasing toxic substances such as nitrate into water sources. The excessive presence of nitrates in drinking water poses a serious health risk, especially for children, and can cause blue baby syndrome, which affects the oxygenation of the blood and causes a bluish colouring of the skin. Prolonged exposure to high levels of nitrates can also increase the risk of gastric cancer due to the formation of carcinogenic substances (Américo-Pinheiro; Mirante; Benini, 2016; Costa; Kempka; Skoronski, 2016; Santos; Silva, 2021).

Nitrate, mainly from agricultural activities, has a low retention in the soil and tends to remain in solution, particularly in the surface layer. Over time, it can be leached into deep water and its accumulation is influenced by factors such as the amount of soil, permeability, climate, management practices and the depth of the water table. Increased nitrate levels can also indicate the presence of other harmful substances, such as synthetic pesticides, which behave in a similar way to nitrates (Bhumbla, 2001; Nugent *et al.*, 2001; Resende, 2002).

In the rainy season, concentrations ranged from 0.20 mg.L^{-1} to 1.38 mg.L^{-1} at a depth of 1 m, and from 0.15 mg.L^{-1} to 4.43 mg.L^{-1} at a depth of 2 m. In the dry season, variations ranged from 0.22 mg.L^{-1} to 4.26 mg.L^{-1} at a depth of 1 m, and from 0.47 mg.L^{-1} to 0.88 mg.L^{-1} at a depth of 2 m (Figure 11). All these values are within the maximum concentration range recommended by CONAMA Resolution 357/2005, which establishes 10.0 mg.L^{-1} as the limit for class II freshwater rivers.

Figure 11: Average nitrate (N-NO3-) concentration values in mg.L^{-1} in the water of the Farinha River -MA at the ten water collection points at depths of 1 m and 2 m, during the rainy season and the dry season.



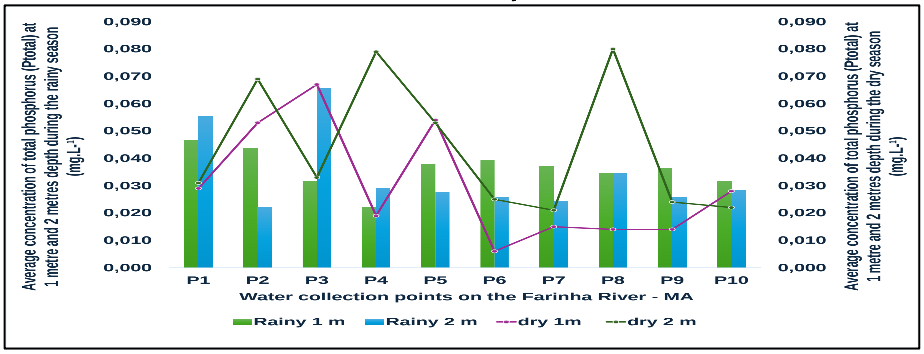
Source: Prepared by the authors (2024).

The Farinha river, in MA, has high levels of nitrates, especially at points 3 and 4, with values of 4.43 mg.L^{-1} and 4.26 mg.L^{-1}, respectively. These sites are subject to a high level of siltation, which may be the result of intense agricultural activity in the region. This agricultural activity may be responsible for increasing nitrate levels in the water, either through the application of nitrogen fertilisers or the loading of nitrate-rich nutrients from agriculture. Studies in the United States and southern Israel show that nitrate concentrations in similar areas tend to be less than 2 mg.L^{-1} or 3.45 mg.L^{-1}, respectively ((Muller e Helsel, 1996; Shalev *et al.*, 2015). There has also been a downward trend in average nitrate concentrations in Australia over time. Values above 2 to 6 mg.L^{-1} indicate possible pollution from human sources (Wick *et al.* (2012).

Phosphorus is an essential nutrient for plants and animals, but in large quantities it can promote the uncontrolled proliferation of algae, resulting in a reduction in the oxygen available to fish and other aquatic organisms (Eco Health, 2024). High phosphorus concentrations can have natural origins or be the result of human activities, such as rainwater drainage from forest, agricultural and urban areas, and sewage effluents (Von Sperling, 2008; Damasceno, 2015). According to the standards established by the National Water and Basic Sanitation Agency (ANA, 2024a), the maximum permitted concentration of total phosphorus is 0.10 $mg.L^{-1}$ for ordinary class 1 or 2 waters and 0.15 $mg.L^{-1}$ for classes 3 or 4 in rivers (lotic environments). For lentic environments, such as lakes and reservoirs, the maximum limits are 0.02 $mg.L^{-1}$ for class 1, 0.03 $mg.L^{-1}$ for class 2 and 0.05 $mg.L^{-1}$ for classes 3 or 4, according to CONAMA Resolution 357/2005.

An analysis of the total phosphorus concentration data in the Farinha River, MA, revealed significant variations. During the rainy season, concentrations varied from 0.02 $mg.L^{-1}$ to 0.05 $mg.L^{-1}$ at a depth of 1 m and from 0.02 $mg.L^{-1}$ to 0.07 $mg.L^{-1}$ at a depth of 2 m. In the dry period, variations ranged from 0.01 $mg.L^{-1}$ to 0.07 $mg.L^{-1}$ at a depth of 1 m and from 0.02 $mg.L^{-1}$ to 0.08 $mg.L^{-1}$ at a depth of 2 m (Figure 12).

Figure 12: Average concentration of Total Phosphorus (Total P) in $mg.L^{-1}$ in the water of the Farinha River -MA at the ten water collection points at depths of 1 m and 2 m, during the rainy season and the dry season.



Source: Prepared by the authors (2024).

During the rainy season, the Farinha River in Maranhão has a lotic behaviour due to the opening of the Estreito dam's floodgates, resulting in total phosphorus concentrations below the 0.1 $mg.L^{-1}$ recommended by CONAMA

Resolution 357/2005. In contrast, in the dry season, with the floodgates closed, the river behaves in a lentic manner, leading to an increase in algae and photosynthesising microorganisms and raising total phosphorus concentrations above the recommended limits (0.03mg.L^{-1} to 0.05 mg.L^{-1}) (ANA, 2024; CONAMA, 2005).

Santos *et al.* (2013) report that phosphate-rich effluents, especially in environments with a high availability of nitrogenous nutrients, can cause eutrophication and promote the uncontrolled growth of photosynthesising organisms. To mitigate eutrophication, Klein and Agnes (2012) suggest practices such as reducing surface runoff in agricultural areas and treating sewage in urban areas, as well as controlling algae and plants, although this process can be challenging and not always entirely effective.

4 CONCLUSION

It can be concluded that the study of the Farinha River, MA, showed significant differences in the physico-chemical parameters of the water between the rainy and dry seasons. In the rainy season, the water was more acidic due to the organic matter in the runoff, while in the dry season, the water was more alkaline. These variations have an impact on aquatic life and water quality, although the values are within acceptable legal limits.

Electrical conductivity was higher in the rainy season, influenced by both natural weathering processes and anthropogenic activities, and lower in the dry season due to the management of the Estreito hydroelectric plant's gates. The percentage of dissolved oxygen saturation was lower in the dry season, which can harm aquatic life. Nutrient concentrations were higher in the rainy season, probably due to soil erosion and surface runoff.

The study's findings are important for both society and academia, helping with sustainable water resource management, conservation strategies and providing valuable data for future research. However, the study has some limitations, and it is recommended that future research include a greater number of sampling points, longer collection periods and consider the direct impact of variations in water quality on local aquatic fauna.

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