Potential for attenuation of a stream in a subtropical region-Rio Grande do Sul-Brazil

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Abstract

The study and knowledge of the attenuation capacity of the water resources, is necessary to preserve them. This study was objective identify the attenuation capacity of the Belo stream - Caxias do Sul - RS / Brazil, through the evaluation of physicochemical parameters, distance and slope between 4 points located along the stream. Were collected five samplings, bimonthly. The data were analyzed through descriptive statistics, one-way Analysis of Variance (ANOVA "one way"), Tukey's test e Pearson's correlation. The results showed that there is an improvement in the quality of water resources from upstream to downstream of the stream. However, despite the stream have a high attenuation potential, is necessary the development of control actions to input of industrial and domestic effluents, to prevent the ecological impairment of the same.

Keywords

Water Quality, urban watershed, depuration

I. INTRODUCTION

Scarcity of good water quality poses one of the major and most important problems to be faced by humanity. This problem is occurring due to rapid population growth and consequent increase in water demand, generation of waste water and improper disposal of domestic and industrial solid waste [1]–[4]. This could causing qualitative and quantitative deterioration of water quality in different regions around the world [5], thus compromising its current and desired uses.

Water pollution resulting from contamination by point or nonpoint sources. Point sources are represented by effluent discharges, concentrating on a single point and, therefore, more easily controllable. Nonpoint sources are a result of superficial runoff in urban and rural areas, distributed along the receiving water bodies [6]–[8].

Effluent discharges as well as storm water runoff leads to issues such as sediment deposits in water bodies, depletion of dissolved oxygen concentration, contamination by pathogenic organisms, eutrophication, damage due to the presence of toxic contaminants or aesthetic changes [9]. Thereby, compromising the determination of the required water treatment efficiency, as well as, the possible allocation of pollutant loads in a watershed, which occur due to the environmental requirements of the receiving water body [10], thus possibly compromising their uses.

Among the ways used to control pollution of water resources, one can mention the study and knowledge of the attenuation capacity of the same, so that eventual intervention measures can be implemented. Attenuation potential is a capability by which rivers are enabled to dilute, lessen or eliminate the undesirable effects of pollutants. Precise specification of such capability may be considered a powerful instrument in rivers sustainable management [11], given that the process in a natural water body is driven by numerous physical, chemical, or mechanical factors and others implemented by aquatic biota [12]–[14].

According to [12] physical processes are those that involve dilution, adsorption, sedimentation and volatilization; chemical processes are those that involve acid-base reactions and precipitation, biological processes involve the bacterial degradation, assimilation and removal of macronutrients by plants. Furthermore, the factors affect auto purification capacity of the water bodies, such as water body velocity, discharge, flow rate, sediment-load, biological population in the rivers, temperature and depth [15], [16].

Depending on the degree of pollution, the attenuation process is very efficient in improving the water quality [17], however, this potential can be minimized when the total amount of pollutants is beyond the attenuation capacity of the river [16].

One can mention that the processes of attenuation in water bodies are important not only for the improvement of water quality for consumption, but also in terms of habitats maintenance and biodiversity conservation [18].

In this context, the main objective of this work was to identify the attenuation capacity of the Belo stream, located in Caxias do Sul - RS / Brazil, through the evaluation of physicochemical parameters, distance and slope between 4 points located along the stream. The results may also support the management and planning of the watershed, since its headwaters are inserted in the urban area, where the greatest impacts from effluent discharges take place. Furthermore, we seek to generate information on the subject, since the works in this area are limited.

II. MATERIALS AND METHODS

A. Description of the study area and sampling station

The Belo watershed is located in the southwest portion of the city of Caxias do Sul, northeastern state of Rio Grande do Sul - Brazil, between latitudes 29° 10' 31.28" and 29° 19' 15.51" S, and longitudes 51° 10' 14.40" and 51° 16' 7.24" O (Fig. 1).

