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DYNAMICS OF WATER QUALITY PARAMETERS IN HYDROGRAPHIC CATCHMENTS WITH NATIVE FOREST AND PINE-PLANTED FORESTS

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Resumo

Dinâmica de parâmetros de qualidade da água em microbacias hidrográficas com floresta nativa e florestas plantadas de Pinus. A busca por florestas produtivas em consonância com o equilíbrio ambiental é uma das tarefas de um bom manejo florestal sustentável, em que estudos sobre a qualidade da água nas zonas de produção corroboram para o aperfeiçoamento de programas de conservação ambiental. Deste modo, este estudo teve como objetivo determinar a qualidade da água em microbacias hidrográficas cobertas com floresta nativa e florestas plantadas de *Pinus* e avaliar os efeitos das operações florestais e da precipitação na dinâmica dos parâmetros físicos e químicos da água. Coletaram-se dados durante 10 anos (2005 - 2015) em frequência de amostragem quinzenal. Determinaram-se as concentrações de nitrato, fósforo, potássio, cálcio e magnésio, e também dos parâmetros físicos de sólidos suspensos totais, pH, turbidez, cor aparente e condutividade elétrica na água. Os dados foram analisados por meio do teste de Mann-Whitney a 5% de probabilidade e por meio da análise multivariada (análise de componentes principais e análise de agrupamento hierárquico). A qualidade da água de ambas as microbacias é semelhante e não apresenta diferença significativa entre os parâmetros físicos. Enquanto a microbacia composta por floresta nativa apresenta maior concentração de NO_3^-, K e Mg na água, a microbacia com florestas plantadas de *Pinus* apresenta maior concentração de Ca. Houve diferença na dinâmica dos parâmetros químicos e físicos da água em relação a precipitação. O manejo florestal em mosaico pode exercer influência na estabilidade dos parâmetros de qualidade.
Palavras-chave: mosaico florestal, ordenamento florestal, hidrologia florestal.

Abstract

The search for productive forests in line with an environmental balance is one of the tasks of good sustainable forest management, in which studies on water quality in production areas support the improvement of environmental conservation programs. Thus, this study aimed to determine the water quality in watersheds covered with native forest and pine-planted forests and to evaluate the effects of forest operations and precipitation on the dynamics of physical and chemical parameters of water. Data were collected for 10 years (2005 - 2015) in a fortnightly sampling frequency. The concentrations of nitrate, phosphorus, potassium, calcium, and magnesium were determined, as well as the physical parameters of total suspended solids, pH, turbidity, apparent color, and electrical conductivity in the water. Data were analyzed using the Mann-Whitney test at 5% probability and through multivariate analysis (principal component analysis and hierarchical cluster analysis). The water quality of both watersheds is similar and there is no significant difference between the physical parameters. While the watershed composed of native forest has a higher concentration of NO_3^-, K, and Mg in the water, the watershed with planted forests of *Pinus* has a higher concentration of Ca. There was a chemical and physical difference in the dynamics of the water concerning its precipitation. Mosaic forest management can influence the stability of quality parameters.
Keywords: forest mosaic, forest management, forest hydrology.

INTRODUCTION

Brazil is a country with approximately 60% of its territory composed of native vegetation, representing the world’s second-largest area of forests (SFB, 2019). Planted forests cover 7.8 million hectares of Brazilian territory (less than 0.9% of the total), with economic growth of around 17.60% of the sector in recent years (IBÁ, 2021). The coverage of planted *Pinus* forests corresponds to 28% of the total and is concentrated in the south of the country, mainly in the state of Paraná (IBÁ, 2021; SFB, 2019).

The transformation of forest plantations for planted forests in the world is a recommendation of the Food and Agriculture Organization of the United Nations (FAO, 1991) since it seeks increasingly sustainable forest management. For Lima (2006), this is a significant conceptual change, as it is not only an adaptation of economic species to the specific objectives of production but also the incorporation of the environmental issue as an integral part of the entire production process.

