USE OF WATER QUALITY INDEX AS A TOOL FOR URBAN WATER RESOURCES MANAGEMENT

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ABSTRACT
The quality of water resources in urban areas has undergone degradation due to the discharge of domestic and industrial wastewaters and urbanization among other factors. Despite the legal instruments that aim to preserve water bodies, other mechanisms should be implemented, such as monitoring networks and reporting results. Another challenge is the interpretation of the results that may support decision making on the actions that must be taken to preserve the water quality. In this study, we examined the results of physicochemical and microbiological analyses in a monitoring network that comprised 12 sampling stations. Results were compared with water quality standards established in legislation and calculation of two water quality indexes, the Canadian Council of Ministers of the Environment water quality index (CCME WQI) and the National Sanitation Foundation–Environmental Sanitation Technology Company of the State of São Paulo (Cetesb) WQI. Conclusion is that the comparison with quality threshold limits as defined in the legislation, although complete, prevents the reporting on the overall quality of the water body. Application of the quality index allowed communication and interpretation of the results. Another conclusion is that the Cetesb WQI can indicate the degree of contamination of waters impacted by domestic sewage, while the CCME WQI is an effective tool to assess water resources considering different sources of contamination and current legal aspects.
Keywords: Water quality index, water quality monitoring, water resources.

1 INTRODUCTION

The quality of water resources in urban areas has been continuously degraded because of problems derived from unplanned urbanization. Unplanned growth has, as a consequence of the lack of suitable sanitation infrastructure, resulted in the disposal of domestic sewage and industrial effluents (treated or not), as well as contributions from urban drainage and solid wastes, into the water sources in urban areas. In Brazil, the responsibility for water resources management is shared by the Water Basin, as defined by legislation, and the municipal authorities that are responsible for the control of polluting activities and soil use and occupation within its geographical limits.

Despite the existing national and state policies that establish instruments, such as water quality standards for water bodies classification and limits for disposal of treated wastewaters, implementation of other mechanisms to address the urban water status is necessary. Such mechanisms include the implementation of monitoring networks, through which samples are collected periodically for determination of physicochemical, physical and microbiological parameters. Monitoring networks can be excellent management tools of environmental and water resources, as shown by Finotti *et al*. [1]. The results should be assessed periodically. Such assessment can be made by comparison with current legislation or by using water quality index.

Water quality index consist of an important tool to summarize and simplify different values of analytical determination and indicate the quality of a water resource. In this regard, Yisa and Jimoh [2] claim that water quality is one of the most effective tools to communicate information on the quality of water bodies to interested citizens and public managers. Furthermore, the use of water

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quality index is an attempt at ensuring that a monitoring program follows up the water quality and possible deterioration throughout the watershed or over time in a summarized form [3].

In Brazil, the classification of water bodies is defined by Resolution no. 357 of the National Environment Council (CONAMA) [4], which defines the threshold concentrations values for each class of water, according to its uses, as described in Table 1. For fresh waters, there are five classes: special class and classes 1 to 4. The special class and class 1 refer to fine waters, that is, they should be of high quality, whereas class 4 refers to water resources with poorer water quality and having very limited uses due to pollution.

Only a comparison between the water quality parameters and current standards established in legislation is insufficient for reporting on the water quality status and its evolution along the basin and over time. The main advantages of the index are easy communication with the lay public, their greater status than isolate variables and the fact of representing an average of diverse variables in a single number, by combining different measurement units to a single totalizer unit. [5]. Examples of water quality index (WQI) are National Sanitation Foundation (NSF) WQI, Canadian Council of Ministers of the Environment (CCME) WQI, Horton index and Dinius index, among others. However, one should be very careful when using quality index. They should be selected according to the type of pollution existing at the site.

