ASSESSMENT OF SURFACE WATER QUALITY OF THE LOWER COURSE OF THE ITAPECURU RIVER BASIN, MARANHÃO STATE, BRAZIL

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Abstract. The Itapecuru River basin is one of the main components of the Maranhão hydrographic system, Brazil. However, this water body has faced serious environmental problems, especially with regards to the pollution of water resources. In this work, the water quality of the lower course of the Itapecuru River was analyzed based on the bimonthly collection of surface water performed at 10 sampling points located on the Itapecuru River and its tributaries between April 2018 and February 2019 using the Water Quality Index (WQI). The data were submitted to descriptive (mean and standard deviation), inferential (analysis of variance) and multivariate (principal component analysis) analyses. WQI values of the water bodies studied were distributed among the good (18.3%), fair (71.7%) and poor (10%) categories. The water in the main channel and most of the streams studied presented fair quality and, therefore, acceptable for public supply purposes only after conventional treatment.
Keywords: *water quality, environment indicator, monitoring, public health, microbiological pollution*

Introduction

Adequate water quality is essential for some of the uses of water bodies, particularly the public supply. Thus, the monitoring of the quality of the water used by society is necessary for the creation of environmental management strategies that ensure the ecological balance of water bodies and the health of the public.

Changes in the physical, chemical and biological characteristics of water bodies, especially those resulting from human actions, affect the quality and quantity of water available for human consumption and other uses, compromising the environmental balance and human health (Tundisi, 2008; Augusto et al., 2012; Souza et al., 2014). In Brazil, the poor sanitary situation found in many densely occupied river basins has resulted in the generalized degradation of natural elements, especially water bodies, culminating in the restriction of multiple uses, a reduction in ecosystem services and the occurrence of water-borne diseases (Periotto and Tundisi, 2018; Cirilo, 2015; Finotti et al., 2015).

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In the state of Maranhão, only 9.93% of the population are connected to the public sewage system, whereas the national average is 52.36% (BRASIL, 2017). This situation has a direct effect on river basins in the state, which are considerably degraded due to the lack of sanitation, disorderly growth as well as inadequate land use and occupation, which contribute to the deterioration of water quality (Soares et al., 2016).

Among the main water bodies in the state of Maranhão, the Itapecuru River drains an area of 53,216.84 km², which is equivalent to 16.03% of the total area of the state. This is the second largest hydrographic basin in Maranhão, passing through 57 municipalities with a total of 1,019,398 residents (15.5% of the population of the state) (Soares et al., 2016; IMESC, 2019). Despite its importance, the Itapecuru River basin has environmental problems, such as the destruction of riparian forests, siltation and pollution throughout its entire course, which is intensified in urbanized stretches of the river (Silva and Conceição, 2011; Soares et al., 2016)

The Water Quality Index (WQI) is an important tool for the assessment of the water quality of water bodies that enables the conversion of various data into a single numerical result (Bajaña et al., 2022). The WQI is a mathematical tool for transforming a set of data on physical, chemical and biological data into a numerical representation of the water quality of a given stretch of a river (Siqueira et al., 2012). This measure of surface water quality is widely used throughout the world and was developed for the assessment of crude water quality and its suitability for the public supply after treatment. Most of the parameters used for the calculation of this index are indicators of contamination caused by the discharge of domestic sewage (Kachroud et al., 2019; Klamt et al., 2019; ANA, 2018).

Due to the considerable environmental and socioeconomic importance of the Itapecuru River, the aims of the present study were to investigate the water quality of the lower course of the river using the WQI, produce information on its suitability for multiple uses with safety for river populations and provide data that can assist in the establishment of environmental management actions in the river basin.

Materials and methods

Study area

This study was conducted in the lower course of the Itapecuru River in the municipality of Itapecuru-Mirim, which is located in the northern portion of the state of Maranhão, Brazil (*Fig. 1*). The river basin is situated in the transition zone of the semiarid climate of the northeastern region of the country and the humid, equatorial climate of the Amazon, with vegetation that transitions from the Cerrado biome (savanna) to the deciduous and semi-deciduous seasonal forest in the northern portion of the basin (BRASIL, 1998).

The lower course of the Itapecuru River extends from the municipality of Caxias to the mouth of the river in Arraial Bay, which is a distance of approximately 360 km. The change in altitude along this stretch is 50 m, with an average declivity of 14 cm/km. The lower course of the river has a maximum width of 130 meters and a total area of approximately 12,090 km², corresponding to about 22.7% of the surface of the hydrographic basin (Barros et al., 2011; Soares et al., 2017).

The municipality of Itapecuru-Mirim has an area of 1,478.56 km^2 and a population of 62,110 residents, corresponding to a demographic density of 42.21 residents/km^2 (BRASIL, 2010). The stretch of the Itapecuru River basin situated in the municipality is

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subject to environmental stresses, such as deforestation, agricultural runoff, the irregular use of the banks, siltation, predatory fishing as well as the input of solid, organic and industrial waste.

Data collection

Data was collected during six sampling campaigns at two-month intervals between April 2018 and February 2019. Sampling was performed at 10 collection points (five in the main channel and five in tributaries of the Itapecuru River) (*Fig. 1*). The sampling points were denominated and georeferenced as follows: P1 Riachão (570804.73 E and 9614934.98 N); P2 Pau de Arara Stream (571743.74 E and 9625113.95 N); P3 Cova Stream (574067.42 E and 9624847.40 N); P4 Vaca Branca Stream (576601.71 E 9625093.40 N); P5 Itapecuruzinho Stream (577891.75 E and 9625331.98 N); P6 Itapecuru River (568171.60 E and 9615921.15 N); P7 Itapecuru River (567239.47 E and 9620770.17 N); P8 Itapecuru River (570526.10 E and 9624656.01 N); P9 Itapecuru River (572786.50 E and 9627510.15 N); P10 Itapecuru River (574636.83 E and 9630720.12 N).

