Use of index analysis to evaluate the water quality of a stream receiving industrial effluents

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Abstract

In this paper, the water quality of a stream that receives industrial effluents is evaluated through the analysis of two indices. Data (dissolved oxygen, biochemical oxygen demand, pH, turbidity, colour, temperature and thermotolerant coliforms) were collected from five stations in the Mussuré Stream, located in João Pessoa (Northeast of Brazil), between January 1992 and December 2004. Spatial and temporary changes were recorded. The quality indices used, Objective Water Quality Index (WQI_{OBJ}) and Bascarón Adapted Water Quality Index (WQI_{BA}), presented similar trends and were considered adequate for evaluating the impacts of industrial effluent on water bodies. The flexibility of these indices relative to the parameters utilised in the calculations facilitates water quality evaluation in developing countries, where high cost and lack of necessary structure for analysis of other parameters are current deterrents to appropriate water quality evaluation.

Keywords: water quality indices; water bodies; industrial effluents

Introduction

The use of water quality indices (WQI) simplifies the presentation of results of an investigation related to a water body, as it summarises in one value or concept a series of parameters analysed. In this way, the indices are very useful to transmit information concerning water quality to the public in general, giving a good idea of the evolution tendency of water quality to evolve over a period of time, besides allowing the comparison between different watercourses or different locations along the same course; indices are important tools for management of hydrographic basins (Almeida and Schwarzbold, 2003; Couillard and Lefebvre, 1985). The index choice depends on the pollution sources existent at the location and the intended use of the water, and also on the possibility of accomplishing analysis for the necessary parameters.

Since the popularisation of the first WQI, proposed formally by Horton (1965), several others have been developed. The most popular WQI was developed in 1970 by the American Public Health Association (Canter, 1998). In 1979, Bascarón developed a highly flexible index denominated WQI_B. This index allows the introduction or exclusion of parameters in agreement with the needs or limitations for data acquisition (Bascarón, 1979).

The objective of this article is to present a water quality evaluation of a stream that receives industrial effluents, through the use of two indices originated from the WQI_B. The Mussuré Stream was chosen for this study because it represents an environmental degradation situation that is becoming more and more frequent in developing countries. Employment opportunities and economic growth of a region being the main objectives, industrial areas are created and their activities are developed without the proper consideration of the environmental impacts. In this way, rivers and streams receive great volumes of effluents daily that, frequently, are incompatible with their flow and auto in-stream recovery capacity.

The Mussuré Stream is located in the state of Paraíba, northeast Brazil, and its length is approximately 5.2 km. Its basin is located between latitudes 7º11' and 7º13' South, and longitudes 34º52' and 34º56' West, occupying an area of 12.94 km^2, which corresponds to 2.2% of the Gramame River basin, where it is situated (Fig. 1).

The climate in the area is predominantly tropical, with considerable precipitation and high humidity and continually high temperatures, averaging 25.6ºC in January and 23.0ºC in July. The Mussuré Stream basin presents a seasonality of two distinct periods: rainy season, comprising the months from March to August, with maximum pluviometry between June and July (average precipitation of 221.1 mm/month), and the dry season, between September and February, with minimum pluviometry between October and November (44.9 mm/month).

A great portion of the Mussuré Stream basin is occupied by the industrial district of João Pessoa, with an area of 646 ha and, according to the Industrialisation Company of the State of Paraíba (CINEP), it comprises 155 companies, but only

