MONITORING OF THE URBAN STRETCH OF ARROIO DOS PEREIRAS (BRAZIL): EVALUATION OF PHYSICOCHEMICAL AND BIOLOGICAL PARAMETERS

MONITORAMENTO DO TRECHO URBANO DO ARROIO DOS PEREIRAS (BRASIL): AVALIAÇÃO DOS PARÂMETROS FÍSICO-QUÍMICOS E BIOLÓGICOS

Waldir Nagel Schirmer
Doutor em Engenharia Ambiental pela Universidade Federal de Santa Catarina (UFSC) /// Professor adjunto do Departamento de Engenharia Ambiental da Universidade Estadual do Centro-oeste (UNICENTRO) /// Corresponding author. Email: wanasch@yahoo.com.br

Ludmila Carvalho Neves
Engenheira Ambiental graduada pela Universidade Estadual do Centro-oeste (UNICENTRO)

Victor Hugo Jangada
Engenheiro Ambiental graduado pela Universidade Estadual do Centro-oeste (UNICENTRO)

Larissa Macedo dos Santos
Doutora em Química Analítica pela Universidade Federal de São Carlos (UFSCar) /// Professora adjunta do Departamento de Química da Universidade Tecnológica Federal do Paraná (UTFPR)

Paulo Costa de Oliveira Filho
Doutor em Ciências Florestais pela Universidade Federal do Paraná (UFPR) /// Professor adjunto do Departamento de Engenharia Ambiental da Universidade Estadual do Centro-oeste (UNICENTRO)

Mayara Ananda Gauer
Engenheira Ambiental graduada pela Universidade Estadual do Centro-oeste (UNICENTRO) /// Mestranda em Bioenergia pela Universidade Estadual do Centro-oeste (UNICENTRO) /// Professora auxiliar do Curso de Engenharia Ambiental do Centro Universitário da Cidade de União da Vitória (UNIUV)

ABSTRACT: The levels of pollution in water bodies are directly related to the health and welfare of the population that uses this water with different purposes. Events such as vegetation suppression, different uses (industrial, agricultural and domestic), sewage discharge, are some of the factors that mostly contribute to the depletion of such water resources, mainly in urban areas. The objective of this study was the physicochemical monitoring of the urban stretch Arroio dos Pereiras, located in Irati (Parana State, Brazil), in areas of low and medium human occupation. The relations between superface water quality and the use of urban soil in that region were also verified employing high resolution orbital images. The water quality parameters analyzed included pH, total solids, turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total and fecal coliforms (*E. coli*). The water in Arroio dos Pereiras presented, for most parameters, characteristics which were in accordance with the Brazilian Federal Legislation; however, total and fecal coliforms values were high above limits permitted by law, making the water unsuitable for use. The sewage discharge along the stretch evaluated was the main reason for the low quality of this water.

Keywords: Environmental monitoring; urban occupation; water quality

*RESUMO: Os níveis de poluição dos corpos hídricos estão diretamente relacionados com a saúde e o bem estar da população que se utiliza desta água para diversos fins. Fatores como supressão da vegetação, usos diversos (industrial, agrícola e doméstico), descarte de esgoto, são alguns dos fatores que mais contribuem para a degradação desses sistemas hídricos, principalmente em áreas urbanas. O objetivo deste estudo foi o monitoramento físico-químico do trecho urbano do Arroio dos Pereiras, localizado no município de Irati (PR), em áreas de baixa e média ocupação populacional. Foram também verificadas relações entre a qualidade das águas superficiais e o uso do solo urbano na região do estudo, obtido por imagens orbitais de alta resolução. Os parâmetros de qualidade de água analisados incluíram pH, sólidos totais, turbidez, oxigênio dissolvido (OD), demanda bioquímica de oxigênio (DBO), coliformes totais e fecais (*E.coli*). As águas do Arroio dos Pereiras apresentaram, para a maioria dos parâmetros, características que se enquadram na legislação federal brasileira; entretanto, os valores de coliformes totais e fecais ficaram muito acima dos limites permitidos pela legislação, tornando a água imprópria para uso. Verificou-se que o principal contribuinte para essa má qualidade do corpo hídrico foi o descarte de esgoto doméstico observado ao longo do trecho avaliado.*

Palavras-chave: Monitoramento ambiental; uso e ocupação do solo; qualidade da água

1. INTRODUCTION

Population growth, allied to the use and unplanned occupation of soil and lack of proper basic sanitation conditions, have generated significant impact to the water resources in urban areas along the years. Several authors have frequently reported on the effects of urbanization on the water behavior as well as alterations of the natural characteristics of such systems. Suppression of vegetal cover, home and industrial sewage disposal, contamination through chemical pollutants and pathogenic agents, silting, eutrophication, are some of the elements related to river and lake degradation (Farias, 2006; Mizutori, 2009; Strobl and Robillard, 2008; Terra *et al.*, 2009.).

