RBES
Revista Brasileira de Engenharia e Sustentabilidade

ISSN 2448-1661
Pelotas, RS, UFPel-Ceng
https://periodicos.ufpel.edu.br/ojs2/index.php / RBES/index
v.11, p.1-25, dez. 2023

WATER QUALITY INDEX APPLIED TO AN URBAN STREAM LOCATED IN PORTO ALEGRE, RIO GRANDE DO SUL, BRAZIL

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Keywords: water quality; urban stream; domestic sewer; sewage collector pipes

Abstract

Water quality monitoring is an important tool to preserve water resources In this study, the water quality index (WQI) adapted by Environmental Company of the state of São Paulo (CETESB) was calculated and used to classify the water quality of an urban stream in the period between 2002 and 2012. It was used raw data on the concentrations of each WQI parameter. The parameters are: water temperature; total solids; turbidity; dissolved oxygen; biochemical oxygen demand; pH; total nitrogen; total phosphorus and *Escherichia Coli*. The results showed that the water quality was classified as "Low" or "Very low" in all samples, according to National Agency of Water (ANA) classification. Statistical analyses were performed for each parameter with the purpose of identifying variations over time and between different locations along the stream. The results showed that these variations were identified in those parameters generally related to domestic sewage, i.e.: DO; BOD5 and *Escherichia Coli*.

Índice de qualidade da água aplicado a um arroio urbano localizado em Porto Alegre, Rio Grande do Sul, Brazil

Palavras-chave: Qualidade da água; rio urbano; esgoto doméstico; tubos coletores de esgoto

Resumo

O monitoramento de qualidade da água apresenta-se como uma ferramenta importante no intuito de preservar recursos hídricos. Neste estudo, o índice de qualidade da água (IQA) adaptado pela Companhia ambiental do estado de São Paulo (CETESB) foi calculado e utilizado na classificação da qualidade da água de um arroio urbano no período entre 2002 e 2012. Foram usados dados brutos das concentrações de cada parâmetro do IQA. Os parâmetros são: temperatura da água; sólidos totais; turbidez; oxigênio dissolvido; demanda bioquímica de oxigênio; pH; nitrogênio total; fósforo total e *Escherichia Coli*. Os resultados mostraram que a qualidade da água do arroio Dilúvio foi classificada como “Ruim” ou “Muito ruim” em todas as amostras. Análises estatísticas foram feitas para cada parâmetro com o propósito de identificar variações ao longo do tempo e entre diferentes locais ao longo do arroio. Os resultados mostraram que essas variações foram identificadas naqueles parâmetros geralmente relacionados com esgoto doméstico, a saber: OD; DBO5 e *Escherichia Coli*.

Artigo Submetido dia 07/01/2023

Artigo Aceito dia 03/07/2023

INTRODUCTION

The main uses of water, as a natural resource, have suffered significant restrictions due to the intense process of urbanization in recent decades, degrading the water quality of urban streams through intense pollution. The release of polluting loads of domestic sewage and modifications in the surface around rivers are the two main factors contributing to water quality degradation in urban rivers (ORTEGA, CARVALHO, 2013; SOUZA et al., 2013; WEINGRAT; BICUDO, 2011).

These impacts caused by anthropogenic activities have been so significant, that several water resources have lost their self-purification capacity because of this increasing number of pollutants (SOOD et al., 2008).

Therefore, information on water quality is essential for an efficient management of these water resources. The monitoring of water quality is shown to be a great assistance tool for public entities, especially when they must plan, decide and act in the sense of preserve streams in urban centers. In addition, the classification of water quality is also important, as it helps to establish goals regarding the ideal scenario for the use of these water bodies (FIA et al., 2015; IQBAL; AHMAD; DUTTA, 2019; LEMOS; NETO; DIAS, 2010).

In view of the above, this study aims to evaluate the water quality of an urban stream located in Porto Alegre, the capital city of Rio Grande do Sul, southest state of Brazil. Through the analysis of physical, chemical and biological parameters, it is sought to determine which of the nine parameters most negatively affects the WQI. It was assumed as an initial hypothesis that installations of domestic sewage collection pipes helps in improving the water quality conditions of the *Arroio Dilúvio.*

It was also assumed that the nine parameters adopted are adequate to evaluate the quality of urban streams located in regions where residential and commercial activities are predominant.

The WQI used in this study is the same used by public institutions that monitor and classify water bodies in Brazil, such as ANA (National Water Agency) and CETESB (Environmental Company of the State of São Paulo), which justifies the use of the nine parameters in this study.

MATERIALS AND METHODS

Study Area

The *Arroio Dilúvio* has an extension of 17,605 km and important tributaries streams, such as *Mato Grosso, Moinho, Cascata* and *Águas Mortas*. Its watershed has 83,74 km², in which 446 thousand people inhabit, representing about one third of the total population of the municipality of Porto Alegre.

The intense growth of the Metropolitan Region of Porto Alegre has brought as a consequence a strong population pressure in its urban centers. Currently in Porto Alegre and Viamão, significant portions of the total population (approximately 20%) are residents of irregular occupations, that is, they inhabit informal areas (precarious villages and slums). From spring of the *Arroio Dilúvio,* as well as along its extension, the presence of these irregular occupation is identified (MOG et al., 2014).

In this study, we analyzed data obtained from samples taken from four sites along the *Arroio Dilúvio* . All the sites are located near to residential and commercial buildings. No agricultural or industrial activities are developed in those areas.

The urban occupation is more dense, continuous and organized between sites 39 and D6A. Upstream from site D6A, the urban space is more fragmented due to the existence of large urban equipment, such as the *Bourbon Ipiranga* mall, university campus of PUC/ RS (*Pontificia Universidade Católica*), large uncovered garage of a bus company and other extensive pavilions. In this stretch is most evident the artificiality around the stream, represented by the rare afforestation and no square or park. These lack of continuity of urban tissues at this area leads to the existence of large irregular occupations in surrounding neighborhoods, which becomes more frequent if compared to its presence in the downstream passage. The regions upstream from site D1 are characterized by a rarefied urban occupation and the stream is integrated to the forest at the base of a hill, which gives rise to the recurrent presence of irregular occupations (slums/ poor villages) (MOG et al., 2014).

The four sites were chosen because they had a bigger amount of available data and they are approximately equally spaced. Those four sites are near areas with different urban features along the stream, which gives a good representation of the urban characteristics that compose the surrounding area.

The location of each site, represented in figure 1, is described as follows:

D1 – Next to the Agronomy School of Federal University of Rio Grande do Sul. 150m upstream from *Beco dos Marianos* Street (entrance of precarious villages located on the slope of a hill);

D6A – Upstream from *Cristiano Fischer* Street;

D9B - Downstream from a large supermarket (*Zaffari* supermarket). Next to *Santa Cecilia* Street;

39 – Estuary of the *Arroio Dilúvio,* downstream from *Borges de Medeiros* Avenue.

Data collection

The data used in this study were provided by the Municipal Department of Water and Sewage (DMAE).

