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The influence of the interception process on the precipitation quality in a catchment covered by subtropical Atlantic Forest

Influência do processo de interceptação na qualidade da água da chuva em uma bacia coberta por floresta Ombrófila Mista

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ABSTRACT

The interception process is responsible for the spatial and temporal redistribution of the precipitation that reaches the ground. The contact of the precipitation with the canopy influences on the water quality, increasing the concentration of various nutrients in the throughfall (*Tf*) and stemflow (*Sf*). The objective of this study was to assess the influence of the interception process on the precipitation quality in a catchment covered by Mixed Ombrophilous Forest. The precipitation (*P*) monitoring consisted of two rain gauges installed outside the basin. Six gauges were installed within the basin for *Tf* monitoring. The *Sf* monitoring was conducted in nine trees. Water sampled at all points was analyzed for color, conductivity, pH, turbidity, and total dissolved solids. The concentrations of Nitrate (NO_3^-), Chloride (Cl^-), Phosphate (PO_4^{3-}), Sulfate (SO_4^{2-}), Acetate ($CH_3CO_2^-$) and Calcium (Ca^{2+}) ions were measured in five points, i.e., one precipitation, two throughfall and two stemflow. Measured precipitation, throughfall and stemflow during the period were 652.1 mm, 584.5 mm (89,6% *P*) and 2.6 mm (0,4% *P*), respectively. Total interception loss was 65 mm, corresponding to 10% of the total precipitation. The highest values of the physicochemical parameters were found in the *Sf* and the *Tf*. The pH was lower in the *Sf*, and it decreases with the diameter at breast height. There was no significant relationship between the physicochemical parameters and the canopy cover fraction. The analysis shows the significant difference in the water quality of the precipitation that reaches the ground after being intercepted.

Keywords: Atlantic Forest; Precipitation interception; Precipitation water quality.

RESUMO

O processo de interceptação é responsável pela redistribuição espacial e temporal da água da chuva que é interceptada antes de chegar no solo. O contato da água da chuva com o dossel e os troncos das árvores altera a qualidade da mesma, aumentando a concentração de diversos nutrientes na chuva interna (*Tf*) e no escoamento pelo tronco (*Sf*). Este trabalho tem por objetivo analisar a influência do processo de interceptação na qualidade da água da chuva em uma bacia coberta por floresta Ombrófila Mista. O monitoramento da chuva externa (*P*) foi realizado com dois pluviômetros instalados fora da bacia. Seis pluviômetros foram instalados dentro da floresta para o monitoramento da *Tf*. O monitoramento do *Sf* foi realizado em noves árvores. Em todos os pontos foram medidos os parâmetros de cor aparente, condutividade, pH, turbidez e teor de sólidos totais. As concentrações de íons de Nitrato (NO_3^-), Cloreto (Cl^-), Fosfato (PO_4^{3-}), Sulfato (SO_4^{2-}), Acetato ($CH_3CO_2^-$) e Cálcio (Ca^{2+}) foram monitoradas em cincos pontos, i.e., um ponto de *P*, dois pontos de *Tf* e dois pontos de *Sf*. A *P* foi de 652,1 mm, a *Tf* foi de 584,5 mm (89,6% da *P*) e o *Sf* foi de 2,6 mm (0,4% da *P*). A perda por interceptação da copa foi de 65 mm, correspondendo a 10% da chuva externa. As maiores concentrações dos parâmetros físico-químicos analisados ocorreram no *Sf* e na *Tf*. O pH monitorado foi menor no *Sf*, decrescendo com o diâmetro na altura do peito. Não foi encontrada nenhuma relação significativa entre os parâmetros físico-químicos e o índice de cobertura do dossel. As análises mostraram que o processo de interceptação tem influência significativa na qualidade da água da chuva.

Palavras-chave: Floresta Ombrófila Mista; Interceptação da chuva; Qualidade da água da chuva.

INTRODUCTION

Before reaching the ground, precipitation falling on a forest passes through the interception process. Some water is temporarily retained in the canopy and evaporates, and this is considered interception loss. The remainder goes to the ground and may fall as canopy drip or flow as stemflow. (DAVID; VALENTE; GASH, 2005; GERRITS; SAVENIJE, 2011). The interception redistributes the precipitation in space and time, influencing the quantity and quality of water (BOUTEN; HEIMOVAARA; TIKTAK, 1992; KEIM; SKAUGSET; WEILER, 2005; STAELENS et al., 2006; SOUZA et al., 2007; WUYTS et al., 2008). Rainfall interception by the vegetation has a great importance for the geochemical cycling of nutrients in crops and tropical forests (LACLAU et al., 2003; FORTI et al., 2005).

The water balance in native forests is influenced by the diversity of ecosystems and the forest canopy structure (DÍAZ; BIGELOW; ARMESTO, 2007; ÁVILA et al., 2014). On average, the interception loss is 20-40% of the total precipitation (OLIVEIRA JUNIOR; DIAS, 2005; MOURA et al., 2009; TOGASHI; MONTEZUMA; LEITE, 2012; FREITAS et al., 2013; LORENZON; DIAS; LEITE, 2013; TONELLO et al., 2014; SÁ; CHAFFE; OLIVEIRA, 2015).