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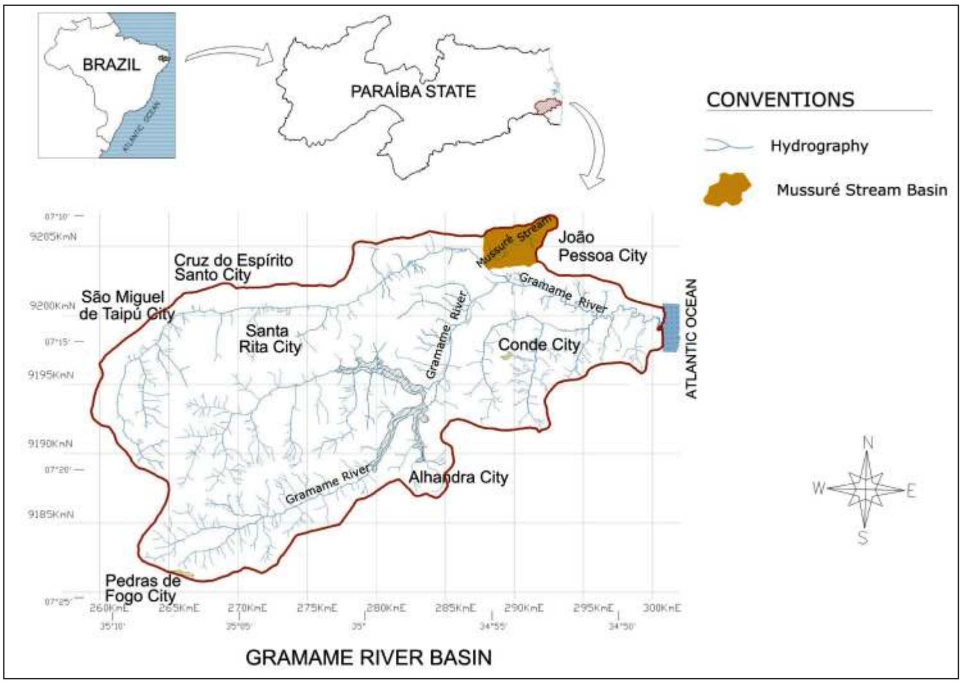

Figure 1
Mussuré Stream basin localisation

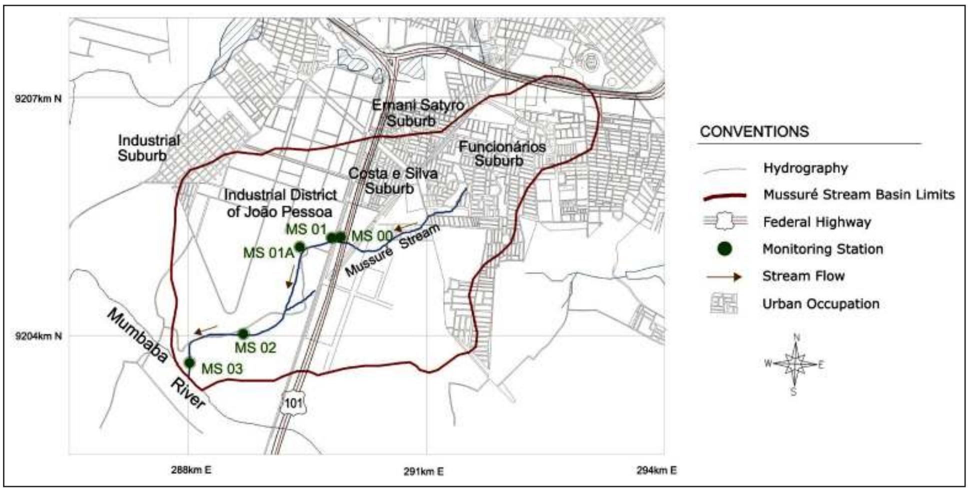

Figure 2
Location of the monitoring stations along the stream

83 are currently in operation. These industries are of several types, the principal types being: food and beverage industries, metallurgical and textile industries, shoe factories, plastic products, paints, graphics (printing industry), seaweed processing, rubber/latex and paper.

Since the commencement of the industrial activities in 1967, the Mussuré Stream has become the principal receiver and diluter of the liquid effluents generated, as the industrial district area is cut off by the stream. Of the 83 active companies, 59 discharge their liquid effluents into the stream, either directly or indirectly (through a collecting system).

According to the Gramame River Water Resource Director Plan (SCIENTEC, 2000), the majority of the industries located in the Industrial District of João Pessoa do not have adequate and efficient treatment of the generated effluents. The problem with effluent treatment occurs more frequently with small industries, which do not use treatment to decrease discharge in the final product, and, due to the lack of adequate inspections, dispose of the effluents in the watercourses of the area, without penalties.

Methodology

Databases and monitoring stations

Data referring to 13 years of monitoring were utilised to evaluate, through the use of the Bascarón Adapted Water Quality Index (WQI_{BA}) and Objective Water Quality Index (WQI_{OBJ}), the impacts of industrial effluents on the water quality of Mussuré Stream.

The water quality data (physical-chemical and bacteriological parameters) gathered in the five collecting stations along the Mussuré Stream were supplied by the Superintendency of Environmental Administration of the State of Paraíba (*Superintendência de Administração do Meio Ambiente do Estado da Paraíba* – SUDEMA). Figure 2 presents the location of the collecting stations along the stream.

