MONITORAMENTO DA QUALIDADE DA ÁGUA COMO FERRAMENTA PARA GESTÃO SUSTENTÁVEL NO ALTO CURSO DO RIO PARAÍBA

WATER QUALITY MONITORING AS A TOOL FOR SUSTAINABLE MANAGEMENT OF THE UPPER PARAÍBA RIVER COURSE

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Resumo
No semiárido nordestino as características climáticas e as pressões socioeconômicas associadas ao uso da água, contribuem para alterar a quantidade e a qualidade dessas águas nas bacias hidrográficas. Como alternativa para minimizar os problemas de déficit hídrico foi implantado o Projeto de Integração do rio São Francisco, que visa levar água da Bacia do rio São Francisco às bacias em quatro estados brasileiros, por meio dos Eixos Leste e Norte. Nesta pesquisa foi analisada a qualidade da água no Alto Curso do rio Paraíba, no Eixo Leste, através da avaliação dos parâmetros físico-químicos da água e dos índices de qualidade de água e de estado trófico, antes e após início da operação do projeto de integração. Entre os parâmetros analisados, o fósforo total, nitrogênio total, sólidos dissolvidos totais e demanda bioquímica de oxigênio, predominaram fora dos limites recomendados pela Legislação brasileira, tanto sazonalmente como ao longo do trecho estudado. Para os índices de qualidade de água e de estado trófico predominaram as classificações Boa e Eutrófica, respectivamente. A redução da vazão influenciou negativamente a qualidade da água. Com relação à chegada das águas do Projeto de Integração foi observado decréscimo na concentração do fósforo, clorofila-α e sólidos dissolvidos totais.
Palavras-chave: Recursos hídricos. Semiárido.Transposição de bacias.

Abstract
In the Northeastern semiarid, the climatic characteristics and the socioeconomic pressures associated with the use of water, contribute to altering the quantity and quality of these waters in the hydrographic basins. As an alternative to minimize water deficit problems, the São Francisco River Integration Project was implemented, which aims to bring water from the São Francisco River basin to basins in four Brazilian states, through the East and North Axes. In this research, the water quality in the Upper Paraíba River Course, in the East Exis, was analyzed through the

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evaluation of the physicochemical parameters of the water and the water quality and trophic status indexes, before and after the beginning of the operation of the project. integration. Among the parameters, total phosphorus, total nitrogen, total dissolved solids and biochemical oxygen demand predominated outside the limits recommended by Brazilian legislation, both seasonally and along the studied stretch. For the indices of water quality and trophic status predominated as Good and Eutrophic classifications, respectively. The flow reduction negatively influenced the water quality. With the arrival of the waters of the Integration Project, a decrease in the concentration of phosphorus, chlorophyll-α and total dissolved solids was observed.
Keywords: Water resources. Semi-arid. Watershed transposition.

1. INTRODUCTION

Water quality is a key factor for sustainable management of water resources and maintenance of ecosystem services, playing a crucial role in biodiversity conservation (BICHSEL et al., 2016; BOUGUERNE et al., 2017).

The Northeastern semi-arid region of Brazil demands special attention regarding water. Despite the presence of several hydrographic basins, its climatic characteristics lead to a water deficit, associated with conflicts over multiple uses of water and discharge of effluent and untreated domestic sewage problems (ARAÚJO-FILHO et al., 2013; ANA, 2017a; 2019b). These contribute to the reduced water availability values, which depend not only on the amount of water, but also on its quality (SOBRAL et al., 2018).

To minimize the water deficit issues, a few alternatives have been applied strategically. Among them is the Integration Project of the São Francisco River with the North Northeast Basins (PISF), which aims to ensure water security for approximately 12 million people in the states of Pernambuco, Ceará, Rio Grande do Norte and Paraíba. This is done by taking water from the São Francisco River, through the East and North axes, to rivers with water deficit in the Northern Northeast (BRAZIL, 2004; 2016).

The waters captured for the East Axis will be directed to other basins, such as that of the Moxotó River, contemplating large reservoirs such as Poço da Cruz, in Ibimirim, Pernambuco. They will continue to the Paraíba River Basin, feeding several reservoirs until they reach Monteiro River, the main tributary of the Paraíba River.

The first interconnection event of the East Axis basins takes place in the Paraíba River Basin, with the start of the Project’s operation in 2017. These waters lead to important reservoirs, such as the Epitácio Pessoa, responsible for the water supply of several cities.

In semi-arid regions, the increase in the frequency or severity of drought periods, associated with poor planning of human activities related to water resources, can lead to the creation of new regions of water scarcity or expand the ones that already suffer from these issues, in addition to increasing the risk of desertification (HE et al., 2017; CHERLET et al., 2018). To reduce the negative impacts arising from this issue, regional development must be based on adaptation to climate change, in order to ensure that demands are met and the environment is preserved (CHERLET et al., 2018).

The efficient and sustainable use of water depends mainly on the implementation of essential water resources management and governance instruments, and the control of water pollution (FARIAS et al., 2017; SHRUBSOLE et al., 2017; VEALE and COOKE, 2017; ANA, 2019b; LIU et al., 2019; PEREIRA et al., 2020).

The assessment of water quality in Brazil is a challenge, especially in the semi-arid region, as some databases may contain several gaps, sampling points are often insufficient, and measurements of water quality parameters have many seasonal flaws (PEREIRA et al., 2020).

The study of water quality aims to generate information that supports decision making regarding sustainable water management and the necessary conditions to meet the water resources demands in the Upper Course of the Paraíba River, especially human supply. Additionally, act in line with the Sustainable Development Goals (SDGs) of the United Nations (UN), in order to contribute to the monitoring and compliance with the SDG 6 - Drinking water and sanitation, which aims to ensure availability and sustainable management of water and sanitation for all (ANA, 2019b).