The canopy architecture leaf area index, density and trees structures are some factors that are responsible for different interactions between the rain and the forest ecosystem (ARCOVA; CICCO; ROCHA, 2003; MELO; MIRANDA; DURIGAN, 2007; CALDATO; SCHUMACHER, 2013). The throughfall quality is given by three factors: washing of deposited elements on leaves (dry deposition); changes that occur directly in the treetops through leaching of nutrients; and the absorption of direct nutrients from leaves (ARCOVA; CICCO, 1987; KRAMER; BOYER, 1995).

The Rainfall contact with the canopy increases the ammonia ($N^-NH_4^+$), phosphate (PO_4^{3-}), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and sodium (Na^+) concentrations both in throughfall and stemflow (KOICHIRO et al., 2001; BALIEIRO et al., 2007; SCHEER, 2009; SOUZA; MARQUES, 2010; DINIZ et al., 2013). The most common chemicals found in precipitation are: cations (e.g. Ca^{2+}, Na^+, K^+, Mg^{2+}) and anions (e.g. SO_4^{2-}, HCO_3^-, NO_3^-, Cl^-, PO_4^{3-}) (DINGMAN; 2002; CONCEIÇÃO et al., 2013). These elements can be derived from: salt spray (e.g. Na^+, Cl^-, Mg^{2+} and K^+), terrestrial aerosols, dust and soil organic emissions (e.g. Ca^{2+}, P and NO^{3-}), and anthropogenic sources (ARCOVA; CICCO; SHIMOMICHI, 1993).

The Atlantic Forest is one of the major biomes in Brazil, extending throughout the eastern portion of the territory. This biome is recognized as one of the 25 areas of greatest biodiversity in the world, with more than 60% of all the terrestrial species (MYRES et al., 2000; BATALHA FILHO; MIYAKI, 2011). Only 10% (72,405 hectares) of the federal conservation units are in Subtropical Atlantic Forest (PIRES; ZENI JUNIOR; GAULKE, 2012).

In the Atlantic Forest, the interception loss varies from 8.4 to 20.6%. In Brazil, there are few studies of the precipitation quality in the Amazon and Atlantic Forest (GIGLIO; KOBIYAMA, 2013). The objective of this study is to analyze the influence of the interception process in the precipitation quality in a watershed covered by Subtropical Atlantic Forest.

MATERIALS AND METHODS

Study area

Araponga catchment is situated in Rio Negrinho city, north of Santa Catarina State, southern Brazil (Figure 1). The road around the experimental catchment is not paved. The catchment has 5.3 hectares and the altitude varies from 880 m to 1006 m above the sea level. It is classified as second order and is completely covered by Subtropical Atlantic Forest (MOTA, 2012).

Rio Negrinho city is situated on the Paraná sedimentary basin, in the geomorphological unit Porch Mafra. The dominant soils in the region are from the Cambisol group, which are derived from sedimentary rocks and from soils characterized by an incipient B horizon, undeveloped and presenting clay of high activity and high saturation bases (MOSER, 1990).

Rainfall, throughfall and stemflow data

The water samples were collected at least once a month from 06/05/2014 until 11/11/2014. Precipitation (*P*) and throughfall (*Tf*) were monitored using hand made polyethylene terephthalate (PET) gauges. The hand-made rain gauges are made up of a funnel with an opening of 0.0195 m^2 and a 5 liter containers (Figure 1a). To check the homogeneity of the precipitation on the experimental catchment, two hand-made rain gauges (*P*1 and *P*2) were installed along the road bordering the catchment (GIGLIO, 2013). Throughfall and canopy cover index (CCI) were monitored at 6 points. Each point was named by *Tf* combined with the average value of CCI as shown in Figure 1.

Stemflow (*Sf*) was monitored on both margins of the main stream (Figure 1). A portion of the collectors was located on the east side of the river (*Sf-e*) and the other one on the west side (*Sf-w*). The slopes of the two margins are similar and the vegetation cover is composed of larger trees than elsewhere in the basin (GIGLIO, 2013). The stemflow volume was collected using spiral collar collectors, and stored in PET bottles of 5 and 10 liters (Figure 1c).

The naming of each point of stemflow was given by *Sf* plus the value of the diameter at breast height (DBH) and according to the side the portion was on relative to the river (i.e. east side is *Sf-e* and the west side is *Sf-w*). On the west side of the river (*Sf-w*) four trees were monitored: one *Tabebuia cassionoides* (DBH = 1.9 cm), one *Myrtaceae sp.2* (DBH = 23.2 cm), one *Cupania vernalis* (DBH = 14.3 cm) and one *Myrsine coriacea* (DBH = 16.7 cm). On the east side of the river (Sf-e) five trees were monitored: two *Vernonanthura discolor* (DBH = 31.8 and 21.6 cm), one *Prumus myrtifolia* (DBH = 13.1 cm), one *Guapira opposita* (DBH = 17.5 cm) and one tree was not identified (DBH 2.9 cm). The estimate of the stemflow was given by the measured volume divided by the area of the projection of the corresponding tree canopy.

