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Effects of forest cover pattern on water quality of low-order streams in an agricultural landscape in the Pirapora river basin, Brazil

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Abstract Low-order streams are important places for river formation and are highly vulnerable to changes in terrestrial ecosystems. Thus, the land-use/land-cover plays an important role in the maintenance of water quality. However, only land-use/land-cover composition may not explain the spatial variation in water quality, because it does not consider land-use/land-cover configuration and forest cover pattern. In this context, the study aimed to evaluate the forest cover pattern effects on water quality on low-order streams located in an agricultural landscape. Applying a paired watershed method, we selected two watersheds classified according to their morphometry and average slope to discard other physical factors that could influence the water quality. Land-use/land-cover pattern was analyzed for composition and forest cover configuration using landscape metrics, including the riparian zone composition. Water quality variables were obtained every two weeks during the hydrological year. This way, watersheds had similar morphometry, slope, and land-use/land-cover composition but differed in forest cover pattern. Watershed with more aggregated forest cover had a better water quality than the other one. The results show that forest cover contributes to water quality maintenance, while forest fragmentation influences the water quality negatively, especially in sediment retention. Agricultural practices are sources of sediment and nutrients to the river, especially in steep relief. Thus, in addition to land-use/land-cover composition, forest cover pattern must be considered in management of low-order streams in tropical agricultural watersheds.

Keywords Stream water quality · Watershed management · Forest fragmentation · Land use · Riparian zone · Atlantic Forest

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Introduction

Conversion of natural landscapes into agricultural and urban areas to support the increasing human demand of resources is one of the main causes of water quality degradation (Goldstein et al., 2012; de Mello et al., 2020). Natural vegetation is often related to good water quality while urban and agricultural lands contribute to the increase in nutrients and sediments in freshwater ecosystems worldwide (Huang et al., 2016; de Mello et al., 2018b; Shehab et al., 2021). However, considering only land-use/land-cover composition may not explain the spatial variation in water quality, because it does not include landscape pattern (i.e., land-use/land-cover configuration in the landscape) such as patch size, shape, density, or connectivity, which can influence water quality parameters (Ding et al., 2016; Shi et al., 2017; Wu et al., 2021). Landscape pattern can be especially important in low-order streams that are highly influenced by terrestrial flows and are located commonly in the steepest area of the river basin (Campos Pinto et al., 2016; Taniwaki et al., 2017; de Mello et al., 2018a). Understanding the relationships between land use patterns and water quality in low-order streams is necessary for effective landscape planning to protect downstream water quality (Bailão et al., 2020; Ding et al., 2016).

Low-order streams (1st to 3rd-order) dominate a riverine landscape and maintain the function, health, and biodiversity of the entire river networks (Vannote et al., 1980). According to Vannote et al. (1980), they are strongly influenced by terrestrial inputs, which makes them fragile ecosystems that can suffer dramatic impact from land-use changes such as deforestation and fragmentation (de Mello et al., 2020). Thus, anthropogenic activities and degradation of native vegetation in low-order streams can increase nutrients and sediments loading into streams, thereby impacting distant downstream ecosystems (Castillo et al., 2012; Ding et al., 2016; Freeman et al., 2007; Gomi et al., 2002; Song et al., 2020). These relationships can be enhanced in tropical watersheds, where headwater streams are highly dynamic in intense hydrological cycles and constant disturbances resulting from their topography that induces fast-flow regimes and substrate instability (Taniwaki et al., 2019). Besides land use impacts, climate change is also a great anthropogenic pressure on small tropical streams, which highlights the importance of studies in these fragile ecosystems (Taniwaki et al., 2017).

Natural vegetation has an important role in biogeochemical cycles in tropical agricultural watersheds, and studies show that this natural vegetation is critical in low-order streams, providing protection against erosive processes, sedimentation in water bodies, pollutant retention, excessive leaching of nutrients, and increased water temperature (de Mello et al., 2018a, b; Schilling & Jacobson, 2014; Tanaka et al., 2016; Taniwaki et al., 2017). The removal of this forest in general causes water quality degradation, which will impact water uses downstream (Turunen et al., 2021). However, early studies have shown that in addition to forest net loss, forest fragmentation influences water quality degradation (Clément et al., 2017; Ding et al., 2016; Shi et al., 2017). According to Shi et al. (2017) landscape pattern, such as size, density, aggregation, and diversity of land-use/land-cover types were important factors impacting stream water quality. Regarding forest cover pattern, Ding et al. (2016) found that patch form was an important predictor of water quality variables. In the same way, Clément et al. (2017) showed that shape and forest patch location have an impact on water quality. However, these studies are still scarce, most studies focused only on the amount of forest cover and not on its configuration (i.e., forest cover pattern) (de Mello et al., 2020).

Therefore, studies are needed to evaluate the effects of forest cover pattern on water quality, especially in agricultural low-order streams. It is important to support conservation and management efforts of these fragile ecosystems, as well as the resulting improvement in water quality of downstream ecosystems.

