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Monitoring of an urban water body under the influence of a wastewater treatment plant: assessment of environmental impacts

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Abstract

Urban streams are increasingly suffering from anthropogenic activities, mainly due to domestic sewage. Thus, this study aimed to assess the impact of treated domestic effluent on a receiving water body. Four sampling points were defined. The first was inside the stream, located upstream on the Wastewater Treatment Plant (WWTP), the second at the WWTP inlet, the third at the plant outlet and the last was located inside the stream, downstream of the WWTP discharge. The study was carried on for a three-year period (2013-2015). Chemical, physical and biological parameters were analyzed. Correlation analysis, Principal Component Analysis (PCA) and Euclidean distance dendrogram then assessed the results. At the sampling points related to the stream (spots 1 and 4), a significant distance between conductivity and the other parameters was observed, suggesting a low relation between them. A group of minor related variables (Trophic State Index - TSI - and Chemical Oxygen Demand - COD) was formed. At the sampling points within the WWTP (points 2 and 3), the formation of 3 clusters was observed, and two of them involved TSI, thus indicating that this parameter changes according to the season of the year and the monitoring point. Therefore, the WWTP influences in a significant and proportional way the TSI of the water body in different seasons of the year, suggesting that this is the main parameter to be controlled. The highest TSI were observed during spring and summer.

Keywords

Trophic State Index, Water resources, Watershed

I. Introduction

Contemporary society is marked by the exacerbated consumption of natural resources and the production of innumerable products and a huge amount of waste, proportional to urban and technological development. According to Alves [1], the 20th century had the highest population growth in history, in this period the world population quadrupled. The UN averaged projections for global population growth says that it will reach 10.9 billion inhabitants by the year 2100. Concerns about the effects that such development and population growth would have on the environment began to be addressed after second half of the 1980s where for the first time the term “sustainability” came about. Since then, actions to prevent and control changes in the environment have been adopted by an increasing number of countries to achieve the sustainable development of their productive sectors.

In addition, Ortiz *et al*. [2] emphasize the importance of creating a sustainable culture, which involves urban planning as a tool to provide a better quality of life for the population. In this way, the lack of urban planning can directly affect water resources. The socioeconomic heterogeneity of urban occupation is a determining factor for studying an urban stream, and the increase in the water body organic load is an indicator of human activities on the urban streams.

Through the Resolution 357/2005 of the National Environment Council (CONAMA) [3], the Brazilian federal government has given its responsibility for regulating the provision of basic sanitation services for the population. Thus, sanitary sewage was defined as the disposal of residential and commercial liquids and infiltration waters in the catchment network, which may or may not, contains percentages of industrial effluents and non-domestic effluents [3]. The lack of basic sanitation has caused several problems for the population due to the proliferation of waterborne diseases generated by the open sewers and by the pollution of the water sources. This problem is directly linked to intestinal parasites, infant mortality, hepatitis A, cholera, typhoid fever, verminosis and gastroenteritis [4].

The study published by Instituto Trata-Brasil [5] reveals that in Brazil the percentage of sewage collected is 48.6%, thus more than 100 million Brazilians do not have access to this basic service. This study also reveals that the amount of effluent treated as a function of the generated is 39%. In the State of Rio Grande do Sul, this study shows that 28.57% of sewage is collected, while 15.51% is treated. Caxias do Sul, the city where this study was carried out, ranks 39th among the 100 largest cities in the country in the Sanitation Ranking, and it is the best-ranked city in the Rio Grande do Sul. The total service of sewage in the municipality meets a percentage of 88.1%.

Water is used daily for the basic needs of the population and industry. After being used, this resource is usually discharged in urban streams and most of the time without any previous treatment. However, it is not only the effluent that directly impacts the quality of urban streams. The rainwater flow

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carries organic and inorganic matter, in suspension or soluble, to the water bodies, increasing the organic load [2]. Costa and Campos [6], evaluation an urban stream waters using only physico-chemical parameters shows great variation regarding the analytical results due to the low concentrations of toxic substances that remain diluted in the water column. With the increased expansion of the industries, the interest in saline effluents is gaining visibility and several treatment techniques are being studied, however, there is still a difficulty in the removal of these pollutants, when at high concentrations, through biological treatment.