The fact that most of the Brazilian population live in urban areas has direct implications on the intensification of the use of rivers and water springs around these areas. This demand reflects directly in the reduction of water flow and consequently the increase in the pollutants concentration. According to Cunha, Rosman and Monteiro (2003), if the pollutant release occurs in water bodies with high depuration power such as bays and coastal areas, the risk of contamination is reduced (also because of the high dilution of such pollutants), otherwise, the population exposure to contaminated water is high (in the case of small rivers that cross urban areas).

The degradation of water sources leads to the necessity of monitoring the water quality, in order to measure the anthropogenic action on these systems. According to Sanders *et al.* (1983) cited by Strobl and Robillard (2008), "water quality monitoring refers to the acquisition of qualitative information, which is representative of physical, chemical and biological characteristics of a water body throughout space and time". Cunha, Rosman and Monteiro (2003) claim that "monitoring and pollution control programs in water systems are able to reduce water quality degradation", being necessary to develop "efficient methodologies to better assess the impacts and then act in order to minimize the pollution effects." Therefore, the monitoring of physicochemical parameters of these systems is an essential element in water resources management processes. The resulting data is fundamental in planning and elaboration of mitigating measures regarding pollution control and sustainable management.

The monitoring of water quality involves actions, such as project of the net monitoring (definition of places and frequency of sampling), laboratory analyses (quality control, operational procedures, water quality index, and modeling), treatment and analysis of data to the use of the information gathered (SANDERS *et al.* (1983) cited by STROBL and ROBILLARD (2008)). Regardless the objectives of the monitoring project and the budget, common sense must prevail when choosing places and sampling frequency. The places from where samples are collected, for example, must be representative regarding pollution spots (sewage disposal) found in the water source under study.

Regarding the frequency of sampling, Strobl and Robillard (2008) point out that the higher the variation verified in the water quality parameters, the larger the number of samples needed to determine statistically representative behavior of the system under study. The variables which characterize the water quality may include physical parameters (dissolved oxygen, water temperature, turbidity, total solids), chemical (organic matter, pH, total phosphorous, total and ammonia nitrogen) and biological (total and fecal coliforms presence) (Plummer and Long, 2007; Thornes, 1984). Even if, in practice, it is not possible to determine all the interesting water quality parameters, resources such as modeling and statistics tools can help to obtain information related to the scenario under study (Strobl and Robillard, 2008).

The relations between soil use and water are clearly demonstrated in several other studies such as Freitas (2000) and Gergel *et al.* (2002). According to these authors, the conversion of forest areas, mainly in agricultural or urban areas, has been associated to decrease in its quality.

Within this perspective, this study aims at identifying the main factors which affect water quality in the Arroio dos Pereiras, in Irati (Parana State, Brazil). Arroio dos Pereiras is an affluent of the Antas River and is part of the Tibagi River watershed. The central region of Irati comprises part of the Arroio dos Pereiras catchment and the part near its spring is characterized by agricultural area and growing occupation, with increasing number of buildings and suppression of natural vegetation (Scariot and Maia, 2009). The region nearest to the watershed drainage area is mainly covered in commercial, public and residential buildings, which already justify the environmental diagnosis of occupation of such area.

O texto deste artigo foi submetido para revisão e possível publicação em Janeiro de 2012, tendo sido aceite pela Comissão de Editores Científicos Associados em Abril de 2012. Este artigo é parte integrante da ***Revista Recursos Hídricos***, Vol. 33, Nº 1, 61-73, Maio de 2012.

2. MATERIAL AND METHODS

The study was developed in the Arroio dos Pereiras catchment, located in the urban area of Irati-PR (25º27'56"S, 50º37'51"W) covering an area of 3.5 Km^2 (Vaeza *et al.*, 2010). Arroio dos Pereiras has a estimated population of 4751 inhabitants (within its 3.5 Km^2). According to the classification of bodies of water by the Conselho Nacional de Meio Ambiente – CONAMA (Environmental National Committee) (2005), the Arroio dos Pereiras is classified as Class 3 (may be used, for instance, for human consumption, after traditional or advanced treatment). This study comprised the monitoring of the following physicochemical parameters of the effluent at three different points (Figure 1): pH, total solids (fixed plus dissolved), turbidity, dissolved oxygen (DO), biochemical oxygen demand (BOD), total and fecal coliforms (*E. coli*). Sampling and analysis of the effluents were carried out according to the *Standard Methods for the Examination of Water and Wastewater* (1998). All campaigns were carried out only after a minimum period of 48 hours after the last precipitation.
Table 1 shows the location and coordinates of the three sampling points.

Literature review points out to the non existence of a single methodology to be used in the water quality monitoring project. Besides that, budget (regarding collection and analysis costs, mainly) is many times one of the factors to establish the logistics of the project (Strobl and Robillard, 2008). In this study, the points were chosen due to the urban occupation of the stretch (from the lowest – point 1 – to the highest – point 3) representing strategically the parameter investigations.
Eight campaigns (all in the morning shift) were carried out altogether from May/2010 to March/2011. Collection dates and other relevant information are presented in Table 2. The parameters analyzed, as well as the methods used in laboratory are in Table 3.
For this study, the river was examined throughout the stretch being assessed, aiming at identifying possible causes of pollution (point and diffuse sources), in order to contribute with better results interpretation. Data was related to results of soil use and occupation obtained by Vaeza *et al.* (2010) using high resolution satellite Quickbird II images, through which a detailed map of use and occupation of the Arroio dos Pereiras watershed was obtained (Figure 2).