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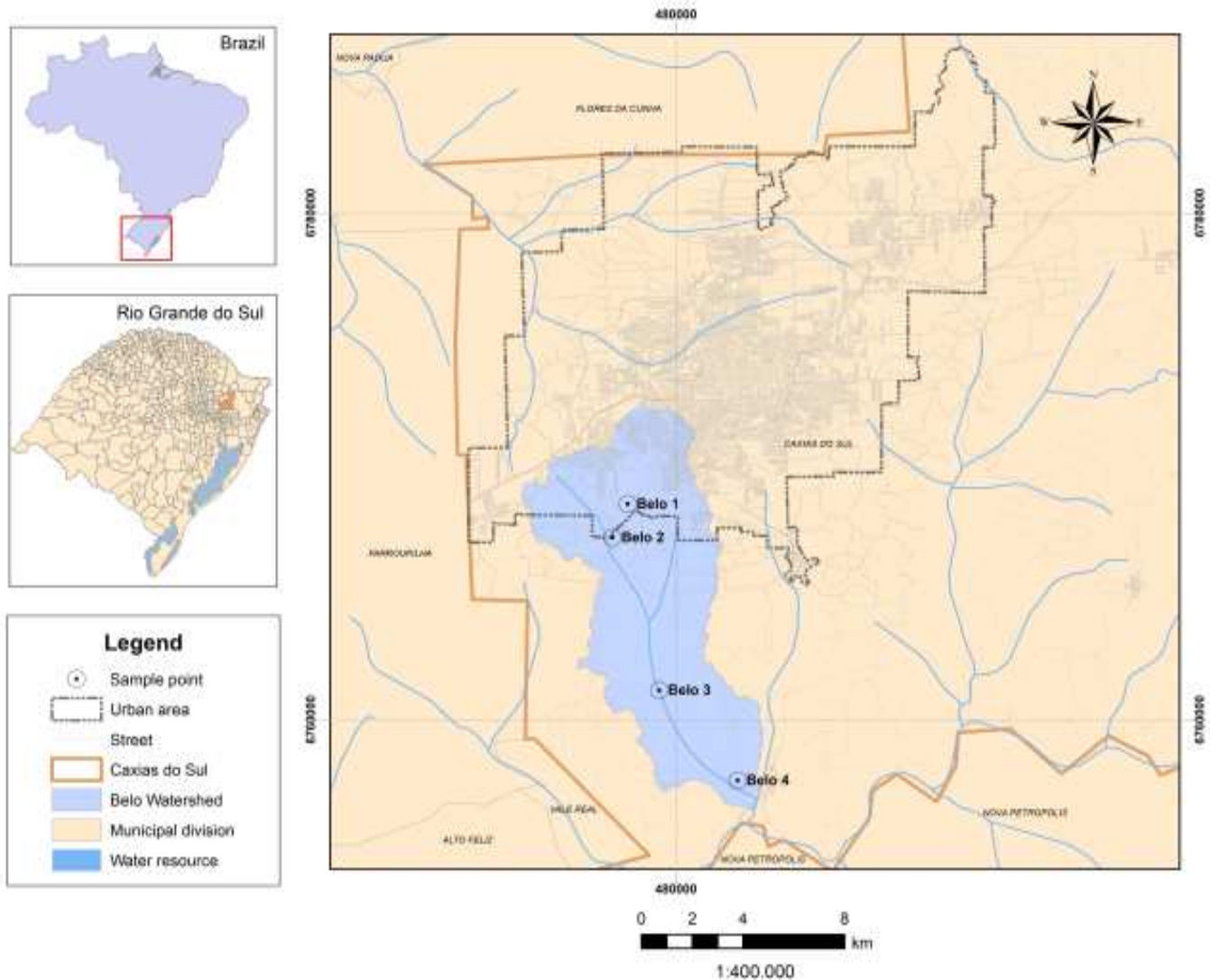
Fig. 1: Location map for the Belo Watershed and sampling points

The area is part of the Meridional Plateau geomorphological unit, which has a dense system of fractures, faults and diaclases. This configures the drainage system in successive meanders slotted in dendritic form. Considering the Köppen system, the climate in the region is classified as humid temperate [19]. Geomorphology, soils and climate determine the occurrence of a typical vegetation of fields and forests, with the predominance of the vegetation type Mixed Ombrophilous Forest - Araucaria Forest [20], inserted in the Atlantic Forest biome. However, the landscape appears to be significantly altered currently, due to agricultural and industrial management, and also by expansion of the urban area [21].

The watershed of the Belo stream has a total area of 75.10 km^2 and a perimeter of 63.11 km. The headwaters of the stream, located in the northern region of the basin, are inserted in the urban area of Caxias do Sul, comprising a 22.24 km^2 area, which corresponds to 29.14% of the total catchment area.