The CCI was calculated from photographs taken from tree canopies. The photographs were converted to gray scale and then transformed into black and white binary images. The white pixels (N_w) represent the open class and the black pixels (N_b) representing the covered class (NASCIMENTO; FAGG; FAGG, 2007). The Equation 1 was used for calculating the CCI:

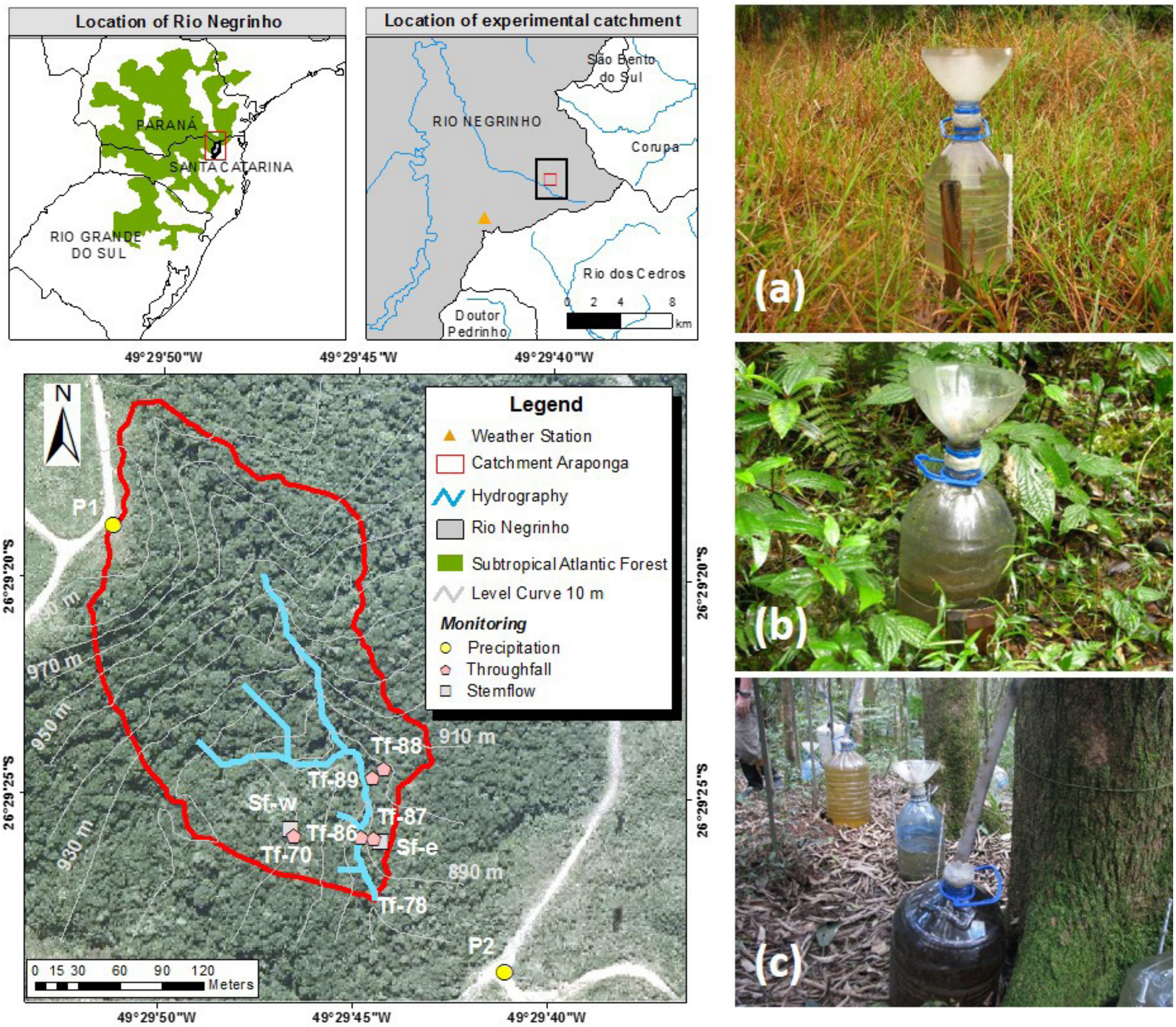

Figure 1. Location of the monitoring points. (a) Rainfall collector, (b) Throughfall collector and (c) Stemflow collector.

$$CCI = \frac{N_b}{N_b + N_w}.100 \quad (1)$$

where CCI is the canopy cover index; N_b is the number of black pixels; and N_w is the number of white pixels.