These data represent the concentrations of each parameter for each sample collected. In total, 106 samples were chosen, seventeen from site 39, twenty-nine from site D1, twenty-seven from site D6A and thirty-three from site D9B. All these samples were collected within a period from 2002 to 2012 and each sample comprises the value from each of the nine parameters. The collection of samples and their respective analysis methodologies followed the indications of the Standard Methods for Examination of Water and Wastewater (RICE; BAIRD; EATON, 2017).

WQI CALCULUS

The WQI adapted by the Environmental Company of the State of São Paulo (CETESB) was the index used in this study. This WQI is calculated from the weighted multiplication of the nine selected parameters, according to Eqs.1 and 2.

Equation 1 - WQI calculation

$$IQA = \prod_{i=1}^{n} (qi)^{wi} \qquad (1)$$

Where: WQI - Water Quality Index, a number between 0 and 100;

qi - quality of the i-th parameter, a number between 0 and 100, obtained from the respective "average curve of quality variation". It varies according to the concentration of the parameter;

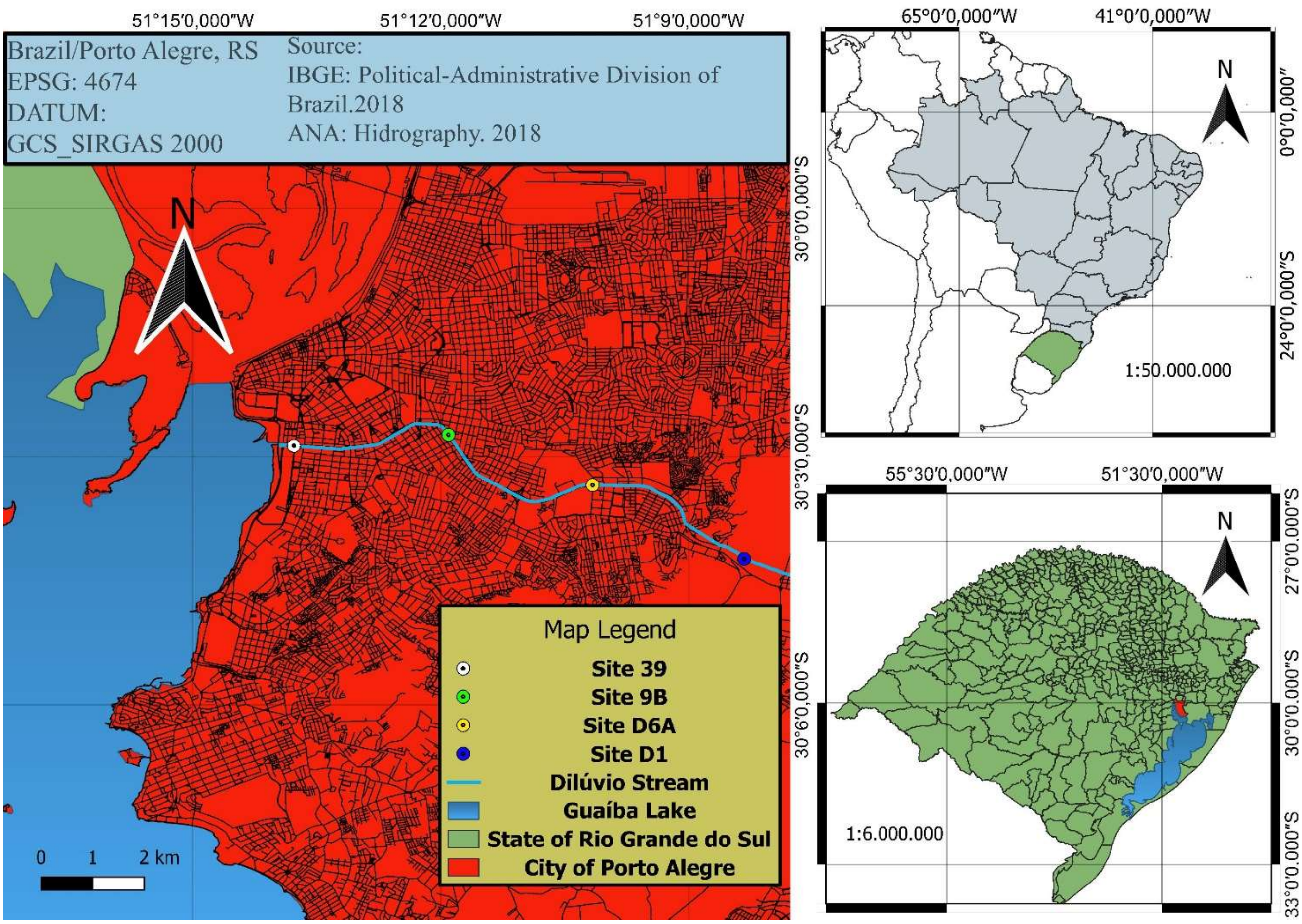
wi - weight corresponding to the i-th parameter, a number between 0 and 1, assigned according to its importance for the water quality.

n - number of variables included in the WQI calculation.

Equation 2 - Sum of weights of each parameter

$$\sum_{i=1}^{n} wi = 1 \qquad (2)$$

Figure 1 - Location of the evaluated sites



The calculus allows to determine the quality of raw waters, which is indicated by the WQI in a scale from 0 to 100, represented in table 2.

Table 1 shows the monitored parameters, their respective units and relative weights.

Table 1- WQI parameters and weights

Parameters	Weight (w)
Dissolved oxygen (mg O_2 /L)	0,17
Escherichia Coli (NMP.100m /L)	0,15
Hydrogenionic potential - pH	0,12
Biochemical oxygen demand - $BOD_{5,20}$ (mg O_2 /L)	0,1
Water temperature (°C)	0,1
Total nitrogen (mg N/L)	0,1
Total phosphorus (mg P/L)	0,1
Turbidity (NTU)	0,08
Total solids (mg/L)	0,08

In the case of this study, the location is within the state of Rio Grande do Sul and, therefore, the classification is according to the first column of table 2.

Table 2- WQI classification by Brazilian states

WQI ranges used in the following states: AL, MG, MT, PR, RJ, RN, RS	WQI ranges used in the following states: BA, CE, ES, GO, MS, PB, PE, SP	Water quality
91-100	80-100	Very high
71-90	52-79	High
51-70	37-51	Moderate
26-50	20-36	Low
0-25	0-19	Very low

(Source: ANA, 2005)

SCORE CALCULUS FOR EACH PARAMETER

The value corresponding to the quality of each parameter is represented by a score that can be obtained by graphs, in which the ordinates axis is the individual quality of the parameter (measured from 0 to 100) and the abscissas axis represents its concentration.

In this study, equations that represent the variation on those graphs were used with a view to facilitate the achievement of their score. Each equation, shown in table 3, was tested and compared with its respective graph and the results were consistent, justifying their use (IGAM, 2004).