Thus, the assessment of forestry practices' effect on environmental quality at the scale of catchments becomes imperative, as they are areas sensitive to changes in land use, occupation, and rainfall intensity (CALIJURI; BUBEL, 2006; FERRAZ *et al.*, 2019). In this sense, to indicate the level of quality in forest management, physical and chemical parameters of the water are used. The values observed in native forest catchment can serve as a reference for establishing maximum permitted values that are more restrictive and consistent with the local reality of forest plantations (CASSIANO *et al*., 2022). Due to the hydrological cycle, water can be directly affected by forest operations, as it participates in the processes of infiltration, surface runoff, and loading of nutrients and sediments from the drainage area to the river bed, and may change crucial characteristics of its quality (BLOYD, 2020).

The importance of considering water quality effects associated with intensive management operations means understanding the complex nature of the response of stream water quality to catchment land use changes and the value of studies that monitor the impact of land cover change over the long term (HUGHES; QUINN, 2019; MUWAMBA et al., 2015). Kreye *et al*. (2014) finds priorities which individuals assign to forest conservation and water resource protection strategies, demonstrating a positive willingness to pay for water quality protection and forest conservation.

Tropical forest cover is a good indicator of water quality, and it plays a central role in minimizing the impacts of human activities on ecosystem services in agricultural watersheds (MELLO *et al.*, 2018). Brogna et al. (2017) demonstrate significant effects of forest cover on water quality from typical large multivariate monitoring datasets. Capturing the effects of land cover, on several water quality variables, simultaneously, from measured data, allows the comparison between them. The most commonly applied multivariate method in watershed studies is principal components analysis, which uses correlation among multiple water quality constituents to successfully reduce the number of variables (OLSEN *et al.* 2012).

Therefore, the objective of this study was to determine the water quality in catchments with native forest and *Pinus*-planted forests; and to evaluate the effects of forestry operations and annual precipitation on the dynamics of physical and chemical parameters of the water.

MATERIALS AND METHODS

Area description

The study was carried out in two second-order hydrographic catchments located in the municipality of Telêmaco Borba, State of Paraná, between latitudes 24° 02' 02" and 24° 27' 48" and longitudes 50° 17' and 50° 55', and with an average altitude of 885 meters (Figure 1).

The predominant climate in the region of Telêmaco Borba, according to Köppen's classification is Cfa/Cfb, transitional subtropical to temperate, humid, mesothermal, with no defined dry season (ALVARES et al., 2013). Summer is hot and tends to concentrate rainfall, and in winter, frosts occur infrequently, with an average temperature in the coldest month below 16 °C and in the warmest month above 22 °C. The average annual precipitation is 1,490 mm, with a water surplus of 557 mm/year, distributed in all months of the year.

The catchment covered with the native forest has an average slope of 17%, and Litholic Neosol soils and the catchment predominantly covered by commercial exotic forest plantations of Pinus spp. has an average inclination of 16% and Rhodic Hapludox soils. Nitrate concentrations and turbidity of the forest plantation exceed the values of the native forest less than 5% of the time. The values of phosphorus, pH and suspended solids in the catchment with forest plantation have 7.4%, 17.2%, and 15.1%, respectively, probability of exceeding the values of the catchment with native forest (CASSIANO *et al*., 2022).

