

# Spatio-temporal study of water quality in a subtropical reservoir and related water bodies in Southern Brazil

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**Abstract**—The importance of hydroelectricity to the world energy grid motivates the implementation of dams and formation of reservoirs. This implies changes in the ecosystem, and therefore those waters must be constantly monitored. Given the relevance of applied scientific research to monitoring data, this study aims at the spatio-temporal characterization of the water quality of Capivari-Cachoeira hydroelectric power plant reservoir located in Southern Brazil, as well as the water supplying it and the water that is restored to the river. Historical monitoring data obtained between 2005 and 2016 were used for the analysis. The factor analysis used for the study of these data resulted in two factors that explain 59.7% of the total variability. The first factor represents the influence of anthropic activities and land use, signaling the existence of polluting sources upstream of the reservoir. The second factor represents seasonality. Kruskal-Wallis tests applied in factor scores and in the variables with higher factor weights resulted in significant spatial and temporal difference. Regarding the first factor, the reservoir station and those located downstream differed spatially from those located upstream. In the reservoir, reduction in concentration of phosphorus and total solids suggests sedimentation, consequently reducing its values downstream. Considering the seasonal factor, the results obtained during winter showed the lowest temperatures and had the highest values of dissolved oxygen, with the exception of the samples from the reservoir. Thus, the control of the nutrient supply in dammed river demonstrated to be an important tool for managing water resources.

**Keywords**— *Hydroelectric reservoir, limnologic monitoring, multivariate statistical analysis, water resources.*

## I. INTRODUCTION

Brazil is part of a group of countries where the production of electricity is massively derived from hydroelectric plants. Approximately seventy five percent of the electric energy generated comes from hydropower. This value is high when compared to other countries indexes, possibly because the country has a great number of plateau rivers, high rainfall and a significant total of watersheds. In this reality, Brazil is considered the country with the world's highest hydropower potential [1], [2].

However, dam implementation in rivers and the flooded areas caused by reservoir formation tend to trigger changes in limnological characteristics of natural area around the dam and downstream. The changes in speed and time of permanence of water can affect the physical and chemical characteristics of the ecosystem, in addition to its biological communities [3], [4].

In this way, hydroelectric reservoirs are subjected to constant monitoring of the quality of their waters, in addition to upstream and downstream areas, as a result of conditioners in environmental licenses of this kind of hydroelectric project. These monitoring programs aim to assess the ecosystem, and the data are discussed in technical reports directed to environmental agencies [1], [5].

Given this context, it is important that these data could be evaluated scientifically, as they express historical information on the behavior of that kind of ecosystem [6]. Scientific studies of the hydroelectric reservoirs and

surrounding water bodies based on long-term monitoring data allows for the observation of ecosystem evolution, in order to better understand problems that interfere with water quality. Thus, they allow the planning and the definition of management proposals for current and future use of the water body [1], [7], [8].

The scientific study of these data often occurs through multivariate statistical analyses, due the complexity of the data, which is related to the large amount of samples and variables, making it possible to find and interpret relationships [6], [8]–[13]. Multivariate statistics are also considered the most suitable for studies of historical series, since they are tools that facilitate the interpretation of spatial and temporal variable relationships related to the object of study, such as anthropogenic influence and seasonality in a specific water body [6], [8], [10].

Thus, through statistical methods, this study aimed the spatio-temporal characterization of water quality of the hydroelectric power plant (HPP) Capivari-Cachoeira reservoir, as well as the water that leads to it and the water returned to the water body, based on prior data from the monitoring program carried out by the concessionaire responsible for the powerplant.

## II. MATERIAL AND METHODS

The study area comprises the reservoir of the hydroelectric powerplant Governador Pedro Viriato Parigot de Souza (also known as Capivari-Cachoeira HPP), Capivari river and the Patos river, both upstream of the reservoir, as well as the Cachoeira river, located down stream of the reservoir, where turbinated water is returned [14].

The power plant went into operation officially in 1971, being the largest underground HPP in Southern Brazil [15]. It features a reservoir with an area of 13.1 km<sup>2</sup>, with a total volume of 178 million m<sup>3</sup> and a drainage area of 1,200 km<sup>2</sup> [14], [15].

The HPP Capivari-Cachoeira produces electric power from a level drop of 740 meters diverting the Capivari river located in a plateau (Ribeira Basin) to the Cachoeira river situated in a littoral plain (Litorânea Basin). The hydroelectric plant's machine house is located in the municipality of Antonina (Litorânea Basin), and the reservoir in the municipalities of Bocaiúva do Sul and Campina Grande do Sul (Ribeira Basin), in the state of Paraná Southern Brazil [14], [15].

