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Spatial-Temporal Analysis of Water Quality in Municipalities Influenced by the Belo Monte Hydroelectric Plant

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Abstract: ***Objective: This study aimed to analyze the limnological and microbiological parameters of water from the Xingu River to establish a water quality profile for municipalities in the Xingu and Transamazon regions affected by the Belo Monte Hydroelectric Power Plant (BMHPP). Methods: A field study employing both qualitative and quantitative approaches was conducted to assess water quality parameters in stretches of the Xingu River within the affected municipalities. The analysis was guided by the limits established in National Environment Council (CONAMA) Resolution No. 357/2005. Results: The water samples collected across the study area complied with CONAMA standards for physicochemical (limnological) parameters. However, microbiological analyses revealed contamination levels that exceeded the permitted thresholds. Conclusion: Although the physicochemical parameters remain within regulatory limits, the microbiological results indicate elevated concentrations of E. coli and total coliforms, significantly surpassing the maximum allowable values for bathing water quality. These findings underscore potential public health and environmental risks in the region.***

Keywords: Spatial-Temporal Analysis, Water Quality, Belo Monte Hydroelectric Plant.

1. INTRODUCTION

The issue of water availability for supply and consumption has emerged as one of the main challenges of the present day, since the perceived abundance of water on the planet can mistakenly suggest an inexhaustible resource. However, it is estimated that of all the water present on Earth, 97.50% is saltwater, 2.49% is freshwater but inaccessible, and only 0.007% is available in rivers and lakes, being suitable for human consumption (Rodrigues; Bueno, 2019).

Brazil is considered a world power in terms of water availability, concentrating 12% of all existing surface freshwater reserves in the world; however, 70% of this water volume is in the Amazon region, following an order inversely proportional to the number of inhabitants in that region (Soito, 2019), (Ramos; Wachholz; Da Silva Neto, 2020). The Northeast region is home to 30% of the Brazilian population and has only 3.3% of freshwater, while the South and Southeast regions are home to approximately 60% of the population and have only 12.5% of freshwater (Silva, 2020).

The Belo Monte Hydroelectric Power Plant (UHEBM) was installed on the stretch of the Middle Course of the Xingu River (Middle Xingu), impacting areas of the municipalities of Vitória do Xingu, Altamira, and Senador José Porfírio (Formigosa; Giongo, 2021). The implementation of UHEBM brought a series of predictable problems ranging from population growth to loss of local biodiversity; however, several unexpected impacts occurred, including vegetation suppression and changes in the river's hydraulic dynamics. These modifications can affect or alter the physicochemical and microbiological characteristics of the water (Da costa et al., 2019).

Water quality can be affected by various types of use, with the main sources of contamination being untreated sewage discharged into rivers and lakes, landfills that affect groundwater aquifers, agricultural pesticides that run off with rain into rivers and lakes, mining activities that release chemicals into rivers and streams, industries that use rivers as carriers of their toxic waste, navigation, effluent discharges, and energy generation (hydroelectric plants) (Da Silveira, 2022).

The discharge of fecal waste can increase their concentrations in the water column and consequently compromise the integrity of the water body, causing the proliferation of other pathogenic microorganisms (Alves et al., 2023). Research related to pathogenic microorganisms in water requires very complex and lengthy procedures, making it necessary to use fecal contamination indicator organisms to assess the bacteriological quality of water (Sampaio et al., 2019).

The Xingu River and several other rivers and streams in the region have suffered for years from the direct discharge of hospital and domestic sewage into their beds, in addition to the still immeasurable impacts caused by the implementation of the Belo Monte Hydroelectric Plant downstream of the river (De Paula, 2019). Bathing water quality conditions are of great social importance due to their direct relationship with public health problems and environmental degradation (Póvoas et al., 2020). Thus, the bacteriological assessment of water proves to be a vital tool in disease prevention, encompassing not only gastrointestinal infections but also a series of other pathological conditions (Da Silva et al., 2019).