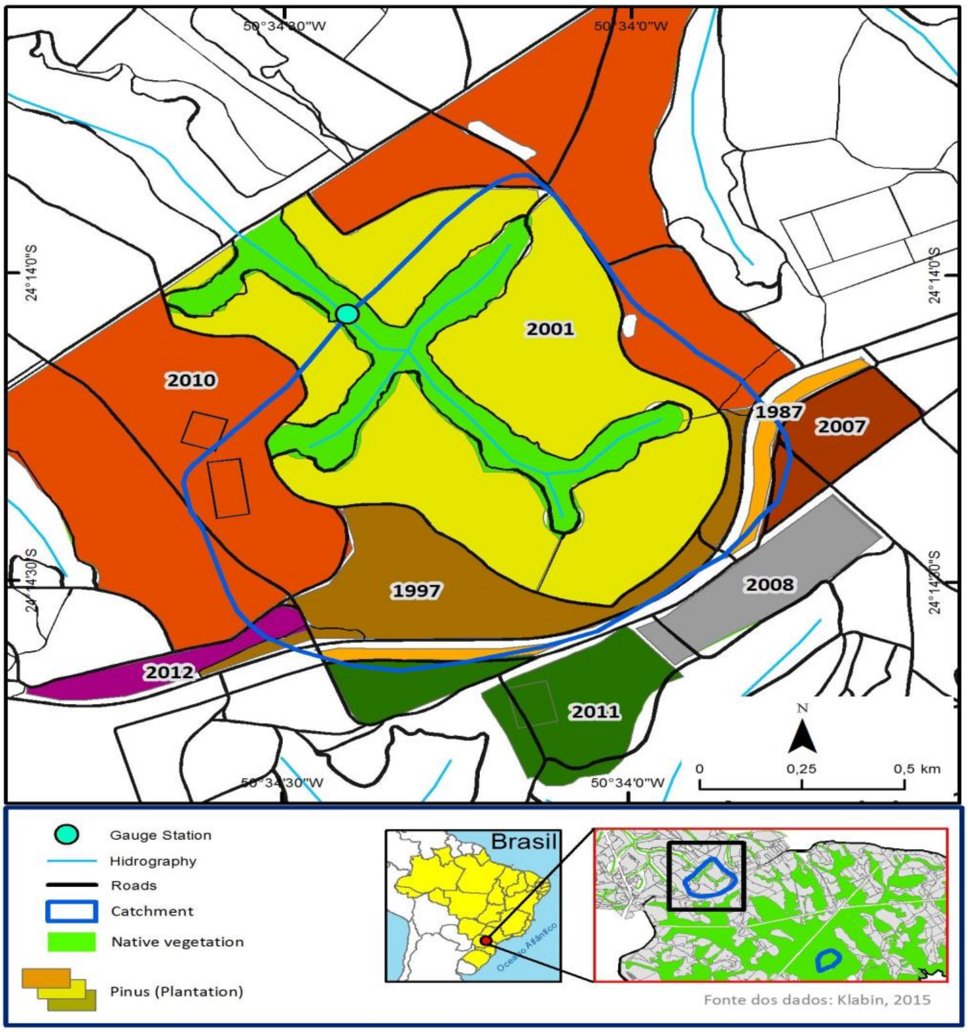

Figure 1. Location of hydrographic catchments with Pinus planted forests and the respective years of the forest operations' occurrence, followed by the placement of the catchment with native vegetation in the municipality of Telêmaco Borba, Paraná, Brazil.

Figura 1. Localização da microbacia hidrográfica com florestas plantadas de *Pinus* e os respectivos anos de ocorrência das operações florestais, acompanhado da localização da microbacia com vegetação nativa no município de Telêmaco Borba, Paraná, Brasil.

Forest coverage and management

The catchment area with native vegetation has an area of 34.4 ha. And it is covered by vegetation in an advanced stage of succession with the presence of typical species (*Araucaria angustifolia*), characterized by being a transition between Mixed Ombrophilous Forest and Seasonal Semideciduous Forest, both from the Atlantic Forest biome.

The catchment zone with planted forests has 135.4 hectares. In 2007 its land use was characterized by 70% *Pinus taeda*, 8% *Eucalyptus grandis*, and 22% Permanent Preservation Area (APP) (IPEF, 2016).

The implementation of *Pinus* began in 1964, with *Pinus elliottii var. elliottii*, and in 1974 with *Pinus taeda*. In 1997, the plot with *Pinus elliottii var. elliottii* was harvested and planted with *Pinus taeda*, adopting a spacing of 2.5 x 3.0 m. In the first stands of *Pinus taeda*, the clear-cut was carried out in 2001 and the same species were planted in a 3.0 x 2.0 m spacing. The catchment area also had a plot of just over 11 ha with *Eucalyptus*, which was harvested in 2010 and, subsequently, the operations of cleaning track with mat, subsoiling, planning, digging, and replacement with planted *Pinus* forests spacing 3 x 2.5 m were carried out. Thus, currently, the catchment zone has *Pinus-planted* forests that were established in 1997, 2001, and 2010, forming a mosaic with 3 different ages.