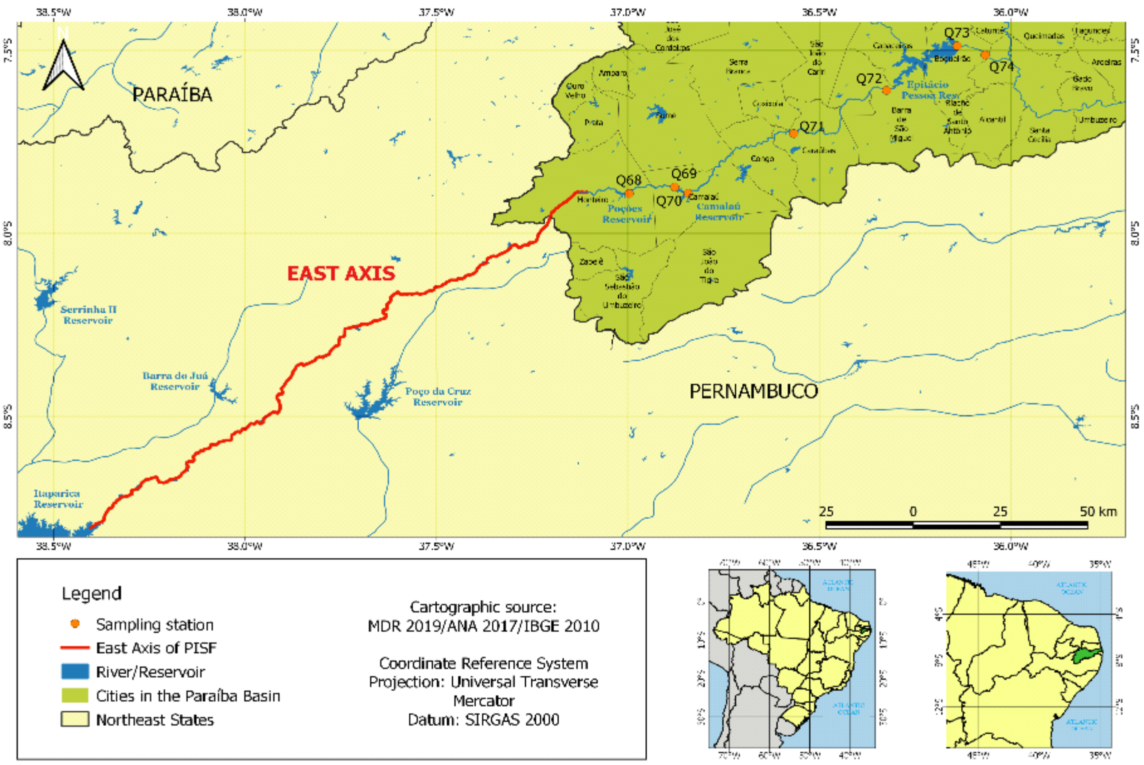
2. MATERIALS AND METHODS

2.1 Study area

The Paraíba River Basin covers 85 municipalities, with an area of 20,071.83 km^2, corresponding to 34% of the territory of the Paraíba state (XAVIER et al., 2012). The basin is divided into different physiographic regions: the sub-basin of the Taperoá River and Upper, Middle and Lower Courses of the Paraíba River (PARAÍBA, 2001).

The Upper Course of the Paraíba River (Figure 1) is in the Southwestern part of the Borborema Highland and drains an area of approximately 6,717.39 km². On the left bank, the tributaries are the Meio and Sucuru rivers, and on the right bank it receives contributions from the Monteiro and Umbuzeiro rivers (ARAGÃO, 2008).

Figure 1 – Location of PISF water quality monitoring sampling points on the Upper Paraíba River Course



Source: CALDAS (2020).

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This region was chosen as the study area because it is part of the Eastern Axis of the PISF and due to the current arrangement of the Project, there are mixing events of different basins and the possibility of changing the water quality. Additionally, due to its economic and environmental importance for the semi-arid region of Paraíba, as it contains reservoirs responsible for the water supply in cities such as Campina Grande and 24 other municipalities.

In this research, lotic and lentic stretches of the Upper Paraíba River Course were considered. The reservoirs analyzed in this work were Poções, with a capacity of 29.86 x 106 m²; Camalaú, with a capacity of 46.43 x 106 m² and Epitácio Pessoa, also known as Boqueirão, with a capacity of 411 x 106 m² (PARAÍBA, 2001).

2.2 Methodological procedures

An analysis of the water quality was structured through the evaluation of physicochemical parameters. These were compared with the limits presented by Conama Resolution 357/05 (BRASIL, 2005), using as a reference the classification of freshwater Class 2 in accordance with the framework established by the Superintendence for the Administration of the Environment of the State of Paraíba (SUDEMA, 1988).

In addition, water quality can be assessed using indices. The Water Quality Index (WQI) reflects the interference by sanitary sewage and organic materials, nutrients and solids present in the water. The Trophic State Index (TSI) assesses water quality and classifies trophic states, considering nutrient enrichment and its relationship with algal blooms (BUCCI and OLIVEIRA, 2014).

The calculation of the WQI used was adapted by the Environmental Company of the State of São Paulo (CETESB) of the National Sanitation Foundation (1975). The TSI was calculated in accordance with the modified Carlson Index as CETESB (2017).

