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# Assessment of the Water Quality of the Mirim Lagoon and the São Gonçalo Channel Through Qualitative Indices and Statistical Methods

Vitória Rovel da Silveira · Marlon Heitor Kunst Valentini · Gabriel Borges dos Santos · Willian Cezar Nadaleti · Bruno Muller Vieira

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**Abstract** The Mirim Lagoon is one of the most important freshwater lagoons in the Brazilian territory, connecting the Patos Lagoon through the São Gonçalo Channel. With the diversification of the uses of rivers, watersheds, and lakes, sustainable management and management of these ecosystems are extremely relevant. For this reason, the monitoring of these environments is of great importance. In view of the above, the water quality index (WQI), the trophic state index (TSI), and statistical methods are tools that enable rapid assessment of water characteristics regarding pollution sources, expressing its quality in a single value, which facilitates understanding. Thus, this study aims to evaluate the water quality of the Mirim Lagoon and the São Gonçalo Channel through these methods. With the proposed methods, it was possible to observe that the Mirim Lagoon and the São Gonçalo Channel suffer strong influence from agricultural activities and the release of untreated effluents into their beds, causing the deterioration of these water resources. Despite this, for the most part, the collection points had a good WQI and TSI varying between quality ranges 1 and 3. Furthermore, the importance of statistical methods to assess the studied parameters is highlighted, since they promote more accurate results.

**Keywords** Water resources · Water quality index · Trophic state index · Correlation · Significance · Pollution

V. R. da Silveira
Federal University of Pelotas, Pelotas, Brazil

M. H. Kunst Valentini (✉) · G. B. dos Santos
Postgraduate Program in Water Resources, Federal University of Pelotas, Pelotas, RS, Brazil
e-mail: marlon.valentini@hotmail.com

W. C. Nadaleti · B. M. Vieira
Engineering Center, Post-graduation Program in Environmental Sciences, Research Laboratory of Energy and Environmental Engineering – LEAE, Federal University of Pelotas, Pelotas, Brazil

## 1 Introduction

Water is an element of extreme importance for all living beings. Although water has undergone changes that compromise its quality. These changes are mainly related to the expansion of urban development, the release of untreated domestic and industrial effluents, pesticides, and waste from agriculture, and also other activities that cause direct or indirect damage to water bodies, affecting their properties (Leite et al. 2019; Silva et al. 2017; Kumar 2015). In Brazil, sanitary sewage and solid waste dumped into water resources are considered one of the main problems in aquatic environments (Santos et al. 2018).

In this context, in 1970 studies were conducted by the National Sanitation Foundation in the USA and resulted in the creation of the WQI, later adapted in Brazil by the

Environmental Technology Company of the State of São Paulo (CETESB). The WQI incorporates nine variables, functioning as a tool that indicates the degree of contamination due to organic materials, nutrients, and solids, which are usually indicators of pollution (Guimarães Neto et al. 2019).

The trophic state index (TSI) is widely used because it establishes trophic levels in relation to the concentration of total phosphorus and chlorophyll a, enabling the classification of waters into trophic classes (Barreto et al. 2013). In the variables used to calculate the TSI, total phosphorus is more prominent, as it is a nutrient, and is often the limiting factor for primary production (Lamparelli 2004). It is worth mentioning that the analysis of the TSI is important for a good management of water resources, because it increases the information about a body of water from the description of the biotic and abiotic relationships within an ecosystem (Zanini et al. 2010).

With regard to statistical methods, these methods have the advantage of providing a simple interpretation for a complex and difficult-to-analyze data set, and they also have greater accuracy and facilitate data manipulation. Therefore, the application of advanced statistical methods is very useful to extract meaningful information without losing accuracy (Hair et al., 2009; Zhao et al. 2012; 2011).

The Mirim Lagoon, located in the extreme south of Brazil, is one of the most important freshwater lagoons in the Brazilian and South American territory. This lagoon, considered to be binational because it is shared between Brazil and Uruguay, stands out because it is of paramount importance for the social and economic development of the southern region of Rio Grande do Sul, Brazil (Piedras et al. 2012). The Mirim Lagoon is connected with the Patos Lagoon through the São Gonçalo Channel, which is approximately 76 km long and is the natural drain of the waters of the Mirim Lagoon. The São Gonçalo Channel is considered to be a strategic source for the region, but its water quality is impacted by pollution processes, requiring continuous monitoring to ensure its multiple uses (Souza 2015).

Thus, the management of water resources, their monitoring, and planning actions are essential measures to ensure water quality ANA (2019). Therefore, this study aims to assess the water quality of the Mirim Lagoon and the São Gonçalo Channel through the water quality index and the trophic state index and statistical methods.