Data collection

The data were provided by the Cooperative Program on Monitoring and Modeling of Hydrographic Basins (PROMAB), of the Forestry Research Institute (IPEF), which develops research in partnership with the company responsible for the area and with the Forestry Hydrology Laboratory (LHF) from Luiz de Queiroz Agriculture School, São Paulo's University (ESALQ/USP).

For the continuous recording and storage of the water depth at regular intervals of 10 minutes, a spillway was built at the outlet of each catchment area, and equipment (Enviro-Systems CS-105S) was installed. A pluviograph (Hobo RG3-M and Hydrological Services TB4) was installed in each catchment zone to record rainfall at 10-minute intervals. The quota data of each catchment area were converted into the flow (Ls^{-1}) through the application of specific equations, elaborated in the technical project of each spillway. Subsequently, the daily average flows (Ls^{-1}) and the daily average specific flows (Ls^{-1} km^{-2}) were obtained. The precipitation records were integrated into the annual scale. The specific average flow rate for the micro-basin with the native forest is 7.08 L s^{-1} Km^{-2} and for the micro-basin with *Pinus*-planted forests is 2.08 L s^{-1} Km^{-2}.

Water samples were collected manually and biweekly in the two catchment areas, and the analyzes were carried out at the Laboratory of Applied Ecology (LEA) at ESALQ/USP. Water quality was characterized by determining the concentrations of nitrate (NO_3^-), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and total suspended solids (TSS); and the levels of pH, turbidity (FTU), apparent color (Pt.Co) and electrical conductivity (µS cm-1). Nutrients were determined according to methods standardized by the American Public Health Association (APHA, 1995). Being K, Ca and Mg by spectrophotometry (Thermo Genesys 105 UV V15), NO3- by the brucine method and phosphorus by colorimetry, pH was determined potentiometrically using a pH meter; turbidity levels were determined by the turbidimetric method and using a spectrophotometer (HACH DR 2000). The total concentrations of suspended solids were obtained using an automatic filtration system (47mm polysulfone, Nalgene), drying in the oven (Fanem) and weighing on an analytical scale (CASSIANO *et al*., 2022).

Data analysis

Water quality in catchment areas

The water quality was determined through the median values obtained by monitoring the physical and chemical parameters of the water in catchment areas. To verify the effect of the management of planted forests on water quality, the median values of the parameters between the catchment areas are compared using the Mann-Whitney test at 5% probability. The monitoring series consists of data collected over a 10-year observation period (July 2005 to December 2015).

Dynamics of water quality parameters

The influence's diagnosis of forest cover and management on the dynamics of water quality parameters was made based on the selection of 4 sample sets taken from the monitoring series: 2006 – less rainy year (n = 20); 2009 – wettest year (n = 21); 2010 – a year of occurrence of forest operations (n = 21) and 2011 – year after forest operations (n = 24) (Table 1).

Table 1. Total annual precipitation for the four selected years.
Tabela 1. Precipitação total anual para ou quatro anos selecionados.

Catchment Area	**Total Annual Precipitation (mm)**			
	2006	**2009**	**2010**	**2011**
Native	1,191	2,511	1,573	1,776
Planted	1,208	2,608	1,627	1,778
Average	1,200	2,560	1,600	1,777

For data interpretation, multivariate statistics were used using Statistical Package for the Social Sciences (SPSS program). Hierarchical cluster analysis was performed to classify data sets by similarity; the Euclidean distance was adopted as a comparison measure. The Principal Component Analysis (PCA) was performed to diagnose which parameters exert the prime influence on the distinction between data sets, using the minimum variance method (Ward's method); the data matrix for the PCA application was constructed using 11 variables and 8 medians of the annual monitoring series. The variables were normalized by Z-score transformation to assign the same weight to parameters with different ranges and measurement units.