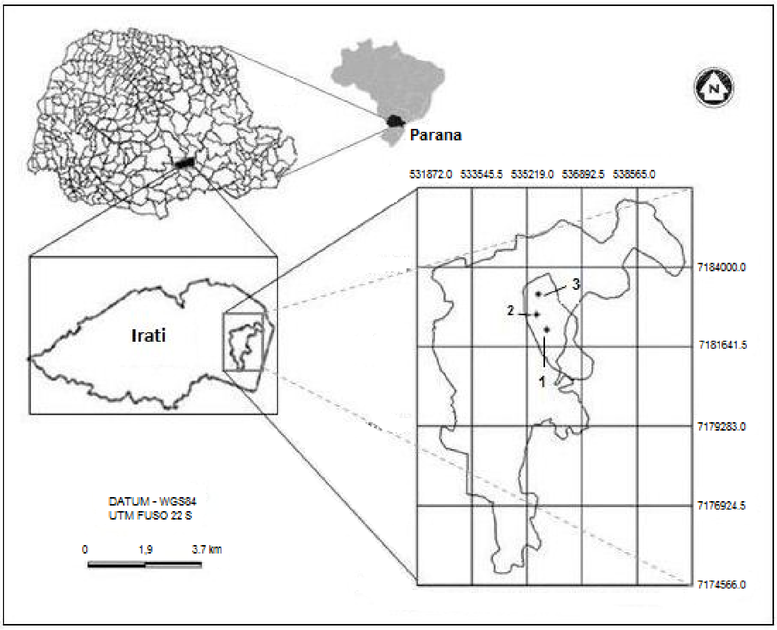

Figure 1 - Location of Arroio dos Pereiras Watershed and points 1, 2 and 3 sampled in the urban stretch of Irati (Paraná, Brazil).

Table 1 - Data regarding the occupation and geographical location of sampling points in the Arroio dos Pereiras.

Point	Location	Coordinate	
		Latitude	Longitude
1	Region with the least urban occupation – beginning of the urban stretch of the river	25°28'40,25'' S	50°38'33,20'' O
2	Central region of the urban stretch	25°28'25,87'' S	50°38'50,48'' O
3	Region with high urban occupation – end of the river stretch*	25°28'05,69'' S	50°38'48,88'' O

** Before joining the Antas River.*

Table 2 - Sampling period in the Arroio dos Pereiras.

Season of the year	Campaign sequence	Date
Fall	1	12/05/2010
Fall	2	09/06/2010
Winter	3	30/06/2010
Winter	4	12/08/2010
Winter	5	15/09/2010
Spring	6	04/11/2010
Summer	7	22/02/2011
Summer	8	16/03/2011

** Before joining the Antas River.*

Table 3 - Parameters analysed and laboratory methods.

Parameter	Unit	Method
BOD_5	$mgO_2.L^{-1}$	Oxymetric
pH	pH Units	Potentiometric
Turbidity	uT[a]	Nefelometric
Total Coliforms	MPN[b]/100mL	Membrane filters
Fecal Coliforms	MPN/100mL	Membrane filters
Total Solids	$mg.L^{-1}$	
Oxigênio Dissolvido	$mgO_2.L^{-1}$	

[a] uT – Turbidiy units
[b] MPN – most probable number of coliforms

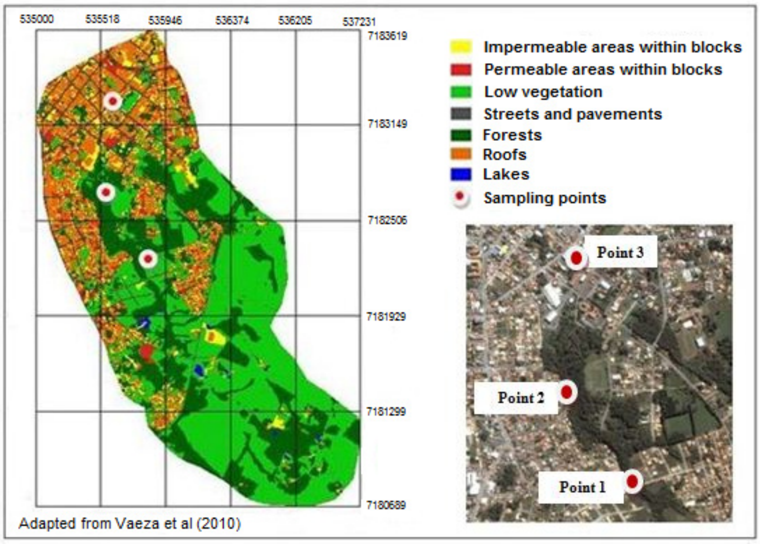

Figure 2 - Detailed use of urban soil at Arroio dos Pereiras watershed and sampling points location.