## 2 Methodology

### 2.1 Description of the Study Location and Sampling

The study was carried out at the Mirim Lagoon, located between the parallels 31° 30′ and 34° 30′ S and between the meridians 52° and 56° W, with surface corresponding to approximately 62,250 $km^2$, in which 47% are in Brazilian territory and 53% in Uruguay. In addition to the Mirim Lagoon, the study was also carried out in the São Gonçalo Channel, a channel responsible for connecting the Mirim Lagoon with the Patos Lagoon (Scalco et al. 2018; Silva et al. 2020)

The data used in this work are part of a monitoring project carried out by the Mirim Lagoon Agency, which belongs to the Federal University of Pelotas (UFPel). From this project, 10 sampling points were established, 6 located in the Mirim Lagoon, and 4 in the Channel São Gonçalo, as shown in Fig. 1. The identification of the collection points, as well as their locations, are presented in Table 1.

### 2.2 Sampling and Analysis

Samples were collected monthly from April 2018 to April 2019. It is worth mentioning that the collection, transportation, and analysis followed the standards described in the Standard Methods for the Examination of Water and Wastewater (APHA 2017). The parameters analyzed were turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total nitrogen, total phosphorus, thermotolerant coliforms, total solids, temperature, pH, and chlorophyll a.

The methodology of the analyses was as follows: pH and temperature were determined "in loco," using a pocket multiparameter meter. To determine the turbidity, a portable turbidimeter was used. For the analysis of DO, BOD, and total nitrogen, the titrometric method was followed. The determination of the phosphorus parameter was through the acid digestion method followed by colorimetry-spectroscopy. Chlorophyll a was performed using the monochromatic spectrophotometric method, also using a spectrophotometer. The thermotolerant coliforms were determined by the multiple tube method. Finally, the total solids were defined using the gravimetric method.

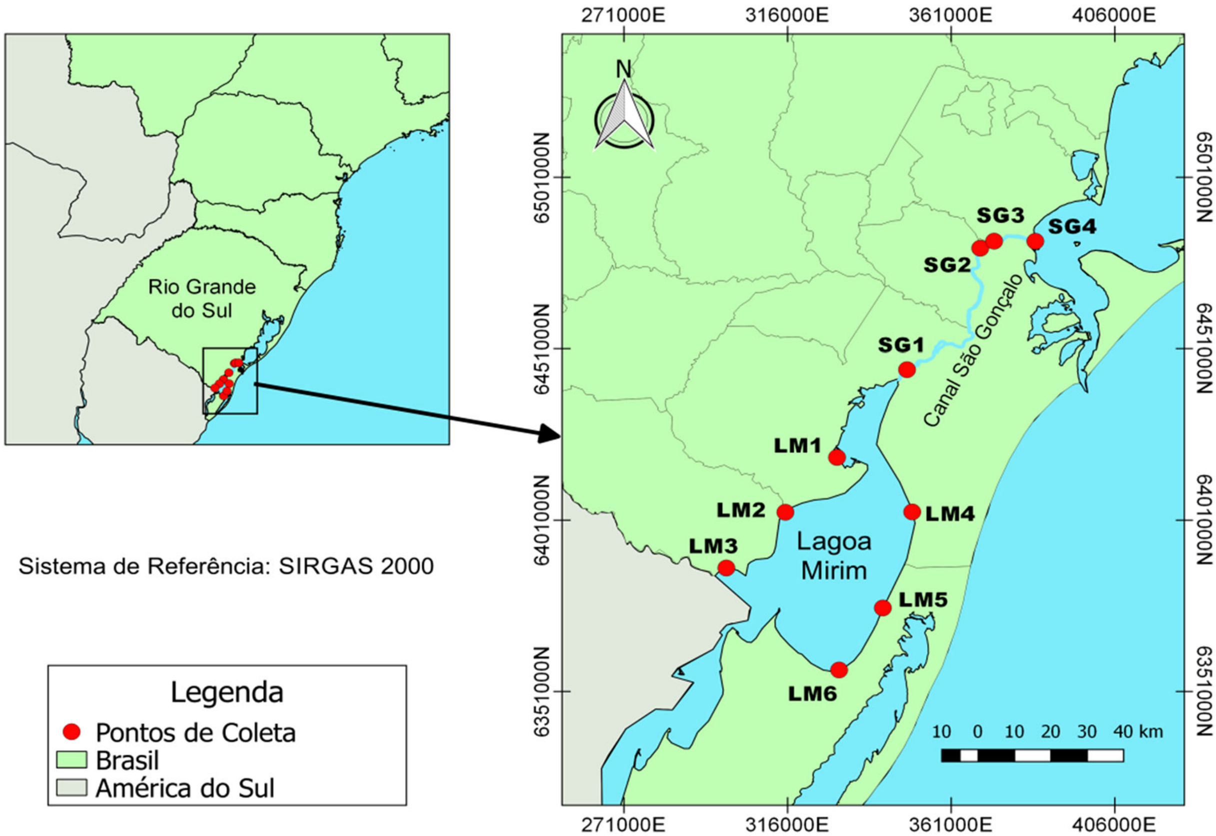


**Fig. 1** Collection points. Source: the authors

2.3 Trophic State Index (TSI)

According to Sperling (2005), the TSI functions as the record of human activities in hydrographic basins and provides support for the establishment of management plans and management of ecosystems, aiming at the sustainability of water resources. The TSI aims to classify water bodies in different trophic classes, using two variables for analysis: total phosphorus and chlorophyll a CETESB (2017).