From the several models developed for effluents treatment, normally the most used is the natural system since this system presents low cost of implementation and maintenance. According to Passos [7], a natural system is defined as the one that presents the full cycling capacity of all the elements present in the effluent in natural ecosystems, without the need to offer the system energy to accelerate degradation processes. Another widespread system is the stabilization ponds. This system focuses on the treatment of domestic sewage, and is used successfully and with great advantages, due to the association between the simplicity of operation and efficiency in the removal of pollutants. Passos [7] points out that one of the main mechanisms of pollutants removal in this system is through biological processes, where the organisms present in the effluent degrade the organic matter and act in the treatment of the effluent.

D'Alessandro *et al*. [8] emphasize that the lagoon system is directly influenced by the region climate and may interfere in the treatment efficiency. Hence, the seasonality of the temperature along the seasons of the year can influence the quality of the treatment in regions with sub-tropical or temperate climate.

The efficiency of the effluent treatment in stabilization ponds is determined by several factors, such as temperature, hydraulic retention time, depth and quantity of bacteria and algae. After their growth and the assimilation of nutrients, the algae in stabilization ponds are dependent on the complex interactions among physical factors such as pH, light intensity, temperature, wind, solar radiation and biotic factors such as the amount of algae present in the aquatic environment [9].

Among the monitoring parameters of a water body, the Trophic State Index is one of the indicators of nitrogen and phosphorus load that is being received. According to Lamparelli [10], the increased eutrophication of water bodies or reservoirs can directly affect the aquatic ecosystem.

Considering the importance of monitoring the discharges of an effluent treatment plant in an urban stream, this study aims to evaluate the impacts caused by the disposal of treated domestic effluent in a receiving water body.

II. Material and Methods

A. *Area of study and collection points*

The urban stream evaluated in this study is in the Municipality of Caxias do Sul as shown in Fig. 1. The basin where this stream is located is at an average elevation of 733 m, within the urban area, this basin has an area of 1.49 km² and a perimeter of 7.09 km, and this basin is part of the Caí river hydrographic basin. The Caí basin has an area of 4,945.70 km² and the main water springs of the river that denominate this basin are in the municipality of São Francisco de Paula at an altitude of 1000 m. Caxias do Sul, a mountain town in the state of Rio Grande do Sul.

B. *Wastewater Treatment Plant Characterization*

The wastewater treatment plant investigated in this study is divided into 4 ponds. As soon as the effluent arrives at the plant, it goes through the first operation that consists of a screening for removal of coarse particles and a Parshall gutter. The first lagoon was built to aerate the effluent and has an area of 240 m², a depth of 3 m and the Hydraulic Retention Time (HRT) of the effluent in this structure is 4 days. The second lagoon, called the sedimentation lagoon, has an area of 144 m², depth of 3 m and HRT of 2 days. After the passage of the effluent through these two first lagoons, it reaches the maturation lagoon, which has an area of 1,170 m², depth of 1 m and HRT of 10.6 days. To finish the treatment process, the effluent goes to the maturation lagoon II, with an area of 1,750 m², depth of 1 m and HRT of 16.3 days.

C. *Physical, chemical and biological analysis*

The samples were collected on the laminar surface of the lagoon and the stream, following the National Guide for Collection and Preservation of Samples [11]. The collection flasks were stored in an appropriate container and kept under refrigeration at 4 ° C until the laboratory tests started. Details about the methodologies used for each parameter tested are presented in a supplementary file along with this submission.

D. *Trophic State Index (TSI)*

The Trophic State Index (TSI) is an index used to determine the eutrophication of reservoirs. Lamparelli [10] defined a TSI with acceptable accuracy for assessing the proliferation of aquatic macrophytes in rivers, considering a relationship between phosphorus concentration (limiting nutrient) and chlorophyll-α. The TSI calculation in this study was performed according to Equations 1, 2 and 3.

$$TSI_{TP} = 10\left[6 - \frac{0.42-0.36lnTP}{ln2}\right] - 20 \qquad (1)$$

$$TSI_{CL} = 10\left[6 - \frac{0.42-0.36lnTP}{ln2}\right] - 20 \qquad (2)$$

$$TSI = \frac{TSI_{TP}+TSI_{CL}}{2} \qquad (3)$$

Where, TSI_{TP} is the total phosphorus index to be calculated, TP is the amount of phosphorus in the sample, TSI_{CL} is the chlorophyll-α index to be calculated, CL is the amount of chlorophyll in the sample and the TSI is the state index trophic.