Source: Adapted from Vaeza et al. (12).

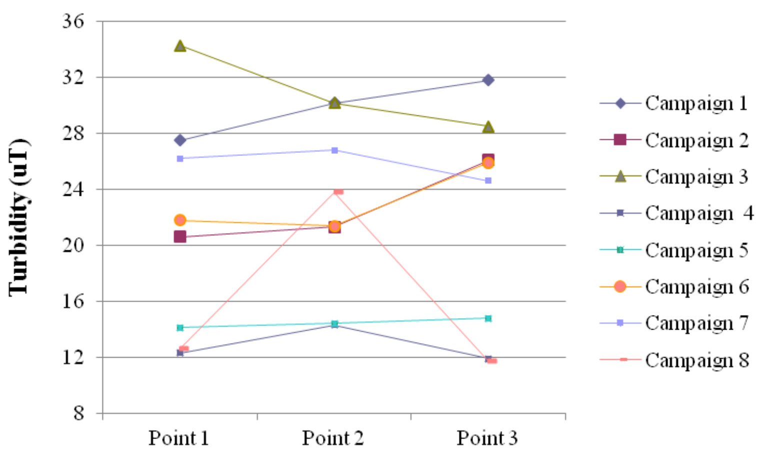

Figure 3 - Turbidity values for the three points of the stretch evaluated (uT).

3. RESULTS AND DISCUSSION

3.1. Turbidity

The turbidity of a water sample is the intensity attenuation degree that a light beam suffers when crossing it due to the presence of suspended solids, such as organic particles, for example algae and bacteria, as well as inorganic particles such as sand and clay (Piveli and Kato, 2005).
Figure 3 presents the turbidity values obtained in laboratory analyses for the three points evaluated (in 8 campaigns). The Act n. 357 from CONAMA (2005) sets limits of turbidity of 40 uT for freshwater class 1 and 100 uT for classes 2 and 3. According to figure 3, turbidity values are under the limit set by law. The graph also shows that there is no correlation between turbidity values and sampling points.
The variation of turbidity values found can be related to several causes, for example, erosion of the river margins, industrial and domestic sewage disposal, inadequate disposal of solid waste, among others (Piveli and Kato, 2005).
Despite the results being within the permitted values, turbidity values determined might be sufficient to cause aesthetic damage to the water body, interfering in water coloration and hampering algae photosynthesis.

3.2. Total solids

Industrial and domestic discharges contribute to this kind of pollution. When in excess in water bodies, they might cause alterations in taste and turbidity, generating aesthetic problems and damaging photosynthetic activity.

The Act n. 357 from CONAMA (2005) establishes 500 mg L^{-1} dissolved total solids as a pattern for maximum emission in freshwater classes 1, 2 and 3. Thus, as shown in figure 4, all the values obtained (for the three points and in all campaigns) are within the law limits (remembering these values comprise fixed plus dissolved solids). Again, no correlation was verified between the total solids values and sampling points.
The values found for total solids can have their causes explained by the erosion in the river margins, leaching of compounds present in the soil, solid residue discharge, industrial and domestic effluents disposal, among others. The total solids show direct relationship with turbidity (because the suspended solids). As the values obtained for total solids are within the law limits, the Arroio dos Pereiras presents no cause or source of concern for significant alteration of such parameter.

3.3. pH

The pH represents the potential of ion hydrogen activity in water (H^+) in a logarithmic form, which initially results from the water molecular dissociation, and then is joined by hydrogen ions coming from other sources such as industrial/domestic effluents. Therefore, it indicates the acidity or alkalinity of a sample (Piveli and Kato, 2005).
The influence of such parameter is of great importance, as at determinate pH bands the precipitation of toxic chemical elements such as heavy metals occurs, and this might also interfere in the nutrients solubility.
The pH bands restrictions are established according to the natural water classes. The Act n. 357 from CONAMA (2005) permits moderate distance from the neutrality values (pH 7.0).

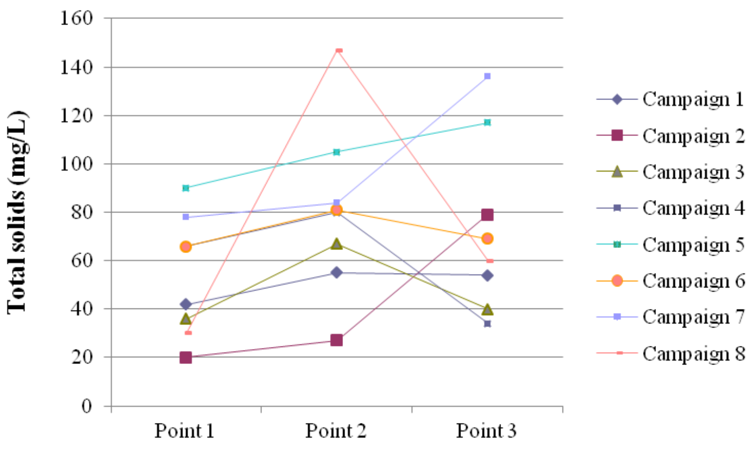

Figure 4 - Total solids values at the three points in the river stretch evaluated (mg L^{-1}).

