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The relationship between water flow and water quality in an experimental coastal watershed microbasin in Northeastern Brazil

Relação entre vazão e qualidade da água em uma microbacia experimental do tabuleiro costeiro no Nordeste do Brasil

Relación entre caudal y calidad del agua en una pequeña cuenca costera experimental en el Noreste de Brasil

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Abstract

Water quality is an important tool to support the planning and management of water resources. This article has as its main objective to evaluate changes in the quality of the surface waters of the Timbó stream as a function of flow in an experimental watershed located in São Cristóvão (SE), northeastern Brazil. Four sampling campaigns were carried out in 2018 to evaluate pH, dissolved oxygen, electrical conductivity, total dissolved solids, turbidity and temperature at three collection points. Data on land use and occupation and the flow of the Timbó stream were also obtained. The land use and occupation survey indicated that 51% of the total area of the microbasin is occupied by forests and that 49% is composed of pasture, undergrowth and exposed soil. The correlation analysis identified a strong correlation (p-value <0.05) between the studied parameters, with an emphasis on a direct relationship between Q and TUR (r = 0.9) and Q and O (r = 0.6) and an inversely proportional relationship between TDS and CE (r = -0.8), confirming the results of a principal component analysis, where the parameters contributing the most to the quality of the investigated water resource were CE, TDS, OD and turbidity.

Keywords: Water resources; Environmental monitoring; Soil use.

Resumo

A qualidade da água é um importante instrumento de apoio ao planejamento e gestão dos recursos hídricos. Este artigo tem como principal objetivo avaliar as alterações na qualidade das águas superficiais do riacho Timbó em função da vazão, em uma microbacia experimental, em São Cristóvão (SE), nordeste do Brasil. Quatro campanhas de amostragem foram realizadas em 2018, para avaliação dos parâmetros pH, oxigênio dissolvido, condutividade elétrica, sólidos totais dissolvidos, turbidez e temperatura, em três pontos de coleta. Também foram obtidos dados de uso e ocupação do solo e vazão do riacho Timbó. O

levantamento de uso e ocupação do solo mostrou que 51% da área total da microbacia é ocupada por floresta e que 49% é composto por pastagem, vegetação rasteira e solo exposto. A análise de correlação identificou forte correlação (p-value < 0.05) entre os parâmetros estudados, com destaque para a relação direta entre os valores de Q e TUR (r = 0.9) e Q e O (r = 0.6) e para a relação inversamente proporcional entre os valores de TDS e CE (r = -0.8), ratificando os resultados encontrados na análise de componentes principais, onde os parâmetro que obtiveram maiores contribuições para a qualidade do recurso hídrico investigado foram a CE, TDS, OD e turbidez.
Palavras-chave: Recursos hídricos; Monitoramento ambiental; Uso do solo.

Resumen
La calidad del agua es una herramienta importante para apoyar la planificación y gestión de los recursos hídricos. Este artículo tiene como objetivo principal evaluar los cambios en la calidad de las aguas superficiales del arroyo Timbó en función del caudal, en una pequeña cuenca experimental, en São Cristóvão (SE), nordeste de Brasil. En 2018 se realizaron cuatro campañas de muestreo, para evaluar los parámetros pH, oxígeno disuelto, conductividad eléctrica, sólidos disueltos totales, turbidez y temperatura, en tres puntos de recolección. También se obtuvieron datos sobre uso y ocupación del suelo y caudal del arroyo Timbó. La encuesta de uso y ocupación de la tierra mostró que el 51% del área total de la pequeña cuenca está ocupada por bosques y que el 49% está compuesto por pastos, sotobosque y suelo expuesto. El análisis de correlación identificó una fuerte correlación (p-valor <0,05) entre los parámetros estudiados, con énfasis en la relación directa entre los valores de Q y TUR (r = 0,9) y Q y O (r = 0,6) y para la relación inversamente proporcional entre los valores de TDS y CE (r = -0,8), lo que confirma los resultados encontrados en el análisis de componentes principales, donde los parámetros que obtuvieron las mayores contribuciones a la calidad del recurso hídrico investigado fueron la CE, TDS, OD y turbidez.
Palabras clave: Recursos hídricos; Monitoreo ambiental; Uso del suelo.

1. Introduction

Population growth results in increased demands concerning the use of natural resources. This growth, however, has accelerated and, in many cases, does not comply with environmental laws (Santos et al., 2017; Ferreira et al., 2020). In view of the possibility of a scarcity of natural resources, there is a need to develop proposals to ensure resource quality maintenance for future generations (Romeiro, 2012; Moraes et al. 2020). Based on this context, Lira and Cândido (2013) define that, due to the high level of dependence that humans and other living being exhibit in relation to water use, aggravating implications may arise due to its availability, both concerning quality and amount.