The trophic state index presented is composed of the trophic state index of phosphorus, $TSI_{(PT)}$, and the

**Table 1** Identification of collection points

| Points | Local | Latitude South | Longitude West |
|---|---|---|---|
| SG1 | Saint Elizabeth | 32° 7′7.39″ | 52° 35′35.15″ |
| SG2 | São Gonçalo Channel Lock | 31° 48′40.59″ | 52° 23′17.48″ |
| SG3 | Train bridge | 31° 47′17.99″ | 52° 20′42.90″ |
| SG4 | Barra Region | 31° 47′11.70″ | 52° 13′28.61″ |
| LM1 | Pontal Beach | 32° 20′4.02″ | 52° 49′18.39″ |
| LM2 | Brittany Farm | 32° 29′12.70″ | 52° 58′14.90″ |
| LM3 | San Francisco Farm | 32° 38′24.95″ | 53° 8′57.77″ |
| LM4 | Capilha | 32° 29′20.70″ | 52° 35′35.36″ |
| LM5 | Curral Alto | 32° 45′4.68″ | 52° 41′2.55″ |
| LM6 | Anselmi Village | 32° 54′32.80″ | 52° 48′5.90″ |

Source: Vieira et al. (2019)

trophic state index for chlorophyll a, $TSI_{(CL)}$ (Lamparelli 2004), according to Eqs. 1 and 2.

$$IET[CL] = 10x\left(6-\left(\frac{-0,7-(0,6xln(CL))}{\ln(2)}\right)\right)-20 \quad (1)$$

$$IET[P] = 10x\left(6-\left(\frac{0,42-(0,36xln(P))}{\ln(2)}\right)\right)-20 \quad (2)$$

In which:

- PT: is the total phosphorus concentration measured on the water surface, in μg. $L^{-1}$
- CL: is the concentration of chlorophyll measured on the water surface, in μg. $L^{-1}$
- ln: natural logarithm

The result of the monthly values presented in the final table of the TSI corresponds to the simple arithmetic mean of the indices related to total phosphorus and chlorophyll a, according to the following equation:

$$IET = \frac{IET[CL] + IET[P]}{2} \quad (3)$$

From the results obtained from the TSI, we obtain the trophic state classification, as shown in Table 2. For better interpretation of the results, in this study, a range of 1 to 6 was assigned to the results of the TSI, with 6 being the worst quality.

### 2.4 Water Quality Index (WQI)

As previously discussed, the WQI was created in the USA and adapted in Brazil by CETESB, in order to better suit the characteristics of the national water resources (Ferreira et al. 2015). This index is calculated using the weighted product of each of its parameters, according to Eq. 4. This calculation results in a single number:

$$WQI = \prod_{i=1}^{n} qi^{wi} \quad (4)$$

Where, according to ANA (2019):

- WQI: results in numbers from 0 to 100, with 100 being the best quality
- qi: is the quality of the i-th parameter, a number between 0 and 100, which is obtained through the quality graph as a function of the measured concentration
- wi: is the weight of the i-th parameter, represented by a number ranging from 0 to 1

For the calculation of this index, each parameter considered has a weight fixed in relation to its relevance for the overall conformity to water quality. These weights are presented in Table 3.

Thus, the results obtained through the calculation of the WQI can be classified into quality ranges (Table 4). In addition, in this study, the values from 1 to 5 were assigned to the WQI result ranges for better interpretation, with 5 being the worst quality.

### 2.5 Analysis Statistics

First, in order to avoid that the order of magnitude of the different variables studied had an influence on the statistical analyses, the data were standardized. This standardization followed the methodology proposed by Wilks (2006).

In order to evaluate the sample distribution, for later use of parametric or nonparametric tests, the Kolmogorov-Smirnov (K-S) and Shapiro-Wilk (S-W) normality tests are performed at a significance level of 0.05. For these

**Table 2** Trophic state classification index

| Category (trophic state) | Track | Weight | P-Total – P ($mg.m^{-3}$) | Chlorophyll a ($mg.m^{-3}$) |
|---|---|---|---|---|
| Ultraoligotrophic | 1 | $TSI \leq 47$ | $P \leq 13$ | $CL \leq 0.74$ |
| Oligotrophic | 2 | $47 < TSI \leq 52$ | $13 < P \leq 35$ | $0.74 < CL \leq 1.31$ |
| Mesotrophic | 3 | $52 < TSI \leq 59$ | $35 < P \leq 137$ | $1.31 < CL \leq 2.96$ |
| Eutrophic | 4 | $59 < TSI \leq 63$ | $137 < P \leq 296$ | $2.96 < CL \leq 4.70$ |
| Supereutrophic | 5 | $63 < TSI \leq 67$ | $296 < P \leq 640$ | $4.70 < CL \leq 7.46$ |
| Hypereutrophic | 6 | $TSI > 67$ | $640 < P$ | $7.46 < CL$ |

