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Effects of land use and land cover on water quality of low-order streams in Southeastern Brazil: Watershed versus riparian zone

Kaline de Mello[a,*], Roberta Averna Valente[b], Timothy O. Randhir[c], André Cordeiro Alves dos Santos[d], Carlos Alberto Vettorazzi[a]

[a] *Department of Biosystems Engineering, "Luiz de Queiroz" College of Agriculture, University of São Paulo (USP), Avenida Pádua Dias, 11, 13418-900 Piracicaba, SP, Brazil*

[b] *Department of Environmental Science, Federal University of São Carlos, Sorocaba Campus, Rodovia João Leme dos Santos (SP-264), km 110, 18052-780 Sorocaba, SP, Brazil*

[c] *Department of Environmental Conservation, University of Massachusetts, 160 Holdsworth Way, Holdsworth Hall, Amherst, MA, USA*

[d] *Department of Biology, Federal University of São Carlos, Sorocaba Campus, Rodovia João Leme dos Santos (SP-264), km 110, 18052-780 Sorocaba, SP, Brazil*

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ABSTRACT

Land-use/land-cover (LULC) pattern influences water quality, however, this relation may be different for various spatial scales. We evaluated the LULC effects on water quality of tropical low-order streams, comparing watershed and riparian zone models. Water quality parameters were analyzed separately and together using linear mixed and multivariate models. The results indicate that the forest cover plays a significant role in keeping water clean, while agriculture and urban areas lead to water quality degradation. Pasture land had mixed effects, but in general was not correlated with poor water quality. Dissolved oxygen, phosphorus, sediment, and fecal coliforms were influenced by LULC pattern at the watershed scale, while nitrogen and organic matter were more affected by the riparian zone composition. The water quality also varies with seasonal changes in streamflow and temperature. The overall water quality variation is explained better by the LULC composition within the watershed than in the riparian zone.

1. Introduction

Conversion of natural habitats into anthropogenic landscapes to cater to the increasing human demand for resources is one of the main factors behind the degradation of water quality (Giri and Qiu, 2016; Su et al., 2016). Increases in agricultural and urban lands have been described as one of the greatest contributors to the increase of nutrients and sediments in freshwater ecosystems worldwide (Uriarte et al., 2011; Huang et al., 2016). However, non-point sources pollution is difficult to assess due to the complex and diffuse nature of interactions between hydrologic and landscape patterns (Chiwa et al., 2012). Also, the relationship between land use/land cover (LULC) and water quality can occur at different spatial scales, from local to regional effects (Wang et al., 2013; Tanaka et al., 2016).

Low-order streams (1st to 3rd orders) dominate a riverine landscape, and they contribute to the function, health, and biodiversity of the entire river networks (Vannote et al., 1980; Wipfli et al., 2007). Terrestrial inputs strongly influence low-order streams (Vannote et al., 1980), which make them fragile ecosystems that can suffer dramatic impacts of land-use changes. The relationship between LULC and water quality in low-order streams, despite its importance for the watershed, is not well documented (Ding et al., 2016). It is crucial to understand those interactions in low-order streams as they are responsible for water flows, organic matter, sediments, and nutrients transportation downstream (Gomi et al., 2002).

Riparian zones play a significant role in maintaining water quality, and represent an important aquatic-terrestrial ecotone. Riparian zones exert important influence on the waterways by mediating the bi-directional flow of matter and energy between the water body and the surrounding hinterland (Hanser et al., 2010). For example, the riparian forest reduces nitrates, phosphorus, and sediment loading into the stream (Krutz et al., 2005; Oliveira et al., 2010; Gonzales-Inca et al., 2015; Ou et al., 2016). It also influences the energy balance in water bodies (Tanaka et al., 2016). Replacing riparian forest with other land-cover types leads to a decrease in water quality due to bank erosion, and consequently increasing nutrient and sediment loads into the stream (Ding et al., 2013; Ou et al., 2016; Yang et al., 2016).

Some studies have shown that the LULC composition in a riparian

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[*] Corresponding author.

E-mail addresses: kaline.mello@usp.br (K.d. Mello), roavalen@ufscar.br (R.A. Valente), randhir@eco.umass.edu (T.O. Randhir), andrecas@ufscar.br (A.C.A. dos Santos), cavettor@usp.br (C.A. Vettorazzi).

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zone is a better predictor of water quality than in the whole watershed (Tran et al., 2010; Shen et al., 2015; Shi et al., 2017). Other studies have found that LULC patterns at the watershed scale can better account for the variability in river water quality (Zhou et al., 2012; Ding et al., 2016). Uriarte et al. (2011) and Tanaka et al. (2016) also observe that the water quality indicators have different responses to LULC patterns when evaluated at different spatial scales. Consequently, authors have highlighted the importance of a multiscale analysis, especially, aiming at the understanding of the impacts of LULC on water quality (Uriarte et al., 2011; Zhou et al., 2012; Tanaka et al., 2016).

In this context, this study aims to examine the land-use/land-cover (LULC) effects on water quality of low-order streams, comparing the watershed and the riparian zone influences. The specific objectives are: (1) to identify the key factors that affect the variability in water quality; (2) to model the relationship between LULC patterns and water quality within the whole watershed and in the riparian zone; and (3) to identify which LULC pattern has the strongest influence on water quality in low-order streams.