RESULTS

Characterization of water quality in catchment areas

In general, the catchment zones with native forest have concentrations of NO_3^- (1.25 mg L^{-1}), K (1.10 mg L^{-1}) and Mg (0.81 mg L^{-1}) in the water higher than the catchment area with planted forests (Table 2). The concentration of Ca is higher in the water from the catchment area with planted forests (1.85 mg L^{-1}). Despite the detection of a significant difference for the concentration of P between the catchment zones, the medians present concentrations close to 0.02 mg L^{-1}. The physical parameters of water quality evidenced by the concentrations of total suspended solids (6.70 – 8.49) and pH levels (6.90 – 7.00), apparent color (21.00 – 24.00 Pt. Co), electrical conductivity (0.004 µS Cm-1) and turbidity (6.00 FTU) did not differ between catchment areas by the Mann-Whitney test at 5%.

Table 2. Nitrate concentrations (NO_3^-), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), total suspended solids (TSS) in mg L^{-1} and apparent color (Pt. Co), turbidity (FTU) and electrical conductivity - EC (µS Cm^{-1}) in the water of catchment areas with native forest and planted forests monitored during a series of 10 years (2005 - 2015) in fortnightly sampling frequency. * denote statistically significant relation ($p < 0.05$).

Tabela 2. Concentrações de nitrato (NO_3^-), fósforo (P), potássio (K), cálcio (Ca), magnésio (Mg), sólidos suspensos totais (TSS) em mg L^{-1} e cor aparente (Pt. Co), turbidez (FTU) e condutividade elétrica - EC (µS Cm^{-1}) na água das microbacias com floresta nativa e florestas plantadas durante a série de monitoramento de 10 anos (2005 – 2015) em frequência de amostragem quinzenal. * significativo ($P < 0.05$).

Catchment Area	Statistical measures	NO_3^-	P	K	Ca	Mg	TSS	pH	Color	Turbidity	EC
		(mg L^{-1})							(Pt. Co)	(FTU)	(µS Cm-1)
Native Forest	**Median**	**1.25***	**0.02***	**1.10***	**1.60**	**0.81***	**6.70**	**7.00**	**21.00**	**6.00**	**0.04**
	Mean	1.35	0.02	1.17	1.75	0.87	8.52	6.97	25.12	6.13	0.04
	SD	0.77	0.01	0.42	0.61	0.22	6.13	0.16	19.98	4.24	0.01
	CV	0.57	0.49	0.36	0.35	0.26	0.72	0.02	0.80	0.69	0.35
	Min	0.20	0.00	0.30	0.70	0.50	0.30	6.60	0.00	0.00	0.02
	Max	6.10	0.05	2.40	3.50	1.40	26.00	7.60	79.00	18.00	0.08
	Kurtosis	6.40	-0.58	-0.05	-0.35	-0.37	-0.39	0.50	-0.37	-0.41	-1.01
	Skewness	1.60	0.51	0.58	0.63	0.50	0.76	0.38	0.69	0.57	0.47
	n	222	217	207	227	219	214	219	214	208	229
Planted Forest	**Median**	**0.90**	**0.02**	**0.90**	**1.85***	**0.71**	**8.49**	**6.90**	**24.00**	**6.00**	**0.04**
	Mean	0.93	0.02	1.02	2.17	0.82	9.76	6.95	27.45	6.56	0.04
	SD	0.40	0.01	0.50	1.10	0.37	6.69	0.22	20.56	3.98	0.02
	CV	0.43	0.50	0.49	0.51	0.45	0.69	0.03	0.75	0.61	0.48
	Min	0.20	0.00	0.20	0.60	0.30	0.30	6.40	0.00	0.00	0.01
	Max	2.00	0.05	2.40	5.00	1.70	28.70	7.50	92.00	16.00	0.18
	Kurtosis	0.04	-0.07	-0.18	-0.29	-0.08	-0.28	-0.15	-0.16	-0.48	7.01
	Skewness	0.55	0.62	0.75	0.82	0.91	0.76	0.04	0.68	0.49	1.46
	n	187	201	213	228	214	214	224	215	207	231
Mann-Whitney (U)		13,318.5	13,366.5	16,290	21,211	178,120	20,416	22,511	21,471	19,978	25,438

Skewness approximates to 0 indicates symmetry with values close to each other in the data, and the curve of the majority of the parameters is platykurtic as kurtosis (less than 3). Only NO_3^- (Native) and EC (*Pinus*) has the curve leptokurtic, because of kurtosis is more than 3, and the positive asymmetry (skewness > 1).