Table 3 – Equations of the score from the nine parameters

Parameter	Equation
Escherichia Coli	
Ecoli >105 NMP/100mL	q1=98,24-34,71× log(EC) +2,61× log(EC) 2+ 0,11× log(EC) 3
Ecoli >105 NMP/100mL	q1=3
pH	
pH ≤2	q2=2
2<pH ≤6,9	$q2=-37,1+41,9\times pH-15,7\times pH^{2}+2,4\times pH^{3}-0,09\times pH^{4}$

Table 3 – Equations of the score from the nine parameters

Parameter	Equation
6,9<pH ≤7,1	$q2=-4,7-21,46\times pH-68,47\times pH^2+21,64\times pH^3-1,59\times pH^4$
7,1<pH ≤12	$q2=-7698,2+3262\times pH-499,5\times pH^2+33,15\times pH^3-0,8\times pH^4$
pH >12	$q2=3$
BOD_5	
BOD_5 ≤30	$q3=100,96-10,71\times DBO_5+0,5\times DBO_5{}^2-0,01\times DBO_5{}^3+10^{-4}\times DBO_5{}^4$
BOD_5 >30	$q3=2$
Total nitrogen	
TN ≤10 mg/L	$q4=5,1\times TN+100,2$
10<TN ≤60 mg/L	$q4=-22,853\times \ln(TN)+101,2$
60<TN ≤90 mg/L	$q4=10^{10}\times(TN)^{5,11}$
TN >90 mg/L	$q4=1$
Total phosphorus	
TP ≤10 mg/L	$q5=79,7\times(TP+0,821)^{-1,15}$
TP>10 mg/L	$q5=5$
Turbidity	
TU≤100	$q6=90,37\times e^{-0,02\times TU}-1,5\times \cos(0,057\times(TU-30))+10,22\times e^{-0,231\times TU}-0,8$
TU>100	$q6=5$
Total solids	
TS≤500	$q7=133,17\times e^{-0,003\times TS}-53,2\times e^{-0,014\times TS}+((-6,2\times e^{-0,0046\times TS})\times \sin(0,0146\times TS)$
TS>500	$q7=30$
Dissolved oxygen	
%DO	$\%DO=(\frac{DO}{Sc})\times 100$
Sc (mg/L)	$Sc=14,62\times e^{-0,021\times T}-0,39\times T+0,007\times T^2-5,9\times 10^{-5}\times T^3$
DO%≤100	$q8=100\times(\sin y1)^2-((2,5\times \sin(y2)-0,018\times DO+6,86)\times \sin(y3))+\frac{12}{e^{y4}+e^{y5}}$
	$y1=0,01396\times DO+0,083$
	$y2=\frac{\pi}{56}\times(DO-27)$
	$y3=\frac{\pi}{85}\times(do-15)$

Table 3 – Equations of the score from the nine parameters

Parameter	Equation
	$y4=\frac{(DO-65)}{10}$
	$y4=\frac{(65-DO)}{10}$
100<DO%≤140	$q8=-0{,}0078\times(DO)^2+1{,}278\times DO+49{,}88$
DO%>140	$q8=47$

Ecoli: Escherichia Coli; TN: Total nitrogen; TP: Total phosphorus; TU: Turbidity; TS: Total solids; %DO: Dissolved oxygen percentage; BOD5: Biochemical Oxygen Demand; Sc: Saturation concentration.

(Source: IGAM, 2004)

CONAMA 357

The resolution 357, established by the National Environmental Council (CONAMA), classifies the quality of each parameter individually, according to its concentration levels, and consequently establishes the permitted water uses for each class.

Classes are divided as follows: Class special (best), class 1, class 2, class 3 and class 4 (worst). Class 3 represents water resources that can be destinated to: supply for human consumption after conventional or advanced treatment; irrigation of tree, cereal and forage crops; amateur fishing; secondary contact recreation and animal dewatering. Class 4 represents waterbodies that can be destinated to: navigation and landscape harmony (CONAMA, 2005).

STATISTICAL ANALYSES

Descriptive statistics were applied for the WQI and the nine parameters. These statistics include: mean, standard deviation, minimum and maximum.

Some statistic correlation structures were used for each parameter in order to establish the correlation between parameter concentration and time. Therefore, we used the Bayesian information criterion (BIC) that compared Gaussian, exponential, first-order autoregressive and rational quadratic correlation structures and defined the most appropriate for each parameter. Due to the asymmetry and outliers in some data of some of the parameters, these were worked through logarithmic transformation, i.e.: Turbidity (UNT), *Escherichia Coli* (NMP/100mL), Total Phosphorus (mgP/L), Total Solids (mg/L) and BOD5 (mg O2/L).

The analysis on the variations in the data obtained from each parameter and the WQI were made from a linear model adjusted by the generalized least squares method.

This model allowed to make three verifications: occurrence of significant difference between sites regarding parameter variation over time; significant variation in parameter concentration over time in each site separately; significant difference between the sites regarding the parameter's average concentration.

In order to facilitate the comprehension of the readers, the above-mentioned verifications received denominations. Therefore, following the order in which these verifications were presented in the previous paragraph, these are referred to as "Site: Day", "Day" and "Site".

Each verification is based on the hypothesis test, in which the initial hypothesis of each verification denies the occurrence of significant variation/difference between sites and/or over time.

In this analysis the inferential statistic used is X^2 (chi-square) and the significance level of the test is 5% (α=5%), that is, the null hypothesis will be rejected if the p-value is lower than 5%.

When the null hypothesis is rejected, it is used the multiple comparison table to specify which sites differ from each other and how much they differ regarding the concentration levels of the parameter.

RESULTS AND DISCUSSIONS

The descriptive statistics of WQI and nine parameters for each site are presented in table 4.1 and 4.2.

Table 4.1 – Descriptive statistics in sites 39 and D1

Parameter	Statistic	Sites	
		39	D1
WTEMP (ºC)	Avg (Sd)	19,12 ± 4,20	18,14 ± 3,63
	Min; Max	12,00; 25,50	11,50; 25,00
pH	Avg (Sd)	7,34 ± 0,11	7,32 ± 0,13
	Min; Max	7,20; 7,60	7,00; 7,50
Turb (NTU)	Avg (Sd)	17,80 ± 19,42	11,41 ± 6,55
	Min; Max	3,80; 90,00	2,40; 39,00
DO (mg O_2/L)	Avg (Sd)	3,31 ± 2,49	4,40 ± 1,48
	Min; Max	0,30; 7,90	1,60; 7,70
BOD_5 (mg O_2/L)	Avg (Sd)	20,30 ± 14,83	13,49 ± 9,71
	Min; Max	6,00; 56,00	2,40; 42,10
TN (mg N/L)	Avg (Sd)	11,77 ± 3,97	11,99 ± 4,31
	Min; Max	7,52; 21,40	3,68; 19,20
TS (mg/L)	Avg (Sd)	224,29 ± 65,25	235,38 ± 71,14
	Min; Max	119,00; 436,00	111,00; 480,00
TP (mgP/L)	Avg (Sd)	1,50 ± 1,16	1,04 ± 0,74
	Min; Max	0,55; 5,16	0,06; 3,74
Ecoli (NMP/100mL)	Avg (Sd)	211.941,18 ± 187.530,15	73.034,48 ± 69.491,77
	Min; Max	32.000,00; 820.000,00	11.000,00; 350.000,00
WQI	Avg (Sd)	29,82 ± 8,58	36,50 ± 7,09
	Min; Max	16,81; 40,55	21,29; 51,54

WTEMP: Water temperature; ph:Potential Hydrogenionic; Ecoli: *Escherichia Coli*; TN: Total nitrogen; TP: Total phosphorus; TU: Turbidity; TS: Total solids; Dissolved Oxygen; Biochemical Oxygen Demand; WQI: Water Quaity Index; Avg: Average; sd: Standard deviation.