2. Material and methods

2.1. Study area

The study area is the Sarapuí River basin located in the São Paulo State, southern Brazil (Fig. 1). The Sarapuí River is a tributary of Tiete River, and it supplies four cities in the State, providing water for domestic, agricultural and other purposes. Most of the soil types in the Sarapuí River basin are red or yellow tropical soils, mainly Latosols, dominated by low-activity clay (Oliveira, 1999; Coelho et al., 2003). The watershed was originally covered by Atlantic Forest, with a dense ombrophilous forest as the predominant forest type. Agriculture, pasture, eucalyptus and urban areas have replaced these forest areas. Agriculture is the backbone of the economy, especially the production of grains, fruits, and vegetables. The region is under the influence of Cwa climate (humid temperate with dry winters), with the annual precipitation between 1354.7 mm and 1807.7 mm (CEPAGRI, 2014), with most rain falling between October and March.

For this study, we selected six 3rd-order streams (numbered S1 to S6) with similar area, shape, average slope and soil types, but with different LULC patterns in the head areas of the Sarapuí Basin (Fig. 1).

2.2. Conceptual model

The conceptual model for this study includes the LULC types within the watershed and riparian zone, water quality data, streamflow, and water temperature data. All data were used in the statistical modeling of each water quality parameter, and a multivariate analysis was used in modeling multiple water quality parameters (Fig. 2).

2.3. Watershed and riparian zone delineation

Map processing and spatial analysis were performed using the Geographical Information System (GIS) with ArcGIS 10.2 (ESRI). We employed the standard tools in hydrology and watershed studies, which are available in the GIS to delineate 3rd-order watersheds in the Sarapuí Basin. These are based on the official stream network data compiled by the Brazilian Institute of Geography and Statistics (IBGE, 2015) (1:50,000 scale) and a 30-m Digital Elevation Map (DEM) from the Environmental Planning Coordination of the São Paulo State (CPLA, 2013), as described in the previous study (Mello et al., 2017). After a pre-selection of similar watersheds and a fieldwork to identify sample sites, we selected six 3rd-order watersheds for the study. 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 refine the physical information of the selected watersheds.

We adopted the Permanent Preservation Area (PPA) that is defined by the Native Vegetation Protection Law of Brazil (Brasil, 2012) as a riparian zone. We have adopted partially the law and used a 30 m-buffer along the river network and a 50 m buffer around springs. We did not consider special cases of the law that allow reducing the PPA to only 5 m. FAO recommendation for riparian zone to water quality protection is also 30 m, as well as proposed by Welsch (1991).

2.4. LULC maps

We used an on-screen digitizing (1:8000 scale) of SPOT images (2.5 m-spatial resolution; panchromatic band, year: 2010) obtained from the Environment Secretariat of the São Paulo State, Environmental Planning Coordination (SMA-CPLA) to create watershed LULC maps. The LULC classes that were pre-defined based on the technical manual on the land use of the IBGE (IBGE, 2013) are water, wetlands, forest, eucalyptus, agriculture, pasture and urban. The land-cover extent of eucalyptus, water, and wetlands had less area and was not used in the analysis. In this study region, agriculture is represented by fast-growing vegetables (short cycle crops) like onion, potato, pumpkin, strawberry, and lettuces. The urban land comprises of rural residential areas, including neighborhoods with paved streets, as there are no large cities or industrial areas in the study area. Pasture includes grassland destined for cattle ranching, but no cattle were observed in the study period. Forest is comprised of native forest (Atlantic Forest).

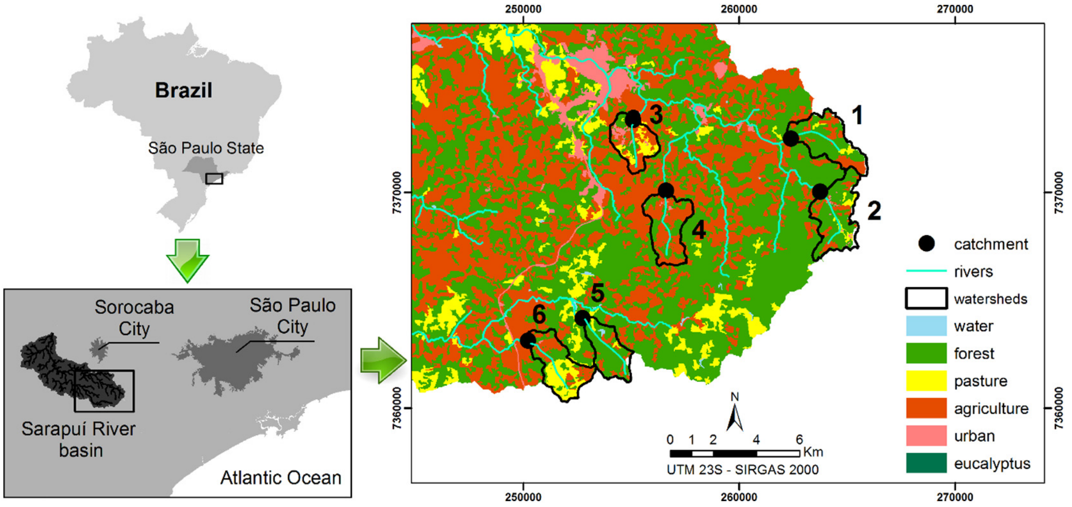

Fig. 1. Study area location and sampling sites in the Sarapuí River basin, Brazil.