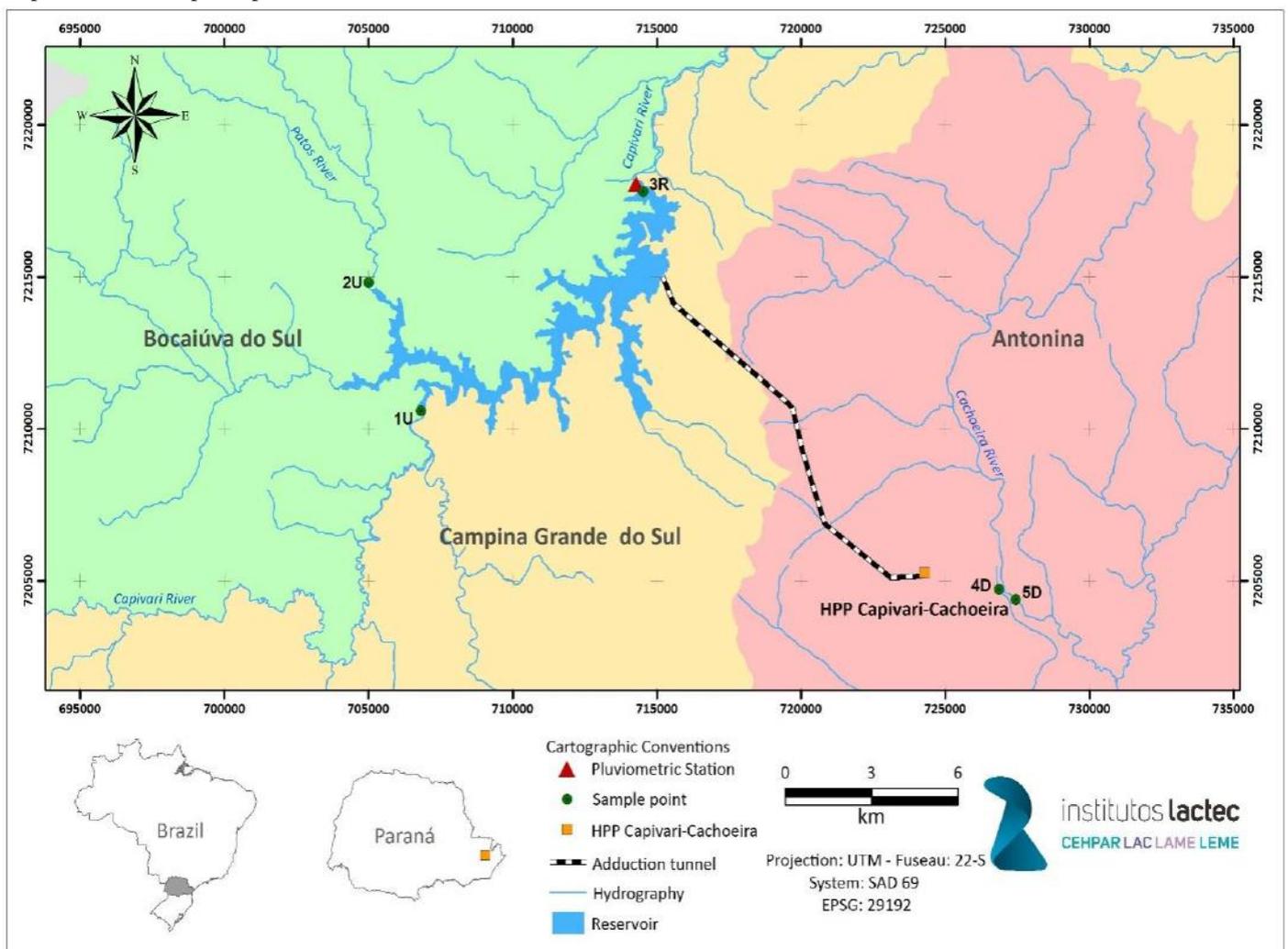


Fig. 1: Location of sampling stations.

Limnological monitoring data from the studied area were collected by from the monitoring program conducted by COPEL – Companhia Paranaense de Energia. These data were collected on a quarterly basis, between 2005 and 2016, in five sampling stations: 1U and 2U, both upstream of the HPP Capivari-Cachoeira reservoir, respectively located in Capivari river, the main river that forms the reservoir and the Patos river, an important tributary of the Capivari river. Sampling station 3R, located in the reservoir, near the dam. And two sampling stations down stream of the reservoir, 4D, located in the restitution channel of turbinated water, and 5D, in the Cachoeira river (Fig. 1).

The variables selected for this study were: water temperature ( $^{\circ}\text{C}$ ), water transparency (m), dissolved oxygen (DO) ( $\text{mg}\cdot\text{L}^{-1}$ ), pH, electrical conductivity ( $\mu\text{S}\cdot\text{cm}^{-1}$ ), total phosphorus (P-Total) ( $\text{mg}\cdot\text{L}^{-1}$ ), total nitrogen (N-Total) ( $\text{mg}\cdot\text{L}^{-1}$ ), total solids (TS) ( $\text{mg}\cdot\text{L}^{-1}$ ), thermotolerant coliforms (NMP.100mL $^{-1}$ ) and biochemical oxygen demand (BOD) ( $\text{mg}\cdot\text{L}^{-1}$ ). The methodology used to collect the samples was the "simple" sampling type, being also based on field data collected at the moment of sampling (data recorded at the field sheet)[16].

Descriptive statistical analysis were applied in order to illustrate variable behavior per sampling station. Factor analysis (FA) was applied to the dataset in order to detect possible patterns in limnological variables and identify spatial and temporal characteristics between the analysed water bodies. This analysis identifies the most significant variables in a large dataset and synthesizes them in to factors [6], [11], [13], [17].

According to França (2009) [17], considering  $X$  a random vector with  $\mu$  mean and covariance matrix  $\Sigma$ , in the factor model,  $X$  is linearly dependent of some non-observable random variables  $F_1, F_2, \dots, F_m$ , named common factors and " $p$ " sources of additive variations  $\varepsilon_1, \varepsilon_2, \dots, \varepsilon_p$ , named errors or specific factors.

In order to eliminate the effects produced by different scales and units, data were log-transformed ( $\log(x+1)$ ), with the exception of pH. In order to apply factor analysis, it was necessary to analyse the data previously to verify whether they were suitable for the application of this technique. Based on this, calculation of the Measure of Sample Adequacy (MSA) was applied according to the Kaiser-Meyer-Olkin (KMO) model. The result of the MSA value under the KMO model shows the proportion of variance that variables presented due to common

factors. In order for the application of factor analysis to be considered adequate for data treatment, the result should be higher than 0.5 [17], [18]. The Bartlett's Test of Sphericity, was also applied. It indicates whether the data matrix presents significant correlations between variables. As a result, p-value must be lower than 0.05[18].

In order to achieve a more suitable setting for the factor model, the MSA was also calculated individually for each variable, using the anti-image correlation matrix, in order to identify variable with MSA lower than 0.5. Those variables, with individual MSA  $<0.5$ , were excluded from the analysis [18].