Source: adapted from CETESB 2017

**Table 3** Relative weights of parameters for the calculation of the WQI

| Parameters | Weight |
|---|---|
| Dissolved oxygen (DO) | 0.17 |
| Thermotolerant coliforms | 0.15 |
| Potential of hydrogen (pH) | 0.12 |
| Biochemical oxygen demand | 0.10 |
| Temperature | 0.10 |
| Total nitrogen | 0.10 |
| Total phosphorus | 0.10 |
| Turbidity | 0.08 |
| Total solids | 0.08 |

Source: ANA 2019

tests, at a *p*-value <0.05, the null hypothesis is rejected, rejecting the sample normality.

After the analysis of the sample distribution, a matrix of correlation with its coefficients and significances was used, with the objective of evaluating the correlation between the variables that make up the TSI, as well as the TSI itself and the WQI. The correlation coefficient to be used depends on the sample distribution of the data, which is why normality tests were previously performed. For data that follow a normal distribution, for example, Pearson's coefficient is the most commonly used, while for data that do not have sample normality, nonparametric coefficients are recommended, such as the Spearman Rhô coefficient (Guimarães 2017).

Certain statistical tests may infer whether there was significant variation of a parameter in relation to a predefined factor. In order to verify whether there is significant variability of the AQI, the TSI and the phosphorus, and chlorophyll variables between the months and between the monitoring points, analysis of variance will be performed with these two parameters as a selection factor. Different tests do this type of analysis, but the default mechanism is the same, the significance test of the null hypothesis. According to Ellenberg (2015), this has been the standard method for evaluating results of scientific research for decades. For these analyses, for *p*-value <0.05, the null hypothesis will be rejected, resulting in a significant variation at a 95% confidence level of 95%.

**Table 4** WQI classification for the state of Rio Grande do Sul

| WQI value | Track | Water quality |
|---|---|---|
| $79 < WQI \leq 100$ | 1 | Great |
| $51 < WQI \leq 79$ | 2 | Good |
| $36 < WQI \leq 51$ | 3 | Acceptable |
| $19 < WQI \leq 36$ | 4 | Bad |
| $WQI \leq 19$ | 5 | Lousy |

Source: adapted from CETESB 2017

## 3 Results and Discussion

From the data collected at the 10 sampling points, along the São Gonçalo Channel and the Mirim Lagoon, 9 parameters were used for the calculation of the WQI and 2 parameters for the study of the TSI.

### 3.1 Trophic State Index (TSI)

The monthly results of the TSI of the São Gonçalo Channel and the Mirim Lagoon are presented in Table 5.

As can be seen from Table 5, the worst results for the São Gonçalo Channel (SG1, SG2, SG3, and SG4), ranging from oligotrophic to mesotrophic, were found in May and August. One of the possible reasons may have been the high values of total phosphorus in May and August, 1.15 and 1.95 mg/L, respectively, which suggest a possible contamination by domestic and agricultural effluents (Table 10 in Appendix).

The study conducted by Valentini et al. (2021a) states that a large part of the lands surrounding Mirim Lagoon and São Gonçalo Channel are used for agricultural activities. Furthermore, these authors point out that the focus of pollution in these water resources is not limited to such activity, but also to the discharges of industrial effluents and domestic sewage without treatment in the São Gonçalo channel.

It is worth noting that the agricultural runoff is a large responsible source for pollutants with compounds like nitrogen and phosphorus in water resources (Tibebe et al. 2019). In the study developed by Caldas et al. (2019), it was evaluated the environmental occurrence of pesticides in the surface and drinking water of the municipality of Rio Grande-RS, waters from the São Gonçalo Channel. That study showed that, although in low concentration, the presence of pesticides in the samples was detected. Such results confirm the vulnerability of these waters to contamination by pesticides due to the large rice plantations that exist in the basin (Oliveira et al. 2015).

A study by Albertoni et al. (2017), also on the water quality of the São Gonçalo Channel, analyzed the relationship of phosphorus and nitrogen with chlorophyll a concentration and found that the São Gonçalo Channel could

**Table 5** TSI results

| | 2018 | | | | | | | 2019 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Apr. | May | Jun. | Jul. | Aug. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. |
| SG1 | 1 | 2 | 2 | 1 | 3 | 2 | 1 | 1 | 1 | 1 | 1 |
| SG2 | 1 | 3 | 2 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 |
| SG3 | 2 | 3 | 1 | 1 | 3 | 1 | 2 | 1 | 1 | 1 | 1 |
| SG4 | 2 | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 1 | 1 |
| LM1 | 3 | 2 | 1 | 1 | 1 | 3 | 1 | 1 | 1 | 1 | 1 |
| LM2 | NR* | 1 | 1 | 1 | 1 | 2 | 2 | NR* | 2 | 1 | 2 |
| LM3 | 1 | 1 | 1 | 2 | 1 | NR* | 3 | 1 | 1 | 1 | 1 |
| LM4 | 1 | 3 | 3 | 1 | 1 | NR* | 3 | 1 | 3 | 1 | 1 |
| LM5 | 2 | 2 | 1 | 1 | 3 | NR* | 3 | 1 | 2 | 3 | 3 |
| LM6 | 1 | 2 | 1 | 1 | 1 | NR* | 3 | 1 | 2 | 1 | 2 |