The physicochemical and biological data for water quality analysis were obtained from seven sampling points: Q68 - Poções reservoir, Q69 - Camalaú reservoir, Q70 - Camalaú reservoir, Q71 - Do Meio river, Q72 - reservoir Epitácio Pessoa, Q73 - Epitácio Pessoa reservoir and Q74 - downstream of the Epitácio Pessoa reservoir (Figure 1). The samples were obtained in 16 campaigns carried out every six months from 2011 to 2019. These data were monitored by the PISF for the Water Quality and Limnology Monitoring of the Basic Environmental Program (BEP-22) and were requested as a condition in the process of obtaining the Preliminary License - LP 200/2005 from the Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA).

The Basic Environmental Program (BEP) 22 of the PISF is carried out through a partnership between the Ministry of Regional Development (MDR) and the Environmental Management Group (EMG) of the Postgraduate Program in Civil Engineering (PPGEC) at the Federal University of Pernambuco (UFPE).

The water quality parameters analyzed were: temperature (°C), dissolved oxygen (DO), hydrogen potential (pH), turbidity, biochemical oxygen demand (BOD), nitrate, nitrite, ammonia nitrogen, total phosphorus (P total), total dissolved solids (TDS), thermotolerant coliforms; and chlorophyll-α. Samples were collected from the surface of the water column and analyzed in the laboratory in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 2017). The results were compared with Resolution 357 of CONAMA/2005 limits, which provides guidelines for the classification of water bodies. The study area is currently classified as Class 2 water body.

For data validation, statistical tests were applied. In this regard, the hypothesis of data normality was verified by the Shapiro-Wilk test. The Kruskal Wallis H test was applied to

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compare whether there were significant differences between the periods studied, with a 5% significance level.

The WQI was calculated based on nine parameters: water temperature, Dissolved Oxygen (DO), Thermotolerant Coliforms (TC), pH, BOD, Total Nitrogen (TN), Total Phosphorus (TP), turbidity and total dissolved solids (TDS). The water quality will depend on the WQI value obtained, which may be very bad (WQI $\leq$ 19), bad (19 < WQI $\leq$ 36), regular (36 < WQI $\leq$ 51), good (51 < WQI $\leq$ 79) or excellent quality (79 < WQI $\leq$ 100) (CETESB, 2017).

The classification of the aquatic environment according to the TSI is given in six trophic states. For rivers that are: ultraoligotrophic (TSI ≤ 47), oligotrophic (47 < TSI ≤ 52), mesotrophic (52 < TSI ≤ 59), eutrophic (59 < TSI ≤ 63), super eutrophic (63 < TSI ≤ 67) and hypereutrophic (TSI > 67) (CETESB, 2017).

If the value of any of the nine variables is not available, the calculation of the WQI is not feasible. Consequently, the sampling points Q69 (2015) and Q73 (2013), both collected in the rainy season, did not show results. In addition to these two points, others do not have WQI results either as they registered an absence of water during the collection period. The same applies to the TSI.

3. RESULTS AND DISCUSSION

3.1 Physicochemical analysis of water

Among the physicochemical parameters analyzed, TP; TN; TDS; and BOD exceeded the limits recommended by Conama Resolution 357/05 for Class 2 water bodies (BRASIL, 2005) at most sampling points, as well as throughout the monitoring period.

Regarding seasonality, the parameters showed a trend towards higher rates in the dry period, except for pH and chlorophyll-α, highlighting the years 2014 to 2016, where reductions in water volumes were observed in the studied stretch due to the lack of rain.

According to the Executive Water Management Agency (AESA, 2019), rainfall levels play a relevant role in the quality of water in the semi-arid of the Northeast region. Periods of water scarcity, such as those between 2013 and 2016, led to a decrease in the water volume and, therefore, a reduction in water quality (ANA, 2019a). Other studies also observed that the hydrological regime directly influences water quality in water bodies in the Northeast region (BARBOSA et al., 2016; GOMES et al., 2016; AESA, 2019a; ANA, 2019b; PRATTE-SANTOS et al., 2018).

Phosphorus and nitrogen are considered indicators of environmental impacts since they are the main elements for the eutrophication of water bodies, promoting the accelerated growth of phytoplankton and consequently significant variations in dissolved oxygen in water (SHIMIZU et al., 2020). Unlike phosphorus, ammonia nitrogen, as well as nitrite and nitrate, exhibited concentrations within the limits established by legislation (Figure 2).

In lentic environments high phosphorus rates can generally be related to high evaporation, low nitrogen concentrations and high temperatures, which are responsible for accelerating the microbial action and the denitrification process (ESTEVES, 2011; GOMES et al., 2016; BUSSI et al., 2017).

The sampling points that registered the highest concentrations of TP were Q71 and Q72, in the Do Meio River and in the backwater of the Epitácio Pessoa reservoir, both in 2015; and in Q74, downstream of that reservoir, in 2013. Its variation throughout the monitoring period was from 0.01 mg/L to 16.2 mg/L, in Q70 (2011) and Q71 (2015), respectively (Figure 2 D).