The NSF WQI was developed by the NSF and is one of the most used indexes, mainly applied to pollution from domestic sewage. In its calculation, nine parameters are originally considered (solved oxygen, thermo-tolerant coliforms, pH, biochemical oxygen demand, total nitrate, total phosphate, temperature, turbidity and total solids). Because of specific needs, it has been changed since its original conception, especially with regard to the weights assigned to the parameters [6]. Example is the WQI adopted by Cetesb (Environmental Sanitation Technology Company of the State of São

Table 1: Uses of water as defined by CONAMA Resolution no. 357 [4].

	Classes				
Possible water uses	S	1	2	3	4
Domestic supply					
Without previous or with simple disinfection	X				
After simplified treatment		X			
After conventional treatment			X	X	
Preservation of natural balanced aquatic communities	X				
Protection to aquatic communities		X	X		
Landscape harmony					X
Recreation with primary contact (swimming, skiing, diving)		X	X		
Irrigation					
Vegetables or fruits (creeping plants) that are consumed raw		X			
Vegetables and fruit plants			X		
Arboreous, cereal and forage cultures				X	
Natural and/or intensive growing of species for human consumption		X	X		
Animals watering				X	
Navigation					X
Less stringent uses					X

Paulo), which replaced the total phosphate and nitrate parameters used in the NSF WQI for the total nitrogen and total phosphorous, maintaining the same weights and quality curves as indicated by NSF [5].

A very interesting index is the CCME WQI, which was developed by the CCME [7]. It is calculated considering the spectrum (number of variables that do not meet the quality standard), frequency (number of times such standards are not met), and amplitude (discrepancy between variable not meeting standards and the standard) of the analyzed data series, which should comprise at least four variables determined during four sampling campaigns. Thus, the index fits the local impact instead of bringing previously established quality parameters. The variables, the objective and period of time used in the index calculation are not specified and may vary according to the region, depending on the local conditions [7].

The quality index may support the decision-making process of a monitoring network. They may also constitute a tool to support environmental and water resources management. To this end, the application should be appropriate to the monitoring and management objectives. One must have a deep knowledge about the nature of the index calculation and the interpretation of its results, as well as its representativeness for the overall water condition. Finally, as the quality index can be used to communicate the water conditions to the public in general, the interpretations of the index should be clarified in order not to mask the effects of a contamination not considered in its calculation.

This study presents the use of WQI as a tool for management of urban water resources through a monitoring network. The monitoring network was implemented in a mid-size city in south of Brazil. The city of Caxias do Sul, the second largest metal mechanic industrial region in the country, has approximately 500,000 inhabitants and is an important industrial complex for the furniture and food industries. Public authorities of Caxias do Sul implemented the monitoring network, comprising 12 stations monitored monthly for 20 water quality parameters and flow rate. Results from this study are compared with the first year of monitoring [1]. The NSF–Cetesb WQI and the CCME WQI were calculated and the results are compared with the municipal environmental management and water resources management.

2 MATERIAL AND METHODS

This study was developed upon the implementation of a monitoring network of urban water resources as a support tool for the environmental management in Caxias do Sul. More specifically, the goal was to identify concentrations of pollutant sources and provide data for the environmental licensing activities of the Municipal Environment Secretary of Caxias do Sul (SEMA). The objective was to give support to the monitoring process and assessment of the water quality of the water resources in the urban area. The conception of the monitoring network and its characteristics were presented by Finotti *et al.* [1]. The monitoring network comprised 12 sampling stations, in which the flow rate and 20 water quality parameters were examined. Monitoring was performed on a monthly basis for one year. Figure 1 represents the map with indication of the water micro-basins and the location of the sampling stations.

The analyzed parameters were selected considering the main components found in domestic sewage and effluents from the industries based in the city. Table 2 shows the parameters that were monitored and the method used in the laboratory analysis performed according to APHA [8]. The hydrological conditions were monitored through bathymetry and linimetric rulers that were installed at each station. The flow rate was conventionally measured with a hydrometric winch, which measures the water speed based on the number of helix rotations. The method consists of direct measurements of the cross-section speed distribution for several levels of water.