(Source: Created by the authors)

Table 4.2 – Descriptive statistics in sites D6A and D9B

Parameter	Statistic	Sites D6A	Sites D9B
WTEMP (ºC)	Avg (Sd)	19,31 ± 4,52	19,56 ± 4,03
	Min; Max	12,00; 28,00	11,50; 27,00
pH	Avg (Sd)	7,58 ± 0,14	7,51 ± 0,10
	Min; Max	7,40; 8,00	7,30; 7,80
Turb (NTU)	Avg (Sd)	10,84 ± 3,37	12,71 ± 6,60
	Min; Max	2,10; 18,70	2,09; 28,00
DO (mg O_2/L)	Avg (Sd)	6,09 ± 1,75	5,45 ± 1,75
	Min; Max	2,20; 9,70	1,90; 9,40
BOD_5 (mg O_2/L)	Avg (Sd)	20,98 ± 23,70	25,60 ± 16,10
	Min; Max	6,00; 120,00	4,40; 59,00
TN (mg N/L)	Avg (Sd)	14,38 ± 5,10	14,68 ± 4,17
	Min; Max	3,79; 24,24	7,17; 21,72
TS (mg/L)	Avg (Sd)	240,04 ± 76,44	254,82 ± 45,63
	Min; Max	137,00; 567,00	193,00; 424,00
TP (mgP/L)	Avg (Sd)	1,52 ± 1,45	1,76 ± 1,10
	Min; Max	0,32; 8,25	0,30; 5,11
Ecoli (NMP/100mL)	Avg (Sd)	407.037,04 ± 268.726,55	517.133,33 ± 430.531,82
	Min; Max	120.000,00; 1.400.000,00	1.400,00; 2.000.000,00
WQI	Avg (Sd)	35,26 ± 5,42	32,31 ± 7,28
	Min; Max	26,80; 45,50	20,25; 46,56

WTEMP: Water temperature; ph: Potential Hydrogenionic; Ecoli: *Escherichia Coli*; TN: Total nitrogen; TP: Total phosphorus; TU: Turbidity; TS: Total solids;DO: Dissolved Oxygen; BOD: Biochemical Oxygen Demand; WQI: Water Quality Index; Avg: Average; sd: Standard deviation.

(Source: Created by the authors)

The results of linear model verifications are in table 5. These verifications were made for the nine parameters, but only the parameters in which significant variations/differences were identified, is shown, that is, those parameters in which the p-value is lower than 0.05.

Table 5 – Linear model verification

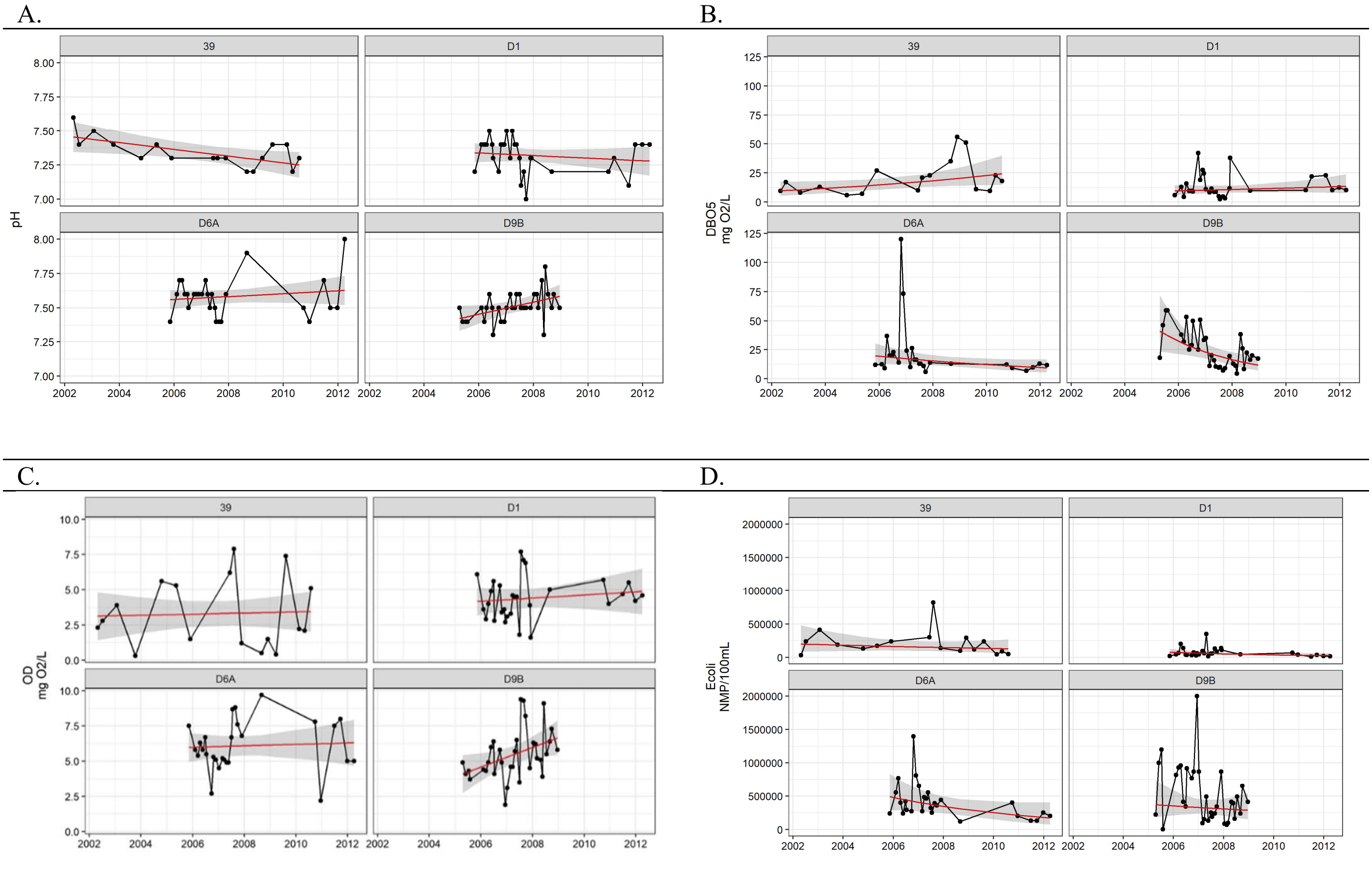
Parameter	Verification	D.F	Statistic χ^2	p-Value	Correlation Matrix
pH	Site	3	83,94	0,0000	Rational quadratic
	Day	1	5,69	0,0170	
	Site : Day	3	11,08	0,0113	
DO (mg O_2/L)	Site	3	30,66	0,0000	Exponential
	Day	1	0,06	0,8035	
	Site : Day	3	3,94	0,2676	
BOD_5 (mg O_2/L)	Site	3	9,25	0,0262	Exponential
	Day	1	4,04	0,0446	
	Site : Day	3	14,99	0,0018	
Ecoli (NMP/100mL)	Site	3	67,91	0,0000	Exponential
	Day	1	0,43	0,5144	
	Site : Day	3	1,22	0,7484	
WQI	Site	3	10,27	0,0164	Exponential
	Day	1	0,64	0,4255	
	Site : Day	3	5,78	0,1228	