The results obtained for the parameter pH in Arroio dos Pereiras water, at the three points, during the monitored period are shown in figure 5.
According to the graph, the Arroio dos Pereiras water presented an average of 7.5 for this parameter, with maximum and minimum pH values 7.8 (point 1) and 7.0 (point 2), respectively.
The results found for the parameter pH were similar throughout the monitoring period. There was a little variation regarding collections and sampling points, and the average values were close to the neutrality, according to the recommendation of CONAMA Act 357 (2005).

3.4. Dissolved oxygen

Oxygen present in the atmosphere dissolves in natural water due to the partial pressure difference. The introduction of molecular oxygen in water occurs at the surface level depending on the hydraulic and velocity characteristics, in rivers for example, this reaeration rate is more accentuated (compared to a dam or lake), due to the river speed (and consequent turbulence) (Piveli and Kato, 2005).
Another source of oxygen in water is the algae photosynthesis, however, this source is less significant in streams, and might have lower significance when the water body presents high color and turbidity, preventing the sun rays to pass and allow photosynthesis. Dissolved oxygen is a parameter of extreme relevance in the classification of natural water by the law and also in the use in auto-purification models in water bodies (Piveli and Kato, 2005).
In this study, data obtained in the campaigns are presented in Figure 6.
Points 1 and 2 present similar DO values (average 8.4 and 8.2 mg L^{-1} for all 8 campaigns, respectively). When evaluating the interval between points 1 and 2 (stretch 1-2), sewage discharge from point and diffuse sources was identified, cooperating with the increase in organic matter at this stretch. However, it could be seen that the domestic sewage disposal was not sufficiently high to promote significant oxygen depletion. Hydraulic falls in the stretch (river water turbulence) and the entrance of dissolved oxygen coming from an affluent (spring) found in the same stretch are likely to have contributed to the self-depuration of the water, resulting in a certain balance between oxygen consumption sources and production sources in the water evaluated.
In the stretch 2-3 (between points 2 and 3), contrary to what had been observed in stretch 1-2, the DO consumption rate was superior to the production rate, causing significant reduction in the average of such parameter (5.8 mg L^{-1} for all 8 campaigns). In fact, significant domestic sewage discharge was identified between points 2 and 3 (Figure 7), taking into consideration the low river flow (the average flow rates measured in points 1, 2 and 3 were 1.89; 2.82 and 1.62 $m^3\ s^{-1}$, respectively).
As it can be seen in Figure 2, there is a significant change in the density of the area built around point 3, which also explains the tendency presented in the DO values reduction.
The inadequate disposal of domestic solid wastes at the river margins together with the reduction in the riparian forest at the stretch 2-3 (Figures 8a and 8b) compared to the stretch 1-2 must have also contributed to the reduction in DO values.
When the organic matter present in the sewage is disposed in a water body, it creates the necessary

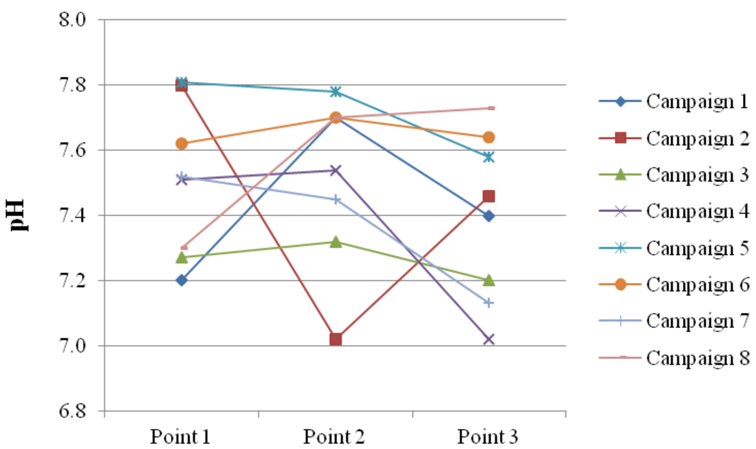

Figure 5 - The pH values obtained at the three points under study (pH units).

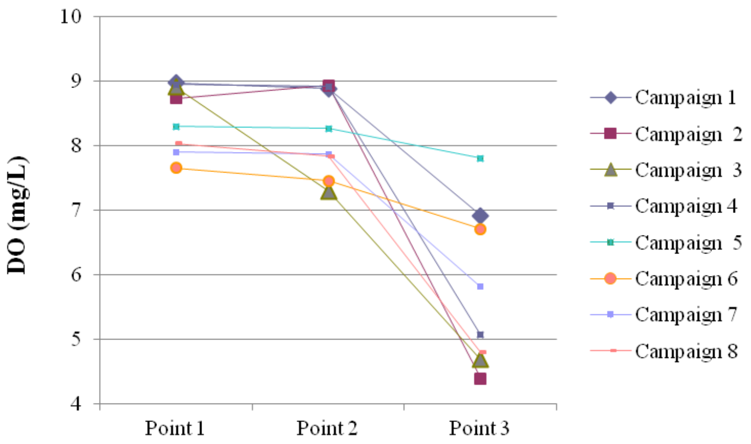

Figure 6 - Dissolved oxygen values regarding sampling points ($mgO_2 L^{-1}$).