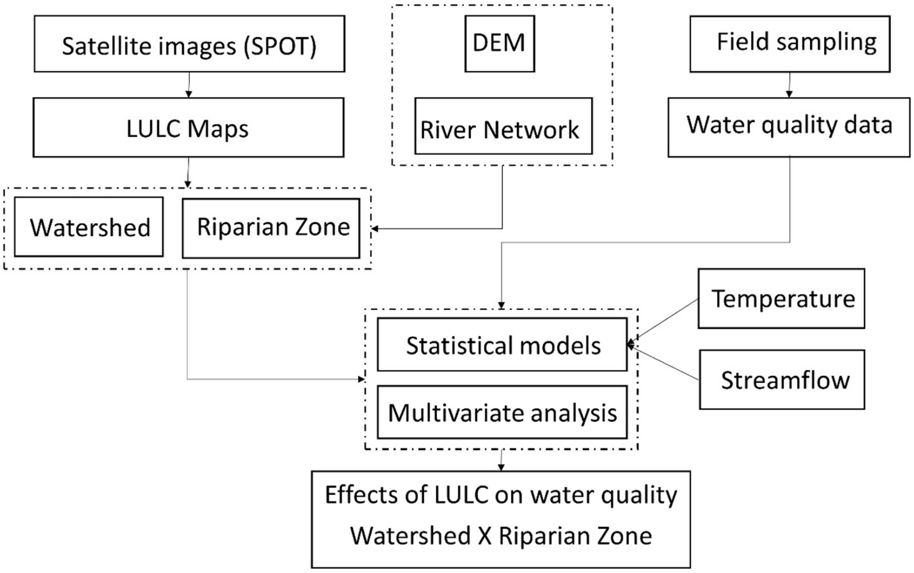

Fig. 2. The conceptual model of the study.

We used a confusion matrix and the Kappa coefficient (Congalton and Green, 1998) to assess accuracy and agreement, based on 121 ground control points distributed along the six watersheds. We obtained 105 overall hits, which represent 87% agreement, and a kappa coefficient of 0.83, indicating an excellent accuracy of the LULC map (Rosner, 2006).

2.5. Water sampling and measurement

Water quality indicators identified to represent impacts produced by anthropogenic activities include dissolved oxygen (DO), total nitrogen (TN), total phosphorus (TP), total suspended solids (TSS), organic suspended solids (OSS), and fecal coliforms (FC). The samples were collected at bi-weekly intervals from October 2013 to October 2014 for the six watersheds, when we also measured the water temperature (T) and streamflow (Q).

We measured DO, and T using an in-situ water quality detector (YSI 556 multiparameter system). Water samples were collected in duplicate to determine TN, TP, TSS and OSS, which were kept refrigerated and transported to the laboratory for advanced analysis, following standard methods (APHA, 2005). The TN was determined by Kjeldahl digestion method, TP by spectrophotometry, and TSS and OSS by using gravimetric analysis (APHA, 2005). For FC, we used the multiple-tube technique (CETESB, 1993), and the results are assessed as Most Probable Number (MPN).

The Q was measured using the current-meter method, which divides the stream channel cross section into various vertical subsections (Santos et al., 2001). In each subsection, we calculated the volume using width and depth measurements, and the water velocity was determined using a current meter (Global Water Flow Probe – 201). The total discharge is the sum of discharges in each subsection. The daily precipitation data for the study period were obtained from our own Weather Station (Davis Vantage Pro2) close to the Itupararanga Reservoir.

2.6. Data analysis

The variables were checked for normality and transformed, when necessary, using a logarithmic transformation. We applied Pearson's correlation to determine the strength and directions of the relationships between LULC patterns and the individual water quality parameters. A multivariate analysis of variance (MANOVA) using the Hotelling-Lawley Trace was used to check differences between rainy (October–March) and dry season (April–September).

After this preliminary analysis, we performed separate generalized linear mixed models (Zuur et al., 2009), to obtain the optimal equation for each water quality parameter through the lme4 package of the statistical software R (R Development Core Team, 2014). First, we modeled each water quality parameter in the riparian zone and watersheds. Each water quality parameter is used as a dependent variable with predictors including the percentage of forest, pasture, agriculture and urban cover types. Based on past literature, models also included Q as predictor and T as a covariate to include the season effect (McDowell and Asbury, 1994; Uriarte et al., 2011). We considered watersheds and time (month) as random components. We also tested a 3-day and a 7-day precipitation period before each water quality sampling, to predict streamflow.

We used the Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC) for model selection (Akaike, 1998). The backward, stepwise removal of predictors was employed to assess which individual predictors were important drivers for each water quality parameters. The final models were selected based on the lowest value of AIC and BIC, but only predictors with a significance level of 0.05 were considered. A Pearson's rank correlation between the LULC types was used to avoid variables that are strongly correlated. The forest cover was not included as a predictor in the final model because it was strongly negatively correlated with other LULC types. We calculated the goodness of fit of the model as the proportion of explained variance (R^2) using the method described by Xu (2003), that computes the residual variance of the full model against the residual variance of the fixed intercept-only null model.

The redundancy analysis (RDA), an extension of multiple regression to model multivariate response data (Zuur et al., 2007), was applied to evaluate the global descriptions about the influences of LULC pattern on water quality, considering the watershed and riparian zone. The RDA is a form of constrained ordination that examines how much of the variation in the set of independent variables explains the variation in the set of dependent variables. This analysis allowed us to simultaneously study the influences of the LULC types on all of the water quality parameters. For this analysis, we used a logarithm transformation to the annual average of each water quality parameter. A Monte Carlo permutation test (999 permutations) was used to determine the statistical validity of the RDA. We used the RDA function in the vegan package of the statistical software R.