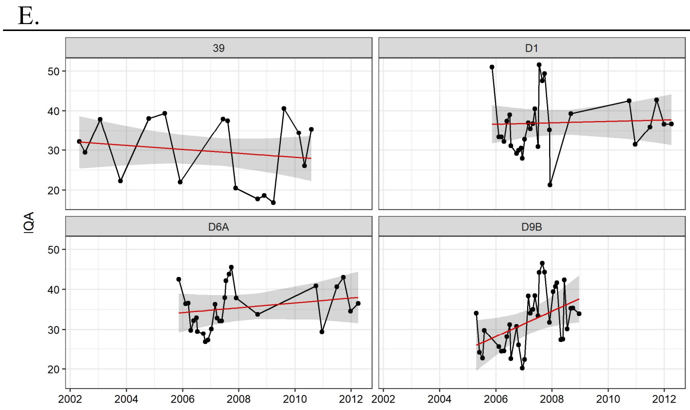
ph: Potential Hydrogenionic; DO: Dissolved Oxygen; BOD: Biochemical Oxygen Demand; Ecoli: *Escherichia Coli*; WQI: Water Quality Index.

(Source: Created by the authors)

Figure 2 contains the graphs that indicate variations over time for the parameters shown in table 5.

Figure 2 – Variation of the concentration of the parameters during the analyzed period





A. Graphic on pH concentration over time in each site
B. Graphic on BOD_5 concentration over time in each site
C. Graphic on DO concentration over time in each site
D. Graphic on Ecoli concentration over time in each site
E. Graphic on WQI score over time in each site

(Source: Created by the authors)

Table 6 shows comparisons between the means of each site.

Table 6 – Multiple comparison tables

A. -→DBO 2006

	39	D1	D6A	D9B
39	[15.04]	0.5327	1.000	**0.0371**
D1	1.541	[9.76]	0.1192	**0.0005**
D6A	0.795	0.516	[18.91]	0.5891
D9B	0.504	0.327	0.634	[29.82]

B. -→DBO 2007

	39	D1	D6A	D9B
39	[16.7]	0.1771	1.000	1.000
D1	1.628	[10.3]	0.1842	**0.0043**
D6A	0.992	0.610	[16.9]	1.000
D9B	0.781	0.480	0.787	[21.4]

C. -→DBO 2008

	39	D1	D6A	D9B
39	[18.6]	0.0884	1.000	1.000
D1	1.718	[10.9]	0.6169	0.7871
D6A	1.238	0.720	[15.1]	1.000
D9B	1.209	0.704	0.977	[15.4]

D. -→DBO 2009

	39	D1	D6A	D9B
39	[20.8]	0.1018	0.4796	0.4211
D1	1.814	[11.4]	1.000	1.000
D6A	1.544	0.851	[13.4]	1.000
D9B	1.873	1.032	1.213	[11.1]

E. →DO

	39	D1	D6A	D9B
39	[3.33]	0.4324	**<.0001**	**0.0003**
D1	-1.028	[4.36]	**0.0048**	**0.0370**
D6A	-2.739	-1.711	[6.07]	1.000
D9B	-2.365	-1.336	0.374	[5.70]

F. →Ecoli

	39	D1	D6A	D9B
39	[149854]	0.0075	0.0195	0.0749
D1	2.669	[56145]	<.0001	<.0001
D6A	0.406	0.152	[369161]	1.000
D9B	0.476	0.178	1.173	[314585]

G. → WQI

	39	D1	D6A	D9B
39	[29.4]	0.0173	0.1271	0.6919
D1	-7.47	[36.9]	10.000	0.7637
D6A	-5.74	1.73	[35.2]	1.000
D9B	-3.84	3.63	1.90	[33.3]

A. Mutliple comparison for BOD_5 in 2006
B. Mutliple comparison for BOD_5 in 2007
C. Mutliple comparison for BOD_5 in 2008
D. Mutliple comparison for BOD_5 in 2009
E. Mutliple comparison for DO
F. Mutliple comparison for *Escherichia Coli*
G. Mutliple comparison for WQI

(Source: Created by the authors)

HYDROGENIONIC POTENTIAL

According to the analysis in the linear model, it was possible to estimate that: the pH at the site 39 reduces, on average, 0.05 units (p = 0.019) every 2 years; the pH at the site D9B increases, on average, 0.09 units (p = 0.035); the variation over time of this parameter was not considered significant in sites D1 (p=0.417) and D6A (p=0.359).

Silva and Lourenço (2016) did similar analysis. The stream studied by these authors also flows through urbanized areas in most of its route and is surrounded by forested areas in its initial stretch (source). The both streams do not pass through industrial zones, which may explain the stability in pH levels. This also indicates that the *Arroio Dilúvio* is not influenced by acidic soils, since it is a watercourse that has undergone interventions throughout its history and has been artificialized in most of its course.

Despite the variations and differences detected, the pH values in absolute terms do not significantly affect water quality, since all pH data were within the quality standard required by CONAMA Resolution 357/05, i.e., between 6.0 and 9.0.

BIOCHEMICAL OXYGEN DEMAND

The verification "Site: Day" presented a p-value lower than 0.05 (p=0.0118), the comparison between the means over time and between sites was made using samples collected within a common period to all sites. Table of multiple comparisons was made for each year in which samples were collected in the four sites, i.e., from 2006 to 2009. We emphasized that BOD_5 was one of the variables in which logarithmic transformation was used. Therefore, the lower triangle (below the main diagonal) in multiple comparison tables represents the relative measure between the site represented in column and the site represented in the row (how many times the concentration of the parameter in the column's site is greater/lower than the row's site). The top triangle (above the main diagonal) shows the p-value of the comparison between the row's site and the column's site. The main diagonal of the table shows the values of the average concentration of the parameter at each site.

Table 6A shows that in 2006 there were progressive increases in BOD_5 in the downstream direction (from site D1 to site D9B) and a significant reduction from site D9B to site 39. In table 6D, in 2009, BOD_5 levels remained similar from site D1 to site D9B, while from site D9B to site 39 there was a significant increase.

It is estimated that every 2 years, the BOD_5 mg O_2/L of site 39 increases, on average, 24.0% (p = 0.0473). It is also estimated that every 2 years, the BOD_5 values of site D9B reduce, on average, 48.3% (p = 0.0082). The BOD_5 levels for site 39 showed an increase trend during the analyzed period, indicating growth in the intake of organic matter at that location and/or in the region just upstream. This intake can be explained by the fact that site 39 is located at the end of *Arroio Dilúvio* , which is near to the most densely populated area when compared to the most upstream stretches. A possible explanation for this worsening is the drag of sediment from the surface of streets, sidewalks and squares during and after rainfall events. However, this cannot be stated categorically because the correlation between rainfall and concentration of parameters was not considered in the present study. Since the region surrounding the site 39 is already well urbanized, the possibilities of irregular urban growth are limited. This leads us to deduce the implausibility of the existence of new irregular occupations that have not connected their domestic sewage in the public sewage collection system. Site D9B had the expected behavior, obeying the inverse relationship between BOD_5 and OD, that is, the decrease in BOD_5 follows the increase in dissolved oxygen. This decrease can be explained by the implementation of pipes that conducts separately the rainwater sewage from domestic sewage in the São Vicente channel, one of the contributory streams to the *Arroio Dilúvio* that discharges its water in the vicinity of site D9B (DMAE, 2009).