This factor becomes even more prominent in regions affected by issues such as the discharge of hospital and domestic sewage into water bodies, as well as the impacts resulting from large-scale projects, such as the UHEBM. Adequate bathing water quality conditions are fundamental not only for environmental preservation but also for public health and the well-being of the population, highlighting the ongoing need for measures and policies that promote water quality and the sustainability of water resources in Brazil. Therefore, the objective of this research is to evaluate the limnological and microbiological parameters of the Xingu River water, a class 2 water body, based on the limits established in National Environment Council (CONAMA) Resolution No. 357/2005, in order to outline a profile of its quality in municipalities in the Xingu and Transamazon regions affected by the UHEBM.

2. METHODOLOGY

This is a field research with a qualitative and quantitative approach to parameters related to the water quality of the Xingu River, in the Transamazon and Xingu regions, which were affected by the implementation of the UHEBM. The study area included stretches of the Xingu River in municipalities in the Transamazon and Xingu regions that were affected by the implementation of the UHEBM.

These affected municipalities include: Altamira, Anapu, Brasil Novo, Medicilândia, Pacajá, Placas, Porto de Moz, Senador José Porfírio, Uruará, and Vitória do Xingu; however, only Altamira, Vitória do Xingu, and Senador José Porfírio were part of the project sample. In these municipalities, three random collection points named P1, P2, and P3 (with recorded position - latitude and longitude) were chosen, which were evaluated every 2 months, from October 2020 to April 2021, over an 8-month period, totaling 4 collections (C1, C2, C3, and C4) in each municipality.

All collections were always carried out at the same time, between 8 AM and 10 AM. At each collection point, two sterile universal collector bottles were collected (for physicochemical analysis and for microbiological analysis). Sterilized containers in an autoclave were used to prevent interference from any other external microorganisms except those present in the water. The container was placed on the surface against the river current at the time of collection and then closed to avoid possible contamination.

In order to identify and quantify the elements and ionic species present in the water samples, for subsequent association with their effects on environmental issues and human health, the following physicochemical parameters were analyzed: pH, turbidity, temperature, and electrical conductivity.

Still at the collection site, pH, temperature, and conductivity were quantified using a pH meter, a microprocessor, and a digital thermometer, respectively. For turbidity analysis, the samples were sent to the laboratory, properly packed in a thermal box and kept at room temperature, where they were analyzed using a microprocessor turbidimeter.

For microbiological analysis, the following parameters were analyzed: Total coliforms and Escherichia coli (E. coli); which were processed using the Colipaper kit from ALFAKIT, which consists of a card with dehydrated gel culture medium used for microbiological analysis, indicating the presence of fecal and total coliforms on a paper DIPSLIDE, recommended for analyses such as water, domestic and industrial effluents, rivers, lakes, swimming pools, milk, surfaces, and vegetables, with an analysis sensitivity range of 80 to 25000 CFU/100mL (ALFAKIT, 2012).

The data from the study were tabulated in Microsoft Excel 2021® and analyzed using descriptive statistics with the BioEstat program, version 5.0. Analysis of Variance (ANOVA) was applied to test the null hypothesis. For comparing means between the study's collection points, the Tukey test ($p<0.01$) was performed to verify possible significant differences between the means of the analyzed data. In accordance with resolutions 466/2012 and 510/2016 of the National Health Council, the present study is exempt from evaluation or any approval by a

Research Ethics Committee/National Commission for Research Ethics (CEP/CONEP).

After analyzing the data obtained from field and laboratory collections, over the four collections at the 3 selected points, for the parameters (1) Limnological and (2) Microbiological of the Xingu River waters, the following results were generated:

2.1 Physico-Chemical Aspects

To analyze the data and prepare the tables, the average between the three collection points (P1, P2, and P3) during the four collections performed (C1, C2, C3, and C4) was used for each limnological parameter in the municipalities.

In the evaluation of pH, there was no significant statistical difference between the municipalities ($p=0.5731$, one-way ANOVA) (Figure 1). However, in Altamira, the pH showed a higher mean value (7.49) and Senador José Porfírio a lower mean (7.12). The values of pH did not vary between the sampled municipalities.