Physicochemical water analysis

The pH and electrical conductivity were measured *in situ* with colorimetric tape and a portable conductivity meter. Water apparent color was measured with an ASTM (APHA, 2005) laboratory colorimeter. The determination of turbidity was made with the HACH-2100N Turbidimeter. The total solids content (*St*) was measured by weighing a fiberglass membrane before (M_0) and after (M_1) filtering a water volume (V) and drying the membrane in an oven. The *St* is calculated according to Equation 2.

$$St = \frac{(M_1 - M_0)10^6}{V} \quad (2)$$

where *St* is the total solids (mg.L^{-1}); M_0 is the mass of the fiberglass membrane (g); M_1 is the mass of the fiberglass membrane with dry residue (g) at 103-105 °C and V is the sample volume which was filtered (ml).

Cluster and correlation analysis

Cluster and correlation analysis were performed using the transformed and standardized variables. The hierarchical clustering was performed by using the complete linkage clustering method and the Euclidean distance as distance measure. The transformed variables were standardized according to Equation 3:

$$x_p = \frac{x_i - x_m}{s} \quad (3)$$

where x_p is the standard variable; x_i is the original value of the variable; x_m is the average of the variable and s is the standard deviation.

In the exploratory analysis we checked charts and histograms in order to verify if the variables followed the normal distribution.

The variables that were not normally distributed were transformed using a mathematical transformation (e.g. natural logarithm or x^3).

The correlation analysis shows how two variables vary together, checking the intensity and the direction of the linear relationship (positive: p=1 and negative: p=-1) or nonlinearity between these variables (NAGHETTINI; PINTO, 2007).

Pearson's parametric and Spearman's non-parametric correlations coefficients were considered in this study. The nonparametric test does not require variables with normal distribution, but has the disadvantage of not finding much difference between the data, when in fact these differences might exist (NAGHETTINI; PINTO, 2007).

The Pearson's correlation measures the degree of linear relationship between two variables. The Spearman's correlation evaluates a monotonic function of the relationship. The calculation of the Pearson's correlation coefficient is shown in Equation (4):

$$p = \frac{\sum_{i=1}^{n}(x_i - x_m)(y_i - y_m)}{\sqrt{\sum_{i=1}^{n}(x_i - x_m)^2}\sqrt{\sum_{i=1}^{n}(y_i - y_m)^2}} \quad (4)$$

where $x_1, x_2, ..., x_n$, and $y_1, y_2, ..., y_n$ are the values of both variables; x_m and y_m are the averages of both variables. All the statistical analysis were performed in MATLAB (MathWorks, Natick, MA).

Ions analysis

Five of the 17 monitored points were selected for ions analysis. Were sampled two stemflow points (*Sf*-02*w* and *Sf*-32*e*) two throughfall points (*Tf*-87 and *Tf*-88) and one gross rainfall point (*P*1), the other points were not considered due to the lack of material availability to realize the analysis.

To determine the concentration of calcium (Ca^{2+}) it was prepared an acid digestion in order to obtain aqueous samples according to the method 3010A (APHA, 2005). The Ca^{2+} concentrations were determined in triplicate with an atomic absorption spectrometer Spectro Flame AA 50B.

The concentrations of nutrients and minerals (Cl^-, SO_4^{2-}, PO_4^{3-}, NO_2, NO_3, $CH_3CO_2^-$) were analyzed by ion chromatography with Thermo Scientific Dionex equipment.

RESULTS AND DISCUSSION

Rainfall, throughfall and stemflow data

Gross rainfall (*P*), throughfall (*Tf*) and stemflow (*Sf*) volumes were monitored from 06/05/2014 to 11/11/2014. Gross rainfall measured in *P*1 and in *P*2 were very similar and can be considered homogeneous in the catchment (Figure 2). Water quality was not analyzed for three of monitored periods (Figure 3). In the period between 05 June to 26 July the collection bottles were all full of water, so the quantitative analysis was not held but the qualitative analysis - physicochemical and ions were.

Gross rainfall during the period was 652 mm, and the throughfall accounted for 89.6% (584 mm) of the total precipitation amount. The proportion of throughfall relative to the precipitation was in the range of the values found in the literature, from 70.0 to 94.4% of the precipitation for Atlantic Forest forests (CASTRO et al., 1983; OLIVEIRA JUNIOR; DIAS, 2005; THOMAZ, 2005; ALVEZ et al., 2007, SOUZA et al., 2007, CICCO et al., 1988; MOURA et al., 2009; SARI; PAIVA; PAIVA, 2015, 2016). The canopy interception loss was 65 mm, corresponding to 10% of precipitation (Figure 3). which is in the range of 8.4 to 20.6% observed in Atlantic Forests (GIGLIO; KOBIYAMA, 2013).