The first level of data analysis of the monitoring network was the descriptive statistical analysis. As the amount of data from the network was too large, the principal components analysis (PCA) was applied to indicate which quality parameters would better represent the dataset under analysis. Finotti *et al*. [1] describe in details the results of application of PCA. These results, which are briefly presented in the results section hereof, were used as a support for the calculation of the quality index, as described below.

To evaluate the potential ways of presenting the information on the quality of the monitored water resources, two alternatives were presented and evaluated. The first one was the systematization and comparison of the results obtained during the monitoring period with the legal limits as established in the CONAMA Resolution no. 357 [4], which is the norm that defines the quality standards of different water classes. In the present study, the results were compared with the limits defined for Class 3. The second alternative was to evaluate the potential use of the WQI as a tool for environmental management and social communication on the quality of water. To this end, two water quality indexes were tested: (a) CCME WQI and (b) NSF–Cetesb WQI. The NSF–Cetesb WQI was chosen because it is one of the oldest and most widely used quality indexes. This index has predefined parameters in its methodology. Due to the kind of parameters it uses, it is an index that can evaluate efficiently the pollution in domestic sewage.

The CCME WQI is aimed at verifying its effectiveness in the analysis of data from the water quality monitoring, based on representative variables. One of the calculation steps of this index is the selection of the variables that will compose it. In the present study, the selection of the variables for determination of the CCME WQI considered two factors: (a) parameters that present threshold concentration values according to CONAMA Resolution no. 357 [4]; and (b) parameters that had better PCA representativeness (groups of parameters that comprise the three first PCA vectors, according to Finotti *et al*. [1]). By applying both these criteria 13 parameters were considered for calculation

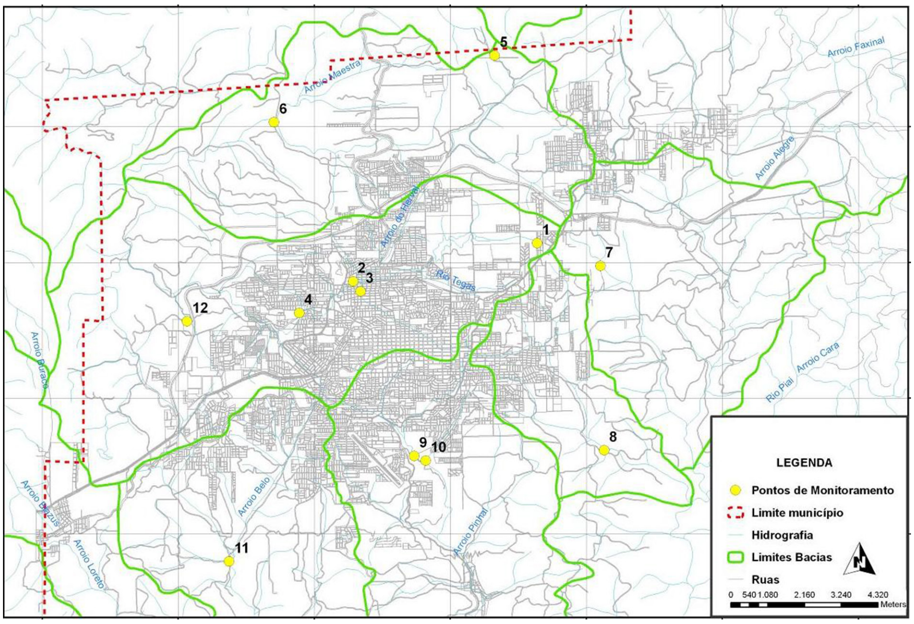

Figure 1: Monitoring network [1].

Table 2: Monitoring network sample parameters and method of analysis.

