Relationship Between Land Use and Water Quality in a Subtropical River Basin

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ABSTRACT

This study investigated the influence of land use on water quality parameters in the subtropical basin of Jundiaí-Mirim river. Water samples were collected to measure nutrients concentration and direct measurements by multiparameter probe were performed, as well as landscape analysis, using satellite images and visits in the sampling sites, besides analysis of population density data. Data were standardized and the correlation between the variables was measured using Spearman approach. Land use in the surrounding area of the sampling points had strong and significant correlations ($p < 0.05$) with some of the water quality parameters evaluated. These correlations had different causes, explained by the land use in a 50 m radius, or 500 m radius, or even beyond these environments studied. Landscape analysis has proved to be an important tool for understanding the interaction between water quality and land use.

Keywords: Geoprocessing; Jundiaí-Mirim River Basin; Landscape Analysis.

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The impact of human activities on inland aquatic ecosystems has caused a continuous and relentless deterioration of water quality and profound changes in the hydrological, biogeochemical and biodiversity cycles. This process of deterioration has had economic and social consequences, in some cases, brought permanent and irreversible alterations in lakes, rivers and reservoirs (Tundisi & Matsumura-Tundisi 2008).

The water resources management enrolls a bunch of factors such as: qualitative and quantitative analyses, decision making, avoidable and/or preventable actions. In the context of water resources protection, the soil use planning of the river basin stands out, because the water quality of streams reflects the economic, social and cultural activities that are developed in this region, besides mesological factors as observed by some authors (Medeiros et al. 2017; Medeiros et al. 2013; Fernandes et al. 2011).

The complexity and synergy of the factors influencing the hydrological dynamics of a river basin emerge the need for methodologies that assess, in an integrated way, the impacts and damages of anthropic activities. One of these approaches is the landscape analysis, which can be used and developed to evaluate these impacts and damages caused by anthropogenic pressures, such as: housing and settlements, soil tillage; roads and buildings (Antrop 2000).

In the present research, we followed the statement of European Landscape Convention (ELC) that relates landscape to an area perceived by people, whose character is the result of the action and interaction of natural and/or human factors (Council of Europe 2000).

Researches related to landscape analysis have used different methodological approaches, but there is a predominance of the geotechnologies, as geographical information system (GIS) (Falconer et al. 2013; Malavasi et al. 2013), supplemented with field visual observations (Gyllin & Grahn 2015; Marques 2016).

The use of both tools may be of interest in the study of river basins, due to their complementary character, since GIS can work with spatial information, and the photographic record and field visits allow registering damages and environmental impacts that satellite imagery can´t identify (Medeiros et al. 2016).

The Jundiaí-Mirim river basin is located close to large urban centers and industrial areas, and supplies 95% of the drinking water consumed by Jundiaí city (Machado et al. 2018). This river basin has experienced an intense urbanization process, bringing an increase of the economic values of their lands, and presents mining and agricultural activities (Fengler et al. 2015; Freitas et al. 2013). These different classes of land use have caused an environmental disturbance in the forest areas (Fengler et al. 2015), hydric scarcity and impacts on water quality (Machado et al. 2018; Beghelli et al. 2015), bringing threats to the water security (Machado 2018).

The importance of this river basin to Jundiaí city and its location between two metropolitan regions (Campinas and São Paulo) has conducted investigations related to several themes related to water resources. In this way, can be highlighted the following themes: environmental quality (Freitas et al. 2013; Fengler et al. 2015), landscape analysis (França et al. 2014; Medeiros et al. 2016), environmental management (Marques 2016; Silva & Medeiros 2017), environmental risks (Picolo 2005) and water quality (Machado et al. 2018; Beghelli et al. 2015).

Therefore, the main goal of this research was to evaluate limnological parameters of the Jundiaí-Mirim river basin and to analyze its relation with the land use, in order to verify the influence of the surrounding areas on the physical-chemical characteristics of the water.

METHODOLOGY

STUDY AREA

Jundiaí-Mirim river basin extends to an area of 11.750 ha, spanning three municipalities in São Paulo state: Jundiaí, Jarinú and Campo Limpo Paulista. Jundiaí city occupies 55% of the total area of this river basin, followed by Jarinu (37%) and Campo Limpo Paulista (8%). The population of the three cities reach 505.000 inhabitants, of whom 80% live in Jundiaí city (Machado et al. 2018).