Aiming at establishing ways to maintain water sustainability, studies involving hydrographic basins become essential, since these are fundamental water resource management and environmental planning units and extremely vulnerable to anthropic interventions (Carvalho, 2014). According to Souza and Gastaldini (2014), water quality reflects environmental hydrographic basin conditions. Thus, understanding basin characteristics expands ecological knowledge concerning these ecosystems, allowing for the detection of changes arising from human activity.

Assessing water quality is essential for water resource management plans, and the use of physical-chemical water quality indicators consists in assessing variables correlated to basin changes, whether anthropic or natural and, in this regard, type of land use and occupation are considered adequate parameters in assessing these variables (Barreto et al., 2014). The link between land use variables and specific response criteria can aid in the choice of better strategies aiming at reducing water quality problems (Carey, 2011; Garcia et al., 2009; Aguiar Netto et al. 2013).

Currently, the use of Geographic Information Systems (GIS) alongside land use and land cover data, has allowed for better hydrographic basin assessments (Carey, 2011). In the last decades, several studies have demonstrated the importance of mapping land cover and investigating its relationship with water quality (Lima, Mamede & Lima Neto, 2018).

Given the above, the present study aimed to verify the influence of different flow levels on water quality variable behavior and map different types of land use and occupation.

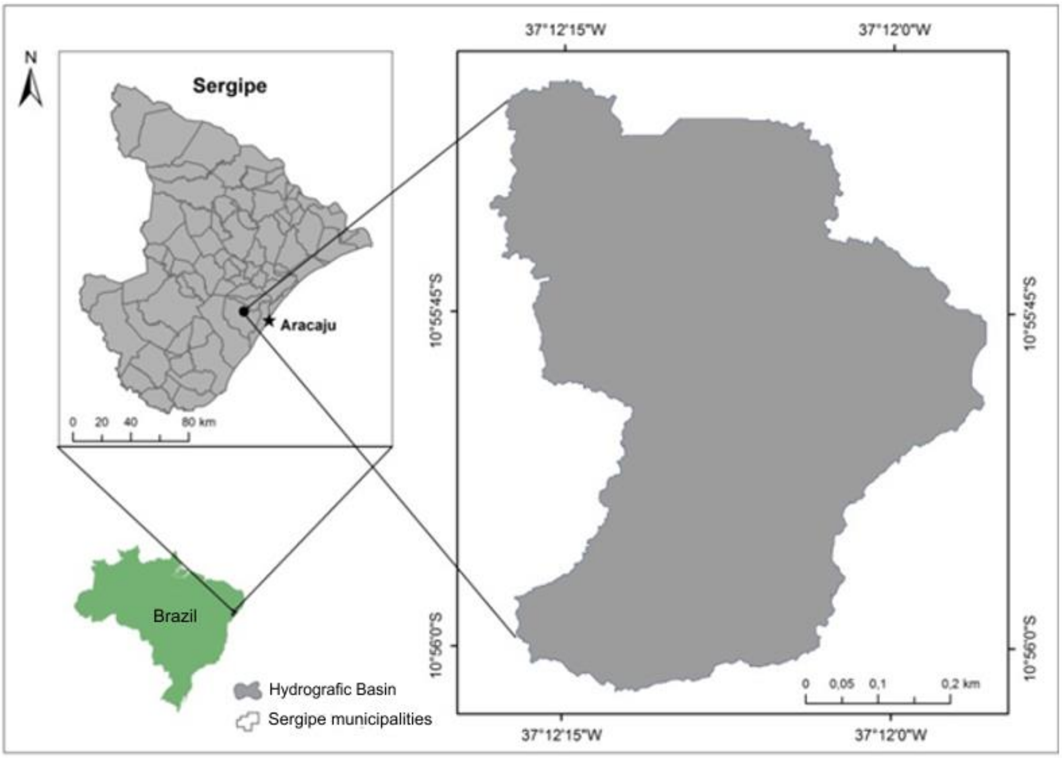
2. Methodology

2.1 Study Area

The present study was carried out at Timbó stream, located at the experimental watershed (MBE) of the Federal University of Sergipe (UFS), in the municipality of São Cristóvão (SE), Brazil, located between coordinates 10°55'38 " and 10°56'00' 'South and 37°12' 21" and 37°12'00" West. The Timbó stream is the main tributary of the Poxim-Açu

River, an essential water body located at the Poxim River hydrographic sub-basin, in the coastal tableland region of Northeastern Brazil (Figure 1). According to Silva et al. (2004), the Poxim River is responsible for 30% of the water supply of great Aracaju city.