In this context, the main objective of this study is to assess the effects of forest cover pattern on water quality of the low-order streams in an agricultural landscape, which forms the main tributaries of a public water supply in Brazil. Thus, a paired watershed method was used in this study. The specific objectives are: (1) to evaluate the relationship between landscape metrics and water quality; (2) to verify if the forest cover pattern influences water quality at small watershed scale; and (3) to evaluate the effect of forest fragmentation on stream water quality.

Material and methods

Study area

We studied the main tributaries of the Pirapora river, regional named as Gurgel (W1) and Vieirinhas (W2). Pirapora river is one of the main rivers of the Tiete River basin, located in the São Paulo State, southeastern Brazil (Fig. 1). They supply three cities and towns, providing water for domestic, agricultural, and other purposes (Silva et al., 2017).

The watershed was originally covered by Atlantic Forest, where Dense Ombrophilous Forest is the predominant forest type. The forest patches remaining are within a complex matrix composed by agriculture (mostly in small scale with annual crops), pasture, planted forest (*Eucalyptus sp.* and *Pinus sp.*), and urban areas. Agriculture is the backbone of the economy, especially the production of grains, fruits, and vegetables (Silva et al., 2017). Thus, the population is predominantly rural in the region (IBGE, 2020). Another characteristic of the study area is the proximity to two protected areas – Itupararanga Environmental Protection Area and Jurupará State Park due to its great forest cover, unique in the São Paulo State (Silva et al., 2017).

The predominant soil types in the Pirapora river watershed are red or yellow tropical soils, mainly Latosols and Argisols (Rossi, 2017). The local altitude varies from 870 m to 1,200 m, with a relief characterized by hills with medium to high slopes, with some mountainous areas (Carneiro et al., 1981; EMBRAPA, 1999).

The region is under the influence of Cwa-type climate (humid temperate with dry winters). The average daily temperature in the hottest months is 22.0 °C and in the colder months is 15.7 °C (CEPAGRI, 2020). Annual precipitation is between 1354.7 mm and 1807.7 mm (CEPAGRI, 2020), and the rain mostly falls from October to March.

A paired watershed method has been used to verify significant differences between watersheds regarding only the land-use/land-cover pattern. According to (Brown et al., 2005), the paired watershed study uses two watersheds with similar characteristics in terms of slope, aspect, soils, area, climate, and vegetation, located adjacent or near to each other.

Thus, we have selected two similar adjacent watersheds (according to the soil, climate, size, shape, slope, and land-use/land-cover composition) based on a previous study (de Mello et al., 2018a). The watersheds have common physical characteristics and land-use/land-cover composition, although having different forest configurations.

Watersheds physical characterization

Spatial analysis was performed using the Geographical Information System (GIS) with ArcGIS 10.2 (ESRI). Considering that some characteristics of the watersheds may influence water quality, and the objective of the study was to evaluate only the effects of land-use/land-cover pattern, we characterized the

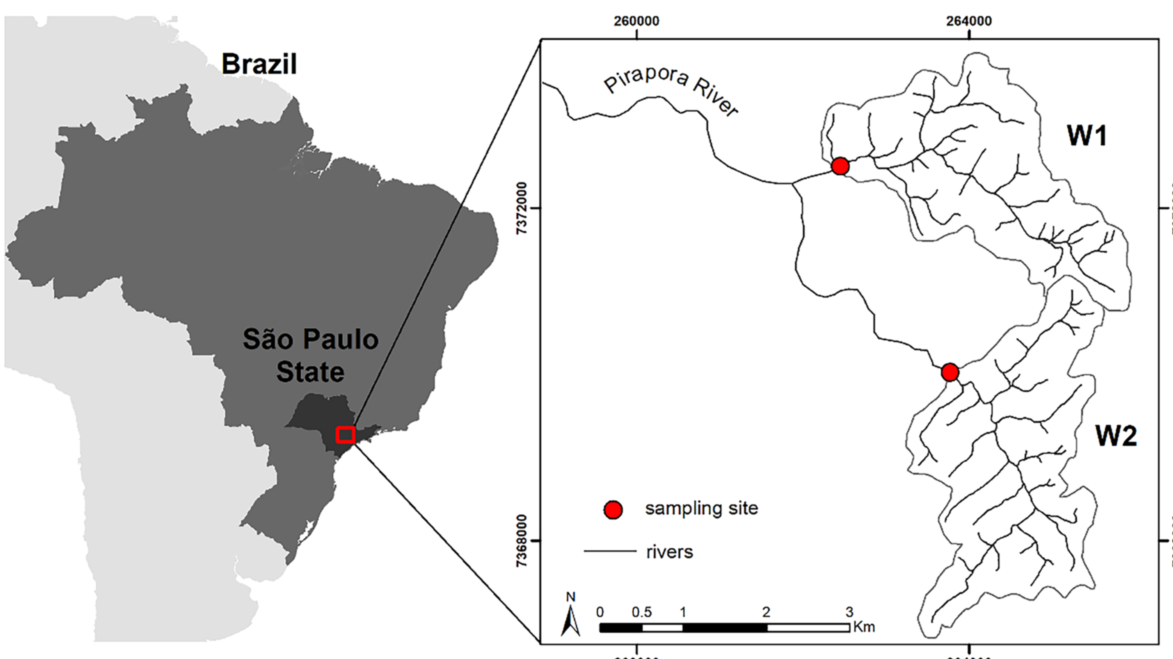

Fig. 1 Location of main tributaries of the Pirapora river, regionally named as Gurgel (W1) and Vieirinhas (W2), São Paulo State, Brazil

watersheds according to morphometry and slope to identify the physical factor that could influence the results of the analysis (Amuchástegui et al., 2016).