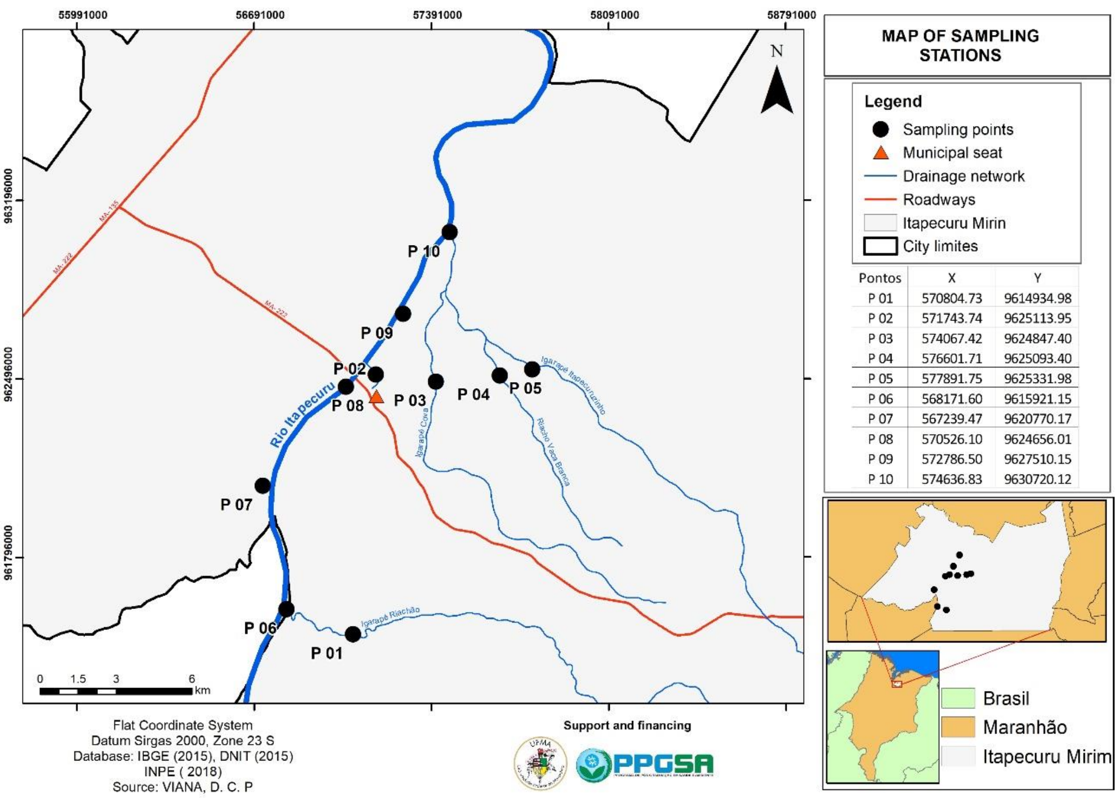

***Figure 1.** Map of sampling stations*

The sampling stations in the tributaries were located in the lower course of the river in urban and semi-urban areas of the municipality of Itapecuru-Mirim. The sampling stations in the main channel of the Itapecuru River were distributed in the upstream-downstream direction to measure water quality for the purposes of the public supply and human consumption. Sampling was distributed as a function of the seasonality of the study area, with three sampling campaigns in each season: rainy season (February, April and June) and dry season (August, October and December).

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The collection procedures followed the methods for the preservation of samples defined by norms of the Brazilian Association of Technical Standards (ABNT) NBR 9897 and 9898, which determine the conditions for the sampling of domestic and industrial effluents, sediments and samples from the surface of water bodies. All sampling was performed *in situ* between 07:00 and 16:00 h.

Eighteen variables were used to measure water quality: pH, dissolved oxygen, temperature, electrical conductivity, total solids, total suspended solids, total dissolved solids, turbidity, total phosphorus, phosphate, total ammoniacal nitrogen, nitrite, nitrate, total nitrogen, total coliforms, thermotolerant coliforms and *Escherichia coli*.

Water samples were collected with the aid of a Van Dorn bottle. The volume was then distributed proportionately among different flasks for the physicochemical and bacteriological analyses to ensure the homogeneity of the sample, with care taken to maintain an empty space in the flask for the subsequent homogenization.

Plastic 1-L flasks were used for the collection of the samples for chemical and physical analysis. The flasks were washed abundantly with the same water collected, placed in a cooler and maintained under refrigeration during transport to the laboratory. For the bacteriological analysis, the samples were collected using sterile disposable 250-mL plastic flasks and submitted to the same conservation process.

Temperature, pH, dissolved oxygen, electrical conductivity and total dissolved solids were measured in situ using a HANNA HI 9828 multiparameter meter. Turbidity (NTU) was measured using a HANNA HI 93703 turbidimeter. Other physicochemical and bacteriological variables were analyzed in the laboratory and determined following the Standard Methods for the Examination of Water and Wastewater (APHA, 2005).

Data analysis

The analyses of the physicochemical and biological variables were respectively performed at the Limnology and Microbiology Laboratory and Food and Water Quality Control Laboratory of the Federal University of Maranhão.

Precipitation data (mm) were obtained from the Itapecuru-Mirim Meteorological Station (Code 00344017) affiliated with the Agência Nacional de Águas (Ana [National Water Agency]) (www.ana.gov.br, through HidroWeb). Fluviometric data from the river basin were obtained from a survey of geodiversity of the state of Maranhão conducted through the Geology Program of Brazil.