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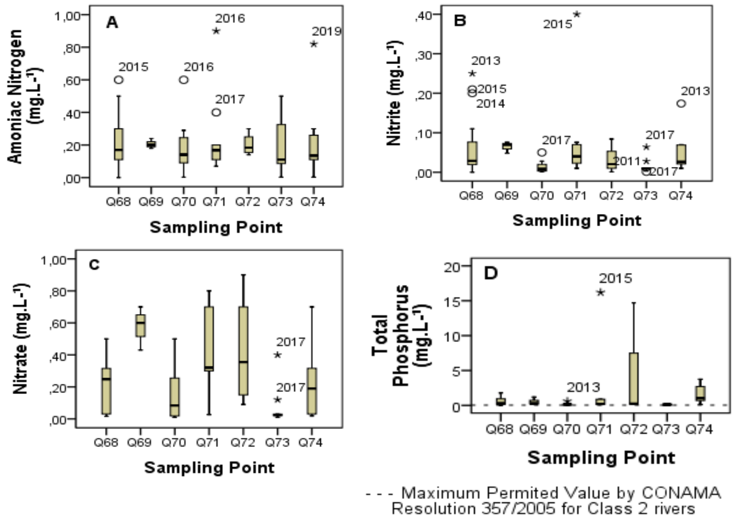
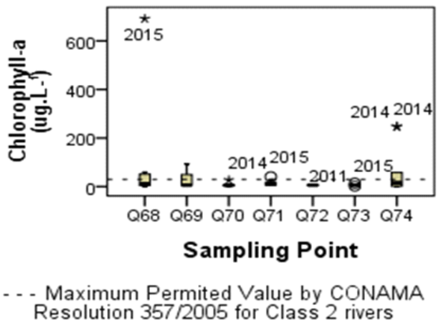
Figure 2 - Seasonal variation of physicochemical parameters in the Upper Paraíba River Course, from 2011 to 2019: A - Ammoniacal nitrogen; B - Nitrite; C - Nitrate; and D - Total phosphorus and the maximum limit of 0.030 mg / L for lentic environments, established by Conama Resolution 357/2005



Source: The authors (2021).

Phosphorus, as one of the main limiting factors in aquatic ecosystems, is essential for the development of phytoplankton (TUNDISI and MATSUMURA-TUNDISI, 2008), thus the concentrations of this parameter are also correlated with chlorophyll-α. The concentrations of chlorophyll-α ranged from 0.002 to 691.5 µg/L, exceeding the limit of 30 µg/L recommended by the legislation. This happened especially in 2014 and 2015, with emphasis on points Q68 and Q74, in the Poções reservoir and downstream of the Epitácio Pessoa reservoir (Figure 3).

Figure 3 - Seasonal variation of chlorophyll-α in the Upper Paraíba River Course, from 2011 to 2019, and the maximum limit of 30 µg/L established by Conama Resolution 357/2005



Source: The authors (2021).

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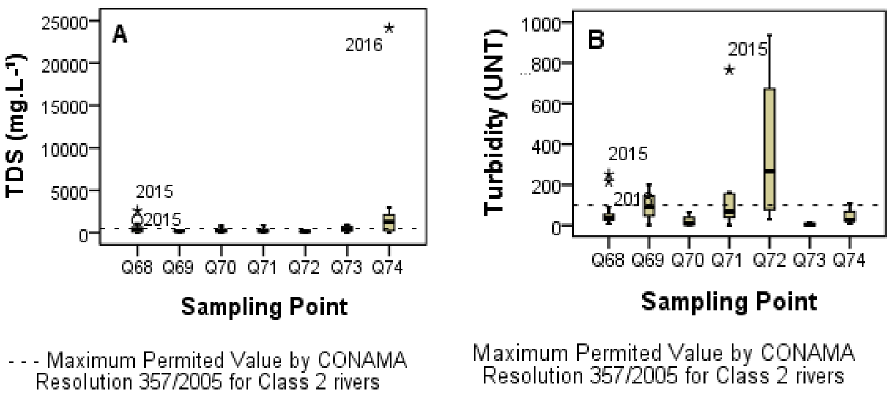
According to Barbosa et al. (2016), the reduction in the water level of the Epitácio Pessoa reservoir during the long periods of drought contributes to the increase in the concentration of nutrients and phytoplankton, reflected by the addition of chlorophyll- α in the water.

Total dissolved solids values showed the same pattern observed for the aforementioned parameters, with high concentrations in periods of extreme weather in the region (2013 to 2016), highlighting points Q68 and Q74. The minimum concentration observed was 0.25 mg/L and maximum 24,143 mg/L, at points Q73 (2018) and Q74 (2016), respectively (Figure 4 A). Only Q69 and Q72 did not present values above the limit of 500 mg/L recommended by legislation. Gomes et al. (2016) found in their research that the water volume of the reservoir tends to favor an increase in the concentration of total dissolved solids.

Turbidity peaked in 2015, with 934.97 UNT in Q72 and 765 UNT in Q71, in the Epitácio Pessoa reservoir, reflecting the presence of dissolved solids in the water column. Despite the high rates in this year, it was usually below the legal limit, with sampling points exceeding the value of 100 UNT as of 2014 (Figure 4 B).

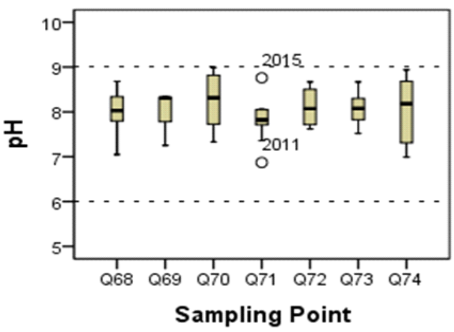
Figure 4 - Seasonal variation of physicochemical parameters in the Upper Paraíba River Course, from 2011 to 2019, and their respective limits established by Conama Resolution 357/2005: A - Total dissolved solids; B – Turbidity



Source: The authors (2021).

The pH presented variations within the range of 6.0 to 9.0 (Figure 5), which is inside the recommended range. The pH influences the dynamics of various nutrients in the water column, such as phosphorus, which can be released from the sediment into water in higher concentration under more alkaline conditions than acidic or neutral (WU et al., 2014).