River network and a 5-m resolution Digital Elevation Model (DEM) for each watershed derived from official topographic information (IGC, 1:10,000 scale) were used to extract physical information of the watersheds.

Morphometry

Watersheds were classified according to their shape, using the following metrics: compactness coefficient (Kc), circularity index (Ic), and shape factor (Kf) (Villela & Mattos, 1975). Kc is a relation between the perimeter of the watershed and the circumference of a circle with the area of the watershed (Villela & Mattos, 1975). This coefficient refers to a dimensionless value that varies with the shape of the watershed, regardless of its size. The more irregular its shape, the greater the Kc, which is determined by Eq. (1):

$$K_c = 0.28 \times \left(\frac{P}{\sqrt{A}} \right) \quad (1)$$

Where Kc is the compactness coefficient; P is the perimeter (m); and A is the drainage area (m^2).

The Ic increases as the watershed approaches the circular shape and decreases as the shape becomes elongated, simultaneously to the Kc (Cardoso et al., 2006). To obtain Ic, Eq. (2) was used:

$$I_c = \left(\frac{(12.57 \times A)}{P^2} \right) \quad (2)$$

where Ic is the circularity index; A is the drainage area (m^2); and P is the perimeter (m).

The shape factor (Kf) associates the shape of the watershed with a rectangle, corresponding to the ratio between the average width and the length of the watershed (Cardoso et al., 2006) (Eq. 3).

$$Kf = \frac{A}{L^2} \quad (3)$$

where Kf is the shape factor; A is the drainage area (m^2); and L is the length of the watershed (m).

Watersheds were classified according to their shape (based on Ic and Kc indexes) as proposed by Villela and Matos (1975): round (Ic = 1.00 to 0.80; Kc = 1.00–1.24); oval (Ic = 0.8 to 0.61, Kc = 1.25 to 1.50); oblong (Ic = 0.60 to 0.40, Kc = 1.50–1.70); and long (Ic < 0.40; Kc > 1.70). According to the authors, these formats allow the respective environmental interpretations, regarding the flood tendency of the watershed: high; medium and low. In this way, the shape similarity among watersheds was evaluated.

Slope

We used the DEM to obtain a slope map in percentage that supported to calculate average slope of watersheds. After, the slopes were classified according to EMBRAPA (1999) to characterize the relief: 0–3% = flat relief; 3–8% = soft-wavy relief; 8–20% = wavy relief; 20–45% = highly wavy relief; 45–75% = mountainous relief; > 75% = highly mountainous.

Landscape composition and configuration

We calculated landscape metrics to evaluate the landscape composition and configuration, based on the land-use/land-cover map, which was created through on-screen digitizing of SPOT images (2.5 m spatial resolution; panchromatic band, year: 2010 – Source: SMA-CPLA) with a 1:8,000 scale.

Based on the IBGE (2013) technical manual of land use, the land-use/land-cover types were defined as water body, wetland, native forest, forestry, pasture, agriculture (annual crops), and urban area (residential and commercial areas).

We calculated the traditional landscape metrics (McGarigal, 2015), named percentage of landscape of each land-use/land-cover type (PLand);

- NP – number of forest patches;
- PD – forest patch density, number of patches in 100 ha of the landscape;
- LPI – largest patch index, obtained by the percentage of the landscape covered by the largest forest patch;
- CV – coefficient of variation of the patch size, obtained by dividing the standard deviation of the size of the forest fragments by the average of the areas;
- LSI – landscape shape index. The SHAPE of each forest patch is calculated by the perimeter of the

patch divided by the square root of the area and divided by four, with the most regular shape = 1;
- ED – edge density, obtained by the sum of total forest edges divided by the total area.

We also quantified the land-use/land-cover composition of the riparian zone, considering the Brazilian Native Vegetation Protection Law nº 12,651, sanctioned, with some vetoes, on May 25, 2012, and altered by Law nº 12,727 from October 17, 2012, which defines its occupation by native vegetation, i.e., forest cover in this case.

This way, we adopted the Permanent Preservation Area (PPA) as a riparian zone, using a 30 m buffer along with the river network and a 50 m buffer around springs as described in the previous study (de Mello et al., 2018b).

Water quality

We evaluated the water quality variables as water temperature (T); pH, dissolved oxygen (DO), total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), inorganic suspended solids (ISS), organic suspended solids (OSS), total coliforms (TC), fecal coliforms (FC), and turbidity.

The water samples were collected at bi-weekly intervals during a hydrological year (October 2013 to October 2014), with a total of 24 observations for each site. We also measured the streamflow (Q).