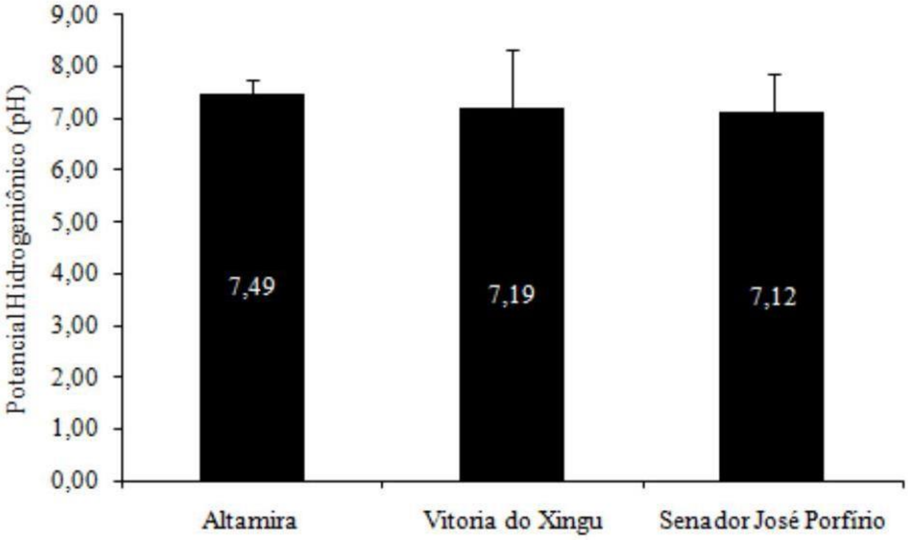

Figure 1: Mean pH values in the municipalities of Altamira, Vitória do Xingu, and Senador José Porfírio.

Regarding turbidity, the values obtained in Altamira and Senador José Porfírio were very close (3.36 NTU and 3.40 NTU, respectively), however, that recorded in Vitória do Xingu was almost double that of the other municipalities (5.64 NTU), with a statistical difference between Altamira - Vitória do Xingu and between Vitória do Xingu - Senador José Porfírio (*$p<0.01$, one-way ANOVA, Tukey Test) (Figure 2).

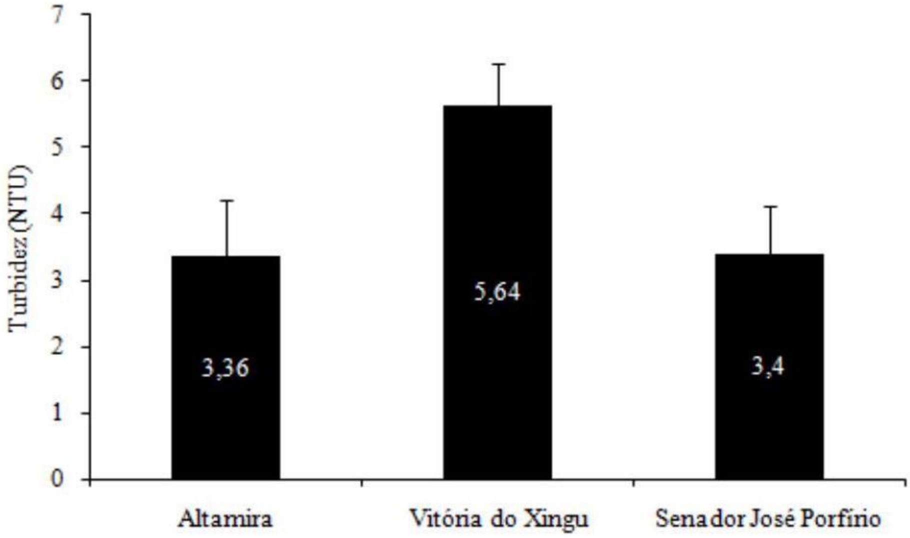

Figure 2: Mean turbidity values (NTU) in the municipalities of Altamira, Vitória do Xingu, and Senador José

Porfírio.