No significant changes were detected on the concentration over time for BOD_5 in sites D1 ($p = 0.399$) and D6A ($p = 0.0717$). Site D1 presented the lowest averages of the BOD_5 parameter, probably because it is located upstream from where the most intensely urbanized region of Porto Alegre begins. Even so, the levels presented indicate a significant presence of organic matter, which can be associated with irregular occupations that discharges domestic sewage near this site. Similarly, this association is also found by Silva and Lourenço (2016) in their studies, where it was observed the increase of BOD_5 concentration due to discharge of domestic sewage in invaded areas.

Morandi and Faria (2002) found a higher intake of pollutant loads and decreased self-purification capacity in the final stretch of the stream, and BOD_5 levels increased continuously from upstream to downstream. In addition, the mean found in the study of these authors for site 39 was significantly higher than the average obtained from the present study for the same site, which may indicate a decrease in the release of organic pollutants in the *Arroio Dilúvio* over time.

Only 6 samples indicated BOD_5 between classes 1 and 2 of CONAMA Resolution No. 357/05. The rest of the samples were classified between classes 3 (24%) and 4 (71%).

Dalmas et al. (2015) assessed the water quality of a river located in a watershed of the metropolitan region of São Paulo state, Brazil. The study area was characterized as rural, since the predominant land use and occupation are forests and reforestation areas. However, some of the sites evaluated are located in areas of urban occupations, in which higher levels of BOD_5 were found when compared to samples where urbanization was not present. The authors affirms that this difference exists due to domestic sewage discharges.

Ramos et al. (2016) also assessed the water quality of two rivers located in the state of São Paulo, Brazil, which suffers a strong anthropogenic influence (domestic effluents, petrochemical industry, oil refineries and areas of agriculture and livestock). The authors found abrupt changes in BOD_5 levels during rainy periods in one of the rivers that crosses areas densely populated wherein intense anthropogenic activities occurs, therefore receiving high pollutant loads of organic and inorganic matter.

Most of the samples (71%) were within class 4, according to CONAMA 357.

DISSOLVED OXYGEN

In table 6E, on the main diagonal are the mean concentration of DO (mg O_2/L) in each site (on average site 39 had dissolved oxygen of 3.33 mg O_2/L). In the lower triangle (below the main diagonal) is shown the difference between the mean concentration of each site (the difference between the mean concentration from site 39 and site D1 is 1.028). In the upper triangle (above the main diagonal) we have the p-value of the comparison between the column’s site and the row’s site.

Significant differences in DO mean concentration were detected between most of the sites, except between sites D6A and D9B ($p=1.0$), sites D1 and 39 ($p=0.4324$). Sites 39 and D1, which are located at the ends of the analyzed stretch this study, had the mean concentration levels lower than the intermediate sites D6A and D9B. This can be explained because these intermediate sites are located just downstream from steps that generate a sudden drop of water (cascade), which can contribute to reoxygenation. Silva and Lourenço (2016) also observed this correlation in their studies, confirming the contribution that these devices have in the reoxygenation of water.

Site D1 is located in a region where exists irregular occupations and without the necessary infrastructure for cloacal sewage collection. Thus, it is assumed that intake of organic matter from domestic sewage was significant in the vicinity of this site, which could contribute to the consumption of dissolved oxygen in water, therefore decreasing its levels.

Although site 39 was not located in a region of irregular occupations, it also showed reduced dissolved oxygen levels. This may characterize the presence of sources of organic matter pollution in the region. Another explanation would be the accumulation of pollution of the stream itself from the upstream sections, since this site is close to the estuary.

Site D9B showed an improvement in its dissolved oxygen levels within the analyzed period (2005 to 2008). This change can be explained by the implementation of sewage connections in the absolute separator system in the São Vicente channel (DMAE, 2009).

Morandi and Faria (2002) also found a tendency to reduce the DO levels along the stream and stated that the reduction can be attributed to lower slope in its final stretch, which causes stagnation of the flow and, therefore, difficulty in reoxygenation of water. In addition, the authors highlighted that this reduction was also caused by concentrated domestic sewage loads that were released upstream, since by that time new sewage collection system were connected to the existing rainwater drainage system.

The studies carried out by Morandi and Faria (2002) and the present study converge by indicating that DO levels are reduced from the initial stretch (site D1 to site D9B) to the final site (site 39).

ESCHERICHIA COLI

The *Escherichia Coli* parameter showed significant differences between some sites, i.e.: 39 and D6A; 39 and D1; D6A and D1; D9B and D1. According to table 6F, no significant differences were found between D6A and D9B ($p=1.0$). The same occurs between D9B and 39 ($p=0.0749$).

The *Escherichia Coli* parameter had higher mean concentration in the intermediate sites (D9B and D6A had higher values compared to sites 39 and D1). The concentration levels found in site D1 can be explained by the discharge of domestic sewage, as there are irregular occupations nearby (e.g., slums, poor villages).

As it advances downstream from site D1 to site D6A, the mean of the concentration levels increases approximately six times. The concentration levels of this parameter remain approximately the same in site D9B. Such variation levels may indicate a strong intake of domestic sewage, since the stream starts to receive more water by entering in a more urbanized stretch. Diffuse pollution should also be taken into account, which is related to the drag of organic sediments/particles from streets, parks and sidewalks into the stream. In site 39, the concentration levels are approximately halved compared to the previous sites, indicating a significant improvement in the intake of organic matter of fecal origin.

In site D9B, there is a slight decrease in *Escherichia Coli* levels over time. Even though the statistical analyses indicated a slight decrease tendency over time, when observing figure 2D, the levels of *Escherichia Coli* oscillate between very high and very low values around the average (high value of standard deviation). Thus, it cannot be affirmed with certainty that this decrease is due to implantations of sewage collector pipes in the São Vicente channel (DMAE, 2009).

Morandi and Faria (2002) also found similar behavior in the variation of this parameter concentration levels between site D1 and site D6A. However, the levels found by the authors in the same four sites were significantly higher than those found in the present study, indicating the generalized improvement in the release of fecal matter. This over time improvement is probably associated with the implementation and expansion of public sewage collector pipes in the overall region where the *Arroio Dilúvio* is situated (DMAE, 2010).

Ramos et al. (2016) also found in their study a correlation between slight sanitary improvements and decrease of *Escherichia Coli* concentrations in some of the analyzed periods.