The five stations are part of the monitoring net of surface water quality operated by SUDEMA. The first two stations (MS 00 and MS 01) are near the source of the Mussuré Stream and upstream of clandestine discharges of domestic sewers originating from residential neighbourhoods and effluent releases

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of one plastics industry. Station MS 01A is located downstream of several disposal locations of industrial effluents, mainly of textile and printing industries, and seaweed processing. Station MS 02 is 5 m upstream of the aeration system of a beverage industry, responsible for the largest volume of effluents directed to the stream and downstream of the release point of the effluent collecting system of the Industrial District of João Pessoa. The last station (MS 03) is 10 m upstream of the confluence of the Mussuré Stream with the Mumbaba River and downstream of all locations of effluent discharges into the stream.

The sample collections were done monthly, during the morning, between 1992 and 2004, highlighting the fact that, up to December 1997, only Station MS 03 was monitored. The data utilised referred to the parameters dissolved oxygen (DO), biochemical oxygen demand (BOD_5), pH, turbidity, colour, temperature and thermotolerant coliforms. All procedures for the analyses carried out are in agreement with the methodology described in *Standard Methods* (1995).

Water quality indices

Two water quality indices were calculated: Bascarón Adapted Water Quality Index (WQI_{BA}) and the Objective Water Quality Index (WQI_{OBJ}). These indices are derived from the Bascarón Water Quality Index (WQI_B), by Eq. (1) (Bascarón, 1979):

$$WQI_B = K \frac{\sum C_i P_i}{\sum P_i} \quad (1)$$

where:

- C_i = percentage value corresponding to the parameter, defined in Table 1
- P_i = parameter weight, defined in Table 1
- K = constant of adjustment in function of the visual aspect of the water, as follows: 1.00 for clear water with no apparent contamination; 0.75 for water with slightly unnatural colour and turbidity, and with foam; 0.50 for polluted appearance water with odour between moderate and strong; 0.25 for dark water that presents fermentation and strong odour (Bascarón, 1979; Rizzi, 2001).

TABLE 1
Percentage values attributed to water quality parameters for calculation of the water quality index proposed by Bascarón (WQI_B)

Parameter	pH	DBO_5 (mg/ℓ)	Dissolved oxygen (mg/ℓ)	Temperature (ºC)	Total coliforms (nº/100 mℓ)	Colour (hansen)	Turbidity (NTU)	Permanganate reduction (mg/ℓ)	Detergents (mg/ℓ)	Percentage value C_i
Weight	**1**	**3**	**4**	**1**	**3**	**2**	**4**	**3**	**4**	**%**
Analytical value of the parameter	1	>15	0	>50 / > -8	>14.000	>250	>400	>15	>3.00	**0**
	2	12	1	45 / -6	10.000	100	250	12	2.00	**10**
	3	10	2	40 / -4	7.000	60	180	10	1.50	**20**
	4	8	3	36 / -2	5.000	40	100	8	1.00	**30**
	5	6	3.5	32 / 0	4.000	30	50	6	0.75	**40**
	6	5	4	30 / 5	3.000	20	20	5	0.50	**50**
	6.5	4	5	28 / 10	2.000	15	18	4	0.25	**60**
	9	3	6	26 / 12	1.500	10	15	3	0.10	**70**
	8.5	2	6.5	24 / 14	1.000	5	10	2	0.06	**80**
	8	1	7	22 / 15	500	4	8	1	0.02	**90**
	7	<0.5	7.5	21 /16	<50	<3	<5	<0.5	0	**100**
Parameter	**Hardness mg/ℓ $CaCO_3$**	**Dissolved solids (mg/ℓ)**	**Pesticides (mg/ℓ)**	**Oil and grease (mg/ℓ)**	**Sulphates (mg/ℓ)**	**Nitrates (mg/ℓ)**	**Cyanides (mg/ℓ)**	**Sodium (mg/ℓ)**	**Free CO_2 (mg/ℓ)**	**C_i**
Weight	**1**	**2**	**2**	**2**	**2**	**2**	**2**	**1**	**3**	**%**
Analytical value of the parameter	>1.500	>20.000	>2	>3	>1.500	>100	>1	>500	>60	**0**
	1.000	10.000	1	2	1.000	50	0.6	300	50	**10**
	800	5.000	0.4	1	600	20	0.5	250	40	**20**
	600	3.000	0.2	0.60	400	15	0.4	200	30	**30**
	500	2.000	0.1	0.30	250	10	0.3	150	20	**40**
	400	1.500	0.05	0.15	150	8	0.2	100	10	**50**
	300	1.000	0.025	0.08	100	6	0.1	75	9	**60**
	200	750	0.01	0.04	75	4	0.05	50	8	**70**
	100	500	0.005	0.02	50	2	0.02	25	7	**80**
	50	250	0.001	0.01	25	1	0.01	15	5	**90**
	<25	<100	0	0	0	0	0	<10	<3	**100**
Parameter	**Ammonia nitrogen (mg/ℓ)**	**Chloride (mg/ℓ)**	**Conductivity (μmhos/cm)**	**Magnesium (mg/ℓ)**	**Phosphorus (mg/ℓ)**	**Nitrites (mg/ℓ)**	**Calcium (mg/ℓ)**	**Apparent aspect (quality)**		**C_i**
Weight	**3**	**1**	**4**	**1**	**1**	**2**	**1**			**%**
Analytical value of the parameter	>1.25	>1.500	>16.000	>500	>500	>1	>1.000	**Worst**		**0**
	1.00	1.000	12.000	300	300	0.50	600	**Very bad**		**10**
	0.75	700	8.000	250	200	0.25	500	**Bad**		**20**
	0.50	500	5.000	200	100	0.20	400	**Unpleasant**		**30**
	0.40	300	3.000	150	50	0.15	300	**Inappropriate**		**40**
	0.30	200	2.500	100	30	0.10	200	**Normal**		**50**
	0.20	150	2.000	75	20	0.05	150	**Acceptable**		**60**
	0.10	100	1.500	50	10	0.025	100	**Pleasant**		**70**
	0.05	50	1.250	25	5	0.010	50	**Good**		**80**
	0.03	25	1.000	15	1	0.005	25	**Very good**		**90**
	0	0	<750	<10	0	0	<10	**Excellent**		**100**