Figure 5 - Seasonal pH variation in the Upper Paraíba River Course, from 2011 to 2019, and the limit range from 6.0 to 9.0 established by Conama Resolution 357/2005



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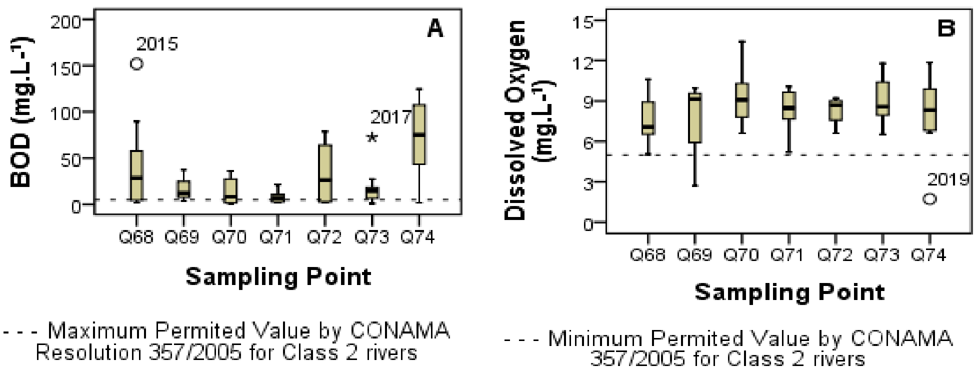
Source: The authors (2021).

BOD showed values above the recommended limit of 5.0 mg/L O_2, with maximum concentrations of 152 mg/L O_2 in Q68 (2015) and 124.8 mg/L O_2 in Q74 (2014) (Figure 6 A). Dissolved oxygen was within the standard indicated by legislation for Class 2 water bodies, above 5.0 mg/L O_2, except for station Q69 (2014), with 2.69 mg/L O_2; and Q74 (2019), with only 1.72 mg/L O_2 (Figure 6 B).

Figure 6 - Seasonal variation of physicochemical parameters in the Upper Paraíba River Course, from 2011 to 2019, and their respective limits established by Conama Resolution 357/2005: A – BOD; B – DO



Source: The authors (2021).

In natural and oligotrophic environments, the concentration of BOD is low and contrary to water bodies that receive sewage discharge. The sewerage circumstances in the municipalities along the Paraíba River is unsatisfactory, with low levels of sewage treatment service; the municipalities of Monteiro and Boqueirão stand out, with the highest BOD launch loads (ANA, 2017b).

The destruction of riparian forests around the Paraíba river basin, responsible for controlling siltation and blocking the supply of nutrients and pollutants to the river, occurs over a large extension of its course (AESA, 2004). In addition, the use of pesticides and fertilizers by crops around the reservoirs has also contributed to increased impacts on water quality and on the dynamics of aquatic organisms (SILVA et al., 2014).

Associated with the previous factors, the release of sewage and effluents, responsible for contributing to eutrophication (LEANDRO and ROCHA, 2019), has its impacts reflected by the concentration of thermotolerant coliforms in the water. This estimate is based on the analysis of a group of bacteria, considered important indicators of fecal contamination and release of untreated domestic sewage into water bodies (CETESB, 2018). In this research, values above 1600 NMP/100 mL were observed in the period 2011 (Q71), 2014 (Q69), 2015 (Q68 and Q72), 2017 (Q71 and Q72), 2018 (Q68 and Q73) and 2019 (Q72 and Q74) (Figure 7).

Figure 7 - Seasonal variation of thermotolerant coliforms in the Upper Paraíba River Course, from 2011 to 2019, and the maximum limit of 1,000 thermotolerant coliforms per 100 milliliters established by Conama Resolution 357/2005

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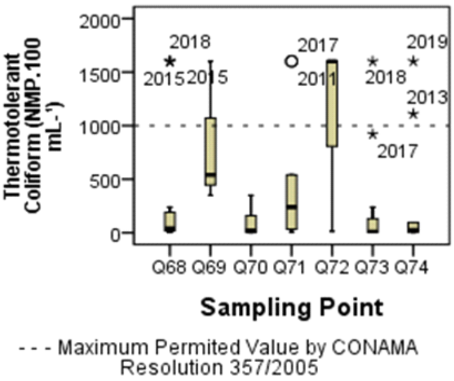
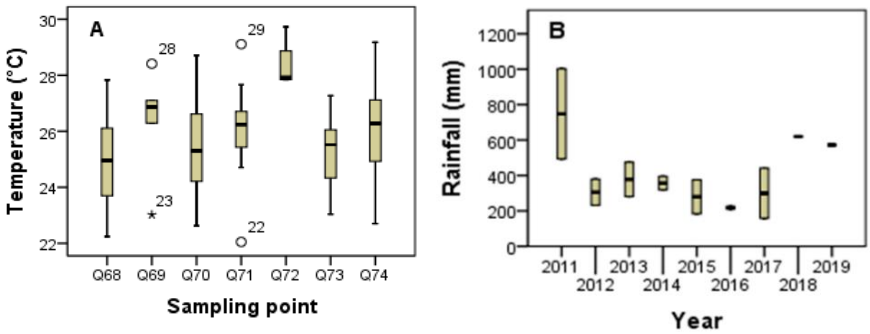


Source: The authors (2021).

Only the Camalaú reservoir (Q70) retained values below those recommended by Brazilian legislation. However, as the sampling was carried out every six months, there were only two samples per year. This makes it impossible to compare with the legislation, as it states a limit of 1,000 thermotolerant coliforms per 100 milliliters should not be exceeded in 80% or more of at least 6 (six) samples collected during a one-year period.

The water temperature behaved similarly at the sampling points, with a predominance of reduced rates in the dry period, ranging from 22.05 ºC (Q71) in 2011 to 29.73 ºC (Q72) in 2019; and a predominance of higher rates in the rainy season (Figure 8 A). Average rainfall ranged from 0.0 mm to 672.5 mm in 2011 in the Upper Course of the Paraíba River (Figure 8 B).