According to CONAMA Resolution 357/2005, Jundiaí-Mirim river and its tributaries are classified as Class I: rivers meant for human consumption supply, after simplified treatment; to the protection of aquatic communities; to primary contact recreation, such as swimming, skiing and diving; irrigation of greenery, fruitful plants and parks, gardens, sports and leisure fields, with which the public might have direct contact; and to aquaculture and to fishing activity. At the end of the river, two reservoirs and pumping station were built to the Jundiaí water supply (Moraes 2003).

According to the Köppen classification, the climate of the Jundiaí region is subtropical with a dry season (Cwa). Temperature reaches 14.6 ºC (average total annual), and the coldest and warmest months correspond to July (average of 17 ºC) and January (average of 24 ºC), respectively. The average total annual rainfall is 1350 mm, with the wettest and driest months being January (average of 223 mm), and August (average of 38 mm), respectively (CEPAGRI 2016).

The methodology consisted in field surveys in September (14th and 28th) 2016 along Jundiaí-Mirim river basin to recognize the area and determine the experimental design. Therefore, the selected sampling sites are described in Table 01 and they can be visualized in Figure 01.

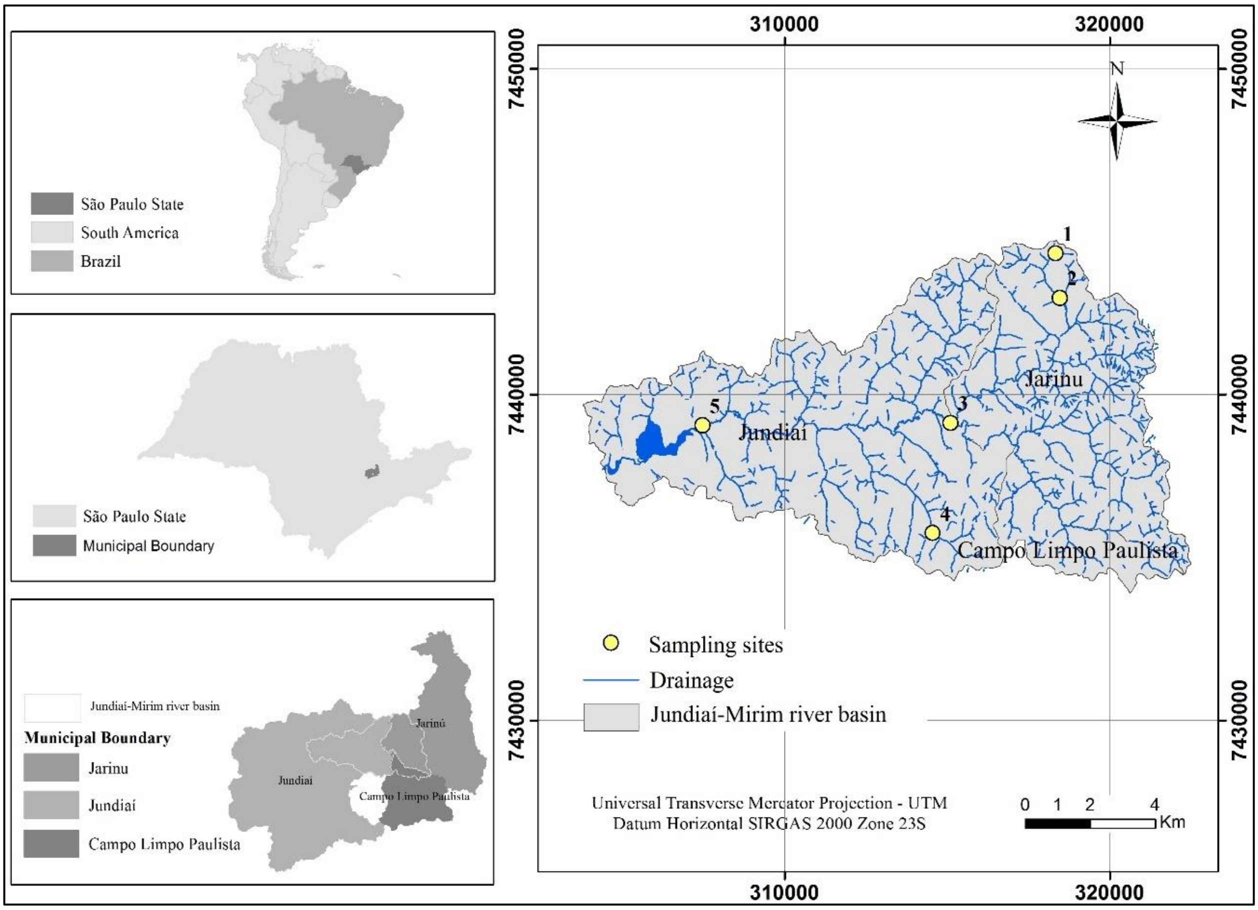
Table 01. Sampling sites, coordinates and description of the study area