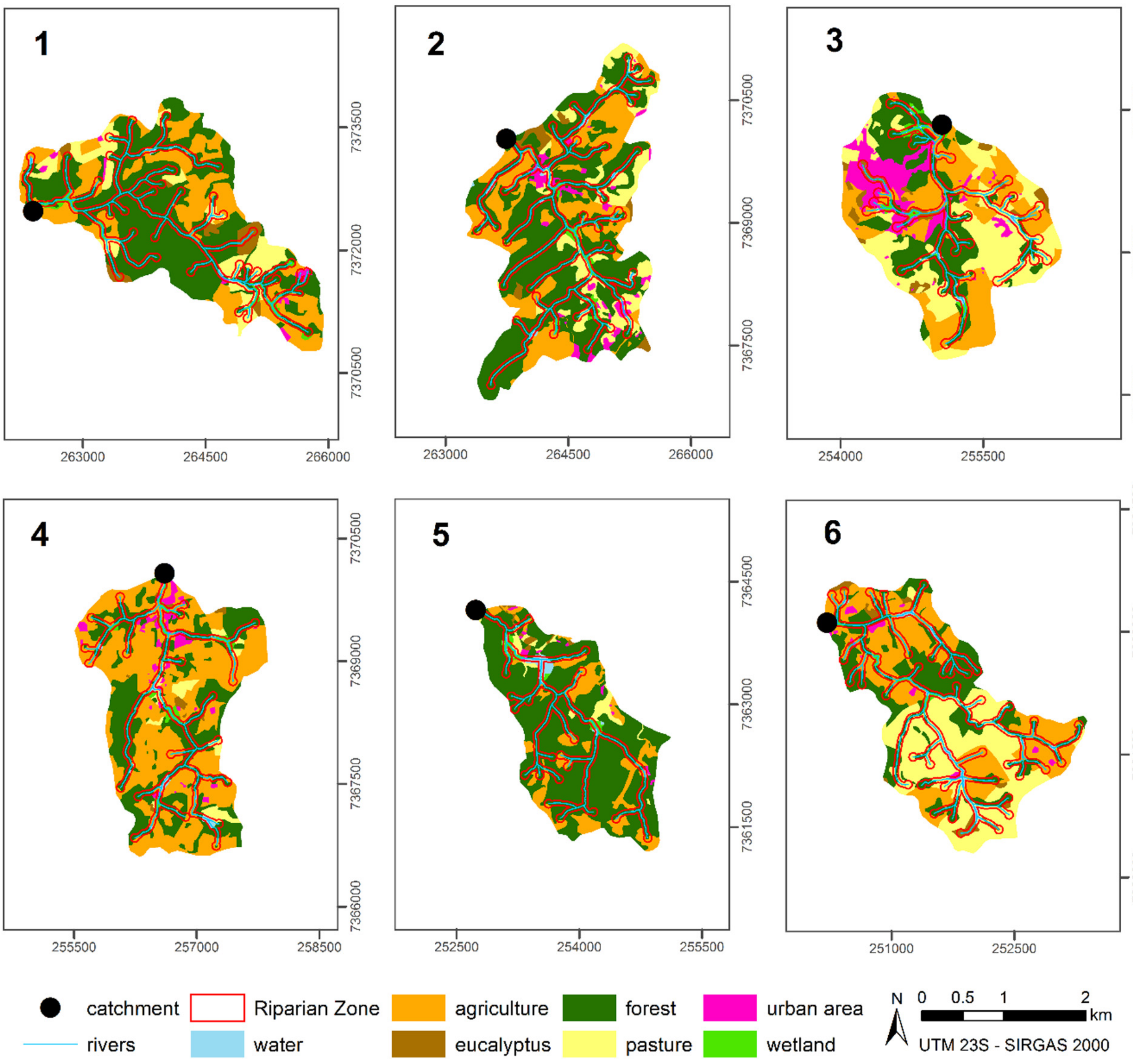

Fig. 3. Land use/land cover for the six watersheds and their riparian zone, in the Sarapuí River basin, Brazil.

3. Results

3.1. LULC composition

The proportion of forest cover at the watershed scale was greater than other land uses in watersheds S1, S2, and S5, whereas S5 showed a high forest cover (75%), followed by S2 (57%), and S1 (55%) (Fig. 3 and Table 1). Conversely, S4, S6, and S3 had 35%, 29%, and 25% of forest cover in the watershed, respectively. Likewise, S4 had the largest agricultural area (54%), followed by S6 (33%), S3 (29%), S1 (27%) and S2 (23%), while the S5 had only 16%. Watersheds S6 and S3 had the highest values of pastureland (32% and 28%), S1 and S2 showed similar values of pasture cover (between 11% and 12%), while S4 and S5 had only 3%. Watershed S3 showed the largest urban area, representing

Table 1
Land use/land cover (%) in the six watersheds (W) and their riparian zone (RZ), in the Sarapuí River basin, Brazil.

Site	Location	Water	Agriculture	Eucalyptus	Forest	Pasture	Urban	Wetland
S1	W	0.50	26.66	3.28	55.16	11.49	1.14	1.77
	RZ	2.06	7.66	2.66	70.39	9.64	1.56	6.04
S2	W	0.75	23.14	1.92	57.40	11.91	3.47	1.40
	RZ	2.61	6.64	0.06	76.85	6.76	2.15	4.93
S3	W	0.54	29.31	3.68	25.17	27.96	11.45	1.90
	RZ	2.32	19.66	5.37	39.40	16.60	10.13	6.52
S4	W	0.81	54.39	0.92	35.21	3.47	3.31	1.88
	RZ	3.99	26.43	0.56	56.01	3.25	2.37	7.39
S5	W	1.76	16.62	0.82	75.01	3.34	0.82	1.63
	RZ	4.99	10.64	0.00	78.11	0.75	0.42	5.09
S6	W	1.64	32.97	2.31	28.96	32.09	1.25	0.79
	RZ	5.90	22.34	3.31	45.70	19.36	0.63	2.76