Figure 7 - Some of the discharge points observed in stretch 2-3.

conditions to the growth of aerobic decomposer microorganisms, which are fed by this organic load and consume the dissolved oxygen of the environment. Thus, the soluble organic matter provokes dissolved oxygen depletion in the water.

In the study of Arroio dos Pereiras water, results were compatible with class 3 in sampling points 1, 2 and 3, based on the CONAMA 357 Act (2005), as the results were higher than 4 mg L^{-1} in all points. All results met law requirements, however, by only analyzing dissolved oxygen it is not possible to reach conclusions about the quality of the water body.

3.5. Biochemical Oxygen Demand (BOD)

The biochemical oxygen demand (BOD) is the amount of oxygen needed to oxydize biodegradable organic matter present in water. In Arroio dos Pereiras, the main source of organic matter in the water is the domestic sewage discharge (there is no industrial activity in the neighborhood).

The BOD_5 corresponds to the biodegradable fraction of compounds present in a sample which is kept five days at 20ºC. The results are obtained through the difference between dissolved oxygen values at the beginning and at the end of the incubation period. The larger the amount of biodegradable organic matter in the samples, the higher is the oxygen consumption during the incubation time (five days) and therefore, higher the BOD value (Piveli and Kato, 2005). Figure 9 shows the evolution of BOD values in the Arroio dos Pereiras along the three points.

As it had been expected (from the DO values observation), the BOD values increased along the river, indicating, in fact, the increase in organic matter load

Figure 8 - a) riparian Forest in stretch 1-2 and b) concrete wall in stretch 2-3.

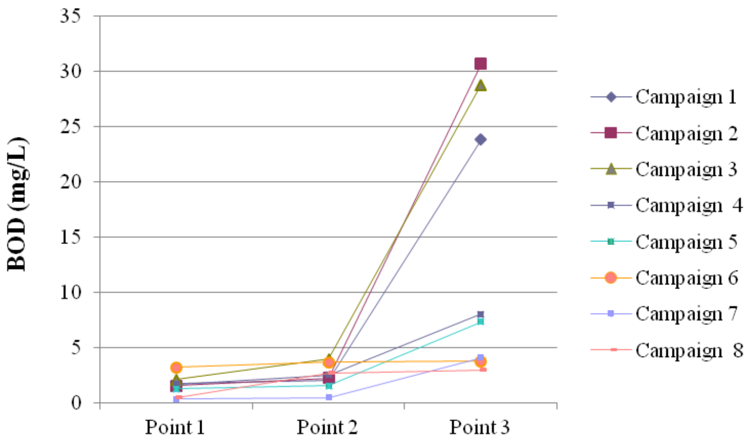

Figure 9 - BOD_5 values at the three sampling points in the stretch evaluated ($mgO_2.L^{-1}$).

(averages of 1.5; 2.4 and 13.7 $mgO_2\ L^{-1}$, respectively for points 1, 2 and 3). The BOD values found at the stretch 1-2 are within the regulation, as Act 357 from CONAMA (2005) permits the maximum value 10 $mgO_2\ L^{-1}$ for water bodies class 3. However, at the stretch 2-3 BOD values observed are superior to the ones permitted by the legislation. Such values confirm that domestic sewage discharge is relevant at this stretch, due to the higher urban density (Figure 2).

3.6. Total coliforms (TC) and Escherichia Coli (E.Coli)

Bacteria from the coliform group are used to evaluate the sanitation conditions of a water sample, acting as indicators of fecal pollution, as they are always present in the human and other hot-blooded animals intestines, and are mostly eliminated through the feces. This group of bacteria comprises the genus *Escherichia* and at a lower degree, the genera *Klebsiella*, *Enterobacter* and *Citrobacter* (Sperling, 2005).

The presence of coliforms in the water indicates contamination, with the potential risk of the presence of pathogenic organisms. The test to identify fecal coliforms (FC) is carried out at high temperature, aiming at inactivating the bacteria of non fecal origin. The fecal coliform group has recently been called thermotolerant coliforms, as these bacteria are resistant to the high temperature of the test. The *Escherichia coli* (or simply, *E. coli*) is the main bacteria in the coliform group, and it is the only coliform that develops in the intestinal flora of the hot-blooded animals only, which is an exclusive indicator of fecal contamination, consequently is a safer indicator of such kind of contamination than the total coliform group bacteria. The *E. coli* was also chosen to indicate fecal contamination as it is more resistant than most of the other coliforms, that is, if a treated water sample does not present significant values of *E. coli* the chances of presenting other kinds of coliforms is reduced, making it safe to public consumption (Sperling, 2005).