POINTS	COORDINATES UTM*		DESCRIPTION
	Latitude	Longitude	
P1	7444334	318320	Transposition between Jundiaí-Mirim and Atibaia rivers
P2	7442974	318456	Bridge near pasture, headwaters and forests
P3	7435749	314551	Confluence of the Jundiaí-Mirim river and Perdão stream
P4	7439129	315094	Area near the horticulture
P5	7439058	307464	Riverine zone of the reservoir

Source: Authors

Caption: *Datum Sirgas 2000.

Figure 01. Water sampling sites in the Jundiaí-Mirim river basin



Source: Authors

WATER PARAMETERS

At the five sampling sites, temperature (°C), pH, redox potential (mV), electric conductivity (µS/cm), turbidity (NTU), dissolved oxygen (mg/L), total dissolved solids (mg/L) were measured in situ using the multiprobe Horiba U-50. Total phosphorus and total nitrogen analysis were made in the laboratory from São Paulo State University (UNESP), at the Sorocaba campus, using visible spectrophotometer and specific reagents (model DR 2700, HACH), following the methodologies established by APHA (2012).

LAND USE AND POPULATION CENSUS CHARACTERIZATION

Land use mapping procedures of the areas surrounding the sample points were done in ArcGis 10.3 (ESRI 2011) through a supervised image classification and manual vectorization. We have been using Google Earth satellite images (June 2016), that is georeferenced and vectorized for the soil cover class definitions. All areas defined comprising a 500 m radius was taken into account the sampling sites, which were located using GPS. Maps were prepared in the SIRGAS 200 system datum (23º S).

We realized field visits and carried out photographic records to evaluate the use and occupation of the soil, as well as identifying damages and environmental impacts in the perceived landscape within a 50 m radius from each sampling point, following procedures reported in Medeiros et al. (2016), Marques (2016) and França et al. (2014). Census data from the Jundiaí-Mirim river basin were obtained from the IBGE database (IBGE 2016).

DATA ANALYSES

Descriptive statistics (minimum, maximum, mean and coefficient variation values), graphics and tables were used for data analyses. In relation to water quality, data were related to CONAMA 357 of 2005 resolution (CONAMA 2005). Spearman correlation test was used to investigate degree associations between water and geographical variables. All statistical analyses were performed at the significance level less than 5% ($p < 0.05$) using PAST software (Palaeontological Statistics, version 2.16).

RESULTS AND DISCUSSION

WATER QUALITY PARAMETERS

Water temperature ranged from 18.5 °C to 23.0 °C. The pH values ranged from 4.8 to 6.5, with values below the minimum limit recommended by CONAMA Resolution 357/2005 for Class 1 rivers (pH 6.0 to 9.0) (Table 02). Sites with more acidic pH waters are located between the head and the central region of the basin (P1, P2 and P3). In general, high concentrations of acidic substances from allochthonous and autochthonous sources cause low pH values in aquatic environments (Esteves 2011). Electrical conductivity and pH may also be associated with weathered soils and the lithological composition (Arcova et al. 1993). In addition, the presence of organic matter and rainfall can influence pH variation (Silva et al. 2008).

Table 02. Limnological variables measured at sampling points in the Jundiaí-Mirim river basin

SITES/VARIABLES	P1	P2	P3	P4	P5	Mean	CV (%)	Limit*
Temp (°C)	20.55	18.55	19.81	22.23	23.01	20.83	7	-
pH	4.77	5.33	5.39	6.46	6.31	5.65	11	6 - 9
ORP (mV)	261	252	263	414	247	287	22	-
CE (μS/cm)	58	77	80	205	145	113	48	-
TURB (NTU)	14.4	3.9	9.8	8.0	37.0	14.6	79	< 40
DO (mg/L)	6.94	8.62	7.66	6.07	7.12	7.28	11	> 6
TDS (mg/L)	39	50	52	133	94	73	43	500
TN (mg/L)	0.0	3.0	7.0	2.0	0.0	2.4	120	-
TP (mg/L)	0.27	0.26	0.26	0.26	0.27	0.26	2	0.1
TN/TP	0.0	25.5	59.6	17.0	0.0	20.4	120	-

Source: Authors

Caption: Temp: temperature; ORP: redox potential; CE: electrical conductivity; TURB: turbidity; OD: dissolved oxygen; TDS = total dissolved solids; TN: total nitrogen; PT = total phosphorus; N/P = ratio between total nitrogen and total phosphorus. Variation coefficient = CV. Limit = limit values for Class 1 rivers. The highlighted values in bold are not in compliance with current legislation.

