



Effects of land use and sampling distance on water quality in tropical headwater springs (Pimenta creek, São Paulo State, Brazil)

Caio Vinicius Ferreira Marmontel ^a, Manuel Esteban Lucas-Borja ^{b,*},
Valdemir Antonio Rodrigues ^a, Demetrio Antonio Zema ^c

^a Department of Forest Science, Univ. Estadual Paulista (UNESP), 18610-307 Botucatu, São Paulo State, Brazil

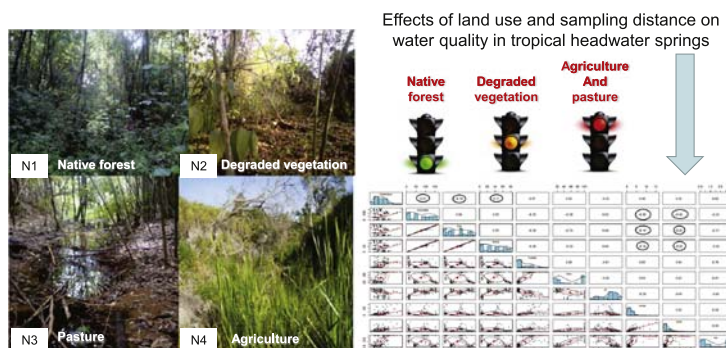
^b Universidad de Castilla-La Mancha, Campus Albacete, 02071 Albacete, Spain

^c Mediterranean University of Reggio Calabria, Department AGRARIA, loc. Feo di Vito, I-89122 Reggio Calabria, Italy

HIGHLIGHTS

- In tropical headwater streams information on water quality are in general scarce.
- Both land use and sampling distances influence water quality of headwaters.
- Springs with riparian vegetation show better conditions in the aquatic environment.
- In springs with pasture/agriculture and degraded vegetation water quality is worse.
- Aquatic environment of headwaters is very sensitive to changes in the environment.

GRAPHICAL ABSTRACT



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ABSTRACT

The studies targeted to hydrology and water quality are scarce in tropical headwater streams. In these delicate ecosystems the comprehension of water quality can constitute a challenge, because the impact of land uses on stream dynamics is particularly severe in tropical areas. To fill this gap, an evaluation of water quality in a headwater streams (Pimenta creek, São Paulo State, Brazil) under tropical conditions was performed. The implementation of linear mixed models to water quality parameters allowed to know how and to what extent water flowing in these headwaters are influenced by: (i) the spatial variation of spring locations; (ii) the different land uses; and (iii) the state of conservation of the riparian vegetation. Both the land uses in the surroundings of water springs (native forest, degraded vegetation, agriculture and pasture) and the sampling points (exactly in the spring and 10, 30 and 50 m downstream) were found to be factors able to explain water quality variability. Most of the analysed parameters, some of which strongly correlated each others (mainly electrical conductivity, Total Dissolved Solids and salinity, but also color, turbidity and iron concentrations), showed significant variations mainly due to the effects of the different land uses, but also to the distance from water spring. The instability of the water quality parameters in springs degraded from its headwater was also demonstrated. The water springs with developed riparian vegetation of natural forest (in a preserved or even disturbed conservation level) showed the best conditions in the aquatic environment (lower temperature, turbidity, color, nitrite and nitrate concentrations, neutral pH). Conversely, in the water springs with pasture or agricultural activities a general worsening of water quality was detected (worse

* Corresponding author.

E-mail address: ManuelEsteban.lucas@uclm.es (M.E. Lucas-Borja).

turbidity, color, pH, nitrate and nitrate concentrations). Overall, the study has confirmed how much aquatic environment is sensitive to changes in the environment.

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1. Introduction

Headwater streams (that is, the first- and second-order channels of a water course, [Strahler, 1952](#)), cumulatively constitute the great majority of channel length within a river network ([Downing et al., 2012](#)). Their importance within the ecology and health of a water course falls in the fact that headwater streams are the source of water, solutes, mineral sediment, and particulate organic matter ([Schumm, 1977](#); [Alexander et al., 2007](#); [MacDonald and Coe, 2007](#); [McClain and Naiman, 2008](#)). These delicate ecosystems are strongly influenced by many disturbances factors, such as precipitation, morphology, land use, geology, vegetation, human impacts, which can affect the entire watershed supplied by their water flows ([Wohl, 2017](#); [Rodrigues et al., 2017](#)). Furthermore, across diverse hydro-climatic regions, headwater streams tend to exhibit more spatial and temporal hydrologic variability than larger channels ([Gomi et al., 2002](#); [Richardson and Danehy, 2007](#)), which strongly influences the river ecosystem. Given such stressing factors, it is necessary to pay attention to the physical, chemical, and biological functions of headwater streams and, in particular, to water quality. Recently, [Wohl \(2017\)](#) highlighted the importance of water chemistry analysis in headwater for at least two reasons: (i) headwater stream chemistry is highly influenced by upland flow paths and chemistry of incoming surface and ground waters; (ii) headwaters are the first line of defense against potential contaminants such as excess fine sediment or nutrients.

Unfortunately, the relatively small streams are currently rather ignored by legal protections (mostly extended to larger rivers) and are aggressively altered in connection with diverse land uses ([Wohl, 2017](#)), even though there has been a recent upsurge in interest in the restoration of riparian habitats, which is focusing attention on understanding and ameliorating such impacts ([Bombino et al., 2007](#)).