E. *Experimental design and statistical analysis*

To evaluate the impact of the WWTP on the urban stream, a monthly monitoring was conducted over three years at four pre-defined points. The Pearson correlation method was used to assess the interrelation between the dependent variables. Next, the correlation matrix was generated, and the data were grouped and evaluated by the Principal Component Analysis

(PCA) method. Thus, the original values were transformed into a smaller number of variables called Principal Components (PC). After defining the number of PCs, the respective eigenvalues were obtained and the biplot graphs were plotted representing the major components based on the vector loads. The Principal Component graphical analysis was considered valid when the cumulative variance of the first two components was equal to or greater than 70% of the total variance. In the evaluations of the interrelationships where this minimum limit was not obtained, the data were demonstrated through the Pearson correlation matrix. All data was processed aided by the Statistica 12 software (by Statsoft). The points outside the plant (1 and 4) and inside the plant (2 and 3) were separated for the analysis of the results.

III. Results

The data obtained during the experiment period was tabulated and organized according to the effects within the WWTP and outside the WWTP. Details concerning the values for each sample collection over time, as well as the detailed physical, chemical and biological parameters, analyzed at all the collection points, are available as supplementary material.

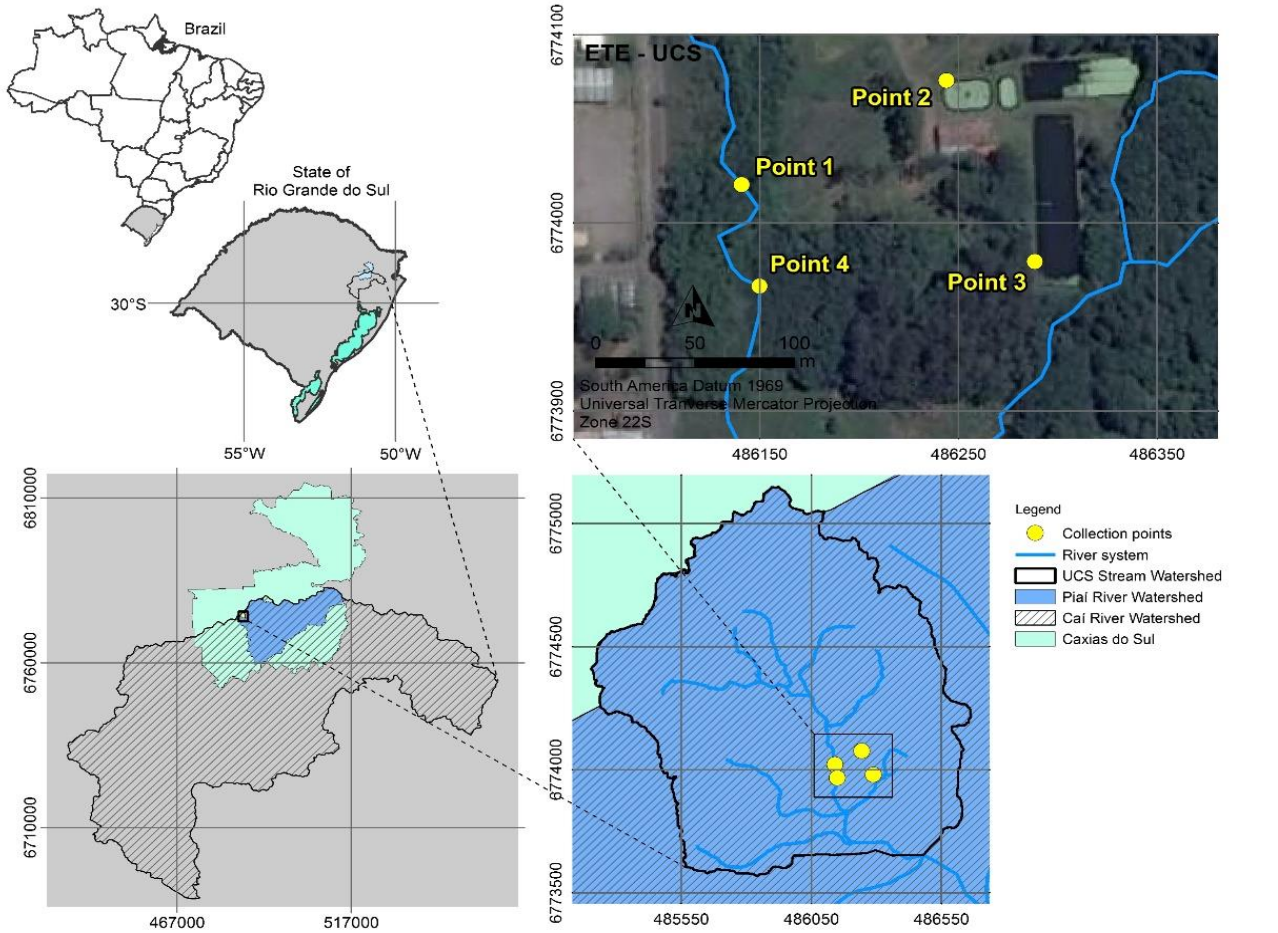

Fig. 1: Sample spots and its location within experimental

F. Outside the WWTP

The correlation analysis (Table 1) shows that some parameters (TKN, Ammonia Nitrogen, and Conductivity) are positively and strongly correlated with each other, apart from being significant ($r>0.6$; $p<0.05$). Considering that conductivity represents the concentration of ionic substances in the effluent, it can be related that this behavior is linked to the concentration of nitrogen in the effluent, since heterotrophic bacteria are responsible for ammonification processes, impacting directly on the electrical conductivity of the effluent, through the conversion of nitrogenous organic matter to ammonia [8].