Figure 1. Map exhibiting the location of the Timbó stream experimental watershed, SE, Northeastern Brazil.



Source: Authors.

2.2 Delimitation of the Timbó Stream Basin

The delimitation of the Timbó stream basin was performed automatically with the aid of a Geographic Information System (GIS). Relevant information acquired using the digital elevation model (MDE) from the Shuttle Radar Topography Mission (SRTM) was used, with a spatial resolution of 30 m. These data are available at the American Space Agency (NASA) USGS (2018) website.

2.3 Data from Unmanned Aerial Vehicle Sensors

Images from unmanned aerial vehicles (UAV) were provided by the Sergipe Remote Sensing Group (GSER). The images were acquired from a Phanton-4 Pró UAV with a multiengine platform. The photogrammetric processing of the images was performed using the Agisoft Photoscan, software (2014). The flight was conducted during a clear day (25/04/2018), at 100 m above the ground at a wind speed of approximately 10 m s^{-1}.

2.4 Land Use and Cover Mapping

Land use and cover mapping was performed manually via a computer screen on a 1:250 scale from the orthoosaic generated in the UAV image processing step. Visual image interpretation elements comprised tonality, shapes, textures and size. Initially, a file with a polygon resource type was created, attached to the appropriate spatial reference. Subsequently, five land use classes were defined by the polygon when analyzing the images, as follows: forest, pasture, exposed soil and undergrowth. The land use and cover mapping was performed using the SIG QGis version 2.3.2 software.

2.5 Hydroclimatic Variables

To calculate the watercourse flow rate (Q), data on the hydraulic load (water depth) were obtained with the aid of a nOTT Thalimedes linigraph. The linigraph was installed in a triangular spillway of a masonry dam located at the exhutory of the experimental Timbó stream watershed. The hydraulic load values were transformed into flow units (L s^{-1}) and then transformed to mm. The flow values were integrated for a daily scale, from the sum of local rain values and the means of the daily Q values of the water quality campaign.

2.6 Water Quality

Four water quality sampling campaigns were carried out, from April/2018 to June/2018 (04/10/2018, 04/30/2018, 05/18/18 and 06/11/2018). The following variables were determined: pH, dissolved oxygen, electrical conductivity, total dissolved solids, turbidity and temperature, all measured *in loco* with a multiparameter probe (Hanna, HI 9829). All electrodes were calibrated with standard solutions prior to the analyses. All determinations were performed at three collection points: PRT-01 (near the source), PRT-02 (near the spillway) and PRT-03 (after the spillway).

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2.7 Data Analysis

The relationship between water quality parameters and flow data was assessed by the correlation coefficient (r). A Principal Component multivariate statistical analysis (PCA) was used to verify which parameters were involved in the maximum water quality variability, (i) considering the different sampling dates and (ii) the three different points analyzed along the stream. All statistical analysis was performed using the R 3.2.2 software.

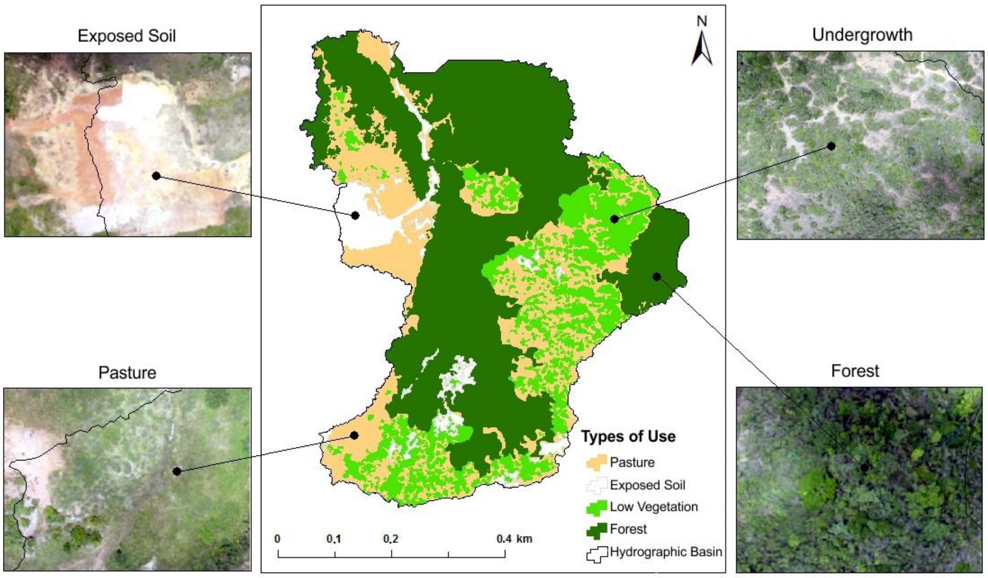
The development and learning process adopted for scientific work, in which it involves experimental work, makes the student the center of understanding science, in this case, practice becomes fundamental for learning. Thus, the research developed is endowed with active methodologies, in which the protagonist is the student, where he must develop experimental strategies to seek to achieve the objectives outlined in the project (Pereira et al., 2018).