Water quality of headwater streams is important, because not only it is highly influenced by both upland flow paths and incoming surface and groundwaters, but also due to the fact that headwaters are the first line of defense against potential contaminants such as excess fine sediment or nutrients and the first receiving point for organic matter ([Alexander et al., 2007](#)). Also land use has significant impacts on river water quality with complex mechanisms, as demonstrated by several comparative studies (e.g. [Wear et al., 1998](#); [Amiri and Nakane, 2009](#); [Ding et al., 2015](#)). Although the significant impact of land use on stream water quality has been well documented ([Johnson and Gage, 1997](#); [Allen, 2004](#); [Hurley and Mazumder, 2013](#); [Bu et al., 2014](#); [Ye et al., 2014](#); [Kändler et al., 2017](#)), further study on the complex association should be considered as much as possible ([Yu et al., 2016](#)). Therefore, it is important to carry out specific monitoring activities about the effects of land use on water quality specifically targeted to water springs of headwater streams.

Many different papers have dealt with monitoring and modeling of water quality at catchment-scale in several environments (e.g. [Emmett et al., 1994](#); [Ferrier et al., 2001](#); [Baker, 2003](#); [Ahearn et al., 2005](#); [Shrestha and Kazama, 2007](#); [Amiri and Nakane, 2009](#); [Hurley and Mazumder, 2013](#); [Bu et al., 2014](#); [Ye et al., 2014](#); [Viswanathan et al., 2015](#); [Yu et al., 2016](#); [Kändler et al., 2017](#)). It has been highlighted that hydrology, light, temperature and water chemistry are controlled by regional factors such as geology, topography or climate (operating at spatial scales of catchments as well as ecoregions), and, in addition, that human land-use activities act to change both local and regional variables at an increasing rate ([Bere and Tundisi, 2011](#)). Therefore, it is evident that the analysis of water quality must be carried out by site-specific studies.

However, the studies targeted to hydrology and water quality in tropical catchments are in general scarce ([Fujieda et al., 1997](#)); in addition, the comprehension of water quality response of a tropical catchment can constitute a challenge, because hydrological processes in these areas are difficult to assess ([Hunke et al., 2015a, 2015b](#)). Moreover, if we consider that the impact of land uses on stream water quality dynamics is particularly severe in tropical areas due to a more rapid mineralization of tropical soil organic matter and often, high erosion than in temperate zones ([Spaans et al., 1990](#); [Malmer and Grip, 1989](#); [Hartemink et al., 2008](#)), it is evident how important the evaluation of water quality and their variability factors under different land uses is in water spring of tropical headwater streams. In these contexts, the role of riparian vegetation typical of tropical forests must be also deepened. As a matter of fact, since riparian vegetation plays important hydrological and ecological functions in soil and natural resources protection, such as for instance stream water flow regularisation as well as conservation of river biodiversity and habitats ([Tabacchi et al., 2000](#); [Rocha et al., 2015](#)), its role towards a greater stability of the physico-chemical characteristics of headwaters must be highlighted and enhanced.

Specific evaluations of water quality in Brazil are conducted at very few research stations, for example, clustered in the IBGE Reserve of the Federal District ([Markewitz et al., 2006](#); [Parron et al., 2010](#)). Although more data are available from local and regional studies by local water managers or environmental protection agencies, they are not published in scientific journals and thus the impacts of land use on aquatic systems, that is, pollution from nutrients and pesticides, their in-stream processes, and their effects on aquatic habitats, are not well understood ([Hunke et al., 2015a](#)). Biome-specific water quality thresholds lack in Brazil ([Hunke et al., 2015b](#)), except for baselines for physical-chemical water parameters ranging from natural to very impacted conditions in the Cerrado area reported by [Fonseca et al. \(2014\)](#).

The objective of this work is the evaluation of water quality as influenced by the spatial variation of spring locations, the different land uses and state of conservation of the riparian vegetation in water springs of a headwater stream (São Paulo State, Brazil) typical of tropical conditions. More specifically, by applying linear mixed models the following questions are answered: (i) is water quality influenced by land use or distance from spring or both? (iii) to what extent water quality is influenced by these factors of change? (iii) are there any correlations among the water quality parameters? Identifying the spatial variability of land use impacts on water quality represents a significant challenge; addressing this issue is critical for assessing the potential risks of development and the cost-effectiveness of water management at the watershed scale ([Ding et al., 2015](#)).

2. Materials and methods

2.1. Study site description

The study was carried out in the headwater stream of Pimenta creek, a tributary of the Paraiso basin. The basin belongs to the São Manuel experimental farm (belonging to UNESP/FCA), in the central-western region of the state of São Paulo (Brazil) ([Fig. 1](#)). The basin of the Pimenta creek is located between the geographic coordinates 22°46'07"S to 22°46'57"S and 48°33'49"W to 48°33'59"W at an average altitude of 779 m. It covers an area of 22.8 ha and is covered by pasture (57.5%), native vegetation and bamboo (25.9%), exotic vegetation (5.5%), agriculture (10.1%) and infrastructure (1.0%); the main stream is 1620 m

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