RICSB
REVISTA INTERDISCIPLINAR EM CIÊNCIAS DA SAÚDE E BIOLÓGICAS

# PARÂMETROS FÍSICOS E MICROBIOLÓGICOS DE UM CORPO HÍDRICO COMO DETERMINANTES DO ÍNDICE DE QUALIDADE DA ÁGUA (IQA) USANDO SOFTWARE DESENVOLVIDO: UMA AVALIAÇÃO DA QUALIDADE DA ÁGUA E DA SAÚDE AMBIENTAL

*PHYSICAL AND MICROBIOLOGICAL PARAMETERS OF A WATER BODY AS DETERMINANTS OF THE WATER QUALITY INDEX (WQI) USING DEVELOPED SOFTWARE: AN ASSESSMENT OF WATER QUALITY AND ENVIRONMENTAL HEALTH*

Fairusa Corrêa Mascarin[1], Maikow Zago[1], Núbia Cristina Weber Freitas[1], Dienefer Frizzo Junkes[1].

[1]Universidade Regional Integrada do Alto Uruguai e das Missões, Campus de Santo Ângelo, Santo Ângelo, Rio Grande do Sul, Brasil.

## RESUMO

Os parâmetros avaliados neste trabalho são importantes ferramentas para determinação da qualidade do rio estudado. Quatro locais (P1, P2, P3 e P4) foram avaliados quanto à classificação da água por meio de software desenvolvido paralelamente às análises. Os resultados mostraram que o rio avaliado possui um bom índice de qualidade da água, porém, este estudo deixa fortes indícios de contaminação antrópica nos pontos P3 e P4, onde há moradias. O software desenvolvido utilizando modelagem matemática resultou em uma avaliação dos parâmetros com excelente correlação ($R^2 \geq 0{,}99$), o que pode ser uma importante ferramenta no processamento dos dados avaliados, a fim de otimizar o tempo de geração dos dados, mantendo a confiança dos resultados.

**Descritores:** Otimização de dados; software IQA; contaminação antropogênica.

## *ABSTRACT*

*The parameters evaluated in this work are important tools for determining the quality of the river studied. Four sites (P1, P2, P3 and P4) were evaluated for water classification using software developed in parallel with the analyses. The results showed that the evaluated river has a good water quality index, however, this study leaves strong evidence of anthropogenic contamination at points P3 and P4, where there are houses. The software developed using mathematical modeling resulted in an evaluation of the parameters with excellent correlation ($R^2 \geq 0.99$), which can be an important tool in processing the evaluated data, in order to optimize the data generation time, maintaining the confidence of the results.*

***Descriptors**: Data optimization; WQI software; anthropogenic contamination.*

DOI: http://dx.doi.org/10.31512/ricsb.v7i2.1570

## INTRODUCTION

Use Bodies of water are important for humanity due to their role in supporting life and providing essential resources and also serve as a source of drinking water and support various species that humans rely on for food, including aquatic species, land animals, and crops[1]. Additionally, water is crucial for economic activities such as industry, energy production, agriculture, and transportation. Ensuring the quality of water is essential for its safe use in these functions.

Moreover, our own bodies, which are primarily composed of water, are interconnected with other bodies of water in a anthropologic and complex relationship[2]. Recognizing the interdependence of water bodies and human bodies can help us address the challenges posed by water scarcity, water commodification, and the development of new hydrological technologies. By promoting a integrated understanding of water as a shared resource, we can work towards a more sustainable and equitable management of water bodies.

Monitoring the quality of water bodies is essential for identifying contamination levels and ensuring safe water for various purposes. Traditional methods involve manual sampling and laboratory testing, which can be time-consuming and unsustainable for large-scale monitoring. To overcome this challenge, satellite-based environmental monitoring and the use of index-based and softwares methods have been explored for monitoring large water bodies like rivers and oceans[3]. To address this, a Water Quality Enhanced Index (WQEI) Model has been proposed, which enables users to determine contamination levels in water bodies with some parameters.

Additionally, the Internet has been utilized for real-time monitoring of multiple water parameters, such as turbidity, pH, and temperature, using sensors and cloud computing platforms[4], in assossiation with softwares implantation. New monitoring techniques offer cost-effective and sustainable ways to assess water quality across diverse water bodies.

The biggest concern regarding water resources is contamination. Water bodies can be contaminated by various sources including aesthetic, biological, chemical, and dissolved solids. Urban runoff and wastewater/sewage input are major contributors to the contamination of urban streams, with urban runoff being particularly important in areas where wastewater input is minimal[5]. Industrial activities such as metal processing, mining, and the use of chemicals containing heavy metals are significant sources of contamination, leading to the presence of high atomic weight metals in water bodies[6].