In the clinographic map of the watershed evaluated in this work, one can observe the declivity classes divided into six distinct intervals proposed by [22]. The predominant relief in the basin covers the classes of declivity from 8-20% (undulated relief) and 20-45% (strongly undulated relief),

which correspond respectively to 35.25% and 40.23% of the total area of the same (Fig. 2).

Through the hypsometric map, one can observe that the greater part of the basin, about 28.62 km^2, or 38.10% of the total area thereof, is comprised in the hypsometric class between 600 and 700 meters (Fig. 3).

B. Sampling stations

Samples were collected at four points located along the main course of the Belo stream (Fig. 1): point 1 (P1) - latitude 29° 12' 42.62" S and longitude 51° 13' 30.99" W, is located in the most urbanized area, on the perimeter urban, where the greatest discard of domestic and industrial effluents occurs; point 2 (P2) - latitude 29° 13' 25.66" and longitude 51° 13' 53.42" W, located 1,509 meters from P1, at the end of the urban area; point 3 (P3) - latitude 29° 16' 41.54"S and longitude 51° 12' 45.93" W, located 7,799 m from P2, outside of the urban perimeter, in an area predominantly occupied by native forests and of agricultural activities; and point 4 (P4) - latitude 29° 18' 37.48 "S and longitude 51° 10' 51.58" W, located 5,153 m from P3, near the river mouth of the watershed, the use and occupation of the region is similar
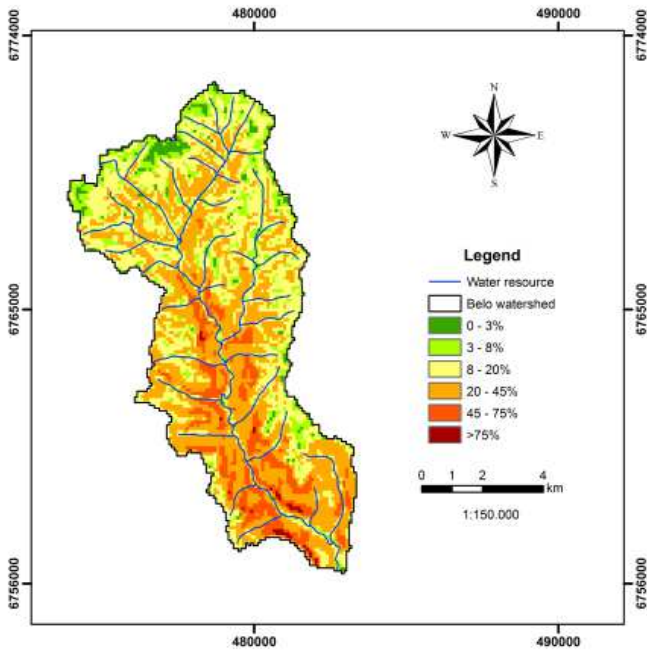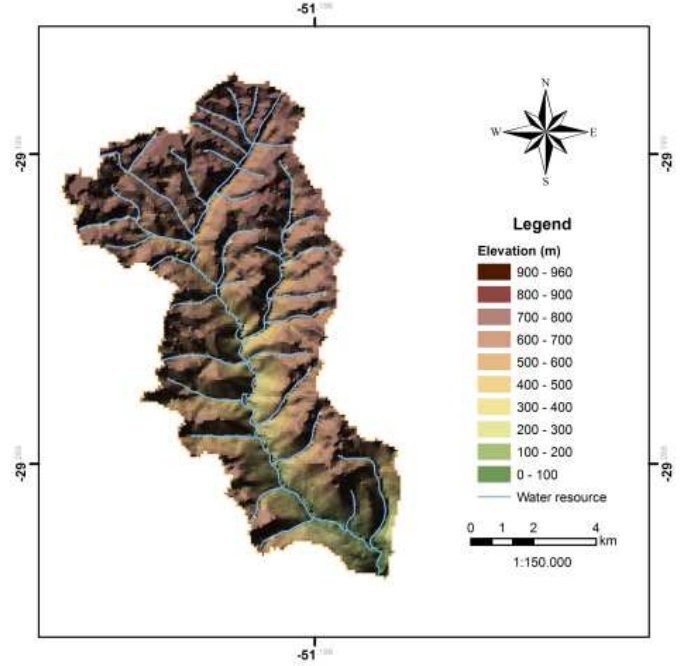
Fig. 2: Clinographic map of the watershed.