The range of pH values of the present investigation was lower than that observed by Machado et al. (2018), in a previous survey performed in the Jundiaí-Mirim river, in 2013, which presented a variation range of 7.3 to 7.7. Researches on water bodies in the Piracicaba, Capivari and Jundiaí watershed (PCJ), in which the Jundiaí-Mirim river basin is inserted, point to a trend of alkaline waters and, therefore, different from those observed in the present study (Medeiros et al. 2017; Medeiros et al. 2009; Silva et al. 2012). Furthermore, the observed trend of pH, from upstream to downstream, contradicts the results of Machado et al. (2018).

The redox potential (ORP) ranged from 252 to 414 mV, when we observe the maximum value in P4. Positive values of ORP indicate oxidizing conditions and negative reducing conditions. In aerobic environments, the ORP presents values above 100 mV and may indicate the presence of different forms of nitrogen in the aquatic environment (Matos et al. 2010), a phenomenon verified in the present study. Redox potential can dramatically alter the mobility of ions in water, and in some cases the toxicity, in a given environmental compartment (Jardim 2014).

The electrical conductivity (EC) represents the capacity of the water to conduct the electric current, meaning an indirect measure of the concentration of pollutants. Although CONAMA Resolution 357/2005 does not provide any reference value of this parameter for the classification of water bodies, levels higher than 100 μS/cm can indicate impacted environments (CETESB 2009).

The range of EC values varied from 58 to 205 μS/cm, following the trend observed for pH and ORP, from upstream to downstream. We measured the highest EC value at P4, indicating a possible sewage discharge and diffuse pollution. This range of EC variation was higher than that observed by Machado et al. (2018) in the Jundiaí-Mirim river (40 to 60 μS/cm). However, the mean (113 μS/cm) was lower than that observed in other streams evaluated in the PCJ, as reported by Daniel et al. (2002) (530 μS / cm), Medeiros et al. (2017) (330 μS / cm) and Silva et al. (2012) (306 μS / cm).

The turbidity indicates the degree of attenuation that a light beam suffers when crossing the water (ANA 2016). Erosion of river banks intensified by inadequate land use in rainy seasons, and the discharge of domestic sewage or industrial effluents are anthropic causes that may result in increased turbidity of the waters (CETESB 2009).

The upper turbidity limit for Class 1 rivers reaches 40 NTU (CONAMA 2005). The water turbidity in the Jundiaí-Mirim river basin ranged from 3.90 to 37.0 NTU, the highest value recorded at the entrance of the Jundiaí reservoir (P5). This was probably due to the increasing flow from upstream to downstream, agreeing with the trend observed by Machado et al. (2018). This range of values is lower than that observed by Machado et al. (2018) (40-60 NTU), and in other reports in the PCJ, such as Medeiros et al. (2017) and Medeiros et al. (2009).

In investigations related to pollution control of water resources, the concentration levels of the various solids fractions results in an overview of the particles size distribution (suspension and dissolved solids) and its nature (fixed or mineral and volatile or organic). Solids in the water correspond to all matter that remains as residue, after evaporation, drying or calcination at a pre-established temperature for a fixed time (CETESB 2009).

Concentrations of total dissolved solids (TDS) ranged from 39 to 133 mg/L. As observed for ORP and EC, point P4 reached the maximum value of TDS. However, the range of the observed TDS values in the Jundiaí-Mirim river basin was lower than those reported in other streams in the PCJ, such as Medeiros et al. (2017), in the city of Americana, state of São Paulo (33 to 1820 mg/L).

High phosphorus content may be associated with the transport of sediments from agricultural land or the discharge of untreated sewage (Tundisi & Matsumura-Tundisi 2008, Medeiros et al. 2009) and may lead to artificial eutrophication of aquatic environments (Esteves 2011). In CONAMA Resolution 357/2005, the total phosphorus limit for the lotic environment in Class 1 rivers reaches 0.1 mg/L.

Concentrations of total phosphorus ranged from 0.26 to 0.27 mg/L, above the limit established for Class 1 rivers, and presented a low spatial variability (CV = 2.1%). In the waters contaminated by the discharge of domestic sewage, in the PCJ, phosphorus levels reached 8.5 mg/L (Medeiros et al. 2017) and 5.0 mg/L (Medeiros et al. 2009).