3. Results and Discussion

3.1 Land Use and Cover Survey

The four land use classes identified based on the interpretation of the UAV images are shown in Figure 2. The findings indicate different existing land uses at the Timbó stream basin. Of the mapped land use classes, the most representative was forests, comprising 18 ha, approximately 51% of the total area. According to Melo et al. (2019) and Luz et al. (2020), forests play an essential role in maintaining water courses, as they facilitates water infiltration during rainy periods and allows for water discharge by springs during dry periods.

Figure 2. Land use and cover map of the experimental watershed located at the Timbó stream, SE. Land use classes: Pasture (8.65 ha, 24.62%), Exposed soil (area 1.99 ha, 5.67%), Undergrowth (6.50 ha, 18.48%), Forest (18.01 ha, 51.23%).



Source: Authors.

Exposed soil was present in approximately 6% of the total area. Despite its low representativeness, it may still result in consequences for the riverbed, as noted by Pinto et al. (2012), since a lack of vegetation can transport large amounts of soil, causing silting and water resource quality degradation.

The grazing class represents approximately 25% of the total area, where the presence of cattle, horses and goats was identified, which use the stream to consume water. When animals enter riparian forest regions, they cause plant felling, trampling and soil compaction, making natural regeneration impossible, in addition to degrading riverbeds. Smith et al. (2013) and Cruz et al. (2019) indicates it is possible identify water quality changes in hydrographic basins containing livestock, due to erosive agricultural system changes and intensification.

3.2 Water Quality Assessment of the Timbó Stream

Table 1 present the parameters measured in loco with the multiparameter probe for each sampling point and the means obtained for the entire experimental watershed. The flow

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values, corresponding to the daily means and the accumulated total on the day, were 0.1146 (10.04.2018), 0.1264 (04.04.2018), 0.1870 (05.05.2018) and 0.1229 (06.11.2018), measured between 08:10 am and 10:30 am.

Table 1. Parameters determined over the study period at the Timbó stream, grouped per sampling points.

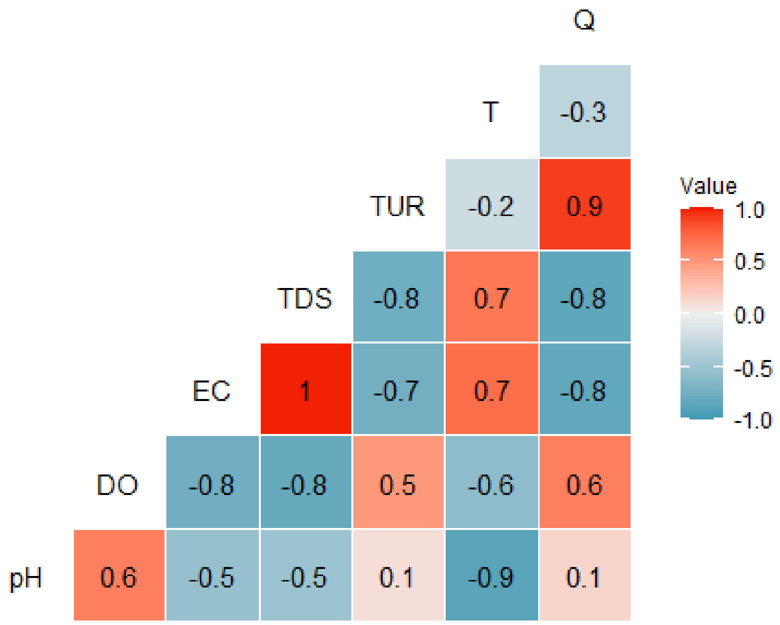
POINTS	DATA	pH	DO* (mg L^{-1})	EC* (μS cm^{-1})	TDS* (mg L^{-1})	TURB* (NTU)	T* (°C)
PRT-1	04.10.2018	7.80	5.37	111.00	51.00	5.20	26.89
	04.30.2018	8.06	4.40	92.00	46.00	5.60	25.21
	05.18.2018	8.32	5.68	67.00	34.00	150.00	24.96
	06.11.2018	8.73	5.44	90.00	45.00	18.60	24.40
PRT-2	04.10.2018	8.09	4.47	117.00	58.00	5.40	26.64
	04.30.2018	8.00	5.20	95.00	47.00	4.80	25.43
	05.18.2018	8.51	6.10	67.00	34.00	80.10	24.91
	06.11.2018	8.99	6.10	79.00	40.00	8.70	24.33
PRT-3	04.10.2018	7.93	4.75	98.00	49.00	7.90	26.31
	04.30.2018	8.35	5.10	94.00	48.00	8.10	24.79
	05.18.2018	8.40	6.50	70.00	35.00	75.10	24.78
	06.11.2018	9.02	5.90	85.00	42.00	7.70	23.82
MEAN		**8.35**	**5.42**	**88.75**	**44.08**	**31.43**	**25.21**