Dynamics of water quality parameters in catchment zones

Hierarchical cluster analysis proved to be a viable instrument for interpreting the variation of data obtained in this study (Figure 2). Based on the observation of the dendrogram, it's inferred that the sample was divided into three main groups according to the monitoring periods. The first group (2010 - 2011) has greater similarity and consisted of samples collected in the years during and after the management interventions in the catchment area with planted forests of *Pinus*, followed by samples collected in the same period for the catchment area with native forest. The second and third groups are formed by samples collected in the wettest (2009) and least rainy (2006) year, respectively.

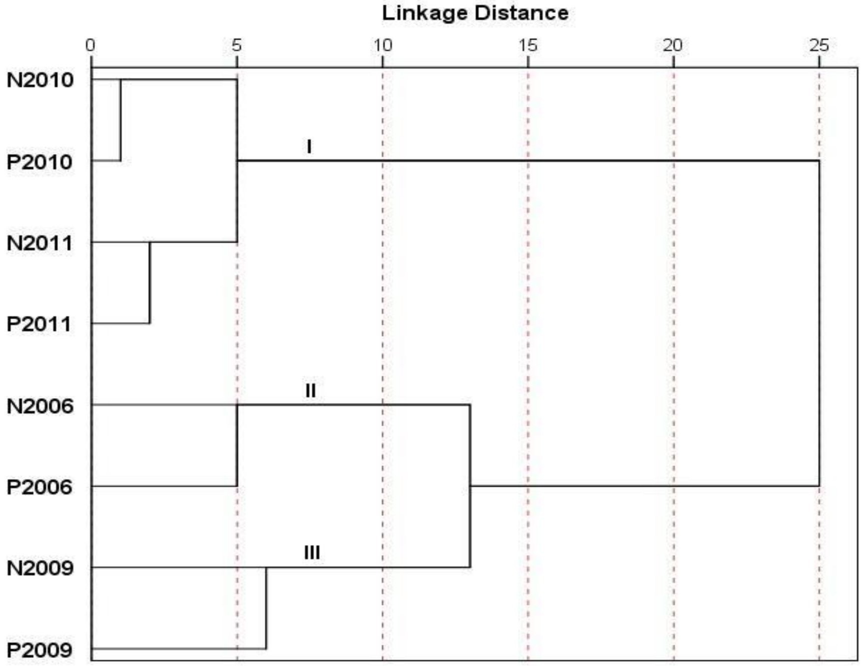

Figure 2. Dendrogram of similarity (Ward's method) of the sample universe grouped by cases, considering the quality parameters determined in the water of catchment areas with planted forests (P) and native forest (N) in the less rainy year (2006), rainier (2009), during (2010) and soon after forestry operations in the catchment zone with planted forests (2011).

Figura 2. Dendrograma de similaridade (*Ward's method*) do universo amostral agrupado por casos, considerando os parâmetros de qualidade determinados na água das microbacias com florestas plantadas (P) e floresta nativa (N) no ano menos chuvoso (2006), mais chuvoso (2009), durante (2010) e logo após as operações florestais na floresta plantada (2011).

The parameters exert the greatest influence on the distinction between data sets, which was established using principal component analysis (PCA). The data generated by the first two components, synthesized an accumulated variance around 82.16% of the total variance. With the observation of the spatialization of the variables through Figure 3, the punctual influence of the water quality parameters according to rainfall and forest management is highlighted.

The main component 1 (PC1) was responsible for 56.08% of the variance, separating the sample set with negative values in the years 2010 and 2011, and with positive values in the years 2006 and 2009. The main component 2 (PC2) was responsible for 26.08% of the variance, which explained the distinction between the wettest (2009) and less rainy seasons (2006) (Figure 3). The wettest year (2009) was governed by the levels of apparent color, turbidity, total suspended solids, electrical conductivity and the concentrations of K and P, whereas in the least rainy year (2006) the variation was represented by pH, Ca and Mg concentrations.