In the same way that phosphorus, nitrogen is another chemical parameter indicative of the aquatic pollution related to the discharge of sewage or transport of nutrients from agricultural lands (Medeiros et al. 2017). In the Jundiaí-Mirim river total nitrogen contents ranged from 0 to 7.0 mg/L, reaching an average of 2.4 mg/L. These values were higher than those observed by Machado et al. (2018) (2.4 mg/L) in the Jundiaí-Mirim river, but lower than those measured by Medeiros et al. (2017) in contaminated streams by sewage discharge (mean of 11.6 mg/L). The TN/TP ratio ranged from 17.03 to 59.61 indicating that the limiting nutrient in the aquatic environment was total phosphorus.

At all sampling points the dissolved oxygen (DO) values exceeded the minimum limit of 6.0 mg/L established for Class 1 rivers by resolution CONAMA 357/2005. DO concentrations ranged from 6.07 to 8.62 mg/L, and were higher, on average, than that observed by Machado et al. (2018). In polluted stream of PCJ, investigations reported average DO values reaching 2.60 mg/L (Medeiros et al., 2017), 0.85 mg/L (Medeiros et al. 2009), and 1.8 mg/L (Daniel et al. 2002). The dissolved oxygen concentrations in the analyzed samples may be related to the topographic gradient, which can promote turbulence in the water flow. According to Maier (1987), in current water the oxygen content can vary due to changes in its environmental characteristics and as a consequence of the climatic conditions.

Land Use and Population Density

The occupation of natural areas is a product of the economic growth of municipalities and causes irreversible damages to the environment, reducing large areas of vegetation in their biomes to small forest fragments. This impact considerably reduces the environmental quality of the river basins, since the conservation of vegetation for the preservation of natural resources, especially water, is extremely important for buffering the pressure of anthropic activities (Marques 2016).

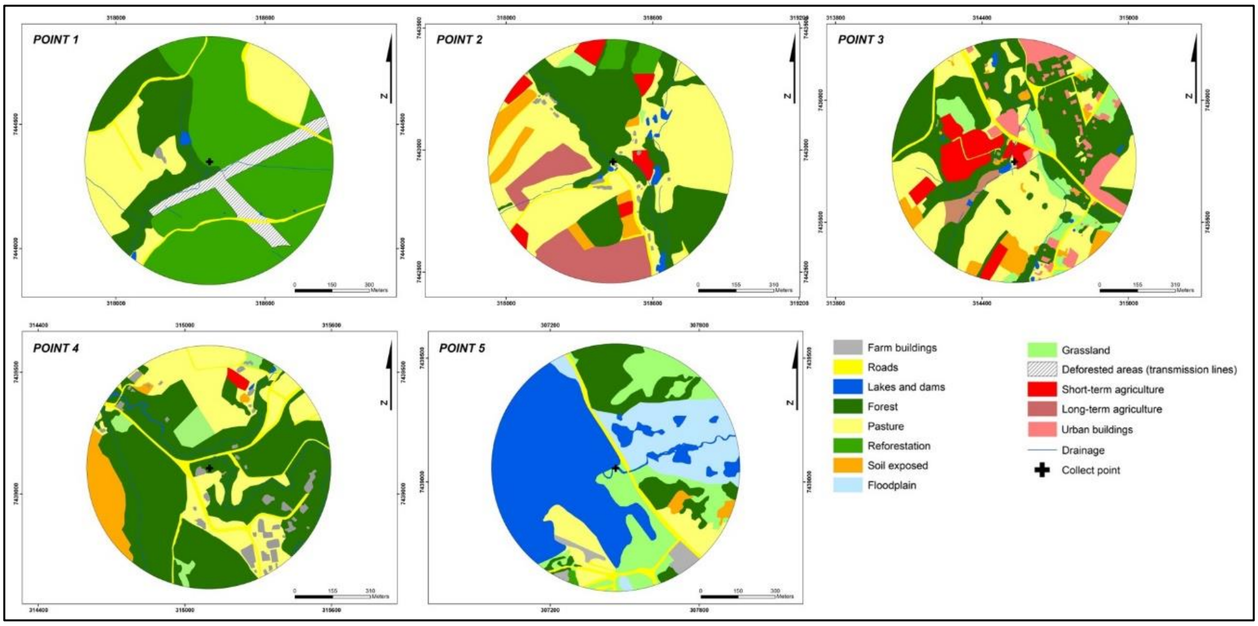
According to Fengler et al. (2015), there was a constant trend of deterioration of the natural vegetation in the Jundiaí Mirim river basin, from 1972 to 2013, attributed to the intense occupation of this region. Table 03 and Figure 02 and show land use around the water sampling points, comprising 500 m radius, in the Jundiaí-Mirim river basin.