Municipal wastewater and industrial waste disposal are major causes of water pollution, along with contaminants that enter the water supply through soils, groundwater systems, and rain[7]. Additionally, fecal contamination from various sources including humans, livestock, poultry, and wild animals can also contribute to water contamination[8].

Legislation for water quality in water bodies is of utmost importance for several reasons. Firstly, it helps to avoid conflicts among water users and minimize public health risks from

DOI: http://dx.doi.org/10.31512/ricsb.v7i2.1570

pollutants, ensuring the safety of drinking water and protecting public health[9]. Secondly, it plays a crucial role in protecting the environment and preserving ecosystems, as water bodies support various species and provide habitats for aquatic life. Thirdly, legislation helps to maintain the recreational and aesthetic value of water bodies, ensuring that they can be enjoyed by the public[10]. Additionally, water quality regulations are necessary to meet the demands of industries, agriculture, and transportation, as water is a vital component in these sectors. Therefore, legislation is a important tool and helps to set specific standards and limits for pollutant discharges, preventing water bodies from violating their water quality standards and ensuring the sustainable use of water resources[11].

Therefore, this study evaluated the water quality of a river in the northwest of Rio Grande do Sul, Brazil, investigating parameters such as electrical conductivity (EC), pH, dissolved oxygen (DO), temperature, turbidity, total solids (TS), thermotolerant coliforms (TC), biological oxygen demand (BOD), total nitrogen (TN) and total phosphorus (TP). The data were analyzed in the IQA URI software, to obtain the response variable referring to the water quality index (WQI).

## MATERIALS AND METHODS

Use Sample collections were carried out at 4 different points throughout the water body. Cleaned and sterilized amber bottles were used for collections. The 4 collection sites are described as source (P1), with a rare anthropic presence, the second point located between the source and the beginning of urban buildings and some industrial plants (P2), the third point (P3) is central in relation to the distribution of the city and the final point (P4) is located at the end of the urban area. The river evaluated in this study is called Itaquarinchim and is located in the northwest of the state of Rio Grande do Sul, Brazil, with coordinates Latitude: -28.3003, Longitude: -54.2635, 28° 18′ 1″ South, 54° 15′ 49″ West and is located in the Ijuí River Basin (U90), belonging to the Hydrographic Region of Uruguay, with its source located in the Comandaí District, continuing to the Ijuí River.

Electrical conductivity was determined using a Servilab® bench conductivity meter (APHA, 2005/2510B) and pH measurements were made using a Digimed DM-22® pH meter (APHA, 2005/4500H). The determination of dissolved oxygen was based on the Winkler method. The on-site temperature was determined with a calibrated mercury thermometer. Turbidity was assessed with a Hanna HI98703 benchtop turbidimeter (APHA, 2005/2130B). The determination of total solids (method 2540), BOD5 (method 5210), total nitrogen (method 4500N) and phosphorus (method 4500P) were determined according American Public Health Association (APHA, 2005/)[12]. The evaluation of microbiological parameters, as thermotolerant coliforms, was carried out using Colilert® (Idexx), according to the manufacturer’s manual instructions.

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To analyze the data and obtain the water quality index (WQI), software IQA URI® was developed at the Universidade Regional Integrada do Alto Uruguai e das Missões, with own resources, through mathematical modeling, generating equations with $R^2$ values > 0.99.

## RESULTS AND DISCUSSIONS

Use The data discussed in this topic refer to the averages between the points of collections divided into a monitoring period of 33 months, with the objective of verifying the influence of temporal variation, the location of the collection points in function of the housing and industrial distribution throughout the water body. Both P1 and P2 showed mud deposition and changes in the river channel like canalization. In terms of the presence of riparian forest, P1 has riparian vegetation, obvious deforestation, sections with exposed soil or eliminated vegetation, and the other points (P2, P3 and P4) have native riparian forest and very pronounced deforestation. P1 demonstrates stable and little affected margins, while P2 presented moderately stable margins with signs of erosion.

Points 3 and 4 are located closer to the city center, and are also the most impacted by residential, commercial and industrial occupation and accentuated anthropogenic impacts on the margins such as plumbing, sewage and garbage. They also presented marked anthropogenic impacts on the bed, as well as moderate and pronounced water odor or sediment. Points 3 and 4 also showed moderate oiliness in the water and the absence of aquatic plants.