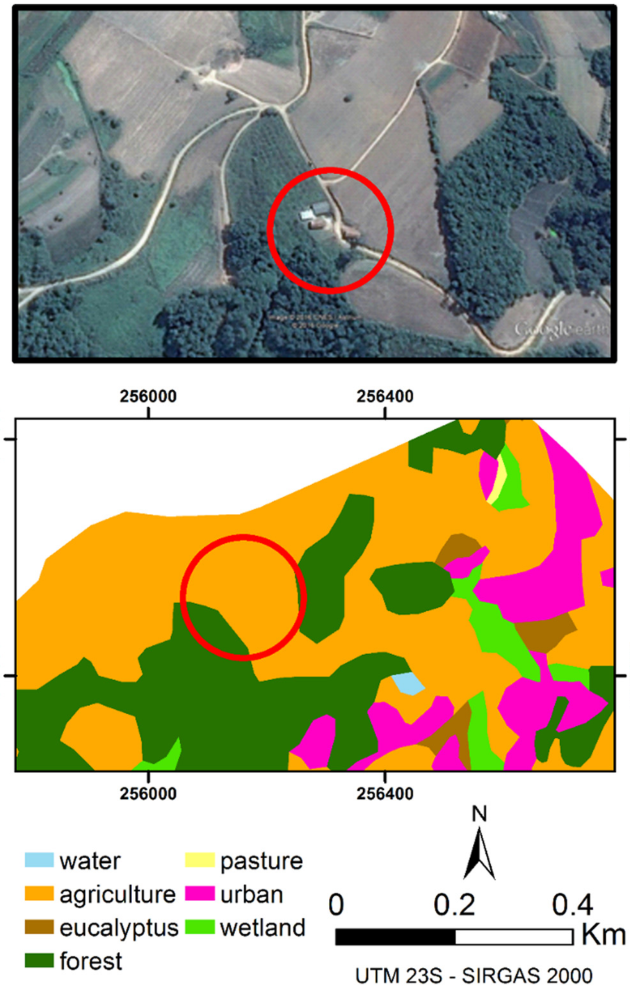

Fig. 4. Details of one small farm, with houses, in Site 4, in the Sarapuí River basin, Brazil.

11.5% of the watershed.

Considering the LULC in the riparian zone, S1, S2, and S5 showed the forest cover to be greater than 70%, while S3 showed the lowest value (39%), followed by S6 (45%), and S4 (56%). The S1 and S2 watersheds showed the lowest value of agriculture in the riparian zone (between 6% and 8%). Watershed S4 showed the highest value for agricultural lands (26%), and S3 for urban areas (10%), the same pattern considering the LULC within the entire watershed. An important characteristic of the study area is the agricultural lands, which are comprised of small farms, having families living, in many cases, on the property (Costa et al., 2011). Consequently, the agriculture class revealed isolated houses (Fig. 4). The predominant fast-growing vegetables found in the study area were onion, potato, pumpkin, cucumber, leek, strawberry, artichoke, and lettuce.

3.2. Impacts of LULC on water quality

We correlate water quality parameters with LULC patterns through the Pearson's correlation (Table 2), and mixed models (Table 3). Forest cover was the primary land cover associated with good water quality, while urban and agricultural areas were related to water quality degradation, considering both, watershed and riparian zone. After forest cover, the next LULC type that showed the lowest impact on water quality was pasture. The proportion of forest cover was positively correlated with DO, and negatively correlated with solids (TSS and OSS), TP, TN and FC within the watershed and riparian zone. The correlation between forest and DO was strongest in the riparian zone. Conversely, urban area was negatively correlated with DO and positively with the other parameters. Agriculture was positively correlated with solids, TP, TN, and FC, but also with DO at the watershed scale.

There was a significant difference between rainy and dry seasons in the water quality (Hotelling-Lawley's $\lambda = 0.26$; $F = 2.85$; $P = 0.015$) due to the changes in precipitation, temperature, and streamflow. Streamflow varied with rainfall, and the 3-day storm period before each water sampling had better value than the 7-day ($R^2 = 0.61$ and 0.58, respectively). Almost all the models for water quality included streamflow as a predictor (Table 3), showing that water quality parameters varied with changes in water discharge. This variable showed a better prediction than previous precipitation in the models. The temperature was also a predictor for DO and TN for both the watershed and for the riparian zone models.

The models explained 49% to 72% of the observed variance in water quality parameters (Table 3). Those parameters showed different responses related to both the whole watershed and the riparian zone. In the case of DO, TSS, TP and FC, they can be explained by the proportion of LULC in the whole watershed. On the other hand, models that considered LULC in the riparian zone were better predictors of the in-stream concentration of TN and OSS.

The DO concentration has the lowest value in the watershed with the highest percentage of urban area (S3). Concerning other LULC types, the proportion of forest increases the DO concentration, while it decreases with pasture. The model of LULC in the watershed also considered agriculture as a predictor of the increase in DO. The water quality parameter responded better to the composition of LULC in the whole watershed than the riparian zone. As expected, DO concentrations increased with streamflow and decreased with temperature (Table 3). Similarly, the parameters TSS, TP, and FC also showed a better response for the LULC composition in the whole watershed; whereas, agriculture was the most important predictor of the increase of those variables, followed by urbanization. On the contrary, forest cover represented a decrease of them. Not surprisingly, TSS increased with streamflow, as well as TP. However, streamflow did not show a relation with FC variation.

The LULC in the riparian zone were better predictors of TN and OSS concentrations. Urban areas in the riparian zone were the most important LULC type for an increase in TN, and agriculture was also important for the input of OSS. We highlight two results: the watersheds covered by forest presented lower levels of TN than the others, and TN and OSS showed a negative relation with pasture. In the case of TN concentration, it decreases with the increase of temperature and decreases with increase in streamflow.