After initial assessment of the data, factor analysis was then applied, factor extraction occurred through the principal component method. Orthogonal transformation was used to facilitate the interpretation of the factors that composed the matrix. Varimax rotation was applied, distributing factor loadings so that high weights for each variable in a single factor and low or moderate weights in other factors were obtained[17]. The latent-root approaches, established by Kaiser (1958)[19] was used for factor selection, where all factors with eigenvalues higher than 1 were considered significant. For factor characterization, the variables with absolute weight higher than or equal to 0.7 were considered [18]. Thus, the factors considered significant in FA were analysed and plotted on a chart [20]–[22].

The FA was followed by the Kruskal-Wallis test, to evaluate the significance of the ordination axes (dependent variables). The Kruskal-Wallis test of the selected factors was conducted to identify the relative contribution of seasonality and the location to variations of the water quality of the different sampling stations. In this way, the axes of the factor analysis selected for interpretation were tested one at a time, using time and space as explanatory variables, and axis score as dependent variable [20]–[22].

Limnological variables that presented more explanation for the FA were also tested by Kruskal-Wallis to check the relationship space-time, being those used as explanatory variables and the empirical data as dependent variables[20]–[22]. For applying AF, the R statistical environment was used [23]. The software Statistica was used to perform the Kruskal-Wallis test and for plotting graphs[24]. The steps for performing statistical analyses previously described were summarized by flowcharts in Fig. 2.

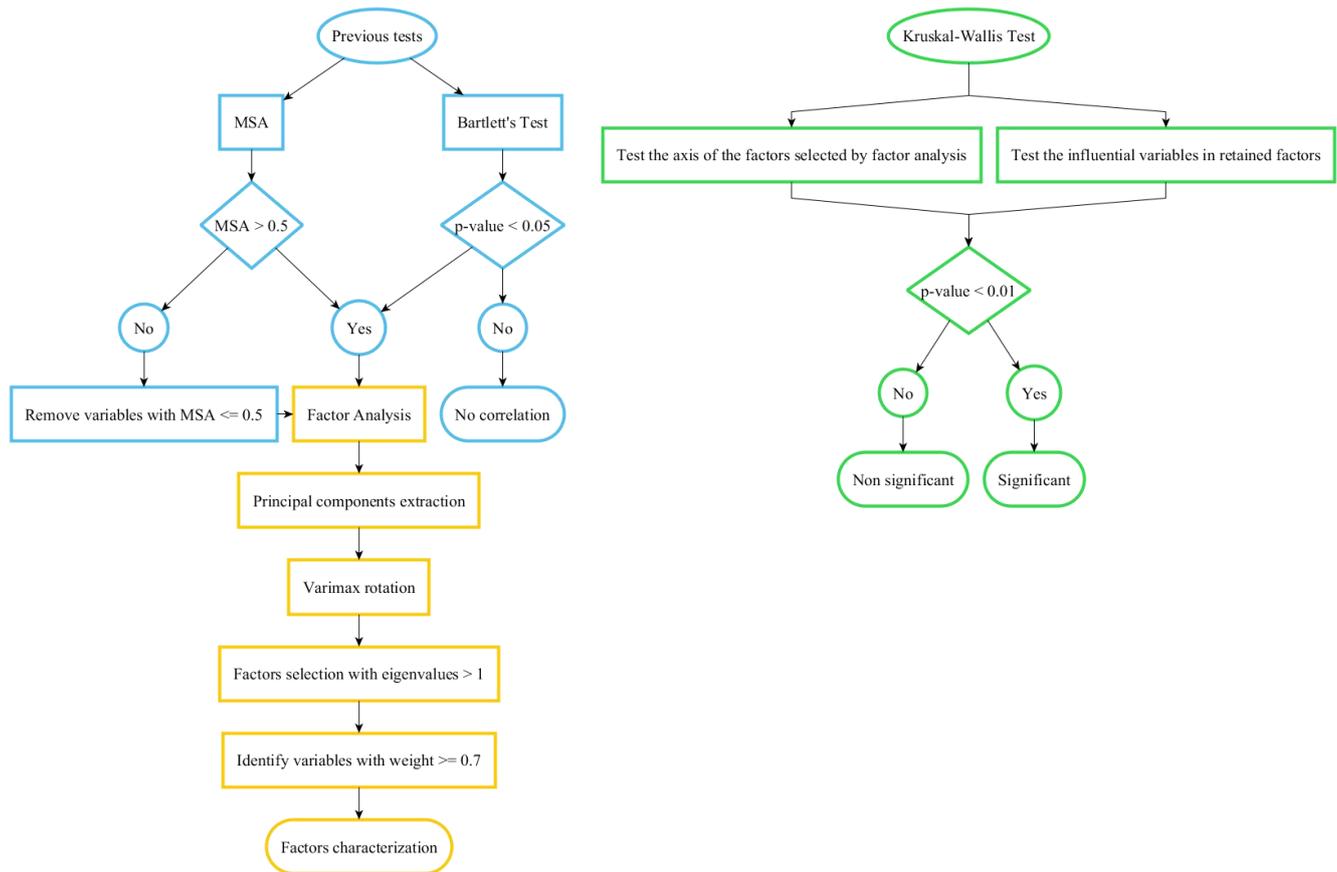


Fig. 2: Flowcharts of statistical methodology stages.

### III. RESULTS AND DISCUSSION

Descriptive statistical analysis per sampling station applied in order to illustrate variable behavior is presented in Table 1.

Table 1: Descriptive statistical analysis of the water quality data studied.