Legend: DO: Dissolved oxygen; EC: electrical conductivity; TDS: Total dissolved solids; TURB: Turbidity; T: Temperature. PRT-01 (near the source), PRT-02 (near the spillway) and PRT-03 (after the spillway). Source: Authors.

According to the means of the variables for all the MBE and according to the Brazilian National Environment Council Resolution [CONAMA] n. 357/2005, which "provides for water body classification and environmental guidelines for their classification, while also establishing the conditions and standards for effluent discharge and gives other measures", the mean pH, turbidity and total dissolved solid values are acceptable for all freshwater classes. The mean dissolved oxygen value is for class 2 freshwater only.

Figure 3 exhibits the correlation graph between the flow values (Q) and the water quality parameters analyzed at the Timbó stream, São Cristóvão (SE), Brazil, where a strong correlation (p-value <0.05) is noted. A direct relationship between Q and TUR ($r = 0.9$) and between Q and O ($r = 0.6$) is also observed, as well as an inversely proportional relationship between TDS and CE ($r = -0.8$).

Figure 3. Correlation graph between flow values (Q) and water quality parameters analyzed at the Timbó stream, São Cristóvão (SE), Brazil.



Source: Authors.

A strong negative correlation was observed between DO and EC and TDS, indicating direct flow influence. The higher the flow, the greater the stream turbulence and dilution (lower water salinity), resulting in higher DO concentrations and lower EC and TDS values.

Figure 4 presents the hydrogen potential (pH), dissolved oxygen (DO), electrical conductivity (CE), total dissolved solids (TDS), turbidity (TUB) and temperature (T), values, depending on the flow.

pH values as a function of flow are exhibited in Figure 4a. Only slight variations in pH weer observed, between 7.80 and 9.02. This may be due to the fact that the study region suffers little anthropic influence, with a large part of the surrounding land occupied by forests. According to Luogon et al. (2009) and Brandão et al. (2017), the most common anthropic changes to water resource quality comprise vegetation cover suppression and the release of domestic and industrial wastewater to water bodies. Only a single pH value (9.02) does not fall into the freshwater class range according to CONAMA Resolution nº. 357, of March 17, 2005, which establishes standard pH conditions between 6 - 9. A relationship between pH behavior only as a function of flow could not be established, as no considerable variations in pH in were observed. According to Fritzons et al. (2003) pH is influenced by numerous factors, such as solids, dissolved gases, hardness, alkalinity, temperature and biotic factors, among others.