Bascarón Method (1979)

Since the K values corresponding to each collection were not available from the SUDEMA database, a small adaptation was made for WQI_B. Therefore, the Bascarón Adapted Index (WQI_{BA}) is calculated through Eq. (1), with the K value being attributed the following criteria:

K = 1.00 for waters with a colour parameter of less or equal to 20 mg Pt/ℓ
K = 0.75 for waters with a colour value of greater than 20 mg Pt/ℓ and less or equal to 80 mg Pt/ℓ
K = 0.60 for waters with a colour value of between 80 mg Pt/ℓ and 200 mg Pt/ℓ
K = 0.50 for waters with a colour value of greater than 200 mg Pt/ℓ or in cases where a colour value was not represented numerically – but by the name of the unnatural colour that the stream water presented at the collection moment (e.g. colour red, colour blue).

The Objective Water Quality Index (WQI_{OBJ}) is also calculated by Eq. (1), with the proviso that the value of K does not vary (K=1), resulting in:

$$WQI_{OBJ} = \frac{\sum C_i P_i}{\sum P_i} \qquad (2)$$

The parameters used for the calculation of the WQI_{BA} e WQI_{OBJ} indices were: temperature, colour, turbidity, pH, DO and BDO_5. The reason for not using thermotolerant coliforms is explained in the **Results and Discussion** section.

The results of index application are presented quantitatively, corresponding to a value or grade of between 0 and 100, and qualitatively, in Table 2.

TABLE 2
Correspondence of the qualitative results according to the numerical result of water quality index calculation (WQI_{BA} or WQI_{OBJ})

Quantitative index result	Qualitative corresponding result
91 ≤ index ≤ 100	Good
61 ≤ index < 91	Acceptable
31 ≤ index< 61	Regular
16 ≤ index< 31	Bad
0 ≤ index < 16	Very bad

Adapted from the Bascarón Method (1979).

Analysis

First, the index trend and the individual quality parameters were verified along the five monitoring stations (spatial analysis). These analyses verified the water quality of the Mussuré Stream as it received the industrial effluents.

To verify the influence of the industrial district on the water quality, the index values for the first and last monitoring station were also compared, through the use of the Mann-Whitney non-parametric test (U test), which is used to compare central tendencies of two groups. The lower values for U showed that the groups are different (Arango, 2001; Callegari-Jacques, 2003). Therefore, the distinctions between the following stations were tested: MS 00, where water contains effluents of only one industry and domestic sewage, and MS 03, where the effluent disposal of all industries is downstream. The groups were considered significantly different when the error probability present was less than 5%, that is, $p < 0.05$.

Thereafter the quality trend by year and by seasonal period was analysed (temporal analysis). With these analyses, it was possible to verify the influence of seasonality on the water quality of the Mussuré Stream, over 13 years of data collection and research (January 1992 to December 2004) at Station MS 03.