Parameters	Methodology
Biochemical demand for oxygen (mg O_2/L)	Dilution and incubation at 20°C for 5 days
Total nitrogen (mg N/L)	Titrimetric with nesslerization
Ammonia nitrogen (mg NH_3-N/L)	Titrimetric with nesslerization
Total phosphorous (mg P/L)	Colorimetric of ascorbic acid
Anionic surfactant (mg/L)	Methylene blue – MBAS
Total solids (mg/L)	Gravimetry at 103°C to 105°C
Cyanides (mg/L)	Spectrometry
Phenol (μg/L)	Extraction with chloroform
Chrome (mg/L)	Atomic absorption
Zinc (mg/L)	Atomic absorption
Iron (mg/L)	Atomic absorption
Nickel (mg/L)	Inductively coupled plasma
Fecal coliforms (NMP/100 mL)	Multiple tubes
pH	Potentiometric method
Conductivity (μs/cm)	Electrometry
Dissolved oxygen (mg O_2/L)	Membrane electrode
Air and water temperature (°C)	Thermometer

of the CCME WQI. They are: pH, dissolved oxygen, biochemical oxygen demand, ammonia nitrogen, total phosphorous, surfactants, cyanide, lead, chrome, nickel, zinc, phenol and thermo-tolerant coliforms.

The calculation of the CCME WQI was performed following the method proposed by CCME [7], which considers three factors: (a) spectrum F_1 calculated by Eqn (1), (b) frequency F2 calculated by Eqn (2), and (c) amplitude F3 calculated by Eqns (3) to (5). These factors are used in the calculation of the CCME WQI through Eqn (6). The overall dataset obtained from 12 monthly campaigns, 12 monitoring stations for 13 quality parameters were considered, and the number of times they exceeded the limit values for Class 3 was determined. The score scale, according to CCME [4], is shown in Table 3.

$$F1 = \left(\frac{number\ of\ \ failed\ variables}{total\ number\ of\ \ variables} \right) \times 100, \tag{1}$$

$$F2 = \left(\frac{number\ of\ \ failed\ tests}{total\ number\ of\ \ test} \right) \times 100, \tag{2}$$

$$F3 = \left(\frac{nse}{0.01nse + 0.01} \right) \times 100, \tag{3}$$

$$nse = \frac{\sum_{i=1}^{n} exciuded}{total\ of\ tests}, \tag{4}$$

$$excluded = \frac{value\ of\ test\ out\ of\ limit}{limit\ value}\ or\ excluded = \frac{limit\ value}{value\ of\ test\ out\ of\ limit}, \tag{5}$$

$$\text{CCME WQ1} = 100\ - \left(\frac{\sqrt{F1^2 + F2^2 + F3^2}}{1.732} \right) \tag{6}$$

The calculation of the NSF–Cetesb WQI was performed through Eqn (7). The nine parameters comprising the Cetesb index [5] with the weight used for calculation between parentheses are as follows: solved oxygen (0.17), thermo-tolerant coliforms (0.15), pH (0.12), biochemical oxygen demand (0.1), total nitrogen (0.1), total phosphorous (0.1), temperature (0.1), turbidity (0.08) and total solids (0.08). In the calculation, the numeric values associated with each parameter (*qi*) are considered and elevated to their respective weights in the evaluation of total variability of water quality (*wi*). The classification scale of the water quality, according to the Cetesb WQI, is presented in Table 4.

$$1QA = \prod_{i=1}^{n} qi^{wi}. \tag{7}$$

where *qi* is the i^{th} quality parameter, a number from 0 to 100, obtained from the respective mean curve of quality variation according to its concentration or extent; *wi* is the weight corresponding to the i^{th} parameter, a number between 0 and 1, attributed according to its importance for the overall quality conformation; and *i* = parameter number, varying from 1 to 9.

Table 3: Water classification scoring based on CCME WQI [7].

Category	Scores
Excellent	95 – 100
Good	80 – 94
Fair	65 – 79
Marginal	45 – 64
Poor	0 – 44

Table 4: Water classification scoring based on Cetesb WQI [9].

Category	Scores
Excellent	95 – 100
Good	80 – 94
Fair	65 – 79
Poor	45 – 64
Very poor	0 – 44

3 RESULTS

3.1 Principal component analysis

The parameters of the 12 stations, monitored during 12 campaigns, were analyzed by PCA and the results are presented in Table 5, which shows the values attributed to each component and their variance percentage. The total group of five components explains 76.54% of the variance.