	1U	2U	3R	4D	5D		1U	2U	3R	4D	5D
<b>Watertransparency(m)</b>						<b>Turbidity (NTU)</b>					
Média	0.53	0.56	1.86	0.72	0.71	Média	20.27	14.63	4.01	7.20	5.27
Mediana	0.45	0.50	1.78	0.50	0.60	Mediana	15.50	11.00	4.00	5.50	4.40
Desvio Padrão	0.30	0.29	0.70	0.35	0.33	Desvio Padrão	15.71	11.76	1.81	4.60	2.80
Máximo	1.50	1.30	3.40	1.80	1.60	Máximo	67.70	55.00	10.30	22.00	13.40
Mínimo	0.10	0.10	0.60	0.30	0.20	Mínimo	1.00	1.00	1.00	2.00	1.00
<b>Watertemperature (°C)</b>						<b>Dissolvedoxygen (mg.L<sup>-1</sup>)</b>					
Média	18.24	18.05	21.91	19.23	19.43	Média	8.22	8.32	7.18	8.65	8.90
Mediana	18.60	18.80	22.25	19.70	19.85	Mediana	8.16	8.30	7.19	8.48	8.85
Desvio Padrão	3.18	3.50	3.35	2.07	2.07	Desvio Padrão	1.46	1.23	2.05	1.26	1.04
Máximo	22.60	27.60	28.30	23.30	24.00	Máximo	13.85	12.75	14.44	11.60	10.90
Mínimo	11.00	11.00	16.10	16.10	15.90	Mínimo	4.16	4.90	3.92	5.00	5.40
<b>pH</b>						<b>Electricalconductivity (µS. cm<sup>-1</sup>)</b>					
Média	7.40	7.57	7.73	7.03	7.13	Média	90	51	69	71	57
Mediana	7.45	7.55	7.65	7.10	7.20	Mediana	93	47	70	72	57
Desvio Padrão	0.34	0.43	0.47	0.30	0.30	Desvio Padrão	20	12	7	9	11

Máximo	7.90	8.70	9.10	7.60	7.70	Máximo	139	96	83	90	78
Mínimo	6.50	6.70	6.80	6.10	6.20	Mínimo	47	30	54	54	39
<b>Totalphosphorus (mg.L<sup>-1</sup>)</b>						<b>Totalnitrogen (mg.L<sup>-1</sup>)</b>					
Média	0.072	0.057	0.023	0.024	0.030	Média	1.73	1.05	1.08	1.14	0.94
Mediana	0.060	0.039	0.020	0.020	0.030	Mediana	1.60	0.78	0.85	0.94	0.70
Desvio Padrão	0.035	0.059	0.042	0.017	0.011	Desvio Padrão	0.89	0.70	0.74	0.70	0.64
Máximo	0.150	0.300	0.290	0.110	0.070	Máximo	3.60	3.40	3.30	3.40	3.70
Mínimo	0.030	0.010	0.001	0.001	0.001	Mínimo	0.50	0.50	0.50	0.50	0.50
<b>Total solids (mg.L<sup>-1</sup>)</b>						<b>Thermotolerantcoliforms (NPM.100mL<sup>-1</sup>)</b>					
Média	92	74	55	60	52	Média	2021	1467	24	107	219
Mediana	87	58	54	57	51	Mediana	785	355	2	2	22
Desvio Padrão	20	49	16	13	13	Desvio Padrão	4247	2643	120	415	558
Máximo	156	316	138	115	107	Máximo	25000	13000	780	2600	3100
Mínimo	63	30	26	30	29	Mínimo	1	1	1	1	1
<b>BOD (mg.L<sup>-1</sup>)</b>											
Média	2.60	2.43	2.14	2.19	2.26						
Mediana	2.00	2.00	2.00	2.00	2.00						
Desvio Padrão	1.97	2.09	1.24	1.44	1.37						
Máximo	10.15	12.90	7.60	9.15	6.06						
Mínimo	1.00	1.00	1.00	1.00	1.00						

The MSA (=0.58) and Bartlett sphericity (p<0.05) tests showed that the data were adequate for applying factor analysis. The adequacy to the factor model was applied more thoroughly by removing the variables with MSA lower than 0.5. In this way, electricalconductivity data, BOD and pH were excluded, whose individual MSA values were: 0.38, 0.41 and 0.43, respectively. Once those variables were removed, general MSA resulted in 0.71.

The factor analysis explained 59.7% of their total variability, retaining the first two factors. The Factor 1 (F1), explained 39.5% of the data variability, and was described by total phosphorus (+), total solids (+) and turbidity (+). Whereas Factor 2 (F2) explained 20.2% of the data variability and was represented by water temperature (+) and DO (-) (Table 2).

Table. 2: Factoranalysis result.

RotatedComponent Matrix		
	F1	F2
Watertransparency	-0.614	0.489
Watertemperature	-0.102	<b>0.741</b>
Dissolvedoxygen	0.122	<b>-0.831</b>
Total nitrogen	0.504	0.220
Total phosphorus	<b>0.797</b>	-0.114
Turbidity	<b>0.866</b>	-0.130
Total solids	<b>0.826</b>	-0.209
Thermotolerantcoliforms	0.673	-0.248
Eigenvalue	3.163	1.612
Variance %	39.500	20.200
Cumulativevariance%	39.500	59.700

Fig. 3 shows the graph of sample scores to analyse the spatial and seasonal behavior of the data series. Fig.4 displays the weight chart for the first two factors. Weights of the original variables in linear combination define each

factor. The relationship between variables can be observed in the weight graph. Based on these relations, it is possible to infer an interpretation for these factors [25].