**NR* not performed (sample not collected)

be undergoing eutrophication processes, with the flowering of cyanobacteria. It is worth mentioning that one of the main causes of eutrophication is the entry of organic matter into water bodies, caused by the release of domestic and industrial effluents and agricultural waste into the water, which have environmental impacts, polluting and contaminating the aquatic environment Talamoni and Liria (2019).

A study by Maia et al. (2015) which compared two trophic indices in the waters of the lower São José dos Dourados River, in São Paulo, found that the high concentrations of phosphorus can be strongly connected to the level of urban occupation, due to the disposal of domestic sewage, effluents released by industries, and the use of fertilizers in rural regions.

Studies conducted by Fia et al. (2009) on the trophic state of the Mirim Lagoon Hydrographic Basin, in which total phosphorus was used as a parameter, observed that in the years 1996 to 1998, phosphorus levels were higher than allowed by the legislation, and the main critical points located in the São Gonçalo Channel were considered, including the Eclusa Dam, because they received part of the pollution in the city of Pelotas. And in relation to the trophic state index, it was concluded that the variable evaluated is unstable, having periods of good water quality and periods of poor water quality, especially in the critical points mentioned above, suggesting deterioration of the quality of the water resources.

For the points located in the Mirim Lagoon (LM1, LM2, LM3, LM4, LM5, and LM6), the results of the TSI showed more variations throughout the study period, with some points classified as mesotrophic (Table 5). According to Lima (2018), mesotrophic environments may have implications for water quality, but at acceptable levels, most of the time.

The values of phosphorus (0.18 to 3.03 mg/L) and chlorophyll a (0.010 to 40.42 mg/L) varied greatly in the points of the Mirim Lagoon, which impacted the results. The high values found for chlorophyll a, especially in December (Table 10 in Appendix), which is the warmest period, were also observed in the study conducted by Cunha et al. (2013). These authors reported on the water quality of a lagoon in southern Brazil, which in the summer months presented higher values for this parameter. In studies conducted by Tormam et al. (2017) on the seasonal variability of water quality, phosphorus also varied throughout the seasons.

In the results observed by Lima (2018) for the Lagoa do Gambá, in Ouro Preto, the high values of phosphorus and chlorophyll a classified the water body as hypereutrophic, and, according to the author, these two parameters, associated with high coliform values, suggest that disposal of domestic effluents occurred there.

In the study by Coradi et al. (2009), on the evaluation of water quality of the main tributaries of the Mirim Lagoon, the results obtained classified water quality as acceptable, and phosphorus is the most impacting pollutant for the quality of water resources.

### 3.2 Water Quality Index (WQI)

The monthly results of the WQI for the São Gonçalo Channel and the Mirim Lagoon are presented in Table 6.

The points located in the São Gonçalo Channel (SG1, SG2, SG3, and SG4) presented, in a few months, regular index for the WQI. The high concentrations of thermotolerant coliforms in these sampling points, especially in May and August (>1600 MLN/100 mL), may indicate contamination by domestic sewage (Table 11 in Appendix). Sanches Filho et al. (2016), point out that the flow that the urban area of Pelotas/RS generates is one of the problems present in the São Gonçalo Channel.

Similar results were reported by Souza (2015) on the water quality of the São Gonçalo Channel. In their study, these authors observed that the parameters studied were in disagreement with the legislation, and had as main causes for the deterioration of water in the São Gonçalo Channel, and of the tributaries, especially the Santa Barbara Canal and Pepino Canal, the anthropic action, because they received urban and industrial effluents, often without previous treatment.

The Mirim Lagoon points of collection (LM1, LM2, LM3, LM4, LM5, and LM6) presented, in general, good water quality index, with worst assessment ranging in maximum regular water quality. A study conducted by Vieira et al. (2019), which evaluated the WQI of the Mirim Lagoon in 2016 and 2017, showed that the worst results of WQI were mostly associated with higher results of concentration of thermotolerant coliforms.

The results presented by Lima (2018) in his study on the Lagoa do Gambá, in Ouro Preto, also showed that the values obtained for the water quality index were associated with high values of thermotolerant coliforms. The same was observed in a study conducted by Malagutti and Tornisielo (2014) on the water quality of the Ribeirão Claro-São Paulo sub-basin, which reported that thermotolerant coliforms greatly impact the results of the water quality index and associated these values with the entry of effluents into the water body.