### *Effect of temperature*

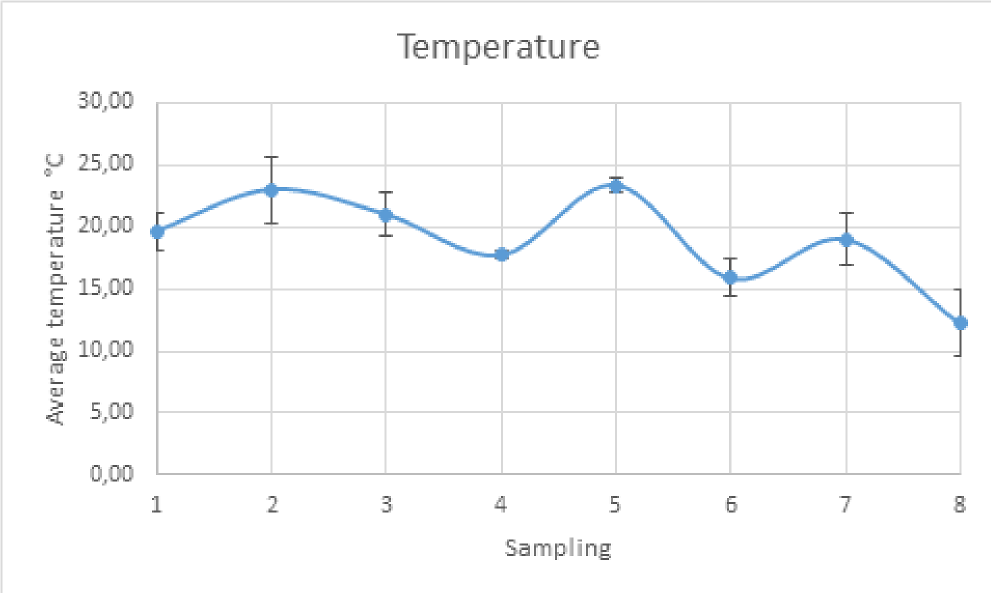
Water temperature has various effects on water bodies. Increasing water temperature can cause the incidence of parasitic diseases in aquatic animals, as can boost the rate of disease spread and lengthen the transmission season. Water bodies, such as rivers and lakes, have a cooling effect on the surrounding microclimate through evaporative cooling, which enhances evaporation and provides daytime cooling. Elevated temperatures in shallow lakes can increase the growth of planktonic algae and decrease benthic algal biomass, contributing to eutrophication and a decline in water quality[13].

Climate change is causing an increase in water temperatures in rivers and lakes, resulting in longer ice-free seasons and changes in the seasonality of fish and plankton populations. Higher water temperatures can accelerate the decomposition dynamics of leaf litter, as observed in the study carried out by SIMON (2021)[14].

In this study, the average temperature values obtained ranged from 12.25 to 23.33 °C, with greater standard deviation (variation) in the months of December and June (Figure 1).

DOI: http://dx.doi.org/10.31512/ricsb.v7i2.1570

Figure 1: Temperature mean values and standard deviations vs. Sampling, where sampling 1 = Sep/2019; 2 = Dec/2019; 3 = Mar/2020; 4 = Sep/2020; 5 = Dec/2020; 6 = Jul/2021; 7 = Dec/2021; and 8 = Jun/2022.;




The water temperature in rivers tends to be lower at their sources, compared to more populated areas, mainly due to the protection provided by the riparian forest and the presence of slopes and natural protections[14]. Riparian tree planting has been shown to successfully mitigate water temperature increase in rivers[15]. In addition, the presence of natural landscapes, such as vegetation and wooded areas, has a positive relationship with surface temperature, leading to lower water temperatures.

Tributaries, which are often located in less populated areas, have lower water temperatures compared to the main stem of rivers, making them potential thermal refugia for cold water fishes[16]. These findings highlight the importance of riparian vegetation, natural landscapes, and tributaries in maintaining lower water temperatures in rivers.

Rains and strong sunlight can cause temperature variations in a body of water, as seen in December in relative samples 2 and 7. The difference in December 2020 (sampling 5) may be related to specific changes in local climate conditions, such as changes in precipitation, for example. Storms, including wind-induced mixing, direct precipitation, and watershed runoff, can lead to small day-to-day decreases in epilimnetic temperature in lakes and reservoirs[17].

Rainfall rates are associated with the largest salinity changes and lowest salinity in certain regions of the tropical oceans[18], which can influence the composition of the waters where precipitation will occur. Diurnal and annual cycles of water temperature are important in small water bodies, with strong temperature stratification during the day and a well-mixed layer developing at night.