Water temperature was one of the parameters that remained similar between the municipalities, with a slight reduction in Vitória do Xingu, with a mean of 28.4℃, but without significant statistical difference (p=0.1214, one-way ANOVA) (Figure 3).

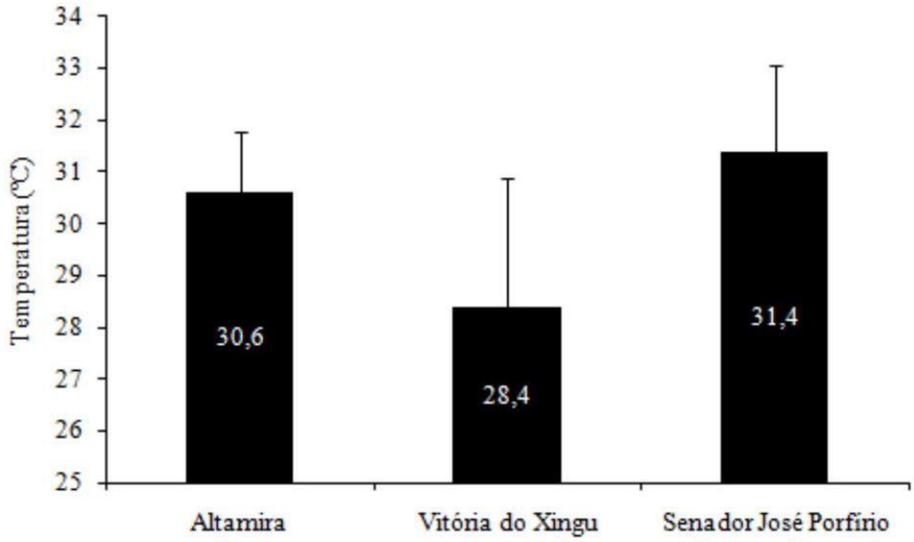

Figure 3: Mean Temperature (°C) of the waters in the municipalities of Altamira, Vitória do Xingu, and Senador José Porfírio.

Regarding electrical conductivity in water samples (Electrical Conductivity: EC), Vitória do Xingu showed the lowest mean (11.08 µS/cm), while the highest was recorded in Senador José Porfírio (20.91 µS/cm), with a statistical difference between Altamira - Vitória do Xingu and between Vitória do Xingu - Senador José Porfírio ($p<0.01$, one-way ANOVA, Tukey Test) (Figure 4).

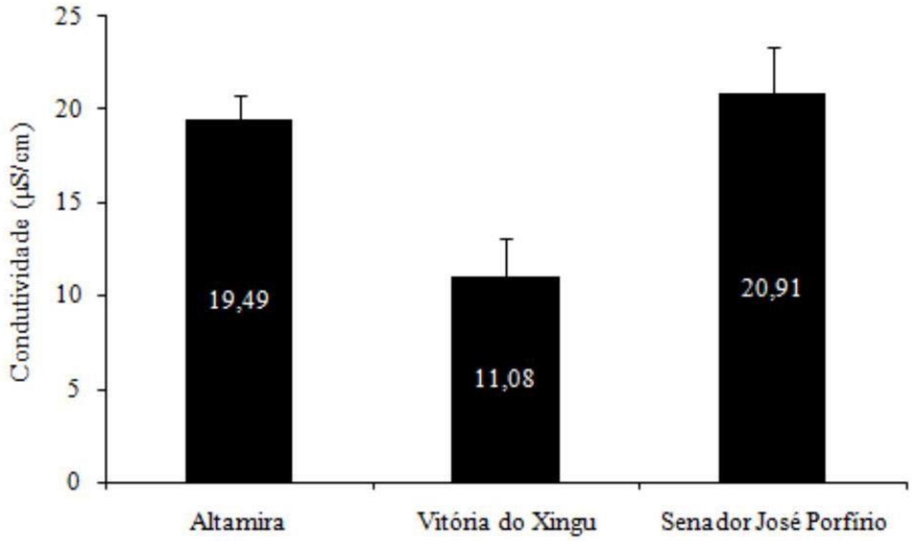

Figure 4: Mean values of Electrical Conductivity (µS/cm) in the municipalities of Altamira, Vitória do Xingu, and Senador José Porfírio.