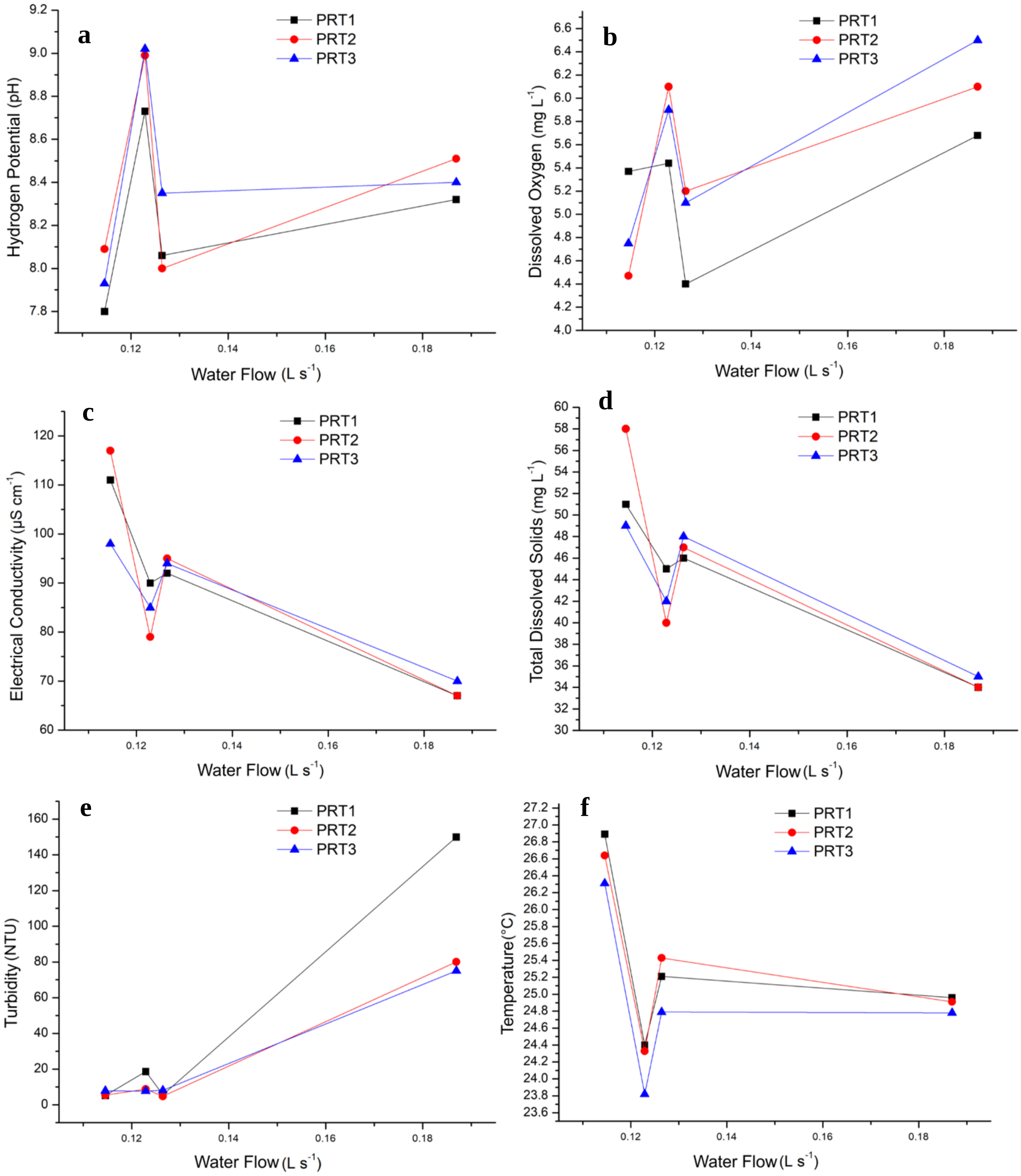
DO values as a function of flow are exhibited in Figure 4b, ranging from 4.40 to 6.50 mg L^{-1}. Among the recorded values, only three did not fall within the acceptable limits, according to CONAMA Resolution nº 357/2005, which establishes standard DO conditions of not less than 5 mg L^{-1} O_2 for class 2 freshwater bodies.

An increasing DO trend in relation to flow was observed, probably due to Timbó stream turbulence caused by increased rainfall. Girardi et al. (2016), when assessing the Concórdia River basin, observed an increase in DO values during all precipitation events, possibly due to increase river flow turbulence.

Electrical conductivity as a function of flow is exhibited in Figure 4c. Greater variations in this parameter were observed, ranging from 67.0 to 117.0 µS cm^{-1}. It appears that the variable had a reduction with increasing flow, probably due to the influence of dilution, which reduces the concentrations of ions present in the water. Salimon et al. (2013), in their study of the Purus River, southwest of the Amazon, reported that increased flow reduces electrical conductivity and that this variable is inversely related to water and rain discharges.

Total dissolved solids (TDS) indicate the presence of organic and inorganic particles present in water bodies, in ionic, molecular or micro granular form. Figure 4d exhibits TDS values as a function of waterflow. A negative correlation between TDS concentration and flow was observed, probably due to the dilution effect. According to the values presented in Figures 5 and 6, a strong relationship between electrical conductivity and total dissolved solids is present, possibly due to the presence of ionized particles in Timbó stream waters.