Table 03. Land use surrounding water sampling sites (500 m radius), in Jundiaí-Mirim river basin

LAND USE	P1	P2	P2	P4	P5
	---------------------- ha ----------------------				
Short-Term agriculture	0.0	3.3	6.1	0.5	0.0
Long-term agriculture	0.0	10.3	0.0	0.0	0.0
Pasture	16.0	31.1	22.7	17.9	5.7
Grassland	0.0	0.8	5.6	2.8	13.1
Forest	14.2	24.5	28.6	45.2	10.1
Floodpain	0.0	0.0	1.4	0.0	12.8
Reflorestation	40.0	2.2	0.0	0.0	0.2
soil exposed	0.0	4.0	3.5	5.1	0.8
urban buildings	0.0	0.0	6.9	0.0	0.0
farm buildings	0.2	0.7	0.1	3.1	1.6
Roads	2.1	1.1	3.3	3.8	2.5
deforested areas	5.7	0.0	0.0	0.0	0.0
lakes and dams	0.4	0.5	0.5	0.2	31.8

Source: Authors

Figure 02. Land use schematic drawings surrounding the water sampling sites (500 m radius) in Jundiaí-Mirim river basin



Source: Authors

The land use category with the largest area, considering all evaluated points, corresponds to forest (122.6 ha or 31.2% of the total), followed by pasture (93.4 ha or 23.8% of the total) and reforestation (42.4 ha or 10.8% of the total). The water surface category was the fourth in area (33.4 ha or 8.5% of the total), and around 95% of this total (31.8 ha) is located close to P5 point. In the individualized evaluation of each point, those with the highest relative forest area were P4 (45.2 ha or 57.5%), P3 (28.6 ha or 36.3%), P2 (24.5 ha or 31.2%), P1 (14.2 ha or 18.1%) and P5 (10.1 ha or 12.8%).

Considering the land use categories related to agricultural and cattle activity, using fertilizers (Short-Term agriculture, Long-term agriculture, pasture and reforestation), P1 was the one with the largest relative area in its surroundings, reaching 56 ha or 71.2%, standing out the eucalyptus crop. In P2 (46.9 ha or 59.7%), P3 (28.8 ha or 36.6%), P4 (18.4 ha or 23.4%) and P5 (5.9 ha or 7.5%) the pasture stands out.

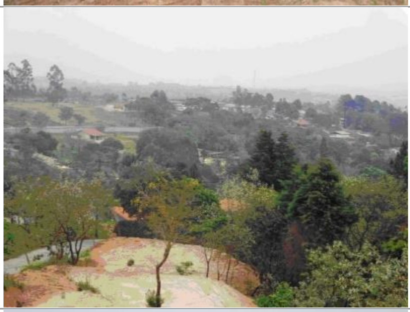
An analysis of land use categories that increase runoff and the generation of domestic sewage (exposed soil, urban buildings, farm buildings, roads, deforested areas) indicated that P2 reached the lowest value (7.4%), outstanding deforested area, followed by P1 (10.2%), highlighting deforested area, P4 (15.3%), exposed soil, and P3 (17.5%), urban building. The P5 point reached 6.2%, standing out the roads.

Therefore, points P1 and P2 have a rural landscape, while P3 and P4 have an urban occupation profile. The P5 point, despite the influence of the water surface of the reservoir, corresponded to an urbanized landscape. Figure 03 shows the main environmental damages and impacts around the water sampling points, considering a 50 m radius. At the point P1 was intense the agricultural activity, basically the eucalyptus crop and the presence of cattle.

The P2 point, although also included in the rural area, presented a surrounding area similar that of urbanized sites. The points P3 and P4 corroborated the results of geotechnologies methodologies. At P5 it was evidenced the vulnerability of the reservoir that supplies Jundiaí to the effects of urbanization, such as risk of road accidents, diffuse solid waste and sedimentation.

The results related to population density around the water sampling points in the Jundiaí Mirim river basin follow the same trend of land use. The agricultural production areas had the lowest population densities (24.5 inhabitants/km^2 in P1 and P2). In the urbanized regions, the points P3 and P4 presented the highest population densities, reaching 117.2 and 93.1 inhabitants/km^2 respectively. The P5 had the lowest population density (30.6 inhabitants/km^2) due to the relative importance of the water surface of the reservoir.