Figure 8 - Seasonal variation of physical characteristics in the Upper Paraíba River Course, from 2011 to 2019: A – Temperature; B – Rainfall



Source: The authors (2021).

As a result of the drought periods, a drop in the volume of reservoirs in the Upper Course of the Paraíba River can be observed (AESA, 2021). The volumes of water in the Poções, Camalaú and Epitácio Pessoa reservoirs have decreased over the last 10 years (Figure 9). The Epitácio Pessoa reservoir exhibited peak volume in the years 2009 (452,126,488 m²) and 2011 (445,412,742 m²) and critical drought events between the years 2013 to 2017, reaching collapse with 3.18% (13,094,571 m²) of its volume in March/2017. After the PISF East Axis started operation in 2017, a slight increase in the volume of the Epitácio Pessoa reservoir can be observed, however reaching only 35.13% (144.639,522 m²) of its maximum volume in April/2018 (AESA, 2021).

Figure 9 – Monthly volume (m^3) of reservoirs in the Upper Paraíba River Course, from 2009 to 2019

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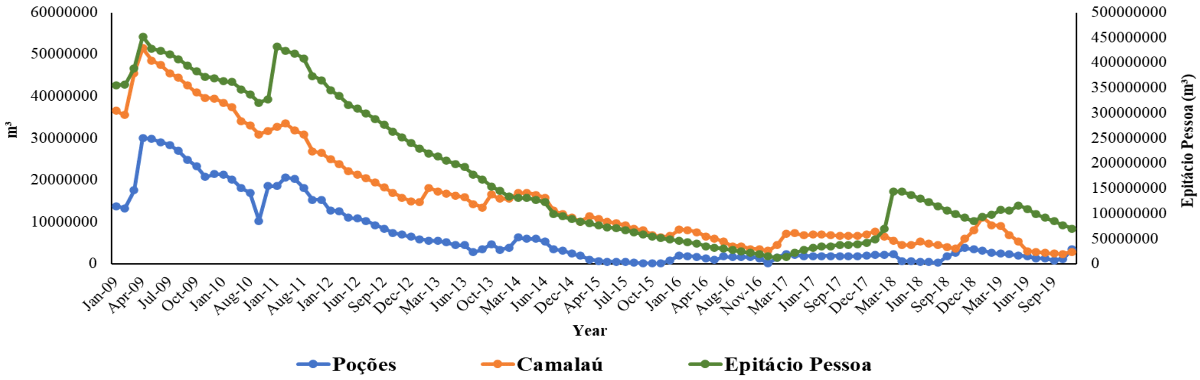
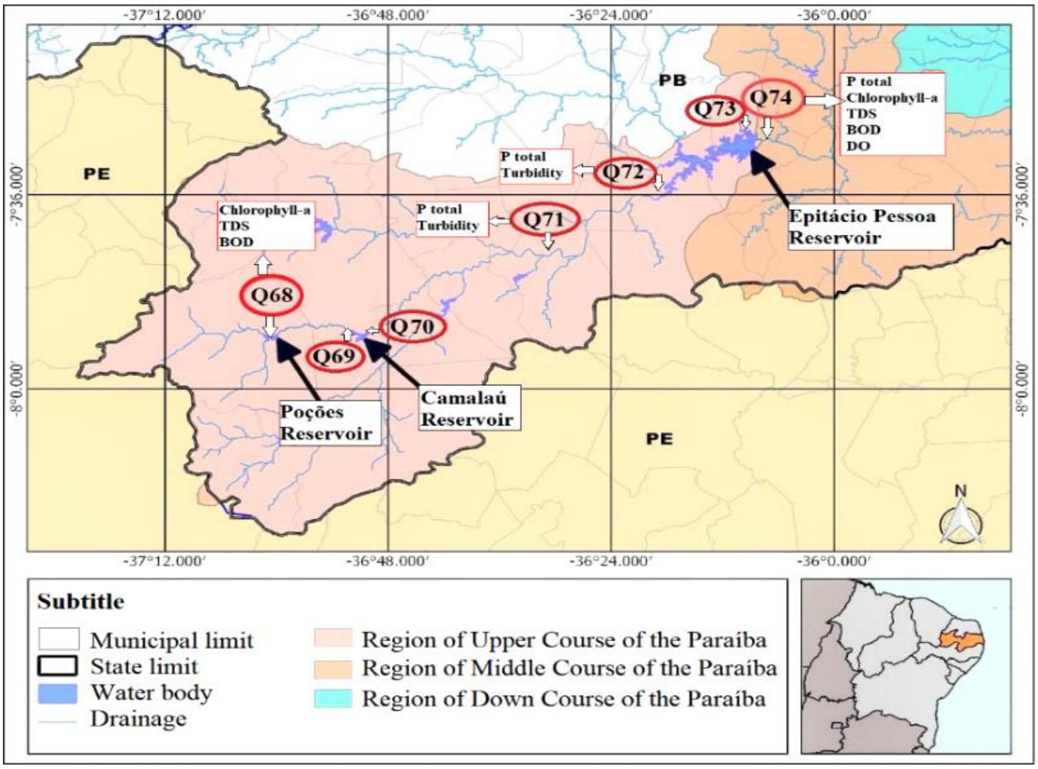


Source: The authors (2021).

Araújo et al. (2009) draws attention to the occurrence of an important change in the average precipitation pattern of the Paraíba river basin, starting to observe more dry periods than wet years. This emphasizes the importance of an efficient management and adequacy of water in the basin. If the dry years growth trend is configured as a pattern, the supply problem will consolidate, negatively impacting the fulfilment of demands.