DOI: http://dx.doi.org/10.31512/ricsb.v7i2.1570

*pH effect*

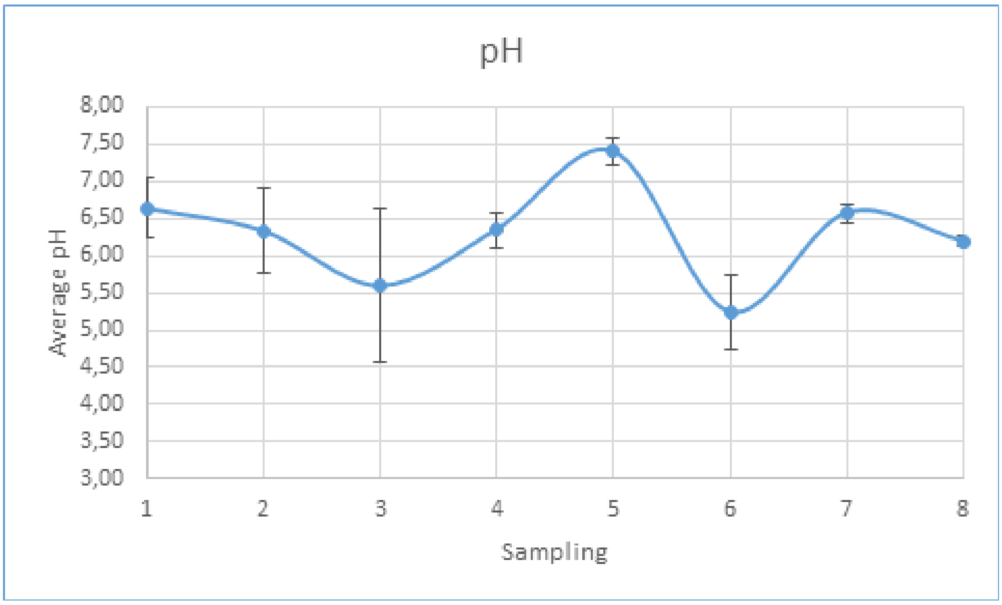
The variation in the pH of the water body throughout the studied period was 5.25 to 7.40 (Fig. 2), March of 2020 being the month with the biggest standard deviation (SD = 1.04). One of the main factors is the presence of pollutants and chemicals released into the river, such as industrial wastewater and chemical compounds from anthropogenic emissions[19]. These pollutants can contribute to acidification (Eq. 1) or alkalization (Eq. 2) of the water, depending on their chemical properties. Another factor is the natural biogeochemical and physical processes occurring in the river, such as photosynthesis, denitrification, carbonate precipitation, and sediment decomposition. These processes can either increase or decrease the pH of the water. Additionally, temperature can also play a role in pH changes, as demonstrated in the study performed by GAŁUSZKA (2020)[20].

$$(CH_2O)n \rightarrow nCO_{2(g)} + nH_2O_{(l)}$$

$$nCO_{2(g)} + nH_2O_{(l)} \rightarrow H_2CO_3 \quad (1)$$

$$\text{Nitrogenous organic matter} \rightarrow NH_3 \quad (2)$$

Figure 2: pH mean values and standard deviations vs. Sampling, where sampling 1 = Sep/2019; 2 = Dec/2019; 3 = Mar/2020; 4 = Sep/2020; 5 = Dec/2020; 6 = Jul/2021; 7 = Dec/2021; and 8 = Jun/2022.




Changing pH in a body of water can have various effects. Acidification of lakes and rivers due to human interference can disrupt the chemosensory abilities of aquatic organisms, affecting their decision-making processes and social behavior. Additionally, altering the pH of water can be achieved by adding granular mineral material, such as calcite and dolomite[21].

Extreme pH values can have a negative impact on the growth and survival of aquatic organisms, making it crucial to monitor water pH in aquaculture practices. Studies have shown

DOI: http://dx.doi.org/10.31512/ricsb.v7i2.1570

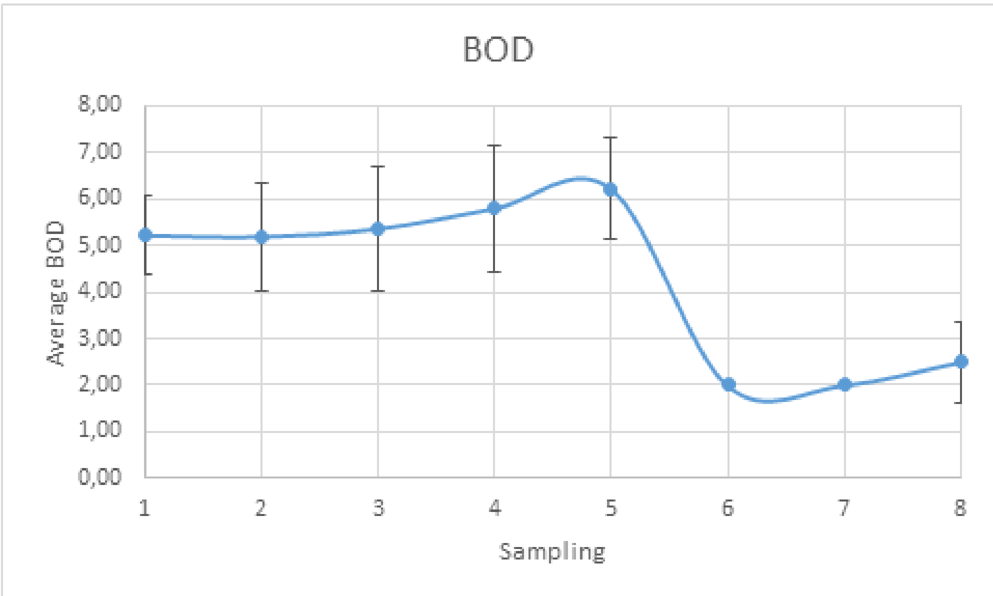
that alkaline pH levels can increase surface hydrophilicity, while acidic pH levels have little effect on hatching rates of crustacean eggs[22]. Additionally, increasing pH levels due to pollution can lead to a decrease in algal life, resulting in lower dissolved oxygen levels and potentially inhibiting aquatic life[23]. This way, it is important to study the effects of aquatic pollutants and their interactions with natural abiotic stressors, not only in the aquatic larval stage but also in the terrestrial adult stage, to fully assess the ecological impact of aquatic pollutants[24].