The average stemflow for each monitored period ranged from 0.01 to 4 mm, corresponding to 0.02 and 3.00% of the gross rainfall. In studies conducted in the Atlantic Forest the highest

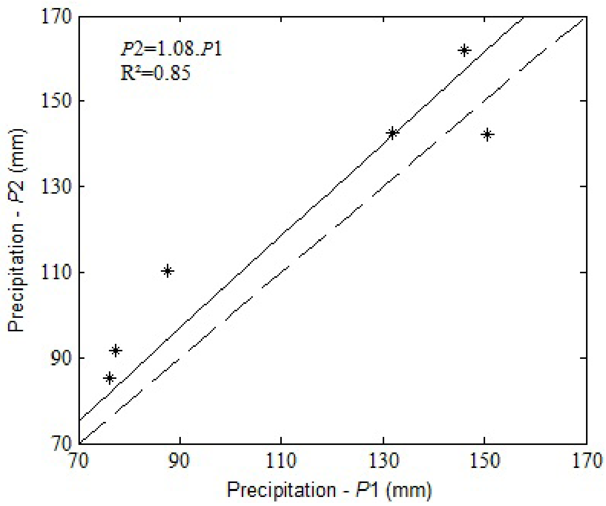

Figure 2. Relationship between the precipitation monitored at two points out of the catchment (*P* 1 and *P* 2). The continuous line represents the regression of the points of the precipitation and the dashed line represents a ratio of 1:1

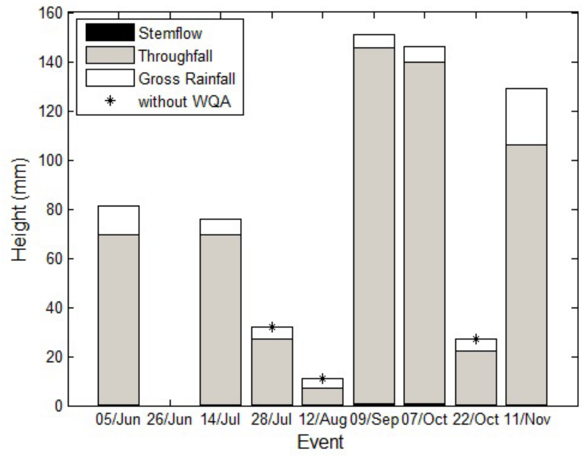

Figure 3. Measure Gross Rainfall (*P*), throughfall (*Tf*) and the stemflow (*Sf*) recorded in each study period. * periods without water quality analysis.

value of stemflow was 3.30% in a secondary forest (SOUZA et al., 2007; GIGLIO; KOBIYAMA, 2013).

The average canopy cover index (CCI) considering all points was 75.0%. The CCI of point *Tf*-70 was the lowest average. This point is located in the flattest part of the basin, where the trees are sparser in comparison to other monitoring points.

Physicochemical parameters of water

The conductivity, apparent color, dissolved solids and turbidity had the highest averages in samples from the stemflow than in the precipitation (Figure 4). According to Souza et al. (2007), this indicates that it would be occurring an increase in the concentration of ions associated with the presence of organic compounds dissolved in the solution. The pH decreased with the increase of DBH (Figure 4d).

The apparent color and conductivity were higher in *Sf*-31*e*. This tree is from the species *Vernonanthura discolo* with brown-grayish trunk and DBH of 31 cm. In many occasions this stem was covered with mosses, which increases the entrainment of particulates in the water, making it darker and with greater conductivity.

In general, the highest average concentration of the physicochemical parameters was found in *Sf*-16*w* point (Figure 4). The trunk of this tree (*Myrsine leathery*) has a greyish outer shell, with small scales and large number of lenticels. Thus, similarly to what occurs in *Sf*-31*e*, the leaching process may cause an enrichment of the solid particles in the water.

The turbidity and total solids were greater in throughfall points *Tf*-88, *Tf*-87 and *Tf*-86 (Figure 4e and Figure 4f). During the monitoring period, it was observed the presence of lichens within these collection bottles which could be associated with this increased turbidity and solids content.

Cluster and correlation analysis

The cluster analysis was used to identify groups of points that presented similar behavior according to their physicochemical parameters. Among throughfall samples, it was not possible to verify a relationship between the groups formed and the physical parameters such as CCI or distance between the trees (Figure 5a).

In clustering stemflow it was possible to identify two distinct groups (Figure 5a). A group composed of points *Sf*-21*e*, *Sf*-23*w* and *Sf*-31*e* and another group by *Sf*-3*e*, *Sf*-13*e* and *Sf*-14*w*. Trees with similar DBH were grouped together, showing that the DBH can be a good predictor of the physicochemical parameters of the stemflow. The water collected in *Sf*-16*w* and points and