It was also observed that in 2010 the catchment area with planted forests distanced itself from the main group with positive values along PC2. Thus, runoff and NO_3^- were the parameters that contributed to the distinction of samples in the year of occurrence of forest operations.

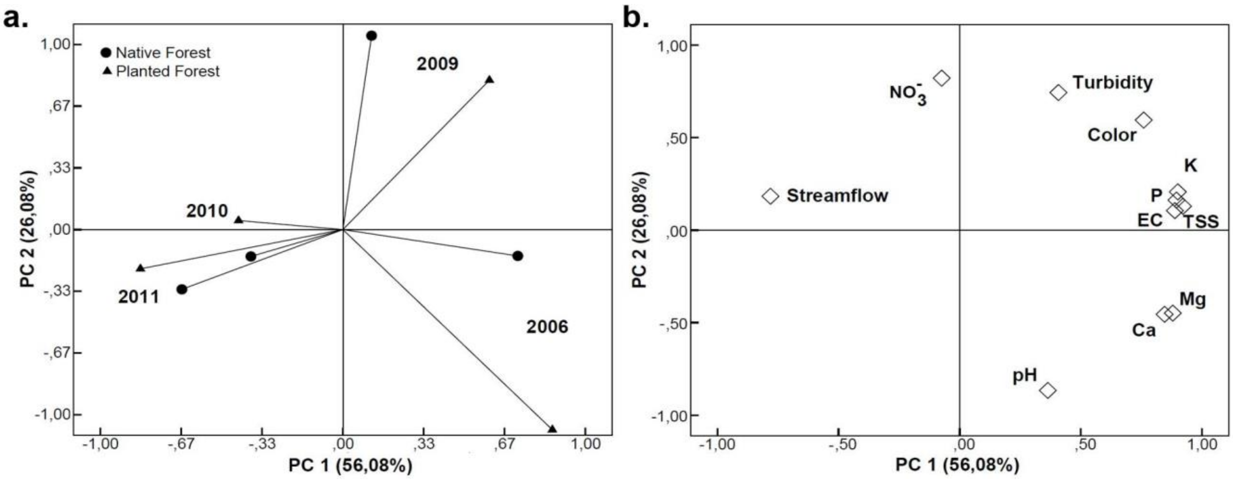

Figure 3. Principal component analysis: a. score chart for the least rainy (2006), most rainy (2009), during (2010) and immediately after forestry operations in the catchment area with planted forests (2011), with reference to the catchment zone with native forest for the same period and b. Graph of loadings of chemical parameters of NO_3^-, P, K, Ca, Mg and physical, such as total suspended solids (TSS), apparent color, turbidity and electrical conductivity (EC) in water from catchment zones with planted forests (P) and with native forest (N).

Figura 3. Análise de componentes principais: a. Gráfico de score com o ano menos chuvoso (2006), mais chuvoso (2009), durante (2010) e imediatamente após as operações florestais na microbacia com floresta plantada (2011), com referência para a microbacia com floresta nativa para o mesmo período.