The analysis of the physicochemical and biological characteristics of the water in the Upper Paraíba River course shows that the water crisis in the semi-arid region is not only quantitative, but also qualitative. The quality of water, especially in public supply reservoirs, is often eutrophic. Some sampling points stood out as more critical with respect to water quality parameters outside the requirements of Conama Resolution 357/05 (Figure 10).

Figure 10 – Location of the most critical sampling points regarding water quality parameters



Source: The authors (2021).

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Regarding the arrival of water from the São Francisco River in the Paraíba River Basin, in 2017, a decrease in the concentration of some parameters such as phosphorus, chlorophyll-α and total dissolved solids can be observed so far. Only total dissolved solids remained above the legal limits after the start of the PISF operation. However, further studies are needed in the coming years to observe the changes in the water quality of the Paraíba River and quantify the flow needed to maintain its quality.

According to Andrade et al. (2017), in this first year of operation, the water from the São Francisco River transposition improved the water quality of the Epitácio Pessoa reservoir, presenting more satisfactory pH, electrical conductivity and dissolved oxygen results after the start of the PISF.

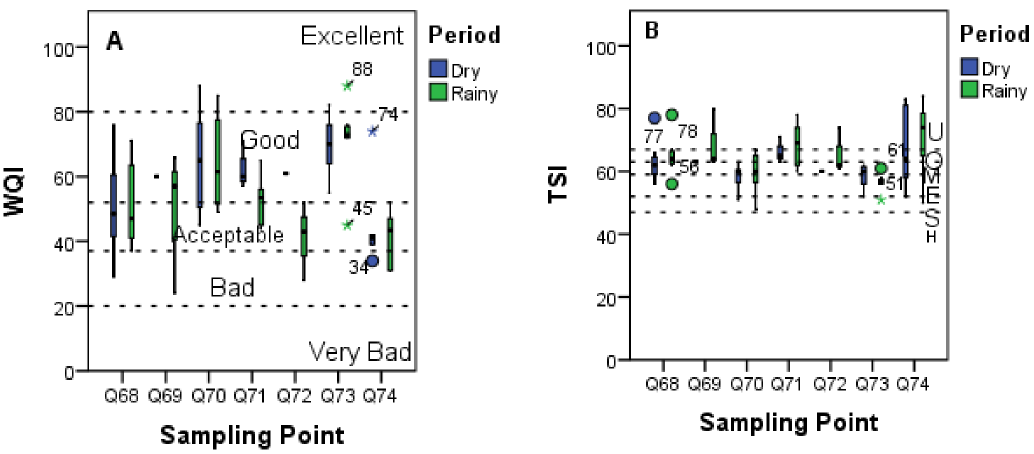
There is a dam system in the course of the São Francisco River and the Paraíba basins, which interferes in the dynamics of the nutrient transport in the hydrographic basin. Therefore, it is essential to consider analysis after a period with high rainfall, when there is transport of high concentrations of nutrients, such as phosphorus and nitrogen, along the river by the currents increased by the rain (SHIMIZU et al., 2020). However, a fact that draws attention in the semi-arid region is that in some periods characterized as rainy by the climatological analysis, there may not have been significant precipitation, as was the case in the study area between 2012 and 2016 (AESA, 2021). These atypical periods need to be analyzed in light of climatology and, if necessary, be renamed so that future comparisons better represent the environment.

3.2 Water Quality Index (WQI) and Trophic State Index (STI)

The WQI analysis showed that 55% of the sampling points were in the Good category, 30% in the Regular (Q68 and Q74), 8% in the Bad (Q74) and 7% in the Excellent category (Q73). The Very Bad rating was not assigned in any of the sampling points.

The Optimal WQI can be observed at points Q70 (2011 and 2019) and Q73 (dry period 2011 and 2019). In these periods, the trophic index of the Camalaú reservoir varied between oligotrophic and mesotrophic, and that of the Epitácio Pessoa reservoir was classified as mesotrophic (Figure 11 A).

Figure 11 – Seasonal variation of the WQI and TSI in the Upper Paraíba River Course, from 2011 to 2019: A - Water Quality Index (WQI); B - Trophic State Index (TSI)



Source: The authors (2021).

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In 2011, the volumes of water in the reservoirs were high in relation to the following periods, of drought. During that year, the Camalaú reservoir operated with volumes ranging between 55.92% and 71.83%, and the Epitácio Pessoa reservoir between 79.64% and 100% of its storage capacity (AESA, 2021).

As of 2017, an improvement in water quality can be observed throughout the study area. This period coincided with the start of the operation of the PISF's East Axis, however more studies need to be carried out to verify the relationship of the contribution of the arrivals of water from the São Francisco River to the improvement of water quality in the Upper Course of the Paraíba River.

For the TSI, a higher percentage of sampling points presenting eutrophic condition (31%) was observed. The sampling points ranged in their part from mesotrophic (22%) to hypereutrophic (19%). No station was considered to be of ultraoligotrophic quality.

The most critical periods observed were from 2013 to 2015 for the WQI, and from 2014 to 2016 for the TSI. Among the sampling points, Q74 stood out with a higher occurrence of samples classified as having a lower quality level and more episodes of samples with a trophic state between supereutrophic and hypereutrophic (Figure 11 B).

The sample points in the Epitácio Pessoa (Q73) and Camalaú (Q70) reservoirs presented better indices for both water quality and trophic state. These results may be related to the greater volume of water at these points in relation to the others, especially in Q73. The same correlation was observed in Q74, especially in periods of extreme weather, when it started to suffer the impacts of the reduced discharge of water from the Epitácio Pessoa reservoir.

In addition to the available amount of water sufficient to dilute the nutrients in the water column, other factors such as the presence of irrigated agriculture around reservoirs and the release of sewage and effluents are some of the main causes responsible for modifying the physicochemical parameters of the water (FERREIRA et al., 2019; LEANDRO and ROCHA, 2019; WU et al., 2021).