Fig. 3: figure
Hypsometric map of the watershed.

to the one given for P3. It is worth noting that although P3 and P4 are outside the city limits, it is possible to occur releases of waste water in the region, due to the presence of farms and houses located on the banks of the stream. Table I presents information on elevation, distance and slope between the points assessed.

TABLE I: Elevation, distance and declivity between points

Stretch	Elevation of points	Elevation difference (m)	Distance between points (m)	Declivity between points
P1 - P2	562 - 549	13	1,509.43	0.86
P2 - P3	549 - 272	277	7,798.54	3.55
P3 - P4	272 - 95	177	5,153.44	3.43

C. Sampling frequency and analysis

The study was conducted among September 2012 to May 2013, with samples collected bimonthly, totaling five samplings.

In situ, the following set of variables was measured with a multiparameter water quality probe (Horiba U50): redox potential (ORP), total dissolved solids (TDS), dissolved oxygen (DO), conductivity (Cond), and turbidity (Turb). Water samples were collected for analysis in laboratory, of total phosphorus (TP); surfactants (Surf); chemical oxygen demand (COD); 5-day biological oxygen demand (BOD_5); ammoniacal nitrogen (NH_3–N) [23] and nitrate (NO_3–N) was determined following the NBR 12620 [24].

D. Data analysis

Data were analyzed through descriptive statistics. The Test of Normality was performed using the Shapiro-Wilk test.

In order to compare the parameters from different sampling points, the One-Way Analysis of Variance (ANOVA "one way") was run. For parameters with $p < 0.05$, obtained in the ANOVA, which demonstrates the occurrence of significant changes in parameters concentrations between points, the Tukey's test and Pearson's correlation was applied. The Tukey's test was conducted aiming to check if the average variability between points is significant ($p < 0.05$), while Pearson's correlation was conducted aiming to identify the correlation between the parameters. The analysis was performed using the statistical software SYSTAT 12 for Windows, version 12 (SYSTAT Software, 2007). For analyzes of "one-way" ANOVA, Tukey's test and Pearson's correlation the data were presented in the logarithmic form.

III. RESULTS AND DISCUSSION

Considering the variation of physicochemical parameters in the five samplings for the four points (Table II), there is a tendency of increment from upstream (P1) at downstream (P4) of the average concentration for ORP, DO, NO_3—N and COD/BOD_5. On another hand, the remaining parameters (TDS, Cond, Turb, TP, NH_3-N, Surf, COD and BOD_5) showed a decreasing trend in concentrations. Although the values of standard deviation are high, which is normal in lotic environments that suffer direct anthropogenic interference, is possible observed the trends presented above.

Results indicate that the relation COD/BOD increases along the course of the stream, demonstrating that the biodegradable fraction is converted rapidly, growing the fraction of difficult degradation, incorporated in solids and can still be found at the sampling stations near the river mouth. According to [5], the COD parameter is directly related to the presence of untreated sewage released in the water body, which was also observed.

The oxidation process of the biodegradable fraction occurs only in the presence of OD, which is the agent responsible

for this reaction. So the points sampled upstream (P1 and P2), where there is a greater amount of organic matter, the OD resulted in lower concentrations.

It was also observed the transformation of nitrogen along the watercourse, increasing nitrate levels and decreasing the concentration of ammonia nitrogen.

By the results of the ANOVA test ("one way"), it was found that the parameters ORP, TDS, DO, Cond and TP showed no significant difference between the studied points ($p >$ 0.05), i.e. there was no statistically significant variation of the data between the sampled points (Table III). However, for the parameters Turb, NH_3-N, NO_3-N, Surf, COD and BOD_5, the results of the p-value were lower than 0.05 ($p <$ 0.05), which indicates a significant change in these parameters, between the sampled points. The r^2 values show that the data differences between the points explained 80.8% variability of the parameter BOD_5, 83.4% of NH_3–N, 63.3% of the NO_3-N, 55.6% of Surf, 52.8% of the COD and 41.1% of Turb (Table III).