In the present study, data obtained for total coliforms and *Escherichia coli* in the campaigns carried out are presented in Figures 10 and 11 respectively.

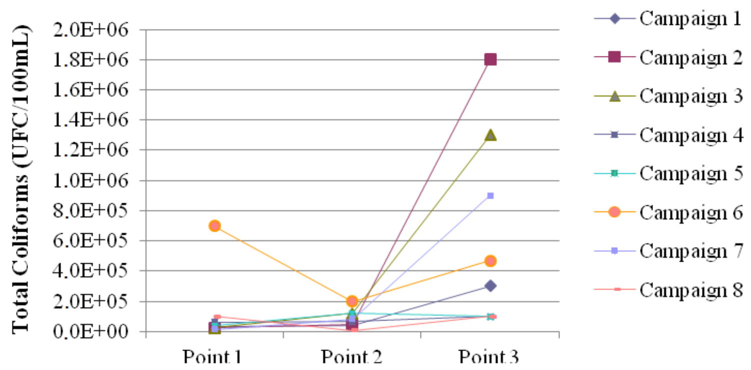

Figure 10 - Total coliforms values at the three points of the river stretch (MPN/100mL).

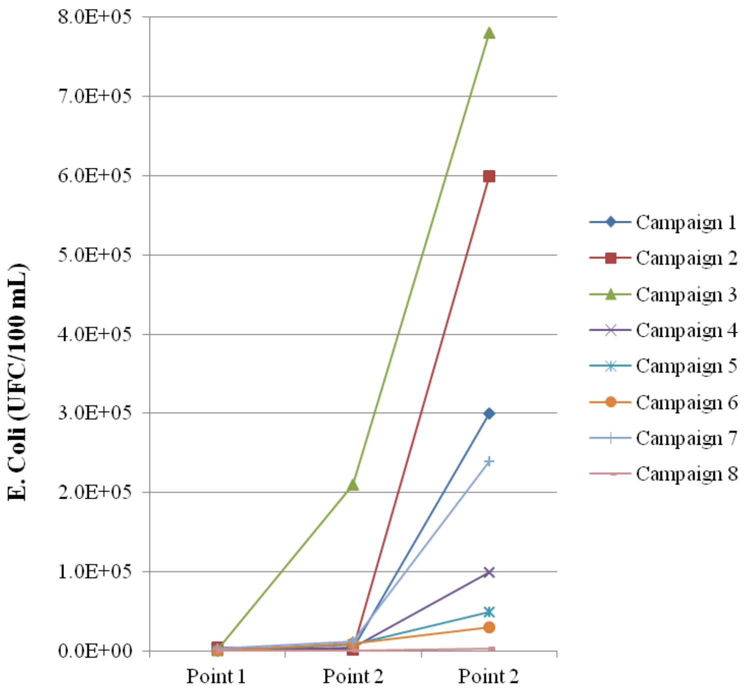

Figure 11 - *E. coli* values at the three points of the river stretch (MPN/100mL).

It can be seen that the difference of values obtained between points 1 and 2 (stretch 1-2) when compared, is not significant, which occurs due to the low pollution level found at this stretch when compared to the level of pollution between points 2 and 3, for example. However, when evaluating the values at the stretch 2-3, great increase in total coliforms and *Escherichia Coli* is evident confirming higher water contamination at this stretch (increment in the flow of domestic sewage discharge).

Microbiologic standards for freshwater defined by the Act 357 of CONAMA (2005) set the limit of 2500 thermotolerant coliforms per 100mL of water for secondary contact recreation, 1000 thermotolerant coliforms per 100mL for animal intake and 4000 thermotolerant coliforms per 100mL for other uses. The total and *E. Coli* coliforms found during the monitoring of the Arroio dos Pereiras water were far above the values permitted by law, making the water insuitable for any use.

Due to the results of TC and *E. coli* obtained during the study, the possibility to find other kinds of pathogenic organisms is higher, as the domestic sewage discharged might also contain bacteria, virus, protozoa and helminthes. The identification and counting of such micro organisms in water bodies are interesting regarding public health protection, as they are able to cause certain water borne diseases such as bacillary dysentery, cholera, amebiasis, hepatitis among others in humans (Sperling, 2005).

Table 4 - Origin of samples studied.