The data were submitted to descriptive statistics with estimates of mean and standard deviation values. Comparisons of the data were performed using the analysis of variance (ANOVA) after the determination of normality and equality of variances, considering a 5% significance level ($p < 0.05$). ANOVA was used to determine significant differences between seasonal periods and sampling sites for all 18 variables of interest with the aid of PAlaeontological STatistics (PAST program, version 2.17 c). The environmental variables were submitted to principal component analysis (ACP) to identify temporal and spatial patterns. The sampling units were organized in relation to their respective variables using correlation matrices, with the data transformed by ranging. For such, the CANOCO 4.5 package was used.

Water quality index – WQI

The WQI adopted to classify the quality of the water incorporated the method employed by Companhia Ambiental do Estado de São Paulo (CETESB [State of São

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Paulo Environmental Company] (2017), which uses the following variables and respective weights: dissolved oxygen (DO; 0.17), thermotolerant coliforms (0.15), pH (0.12), biochemical oxygen demand (BOD5,20° (0.10), temperature (0.10), total nitrogen (TN; 0.10), total phosphorus (TP; 0.10), turbidity (0.08) and total solids (TS; 0.08). The WQI was calculated as the weighted product of the water quality variables that compose the index using the following expression:

$$\mathrm{WQI} = \prod_{i=1}^{n} q_i^{\,w_i} \quad \text{(Eq.1)}$$

in which: WQI: Water Quality Index, a nondimensional number ranging from 0 to 100; *qi:* quality of the i^{th} parameter, a number between 0 and 100 obtained from the respective “mean curve of quality variation” as a function of its concentration or measurement; *wi:* weight corresponding to the i^{th} parameter, a number between 0 and 1 attributed as a function of its importance to the overall quality; and *n:* number of variables in the calculation of the WQI.

The WQI values of the water bodies of the lower course of the Itapecuru River were distributed among the “poor”, “fair” and “good” classes, using the recommended values listed in *Table 1*.

Table 1. *Categories for classification of water quality based on water quality index*

Category	Weighting
Excellent	79 < WQI ≤ 100
Good	51 < WQI ≤ 79
Fair	36 < WQI ≤ 51
Poor	19 < WQI ≤ 36
Very poor	WQI ≤ 19

Source: CETESB (2013)

Results and discussion

Spatio-temporal variability of the parameters of water quality of the Itapecuru River and its tributaries are displayed in *Table 2*, along with the reference values determined by Resolution n° 357 of Conselho Nacional do Meio Ambiente (CONAMA [National Environmental Council]) from March 17, 2005. Among the variables analyzed, 10 differed from the reference values. The largest differences were with regards to thermotolerant coliforms and total phosphorus, which were above the maximum permitted limits at 100% of the sampling stations. The concentration of dissolved oxygen was lower than the minimum limit established by the CONAMA resolution at 60% of the stations, suggesting altered environments.

No significant spatial differences were found regarding the environmental variables analyzed in the main channel of the Itapecuru River, demonstrating a homogenous pattern in the stretches analyzed. Regarding temporal variability, significant differences were found for all variables, except total phosphorus. Higher pH, DO, temperature and E. coli values were found in the dry season, whereas higher values for electrical conductivity, total solids, total suspended solids, total dissolved solids, turbidity, phosphate, ammoniacal nitrogen, nitrite, nitrate, total nitrogen, total coliforms and thermotolerant coliforms were found in the rainy season.

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Table 2. *Spatio-temporal variation of parameters of water quality of the lower course of the Itapecuru River and tributaries and Class 2 reference values of CONAMA Resolution n° 357/2005*

Variables		(pH)	(DO)	(Temp)	(Cond)	(TS)	(TSS)	(TDS)	(Turb)	(PO_4)
Tributaries	**Point 1**	6.63±0.42	4.23±1.71	26.79±0.97	40.58±11.65	116±53.99	76.66±54.93	40.16±11.85	46.35±27.28	0.85±0.18
	Point 2	6.76±0.47	1.14±0.44	27.86±1.70	333.21±128.55	361.58±137.27	29.00±24.23	332±128.44	29.19±14.26	0.80±0.26
	Point 3	6.65±0.36	3.63±1.34	27.54±1.24	86.65±47.06	158±40.88	72.83±41.96	85.83±46.76	58.18±32.08	0.57±0.18
	Point 4	6.51±0.27	3.17±2.12	26.83±1.25	65.8±42.62	151±89.69	85.83±74.53	65.16±42.58	50.63±25.75	0.92±0.3
	Point 5	5.65±0.27	4.69±1.47	26.63±1.48	67.71±47.73	145±43.90	77.83±9.28	67.16±47.52	56.35±18.29	0.84±0.1
Itapecuru River	**Point 6**	6.96±0.39	5.53±1.98	29.43±1.99	69.98±14.72	130±60.98	60.5±52.14	69.5±15	58.77±32.15	0.88±0.18
	Point 7	6.48±0.37	5.32±1.72	29.29±2.05	68.2±13.47	138±42.36	71.17±32.30	67.67±13.52	55.28±24.16	0.95±0.23
	Point 8	6.83±0.37	5.31±1.75	29.44±2.11	67.92±13.01	138±40.05	70.33±33.07	67.67±13	57.9±26.15	1.34±0.27
	Point 9	6.85±0.39	5.38±1.75	29.33±2.12	67.03±12.37	135±45.53	69±36.06	66.67±12.55	61.52±38.55	1.27±0.69
	Point 10	6.84±0.44	4.82±1.60	29.38±2.38	65.85±10.40	144±52.05	78.33±50.46	65.67±10.41	63.85±38.12	1.47±0.85
Tributaries	**Apr**	7.08±0.27	3.06±1.22	27.37±1.12	79±103.61	120.7±89.51	42.6±21.84	78.1±103.81	38.13±20.2	0.93±0.19
	Jun	6.22±0.11	2.59±1.01	27.73±0.85	112.66±113.1	156±99.32	43.8±20.69	112.2±112.84	36.63±16.34	0.93±0.16
	Aug	6.24±0.07	2.99±1.22	29.12±0.27	164.02±134.12	206.8±122.68	40.8±20.12	163±133.63	42.8±8.99	0.61±0.23
	Oct	6.48±0.21	1.87±1.13	27.12±0.65	188.38±175.56	276.2±179.8	88.4±74.79	187.8±175.7	53.8±26.64	0.86±0.2
	Dec	6.82±0.2	3.94±1.66	26.18±0.8	96.56±108.44	162.4±85.93	66±34.43	96.4±108.51	38.22±13.99	0.86±0.2
	Feb	6.87±0.24	6.01±2.04	25.24±0.45	54.86±8.44	174.8±41.53	120.4±52.69	54.4±28.54	81.28±32.77	0.70±0.17
Itapecuru River	**Apr**	7.38±0.15	3.20±0.12	27.8±0.19	54.6±0.48	111.2±6.73	57.6±6.71	53.6±0.48	67±4.73	1.69±0.63
	Jun	6.2±0.1	3.28±0.16	29.33±0.14	81.87±0.57	139.2±7.46	57.8±7.73	81.4±0.48	54.37±4.01	1.59±0.6
	Aug	6.88±0.09	6.75±0.3	31.28±0.64	62.04±0.68	119.2±8.44	56.8±7.53	61.4±1.01	22.4±1.01	1.03±0.23
	Oct	6.98±0.04	5.54±0.16	32.5±0.28	53.86±1.43	91.6±15.56	37.6±15.51	54±1.26	37.8±6.01	1.08±0.16
	Dec	6.79±0.03	6.04±0.32	28.02±0.07	75.64±1.13	158±45.53	82.4±46.18	75.6±1.35	60.3±4.25	1.08±0.16
	Feb	6.92±0.06	6.80±1.48	27.26±0.38	78.86±7.38	204.6±38.41	126±39.57	78.6±7.25	112.38±14.06	0.61±0.11
CONAMA n° 357/2005 Class 2		6.0 to 9.0	Not lower than 5 mg/L O_2	-	-	-	-	500 mg/L	Up to 100 NTU	-