The study conducted by Dantas et al. (2020) evaluated the data from surface water quality monitoring through the fecal contamination indicator, composed of the parameters E. coli and Thermotolerant Coliforms in relation to part of the São Francisco River basin, one of the most important hydrographic basins in Brazil. This study showed that the most impacted sub-basins were also the most densely populated.

For Costa et al. (2018), the generation of organic matter and contaminant loads in aquatic environments due to the discharge of domestic effluents constitute one of the most significant vectors of threats to human health. In their study in Guanabara Bay (Rio de Janeiro/Brazil), these authors also demonstrated that disordered urban occupation and the lack of sanitation result in high levels of river degradation.

### 3.3 Statistical Analysis

With the standardized data, the sample distribution was analyzed using the K-S and S-W tests. As can be seen in Table 7, only the WQI has a normal distribution, obtaining a $p$-value > 0.05 for both tests. The other variables analyzed obtained $p$-value < 0.05, rejecting the hypothesis of sample normality.

Valentini et al. (2021a), also in a study concerning Mirim Lagoon, used the annual averages of the studied parameters to perform correlation analysis between them, considering all monitoring points together. In

**Table 6** WQI results

| | 2018 | | | | | | | 2019 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Apr. | May | Jun. | Jul. | Aug. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. |
| SG1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 |
| SG2 | 2 | 3 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| SG3 | 3 | 3 | 3 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| SG4 | 2 | 3 | 2 | 2 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| LM1 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 2 |
| LM2 | NR* | 2 | 2 | 2 | 2 | 2 | 2 | NR* | 2 | 2 | 2 |
| LM3 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 1 | 2 | 2 |
| LM4 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| LM5 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| LM6 | 2 | 2 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |

*NR* not performed (sample not collected) their study, a sample distribution was confirmed as normal, which possibility the use of correlation matrix with Pearson coefficient. On the other hand, Santos et al. (2020a), in a study carried out in the Moreira/Fragata stream in the municipality of Pelotas, obtained results showing parameters which did not follow a normal distribution, and therefore a non-parametric Spearman's coefficient was used to perform its correlation matrix.

Since it was confirmed that most variables do not follow a normal sample distribution, Spearman's coefficient was used for correlation analysis, as recommended by Guimarães (2017), as well as the Kruskal-Wallis analysis of variance, since this is a nonparametric analogue of the ANOVA test. The results of the correlation analysis, their coefficients, and *p*-significance values are shown in Table 8.

As can be seen in Table 8, only the correlation between the WQI and chlorophyll a obtained a $p$-value $> 0.05$, showing no significance to the correlations between these two variables. The non-significance of this correlation was already expected, and chlorophyll a is not one of the parameters related to the calculation of the WQI, according to the adaptation of Environmental Company of the state of São Paulo (CETESB). All other correlations were significant.

Regarding the intensity of these correlations, Helena et al. (2000) consider that strong correlations are those that, in module, obtain a coefficient higher than 0.5. However, according to Levine et al. (2013), correlations closer to |1.0| are close to perfect, and for there to be a perfect correlation between the variables the coefficient ($r$) must be equal to |1|. It is worth mentioning that there is a positive correlation coefficient ($r > 0$) when there is positive correlation between the variables, that is, as the value of one of the variables increases, the value of the other also increases. But if $r < 0$, the correlation between the variables is negative (Moura et al. 2013).

Thus, the correlation between phosphorus and TSI ($r$=0.875) stands out as a very strong correlation. Lamparelli (2004) associates the greater importance of phosphorus in eutrophication processes with the fact that phosphorus is a limiting nutrient for primary production. Furthermore, the positive correlation between phosphorus and chlorophyll should be noted; although it is weaker, it is also above the threshold considered by Helena et al. (2000). Chlorophyll a is a phytoplankton biomass indicator CETESB (2017), and this justifies its correlation with phosphorus, which is a nutrient used for primary production, in this case, for phytoplankton.

**Table 7** Normality tests

| Variables | *p*-value (significance) | |
|---|---|---|
| | K-S | S-W |
| Phosphor | 0.000 | 0.000 |
| Chlorophyll *a* | 0.001 | 0.000 |
| WQI | 0.070 | 0.347 |
| TSI | 0.000 | 0.000 |

Also related to the correlation analysis, there were strong negative correlations between phosphorus and the WQI (−0.603) and between the TSI and the WQI (−0.531). According to Rocha and Pereira (2016), phosphorus is a main component of many chemical additives used in crops, being then associated with pollution from agricultural activities. According to Oliveira et al. (2015), most of the areas surrounding the Mirim Lagoon watershed are used for this type of activity, which corroborates the fact that this variable has a strong negative correlation with the WQI.

Still in relation to phosphorus, Valentini et al. (2020) used the statistical method of principal component analysis, also for water quality monitoring data referring to Mirim Lagoon, and inferred that the main component to which this variable was related could be linked to pollution from agricultural sources, contributing to the decrease in water quality. Nevertheless, Valentini et al. (2021b) used the multiple linear regression analysis method to model a new water quality index for Mirim Lagoon. For the construction of the regression model for this new index, the authors used only the parameters that obtained the greatest correlation with the original quality index and found that phosphorus is, in fact, one of the most representative variables for the quality of this water resource.