TABLE III: Results of ANOVA ("one-way")

Variables	F-ratio	*p*-value	r^2 (squared multiple R)
ORP	3.091	0.057	0.367
TDS	2.262	0.121	0.298
DO	2.861	0.070	0.349
Cond	2.279	0.119	0.299
Turb	3.719	0.033	0.411
TP	1.358	0.291	0.203
NH_3–N	26.765	0.000	0.834
NO_3–N	9.182	0.001	0.633
Surf	6.684	0.004	0.556
COD	5.963	0.006	0.528
BOD_5	22.402	0.000	0.808

From the parameters that presented no statistically significant difference, three hypotheses can be inferred. The first one refers to the insufficient distance between the sample points, which would have made the significant variation in these parameters impossible; the second option refers to a load that is much larger than the ability to attenuation of the watershed; and the third option refers the input of nutrients along the section sampled by diffuse sources and even the local geology. As for phosphorus, it may be due to the use of phosphorus fertilizers used in the watershed [5]. Although the results of the DO parameter do not indicate a statistically significant increase, it is important to remember that such parameter is essential in attenuation of a water resource, as it can restore and enhance the growth and the vitality of micro-organisms to improve the water quality [3].

Parameters that showed significant statistical differences, with the exception of NO_3–N,the high observed concentrations in the first two points upstream, are related to the input of domestic and industrial effluents.

The surfactants are the main components of the synthetic detergents. According to [25], when synthetic surfactants get into natural water bodies they form films on the water surface to interfere with normal aeration and inhibit attenuation of water from other pollutants. Furthermore, depending on the situation, synthetic surfactants and other pollutants may have

different effects of hydrobionts, which can affect the water purification process [18].

Apart from the erosion of riverbanks intensified by the misuse of land, domestic and industrial sewage can also promote increases in turbidity, affecting aquatic biological communities [26]. Environmentally, the main consequence of the change in turbidity in a water body, is the reduction of sunlight penetration and consequent reduction in the photosynthetic rate. In stagnant waters or rivers of low turbulence [27], where photosynthesis is the main source of oxygen in the environment [28], the oxygenation is hindered. However, this is not a feature of the area.

Results of the Tukey's test showed that the variation of mean turbidity data among the sites sampled, were significant between P1 and P3 (p = 0.050) (Fig. 4). The variation of ammonia nitrogen was significant between P1 and P3 (p = 0.000), 1 and 4 (p = 0.000), 2 and 3 (p = 0.000), and also between P2 and P4 (p = 0.000). For nitrate the values were significantly different between P1 and P3 (p = 0.001), as well as between P1 and P4 (p = 0.004). The values of p-value for surfactant were significant between P1 and P4 (p = 0.008) and between P2 and P4 (p = 0.016). The mean COD values varied significantly between P1 and P4 (p = 0.005), while for BOD values, the variation was significant between P1 and P3 (p = 0.001), P1 and P4 (p = 0.000), P2 and P3 (p = 0.007) and P2 and P4 (p = 0.000). Of the parameters shown, only nitrate has increased concentrations from upstream to downstream of the stream, while the other parameters showed a decrease.

The parameters Turb, NH_3–N, NO_3–N, Surf, COD and BOD that showed significant variation on Tukey'stest, it is observed that the significant variation, for most parameters, occurred between points 1 and 3 or between 1 and 4. The distance between points 1 and 3 was of 9,300 m, and the variation of elevation of 290 m, creating a slope of 4.41%. Between points 1 and 4 variation of elevation was approximately 467 m, with a slope of 7.84% and distance of 14,500 between the points. The slope between points probably favored the incorporation of oxygen in the water resource, which accelerates the occurrence of microbiological processes and degradation of organic matter.

The pattern observed for the representative parameters of the nitrogen forms can be linked to the higher contribution of ammonia nitrogen from discharging of domestic effluents, coming from the area with highest population concentration. The subsequent increases of the oxidized forms of nitrogen (nitrate) are arising from the distance of release sources and attenuation of water body. Thus, as the concentration of nitrate increases, the ammonia nitrogen decreases. The analysis of the nitrogenated forms allows the identification of points with higher anthropic influence, since the points allocated closest urban area have higher concentrations of organic / nutrient matter and consequently ammonia nitrogen. According to [12] the reduction of NH_3–N is considered normal in oxygenated waters and has been observed in several studies of attenuation. Further, it suggests that this reduction is caused by several mechanisms, including oxidation (nitrification) and biological assimilation.