The temperature (°C), pH, and DO (mg/L) were measured through an in-situ water quality detector (YSI 556 multiparameter system). Water samples were collected in duplicate using polyethylene bottles to determine Turbidity, TN, TP, TSS, ISS, and OSS, which were kept refrigerated and transported to the laboratory for advanced analysis, following standard methods (APHA, 2005). Turbidity was obtained using an automatic turbidimeter (MS TEC – TB 1000).

The TN was determined by Kjeldahl digestion method (APHA, 2005) using an automatic digester (Buchi – K449). Digestion and spectrophotometric determination were used to measure TP by ascorbic acid method (4500-P E, APHA, 2005).

The gravimetric analysis was used to obtain TSS, ISS, and OSS (APHA, 2005). The 1,2 µm glass-fiber filters were calcined for 1 h at 550 °C in the muffle, and after cooling in the desiccator, they were weighed on an analytical balance to obtain the initial weight (P1). For each sample, 500 ml were filtered using a vacuum pump, and the filters were taken to an oven for 24 h at 105 °C. After this procedure, the filters were weighed again to obtain P2. After weighing, the filters were calcined at 550 °C for 1 h in the Muffle to obtain the final weight (P3). TSS is the total residue portion on the filter, ISS is the total solid portion that remains after the calcination, and OSS is the portion of the solids that is lost in the calcination process, as described below:

- Total suspended solids (TSS): Portion of the total residue retained in the filter (P1 – P2);
- Fixed or inorganic suspended solids (ISS): Portion of the total suspended solid, which remains after calcination at 550 °C for 1 h (P3 – P1);
- Volatile or organic suspended solids (OSS): Portion of the total suspended solid that is lost in the calcination of the sample at 550 °C for 1 h ((P1-P2)-P3).

TC and FC were detected by the multiple-tube technique with a 100 mL sample (CETESB, 2018), and the results are given in Most Probable Number (MPN) per 100 ml of sample. We used a Lactose Broth with incubation at 35 °C for 24/48 h for the presumptive identification of Coliforms. Confirmation test and mensuration were performed with 2% bright green lactose broth Bile 2% for TC, with incubation at 35 °C for 24/48 h, and EC broth for FC, with incubation at 44.5 °C for 24/48 h.

Streamflow (Q) was measured during all sampling times using a current-meter method by dividing the stream channel cross-section into various vertical subsections (Santos et al., 2001). In each subsection, the area was obtained by measuring the width and depth, and the water velocity was determined using a Current Meter (Global Water Flow Probe – 201). The total discharge was computed by summing the discharge of each subsection.

Statistical analysis

Relating the water quality, the variables were checked for normality and transformed, when necessary, using a logarithmic transformation. We calculated the mean and standard deviation of the water quality variables for watersheds. To evaluate if the watersheds with different forest cover patterns present different water quality, a multivariate analysis of variance (MANOVA) was applied with the use of the Hotelling–Lawley test in order to identify the differences between the watersheds regarding water quality variables. The Hotelling–Lawley Trace is the multivariate equivalent of the t-test, whether the two vectors of means for the two watersheds are sampled from the same sampling distribution (Carey, 1998). We compared landscape metrics to identify which metrics could be responsible for this result.

The principal component analysis (PCA) was applied to check for differences in groups of variables between the watersheds and identify the water quality variables that influenced this result and their relation.

We also performed a Pearson's rank correlation to check for covariance between water quality variables.

The statistical analyses were performed using the software RStudio (R Core Team, 2014) and MVSP 3.22 (Kovach Computing Services, 2007).

Results

Watersheds physical characterization

The W1 and W2 watersheds presented similar size (544.5 ha and 597.5, respectively), average slope (24.5% and 26.6%, respectively) and morphometric indexes (Kc, Ic and Kf). W1 presented values of Kc = 1.48, Ic = 0.45 and Kf = 0.31. W2 presented values of Kc = 1.50, Ic = 0.44 and Kf = 0.37. Both watersheds have an oval shape considering Kc and an oblong shape according to Ic. Thus, they can be classified into oblong/oval shape according to Villela and Mattos (1975).

According to the slope classes proposed by EMBRAPA (1999), their reliefs are wavy to highly wavy (Fig. 2B), considering that 51% of both watersheds belong to 20–45% slope class (highly wave relief) (Fig. 2A) and about 32% of the W1 and 30% of the W2 presented slope values between 8 and 20% (wavy relief). The flat areas, with slope values lower than 3%, occur in only about 1% of each watershed; slope between 3 and 8% (soft-wavy relief) represented about 7%; and the mountainous relief (45% to 75%) represented 8% and 11% of W1 and W2, respectively. Finally, the class of steeper relief (> 75% slope) was the least representative class in the watershed with less than 0.5% in the occupied area.