Regarding the strong negative correlation between TSI and WQI (−0.531), this is related to the fact that the TSI is a measure of eutrophication of the aquatic environment, which may be strongly related to the decline in water quality Talamoni and Liria (2019).

Last but not least, the results of the variance test (K-W test) are presented in Table 9. As can be observed, with regard to the variance between the monitoring points, only the WQI had a $p$-value $< 0.05$, demonstrating a significant variability, which is due to the fact that different activities are performed in the areas surrounding the monitoring points, influencing the WQI. In relation to the variation between the months studied, all obtained significant variability.

Valentini et al. (2021a) and Valentini et al. (2021c) also used analysis of variance to analyze whether there was

**Table 8** Correlation matrix with significance test

| | | Phosphorus | Chlorophyll a | WQI | TSI |
|---|---|---|---|---|---|
| Phosphorus | Correlation coefficient | 1.000 | 0.259 | −0.603 | 0.875 |
| | *p*-value | | 0.009 | 0.000 | 0.000 |
| *Chlorophyll a* | Correlation coefficient | 0.259 | 1.000 | −0.120 | 0.527 |
| | *p*-value | 0.009 | | 0.233 | 0.000 |
| WQI | Correlation coefficient | −0.603 | −0.120 | 1.000 | −0.531 |
| | *p*-value | 0.000 | 0.233 | | 0.000 |
| TSI | Correlation coefficient | 0.875 | 0.527 | −0.531 | 1.000 |
| | *p*-value | 0.000 | 0.000 | 0.000 | |

significant variability in the water quality of Mirim Lagoon between the monitoring points. Using ANOVA, the authors also found a *p*-value less than 0.05, demonstrating that there is, in fact, a significant variation in the WQI between the monitoring points of this water resource. Santos et al. (2020a), in their study referring to a water resource in the region of the city of Pelotas, also found significant WQI variability in relation to the monitoring points used in their study Oliveira and Cunha (2014).

As for the monthly variation, the significant variability of quality parameters between the months studied can be strongly associated to the effects that seasonality and different sowing times can have on the water quality. Seasons of intense rains, for example, in regions with overloaded sewage collection systems contribute to the transport of pollutants and contaminants to surface water (Aguilera et al. 2019). According to Huang et al. (2014), Oliveira et al. (2015), Girardi et al. (2016), Ling et al. (2017), and Rostami et al. (2018), rainfall events cause significant influence in water bodies, changing their quality and hydrological conditions, also corroborating the fact that there is a significant variation in the quality parameters between the months studied here.

Nevertheless, different planting and harvesting seasons can also influence water quality. Considering the application of agricultural additives, for example, the phosphorus is one of the main components of these products and may be carried by surface runoff toward to water body (Drose et al. 2020; Rocha and Pereira 2016). Santos et al., (2020b) also state that factors from agriculture such as harvest times and the different crops grown can influence water quality and that, coupled with climatic factors, can explain the fact that there is significant variability in the quality parameters of water when analyzing the monthly variation for waters bodies.

**Table 9** Kruskal-Wallis variance test

| | Significance | |
|---|---|---|
| | Monitoring point | Monthly |
| Phosphorus | 0.995 | 0.000 |
| Chlorophyll a | 0.498 | 0.000 |
| WQI | 0.004 | 0.006 |
| TSI | 0.920 | 0.000 |

## 4 Conclusion

The results obtained in this study shows that it was possible to assess the water quality for the points studied of the Mirim Lagoon and the São Gonçalo Channel through the proposed methods. Furthermore, we highlight the applicability of the statistical methods to assess the factors related to water quality, evidencing that these methods are of great importance for qualitative hydrological monitoring. Through these methods, it was possible to evaluate the correlation between the variables here studied and, through this, infer what factors were more representative to the quality of the analyzed water resources.

Moreover, regarding the variance of the parameters used here to assess water quality, it was demonstrated that there was significance variability of these parameters in relation to the months in which this research was conducted and in relation to the points of study. Through this, it is possible to conclude that the effects related to the different seasons and the different sowing seasons, allied to the different activities developed around these water resources, play an important role in the variability of water quality.