Principal Component 1 variables indicate that the main contamination source of the water bodies in Caxias do Sul is domestic sewage. The main components of the sewage are organic matter, nitrogen and phosphorous. Perona *et al*. [10], Shrestha and Kazama [11] and Bouza-Deaño *et al*. [12] found similar results monitoring rivers in Spain and Japan. In CP 2 the group parameters indicate that another relevant source of water pollution is the release of wastewater from galvanic industries. CP 3 presents total aluminum and total iron as variables. Both are metals that constitute the soil in the region and indicate that soil leaching is carried by the rivers of that area. It is, therefore, a natural process, but which can be magnified by urbanization. CP 4 included the air temperature and sample temperature variables. These variables are intrinsically related. Bouza-Deaño *et al* [12] have found that water and air temperatures were highly significant factors, explaining 11.4% of the variation, and the authors called it the climate factor. Finally, CP 5 includes thermo-tolerable coliforms, ammonia surfactants, and dissolved oxygen, which are also related to domestic or industrial sewage discharged in the monitored rivers.

Table 5: Factorial value matrix of variables for the top five components selected.

	Component				
Parameter	CP 1	CP 2	CP 3	CP 4	CP 5
Total nitrogen	0.935	0.132	–0.061	0.059	0.065
Ammonia nitrogen	0.931	0.094	–0.105	0.064	0.029
Total phosphorous	0.919	0.002	0.073	0.118	0.086
Conductivity	0.859	0.224	–0.062	0.080	0.030
Biochemical oxygen demand	0.778	0.057	0.141	–0.060	0.209
Chemical oxygen demand	0.742	0.060	0.437	–0.003	0.200
Total chrome	0.129	0.932	0.008	0.018	–0.010
Total zinc	0.173	0.763	0.162	0.061	–0.142
Total nickel	0.035	0.677	–0.119	–0.016	0.179
Total aluminum	0.104	–0.049	0.901	–0.035	0.001
Total iron	–0.050	0.056	0.877	–0.017	0.059
Sample temperature	0.116	0.046	–0.040	0.895	0.093
Air temperature	0.030	0.011	–0.008	0.894	0.099
Tolerant fecal coliforms	0.049	–0.083	–0.034	0.092	0.868
Anionic surfactant	0.453	0.144	0.282	0.137	0.625
Dissolved oxygen	–0.437	–0.339	–0.029	–0.155	–0.455
% explained variance	30.95	13.39	12.13	10.56	9.51
% accumulated variance	30.95	44.34	56.47	67.03	76.54

Table 6: Parameters used in the calculation of the quality indexes

CCME WQI	NSF Cetesb WQI
pH	pH
Dissolved oxygen	Dissolved oxygen
Biochemical demand for oxygen	Biochemical demand for oxygen
Thermo-tolerant coliforms	Thermo-tolerant coliforms
Ammonia nitrogen	Total nitrogen
Total phosphorous	Total phosphorous
Surfactants	Total solids
Phenol	Turbidity
Cyanide	Temperature
Lead	
Chrome	
Nickel	
Zinc	

The results from PCA combined with the variables considered for the water classification as proposed by CONAMA [4] in Class 3, defined which parameters should be used in the calculation of the CCME WQI. The parameters defined are shown in Table 3. The parameters that were considered for calculation of the NSF–Cetesb WQI are those defined by the method of calculation of the index.

The results from PCA pointed to total nitrogen, electrical conductivity, chemical oxygen demand, aluminum, iron and temperature, which were not considered for the CCME WQI because they had limited values defined in the CONAMA resolution no. 357 [4]. Finally, phenol and lead parameters were included in the calculation of the index for showing the limit in the CONAMA resolution, although they have not been pointed as the most frequent components in the PCA. The quality index defined by these parameters meets the legal limits as established by the Brazilian standard for water quality, Class 3 in Resolution 357, and at the same time incorporates the result of 1 year obtained by the monitoring network for Caxias do Sul, when assuming the parameters established by the PCA method. The frequent presence of such parameters in the monitoring network showed that the water resources were contaminated by improper disposal of domestic wastewaters and also from the metal industries.

