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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

* 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).

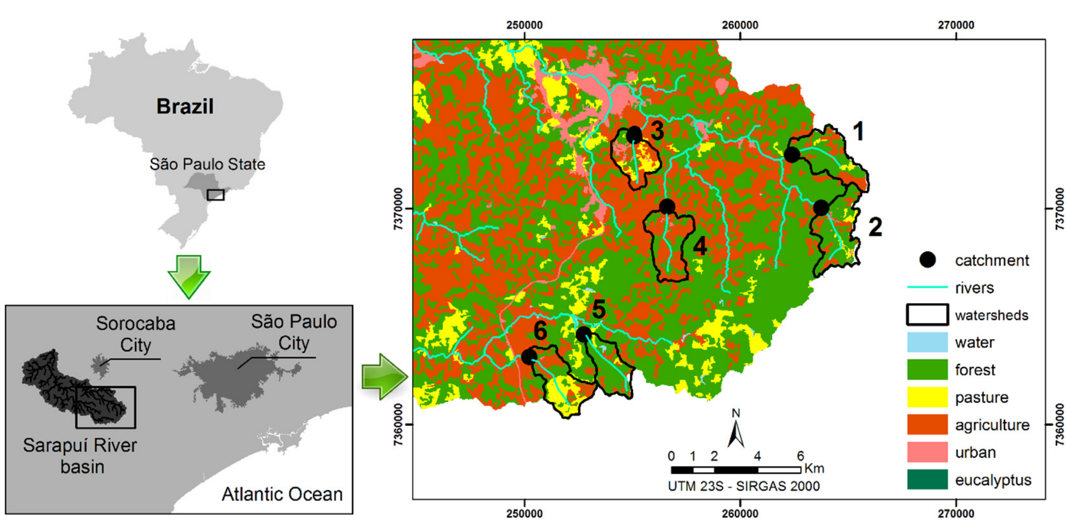

Fig. 1. Study area location and sampling sites in the Sarapuí River basin, Brazil.