Monitoring water quality in aquaculture is essential for maintaining a safe environment for aquatic organisms and ensuring their optimal growth and survival[25].

BOD

The observed variation in BOD was considerably high. The values obtained ranged from 2 to 6.23 (Fig. 3), with lower values in the latest analyses in recent periods, which suggests an improvement in water quality in terms of contamination by organic compounds. The highest BOD values at sites 3, 4 and 5 corroborate the presence and anthropogenic interference in the water body, mainly due to the likely discharge of domestic eluents, which directly affects this parameter[26].

Figure 3: BOD5 mean values and standard deviations vs. Sampling, where sampling 1 = Sep/2019; 2 = Dec/2019; 3 = Mar/2020; 4 = Sep/2020; 5 = Dec/2020; 6 = Jul/2021; 7 = Dec/2021; and 8 = Jun/2022.




The effluents from domestic waste contain high levels of BOD, which is a measure of the organic matter present in the water. High BOD levels indicate a high level of pollution and can lead to oxygen depletion in the water, negatively impacting aquatic organisms. Monitoring and treatment of domestic wastewaters are essential to prevent the discharge of high BOD levels into water bodies.

By monitoring the quality of river water, discharge monitoring stations can detect changes in the environment and climate, as well as the impact of selected climatic and environmental

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variables. Environmental monitoring of water bodies is essential for sustainable development and the rational use of water resources, as mentioned LAZAREVA (2021)[27]. A water safety plan approach, which includes monitoring, is necessary to protect water supplies from accidental and intentional contamination. In some situations, it is proposed a water monitoring system using autonomous surface vehicles equipped with water quality sensors has been proposed. This system This system can help to estimate water quality models and detect pollution zones[28].

*Dissolved oxygen*

The values for DO remained between 5.03 and 7.47 (Fig. 4), so that the highest value of this parameter was observed in the collection in the local winter period. Temperature has a significant influence on the concentration of dissolved oxygen (DO)[29] in a body of water and in the literature, it is possible to find studies that mention the relationship between temperature and DO from work carried out in past decades.

There is a large negative correlation between temperature and DO, indicating that as temperature increases, the concentration of DO decreases. This relationship is supported by the finding that the rate of solution of oxygen in water increases linearly with increasing temperatures in the range of 0-35°C[29]. The temperature coefficients, which measure the increase in the rate of solution per degree Centigrade increase in temperature, have a mean value of 2.37[30].

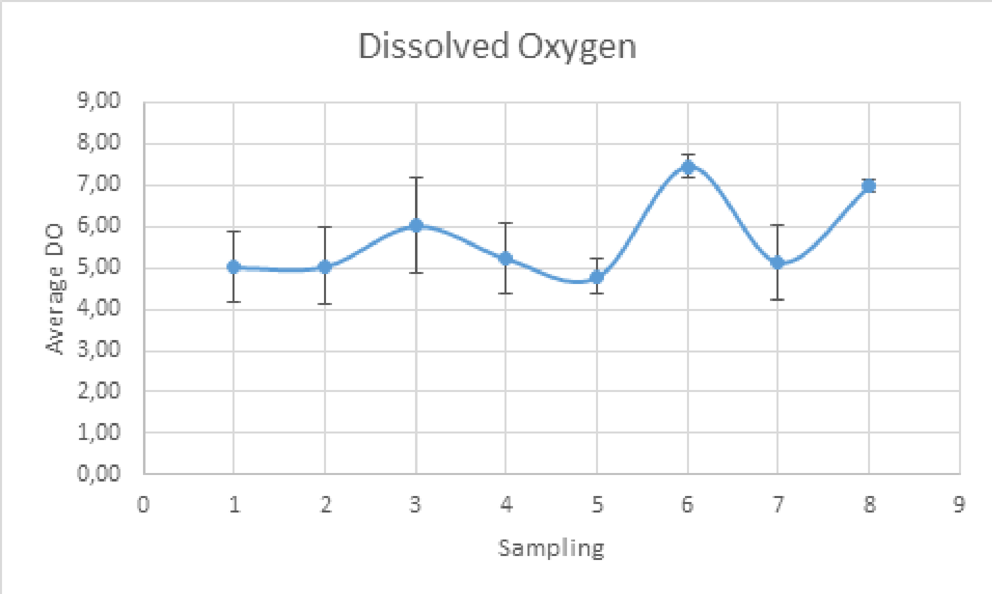
The behavior of DO showed a relationship with BOD, since at site 1 (spring) the DO values were higher and depending on the watercourse, the value reduces. Note that it is the opposite behavior in relation to BOD.