Figure 03. Photographic records of the environmental characterization (50 m radius) around the water collection sites in Jundiai-Mirim river basin

SITE	IMAGE	DESCRIPTION OF DAMAGES AND IMPACTS
1		At this site, we observed intense agricultural activity, as eucalyptus crop and the presence of cattle. The main environmental aspect perceived in the landscape was the planting of the eucalyptus downhill and the soil exposed due to the electric transmission lines, promoting erosion and surface runoff.
2		Presence of housing, effluent disposal and urban solid waste on the banks. The proximity of a road, with an intense traffic, contributed to diffuse waste presence (plastic waste, paper and packaging). We observed absence of riparian forest around the river. Near the body of water, there was a slope without vegetation and with signs of sliding, becoming more critical during the rainy season.
3		Urbanized area, in which we observed a greater amount of solid waste in relation to the other points, such as rubble, plastic packaging, paper and bottles. The river received drainage from the road. In the surrounding area there were horticulture and residences, in addition to high flow of vehicles. We noted the absence of riparian forest. Probably there was a sewage dump, evidenced by the color and odor of the water.
4		This point presented a perception of greater conservation of its surrounding area, because it was a zone of small farms.
5		In the supply reservoir of Jundiaí city we observed a high amount of garbage in its surroundings. We do not observe any protection around the reservoir, making it vulnerable to road accidents. The water level was low upstream and with sediment deposition downstream.

Source: Authors

RELATIONSHIP BETWEEN LAND USE AND WATER QUALITY

We found strong and significant correlations ($p < 0.05$) between short-term agriculture and TN ($r = 0.99$), pasture and turbidity ($r = -0.90$), forest and ORP ($r = 0.90$) (Table 04). We did not consider the correlation between pasture and temperature, since this parameter of water quality was very influenced by the time of the measurement.

Table 04. Correlations between land uses, demographic density and limnological parameters in Jundiaí-Mirim river basin

LAND USE/VARIABLES	TEMP	pH	ORP	EC	TURB	DO	TDS	TN	TP
	oC	--	mV	µS/cm	NTU	---------- mg/L ----------			
Short-term agriculture (ha)	-0.72	0.05	0.41	0.05	-0.67	0.56	0.05	0.99	-0.89
Long-term agriculture (ha)	-0.71	-0.35	-0.35	-0.35	-0.71	0.71	-0.35	0.36	-0.41
Pasture (ha)	-0.90	-0.20	0.30	-0.20	-0.90	0.60	-0.20	0.87	-0.87
grassland (ha)	0.50	0.70	-0.20	0.70	0.40	0.10	0.70	0.10	0.00
Forest (ha)	-0.30	0.40	0.90	0.40	-0.70	-0.20	0.40	0.67	-0.87
Floodpain (ha)	0.45	0.34	-0.45	0.34	0.67	0.22	0.34	-0.06	0.32
Reforestation (ha)	-0.21	-0.82	-0.56	-0.82	0.15	0.15	-0.82	-0.53	0.59
soil exposed (ha)	-0.20	0.60	0.50	0.60	-0.80	0.00	0.60	0.56	-0.87
urban buildings (ha)	-0.35	0.00	0.35	0.00	0.00	0.35	0.00	0.73	-0.41
farm buildings (ha)	0.60	0.70	0.00	0.70	-0.10	-0.50	0.70	-0.41	0.00
Roads (ha)	0.50	0.80	0.70	0.80	0.10	-0.60	0.80	0.15	-0.29
deforested areas (ha)	0.00	-0.71	0.00	-0.71	0.35	-0.35	-0.71	-0.54	0.61
lakes and dams (ha)	0.10	0.00	-0.70	0.00	0.50	0.60	0.00	0.05	0.29
Population density (inhab./km²)	0.21	0.67	0.56	0.67	0.05	-0.15	0.67	0.50	-0.44

Source: Authors

Caption: Temp: temperature; ORP: redox potential; EC: electrical conductivity; TURB: turbidity; DO: dissolved oxygen; TDS = total dissolved solids; TN: total nitrogen; PT = total phosphorus. Bold values ($p < 0.05$).