Figure 4. pH (a), DO (b), electrical conductivity (c), total dissolved solids (d), turbidity (e) and temperature (f) parameters, depending on the flow, for the PRT-01 collection points (near the source), PRT-02 (near the spillway) and PRT-03 (after the spillway) at the Timbó stream.



Source: Authors.

CONAMA Resolution no. 357/2005, establishes the standard conditions for total dissolved solids of 500 mg L^{-1} for all freshwater classes, and all TDS values in the analyzed samples fell within this range, with the highest recorded value of 58.0 mg L^{-1} at PRT-1.

Turbidity values as a function of flow are exhibited in Figure 4e. A wide variation in turbidity values was observed, from 5.20 to 150.0 NTU, associated to increased flow, as high turbidity increases were detected at the three sampling points at the maximum recorded flow. As reported by Santos et al. (2013) and Britto et al. (2018), peaks in turbidity values were observed during the rainy period, with a consequent increase in suspended solids, as these particles prevent light from penetrating the water. Only a single recorded turbidity value (150.0 NTU) did not fall into class 2 for freshwater bodies, up to 100 NTU according to CONAMA Resolution no. 357/2005.

The PRT-1 point, where this maximum elevation was recorded, is close to the source of the Timbó stream, a shallower region with low vegetation and forest influences. This fact probably facilitates water flow turbulence, when the pluviometric index is higher, causing bottom sediment turning and transportation. Similar observations were also mentioned by Moura et al. (2009) when assessing the water quality of the Cascavel River, in western Paraná.

Runoff also significantly influenced increasing turbidity values, since increased flow and precipitation result in particle detachment from the watershed slopes. Kuhlmann et al. (2014) reported for the Ipiranga river that, although the river is fully inserted in a protected area, it exhibits a strong correlation between precipitation and runoff, increasing turbidity values.

Figure 4f presents temperature values as a function of flow. Low temperature variations were observed (23.82 to 26.89 ºC), which may be related to land use and occupation, as the study area is a forest region with preserved riparian forest. Studies report that the maintenance of riparian vegetation is the most effective way to prevent water temperature increases (Sugimoto, Nakamura & Ito, 1997).

Higher temperature values were observed at the beginning of April, where the lowest flow values were recorded. The lower amounts of water in the stream during this warmer period compared to the other study months are a possible explanation for this behavior. This corroborated Fernandes et al. (2012) who, when studying the influence of soil cover at the Palmital microbasin, Macaé - RJ, indicated that areas occupied by preserved forest cover favor water quality parameter improvements. Therefore, forest cover preservation plays a fundamental role in maintaining the water body quality (Gardiman & Simoura, 2016).

3.3 Principal component analysis (PCA)

The behavior of all analyzed variables at the experimental watershed was verified through a Principal component analysis (PCA), where parameters involved in the maximum water quality variability were identified. Table 2 presents the weights of the analyzed parameters of the first five main components for the entire micro basin.

The first two main components (PC) represented 90.76% of the total data variability, sufficient to describe the system. PC1 presented 68.60% of the data variability and PC2, 22.16%.

PC1 is positively associated to pH (0.626), DO (0.847), TUB (0.748), TDS (0.8439) and Q (0.832), and negatively associated to EC (-0.975), TDS (-0.975) and T (-0.735). The weights indicate correlations between the variables, corroborating the previously presented correlation graph, with a significant correlation between turbidity and dissolved oxygen with flow rate, and between electrical conductivity and total dissolved solids. PC2 is noteworthy regarding pH (-0.735), presenting a negative weight, and TUR (0.588), T (0.605) and Q (0.517), both presenting positive weights. These variables, therefore, comprise the second largest data variations sources.