DISCUSSION

In general, the values of the water quality parameters found in this study are lower than the values found by other studies when changing the use and occupation of the soil. De Paula et al. (2018) studied water quality in catchment areas with anthropogenic influences and different levels of forest cover in southeastern Brazil, with minimum and maximum values of the parameters expressed as follows: P (0.02 – 0.63 mg L^{-1}); K (0.10 – 8.00 mg L^{-1}); Ca (0.60 – 64.70 mg L^{-1}); Mg (0.30 – 43.50 mg L^{-1}); TSS (4.00 – 2.868.30 mg L^{-1}); color (1.00 - 3,125.00 Pt. Co); EC (0.05 – 0.04 mS Cm^{-1}); pH (6.00 - 8.30). Mello *et al*. (2018) evaluating forest cover as an indicator of stream health in tropical agricultural watersheds: turbidity (11.68 – 29.66 NTU), TSS (5.15 – 21.13 mg L^{-1}), P (0.04 – 0.09 mg L^{-1}). Fritzsons and Mantovani (2021) monitored several parameters to assess how the land use affect water quality in Mixed Ombrophilous Forests: turbidity (0 – 650 NTU), color (0 – 400 Hu), conductivity (30 – 567 µS Cm^{-1}), NO_3^- (0.01 – 1.64 mg L^{-1}). Muwamba *et al.* (2015) investigate the effects of intercropping in a pine plantation: NO_3^- (0.00 – 0.78 mg L^{-1}) and Hughes and Quinn (2019) search for the effects of forestry management activities: NO_3^- (0.4 - 1.5 mg L^{-1}). In this sense, it's evident that both catchment areas in this study throughout the monitoring series are similar and did not exceed the limits of the aforementioned authors, demonstrating the role of forest conservation in the stability of water quality parameters, refining the hypothesis that forests improve water quality (BROGNA et al., 2017).

Although NO_3^- is one of the parameters that was influenced by the harvest, its concentrations in water remain lower than those observed in other *Pinus* forests after forestry operations (HUGHES; QUINN, 2019), and higher than those observed in the intercropping of the pine plantation (MUWAMBA et al. 2015). Despite the fact that native forest has higher nitrate presence in the pine forests, Brazil's regulations for human consumption only when nitrate concentration is over 10 mg L^{-1}, the value we found was lower (CONAMA Resolution n. 357, 2005). Although the limits of classification of water bodies in Resolution may not be suitable for use as a reference, when the goal is to understand the effects of forest management on water resources, it's understood that the evaluation of forest management in forest plantations should be carried out through continuous and long-term monitoring (CASSIANO *et al*., 2022).

The forestry operations were of low impact, probably due to the small area of 11 ha (8.10% relative to the total area inside the watershed). In this sense, mosaic forest management can ensure that the replacement and management of planted forests does not change the water quality parameters, as it has similarities with the catchment area with native forest. The results also showed that precipitation is able to influence the behavior of the variables. Although forest operations do not change the dynamics of water quality parameters, according to

Neary (2016) and Ferraz (2019), the growth of homogeneous forests is a considerable factor in reducing runoff, and after harvesting there may be greater water production.

Base cations (Ca and Mg) are major elements in ecosystems and are found naturally in large amounts in rivers, exhibiting strong dilution across humid sites (GODSEY *et al.*, 2019). Both Ca^{2+} and Mg^{2+} ions are generally associated with HCO_3^- and CO_3^{2-}. At slightly acidic pH (6.09 – 7.00), with high availability of H^+, carbonate (CO_3^{2-}) tends to dissociate from Ca. Precipitation occurs when the concentrations of bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) ions surpass the concentrations of Ca^{2+} and Mg^{2+} cations. Thus, the availability of CO_3^{2-} in the water column and the pH of the medium, constitute important factors in the processes of removal to the sediment or remobilization to the water column (BARKAT, A. *et al.*, 2021). Its concentrations in the rainy season can significantly decrease, due dilution process (CHEN *et al.*, 2002). The supply of water resources in dry periods is mainly ensured by the flow of groundwater, and in periods with little rain, the runoff may contain a higher concentration of these salts, which explains the contribution of these elements in the less rainy year of 2006. However, in rainy periods, the excess of water volume generates surface runoff, a process that can carry soil particles and organic matter to the water bed, modifying the color and turbidity, a fact that explains the distinction of these parameters in the samples of the wettest year of 2009 (BOYD, 2020). De Paula *et al*. (2018) found similar results when observing greater variations in nutrient parameters in the dry season and in physical parameters, such as color and turbidity in the rainy season.

CONCLUSIONS

- The water quality of native forest is very similar to the water quality of *Pinus* forests, and both are influenced by precipitation.
- The management of *Pinus* forests is not capable of harming the quality of the water resource, regarding the dynamics of physical and chemical parameters of the water.
- Mosaic forest management and Permanent Preservation Area (APP) can reduce the environmental impacts of forest harvesting operations on the dynamics of water quality parameters.

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