Samples	Sampling points	Campaign
1 - 8	1	1 - 8
9 - 16	2	1 - 8
17 - 24	3	1 - 8

3.7. Statistical analysis

The values obtained for chemical and microbiological parameters (total solids, turbidity, pH, DO, BOD, *E. coli* and total coliforms) of 24 samples collected at 3 different points throughout 8 campaigns carried out were statistically treated through the principal components analysis (PCA), using the software Pirouette version 4.0 (Infometrix, Seattle, Washington, USA). The pre-processing of data used in this study was auto-stepped, in which each variable is centered at the average and divided by its standard deviation. Table 4 describes each sample regarding its origin (sampling point and campaign).
The PCA obtained through chemical and microbiological parameters of 24 samples revealed that with only two main components it is possible to describe 70% of the results obtained, and 50% of the total variance is described by the first principal component (PC1) while 20% is described by the second principal component (PC2) (Figure 12).
The scores graph (Figure 12) shows the separation between the sampling points, with the samples collected at points 1 (1 to 8, according to Table 4) and 2 (9 to 16) being very distinct from the samples collected at point 3 (17 to 24). Such result can be clearly seen in previous graphs (Figures 9 and 11), which show the increase in BOD and *E. coli* values along the river, indicating the increase in organic matter load at points 1, 2 and 3 and confirming the increase in water contamination along the river, and thus highlighting the clear separation between sampling points. Such results can be clearly explained by the loadings graph presented in Figure 13, which shows that the separation is mainly due to variables described above BOD, *E. coli* and total coliforms.

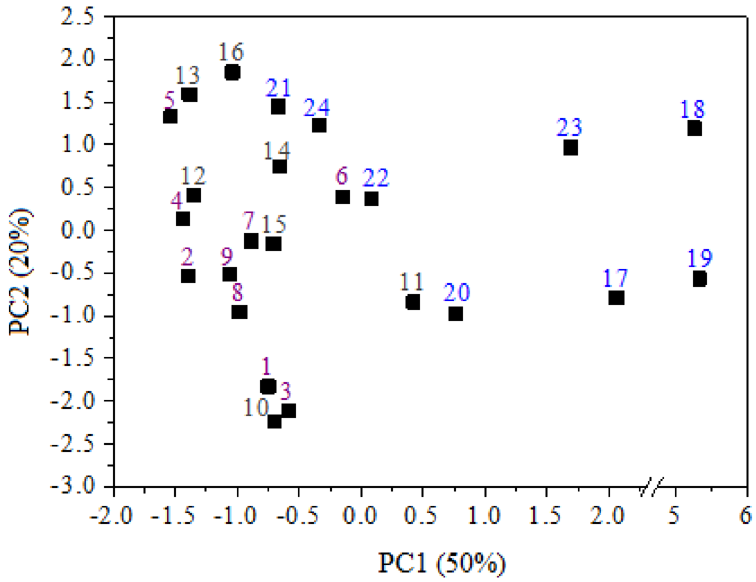

Figure 12 - Graph of PC1 versus PC2 scores at the three points of the river stretch.

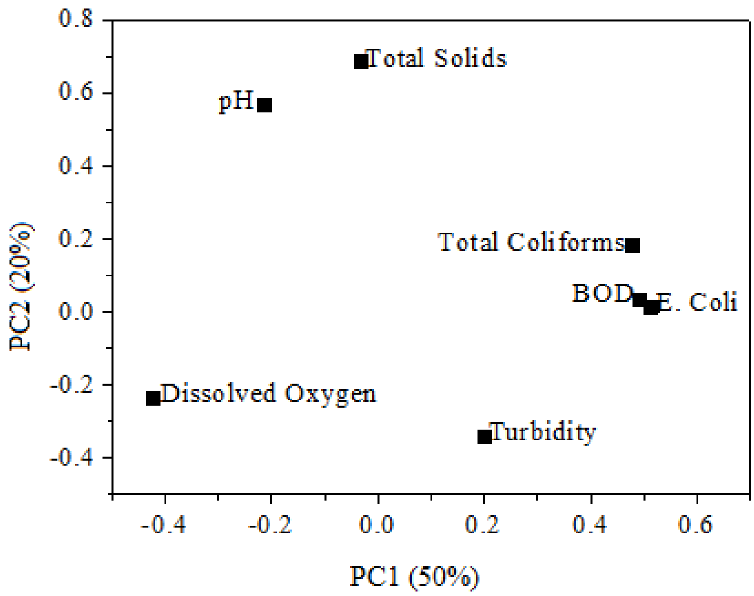

Figure 13 - PC1 versus PC2 loadings graph at the three points of the river stretch.

From the results obtained, it is possible to confirm that the chemical and microbiological parameters show the significant statistical difference between sampling points regarding the multi-varied analyses of the samples.

4. CONCLUSION

Physicochemical and bacteriological results obtained throughout the study revealed direct relation of pollution levels in the river stretch with the increase in the occupation density levels. It could be seen that stretch 1-2 suffered lower influence of urban occupation levels than stretch 2-3, regarding both physicochemical parameters (BOD, DO) and microbiological (total and fecal coliforms).

That the main contributor for the low quality of the water body (at least at the stretches evaluated) was the domestic sewage discharge, which was observed along both stretches, but mainly the second.

Although physicochemical parameters chosen for the monitoring of water quality in this study were within the specific legislation, microbiological parameters values make the water insuitable for use.

The result of this study might contribute to future projects of water quality recovery in the Arroio dos Pereiras, as well as to the implementation, viability and improvement of sewage collection systems that are still discharged without proper treatment.

Further studies should be carried out aiming at characterizing areas of higher anthropogenic impact so that mitigating measures can be proposed in order to improve the Arroio dos Pereiras water.

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