The relationship between biochemical oxygen demand (BOD) and dissolved oxygen (DO) is important for assessing water quality. Rising water temperatures can decrease the ability of natural waters to assimilate oxygen-demanding wastes beyond the damage caused by reduced DO saturation alone[31]. BOD oxidation depletes oxygen faster than reaeration can replenish it, resulting in decreased assimilative capacity[32].

Nitrogenous BOD is more sensitive to rising temperatures than carbonaceous BOD. The concentration of DO is closely related to water quality, as chemical reactions in water bodies are mainly dependent on DO. A BOD-DO model can be used to understand the relationship between BOD or DO and the physical characteristics of a river[33].

DOI: http://dx.doi.org/10.31512/ricsb.v7i2.1570

Figure 4: DO mean values and standard deviations vs. Sampling, where sampling 1 = Sep/2019; 2 = Dec/2019; 3 = Mar/2020; 4 = Sep/2020; 5 = Dec/2020; 6 = Jul/2021; 7 = Dec/2021; and 8 = Jun/2022.



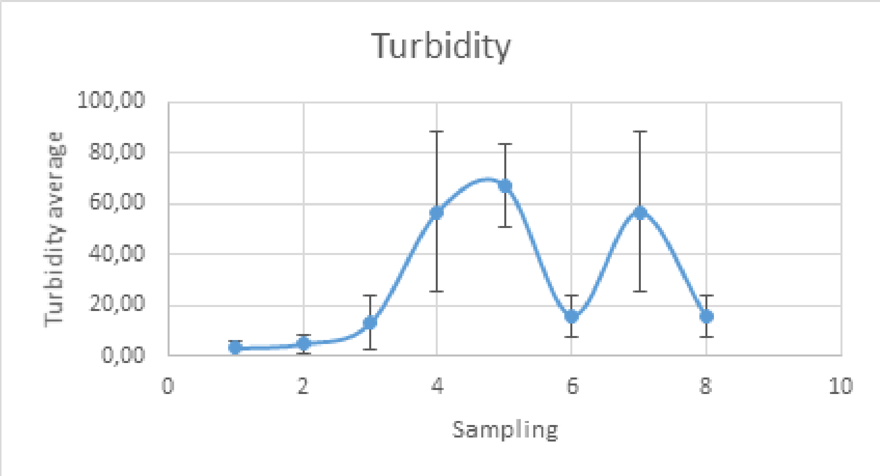

*Turbidity*

The evaluated turbidity values remained in the ranges of 3.23 and 67.37, with lower values at the source (0.99) and increased values in sites where there is anthropic presence and action, at points 3 and 4, with values of 77.58 and 76.33, respectively.

Anthropogenic factors can be divided into two groups based on their effects on surface water quality. The first group includes the regulation of rivers, construction of hydropower stations and reservoirs, and thermal and nuclear power plants, which primarily affect hydrological and biological processes[34]. The second group includes industrial, municipal, and agricultural wastewater, as well as petroleum products, which mainly impact physico-chemical and biological processes. This second case appears to be the one that most significantly affects the water in the river under study.

DOI: http://dx.doi.org/10.31512/ricsb.v7i2.1570

Figure 5: Turbidity mean values and standard deviations vs. Sampling, where sampling 1 = Sep/2019; 2 = Dec/2019; 3 = Mar/2020; 4 = Sep/2020; 5 = Dec/2020; 6 = Jul/2021; 7 = Dec/2021; and 8 = Jun/2022.