Costa and Campos [6] emphasizes that nitrification is a biological process, which occurs naturally in environments where there are aerobic conditions and the presence of ammoniacal nitrogen. In this way, the presence of ionic substances in the effluent directly affects the conductivity parameter, explaining the strong correlation between the two parameters. Observing the COD and TKN, COD and ammonical nitrogen parameters, it is possible to verify the existence of a significant positive correlation ($r> 0.5$, $p <0.05$) between them. In one study, Lau *et al.* [9] showed that the development of cyanobacteria in the absence of light and in the presence of organic matter, there is a greater removal of COD and nitrogen. The other parameters showed moderate or weak correlation, indicating that an individual approach to each of them can be performed. The inter-relationship between the conductivity and the other parameters evaluated are presented in Fig. 2.

Table 1: Correlation analysis of the parameters evaluated in the study.

	pH	*TSI*	*AN*	*TC*	*TKN*	*BOD*	*COD*	*Cond*	*DO*
pH	1								
TSI		1							
AN	0.43		1						
TC				1					
TKN	0.37		***0.94***		1				
BOD					0.29	1			
COD			0.50		0.52	0.67	1		
Cond			***0.68***		***0.71***		0.52	1	
DO	-0.33								1

* Highlighted values showed strong correlation and statistical significance (| r |> 0.7, p <0.05). The other correlations presented only showed statistical significance (p <0.05). Correlations with hidden values did not present statistical significance between the parameters (p> 0.05).

It can be observed the formation of a large distance between the conductivity parameter of the others, indicating a low relationship with the other parameters. It is also possible to highlight the formation of a group of smaller correlated variables (TSI and COD), closer to a last group that comprises the rest of the evaluated parameters.

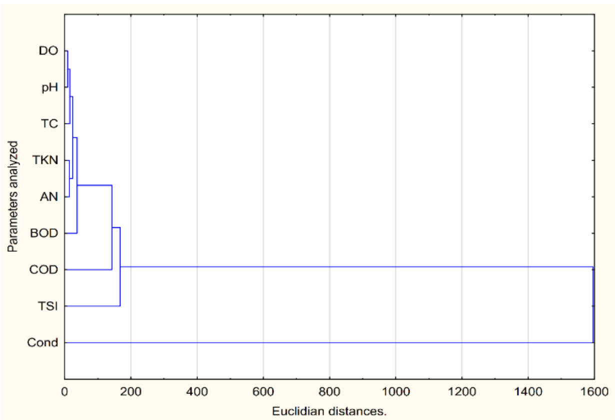

Fig. 2. Parameter analysis based on the Ward algorithm and Euclidean distance coefficient

According to Boesch [12], one of the causes of eutrophication is the discharge of untreated domestic or industrial effluent. For Elser and Benett [13] eutrophication results in loss of submerged vegetation, depletion of dissolved oxygen, alteration of aquatic communities and loss of diversity in water bodies due to the population increase over the years. Thus, eutrophication in urban streams is likely to rise, mainly due to anthropogenic activities, so it is important to apply this index in the water bodies to reach a better parameter for quality control. The degradation of the aquatic system quality is associated with occupation of the micro basin as well as by the residues generated by the urban population through punctual and diffuse sources of pollution [14].