2.2 Microbiological Aspects

The results obtained from the analysis of Escherichia coli in the collected samples are shown in Figure 5. The municipality of Vitória do Xingu had the highest concentration of E. coli, with a value of 4433.3 CFU/100mL. There was a significant statistical difference in E. coli concentration between the municipalities of Altamira - Vitória do Xingu and between Vitória do Xingu - Senador José Porfírio ($p<0.01$, one-way ANOVA, Tukey Test). However, there was no difference in Escherichia coli concentration between the municipalities of Altamira - Senador José Porfírio (p=0.6697, one-way ANOVA).

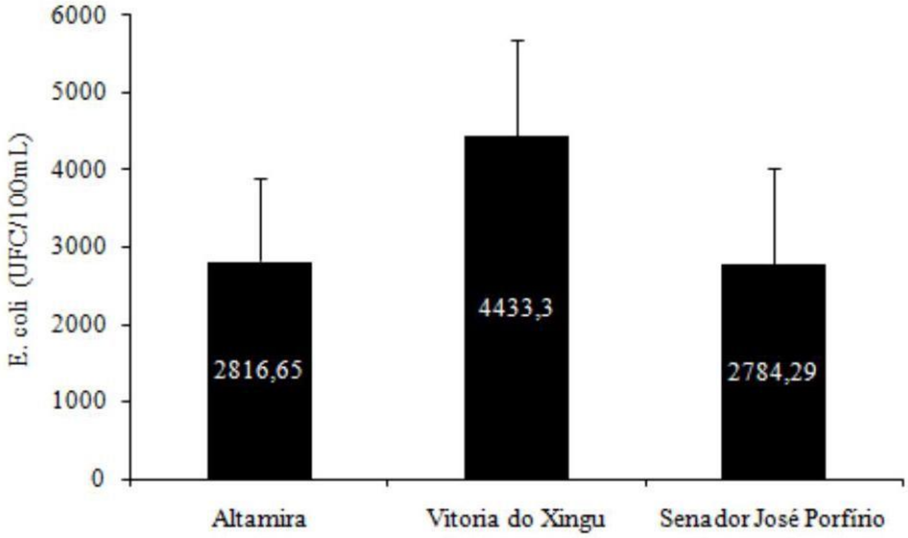

Figure 5: Comparison of mean E. coli values in the evaluated municipalities.

The results obtained from the analysis of total coliforms among the municipalities are shown in Figure 6. In this regard, the municipality of Senador José Porfírio had the highest concentration of total coliforms, with a mean of 19618.89 CFU/100mL, with a significant statistical difference between all municipalities ($p<0.01$, one-way ANOVA, Tukey Test).

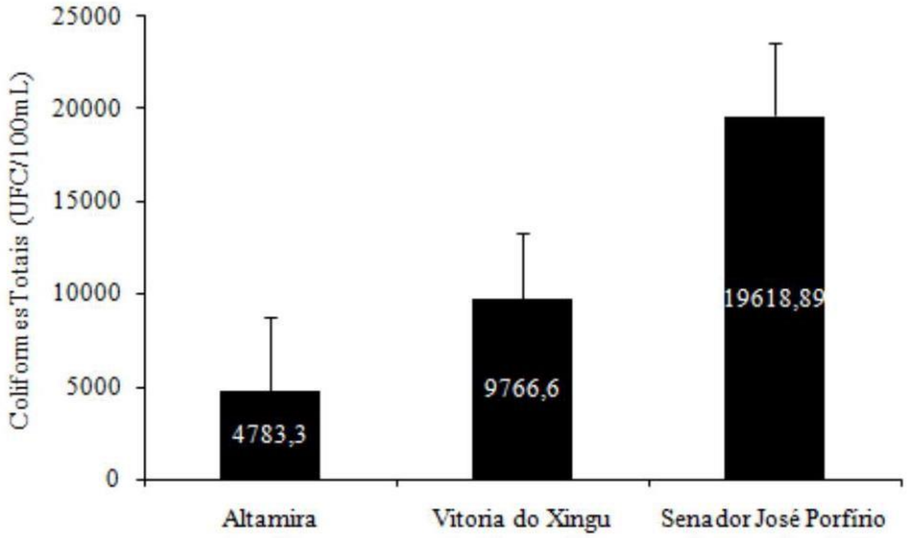

Figure 6: Comparison of mean total coliform values in the evaluated municipalities.