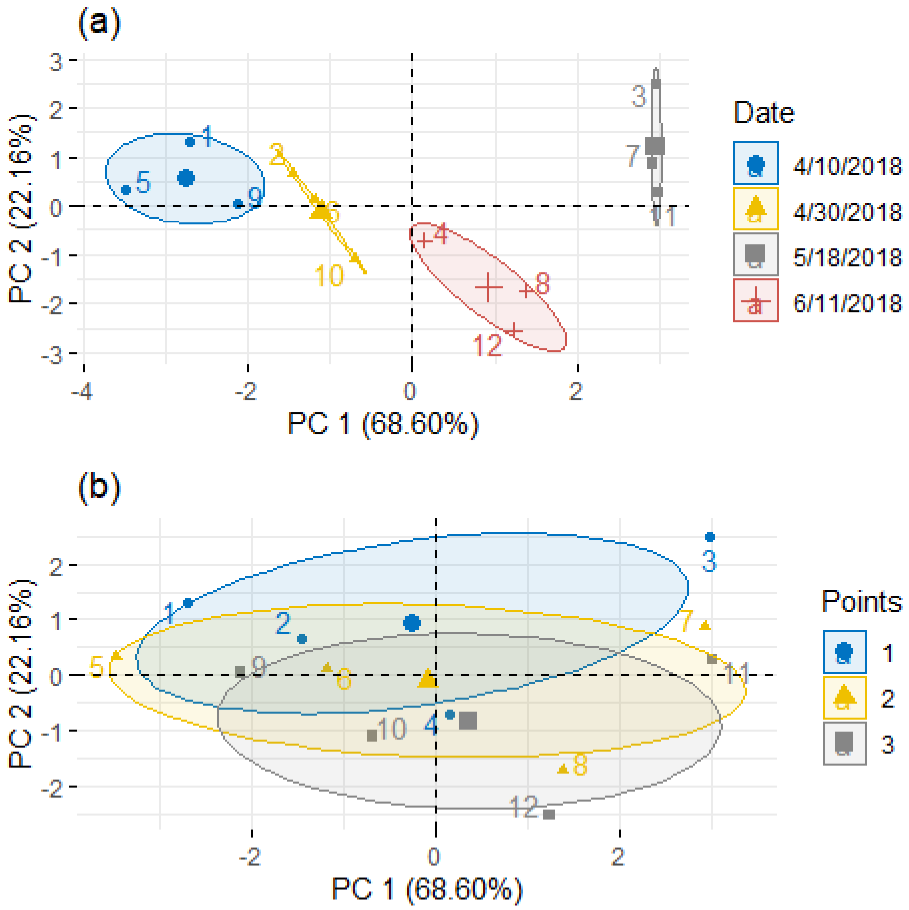
Table 2. Principal components of the analyzed variables at the Timbó stream, São Cristóvão (SE), Brazil.

VARIABLES	CP1	CP2	CP3	CP4	CP5
pH	0.626	-0.735	-0.008	0.241	-0.021
DO	0.847	-0.141	0.508	-0.004	0.015
EC	-0.975	-0.059	0.119	0.145	0.073
TDS	-0.975	-0.100	0.013	0.157	0.108
TUB	0.748	0.588	-0.132	0.259	-0.066
T	-0.735	0.605	0.259	0.073	-0.095
Q	0.832	0.517	-0.010	0.009	0.188
VARIANCE (%)	68.60	22.16	5.10	2.52	1.62
TOTAL DATA VARIANCE (%)	68.60	90.76	95.86	98.38	100

Source: Authors.

Figure 5a shows the plane formed by the first two principal components (PC1 and PC2), where a trend towards the formation of four sets of points representing the period of the year in which the samplings were carried out. Figure 5b exhibits the arrangement of three sets, representing the sampling points.

Figure 5. Score graph for the plane formed by the first two principal components (PC1 and PC2), considering the period of the year in which samples were obtained (a) and the sampling points (b).



Source: Authors.

These observations come mainly from PC1 turbidity and flow contributions, with positive scores, and electrical conductivity and total dissolved solids, with negative scores, demonstrating the strong flow influence, the result of rainfall, on these variables. Rodrigues et al. (2018), when studying the water quality at the the Água Limpa stream basin, in São Paulo, also applied a PCA to indicate that water quality variables were influenced by the high rainfall rates recorded in the region.

Considering the above, it is possible to mention the need for more detailed studies in microbasins, covering more regularly and also greater chronological time, thus enabling the understanding of the hydrodynamics of the region studied.

4. Conclusions

The land use and occupation survey indicated that most of the studied microbasin area is occupied by forests, suggesting preserved natural resources and demonstrating the relevant role of forest sin the water quality of this ecosystem.

The study of water quality parameter behavior as a function of flow indicated a positive correlation to dissolved oxygen and turbidity, while electrical conductivity, total dissolved solids and temperature exhibited a negative correlation. Based on these assessments, the waters of the Timbó stream watershed fit the established Brazilian standards for all freshwater classes as set by the CONAMA Resolution n. 357/2005.

The principal component analysis demonstrated that the greatest contributions to the quality of the investigated water resource were EC, TDS, DO and turbidity, suggesting that the relationship of these parameters with the water flow confirmed the evident influence of precipitation on the water quality variables of the Timbó stream.

Thus, the present work highlights the importance of studies in microbasins, and studies regarding water quality and hydrodynamics involved in the design of water resources in a region.

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