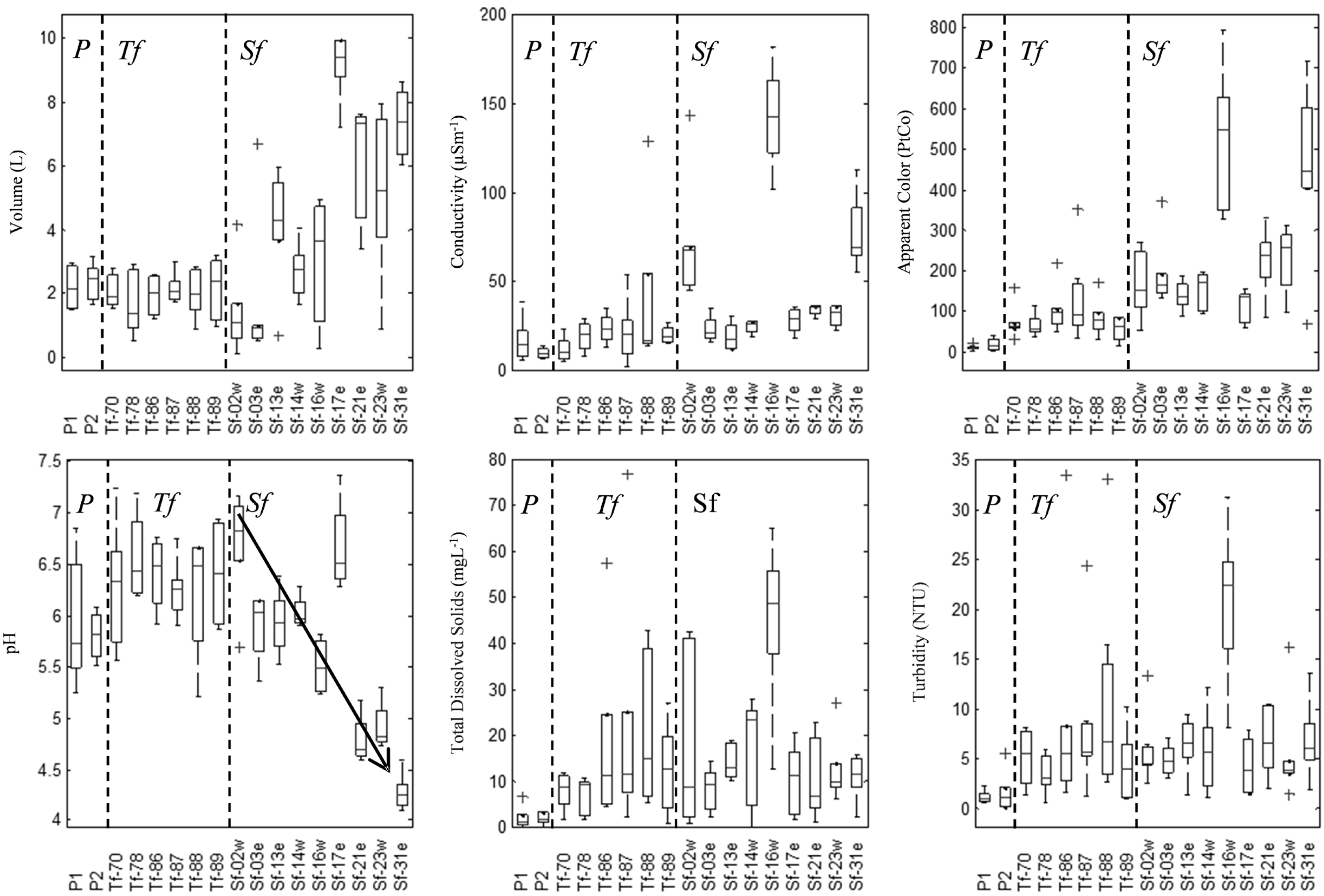

Figure 4. Boxplots of the physicochemical parameters in each of the monitoring points. Top and bottom of the box represent 25 and 75% of the sample, the line inside the box represents the median, the outliers are displayed with + and the dashed line represents the average of all points for each parameter.

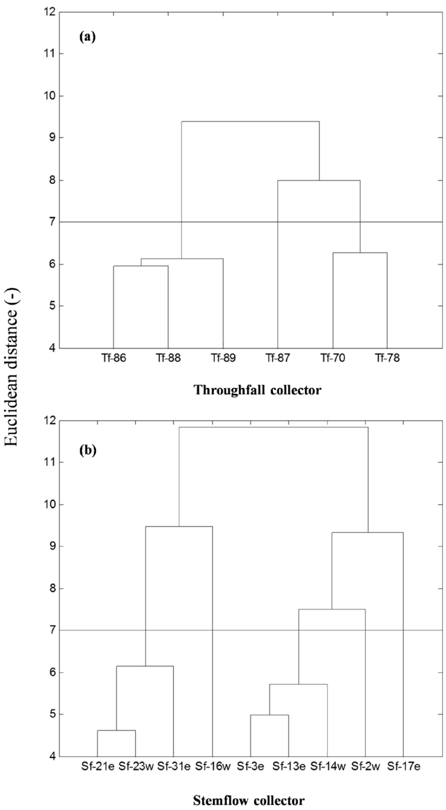

Figure 5. Clustering with complete linkage method using physicochemical parameters of the water. (a) throughfall (n = 35) and (b) stemflow (n = 33).

Sf-17*e* differs from most of the other points on the magnitude of the physicochemical parameters (Figure 4).