High hydraulic exchange between the water column and the river sediment increases the transport of nitrate to pore water with low-oxygen concentrations and therefore increases the

TABLE II: Mean and standard deviation of each point at the 5 samplings

Variables/Points	P1	P2	P3	P4
ORP (mV)	124.20 ± 67.35	196.2 ± 74.5	255.0 ± 82.66	255.4 ± 68.97
TDS (mg/L)	223.20 ± 94.50	185.40 ± 64.75	126.80 ± 43.06	97.00 ± 42.50
DO (mg O_2/L)	10.01 ± 1.66	9.92 ± 1.62	12.32 ± 1.44	12.22 ± 1.43
Cond (mS/cm)	343.80 ± 145.62	285.0 ± 98.64	195.0 ± 66.08	182.0 ± 70.72
Turb (NTU)	6.74 ± 3.85	3.88 ± 1.83	2.24 ± 1.27	2.08 ± 1.00
TP (mg/L)	1.03 ± 0.67	0.98 ± 0.60	0.64 ± 0.39	0.43 ± 0.25
NH_3–N (mg/L)	12.77 ± 6.83	8.43 ± 3.89	0.32 ± 0.33	0.15 ± 0.22
NO_3–N (mg/L)	8.30 ± 3.38	14.34 ± 2.78	41.61 ± 19.22	33.84 ± 15.80
Surf (mg/L)	0.21 ± 0.04	0.19 ± 0.05	0.11 ± 0.04	0.08 ± 0.04
COD (mg O_2/L)	38.60 ± 18.25	24.60 ± 7.74	17.00 ± 7.29	9.20 ± 5.04
BOD_5 (mg O_2/L)	13.46 ± 7.07	8.25 ± 0.70	2.92 ± 1.50	1.31 ± 0.51
COD/BOD_5	3.07 ± 1.14	2.95 ± 0.76	6.62 ± 3.16	8.05 ± 5.67

denitrification rate [29].

Analyzing the Pearson correlation between variables with results of $p < 0,05$ in ANOVA test, strong positives correlations were identified ($\rho > 0.7$) between: BOD and NH_3–N ($\rho = 0.851$); BOD and COD ($\rho = 0.813$); TDS and COD ($\rho = 0.729$); COND and COD ($\rho = 0.730$); and strong negatives correlations ($p > -0.7$) between: NH_3–N and DO= -0.707; TDS and DO $\rho = -0.734$; NO_3–N and Turb= -0.825; DO and cond $\rho = -0.733$; and BOD and NO_3–N ($\rho = -0.734$).

Since all parameters with positive correlations are associated with high levels of organic matter, it is inferred that these are related to the dumping of domestic and industrial effluents with high organic load, thus justifying the correlations with the BOD and COD parameter.

The negative correlation between NH_3–N and DO indicates that when the concentration of one of these parameters increases, the concentration of another parameter decreases. At points upstream of the water resource, were observed the highest NH_3–N values and lowest DO, while downstream there is an inverse relationship. Lowest DO values at points upstream may be associated with the release of domestic and industrial effluents, as well as the consumption of DO in the nitrification process. According to [17], autotrophic bacteria utilize dissolved nitrogen forms to transform organic matter, which is one of the main interactors phenomena in oxygen consumption.

Sperling [30] mentions that the main constituent of turbidity are the suspended solids of anthropogenic origin, such as domestic sewage, industrial and erosion. In these particles solid nutrients are found, including nitrogen. Thus, the negative correlation between NO_3–N and Turb can be explained by the oxidation of nitrogen, i.e. with increasing NO_3–N there is a reduction of the turbidity parameter, since the amount of suspended solids decreases.

IV. CONCLUSION

Results showed that in the points more nearby the urban area (upstream - P1 and P2), occur increase of organic matter and nutrients, due to launch from of domestic and industrial effluents without treatment, with reduction of these parameters at the points downstream (P3 and P4).

Attenuation can be observed through by reduction of BOD, COD and nutrients such as phosphorus and ammonia nitrogen, as well as, by the increase of DO, ORP and nitrate concentration. It was also found that, the levels of the organic matter have had a reduction of approximately 80% and the nitrogen of over 95%. Thus, it can be shown that the Belo stream has effective debugging capability, considering the variability of concentration patterns in sampling points. This ability to attenuation, checked more clearly, between points 1 and 3 or 1 and 4, this possibly associated with distance and slope (greater than 4% and 9,000 m respectively) observed between these points.