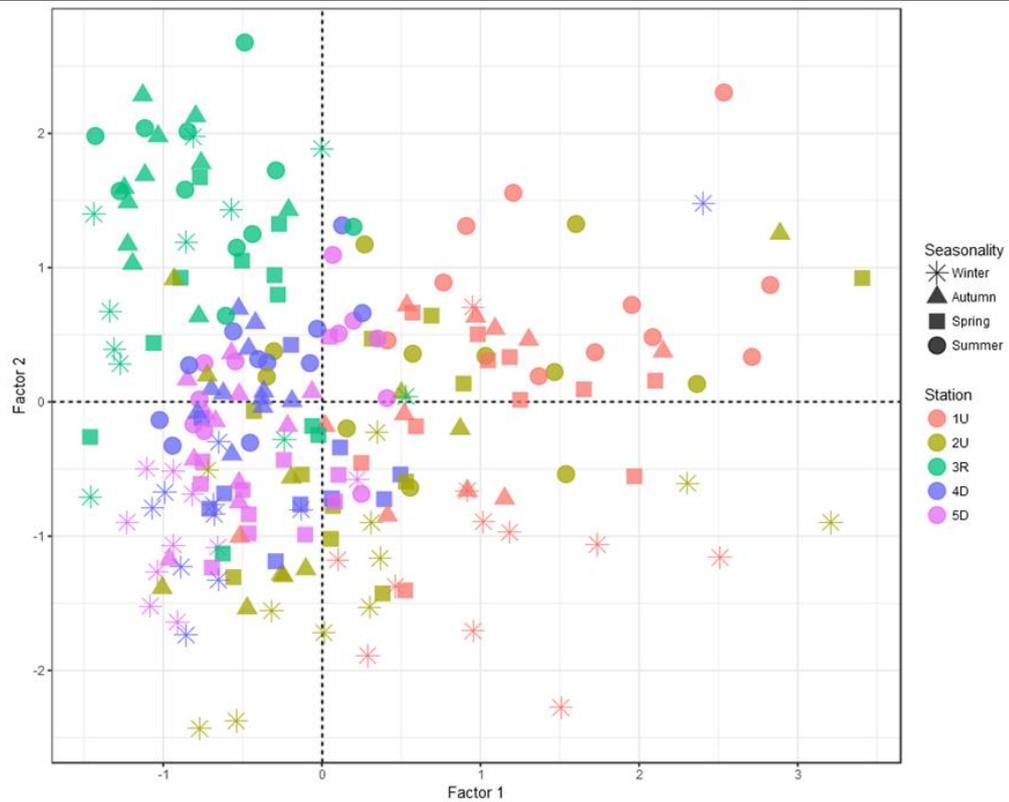


Fig. 3: Scores of the samples plotted in the plane defined by factors 1 and 2.

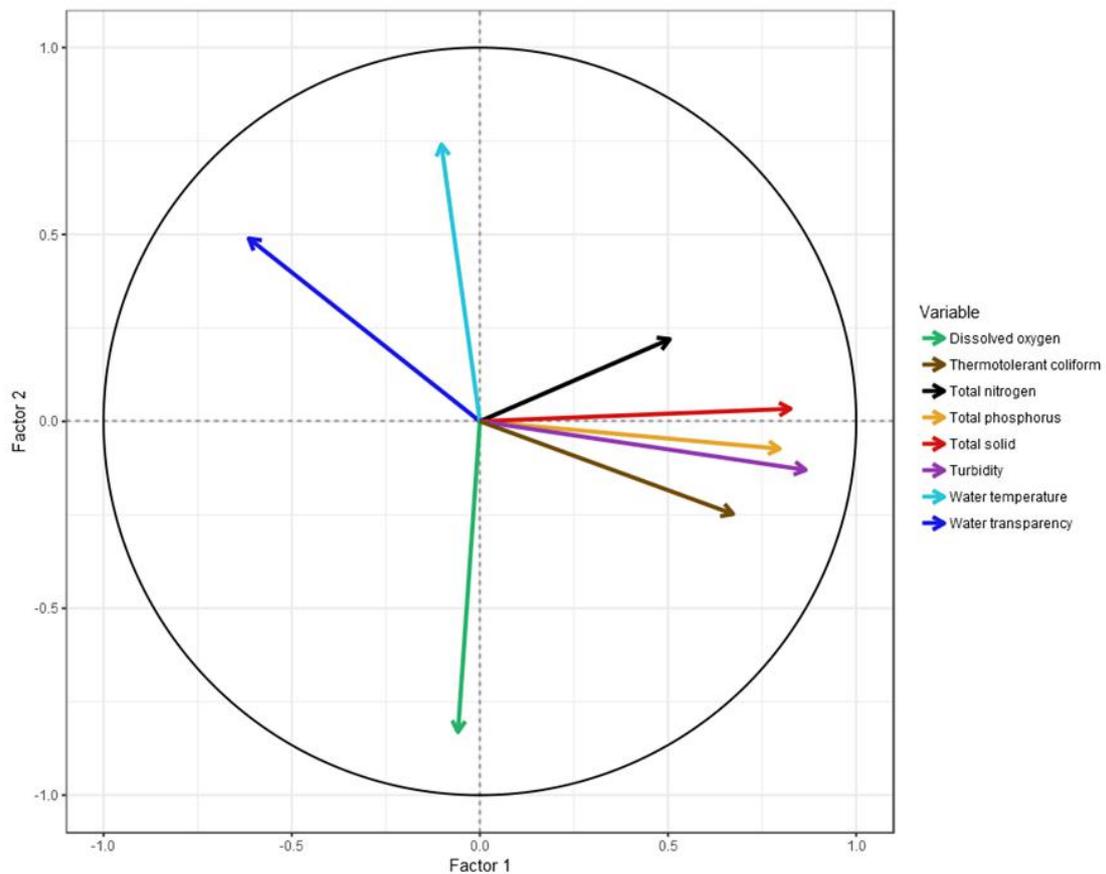


Fig. 4: Weights of the variables of the factors plotted in the factor 1 x factor 2 plan.

It is possible to identify that the variables constituting the F1 represent the influence of anthropogenic activities and land use of the surroundings, signaling the existence of polluting sources upstream of the reservoir. Over the studied years, sampling stations 1U and 2U presented the higher values for these abiotic variables (P-Total, TS and turbidity) (Table 1).

The sampling events conducted in Capivari river (1U) were more influenced by the first factor (Fig. 3). The surroundings of the Capivari river present high population density, which generates environmental pressure, such as the dumping of untreated waste, farming activities on the banks of the river, and deforestation [26],[27].

At the station of Patos river (2U), there was a higher dispersion of points (that represent samplings at this location) (Fig. 3), according to the seasons of the year and possibly due to the entry of allochthonous material originated from anthropic action in this water body. Land use in the region of Patos river is mostly rural, especially with regard to livestock, with generation of pollution loads possibly occurring due to animal waste dump in the water body [26]. Patos river, for being one of the main affluent of the Capivari river, directly interferes in its quality, and also in the quality of Capivari-Cachoeira reservoir.