The relation between the indices and the environmental variables' average air temperature and average precipitation was observed for every year, through the use of the Spearman correlation test. The climatological data were obtained from Castro Pinto Airport, because of its proximity to the study area. The correlation was considered significant for a probability of less than a 5% error ($p < 0.05$).

An analysis comparing groups using the Mann-Whitney test (U test) was also accomplished, splitting data between the humid season (March to August) and the dry season (September to February).

The central trend measurement chosen to analyse data was the median, as it is not influenced by extreme series values. Box-plot graphs were utilised to facilitate visualisation of the results, so that the median and the data distribution could be identified.

Results and discussion

By applying the Objective Water Quality Index (WQI_{OBJ}) it was verified that, along the stream, the worst water quality was found at Station MS 01A. This station presented the lowest median (31.33), indicating a critical water quality location at the Mussuré Stream (Fig. 3).

The qualitative result of WQI_{OBJ} classified the water of all stations as 'regular', according to Table 2, presented previously. The greater WQI_{OBJ} values, which indicate a better water quality, were found near the spring of the stream, at Stations MS 00 (47.67 median) and MS 01 (47.33 median). This highlights the delicate situation of the water quality, as it is necessary to reach a median value of 61.00 to be considered 'acceptable', in terms of Table 2. This is evident when observing Fig. 3, where it is presented that more than 75% of the analysed data were below this value; this means that less than 25% of data had an acceptable qualification at all stations. The Stations MS 01A and MS 02 presented medians very close to 'bad' classification, next to 'very bad' values.

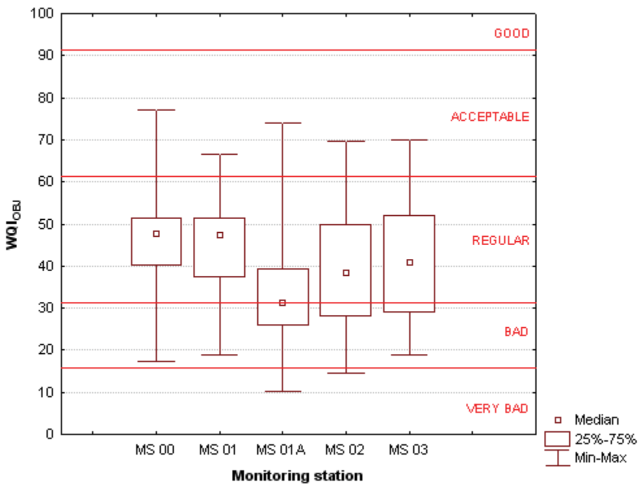

Figure 3
WQI_{OBJ} variation along the Mussuré Stream

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Through the Mann-Whitney test a significant decrease in water quality between Stations MS 00 and MS 03 was verified [U=2509; p=0.0184]. In this way, it was proved that the industrial discharges negatively influence the Mussuré Stream.

The variation of the Bascarón Adapted Water Quality Index (WQI_{BA}) values along the stream is presented in Fig. 4. Compared to the WQI_{OBJ}, it is observed that the water colour parameter has a considerable weight in the final results, as the constant K is directly related to this parameter. In this way, WQI_{BA} can be considered more rigorous than WQI_{OBJ}. All results found were below the 61.00 value, varying between ‘regular’, ‘bad’ and ‘very bad’.

The water colour results from the existence of dissolved substances, originated mainly from organic matter decomposition processes that occur in the aquatic environment, as well as being associated with the presence of some metallic ions - iron and manganese, for example, or planktons, macrophytes and coloured discharges of effluents of some industries (Esteves, 1988). As the Mussuré Stream receives a great quantity of industrial effluents (approximately 114.0 ℓ/s) and there is a small base flow (approximately 128.2 ℓ/s in the dry season, upstream of the industrial discharges), the quality of these effluents has a great influence on the water colour. During night sample collection – because it is the period of greater effluent discharge in the stream – a difference regarding the colour parameter between two monitoring stations (MS 01 and MS 02) was observed. At Station MS 02, the water presented a non-natural dark blue coloration, completely distinct from the colour observed approximately 2.0 km upstream, that is, at Station MS 01 (Fig. 5). This coloration is due, probably, to the direct effect of the textile and graphical industries effluent disposal.

It can be observed in Fig. 4 that the first two stations presented median classified as ‘regular’, while the last three stations are classified as ‘bad’. Again, Station MS 01A presented the smallest values (19.83 median), and it was also verified that a slight improvement in water quality at the last two stations occurred. Even so, through the comparison test a significant decrease in water quality was observed between Stations MS 00 and MS 03 [U=2342; p=0.0034], confirming the negative influence of the industrial district on water quality.