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Variables		**(NH_4)**	**(NO_2)**	**(NO_3)**	**(TN)**	**(TP)**	**(BOD)**	**(Total Coli)**	**(Therm Coli)**	
Tributaries	**Point 1**	0.21±0.35	0.01±0.01	2.53±0.86	3.42±0.77	1.21±0.36	3.78±0.99	2400±0.00	1966±612.82	
	Point 2	1.24±0.69	0.07±0.06	3.39±1.73	4.85±1.14	1.27±0.32	9.51±2.29	2183±484.48	1860±785.7	
	Point 3	0.07±0.03	0.01±0.01	1.81±0.94	3.18±0.27	0.96±0.1	5.49±1.52	2183±484.48	2183±484.48	
	Point 4	0.08±0.04	0.01±0.01	2.19±1.09	3.86±0.87	1.17±0.23	6.28±2.91	2400±0.00	2183±484.48	
	Point 5	0.15±0.16	0.01±0.01	2.03±1.13	3.59±0.84	1.05±0.19	5.38±1.6	2400±0.00	2076±772.99	
Itapecuru River	**Point 6**	0.03±0.02	0.03±0.03	1.96±1.17	3.19±0.77	1.12±0.10	3.85±1.21	1798±984.26	1582±968.42	
	Point 7	0.05±0.03	0.02±0.025	2.12±1.03	2.93±0.76	1.32±0.33	4.27±1.98	2400±0.00	2183±530.72	
	Point 8	0.04±0.03	0.02±0.04	2.03±1.27	3.25±0.50	1.74±0.64	3.93±1.51	1966±671.32	1860±860.70	
	Point 9	0.03±0.01	0.03±0.05	2.27±1.18	3.01±0.95	1.92±0.88	4.03±1.19	2183±530.72	2183±530.72	
	Point 10	0.03±0.02	0.02±0.02	2.13±1.16	3.44±0.67	2.17±1.08	4.35±1.68	1860±860.70	1582±968.42	
Tributaries	**Apr**	0.22±0.31	0.03±0.06	2.68±2.73	4.01±1.15	1.10±0.2	4.71±1.76	2400±0.00	2400±0.00	
	Jun	0.21±0.29	0.03±0.05	3.33±0.27	3.96±0.63	1.11±0.18	4.78±1.5	2400±0.00	2400±0.00	
	Aug	0.83±0.6	0.02±0.03	1.33±0.69	3.67±1.22	1.13±0.25	5.28±1.46	2140±520	1364±877.57	
	Oct	0.58±0.92	0.01±0.01	2.06±0.85	4.17±1.36	1.29±0.35	9.56±2.77	2140±520	2140±520	
	Dec	0.28±0.44	0.01±0.01	3.40±0.35	3.96±0.25	1.2±0.39	6.32±2.91	2400±0.00	1620±636.86	
	Feb	0.1±0.12	0.01±0.01	2.28±0.25	2.99±0.12	1.03±0.04	6.44±2.05	2400±0.00	2400±0.00	
Itapecuru River	**Apr**	0.04±0.01	0.01±0.01	0.92±0.03	2.65±1.11	2.22±1.12	2.38±0.39	2400±0.00	2400±0.00	
	Jun	0.05±0.01	0.01±0	3.14±0.16	3.41±0.41	1.97±0.73	2.96±0.08	2400±0.00	2400±0.00	
	Aug	0.04±0.03	0.04±0.02	0.81±0.12	2.79±0.41	1.87±0.59	3.04±0.08	1030.6±786.07	569.2±45364	
	Oct	0.01±0.01	0.08±0.01	1.74±0.27	2.99±0.09	1.64±0.31	5.6±0.46	1620±636.86	1620±636.86	
	Dec	0.03±0.01	0.01±0.01	3.69±0.24	4.08±0.1	1.17±0.07	5.58±0.54	2400±0.00	2140±520	
	Feb	0.02±0.01	0.01±0.01	2.29±0.25	3.07±0.03	1.03±0.04	4.96±0.95	2400±0.00	2140±520	
CONAMA n° 357/2005 Class 2		3.7 mg/L N. for pH≤7.5	1 mg/L N	10 mg/L N	-	0.1 mg/L P	to 5 mg/L O_2	-	1000/100 ml	