This river has recently been classified from class 2, to class 4, according to its river basin committee. This reduction of class also restricts the multiplicity of uses these waters have, since the quality required for class 4 is lower than the one needed to sustain the water uses displayed for the class 2 [28], [29].

According to a study conducted using data from 2005 to 2009 of rivers and reservoirs in the state of São Paulo (southeastern Brazil), class 4 environments can be considered irrecoverable or as final, inevitable destination for domestic or industrial effluents [30].

Thus, the rivers Capivari and Patos are affected by diffuse pollution originated from the land use (industrial and rural activities), which possibly contributed to the values of phosphorus and total solids [26], [27]. It is important to note that the Capivari river lies in the expansion plan of the watersheds that supply Curitiba, being aimed for future use [31].

One of the consequences of urban growth in Brazil is the vulnerability of water resources in industrialized and densely populated regions, aggravated by changes in land use and poor sanitation infrastructure [32].

The high concentrations of phosphorus upstream to the Capivari-Cachoeira reservoir are worrisome, since it is expected that these concentrations will enrich the reservoir over time, contributing to eutrophication. This fact occurs since phosphorus is, in part, retained in the reservoir, be it due to sedimentation related to the

elevated residence time, or due to the use of phosphorus by phytoplankton.

Limnological characteristics of reservoirs make them function as accumulators of information of the drainage basin in which they are located, as well as reflecting the activities conducted in the surroundings [33].

Waste produced by anthropogenic activities, such as industrial effluents and drainage from urban areas, when discarded without proper treatment, can be a source of pollution for the river and, consequently, for the reservoir [25].

In this way, the reservoir water quality becomes an important indicator of the influences in the basin and may act as an accumulator of the changes occurring upstream.

Factor 2 (F2) retained the variable water temperature (+) and dissolved oxygen (-), representing the seasonality. Such factor demonstrates the relationship between the solubility of this dissolved gas in the water body with the temperature. Gases behavior, including dissolved oxygen, is related to temperature, since its increase makes gases less soluble [1].

Temperature is a determining factor in water quality, as it may interfere with chemical and biochemical reactions, in addition to altering biological processes that occur in the water [12], [34].

According to the results of FA (Fig. 3) it was possible to identify that the winter and summer samples at the lotic environment stations presented greater distances from each other. The increase in water temperature also provides increase in the metabolic activities of organisms, elevating their respiratory rates, triggering an increase in the consumption of dissolved oxygen in the water [13], [35].

Water samplings conducted during winter presented the lowest temperatures and had the highest DO values, at the lotic environment. In the other hand, the ones conducted in reservoir did not follow that pattern. This result may be related to stratification processes of this reservoir, as well as the dynamics of its phytoplankton community [36].

In a study conducted in the state of Paraná, in the region of the HPP Foz do Areia reservoir, the relationship between DO and water temperature in the sampling stations located upstream and downstream of the reservoir and the lack thereof in the reservoir was observed [1]. It is possible that such a relationship between DO and temperature has not been registered in the reservoir stations, due to the influence of stratification processes [1]. Thermal stratification forms a physical barrier, with significant differences in water density. This way, heat is not distributed homogeneously in the water column, as well as DO.

Samples with highest values of water temperature collected downstream of the reservoir and Patos river are similar to those collected at the reservoir (Fig. 3).

Seasonality had a higher weight in defining the similarity of water quality than spatial variation in a study conducted in the surface waters of the drainage basin of Bandeira stream, Mato Grosso do Sul state (Brazil)[12].

The Kruskal-Wallis test of the factor axes selected for interpretation resulted, for F1, insignificant differences for space ( $p < 0.01$ ) and time ( $p < 0.01$ ).

In general, there is a clear spatial difference between the sampling stations. The station in Capivari river, upstream from the reservoir (1U) is the site with major differences between the reservoir station (3R) and downstream (4D and 5D), also being a little more similar to 2U, a sampling station in Patos river, also upstream of the reservoir (Fig. 3 and Fig. 5).

The sampling station in Capivari river showed seasonal variation in summer compared to other seasons. In general, during summer it was recorded the highest values for the variables retained in F1 (total phosphorus, total solids and turbidity). Regarding samples from station 4D, it is possible to notice that those collected during winter were quite different from the remaining. Samples from winter 2012 had the highest values of phosphorus, total solids and turbidity (Fig. 3), making it more similar to the samples collected at Capivari river (1U) and some samples (spring 2010 and fall 2012) from Patos river (2U) (Fig. 3). The major seasonal variations for the variables retained in this factor were found, at 3R and 4D sampling stations, between fall/winter and fall/spring and for the remaining sampling stations, between summer/winter.

The Kruskal-Wallis test performed on the variables retained in FA, factor 1, resulted in spatial ( $p < 0.01$ ) and

time ( $p < 0.01$ ) differences for turbidity, whereas total phosphorus and solids only presented significant spatial difference ( $p < 0.01$ ).