The index analysis allows the evaluation of water quality changes due to the combined effect of several parameters. However, the indices are only partially indicative of quality and may be considered as somehow limited instruments of analysis and must not be the only way of evaluation (Rizzi, 2001; Conesa Fdez-Vitora, 1995). Therefore, it is very important that the parameters be analysed individually.

Comparing the WQI results with the composing parameters that have a greater effect on the index calculation (see Table 1): DO, BOD_5 and colour, a worse water quality was observed in Stations MS 01A and MS 02 (Figs. 6, 7 & 8).

The large quantity of organic matter present in the effluents discharged starting from Station MS 01A is verified through the high values of BOD_5 found in the last three stations (Fig. 6). Maximum values of 108.00 mg/ℓ can be found at Station MS 02.

The introduction of organic matter in a water body results in the increased consumption of dissolved oxygen by the decomposing micro- organisms (Von Sperling, 1996). This statement can be verified in the waters of the Mussuré Stream, where the lowest DO values are found at Station MS 02 (Fig. 7). Nevertheless, the DO values are extremely low along the entire length of the stream. This fact shows that the stream is losing its auto water quality recovery capacity.

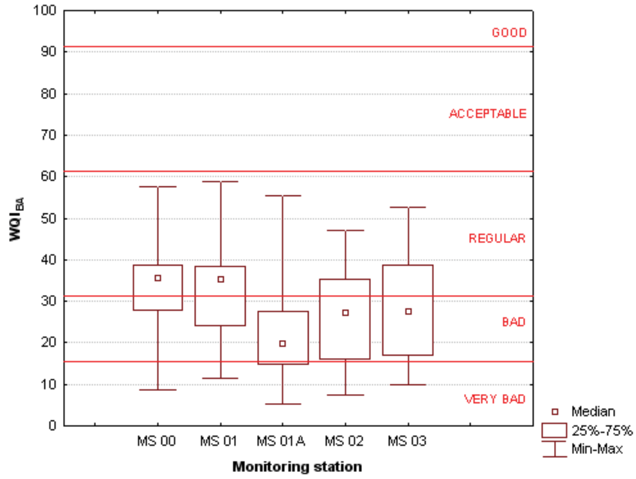

Figure 4
Variation of WQI_{BA} along the Mussuré Stream

Figure 5
Water samples collected at night, at distinct locations of the Mussuré Stream: Station MS 01 (left) and Station MS 02 (right)