However, even with the higher percentage of sewage collector pipes in the study area when compared to other regions of Porto Alegre, there are still high levels of domestic sewage pollution. One of the possible causes for the persistence of this pollution may be related to a mismatch between the most recent urban occupation and lack of monitoring of residential sewage connections with the public sewage collector system. Several residences of *Arroio Dilúvio* basin, especially in upstream regions, due to lack of technical information and/or cultural problems, have not yet connected their domestic sewage to the public sewage system, keeping their effluents conducted to rainwater collector pipes that flow directly to the *Arroio Dilúvio* (DMAE, 2010).

Silva e Lourenço (2016) found higher levels of *Escherichia Coli* at the site located downstream the most urbanized areas of their studied basin. The authors state that lack of basic sanitation in urban areas and deliberated discharge of domestic sewage are the main causes.

Dalmas et al. (2015) also found higher levels of *Escherichia Coli* as a consequence of the intense release of domestic sewage in urbanized areas. Almost all samples (99,06%) were within class 4 of the CONAMA 357 classification. Only one sample fit class 3.

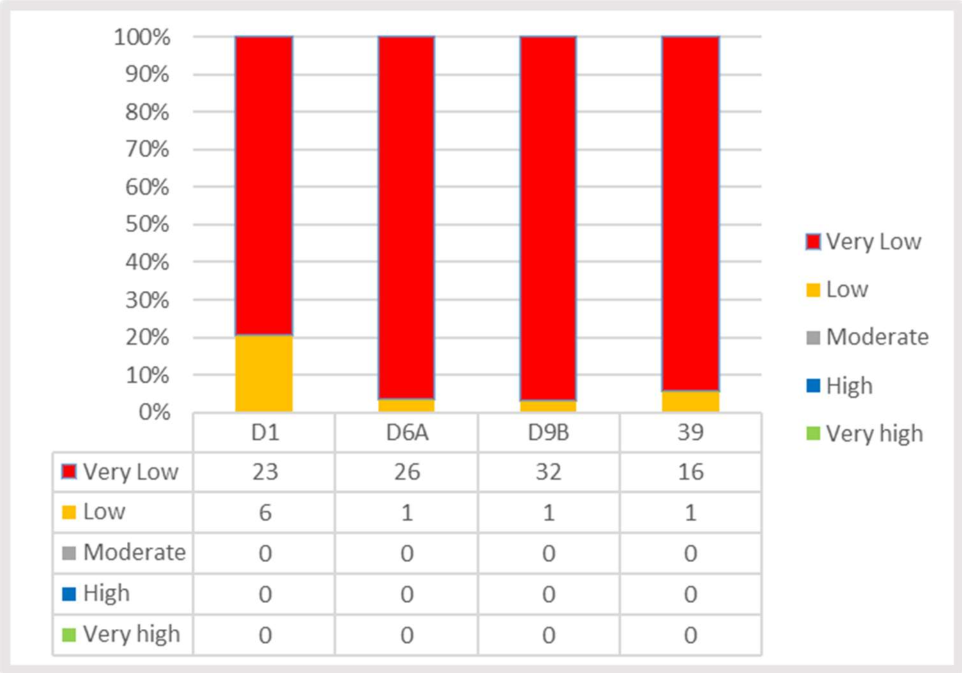
WQI

The water quality indicator showed significant differences between sites D1 and 39, according to table 6G. The rest of the comparisons between sites did not present significant differences.

Figure 2E shows that site D9B had an increase in WQI, showing that the implantation of sewage interceptors in the São Vicente channel, tributary of the *Arroio Dilúvio,* contributed to the improvement of water quality in this location (DMAE, 2009).

The results of the WQI calculations, showed at figure 3, indicate that nine samples indicated water quality of the stream as "Low". The rest presented as a "Very low" level.

Figure 4 – Classification of samples

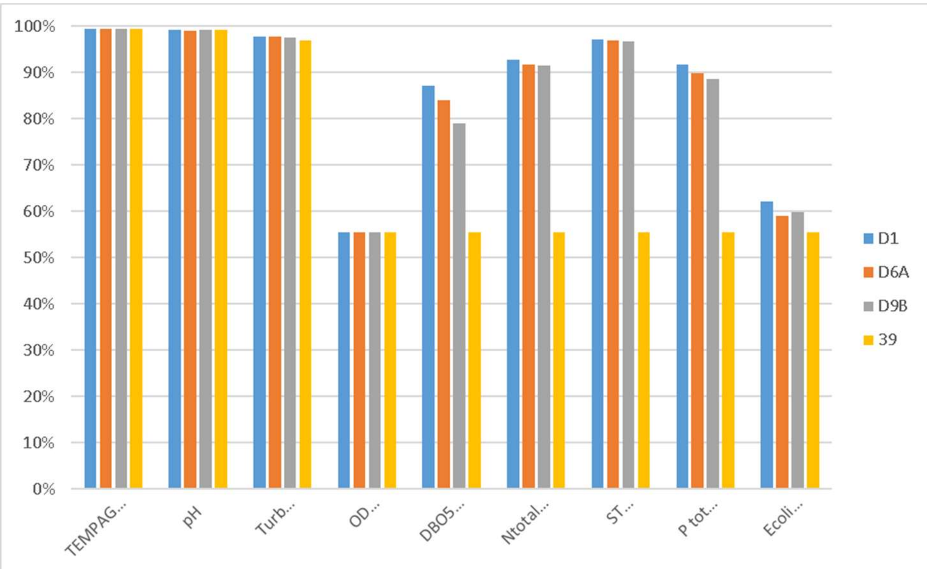


	D1	D6A	D9B	39
Very Low	23	26	32	16
Low	6	1	1	1
Moderate	0	0	0	0
High	0	0	0	0
Very high	0	0	0	0

(Source: Created by the authors)

Figure 4 shows the results of each parameter (qi^w) as a percentage of the maximum value that could be reached in each of the sites, i.e., 100%.

Figure 4 - Average percentage compared to the maximum qi^w possible for each parameter in the four sites



TEMPAG: Water temperature; ph: Potential Hydrogenionic; Turb: Turbidity; OD: Dissolved Oxygen; DBO5: Biochemical Oxygen Demand; Ntotal: Total nitrogen; ST: Total solids; P tot: Total phosphorus; Ecoli: *Escherichia Coli.*

(Source: Created by the authors)

Escherichia Coli, BOD_5 and DO were the parameters that most negatively contributed to WQI score. This reinforces the direct correlation between the release of domestic sewage and the decrease in water quality levels.

Dalmas et al. (2015) used the statistics of Pareto in the same nine parameters and observed that *Escherichia Coli* (approximately 80%), BOD_5 (7,7 %) and DO (4,4%) were the ones that most negatively impacted water quality in their study.

Ramos et al. (2016) found in most of their sampling that *Escherichia Coli* and BOD_5 negatively affected the water quality of their two rivers studied.

Another study made in an urban perimeter located in the northeast of Brazil, found that the river had its water quality index decreased mainly due to release of domestic sewage, especially near the surrounding most urbanized areas (SANTIAGO; DE JESUS, 2016).

Britto et al. (2018) assessed the São Francisco River, located in northeast of Brazil. The low WQI values observed in their study suggested a tendency to degradation of the water quality due to anthropic activities in the rainy and dry periods. Among those activities is the release of urban pollutants from riverside cities, which in most cases do not have proper systems to treat their effluents. The authors reported that this condition is mainly related to high values of the thermotolerant coliform and dissolved oxygen parameters.