3.2 Comparison of the water quality with legislation standards

Table 7 shows the mean results from the physicochemical and microbiological analyses conducted throughout the 12 campaigns, and the standards for Class 3, as defined by the CONAMA Resolution no. 357 [4]. Table 7 shows the parameters for which there are quality standards defined. The values highlighted in gray on the table are those that were found above the limit values allowed for Class 3, which would score them to class 4, the worst of all classes. Waters included in Class 4 are limited to landscape harmony, navigation and other less stringent uses.

By analyzing the data of Table 7, one can observe that the stations 1, 5 and 11 are the ones that showed the smallest number of parameters exceeding the concentration limits for Class 3. Such

Table 7: Comparison of the annual mean results found at the SS to the Class 3 parameters defined by the CONAMA Resolution no. 357 [4].

Parameters (mg/L)	SS 1	SS 2	SS 3	SS 4	SS 5	SS 6	SS 7	SS 8	SS 9	SS 10	SS 11	SS 12	Class 3 Standard
pH	6.50	7.10	7.37	7.28	6.29	7.60	6.92	7.78	7.77	7.54	7.42	7.74	6 – 9
Dissolved oxygen	3.63	4.00	2.42	4.22	5.63	6.93	6.25	6.59	6.10	4.67	6.82	6.84	> 4
BOD (mgO_2/L)	4.85	30.48	108.67	25.63	2.32	6.80	5.33	11.92	22.03	58.87	8.11	7.95	≤10
Ammonia nitrogen ($mgN\text{-}NH_3/L$)	1.16	10.51	18.81	11.64	0.49	7.16	2.41	12.63	11.99	13.52	7.81	2.63	13.3/5.6
Total phosphorous (mgP/L)	0.065	1.514	3.403	1.785	0.135	1.026	0.385	1.136	1.937	2.513	1.177	0.263	0.150
Anionic surfactant	0.490	1.860	3.290	1.890	0.100	0.240	0.270	0.220	2.290	2.630	0.220	0.160	0.500
Total cyanide	0.012	0.277	0.027	0.146	0.029	0.009	0.005	0.01	0.041	0.017	0.005	0.007	0.022
Total lead	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.016	0.016	0.015	0.015	0.033
Total chrome	0.040	1.460	0.300	0.350	0.040	0.040	0.045	0.039	0.06	0.06	0.04	0.04	0.050
Total nickel	0.009	1.097	0.010	0.250	0.009	0.012	0.116	0.088	0.156	0.010	0.009	0.014	0.025
Total zinc	0.050	0.980	0.360	0.610	0.030	0.030	0.16	0.03	0.17	0.17	0.05	0.03	5.000
Phenol	1.82	2.50	9.19	8.82	3.30	2.05	6.82	2.54	7.50	3.12	2.74	2.94	10.00
Total dissolved solids	89.61	187.17	260.12	190.97	41.07	89.11	136.60	132.89	179.50	236.73	102.86	543.33	500
Thermo-tolerant coliforms (NMP/100mL)	9.6×10^3	5.8×10^5	1.6×10^7	1.2×10^6	2.7×10^2	1.2×10^4	1.6×10^4	1.2×10^5	5.7×10^5	1.3×10^6	2.1×10^4	2.4×10^4	2.5×10^3

SS: Sampling stations

result was expected as these sampling stations are located at the sources of the rivers of the micro-basin and in less urbanized sites. However, even presenting fewer parameters inside the Class 3 limits, these sites showed that the water quality was impaired by low dissolved oxygen and high coliform counts, or the presence of total cyanide, which can indicate discharge of domestic wastewaters or even the presence of any specific industrial activity.

Stations 2, 3, 4, 8, 9 and 10 had more than six parameters exceeding the Class 3 standards. The parameters with concentrations above the limits defined in Class 3 are the following: Biochemical demand for oxygen, total phosphorous, ammonia nitrogen, surfactants, total coliforms, total cyanide, total chrome and total nickel. For this group of stations, station 3 indicated concentrations outside the standards for dissolved oxygen.