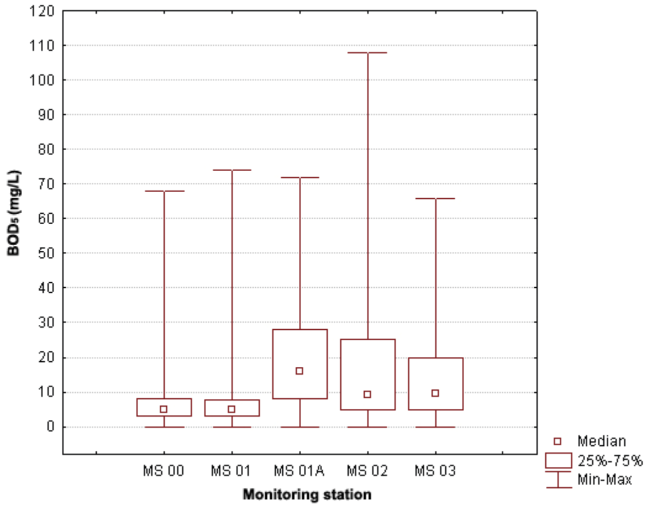

Figure 6
BOD variations along the Mussuré Stream

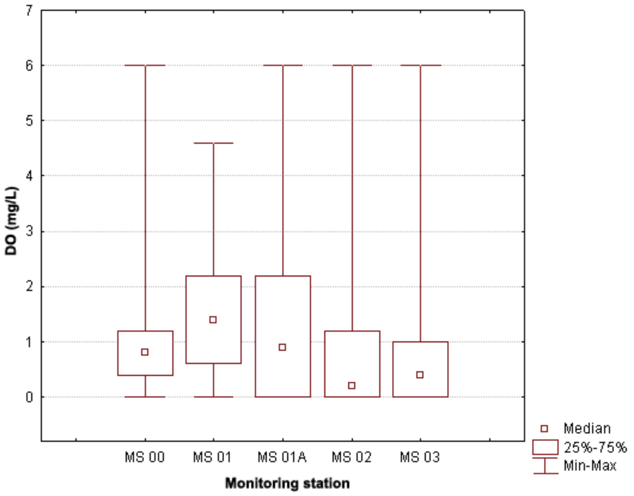

Figure 7
DO variations along the Mussuré Stream

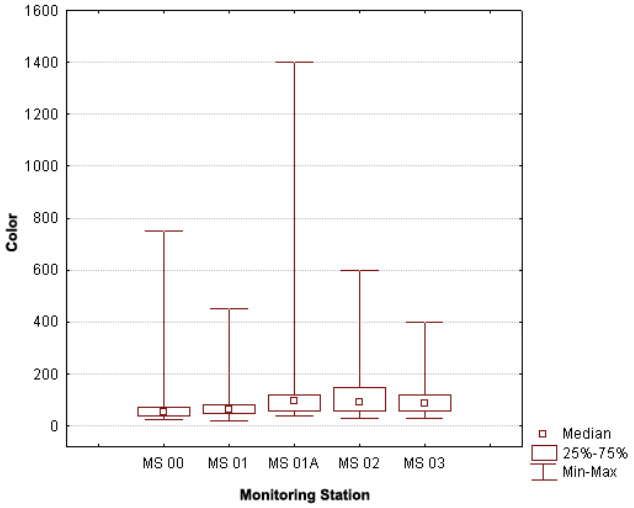

Figure 8
Colour content variations along the Mussuré Stream

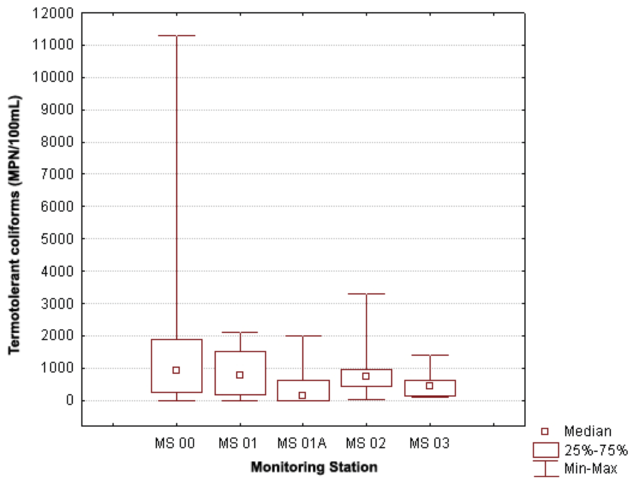

Figure 9
Variation of the thermotolerant coliform number along the Mussuré Stream

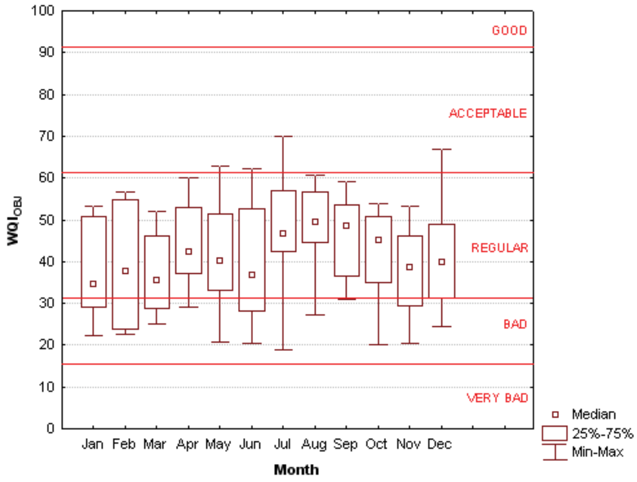

Figure 10
WQI_{OBJ} variation over the year

In relation to the colour parameter, values of up to 1 400.00 mg Pt/ℓ were found at Station MS 01A (Fig. 8).

Therefore, the water quality evaluation for the Mussuré Stream through the use of WQI_{BA} and WQI_{OBJ} can be considered valid. These indices can certainly be used to evaluate other water bodies that receive industrial effluents.

Due to the flexibility of these indices, the calculation may be accomplished by inserting the parameters available. Pesce and Wunderlin (2000) obtained an index, starting from the Bascarón WQI, which uses only three parameters with similar results to two other indices with 20 parameters involved in the calculation. The development and improvement of such indices is of great importance, especially for developing countries, where the costs involved in the analysis of some parameters may limit water quality evaluation. Therefore, even without the resources necessary to determine important parameters (such as heavy metals, in the case of industrial pollution), it is possible to obtain legitimate representative results.