The analysis in the study made by Finkler et al. (2018) suggest that parameters strictly related to domestic sewage discharged without proper treatment, among them BOD_5 and *Escherichia Coli*, were the main responsible for variation in water quality of an urban stream located in southern Brazil.

FINAL CONSIDERATIONS

1. This study presented data analysis on the water quality of an urban stream. The study revealed that the evaluated stream contains high levels of contamination related mainly to urban occupation in its surroundings. Parameters that most negatively affected its water quality were BOD_5 and *Escherichia Coli*.
2. The stream studied has the function of receiving rainwater from the watershed where it is

located, thus, we conclude that its water quality was classified at levels below expected (i.e.: Low, Very Low, Class 4).

3. According to the analysis and discussions, we suspect that part of this urbanization remains irregular, discharging domestic sewage without proper treatment. It is important to note that the sewage system is already implemented in most neighborhoods near the *Arroio Dilúvio,* especially in regions further downstream. Therefore, it is deduced that the most likely cause of contamination by organic matter is the lack of connection between the domestic sewage of some households with the existing public sewage system.
4. Finally, we suggest that analysis of more recent samples of the *Arroio Dilúvio* should be made, preferably from the last five years, in order to maintain continuous control of water quality. Special attention should be given to *Escherichia Coli* parameter, that should be considered as a reference in the analysis of water quality indexes of urban streams/springs. Besides, further studies should consider other factors that might influence the water quality of the *Arroio Dilúvio,* such as rainfall events and other parameters. This might help public authorities to make more assertive decisions that match the real situation of the environment in which this stream is inserted.

ACKNOWLEDGEMENTS

To the Municipal Department of Water and Sewage (DMAE), a public institution that contributed to this work by providing the data of physicochemical and microbiological parameters of the evaluated stream.

REFERENCES

ANA. Agência Nacional das Águas. **Panorama da qualidade das águas superficiais no Brasil.** Superintendência de Planejamento de Recursos Hídricos. – Brasília, ANA, SPR, 2005.

BRITTO, F. B.; VASCO, A. N. do; AGUIAR NETTO, A. de O.; GARCIA, C. A. B.; MORAES, G. F. O.; SILVA, M. G. da. Surface water quality assessment of the main tributaries in the lower São Francisco River, Sergipe. **RBRH**, [*s. l.*], v. 23, n. 28, 2018.

CONAMA. Conselho Nacional do Meio Ambiente. **Resolução nº 357, de 17 de março de 2005**. Brasília, CONAMA, 2005

DMAE. Departamento Municipal de Água e Esgoto. **A melhoria da qualidade da água do Arroio Dilúvio (sub-bacia D-11, Porto Alegre/RS) e sua relação com as ligações de esgoto no sistema separador absoluto do DMAE**. Porto Alegre, DMAE, 2009.

____. Departamento Municipal de Água e Esgoto. **Plano diretor de esgotos**. 5. ed. Porto Alegre, DMAE, 2010.

DALMAS, F. B. et al. Reflexos do uso e ocupação do solo na qualidade da água do rio Embu-Guaçu, região metropolitana de São Paulo. **Geociências (São Paulo)**, v. 34, n. 1, p. 130–144, 2015.

FIA, R. et al. Qualidade da água de um ecossistema lótico urbano. **Revista Brasileira de Recursos Hídricos**, v. 20, n. 1, p. 267–275, 2015.

FINKLER, N. R. et al. Water quality monitoring in urban basins as support for water resources management: A case study from southern Brazil. **International Journal of Environmental Impacts: Management, Mitigation and Recovery**, v. 1, n. 3, p. 298–311, 2018.

IGAM. Instituto Mineiro de Gestão das Águas. **Relatório de Monitoramento das águas superficiais na bacia do rio Paraíba do sul em 2003**. Belo Horizonte, IGAM, 2004.

IQBAL, K.; AHMAD, S.; DUTTA, V. Pollution mapping in the urban segment of a tropical river: is water quality index (WQI) enough for a nutrient-polluted river? **Applied Water Science**, v. 9, n. 8, p. 197, 2019.

LEMOS, M. DE; FERREIRA NETO, M.; DIAS, N. DA S. Spatial variability and seasonality of the water quality in the Lagoa do Apodi Lagoon, RN, Brazil. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 14, n. 2, p. 155–164, fev. 2010.

MOG, W.; CAMPOS, H. Á.; PICCININI, L. S. Análise morfológica de espaços urbanos em bacias hidrográficas: um olhar sobre o entorno do Arroio Dilúvio em Porto Alegre. **Cadernos Metrópole**, v. 16, n. 31, p. 221–239, jun. 2014.

MORANDI, I. C.; FARIA, C. M. A difícil recuperação de arroios em áreas urbanas - Arroio Dilúvio - Porto Alegre - RS. In: XXVII Congresso Interamericano de

Engenharia Sanitária e Ambiental, v. 3, n. 6, p. p.7-22, 2002.

ORTEGA, D. J. P.; DE CARVALHO, S. L. Avaliação dos Efeitos das Atividades Antropóficas nos Recursos Hídricos na Sub-Bacia Hidrográfica do Córrego do Ipê — SP. **Revista Brasileira de Recursos Hídricos**, v. 18, p. 12, 2013.

PINHEIRO SILVA, F.; DO SANTOS OLIVEIRA LOURENÇO, E. Avaliação qualitativa e índice de qualidade das águas do Arroio Ouro Verde - Foz do Iguaçu - PR.pdf. **Revista Cultivando o Saber**, v. 9, n. 1, p. p.51-69, 2016.

RAMOS, M. A. G. et al. Water Quality Index (WQI) of Jaguari and Atibaia Rivers in the region of Paulínia, São Paulo, Brazil. **Environmental Monitoring and Assessment**, v. 188, n. 5, p. 263, 2016.

RICE, E.W., BAIRD, R.B., EATON, A.D. **Standard methods for the examination of water and wastewater**. 23rd ed. Washington, DC, 2017.

SANTIAGO, B. E. C.; DE JESUS, T. B. Avaliação da qualidade da água no perímetro urbano de Riachão do Jacuípe, Bahia, Brasil. **Revista Brasileira de Geografia Física**, [*s. l.*], v. 09, n. 4, p. 14, 2016.

SOOD, A. *et al.* Assessment of bacterial indicators and physicochemical parameters to investigate pollution status of Gangetic River system of Uttarakhand (India). **Ecological Indicators**, v. 8, n. 5, p. 709–717, 2008.

SOUZA, M. F. DE *et al.* Monitoramento da qualidade da água de um manancial hídrico sob influência de atividades antrópicas, no município de Pelotas, RS – BRASIL. **Associação Brasileira de Recursos Hídricos**, p. 7, 2013.

WEINGRAT, S.; BICUDO, D.C. Spatial evaluation of water quality in an urban reservoir (Billings Complex, southeastern Brazil). **Acta Limnologica Brasiliensia, Rio Claro**, v.23, n.2, p.200-216, 2011.