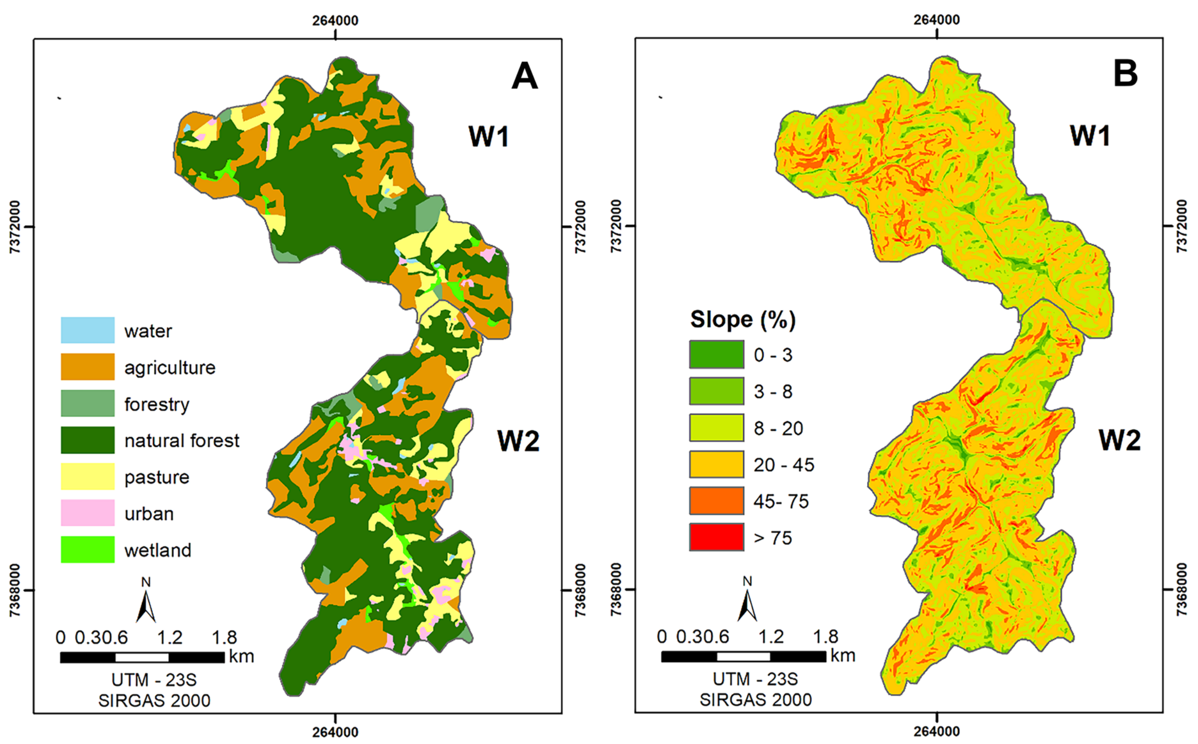

Fig. 2 Land-use/land-cover composition (**A**) and slope (**B**) of the low-order watersheds, regionally named as Gurgel (W1) and Vieirinhas (W2), in the Pirapora river basin, State of São Paulo, Brazil

Table 1 Land-use/land-cover composition (%) of the low-order watersheds, regionally named as Gurgel (W1) and Vieirinhas (W2), in the Pirapora river basin, State of São Paulo, Brazil, and their respective riparian zones

	W1		W2	
land-use/land-cover	Watershed	Riparian Zone	Watershed	Riparian Zone
Water	0.50	2.06	0.75	2.61
Agriculture	26.66	7.66	23.14	6.64
Forestry	3.28	2.66	1.92	0.06
Forest	55.16	70.39	57.40	76.85
Pasture	11.49	9.64	11.91	6.76
Urban	1.14	1.56	3.47	2.15
Wetland	1.77	6.04	1.40	4.93

Landscape composition and configuration

The watersheds are mostly covered by native forest (Fig. 2A) with 55% and 57% for W1 and W2 watersheds, respectively. Agriculture and pasture were the second and third most important land-use/land-cover types in the study area.

Agriculture comprises fast-growing vegetables (e.g., onion, potato, pumpkin, strawberry, and lettuce), representing 27% and 23%, respectively, of W1 and W2 watersheds (Table 1). Pasture comprised grassland destined for livestock activity, even without cattle, covering 11.5% and 12.0% of the respective watersheds. Forestry, urban areas, wetlands, and water covered less than 4% of each watershed (Table 1).

Considering the riparian zone composition, both watersheds presented a similar pattern, with the predominance of forest cover (70.39% and 76.85% for W1 and W2 watersheds, respectively), followed by pasture and agriculture (Table 1).

We can observe that the watersheds have a similar number of patch (NP) and patch density (PD); however, their forest patches presented distinct spatial pattern (distribution and configuration). The W1 watershed has 18 forest patches and 3.28 NP/100 ha and W2 has 19 forest patches and 3.18 NP/100 ha (Table 2). W2, however, showed smaller value for the largest patch index (LPI = 26.87%) and smaller value for coefficient of variation in patch area (CV = 218.00%), and concomitantly higher values for mean shape index (LSI = 1.75) and for edge density (ED = 91.02 m/ha) (Table 2). Thus, W2 has more elongated fragments, consequently larger edge area and less aggregate forest cover, when compared to W1.

where NP: number of patches; PD: density of patches; LPI: largest patch index; CV: coefficient of variation of the patch size; LSI: mean patch shape index; e ED: edge density.