The RDA results showed that by considering all the water quality parameters simultaneously, the variation was better explained by LULC composition within the whole watershed than of the riparian zone (Fig. 5). The first canonical axis (Fig. 5) explained most of the water quality variation. In this scenario, the RDA model explained 82% of the variation for the whole watershed, and 75% for the riparian zone composition.

Considering the LULC in the watershed, the first axis separated sites with the highest percentage of agriculture and urban lands (S3 and S4) from those with the highest forest cover (S5, S1, and S2) (Fig. 5.A). This first axis consistently displayed a pollution gradient, where sediments, nutrients, and fecal coliforms were negatively correlated with forest cover, and they were also positively correlated with urban and agricultural lands. Watershed S5, which has the highest forest cover than the other sites, was also associated with the best water quality. On the other hand, S3 and S4, which have the highest percentages of urban and agriculture areas, respectively, were associated with poor water quality. Although it has no extensive forest cover, S6 did not show the same pattern as S3 and S4, and presents the highest percentage of pasture between the sites.

Table 2

Pearson's correlation between land use/land cover (LULC) and water quality parameters, in the Sarapuí River basin, Brazil.

Location	LULC (%)	DO (mg·L^{-1})	TSS (mg·L^{-1})	OSS (mg·L^{-1})	TN (mg·L^{-1})	TP (μg·L^{-1})	FC (MPN)
Watershed	Forest	0.20	−0.55	−0.51	−0.47	−0.74	−0.59
	Agriculture	0.34	0.88	0.70	0.76	0.94	0.87
	Pasture	−0.55	−0.06	0.09	−0.21	0.07	−0.12
	Urban	−0.32	0.12	0.06	0.51	0.39	0.50
Riparian zone	Forest	0.47	−0.49	−0.55	−0.28	−0.59	−0.47
	Agriculture	−0.25	0.79	0.80	0.48	0.78	0.73
	Pasture	−0.45	−0.06	0.03	−0.13	0.12	−0.08
	Urban	−0.34	0.04	0.14	0.53	0.35	0.47

Where: DO = dissolved oxygen, TSS = total suspended solids, OSS = organic suspended solids, TN = total nitrogen, TP = total phosphorus, and FC = fecal coliforms.

4. Discussion

The LULC maps indicate that some watersheds are predominantly covered by agriculture and pasture lands due to the agricultural expansion that occurred in this region (Schneider and Costa, 2013). The S4 is an example where more than 50% of the watershed is covered by agriculture. Vettorazzi and Valente (2016) observed that watersheds which had an increase in agricultural areas also had a drastic reduction in forest cover, thereby impairing water quality and leading to increase in sediment and nutrients loading (Table 2).

Conversely, the studied sites had their riparian zone with a higher percentage of forest cover compared to the whole watershed, i.e. the conversion of natural vegetation into other land cover or land use was greater in other areas of the watershed than in the riparian zone. This reflects the efforts of conservation of riparian zones in Brazil, and the difficulty in expanding agricultural activities over those areas due to the steep relief or the predominance of wetlands (Mello et al., 2014).

The forest cover, both for watershed and for the riparian zone, is related to good water quality, and it plays a significant role in improving water quality in different watersheds of the world (FAO, 2008; Wang et al., 2013; Oliveira et al., 2016). Forest cover acts as a filter, controlling and decreasing the sediment and pollutants, that are carried in surface runoff (Ding et al., 2013), also increasing DO concentration (Table 2 and Fig. 5).

Specifically, sediments, nutrients, and fecal coliforms are positively related to the agricultural and urban uses and negatively to forest cover. Studies have shown that agriculture and urban areas represent the most important land-use types that increase water quality degradation, as presented in our study (Zhou et al., 2012; Ding et al., 2016; Huang et al., 2016; Ou et al., 2016). In agricultural lands, excessive fertilizers, runoff, and soil erosion can lead to an increase in sediment, nutrients, chemical contaminants, and organic matter into the water body (Poudel, 2016). In urban areas, the increase of wastewater and pollutants accumulating on the impervious surfaces result in water deterioration (Lee et al., 2009; Ding et al., 2016), and although small in percent coverage, it exerts a disproportionately large influence on water quality (Zhou et al., 2012),

Unlike other studies that showed negative impacts of pasture on water quality (Uriarte et al., 2011; Tanaka et al., 2016; Ou et al., 2016), our results did not associate this land use with water degradation for most of the water quality parameters. Pasture only had an adverse impact on the levels of DO. Ding et al. (2013) and Wang et al. (2013) found a positive correlation between water quality and grassland area, which means that both forest and grassland can effectively mitigate water quality degradation (Wang et al., 2013; Ding et al., 2013; Ding et al., 2016). It is important to note that our study area does not have large cattle ranches, and many of those areas are abandoned pasture lands. Thus, adverse impacts from the presence of the animals on the water quality may not occur in the same magnitude as found by other studies. According to Latawiec et al. (2015), the low-productivity pasturelands with few cattle are a great opportunity for forest restoration in the tropical agricultural landscapes.

Besides the spatial variation in water quality, we also observe a temporal variation linked to seasonal changes. According to Huang et al. (2016), seasonal variations in precipitation, surface runoff, interception, and abstraction have a strong influence on river discharge and, consequently, changes in sediment and nutrient concentrations become a seasonal phenomenon. Oliveira et al. (2016) highlighted that in regions with a distinct rainy season, like many parts of Brazil, the non-point pollution sources usually have a reduced effect on stream water quality due to the decrease in runoff during the dry season. Therefore, the addition of temporal and hydrological data is essential to determine the effect of the land use pattern on water quality in the region.