Based on the results obtained, it can be inferred that there is an improvement in the water resources quality from upstream to downstream. However, despite the stream have a high attenuation potential, is necessary the development of control actions to input of industrial and domestic effluents, to prevent the ecological impairment of the same.

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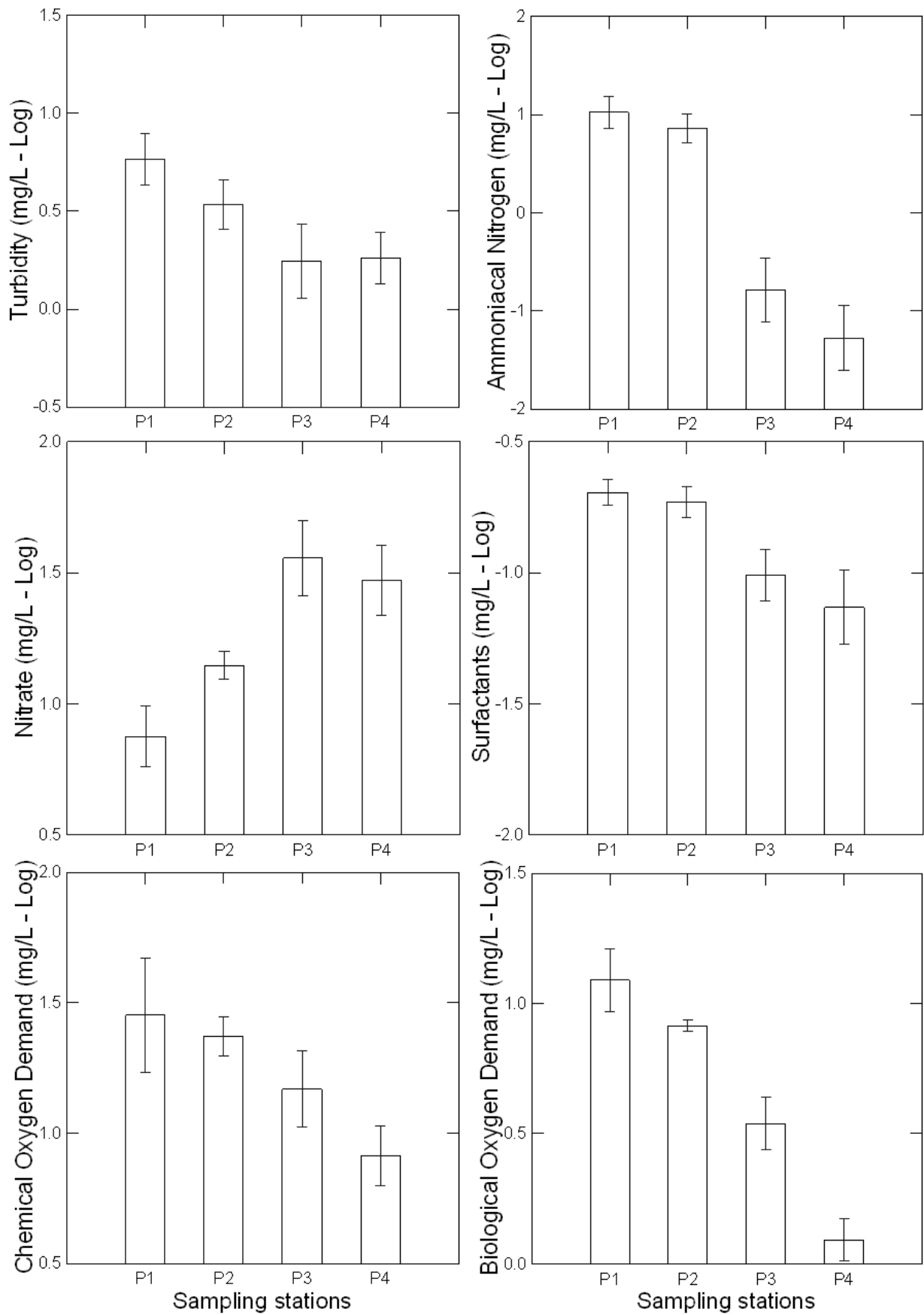
Fig. 4: Results of Tukey's test

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