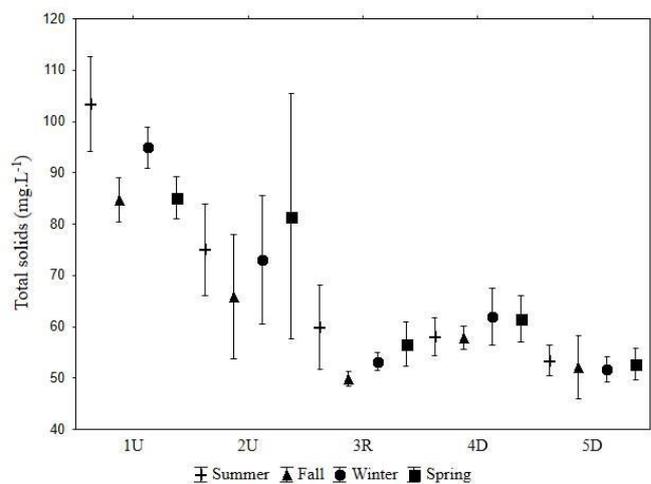
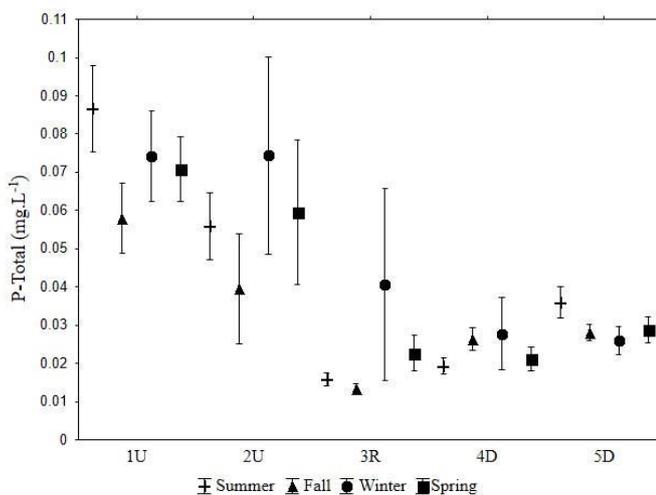
The results of these variables have shown the characteristics of the reservoir over them, since station 3R and the stations located downstream of it differed from the upstream sampling stations (Fig. 5).

In the reservoir, reduction in variable values constituting F1 seem to imply sedimentation of phosphorus and total solids, consequently also reducing its values downstream (Fig. 5). Hence, it was possible to identify that the upstream stations (1U and 2U) are more similar to each other, as well as the downstream ones (4D and 5D) (Fig. 3 e Fig. 5)

Sediments and particles can be transported from a watershed and into reservoirs, where a fraction can be retained due to the reduced flow[4]. Dams act as nutrient sinks, which may promote the accumulation of nutrients in reservoirs, consequently leading to decrease in downstream nutrient concentration [3], [4].

A study also conducted in the HPP Capivari-Cachoeira reservoir identified that the analysed nutrients, including total phosphorus and total nitrogen, presented high concentrations near the river portion with decrease in values and turbidity towards the dam, where the Capivari reservoir showed a clear longitudinal gradient[36].

A similar situation was also observed upstream of reservoirs located in Santa Maria da Vitória watershed, at Espírito Santo state (Brazil), where water quality was degraded by the presence of domestic sewage released without treatment, improving downstream water quality due to sedimentation promoted by the reservoir [37].



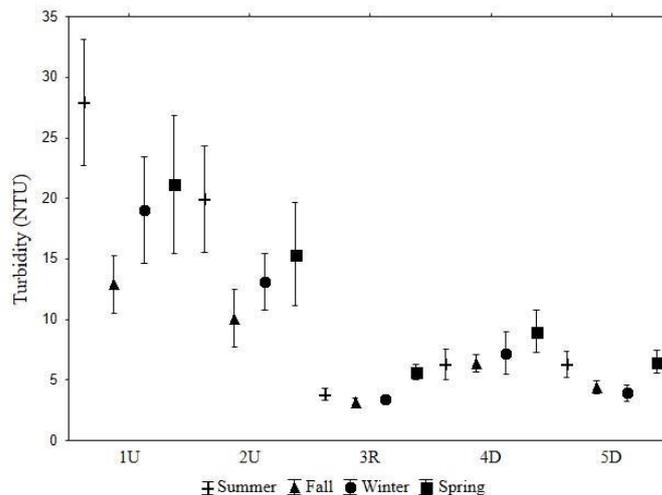


Fig. 5: Representation of the Kruskal-Wallis test result for the variables retained in F1.

Fantin-Cruz et al. (2015)[38] identified that, compared to a reference site upstream, the HPP Ponte de Pedra reservoir, located in Pantanal ecosystem (Brazil), significantly decreased the turbidity and concentrations of total solids, total phosphorus and nitrate. Similarly, to what was found in this study, the changes were not always negative. Thus, oftentimes, but not always, the reservoir caused reductions in these variables concentrations with regard to upstream stations. Also, in a study conducted in the upper Paraná river (Brazil), the large reservoirs built there were found to be responsible for the decrease in sediment load of the river downstream [39].

The study conducted by Santana et al. (2017)[22], also in the upper Paraná river, identified that the dam Porto Primavera retains more than 70% of total phosphorus of the Paraná river. Similarly, to what was found in this study, low values of total phosphorus and nitrogen

occurred, as well as high values of transparency of the water downstream of the dam.

The Kruskal-Wallis test of the factor axes selected for interpretation also resulted, for F2, into significant differences for space ( $p < 0.01$ ) and time ( $p < 0.01$ ).

This result demonstrates the difference in the influence of seasonality on the reservoir in relation to the upstream and downstream sampling stations located in lotic environments. As previously discussed, all the sampling stations, with the exception of the reservoir, presented the lowest temperatures and the highest values of dissolved oxygen in winter, showing the relation of the solubility of the DO with temperature. The reservoir presents distinct characteristics, such as stratification processes, a fact that may explain its distinct pattern.

Regarding to the variables retained in factor 2, dissolved oxygen presented statistically significant spatial and temporal difference ( $p < 0.01$ ) (Fig 6).