Forest, agriculture, and urban lands were the most important LULC types that explain the spatial variation of water quality parameters (Table 3), wherein urbanization and agriculture were the main predictors of the increase of water quality parameters. Recent studies also showed that independent variables in models with LULC class can be reduced because of the existing collinearity between the LULC classes (Gonzales-Inca et al., 2015; Li et al., 2015; Oliveira et al., 2016).

Our models showed that the DO concentration responded better to

Table 3

Parameter estimates for the best models of water quality variation, in the Sarapuí River basin, Brazil.

Variable	Location	AIC	BIC	R^2	Int.	Flow	T	Agri	Past	Urban
DO (mg·L^{-1})	W	249.4	271.7	0.72	8.64**	2.46*	−0.13**	1.24*	−2.41*	
TSS (mg·L^{-1})	W	229.7	250.5	0.60	0.79**	15.21**		1.69**		6.42**
OSS (mg·L^{-1})	RZ	171.3	192.1	0.51	0.55**	9.69**		1.75**		2.46*
TN (mg·L^{-1})	RZ	319.5	336.8	0.49	4.43**	−0.06*	−0.09**			5.67**
TP (μg·L^{-1})	W	206.0	226.1	0.67	3.03**	5.67**		1.64**		4.86**
FC (MPN)	W	340.4	355.8	0.65	2.26**			4.91**		5.04*

Where: W = Watershed, RZ = riparian zone, Agri = Agriculture, Past = Pasture, DO = dissolved oxygen, TSS = total suspended solids, OSS = organic suspended solids, TN = total nitrogen, TP = total phosphorus, and FC = fecal coliforms.

* Significance level of 0.05.

** Significance level of 0.01.

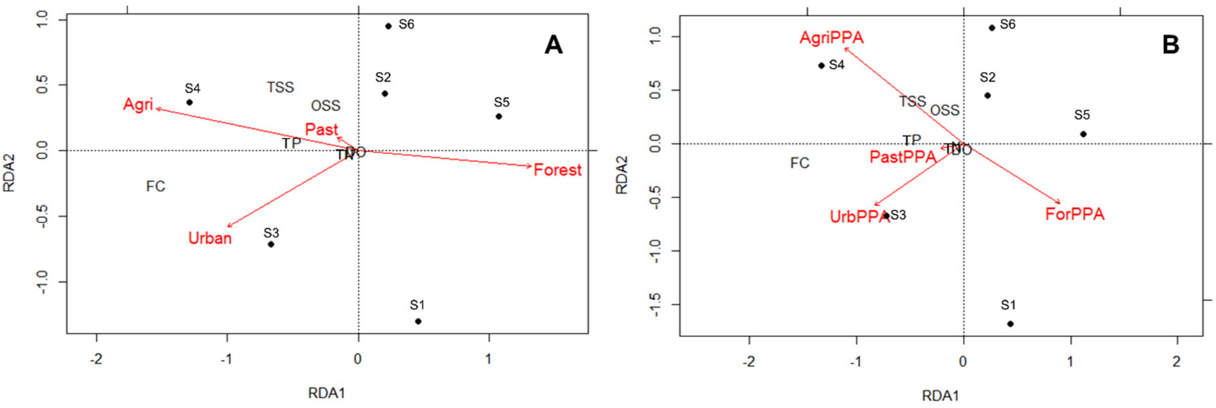

Fig. 5. Biplot of the RDA based on water quality and land cover percentages of the six sampling sites for the watershed (A) and the riparian zone (permanent preservation areas - PPA) (B), in the Sarapuí River basin, Brazil. Where: Agri = Agriculture, Past = Pasture, Urb = Urban, For = Forest, DO = dissolved oxygen, TSS = total suspended solids, OSS = organic suspended solids, TN = total nitrogen, TP = total phosphorus, and FC = fecal coliforms.

LULC pattern within the watershed than in the riparian zone, as also found by Uriarte et al. (2011) and Ding et al. (2016). However, the correlation analysis showed that the riparian forest had a significant role in increasing DO concentration, which is greater than that considered for the forest in the whole watershed. According to Abell and Allan (2002), forested streams have cooler water and higher oxygen concentration levels once the DO demand increases with the increase in temperature, while the oxygen solubility in the water decreases (Manahan, 1994). Pasture lands can increase the water temperature, and urban areas lead to a decrease in DO concentration due to the discharge of organic matter (Calijuri et al., 2015).

The results also indicated that TP and TSS were strongly explained by the LULC composition in the watershed and weakly in the riparian zone, and increased with stream discharge, as found by Uriarte et al. (2011) and Ding et al. (2016), where agriculture represented the primary source of these parameters. The intense agricultural activity, where the farmers do not implement conservation practices, leaves the soil regularly exposed and subject to erosion in rainfall events, and sediments with nutrients are transported into the river (Calijuri et al.,2015; Poudel, 2016), intensified by the hill slopes in the study area. In this way, this study highlights that the agricultural practices in fast-growing vegetable crops need to adopt strategies to minimize soil erosion and runoff.

The FC were also better explained by the percentage of agriculture and urban area in the watershed, which is common observation in the literature, especially the link to human activities and animal waste (Meays et al., 2004). However, in our study, they were more correlated to agriculture than with urbanization and it can be related to the small percentage of urban areas (Ou et al., 2016). Also, agricultural lands in the study area present isolated houses without sewage collection, as well as the residential areas (Costa et al., 2011). It brings the importance of the basic sanitation services in rural areas, and the biodigester has been an alternative in some agricultural watersheds of Brazil (Costa and Guilhoto, 2014).