Abbreviations: Ph (hydrogen potential), DO (dissolved oxigen mg/L), Temp (temperature °C), Cond (conductivity μS/cm), TS (total solids mg/L), TSS (total suspended solids mg/L), TDS (total dissolved solids mg/L), Turb (turbidity UNT), PO_4 (phosphate mg/L) NH_4 (ammonia mg/L) NO_2 (nitrite mg/L), NO_3 (nitrate mg/L), TN (total nitrogen mg/L), TP (total phosphorus mg/L), BOD (biochemical oxygen demand mg/L), Total Coli (total coliforms NMP/100 ml), Therm coli (thermotolerant coliforms NMP/100 ml)

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The increase in these variables in the rainy season suggests surface runoff and an increase in sewage discharge, with the consequent input of these elements in the water body. These are important factors that contribute to the degradation of the water quality in the rainy season. According to Tucci and Mendes (2006), the increased capacity for surface runoff through pipes and impermeable canals results in a reduction of infiltration to the soil, increase in erosive processes, increase in sedimentation, the transport of solid matter, inadequate sewage disposal and the deterioration of the quality of surface water.

Significant spatial differences were found in the tributaries of the Itapecuru River, with higher concentrations of dissolved oxygen at P1 and P5 as well as high values of electrical conductivity, total solids, total dissolved solids, ammoniacal nitrogen, nitrite, nitrate, phosphate and BOD at P2 and P4. The environmental variables also exhibited significant temporal differences, with a higher concentration of dissolved oxygen and water temperature in the dry season and higher turbidity, thermotolerant coliforms and E. coli values in the rainy season.

The results indicate that streams more distant from the urban center (P1 and P5), which receive fewer effluents, have better water quality, whereas streams that pass through more urbanized areas (P2 and P4) receive a considerable quantity of effluents and, therefore, have water with more degraded quality. Similar results were also found by Cerqueira et al. (2020) who analyzed the effects of land use change on the rivers and streams of the Cachoeira River Basin in the Northeast of Brazil. In a study conducted in the São João Stream in the city of Porto Nacional in the state of Tocantins, Brazil, Carvalho et al. (2016) detected a greater concentration of nutrients and organic matter in the stretch of the water body that drains the most urbanized zone of the city.

Principal component analysis (PCA) enabled the identification of spatial and temporal patterns related to the environmental variables analyzed in the Itapecuru River. The first two axes explained 55.86% of the total variability in the data. Axis I explained 32.26% and Axis 2 explained 23.60%. TSS, TS, electrical conductivity, TDS, NO3, E. coli, turbidity, total coliforms and thermotolerant coliforms were positively correlated with Axis 1 and were associated with rainfall in June 2018, December 2018 and February 2019, whereas nitrate and water temperature were negatively correlated with the axis and were associated with the dry season (August and October 2018) (*Fig. 2*). TP, PO4, flow and pH were positively correlated with Axis 2 in April and June 2018, whereas BOD, DO and *E. coli* were negatively correlated with the Axis during August, October and December 2018.

The temporal pattern shown in the PCA revealed a strong influence of the rainy season on the increase in variables commonly associated with surface runoff, especially nutrients associated to phosphorus and nitrogen, as well as particulate matter, dissolved solids, total coliforms and thermotolerant coliforms. The greater concentration of dissolved oxygen in the dry season may be related to the increase and intensification of air currents in the region (northeast trade winds), especially in the months of August to November, suggesting greater transference of atmospheric oxygen to the water body.

In a study conducted in the Carmo River basin in the state of Rio Grande do Norte, Silva and Souza (2013) report that the limnological variables of rivers are strongly influenced by rainfall due to lixiviation, percolation and the transport of components to these ecosystems. The authors found a greater concentration of particulate and dissolved matter in the water associated with the rainy season and a greater concentration of dissolved oxygen in the dry season.

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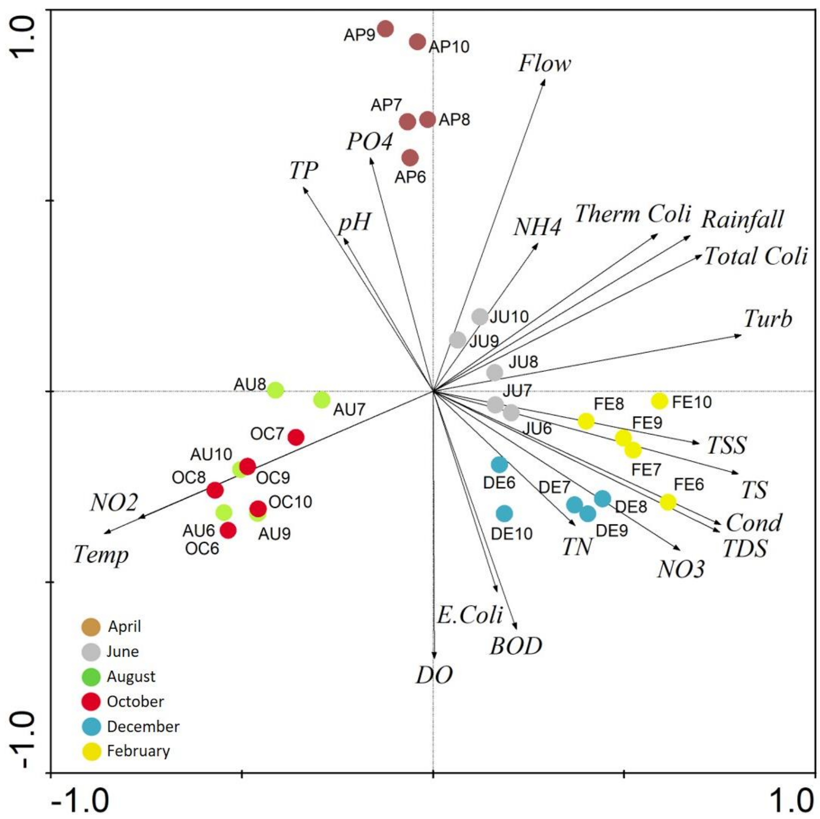