In this way, the region where the stream is located suffers large anthropogenic impacts, mainly due to the domestic discharges and the occupation of the predominantly residential region. The discharge of the upstream effluent without pretreatment may be causing the large values observed in Fig. 3 for the electrical conductivity, but this condition directly influences the other evaluated parameters such as eutrophication, BOD, and COD.

G. *Inside the WWTP*

Table 2 presents the results obtained for the principal component analysis (PCA), based on a variance - covariance matrix of the analyzed data. Two components were selected due to their representability of 79.9% of variation of the data set. Thus, the first component (Factor I) is dominant because it represents 68.14% of the data variance. The second component (Factor II) represents only 11.76% of the data variance. As the accumulated variance of the first two components was greater than 70%, a graph with the loads of the eigenvectors could be plotted to investigate the formation of clusters of variables (Fig. 3).

In Fig. 3, it is possible to observe the formation of three distinct clusters. The Cluster 1 (C1) is formed by the collection points and the TSI parameter, this one at the same distance from the "collection time" factor, forming Cluster 2 (C2). Cluster 3 (C3) is formed by the other parameters analyzed, excepting the DO, which did not present a direct relationship with the rest of the variables.

Table 2. Statistical analysis of the PCA of the parameters studied.

Components	**Eigen value**	**Variance (%)**	**Cumulative (%)**
1	6.13	68.13	68.13
2	1.05	11.76	79.90
Components Load			
Parameter	Factor I	Factor II	
pH	-0.829	-0.310	
TSI	0.327	0.112	
Thermotolerant Coliform	-0.916	-0.036	
Ammoniacal Nitrogen	-0.963	0.036	
TKN	-0.980	0.012	
BOD	-0.943	-0.055	
Condutivity	-0.885	0.129	
COD	-0.945	0.030	
DO	0.196	-0.962	

Legend: Dissolved Oxygen (DO), Thermotolerant Coliforms (TC), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Kjeldahl Nitrogen (TKN), Ammoniacal Nitrogen (AN), Conductivity (Cond).

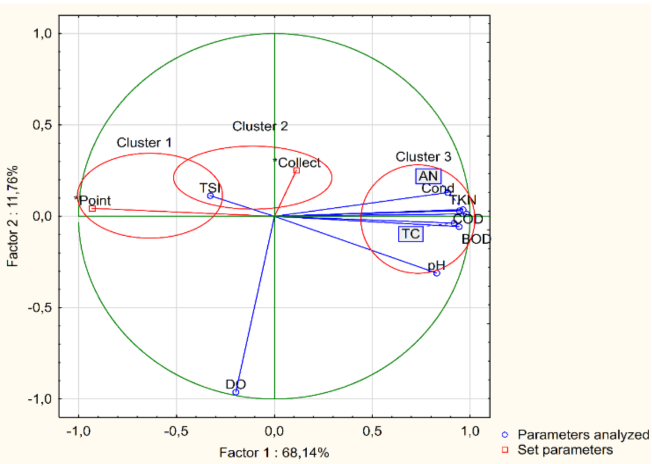

Fig. 3: Graph of the loads of the auto-vectors (Factor I and II) of the parameters analyzed during the study along the time of observation.

The formation of C1 and C2 and its correlation with the TSI parameter indicates that it is highly relevant throughout the season (point) and over time (collection time), indicating that the trophic state changes significantly depending on these two factors, thus corroborating the fact that this is an important variable to be monitored in future studies. Zanini *et al.* [14] presented in their study the variability of the TSI as a function of the samples collection point and rainfall index, which can directly affect the TSI due to domestic sewage discharges. The other parameters did not show any dependence relationship with the time of collection and the point, thus being independent of these factors, indicating that the intrinsic characteristics of the waste and effluents discharged in the stream are responsible for the observed responses of the isolated parameters.

IV. Conclusion

Through this work, one can conclude that the WWTP influences in a significant and proportional way the trophic state of the stream. The collection period, which reflects the environmental conditions throughout the year in the study region, indicates that this parameter suffers significant influence in the different seasons over the year, requiring additional attention in the conditions most favorable for algae proliferation. These conditions were observed mainly in spring and summer.

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