The LSI (1.75) value describes the predominance of irregular patches, that were associated with individual SHAPE values larger than 3 as also described by Forman (1995). For instance, the two largest patches in W2 had SHAPE > 3 while the largest patch in W1 presented SHAPE = 2.97. In addition, W2 watershed presented higher values of ED than W1 (91 vs 69) representing the edge effect on the forest fragments. On the other hand, W1 has an only patch covering 40.6% (LPI – Table 1) of the landscape that influenced the high value of CV.

Water quality

The watersheds showed different water quality pattern, considering the variables evaluated. MANOVA analysis indicated that there is a significative difference (Hotelling–Lawley´s $\lambda = 2.86$; $F = 6.55$; $P = 0.001$) between the watersheds regarding water quality variables, especially related to TSS, ISS, OSS, turbidity, and TC with superior values of mean (M) and standard deviation (Sd) for W2. Conversely, other variables (T, pH, DO, TN, TP, and FC) had no significative

Table 2 Landscape metrics for forest patches of the low-order watersheds, regionally named as Gurgel (W1) and Vieirinhas (W2), in the Pirapora river basin, State of São Paulo, Brazil

Metrics	Watersheds	
	W1	W2
NP	18.00	19.00
PD (NP/100 ha)	3.28	3.18
LPI (%)	40.56	26.87
CV (%)	300.00	218.00
LSI	1.57	1.75
ED (m/ha)	69.25	91.02

Table 3 Water quality variables (WQ), their mean values (M) and standard deviation (PD), for the low-order watersheds, regionally named as Gurgel (W1) and Vieirinhas (W2), in the Pirapora river basin, State of São Paulo, Brazil

WQ	W1		W2	
	M	PD	M	PD
T (C°)	13.52	2.76	13.81	2.44
pH	5.78	0.93	6.40	0.92
DO (mg/L)	7.75	0.73	8.04	0.74
Turbidity (NTU)	13.95	3.59	17.90	9.28
TSS (mg/L)	5.15	3.03	11.51	6.29
ISS (mg/L)	2.80	2.35	7.22	4.97
OSS (mg/L)	2.35	0.90	4.29	1.47
TN (mg/L)	0.22	0.15	0.21	0.15
TP (μg/L)	49.66	35.43	56.52	36.68
TC (NMP)	298	415	540	544
FC (NMP)	106	134	102	134

difference, even with a general higher value for W2 watershed (Table 3).

where T=temperature; DO=dissolved oxygen; TSS= total suspended solids; ISS=inorganic suspended solids; OSS=organic suspended solids; TN=total nitrogen; TP=total phosphorus; TC=total coliforms; FC=fecal coliforms.

Observing the individual variables values (Table 3), we noticed pH near 6, that is considered slightly acidic and DO values were higher than 6 mg.L^{-1}.

In general, turbidity values were below 20 NTU, having W2 a turbidity of 17.9 NTU (PD=9.28) and W1 a value of 13.95 NTU (PD=3.59), but we can observe that the variation of turbidity values during the year was higher in W2 than W1 (PD – Table 3). The higher value for W2 was 56.7, while for W1 all values remained below 20. The same tendency was found for TSS, ISS and OSS, with higher values of M and PD for W2.

Concerning nutrients, we can observe that the watersheds obtained similar values for TN with M values of 0.2 mg/L (PD=0.15 mg/L) and, TP with higher value for W2 (56.5 μg/L) than W1 (49,7 μg/L), however it did not present statistical different. Nevertheless, TP varied during the year, and we had three samples (at the two watersheds) with values superior to 0.01 mg/L, increasing PD value. TC had the same pattern with superior values in W2 despite its FC, that was a little bit low, compared with W1 mean (Table 3).

The principal component Analysis (PCA) indicated a data grouping by watersheds with the first axis explaining 36.0% of the data variability and the second axis 27.4%, that means a total of 63.4% of explanation (Fig. 3).

The first axis comprises Q, ISS, OSS, TSS and turbidity, indicating relationships among them and, showing that the highest NTU and TSS values occurred at W2. Since the increase in Q corresponds to an increase in the TSS in the water, the Q variation in function of the precipitation should have an influence on the inflow of solids into the river.

We can observe that there is a higher solids runoff with streamflow increasing in W2 than in W1 as well as for TC and FC (axis 2 – Fig. 3).

There is a correlation between suspended solids and turbidity, especially for ISS (r=0.82) and TSS (r=0.78), which presented a high correlation between them (r=0.99). OSS presented a correlation of 0.86 with TSS. Other variables that presented correlation with TSS and ISS were P (r=0.52 and 0.53 respectively) and TC (r=0.53). Both TSS and ISS presented a correlation with Q (r=0.67 and 0.62, respectively). Another relation found with Person's correlation was DO and TN with temperature, but in this case, a negative correlation (r=-0.45 and -0.48, respectively).

Discussion

The headwaters of Pirapora river basin presented similar morphometry and slope, which allows the analysis of the effect of land-use/land-cover pattern on water quality of these watersheds. Although they are covered mostly by forest, the agricultural activities may be responsible for inputs of solids and nutrients into the streams, especially phosphorus. The watersheds have similar land-use/land-cover composition and riparian zone characteristics but differ in forest cover pattern, and they presented differences regarding the water quality variables, which indicates that land-use/land-cover configuration is important to water quality response in low-order streams.