***Figure 2.** Diagram of principal component analysis of environmental variable of water quality of main channel of lower course of Itapecuru River*

In the PCA for the tributaries of the Itapecuru River, the first two axes explained 48.30% of the total variability in the data (33.70% explained by Axis 1 and 14.60% explained by Axis 2). A strong spatial pattern was found on Axis 1, with the dominance of samples from P2, which were strongly correlated with NO2, NO3, NH4, TN, electrical conductivity, TDS, TS, BOD and temperature. In contrast, the samples from P2 were negatively correlated with DO, TSS, total coliforms and thermotolerant coliforms, influenced by turbidity and precipitation, especially in February and Abril (*Fig. 3*).

Axis 2 presented the distribution of samples with higher values of turbidity, TSS and E. coli, whereas a greater association with phosphorus compounds (PO4 and TP) was found in the negative quadrant.

The spatial pattern revealed by the PCA of the tributaries of the Itapecuru River analyzed in the present study is related to the isolation of nutrients associated with phosphorus and nitrogen as well as particulate and dissolved matter in the water at P2. This situation may be attributed to the location of the sampling point, which was in the most urbanized region of the municipality of Itapecuru-Mirim and received a considerable quantity of domestic effluents and sediments as a function of surface runoff.

In a study conducted in the Machado River basin in the municipality of Ji in the state of Paraná, Rocha and Andrade (2018) found that the degradation of water quality was directly associated with the increase in population density, reporting that the WQI was much lower in the most urbanized stretch of the river compared to regions with a lower

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population density. The authors also reported that the degradation of the water was due to the lixiviation of pollutants resulting from the improper disposal of urban waste and the discharge of untreated sewage directly into the river.

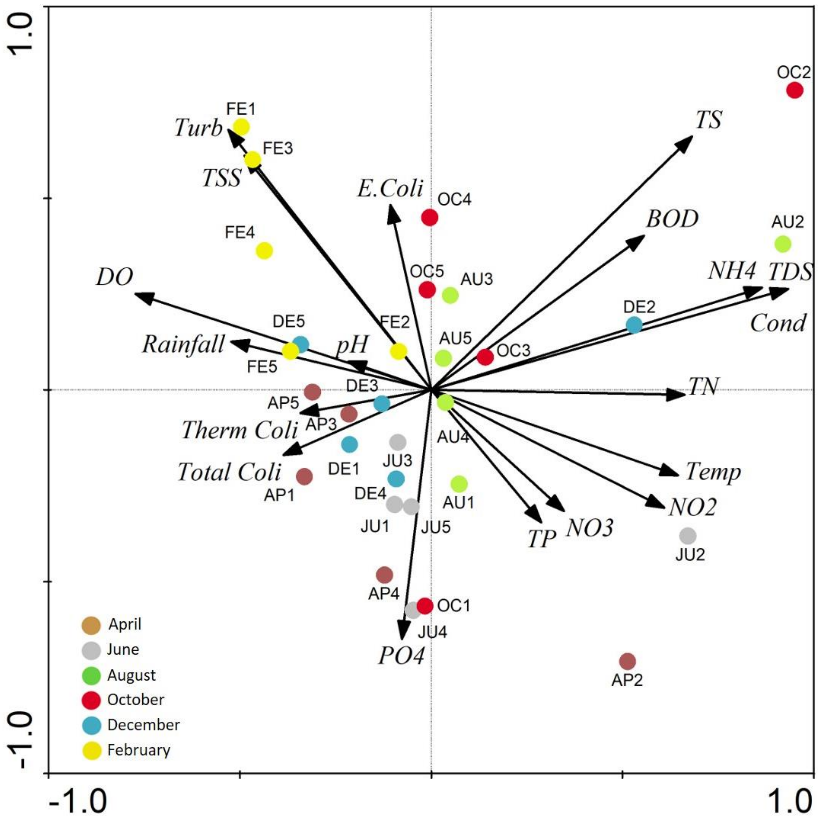

***Figure 3.** Diagram of principal component analysis of environmental variable of water quality of tributaries of lower course of Itapecuru River*

The data for the tributaries of the Itapecuru River revealed no substantial seasonal changes in the WQI, with most sampling points classified as “fair”. This suggest that seasonality is not a determinant factor in the change of the behavior of the variables in the tributaries of the river, despite small fluctuations within the class. The stretch corresponding to P1 had the best water quality in the rainy season (February, April and June), whereas the other sampling points had a better performance in the dry season (August, October and December) (*Fig. 4*).

The spatial distribution of the WQI revealed more satisfactory indices at P5 and more restrictive indices at P2. This difference may be related to the fact that P5 is located in the peri-urban zone relatively distant from the urban center of Itapecuru-Mirim, whereas P2 is located in the central region of the urban center of the municipality. Such spatial variability may be related to the absence of basic sanitation as well as disorganized land use and occupation in the center of the municipality. Thus, water bodies located in urbanized areas tend to have degraded water quality. According to ANA [National Water Agency] (2018), most problems related to water quality, especially those regarding organic matter and nutrient content, are concentrated near urbanized areas, especially large urban agglomerations, and indicate pollution due to the discharge of untreated or inadequately treated sewage.