However, the choice of the most appropriate water quality parameters is fundamental for a correct evaluation. In the Mussuré Stream case, to verify the influence of industrial effluents in the water quality, it would not be appropriate to include the thermotolerant coliforms in the index calculation, for example. As there are some clandestine discharges of domestic sewage along the first kilometres of the stream, the first stations present the highest coliform concentrations (Fig. 9). Therefore, the inclusion of such parameter in WQI_{OBJ} and WQI_{BA} would result in lowest 'grades' for the first stations and, consequently, an incorrect evaluation of the influence of the industrial effluents in the water quality of the Mussuré Stream.

When the monthly variation was analysed over a year, the WQI_{OBJ} values portray a slightly better water quality during the rainy season, which covers the months from March to August. Even so, the medians of all months were considered as being of 'regular' quality (Fig. 10). A negative correlation was observed between WQI_{OBJ} and the average air temperature over the year [r=-0.78; p=0.0025]; however, no correlation was observed between WQI_{OBJ} and the average precipitation, which was confirmed by the seasonal analysis of this index, showing no significant difference between the rainy season (WQI_{OBJ} = 44.29) and the dry season (WQI_{OBJ} = 41.50).

Through the WQI_{BA} it was verified that there was a slightly better water quality during the dry season (WQI_{BA} = 31.12), in

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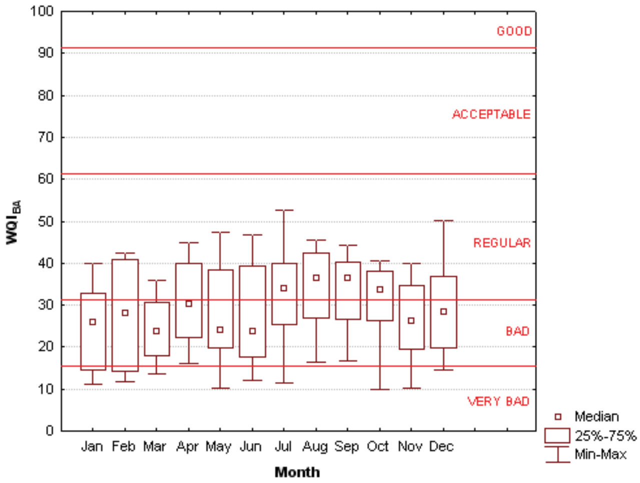

Figure 11
WQI_{BA} variation over the year

comparison with the rainy season (WQI_{BA} = 28.65), but with no significant difference. Such a difference in relation to the WQI_{OBJ} results is due to the parameter K, related to the water colour, whose values were higher during the rainy season. The water quality trend over the year is presented in Fig. 11. There was a significant marginal negative correlation between WQI_{BA} and the average air temperature [r=-0.54; p=0.067] and no correlation was observed between WQI_{BA} and the average precipitation over the year.

With these results it was observed that seasonality does not significantly influence the water quality of the Mussuré Stream. The quality is predominantly influenced by industrial effluents, mostly those discharged upstream of Station MS 01A, originating from textile, seaweed processing plants and printing industries.

Both indices can be used conjunctly to evaluate other water courses located in industrial areas. However, WQI_{BA} showed itself more appropriate to evaluate the water quality for the Mussuré Stream. Besides incorporating the adjust constant K, which represents, indirectly, the perspective of those who 'live' that reality (Borja and Moraes, 2003), the WQI_{BA} presents a more accurate result according to the individual parameters.

Conclusions

The effluents produced by the industrial district of João Pessoa have a negative effect on the water quality of the Mussuré Stream. Both indices used, WQI_{BA} and WQI_{OBJ}, showed that monitoring Station MS 01A presents the worst water quality results, due to the discharge of untreated effluents upstream of this station. The indices also allowed verification of the poor water quality of the stream along its entire course, clearly influenced by the presence of the industrial district of João Pessoa.

WQI_{BA} and WQI_{OBJ} presented similar trends. However, WQI_{BA} is more rigorous and showed itself more suitable to evaluate the water quality of the Mussuré Stream.

The applied water quality indices were considered satisfactory to evaluate watercourses receiving industrial effluents. The flexibility of these indices relative to the parameters inserted in the calculations facilitates water quality evaluation in developing countries, where high cost and lack of necessary structure for analyses of other parameters are current deterrents to appropriate site-specific water quality evaluation.

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