Both watersheds presented an oblong/oval shape, which indicates low to medium tendency of floods according to Villela and Matos (1975). According to Villela and Mattos (1975), elongated basins do not favor the concentration of the fluvial flow, that is, the

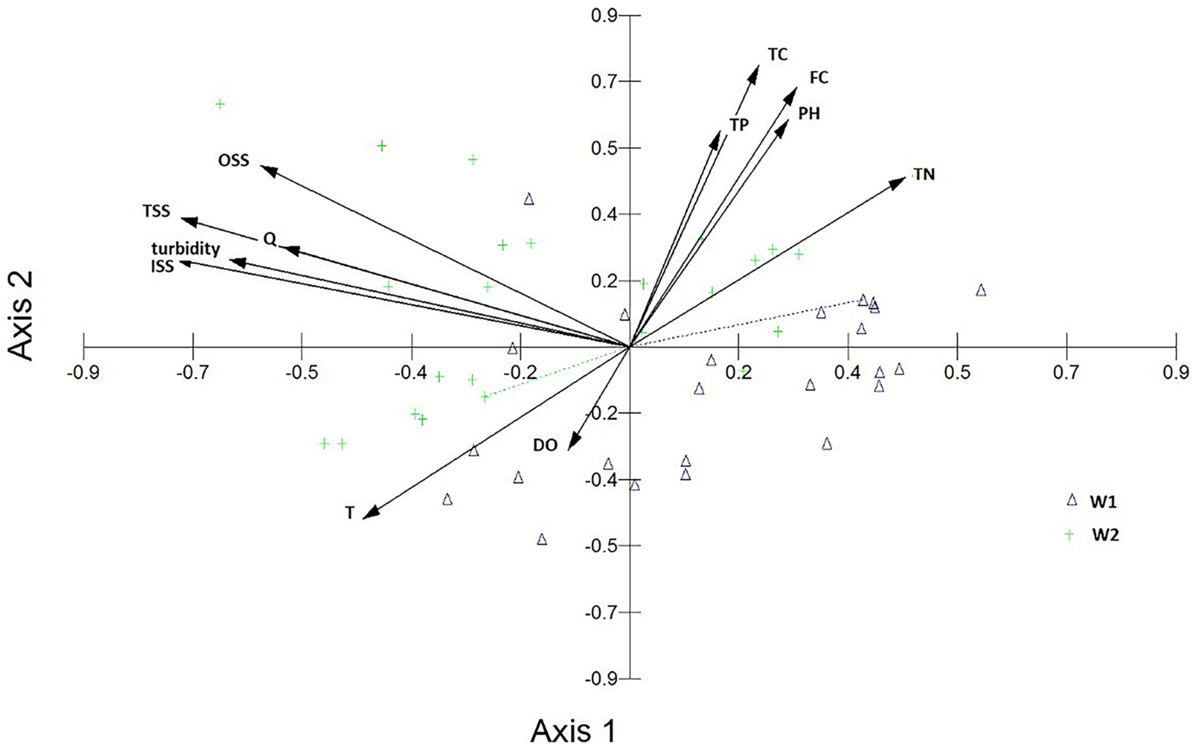

Fig. 3 Principal Component Analysis (PCA) of water quality variables for the low-order watersheds, regionally named as Gurgel (W1) and Vieirinhas (W2), in the Pirapora river basin, State of São Paulo, Brazil

water flows reach the outlet of the watershed at different times from the beginning of the rain event. Thus, there is a low tendency to flooding and, consequently, less permanence of pollutants. On the other hand, the watersheds have wavy to highly wavy relief, indicating that they have very steep areas, the same found by Pissarra et al. (2010) for headwater streams in Brazil. The authors emphasize that head watersheds are characterized by steep relief and dendritic drainage network, which makes erosion more rapid in headwater watersheds than in larger, higher-order but lower slope watersheds (Campos Pinto et al., 2016; Sosa Gonzalez et al., 2016). The slope is one of the main factors related to the erosive processes especially in tropical areas (Sosa Gonzalez et al., 2016), influencing agricultural management practices (Vijith et al., 2018), which is the case of short-cycle crops in our study area.

Although they are covered mostly by native forest, both watersheds presented agriculture as the second most important land-use/land-cover class. This generates a concern about the adequate management of this land use for the maintenance of water quality of the Pirapora river. The streams, however, presented in general good water quality, been classified into the class I, according to CONAMA Framework Resolution 357/05 that fixed the conditions for establishing water quality categories in Brazilian aquatic ecosystems. Similar results were found by Pinto et al. (2013) and Fernandes et al. (2015) in small watersheds in the Atlantic Forest. Both watersheds in our study presented more than 70% of the riparian zone covered by native forest, which is a high percentage of compliance of the environmental law and can be related to the good water quality in the agricultural watersheds (de Mello et al., 2017). These results highlight the importance of forest cover for the maintenance of water quality in agricultural small watersheds.