Regarding the stemflow samples, the pH was strongly correlated with three other parameters: the canopy area (A_{Canopy}), diameter at breast height (DBH) and color (Table 1). The higher the DBH, the lower the pH value (Pearson's correlation coefficient was -0.75 and Spearman's coefficient was -0.71). In stemflow samples, conductivity was correlated to turbidity and color, considering both correlation coefficients (parametric and non-parametric). This is because the conductivity is directly related to dissolved ion concentrations or the concentration of nutrients.

pH value to throughfall samples was correlated with volume. The larger the volume, the lower the pH value. Their correlation coefficients were -0.72 (Pearson) and -0.65 (Spearman). No significant correlation between physicochemical parameters and CCI in throughfall points (Table 2) was observed.

Ions analysis

The vegetation influence on the concentration of the ions NO_3^-, Cl^-, PO_4^{3-}, SO_4^{2-}, $CH_3CO_2^-$ and Ca^{2+} can be observed in Figure 6. Regarding precipitation, the NO_3^- and Ca^{2+} levels in gross rainfall were in the same range found by Arcova, Cicco and Lima (1985). The stemflow (*Sf*-02*w* and *Sf*-31*e*) is richer in ions than throughfall (*Tf*-87 and *Tf*-88) and the precipitation (*P*1).

The increase of nutrients, especially of Ca^{2+} in the throughfall and stemflow is related to the presence of vegetation and decomposition of twigs and branches in the trees (SCHEER, 2009). The water that flows through the trunk has greater contact with vegetation than with the throughfall.

Table 1. The stemflow correlation matrix (n = 36). The upper diagonal presents the parametric Pearson's correlation and the lower diagonal nonparametric Spearman's correlation.

	A_{canopy}	DBH	Vol.	Turb.	Color	pH	Cond.	TDS
A_{canopy}	1.00	**0.90**	0.33	-0.21	0.24	**-0.57**	0.01	-0.18
DBH	**0.87**	1.00	**0.34**	0.03	**0.48**	**-0.75**	0.18	0.02
Vol.	**0.47**	0.31	1.00	-0.12	-0.14	0.01	-0.18	-0.09
Turb.	-0.17	0.01	-0.11	1.00	**0.67**	-0.17	**0.57**	**0.76**
Color	0.17	**0.49**	-0.08	**0.53**	1.00	**-0.67**	**0.81**	**0.51**
pH	**-0.46**	**-0.71**	0.01	-0.09	**-0.72**	1.00	-0.27	-0.06
Cond.	-0.04	0.24	-0.13	**0.40**	**0.73**	-0.31	1.00	**0.48**
TDS	-0.25	-0.13	0.03	**0.79**	**0.46**	0.07	**0.42**	1.00

A_{canopy} is the canopy area, DBH is the diameter at breast height, TDS is total dissolved solids. In bold are the significant correlations ($p < 0.05$).

Table 2. The throughfall correlation matrix (n=24). The upper diagonal present the parametric Pearson's correlation and the lower diagonal nonparametric Spearman's correlation.

	CCI	Vol.	Turb.	Color	pH	Cond.	TDS
CCI	1.00	-0.22	0.13	0.34	0.15	**0.41**	0.21
Vol.	-0.27	1.00	-0.29	-0.16	**-0.72**	0.21	-0.21
Turb.	0.09	-0.29	1.00	**0.68**	-0.03	0.03	**0.72**
Color	0.28	-0.32	**0.66**	1.00	-0.06	0.38	**0.72**
pH	0.16	**-0.65**	-0.12	-0.08	1.00	-0.33	-0.19
Cond.	0.38	0.07	-0.08	**0.41**	-0.12	1.00	0.19
TDS	0.24	-0.31	**0.77**	**0.69**	-0.20	0.08	1.00

CCI is canopy cover index, TDS is total dissolved solids. In bold are the significant correlations ($p < 0.05$).