## Appendix

**Table 10** Values of phosphor (P) and chlorophyll *a*

| | 2018 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | April | | May | | June | | July | | August | | November | |
| | P | Chlorophyll a | P | Chlorophyll a | P | Chlorophyll a | P | Chlorophyll a | P | Chlorophyll a | P | Chlorophyll a |
| SG1 | 1.1 | 3.74 | 0.55 | 15.53 | 1.58 | 9.31 | 0.02 | 5.88 | 3.03 | 23.11 | 1.71 | 8.02 |
| SG2 | 0.39 | 4.28 | 1.74 | 19.80 | 1.15 | 5.35 | 0.12 | 6.4 | 1.47 | 9.73 | NR | 9.09 |
| SG3 | 1.41 | 8.02 | 1.15 | 13.57 | 1.26 | 3.47 | 0.33 | 6.82 | 1.95 | 11.5 | 0 | 10.96 |
| SG4 | 0.18 | 14.97 | 1.68 | 5.61 | 1.36 | 0.53 | 0.33 | 6.15 | 1.25 | 6.47 | 0 | 12.23 |
| LM1 | 0.49 | 20.53 | 1.21 | 8.02 | 0.09 | 6.42 | 0 | 7.62 | 0.02 | 4.28 | 1.47 | 11.18 |
| LM2 | NR | NR | 1.65 | 2.94 | 0.41 | 1.07 | 0 | 0.27 | 0.46 | 5.61 | 1.71 | 8.98 |
| LM3 | 0.18 | 4.81 | 0.22 | 0.27 | 1.15 | 1.34 | 0.23 | 10.16 | 0 | 12.03 | 1.47 | NR |
| LM4 | 0.39 | 1.32 | 1.21 | 19.78 | 1.68 | 9.69 | 0.33 | 4.59 | 0 | 7.48 | 0 | NR |
| LM5 | 0.29 | 10.67 | 1.32 | 7.64 | 0.41 | 6.36 | 0.12 | 8.34 | 0.24 | 34.49 | 0.56 | NR |
| LM6 | 0.29 | 5.15 | 1.54 | 9.46 | 0 | 3.74 | 0 | 4.28 | 0.24 | 6.26 | 1.04 | NR |

| | 2018 | | 2019 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | December | | January | | February | | March | | April | |
| | P | Chlorophyll a | P | Chlorophyll a | P | Chlorophyll a | P | Chlorophyll a | P | Chlorophyll a |
| SG1 | 0 | 14.51 | 0 | NR | 0.08 | 7.48 | 0 | 0.67 | 0.26 | 7.75 |
| SG2 | 0.98 | 10.33 | 0 | 0.007 | 0 | NR | 0 | 1.07 | 0 | 7.75 |
| SG3 | 1.23 | 9.67 | 0 | 0.007 | 0 | 8.55 | 0 | 10.69 | 0 | 7.48 |
| SG4 | 1.23 | 11.35 | 0.34 | 0.006 | 0 | 8.019 | 0.06 | 10.69 | 0.1 | 11.49 |
| LM1 | 1.61 | NR | 0 | 0.02 | 0.08 | 1.87 | 0 | 6.68 | 0.1 | 12.83 |
| LM2 | 1.26 | 6.68 | 0 | NR | 1.27 | 7.94 | 0 | 1.08 | 0.34 | 9.45 |
| LM3 | 1.49 | 14.17 | 0.25 | 0.01 | 0 | 6.68 | 0 | 16.65 | 0.1 | 7.07 |
| LM4 | 1.36 | 23.05 | 0.08 | 0.01 | 0.68 | 19.68 | 0 | 0.91 | 0.1 | 11.89 |
| LM5 | 1.2 | 24.95 | 0.25 | 0.03 | 0.59 | 14.5 | 0 | 40.42 | 0 | 11.76 |
| LM6 | 2.09 | 15.46 | 0 | 0.01 | 0.42 | 11.79 | 0 | 1.6 | 0.42 | 9.12 |

**Table 11** Values of thermotolerant coliforms

| | Values of thermotolerant coliforms (MLN/100mL) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2018 | | | | | 2019 | | | | | |
| | Apr | May | Jun | Jul | Aug | Nov | Dec | Jan | Feb | Mar | Apr |
| SG1 | 11 | >1600 | 22 | 22 | 17 | 1600 | 17 | 79 | 2 | 43 | 33 |
| SG2 | 110 | 1600 | 3.7 | 130 | >1600 | 430 | 11 | 340 | 6.8 | 23 | 31 |
| SG3 | >1600 | >1600 | >1600 | 340 | >1600 | >1600 | 17 | >1600 | 11 | 79 | >1600 |
| SG4 | 920 | >1600 | 33 | >1600 | >1600 | >1600 | 350 | >1600 | 170 | >1600 | >1600 |
| LM1 | 79 | 22 | 22 | 540 | 170 | 17 | 0 | 70 | 7.8 | 0 | 79 |
| LM2 | 46 | 350 | 350 | 350 | 920 | 17 | 4 | NR | 33 | 46 | 94 |
| LM3 | NR | 2 | 4.5 | >1600 | 46 | 79 | 79 | >1600 | 33 | 23 | 350 |
| LM4 | 2 | 21 | 33 | 70 | 170 | >1600 | 17 | 1600 | 70 | 17 | 23 |
| LM5 | 5.6 | 130 | 11 | 79 | 350 | >1600 | 9.3 | 1600 | 340 | 23 | 240 |
| LM6 | 15 | >1600 | 9.3 | 130 | 9.3 | >1600 | 130 | 1600 | 31 | 34 | 49 |

*MLN* most likely number

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