3. DISCUSSIONS

The water samples collected in the municipalities that make up the study area of the present work, with regard to limnological parameters, were within the standards accepted by CONAMA for bathing water quality, but the analyses of microbiological aspects are outside those established by CONAMA.

3.1 Analysis of Physico-Chemical Parameters of Water

Observing the sample analysis, there was no significant variation in the pH value in the water under analysis between the collection periods, with the maximum value observed in the municipality of Altamira and the minimum value in the municipality of Senador José Porfírio.

Nascimento et al. (2021) state that low pH values are frequently reported, being related to the natural characteristics of the region’s rivers. For example, Nascimento et al. (2021), when analyzing the pH of the Xingu River, obtained a maximum value of 8.22 during the rainy season and a minimum of 5.3 during the dry season. However, Batista et al. (2022) explain that this is probably related to the availability of organic matter present in the reservoir or anthropic actions, such as the discharge of domestic sewage and effluent disposal.

As established in the 2005 CONAMA Resolution, the pH values in the three municipalities comply with the standards set for Class 2 freshwater, which range from 6.0 to 9.0.

However, during the collections, it was observed that Altamira and Senador José Porfírio presented close turbidity values, with 3.36 NTU and 3.40 NTU, respectively. In contrast, Vitória do Xingu recorded a significantly higher turbidity, reaching 5.64 NTU, almost double that of the other municipalities. This increase may be related to the concentration of leached material from soil use and anthropogenic activities, such as sewage discharge or deforestation (Varela et al., 2020).

Lustosa et al. (2019), when analyzing four points along the Guará Velho stream, found significant variations in turbidity. The results ranged from 3.36 NTU/100mL to 26.5 NTU/100mL. This notable variation was attributed to the amount of sediment present along the stream.

Therefore, both in the case of the Xingu River and the Guará Velho stream, water turbidity is shown to be influenced by various factors, including human activities, environmental and seasonal changes, and the amount of sediment present in the water. These observations highlight the importance of constant monitoring and the implementation of management measures to maintain water quality in compliance with established environmental standards.

According to CONAMA Resolution 357/2005, which sets a maximum allowed turbidity limit of 100 NTU for Class 2 waters, it is evident that the results obtained for this parameter are below the established limit.

Regarding the temperature parameter, the values were measured in situ, and it can be observed that there were no significant variations and they remained similar among the municipalities. However, the temperature in the municipality of Vitória do Xingu had the lowest recorded value, with an average of 28.4 °C, and the municipality of Senador José Porfírio presented the highest value, 31.4 °C, which can be explained by the time of year, when part of the collections were carried out in summer (dry season) and the other part in winter (rainy season).

Nascimento et al. (2021), analyzing the waters of the Xingu River, recorded a maximum value of 32.5℃ during the dry period and a minimum value of 28.3℃ in the rainy period, considering that the Amazon Region does not have a very significant climatic difference.

Throughout the collections, there were significant variations in electrical conductivity (EC) values, with the minimum value from the municipality of Vitória do Xingu, which had an average of 11.08 µS/cm, and the maximum value in the municipality of Senador José Porfírio, with 20.91 µS/cm.

Furthermore, electrical conductivity can be a valuable indicator of environmental changes. In areas near hydroelectric plants, water often comes into contact with geological materials that release dissolved minerals, contributing to conductivity (Águas et al., 2020). However, it can also reflect land use practices, such as deforestation or intensive agriculture, which affect the quantity and composition of these dissolved ions in water (Simonetti; Silva; Rosa, 2019). Electrical conductivity is an important tool for monitoring water quality over time and identifying trends that may require management interventions. This is particularly relevant in regions near hydroelectric plants, where environmental changes can be significant and have direct implications for the conservation of water resources and aquatic life (Ríos-Villamizar et al., 2019).