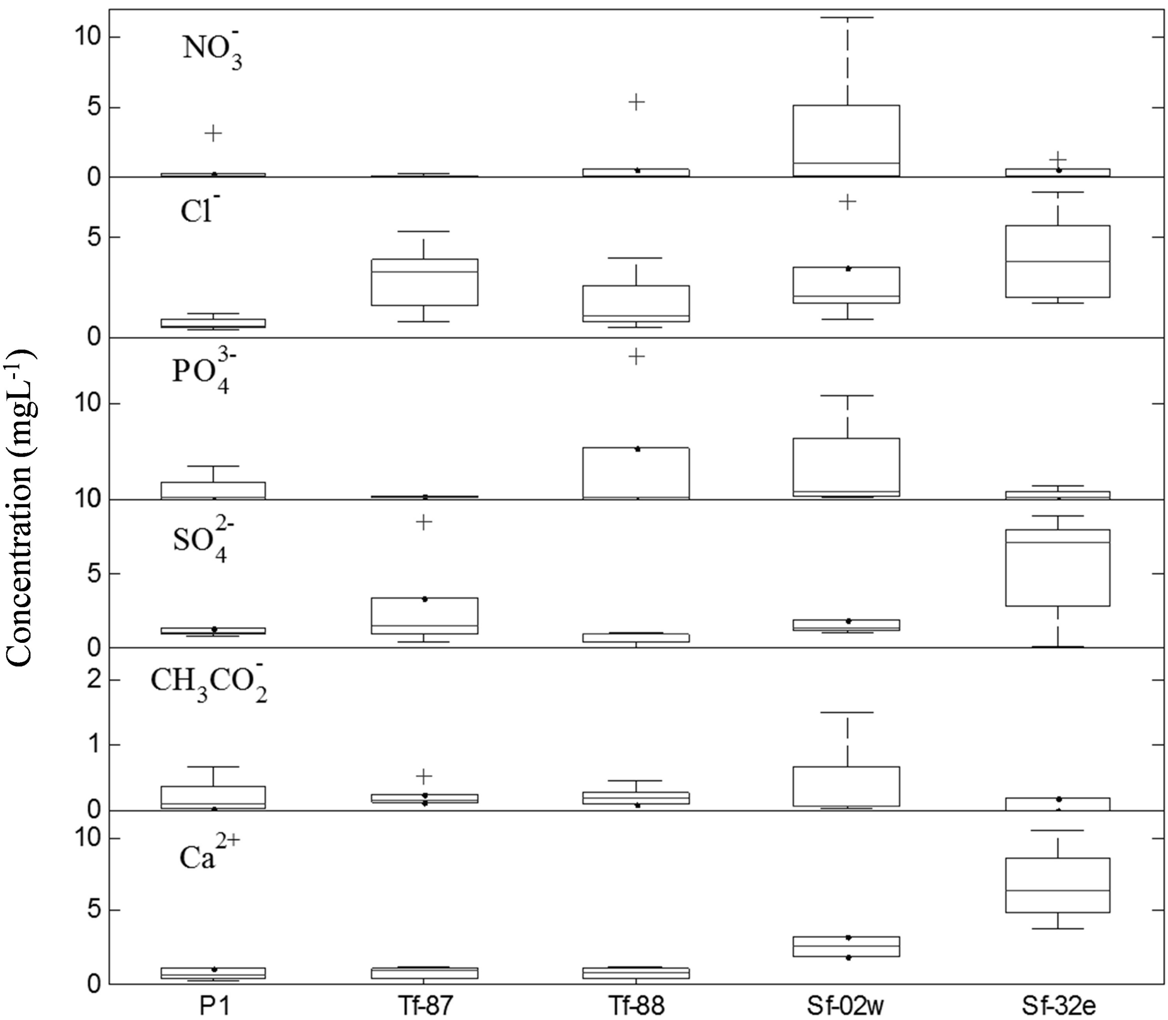

Figure 6. Boxplot of NO_3^-, Cl^-, PO_4^{3-}, SO_4^{2-}, CH_3CO^{2-} and Ca^{2+} concentrations of the samples *Sf*-02*w* and *Sf*-31*e* (stemflow); *Tf*-87 and *Tf*-88 (throughfall); and precipitation *P*1 (n = 4). Top and bottom of the box represent 25 and 75% of the sample, the line inside the box represents the median, the outliers are displayed with +.

This process of deposition and subsequent leaching might be the responsible for high amounts of Ca^{2+} and SO_4^{2-} concentrations in the stemflow samples. The concentrations of NO_3^- and PO_4^{3-} showed no clear trend. In the case of PO_4^{3-}, the point *Tf*-88 showed a high average.

CONCLUSIONS

In this study, we measured several water quality parameters in the interception process in a catchment covered with Subtropical Atlantic Forest. Conductivity parameters, apparent color, turbidity and dissolved solids showed on average higher values in stemflow samples than in the throughfall and precipitation. The results showed the influence of the interception process in water quality of throughfall and stemflow samples.

The greater contact with vegetation (leaves and bark of trees), has led to the higher turbidity, the apparent color, conductivity and concentrations of nutrients and minerals.

In general, the pH values decreased with the increase in DBH. No significant correlation between physicochemical parameters and the canopy cover ratio was observed. The largest values of physicochemical parameters were found in *Sf*-16*w* point, which can be attributed to characteristics of the species *Myrsine coriácea*. Lichens around the trunks were often present in *Sf*-31*e* point (*Vernonanthura discolor*), which may have contributed to the high color and conductivity values.

This study examined a period from July to November. We recommend a longer-term study to verify, whether there is influence of seasonality on the quality of water samples measured. The results of some stemflow samples may have been influenced by the species of the trees. Thus, it is suggested to choose more trees of the same species in order to determine the influence of morphological parameters that may determine the variation in ion concentration.

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Authors contributions

João Henrique Macedo Sá: he designed the experiment, installed the equipment, were responsible for monitoring, analysis in laboratory and wrote the article.

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Matthieu Jack Joseph Quillet: he installed the equipment and were responsible for monitoring and analysis in laboratory.