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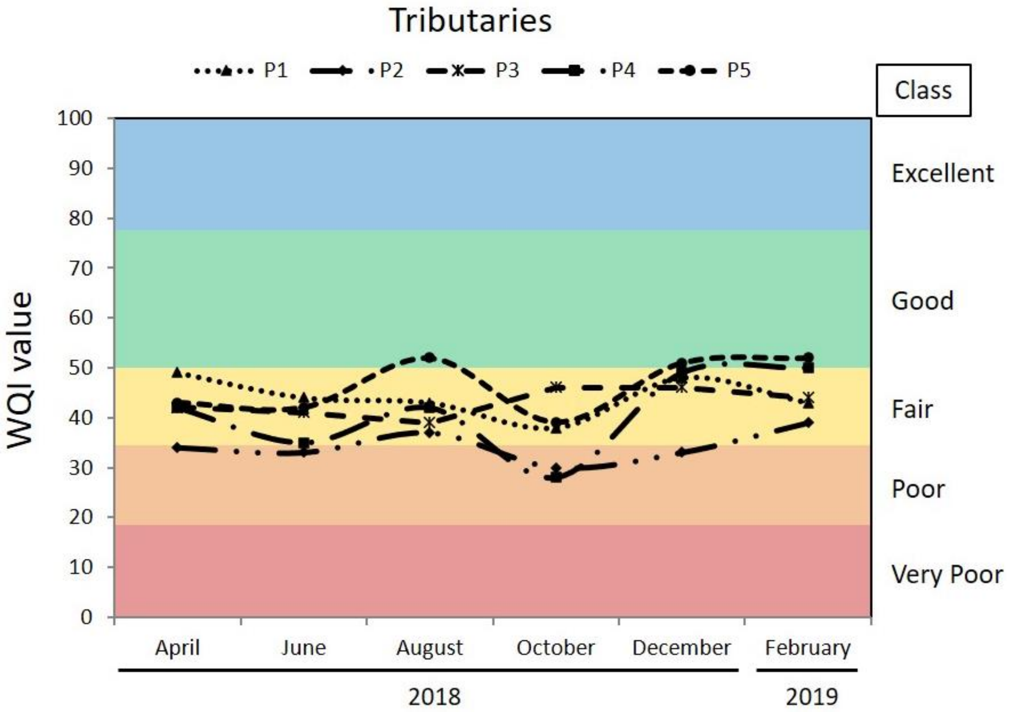

Figure 4. *Water quality index values and classification of sampling points in tributaries of Itapecuru River between April 2018 and February 2019*

Regarding the dynamics of the variables that compose the WQI, thermotolerant coliforms, total phosphorus, dissolved oxygen and turbidity exerted an influence on the lower WQI values at the five sampling stations. This indicates that the main source of pollution in the tributaries studied is untreated domestic sewage, which plays an important role in the degradation of water quality in the lower course of the Itapecuru River.

Data from CETESB [State of São Paulo Environmental Company] (2013) show that the increase in the quantity of thermotolerant coliforms in water is one of the two main indicators of the disposal of untreated domestic sewage. The consequent increase in the concentration of organic matter and its decomposition by microorganisms determine a reduction in the concentration of dissolved oxygen in the aquatic environment.

The WQI values among the sampling points of the main channel of the Itapecuru River were distributed in the “fair” and “good” classes due to seasonality. Water quality was better in the dry season (August, October and December) and a reduction in quality was found in the rainy season (February, April and June) (*Fig. 5*). An increase in the content of dissolved and particulate organic matter occurs in the rainy season due to the discharge of domestic sewage, surface runoff and the resuspension of sediments (Damasceno et al., 2015).

The spatial distribution of the WQI revealed slightly higher values in the zone upstream of the urban center of the municipality of Itapecuru-Mirim (represented by the sampling stations P6 and P7), with a small reduction in the central region of the most urbanized zone (P8) and stations downstream from this central region (P9 and P10). This suggests the action of the tributaries, especially those that drain the more urbanized area, such as effluent outflow channels to the Itapecuru River, thereby contributing to a reduction in water quality.

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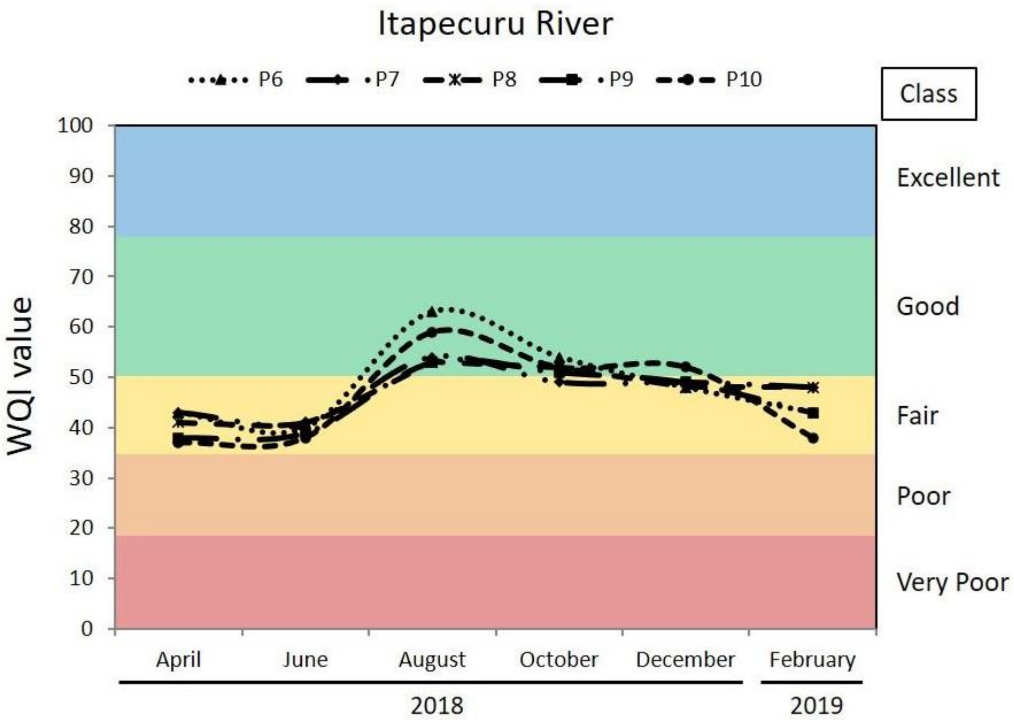