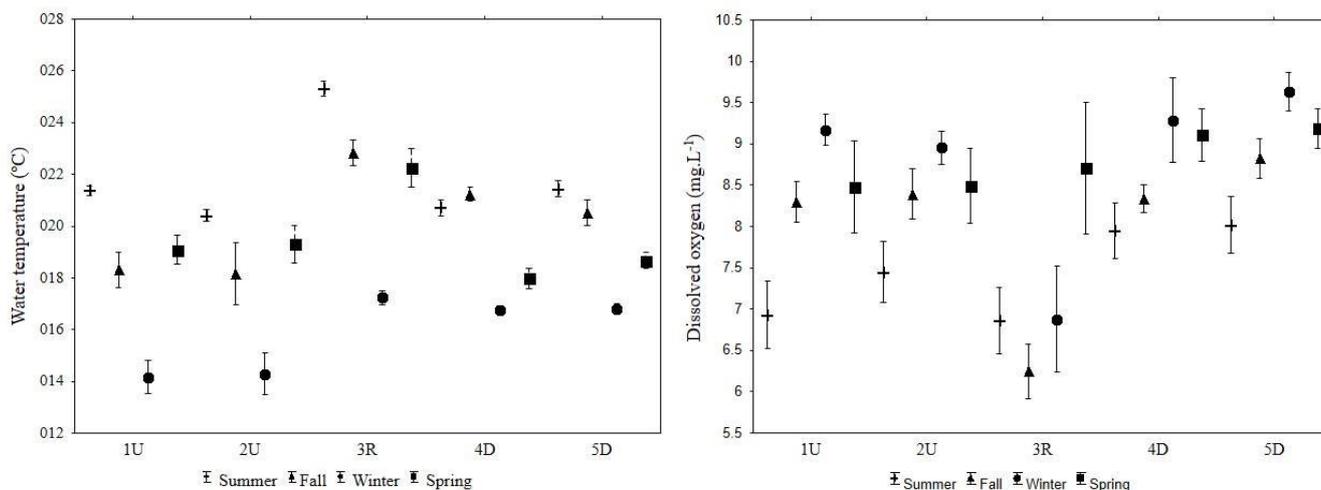


Fig. 6: Representation of the Kruskal-Wallis test result for the variables retained in F2.

The mechanisms that interfere with the balance of dissolved oxygen in aquatic environments are mainly atmospheric diffusion and photosynthesis. Organic matter oxidation, biological demand and nitrification determine the decrease in dissolved oxygen concentrations, where the first can be the main responsible for the consumption of dissolved oxygen in the water [34].

In general, the river points presented the highest values for the variable dissolved oxygen, and the reservoir presented the lowest values and highest oscillation (Fig. 6). Similar results were found in studies conducted in rivers located in Paraná (Brazil), where the high DO concentration is explained by the characteristics of the rivers, which cause greater turbulence and consequently increase oxygen transfer at the interface air-water[40], [41].

The dissolved oxygen concentrations in the reservoir station (3R) were the most diverse compared to the other locations studied, with its highest values occurring during spring. The reservoir offers more favorable conditions for the development of phytoplankton communities, in addition to the accumulation of nutrients [42]. Thus, this result is possibly related to phytoplankton communities that, due to photosynthesis and respiration processes, cause changes in DO concentrations in a seasonal or even daily basis. The widest range of values also occurred in the sampling station of the reservoir (3R), and may be related to possible events of algae blooms, which provide greater primary production and, therefore, peak increases in dissolved oxygen concentration during the day [1]. The smallest DO values of the reservoir may also be related to slower water flow compared to the sampling stations located in lotic environments.

The stations upstream of the reservoir (1U and 2U) did not present significant differences between them (Fig. 6). This result may be related to the existence of increased anthropogenic influences around these rivers, which increase labile allochthon matter and can interfere with DO values, due to decomposition processes [34].

The concentrations of DO studied by Pedrosa et al. (2015) in a section of the Paraná river were directly influenced by dumping of sewage, presenting reduced values in that portion after the sewage discharge [43]. Another study conducted in the state of Paraná, in Pitangui river, also related lower dissolved oxygen values to the influence of domestic sewage and agricultural areas[44]. This relationship was also identified in the Iguaçú river in the metropolitan region of Curitiba, Paraná, in a section with higher population density, where high deposition of unstable organic matter originated from wastewater probably caused consequent DO depletion and water quality degradation[45].

Higher dissolved oxygen values in the sampling stations downstream of the reservoir were observed (4D and 5D). This factor may be related to the flow rate being increased due to the basins diversion [46]. Physical conditions are favored in rivers that are more turbined, having therefore higher reaeration, thus influencing dissolved oxygen values [47].

The water temperature showed significant spatial-temporal differences ( $p < 0.01$ ) (Fig. 6). The wide range of variation in the data during all monitoring seasons occurred due to the seasonality of the sampling periods (four seasons).

The sampling station located in the reservoir (3R) is the one that differed most compared to the remaining stations (Fig. 6). The seasonal pattern has shown that collections performed during summer and autumn are more similar to each other.

Variations in water temperature occur due to natural causes, such as altitude, latitude, season, time of day, flow rate, depth and solar energy, as well as by anthropogenic factors, among them, industrial dumps. Water temperature also suffers seasonal and diurnal variation, in addition to vertical stratification [35].

In a study conducted in the region of HPP São Jorge reservoir (Alagados reservoir), Paraná, results showed the influence land use and passage of water through the reservoir as well as seasonality, in which samples collected in the same season had more similar water quality[44].

Arruda, Knopik e Sottomaio (2017)[6] when using factor analysis for analysing water quality of Tibagi river, in Paraná, also found the descriptive factors of the influence of urban centers as well as that of seasonality in water quality. These factors also retained the variables total solids, total phosphorus and water transparency in opposite directions; in another factor, coliforms represented the land use, and the dissolved oxygen and water temperature, seasonality.

#### IV. CONCLUSION

The analyses demonstrate the significant influence of surrounding land use upstream of the reservoir, characterized by population density and farming activities.

It was possible to identify that nutrients supply from the tributaries, generates a high concentration of total solids which, due to lower flow and considerable water retention time in the reservoir, makes it function as a nutrient sink, influencing therefore the concentrations observed downstream.

Seasonality was also a significant factor for water quality as well as for differentiating the reservoir from the other sampling stations. The sampling station located in

the reservoir was the one that differed most compared to the others.

Thus, according to the analysed data, the cause of possible changes in water quality of the reservoir is related to contributions coming from upstream.

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