Parameters such as electrical conductivity, total dissolved solids, and temperature show a direct correlation with the distance of the collected samples. Santos (2023) highlights that soil conservation practices have a significant impact on water quality and aquatic ecosystems. Changes in land use can directly affect river characteristics due to ecosystem transformations. Additionally, the physicochemical properties of water reflect local geology (Águas et al., 2020).

In general, although considered a quality parameter, CONAMA Resolution 357/2005 does not establish a specific value for EC. However, great attention is needed, as this parameter determines the presence of dissolved substances in water, which decompose into anions and cations (Batista et al., 2022).

3.2 Analysis of Water Microbiological Parameters

The results of the microbiological parameter analyses conducted in the three municipalities were compared to the values required by CONAMA for freshwater, which in its resolution No. 357/05 establishes maximum permitted values (MPV) for bathing water quality.

Analysis of the collection points in the three municipalities observed very high concentrations of E. coli and total coliforms, with values well above the MPV set by CONAMA Resolution No. 357/05. When the average values obtained from E. coli analyses were observed, the municipality of Vitória do Xingu had the highest concentration, with a statistically significant difference between the three municipalities. As for the average values obtained from total coliform analyses, the municipality of Senador José Porfírio had a very high concentration relative to the average, with a statistically significant difference between all municipalities.

The results of the water quality parameters, particularly the levels of E. coli and total coliforms, in the municipalities of Altamira, Vitória do Xingu, and Senador José Porfírio, point to significant concerns regarding water health and compliance with the guidelines established by CONAMA.

It is important to note that E. coli values in Altamira, Vitória do Xingu, and Senador José Porfírio are well above the limit established by CONAMA, which is up to 800 CFU/100mL. This indicates serious contamination of the water by fecal coliforms, which are indicators of pollution by human and animal waste. The presence of E. coli at such high levels suggests significant risks to public health and the possibility of contamination by related pathogens (Sampaio et al., 2019).

Regarding total coliforms, again the values in all municipalities far exceed the limit established by CONAMA, which is up to 1000 CFU/100mL. The presence of these organisms in high concentrations indicates possible water pollution from various sources, such as sewage, intensive agricultural activities, industrial effluents, and other organic residues. This can negatively affect water quality, making it unsuitable for various uses such as public supply and recreation, in addition to posing risks to aquatic life (Neves, 2023) (Motta; Neumann, 2020).

According to Cruz (20), coliform micro-organisms are not naturally present in water; they are introduced through human feces. Da Silveira Dib et al. (2022) explain that the high concentration of E. coli and total coliforms may be related to the discharge of domestic sewage and the unplanned population growth, as in most cases, there is no basic sanitation infrastructure for this population.

It is observed that the results obtained for the microbiological analyses in the three municipalities have values outside the limits established for consumption. However, the most polluted municipalities were Vitoria do Xingu and Senador José Porfírio, as they had the highest values among the three municipalities in the microbiological analyses.

Furthermore, unplanned population growth, often driven by the construction of large projects such as hydroelectric dams, further overloads sanitation systems, making it difficult to keep up with the growing demand for water and sewage treatment services. Deforestation, intensive agriculture, and other human activities can also contribute to soil erosion and increased sediment load in rivers, negatively affecting water quality.

4. CONCLUSION

The impact caused by the construction of the Belo Monte Hydroelectric Dam in the Transamazonian and Xingu regions transcended the environmental scope, reflecting in significant changes in population dynamics and the social challenges faced by the area. Although the physicochemical parameters comply with the standards established by CONAMA, the microbiological analyses point to alarming levels of contamination by E. coli and total coliforms, far exceeding the maximum allowed value for bathing water quality. The importance of continuous monitoring of water quality in areas affected by large-scale projects, such as hydroelectric dams, is also emphasized. This not only ensures the health of the population but also helps preserve aquatic ecosystems and the region’s biodiversity.

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