Contrary to other water quality parameters, TN and OSS were strongly correlated with the LULC composition in the riparian zone than in the watershed (Table 3). Sewage from domestic and food processing sources contains a wide variety of pollutants, including organic pollutants (Manahan, 1994). In the same way, Gonzales-Inca et al. (2015) found that riparian vegetation is critical in explaining nitrate concentrations due to its potential of nutrient pollution mitigation in agricultural watersheds. The nitrogen is in constant transformation, and it is used by many organisms in the waterbody and the riparian ecosystem (Korol et al., 2016). In the same way, organic matter (OSS) is also strongly linked to the riparian composition and its interaction with the aquatic ecosystem (Korol et al., 2016). As expected, TN concentration in the water decreases with the increase in temperature, because the microorganisms' activities in the water and soil are affected by temperature (Han et al., 2016). However, in contrast to other studies that showed a positive relation between streamflow and nitrogen (Uriarte et al., 2011), our study showed a negative relationship. According to Dellagiustina (2000) and Gallo et al. (2015), the agricultural activities may be not enough to overcome the dilution effect of the precipitation events, and these sites are more sensitive to shifts in hydrologic partitioning in response to land-cover change than those associated with climate change (Gallo et al., 2015).

Concerning the RDA results, we observe that the overall water quality was better explained by the LULC pattern in the watershed than at the riparian zone, as also found by Ding et al. (2016) and Gonzales-Inca et al. (2015) for low-order streams. However, mixed models show that different parameters of water quality varied in their responsiveness to different scales when analyzed separately, as also reported elsewhere (Uriarte et al., 2011; Zhou et al., 2012). These multiple points of view suggest that the water management and forest restoration planning need to adopt a multi-scale perspective, but the actions must be directed to the whole watershed. Although the importance of the riparian zone, our study demonstrates that the watershed management in low-order streams is extremely necessary for maintaining water quality.

It is important to note that our study considered a 30 m-riparian buffer along rivers and a 50 m-spring buffer as riparian zone (PPA) following the Native Vegetation Protection Law of Brazil general recommendation. Ou et al. (2016), studying the influence of the buffer zone width on water quality, highlighted that the 50 m-riparian zone accounts for a low proportion of the whole watershed area, which weakens, at this scale, the influence of landscape features on river conditions. The authors found that the 100 m-riparian zone had the largest effect on stream water quality. It brings the question about the effectiveness of the 30 m-buffer for the water sources conservation, and a greater concern with cases where the Brazilian law allows the reduction of the PPA to only 5 m. In our study, the forest conservation and the anthropogenic activities at the watershed scale, in general, had greater importance for the water quality maintenance than the 30 m-riparian zone. The studies which reported that the LULC pattern in the riparian zone plays a greater role than the LULC within the watershed used different buffer widths. For example, Tran et al. (2010) considered 200 m of riparian zone along the rivers in the USA, while Shen et al. (2015) worked with a buffer zone of 100 m in China.

Ding et al. (2016) highlight that different results in studies regarding the LULC impact on water quality might be because of differences in methods adopted to delineate the local buffer zone, differences in regional settings, and water quality parameters. Ou et al. (2016) also linked these differences to the sampling strategy and data resolution. The higher or lower resolution of the land-use data may miss some crucial landscape features of the land-use composition and configuration. In our study, we considered the seasonal variation, and we used high-resolution spatial data, which can differ from studies that only considered rainy season or used low-resolution data. Another difference in our work is that the agricultural land was comprised of small farms, with isolated houses, without sewage collection, which was strongly connected to water quality degradation.

Nevertheless, our findings highlight the forest cover as a key landscape feature to prevent deterioration in water quality. Additionally, we found that pasture with few cattle does not lead to water degradation as agriculture and urbanization, and it could be a good opportunity for forest restoration plans. This information can help managers to establish best alternatives for water quality improvement in the headwater streams. We show that the environmental planning must consider the whole watershed to design public policies (Ekness and Randhir, 2015) aiming at water resources conservation, not only the riparian zone, although the riparian forest restoration can be prioritized as a short-term action aiming at water quality improvement (Vettorazzi and Valente, 2016). According to Rodrigues et al. (2011), better agricultural and cattle production practices can provide new areas for restoration actions in rural watersheds. Low-order streams, often located on steeper slopes, are more sensitive to nonpoint source pollutants loading than flat areas in the watershed (Yang et al., 2016; Yu et al., 2016). Thus, the environmental planning of these areas is crucial to ensure water with high quality downstream.

5. Conclusion

We conclude, based on our results, that forest cover is the most important LULC type to maintain the water quality of low-order streams, and agriculture and urban areas are responsible for water quality degradation. The sewage from residential areas, sediments, and nutrients loading from the short-cycle crops lead to the nonpoint source pollution into the small rivers. Grassland has mixed impact on water quality, and in general does not result in water quality degradation, if they have low-productivity or are abandoned pasturelands.

Besides the spatial variation, water quality also varies with seasonal changes, especially with streamflow and temperature variability. Thus, streamflow and temperature are also important predictors that explain some of the variation in water quality parameters. The water quality parameters have different responses regarding the landscape composition within the watershed and the riparian zone. However, the overall water quality variation is better explained by LULC composition at a watershed scale than at a riparian zone. It suggests that the water management and forest restoration planning need to adopt a multi-scale perspective, but the actions must be directed to the watershed management. In addition to the importance of a riparian zone, our study demonstrates that the watershed management in low-order streams is extremely necessary for the water quality maintenance aiming at the water resources conservation downstream. Nevertheless, the riparian restoration can be prioritized as a short-term action aiming at water quality improvement.

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