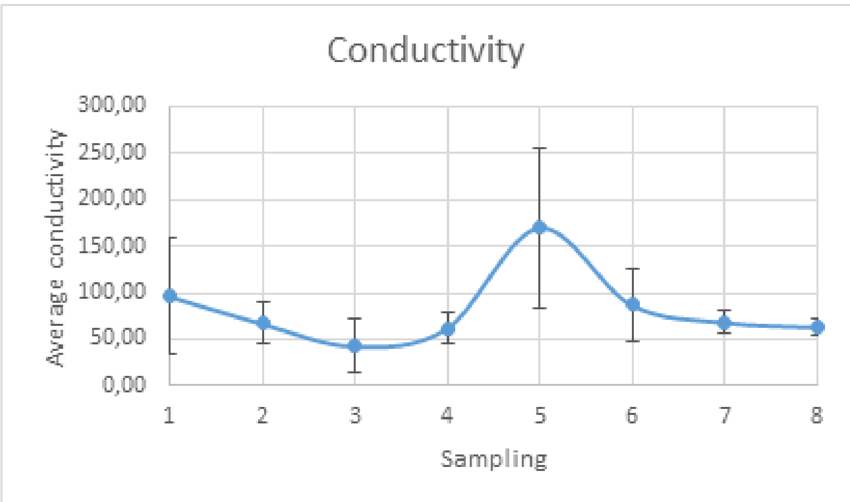



According to STEVENSON (2019)[35], the presence of high organic load and algal blooms in water can be associated with anthropogenic stresses.

*Conductivity*

The analyzed conductivity of the samples was lower at the source and higher at sites 3 and 4, where there are houses. The values varied between 42.73 and 170.33 (Fig. 6), with the highest value being at the last point (P4).

Figure 6: Conductivity mean values and standard deviations vs. Sampling, where sampling 1 = Sep/2019; 2 = Dec/2019; 3 = Mar/2020; 4 = Sep/2020; 5 = Dec/2020; 6 = Jul/2021; 7 = Dec/2021; and 8 = Jun/2022.




Conductivity in water bodies is caused by the presence of ionized substances which allows it to conduct electricity. The discharge of domestic effluents can contribute to an increase in water conductivity. In polluted urban streams, the specific electric conductivity of water samples can be increase downstream of canalization outlets that discharge drainage waters and residential waste waters. Similarly, the effluent discharge from industries, residential areas, abattoirs, and farms have adverse effects on the physico-chemical characteristics of receiving water bodies, leading to increased conductivity[36].

Temperature also plays a role in conductivity, as an increase leads to an increase in conductivity due to a decrease in viscosity in soils and possibly in liquid samples[37].

### *Coliforms*

At sites 1 and 2, where there is no anthropic action, the values of this parameter were lower (20 and 1100, respectively) in relation to sites 3 and 4 (160000 and 92000, respectively), where there is human interference in the water body.

The presence of coliforms in water bodies is commonly used as an indicator of water quality and potential contamination by harmful microorganisms. Coliform bacteria, including Escherichia coli (E. coli), are found in the environment and in the intestines of mammals, including humans. The presence of E. coli in water indicates recent fecal contamination and the possible presence of disease-causing pathogens.

Domestic waste, including sewage, is a major source of water pollution, contributing to the high incidence of coliforms in water bodies. Discharge of domestic effluents can lead to increased levels of coliforms, potentially exceeding acceptable limits for both ecological and human health. Effluent discharge can also impact bacterial diversity, with specific taxa typically found in effluents becoming over-represented in stream water samples. However, the environmental safety of effluent discharge procedures should be evaluated through comprehensive assessments of physico-chemical parameters, acute toxicity, and changes in bacterial diversity[38].

### *Determination of the Water Quality Index (WQI)*

To determine the WQI, a software was developed based on the follow parameters: pH, temperature, BOD5, dissolved oxygen, turbidity, electrical conductivity, coliforms, nitrogen and phosphorus, through mathematical modeling using standard graphs in the literature with estimation of axis points, considering a minimum value of 99% for confidence intervals. The software layout is demonstrated in Figure 7.

The equations of the mathematical model are shown in Eqs. 3 - 11, as well as the $R^2$ values, which demonstrate the precision of the method.

Revista Interdisciplinar em Ciências da Saúde e Biológicas, 2023; 7(2)25-40
DOI: http://dx.doi.org/10.31512/ricsb.v7i2.1570

y = -2E-11X6 + 4E-8X5 – 1E-5X4 0,001X3 - 0,026X2 + 0,6178X + 4,5848 (DO, $R^2$ 0.9984) (Eq. 3)

y = 0,0002X6 - 0,0053X5 + 0,0449X4 + 0,1605X3 - 2,9488X2 - 1,3158X + 91,856 (TºC, $R^2$ 0.9987) (Eq. 4)

y = 3E-13X4 – 3E-8X3 + 0,00003X2 - 0,3089X + 68,062 (Coliforms, $R^2$ 1) (Eq. 5)

y = 0,0002X4 – 0,0197X3 + 0,6602X2 – 11,586X + 99,95 (OBD, $R^2$ 1) (Eq. 6)

y = 6E-6X4 – 0,0015X3 + 0,131X2 – 5,2914X + 97,469 (TN, $R^2$ 0.9913) (Eq. 7)