All sampling stations had at least one parameter outside reference standards of Class and therefore they should be Class 4, according to CONAMA Resolution no. 357 [4]. The results found for the sites with greater contamination indicate that the waters are contaminated by domestic and industrial wastewaters. Von Sperling [13] cites that the main parameters for domestic sewage are the following: organic matter, nitrogen, phosphorous, solids and fecal contamination indicators. The presence of metals at concentrations above the standards is indicative of the influence of disposal of industrial wastewaters into surface waters.

3.3 WQI applied to the monitoring network

Table 8 shows the results from the calculations of CCME WQI and mean NSF–Cetesb WQI for the 13 campaigns. It can be seen that all sampling stations were classified as "poor" when CCME-WQI was used. The lowest scores (below 25) were found at stations 2, 3, 4, 8, 9 and 10.

Regarding the NSF–Cetesb WQI, the results varied among three categories: good, fair and poor. The sites with the poorest water quality were those that also had the lowest scores according to the

Table 8: Comparison between the mean results from the CCME WQI and NSF–Cetesb index for the sampling stations.

	CCME WQI		Mean NSF–Cetesb WQI	
Sampling station	Score	Category	Score	Category
Station 1	28	Poor	53	Good
Station 2	16	Poor	33	Poor
Station 3	18	Poor	22	Poor
Station 4	16	Poor	34	Poor
Station 5	33	Poor	69	Good
Station 6	30	Poor	55	Good
Station 7	28	Poor	60	Good
Station 8	25	Poor	43	Fair
Station 9	23	Poor	35	Poor
Station 10	22	Poor	28	Poor
Station 11	31	Poor	52	Good
Station 12	32	Poor	55	Good

CCME WQI. Therefore, there is an agreement between the scores obtained by the CCME WQI and the NSF–Cetesb WQI for each sampling station. However, the CCME WQI indicates contamination by both domestic and industrial wastewaters, whereas the NSF–Cetesb WQI shows the presence of pollution caused by domestic sewage only. Furthermore, the sampling sites that had the lowest scores are the same sites that showed the greatest amount of parameters over the standard limits for Class 3, according to CONAMA Resolution no. 357 [4].

By examining the classification of the CCME and NSF–Cetesb index for each sampling site, a disagreement between the results can be observed. The results from the CCME WQI in all sampling sites indicated that the water quality is “poor”. On the other hand, the NSF–Cetesb WQI indicated that the stations 2, 3, 4, 9 and 10 were scored “poor”, site 8 as “fair” and sites 1, 5, 6, 7, 11 and 12 as having “good” water quality. This disagreement can be explained by the fact that the CCME WQI is built based on the selection of parameters, while NSF–Cetesb WQI comprises only 9 parameters. According to Cetesb [14], for the calculation of the NSF–Cetest WQI, the water quality variables considered are those that indicate the disposal of domestic sewage into water bodies, and may indicate some contribution from industrial wastewaters as long as they present biodegradable organic matter constituents.

The NSF–Cetesb WQI indicates a contamination scale that reflects water bodies most impacted by domestic sewage disposals. However, such contamination scale may not represent faithfully the water conditions if the impact is caused by another pollution source not necessarily organic. According to this study, stations 1, 5, 6, 7, 11 and 12 showed “good” water quality by NSF–Cetesb WQI, but exceeded at least one parameter of the concentration limit values of Class 3.

Regarding the analysis of the results from the CCME WQI and in the CONAMA Resolution no. 357 [4], the water quality at all sampled sites was “poor”, and the standard values for Class 3 were not attained, with higher or lower variation in the occurrence. Such similarity of the results is due to the fact that the CCME WQI was built based on the PCA and the limit values of Class 3 as standards for water classification. Mophin-Kani & and Murugesan [15] indicate that the WQI has been considered a criterion for the classification of surface waters, based on standard parameters for water characterization.