The use of water quality indices has been widely applied in studies on the subject and reported as an efficient tool for the management of water resources. It presents data analysis that is easy to interpret and understand the variations in water quality parameters in a water body, and with the results obtained, categorize different water quality situations and their respective management methods (NOORI et al., 2019; DASH and KALAMDHAD, 2021; UDDIN et al., 2021).

Some contradictions were observed when comparing analyzes of the two studied indices. The study area presented waters with quality classified as Good in most of the monitoring period, while the predominant trophic state was eutrophic, therefore pointing two different states in water body quality. The research by Souza et al. (2018), in a semi-arid reservoir, highlights that there is no significant correlation between these indices and that the isolated assessment of the WQI is not indicated to determine the conservation status of the reservoir. The authors highlighted that the TSI proved to be more efficient in measuring the quality of the studied water body.

3.3 Guidelines for sustainable water management

In Brazil, events related to natural disasters arising from drought recorded an increase of over 100%, and the average annual amount of the affected population increased by over 400%, when comparing data from the period 1991/2012 to 2013/2016 (SOUZA and OLIVEIRA, 2019).

Paraíba is among the three states most susceptible to the occurrence of droughts and is part of the list of states in the country with investment priority to minimize the effects of droughts, with main areas: mapping, prevention, monitoring and warning (SOUZA and OLIVEIRA, 2019). Peacock; Nascimento (2019) emphasizes that the entities responsible for water management have a

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still incipient role in terms of notes and guidelines that can support the confrontation of crises, contributing to the lack of adequate planning.

The recurrent problems of reduced water quality further limit the availability of drinking water, raise the cost of supply due to the need for water treatment, and deteriorate the aquatic ecosystem. The issue of water pollution needs to be addressed in an integrated manner with the regions covered by the PISF. The treatment of the domestic sewage discharged into the East Axis basins is deficient, and contributes to the increase of nutrients in the water.

Taking these into account, some proposals were formulated in order to contribute to the improvement of water resources management in the study area. The proposals prioritize environmental mapping and monitoring, and inspection of multiple uses in the reservoirs (Table 1).

Table 1 – Guidelines for institutions that participate in the management of water resources in the Upper Course of the Paraíba River and in the PISF

Institutions	Recommendations
Ministry of Regional Development (MDR)	- Expertise in controlling and restricting access to PISF channels and reservoirs. - Promote greater integration among the entities operating in the São Francisco and Paraíba basins.
National Health Foundation (FUNASA)	- Prioritize the allocation of resources for treatment and reuse in the PISF receiving basins to municipalities with a population of less than 50,000 inhabitants.
National Water Agency (ANA)	- Establish a regulatory framework for the reuse of water, enabling its application in certain uses, reducing demand in water sources.
Executive Agency for Water Management (AESA)	- Identify and protect ecosystem services offered by freshwater systems. - Establish water abstraction rates that forecast the environmental and administrative costs of system management.
National Department of Works against Droughts (DNOCS)	- Expertise in collecting water collection fees.
Paraíba Water and Sewage Company (CAGEPA)/São Francisco and Parnaíba Valleys Development Company (CODEVASF)	- Act to ensure efficiency in combating water waste in the system. - Implement effluent treatment points.
City Halls	- Partner with higher education institutions to implement environmental awareness programs in the municipalities that are part of the Upper Course of the Paraíba River.
Paraíba River Hydrographic Basin Committee - CBHRP	- Apply cooperation programs between users and associations (fishermen, farmers, etc.) in order to raise their awareness to act as local socio-environmental actors.

Source: The authors (2021).

4. CONCLUSIONS

The analysis of physicochemical parameters in the Upper Paraíba River Course showed that total phosphorus, total nitrogen, total dissolved solids and BOD were above the limits recommended by Conama Resolution 357/05, at most sampling points during the monitoring

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period. The parameters showed a trend towards higher rates in the dry period, except for pH and chlorophyll-α. The analysis of the WQI showed 55% of the points classified as Good and the TSI with 31% presenting a eutrophic condition.

The most critical periods observed were from 2013 to 2016 regarding the quality of the water body under study. Among the sampling points, Q74, downstream of the Epitácio Pessoa reservoir, stood out with a higher occurrence of samples classified as having a lower quality level, physicochemical parameters with concentrations above the relevant legislation and more episodes of samples with a trophic state between supereutrophic and hypereutrophic.

The sampling points in the Epitácio Pessoa (Q73) and Camalaú (Q70) reservoirs presented the best indices for both water quality and trophic state. These results may be related to the greater volume of water at these points in relation to the others. The same can be related to station Q74 (downstream of the Epitácio Pessoa reservoir), especially in periods of extreme weather, when it started to suffer the impacts of the reduced water discharge from the Epitácio Pessoa reservoir.

Rainfall rates played a relevant role in the Upper Paraíba River Course water quality. This is due to periods of water scarcity, such as those between 2013 and 2016, leading to a decrease in the volume of water and, consequently, a reduction in water quality.

Regarding the arrival of water from the São Francisco River in the Paraíba River Basin in 2017, there was a decrease in the concentration of some parameters such as phosphorus, chlorophyll-α and total dissolved solids, but only total dissolved solids remained above the legislation limits after the beginning of the PISF operation. These data served as preliminary studies to support future research during the next years of the PISF operation.

Investments in improvements in water quality monitoring networks, and control and treatment of sewage and effluents released into the Paraíba and São Francisco Rivers are strategic issues for the sustainable management of water resources in the study area. The decentralized action of regulatory institutions will strengthen the management of these waters and will be important in providing support for dealing with crises.

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