Figure 5. *Water quality index values and classification of sampling points in main channel of Itapecuru River between April 2018 and February 2019*

The discharge of effluents in water bodies without treatment or with inadequate treatment results in the degradation of water quality, with stretches of water bodies located in urban areas affected most. This can have negative impacts for the health of the population and limit the different uses downstream, especially those that require a higher quality standard, such water for the human supply (ANA, 2017b).

The variables of the WQI responsible for the reduction in the value of the index at the five sampling stations were thermotolerant coliforms, total phosphorus, dissolved oxygen and turbidity, which are associated with the discharge of untreated domestic sewage in the lower course of the Itapecuru River and its tributaries from the river communities along the hydrographic basin, especially the municipality of Itapecuru-Mirim.

According to Simedo et al. (2018), waters polluted by sewage have a large quantity of thermotolerant coliforms. These bacteria occur in the intestinal tract of warm-blooded animals and are indicators of pollution by domestic sewage. Despite not being pathogenic, large concentrations of thermotolerant coliforms indicate the possibility of the occurrence of pathogenic microorganisms responsible for the transmission of water-borne diseases. Moreover, waters polluted by sewage have a low concentration of dissolved oxygen, which is consumed during the decomposition process of organic matter.

Excess phosphorus is another of the main indicators of the pollution of freshwater environments and can cause eutrophication. Domestic sewage is among the sources of phosphorus due to the presence of phosphate detergents and fecal matter. Rainfall drainage from agricultural and urban areas is another significant source of phosphorus in water bodies (Sklenicka et al., 2020).

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Similar results have been reported in studies conducted at other sites along the lower course of the Itapecuru River. Soares et al. (2016) found WQI values indicating poor, fair and good water quality related mainly to high levels of thermotolerant coliforms, total phosphorus and turbidity. The authors report that high concentrations of thermotolerant coliforms and total phosphorus are associated with the pollution of water by domestic sewage.

In a study conducted by Siqueira et al. (2012) in the Parauapebas River in the state of Pará, the WQI determined for the water body was 40.01, which classifies fair water quality. The variable that most contributed to the definition of the WQI was thermotolerant coliforms, indicating contamination by organic effluents in the region, especially those of a domestic origin.

In a study carried out in the Cria Monte Negro Stream in the state of Rio Grande do Sul, Almeida and Schwarzbold (2003) found that most WQI values indicated fair water quality (70%), followed by good (20%) and poor (10%) quality. WQI values indicating worse water quality occurred in summer, when the water level of the stream was quite high. The sampling stations with the lowest WQI values were associated with high concentrations of thermotolerant coliforms, turbidity and total phosphorus as well as low oxygen saturation.

The WQI was created to measure water quality for human consumption and assist in the determination of the type of treatment needed so that no risk is posed to public health. Water classified a poor or very poor is considered unsuitable for conventional treatment for the purposes of the public supply, whereas water classified as fair, good and excellent is considered suitable (Gomes et al., 2016). The waters at sampling stations P2 (Pau de Arara Stream) and P4 (Vaca Branca Stream) were classified as poor and therefore require more advanced treatment to meet the needs of the public supply. The waters in the other streams and main channel of the Itapecuru River were classified as fair to good and are suitable for conventional treatment. However, the water at all sampling points was unsuitable for human consumption, requiring boiling, disinfection and simplified treatment.

This serves as an alert for the population and public authorities, given the existence of numerous communities along the lower course of the Itapecuru River and the non-universal distribution of treated water throughout the municipality, especially rural communities, by the water supply system of Itapecuru-Mirim, which is the responsibility of *Companhia de Água e Esgotos do Maranhão* (CAEMA [Maranhão Water and Sewage Company]). According to the 2010 rural census of *the Instituto Brasileiro de Geografia e Estatística* (IBGE [Brazilian Institute of Geography and Statistics]), only 30% of the rural population of Itapecuru-Mirim are connected to the water distribution system; 28% use wells or springs on the property and 42% of rural communities use other forms of water supply.

The WQI is an important measure that assists in the definition of the type of treatment required to ensure safe consumption on the part of the population with no risk to human health. This index is also useful for locations that do not have environmental sanitation and dump their untreated effluents into rivers, which are the main sources of crude water used for the public supply. However, the WQI is restricted to the measurement of water quality for a single use (public supply). As other multiple uses of water are not addressed by the index, different indicators based on physicochemical variables are needed to ensure the appropriate quality for users of water resources.

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Conclusion

Based on the physical, chemical and biological variables that compose the Water Quality Index, most waters of the lower course of the Itapecuru River and the tributaries that compose the drainage basin have fair quality. Thermotolerant coliforms, total phosphorus and dissolved oxygen were the components of the index that most contributed to the low values of this Water Quality Index and are associated with the degradation of the water quality of the Itapecuru River and its effluents due to the discharge of untreated domestic sewage. Thus, the resource from the water bodies investigated can only be used for human consumption after conventional treatment. The present findings can serve to inform the population that uses the water from these rivers and streams, warning of the deteriorated quality and associated risks regarding uses that require better water quality.

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