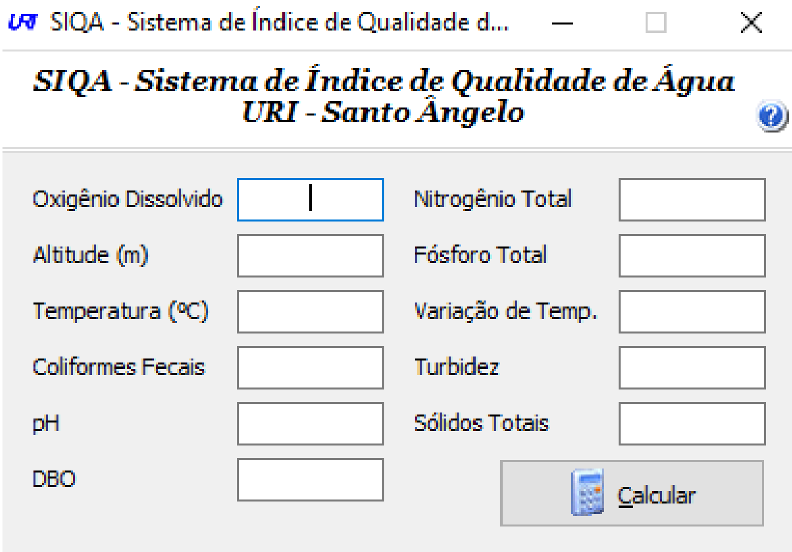
y = -0,0191X5 + 0,5659X4 – 6,3156X3 + 32,994X2 – 82,957X + 99,058 (phosphor, $R^2$ 0.9955) (Eq. 8)

y = 0,0002X6 – 0,0053X5 + 0,0449X4 + 0,1605X3 – 2,9488X2 – 1,13158X + 91,856 (ΔT, $R^2$ 0.9987) (Eq. 9)

y = -0,0001X3 + 0,0258X2 – 2,1827X + 97,65 (turbidity, R2 0.9954) (Eq. 10)

y = 6E-7X3 – 0,0006X2 + 0,0628X + 83,515 (total solids, R2 0.9939) (Eq. 11)

Figure 7: Layout of the developed software. Source: Author.




After entering the data into the software, the resulting WQI was 68, considered good, according to the classification bands. Despite the high coliform values, the resulting WQI index was considered good, as the other parameters proved to be adequate to maintain water quality, considering that the averages of the 4 collection sites were considered. Therefore, in a general context and considering the characteristics of the 4 sites, the parameters were satisfactory. However, it is important to keep the coliform and BDO values under close attention, as at specific sites, there is a strong indication of contamination by anthropogenic action.

Table 1: Parameter values determined for WQI evaluation.

| **Parameter (average)** | **Value** | **Unit** |
|---|---|---|
| DO | 5,14 | mg $L^{-1}$ |
| Temperature | 19,33 | ºC |
| Temperature variation | 4,5 | ºC |
| Coliforms | 47773 | MLN |
| pH | 6,34 | - |
| BDO | 5,22 | mg $L^{-1}$ |

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| | | |
|---|---|---|
| Total nitrogen | 0,5 | mg $L^{-1}$ |
| Total phosphor | 0,055 | mg $L^{-1}$ |
| Turbidity | 16,07 | NTU |
| Total solids | 157 | mg $L^{-1}$ |
| Altitude | 200 | m |

## CONCLUSIONS

The river water samples evaluated and separated into 4 sites showed differences in relation to human influence, presenting high BOD and coliform values at sites P3 and P4, suggesting the dumping of domestic effluents. The quality of the water analyzed was higher at sites P1 and P2, where there is no human interference, with parameters such as higher DO and lower BOD in relation to other sites, demonstrating that at the source and in the initial part of the river there is conservation of water quality due to preservation by riparian forest and the absence of housing and activities in general. High BOD and presence of coliforms at sites 3 and 4 strongly suggest contamination through the discharge of domestic effluents, which demonstrates the need to monitor parameters as a basis for preventive and corrective measures. The WQI of the river water was 68, which suggests good quality, mainly due to the good parameters in the initial course of the river. The developed software was used and presented good correlation values for the parameters ($R^2 > 0.99$), suggesting a suitable model for evaluating the WQI in water samples from water bodies.

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**Autor Correspondente:** Maikow Zago[1]

E-mail: maikowzago@hotmail.com

**Recebido em:** 2024-02-16

**Aprovado:** 2024-05-26