The CCME WQI reflects the water status more accurately because it can be built upon a larger number of variables and may include those that are indicators of different polluting sources. According to Akkoyunlu & Akiner [16], water quality index should be developed considering the local characteristics and the ecosystem pollution conditions.

Another aspect to be considered is that the CCME WQI indicates the quality of the water based on the monitoring of historical records, whereas the NSF–Cetesb WQI can be calculated for each sampling event, as shown in Table 9. In this regard, Almeida [17] affirms that, although the analytical calculation of the NSF–Cetesb WQI provides specific information on the water quality at a site in the area, the statistical calculation based on the CCME WQI yields safer information on quality.

3.4 Quality index as an environmental management tool

The three alternatives for evaluation of the quality of water resources showed quite different ranges. Comparison of the results with the limits defined in legislation is quite complete and provides details that the quality index may mask, as evidenced in Table 7. It is important to emphasize that the data shown are annual averages of each sampling site. Therefore, the complete result would comprise 12 tables, one for each sampling month. On the other hand, the information, although detailed, may be disperse and hinder a prompt understanding of the water quality.

Table 9: NSF Cetesb WQI for each sampling campaign

Sampling station (SS)	Campaigns													
	1	2	3	4	5	6	7	8	9	10	11	12	13	Mean
SS 1	60	65	69	44	51	45	40	49	50	50	46	66	57	53
SS 2	19	43	23	25	16	36	22	39	24	47	42	38	56	33
SS 3	17	24	18	20	16	22	23	18	21	31	18	25	35	22
SS 4	17	39	27	25	15	37	25	39	27	42	45	46	54	33
SS 5	44	69	64	60	70	72	79	72	82	71	77	73	70	69
SS 6	85	62	46	59	46	43	55	46	56	58	55	54	57	55
SS 7	75	69	69	64	60	47	71	51	53	51	54	57	55	59
SS 8	33	46	39	29	31	41	51	43	48	46	46	51	50	42
SS 9	45	40	26	31	26	37	40	27	43	29	32	31	45	34
SS 10	32	32	20	23	20	19	24	24	36	28	31	31	42	27
SS 11	51	72	45	41	48	43	55	49	50	48	56	61	56	51
SS 12	52	62	58	48	39	57	56	58	57	54	52	57	59	54

The quality indexes summarize the information, as shown in Table 8. The 12 sampling campaigns are translated into a single value that expresses the overall quality of the sampling station for both calculated index. In the case of the CCME WQI, the calculation requires that the historical records of the site be considered, without which the index cannot be applied. The NSF–Cetesb WQI allows calculating the value for each campaign, as shown in Tables 8 and 9. The value shown in Table 8 is the average of the values from the index calculated for each campaign shown in Table 9.

Another key issue is related to the choice of the index used to express quality. The NSF–Cetesb WQI can only indicate organic pollution. Interpretation of the results from this index should necessarily consider this aspect. However, the CCME WQI will take into consideration the parameters that have higher representativeness for the site to be monitored. In the present study, the application of PCA and the parameters defined by the CONAMA legislation proved critical to represent accurately the quality of water resources regarding pollution and the required control actions.

4 CONCLUSIONS

All monitored sampling sites showed different levels of contamination by domestic sewage or industrial effluent. This is clear when the mean concentrations of the samples are compared to the standards defined by the CONAMA Resolution no. 357 [4].

The CCME and NFS–Cetesb WQIs can be an appropriate alternative to evaluate urban water resources, despite having different responses. Thus, the choice of the index used to evaluate water quality will depend on the objectives to be met.

To determine the level of contamination by domestic sewage, the NSF–Cetesb WQI can provide reliable results regarding the water conditions. However, to assess the degree of contamination by domestic and industrial wastewaters, the CCME WQI is the most appropriate indicator, because it also allows considering the pollution caused by the presence of metals.

The water quality indexes have many advantages with respect to the communication of the results from monitoring. However, the objectives of using these indexes must be clear and the communication of the results must always include such objectives.

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