Strong correlations, but not significant, were found between short-term agriculture and TP (-0.89), long-term agriculture and turbidity ($r = -0.71$), long-term agriculture and DO ($r = 0.71$), pasture and TN ($r = 0.87$), pasture and TP ($r = -0.87$), forest and TP ($r = -0.87$), reforest and pH ($r=-0.82$), reforest and CE ($r=-0.82$), reforest and TDS ($r=-0.82$), soil exposed and turbidity ($r = -0.80$), soil exposed and TP ($r = -0.87$), urban buildings and TN ($r = 0.73$), roads and pH ($r = 0.80$), roads and CE ($r = 0.80$), roads and TDS ($r = -0.80$), deforested areas and pH ($r = -0.71$), deforested areas and EC ($r = -0.71$), deforested areas and TDS ($r = -0.71$).

The largest area of short-term agriculture was found in P3, in which the highest measured value of TN (7.0 mg / L) was also recorded. In this point, specifically, there is a strong influence of aspects related to land use near the sampling site, such as sewage discharge, drainage of road and horticulture production area, and presence of garbage, which probably influenced the result of this water quality parameter. Consequently, the analysis of the landscape around the sampling point (50 m radius) revealed that urbanization effects, instead of rural activity, conditioned the result at that point.

In the strong and significant negative correlation between pasture and turbidity, the P2 point was the one that presented the largest pasture area in its surroundings (31.1 ha) and the lowest turbidity concentration (3.9 NTU), while P5 was the one with the lowest pasture area (5.7 ha) and higher turbidity (37.0 NTU). The pasture promotes better soil cover and infiltration in relation to urban areas, and the occupation of the environment (500 m radius) justifies the best performance of this point for this water quality parameter. However, the land use in the surroundings was not the cause for the observed result in P5, in this case the transport of sediments from the upstream to the mouth of the watershed was the conditioning factor of this result, agreeing with Machado et al. (2018).

The strong and significant correlation between redox potential and forest areas ($r = 0.90$, $p < 0.05$) may be related to the sedimentation of organic matter from the litter in the water course, which in turn is oxidized by decomposing organisms (Camargo et al. 1999; Vanzela et al. 2010).

Despite the complexity of water quality dynamics in a river basin, and the nature of the causes involved (point source or non-point source, anthropogenic or natural, rural or urban source), some of the strong but not significant correlations found (long term agriculture and turbidity, urban buildings and TN, roads and EC, roads and TDS) allow to infer that urban expansion has been a degrading factor of the water resources in Jundiaí-Mirim river basin. This statement is corroborated by Fengler et al. (2015) where the degradation of the environmental quality of forest fragments was correlated with the expansion of the road network, which preceded the replacement of agricultural properties by allotments.

In this context, the preservation of forest, pasture and agriculture areas, if well managed, can promote ecosystem services to preserve regional water resources, corroborating other authors (Medeiros et al. 2017; Martinico et al. 2014).

Conclusion

The results of the present study allowed us to conclude that land use of surrounding area of the water sampling points was strongly and significantly correlated with some water quality parameters in the Jundiaí-Mirim river basin. However, this correlation presented different causes, explained by the land use in a 50 m radius, or 500 m, or even beyond these environments studied. To reach this understanding, the analysis of the landscape was very important both with the use of geotechnologies and through field visits at the water sampling sites.

The results allowed to infer about the importance in the maintenance of the green areas (natural or anthropic) for the provision of ecosystem services related to the preservation of water quality in watersheds.

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Relação entre a Ocupação do Solo e Qualidade da Água em uma Bacia Hidrográfica Subtropical

Resumo

A influência do uso do solo sobre a qualidade da água foi investigada na bacia hidrográfica subtropical do rio Jundiaí-Mirim. Amostras de água foram coletadas para determinação de nutrientes e medidas diretas por meio de sonda multi-parâmetros foram realizadas, assim como a análise da paisagem, por meio de sensoriamento remoto e visitas nos locais de amostragem, além da avaliação de dados sobre da densidade populacional. Os dados foram padronizados e o grau de correlação entre as variáveis foi analisado usando a abordagem de Spearman. O uso da terra no entorno dos pontos de amostragem apresentou fortes e significativas correlações ($p < 0{,}05$) com alguns dos parâmetros da qualidade da água avaliados. Essa correlação se deu por diferentes causas, explicadas pelo uso da terra em um raio de 50 m, ou 500 m, ou mesmo além desses entornos estudados. A análise da paisagem demonstrou ser uma importante ferramenta para o entendimento da interação qualidade da água e uso da terra.

Palavras-Chave: Geoprocessamento; Bacia do Rio Jundiaí-Mirim; Análise da Paisagem.

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