Nevertheless, agricultural activities may have been responsible for TP runoff into the river, in concentrations higher than those established for class I rivers (0.01 mg / L), in some samples during the period evaluated. The water drained from agricultural lands leads to the runoff of components present on the soil surface, such as phosphorus (Gonzales-Inca et al., 2015). The contribution of phosphorus in the rivers is one of the major causes of waterbodies eutrophication, being limiting for the aquatic community. In the other hand, the results indicate that DO is not a limiting factor for most aquatic vertebrates and invertebrates, which usually does not support concentrations below 3 mg/L. According to Welch and Lindell (2004), there is a limit of 5 mg/L for warm water (tropic rivers) to sustain fish populations. Contrasting to phosphorus, nitrogen (TN) showed similar values for the two watersheds and the values were in accordance with the standards established for rivers class I (CONAMA, 2005).

Besides the importance of land-use/land-cover composition, our results show that forest cover pattern also influenced water quality, and forest fragmentation has a negative impact on water quality. The watershed W2, which has more elongated fragments, larger edge area and less aggregate forest cover, presented higher values of suspended solids, turbidity, and TC than W1. The watershed W1 presented forest configuration more aggreged than the W2, with LPI of 40.56%, while W2 presented higher values of LSI and ED (Table 2). de Mello et al. (2018a, b) observed that even in the presence of agricultural areas, basins covered with less degraded forest areas have better water quality than degraded ones, indicating the importance of forest cover to minimize the loads of sediments, nutrients and coliforms in streams. The same occurs Ding et al. (2016) and Ou et al. (2016) that observed that landscapes with aggregated forest areas tend to have greater ability to absorb and attach pollutants than landscapes with scattered forest areas. Other studies also found a negative relationship between LSI and ED with water quality (Uuemaa et al., 2005). These metrics are related to the complexity of forest patches shape and to the edge effect: the larger the value, the more elongated (or irregular) and complex the patch shape. Thus, our results show that the complexity of forest patches, such as shape, can be a useful indicator of stream health in tropical agricultural basins.

When residual forests are left in the landscape, these forests may be distant from streams and recharge areas in the watershed, or have lower forest complexity compared to aggregated forest, reducing their ecological functions of stream and water protection (de Mello et al., 2020). In another study conducted in the Atlantic Forest for example, streams in catchments dominated by sugarcane had altered nitrate, conductivity, and dissolved carbon even with the existence of riparian forest because of deforested headwaters (Taniwaki et al., 2017). Forest remnants in Atlantic Forest watersheds are characterized by high levels of fragmentation (Ribeiro et al., 2009), which compromises their ecosystem services, such as water regulation and purification (Ferraz et al., 2014). Besides, runoff pathways in agricultural watersheds may severely reduce the mitigation capacities of buffer strips (Gomes et al., 2019).

The same occurs for water quality variability during the year, that is higher for W2 than W1, which is also an indicative of anthropogenic disturbance on water resources (de Mello et al., 2018a, b). Regarding the water quality variables, solids and turbidity are correlated, specially TSS and ISS, since both represent particles present in the water. According to Mansor et al. (2006), diffuse pollution in rural areas is largely due to surface runoff from agricultural lands, which carries sediments and nutrients into the stream channel, and this process is accentuated in rainy periods (Gonzales-Inca et al., 2015). TP and TC were correlated to suspended solids, showing that both variables are dependent on sediment (Huang et al., 2016), and because TP is easily adsorbed on mineral particles (G. S. da Silva et al., 2009). In the present study, solids in water are associated with streamflow variations, showing that sediment input in streams is influenced by increased runoff, which is expected for tropical rivers (Uriarte et al., 2011). This relationship was more pronounced in the watershed W2, showing that forest fragmentation negatively impacts the potential retention of these particles. TN values were similar for both watersheds, which did not show a correlation with forest cover pattern. The nitrogen is in constant transformation, and it is used by many organisms in the waterbody and the riparian ecosystem (Korol et al., 2016). Because of that, TN can be more related to riparian forest than with forest cover pattern in the watershed (de Mello et al. 2018a).

Therefore, forest cover pattern is an important aspect to be considered in the management of headwater watersheds since it affects stream water quality (Zhang et al., 2018). The conservation and configuration of forest areas in watersheds of low-order streams is extremely important to ensure the maintenance of water quality for public supply, and agricultural management should be done in a way that minimizes the contribution of sediment and nutrients into the waterbodies, considering the seasonal hydrological variations and the generally steep relief of these regions.

Thus, land-use planning and best agricultural practices are essential to protect and improve river basins' water quality. The degradation of water quality affects not only the environment but also human health (Hutton, 2012). Hence, the improvements in the environmental quality of the waters impact the health and well-being of the population (World Health Organization, 2017).

Conclusion

Forest pattern, considering its area and configuration, contributes to the maintenance of water quality, and forest fragmentation has a negative impact on water quality in low-order streams, especially during rainy periods, increasing mainly particles in the water. Besides the forest cover, agricultural activities may be responsible for inputs of solids and nutrients into the streams, especially phosphorus, considering that these areas have steep relief. Thus, it is necessary to consider the forest cover pattern for the management of low-order streams in agricultural landscapes. Future extensions of this study can evaluate the effects of forest configuration in watersheds of different size, relief, and land-use/land-cover composition.

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Declarations

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