REGET/UFSM
Revista Eletrônica em Gestão, Educação e Tecnologia Ambiental

UFSM

Rev. Eletr. Gest., Educ. Tec. Ambient.
Santa Maria v.23, e34, p. 01-10, 2019
DOI:10.5902/2236117039836 - ISSN 2236-1170

Edição Especial Submissão: 03/09/2019 Aprovação: 03/09/2019 Publicação: 25/09/2019

Artigo Original

Spatial-temporal analysis of the risk to water pollution against land use changes in Lobo Stream Drainage Basin, Itirapina-SP, Brazil

Análise espacial-temporal do risco à poluição hídrica frente às mudanças de uso e ocupação do solo na bacia hidrográfica do ribeirão do Lobo, Itirapina-SP, Brasil

Phelipe da Silva Anjinho[I], Allita Rezende dos Santos[II], Mariana Abibi Guimarães Araujo Barbosa[III], Frederico Fabio Mauad[IV]

Abstract

The landscape transformation caused by economical activities generates impacts on natural ecosystems and the water system is one of the most susceptible to anthropic alterations. In this context, the objective of this study was to analyze the vulnerability of the water resources of the Lobo Stream Drainage Basin (LSDB), Itirapina-SP, through the application of the Environmental Quality Index of Water Resources (EQI-Hydro), in a 32 years period, corresponding to the years 1985 and 2017. The EQI-Hydro was calculated from the analysis of the Euclidean distance of the water resources to the impacting sources, determined by means of land use classification, and then rescaled based on fuzzy logic. The results show that approximately 57% of the watershed area is classified as high and very high EQI-Hydro. The Itaqueri River and the Água Branca Stream are the most vulnerable to pollution due to their proximity to pollution sources. This manifests the need for adequate agricultural practices and public policies for forest restoration, aiming the preservation of the LSDB water resources.

Keywords: Water resources; EQI-Hydro. Fuzzy logic; Water pollution; Vulnerability.

Resumo

As transformações na paisagem causadas pelas atividades econômicas geram impactos sobre os ecossistemas naturais, sendo os sistemas hídricos um dos mais susceptíveis às alterações antrópicas. Em vista disso, o objetivo desse estudo foi analisar a vulnerabilidade dos corpos hídricos da bacia hidrográfica do ribeirão do Lobo, Itirapina-SP, mediante aplicação do Índice de Qualidade Ambiental dos Recursos Hídricos (IQA-Hidro), no intervalo de 32 anos, que compreende o período de 1985 e 2017. O IQA-Hidro foi elaborado com base na análise da distância euclidiana dos recursos hídricos em relação às fontes impactantes, determinadas por meio da classificação do uso e ocupação do solo e, em seguida, escalonados com base na lógica fuzzy. Os resultados mostraram que aproximadamente 57% da área da bacia se encontram nas classes com valores alto e muito alto para IQA-Hidro. O rio Itaqueri e o córrego Água Branca são os mais vulneráveis à poluição devido à proximidade às fontes de poluição. Tal situação manifesta a necessidade de práticas adequadas de manejo das atividades agropecuárias e políticas públicas voltadas à restauração florestal, visando a preservação das regiões fluviais da bacia.

Palavras-chave: Recursos hídricos; IQA-Hidro; Lógica Fuzzy. Poluição hídrica; Vulnerabilidade.

[I, II, III] Postgraduate student, Program in Environmental Engineering Sciences, Center of Water Resources and Environmental Studies, University of São Paulo, São Carlos, SP, Brazil - phelipe.anjinho@usp.br; allita.santos@gmail.com; marianagb2@gmail.com

[IV] Professor, PhD, Program in Environmental Engineering Sciences, Center of Water Resources and Environmental Studies, University of São Paulo, São Carlos, SP, Brazil - mauadffm@sc.usp.br

1 Introduction

The conservation of aquatic environment depends on several factors and interactions among the ecological systems, which are very important for the living beings. The impact of anthropic activities in natural landscape have socioenvironmental and economic effects, assigned to the development that modifies the spatial disposition of land use. As the world population grows, sustainable development becomes a greater challenge, but also, increases the importance of sustaining natural resources for future generations. The search for rational land use tries to balance the environmental conservation with the food and energy production (TREVISAN; MOSCHINI; GUERRERO, 2017).

The changes in land use are directly related to the accelerated process of environmental modifications and the devastating effect on the environment (MISHRA; RAI, 2016), as anthropic activities are responsible for many impacts on aquatic environments (TUNDISI; MATSUMURA-TUNDISI; RODRIGUES, 2003). In addition, increased urbanization, intensified agricultural activities, uncontrolled deforestation and inadequate management in river basins promote excessive water and soil degradation.

The changes in natural ecosystems without strategic planning increase sediment production, which is carried out to water bodies, causing water level to decline, toxic contamination, eutrophication and acidification. These generate other negative impacts as the alteration of river dynamics and the water quality commitment (CALIJURI et al., 2015).

So, it is important to disseminate the use of simplified procedures of analysis that provide an equilibrium between water resources quality and economic activities developed on the watershed, supporting management practices. Thus, spatial modelling has shown an increased use as a tool for optimization in landscape ecology and territorial expansion issues. Among the most covered topics in landscape modelling are: population dynamics, fragmentation effects, environmental vulnerability, land use alterations and landscape connectivity (TREVISAN; MOSCHINI, 2015).

Currently, there are a variety of methods in the literature used to assess and quantify the effects of water resources pollution in a watershed scale, as hydrological models (ARNOLD et al., 1998; HUANG; HONG, 2010; XIANG; WANG; LIU, 2017). However, most of these models are complex and demand a great quantity of raw data, which compromise its use in areas with no measurement instruments or limited data availability. With this, it is clear the importance of simple methods to identify in advance critical areas to water resources management.

The use of landscape indexes is increasingly recognized in the last decades in studies that aim to analyze the landscape structure and operation (TURNER; GARDNER, 1991; LI; WU, 2004). Over the years, indexes were developed to describe the landscape special patterns (TURNER, 1987; O'NEILL et al.; 1988; Schumaker, 1996). In this work, we chose to use the Environmental Quality Index of Water Resources (EQI-Hydro), developed by Moschini (2008), based on the studies of Canter (1996) and Bojórquez et al. (2002).

The EQI-Hydro indicates the susceptibility of water resources to the sources of pollution, determined by means of the land use. The analysis of this index is based on the proximity relation of water bodies with the pollution sources, as greater is the proximity, greater is the susceptibility of water resources, indicating possibly the absence of riparian vegetation.

Many studies used the EQI-Hydro with the purpose of analyzing the vulnerability of water resources (MOSCHINI, 2008; DE SOUZA et al., 2017; DA SILVA et al., 2017; TREVISAN; MOSCHINI, 2017). In those studies, it is emphasized the importance of this index to identify critical areas in relation to the risk of water resources degradation, supporting the proposition of actions for water management, proving to be a relevant instrument for prevention of potential impacts generated from anthropic activities.

Therefore, the objective of this study was to verify the environmental vulnerability of water resources of the Lobo Stream Drainage Basin (LSDB), Itirapina-SP, through the EQI-Hydro. It is expected that this work may guide environmental management actions, in a way to assure the water conservation in the drainage basin.

2 Methodology

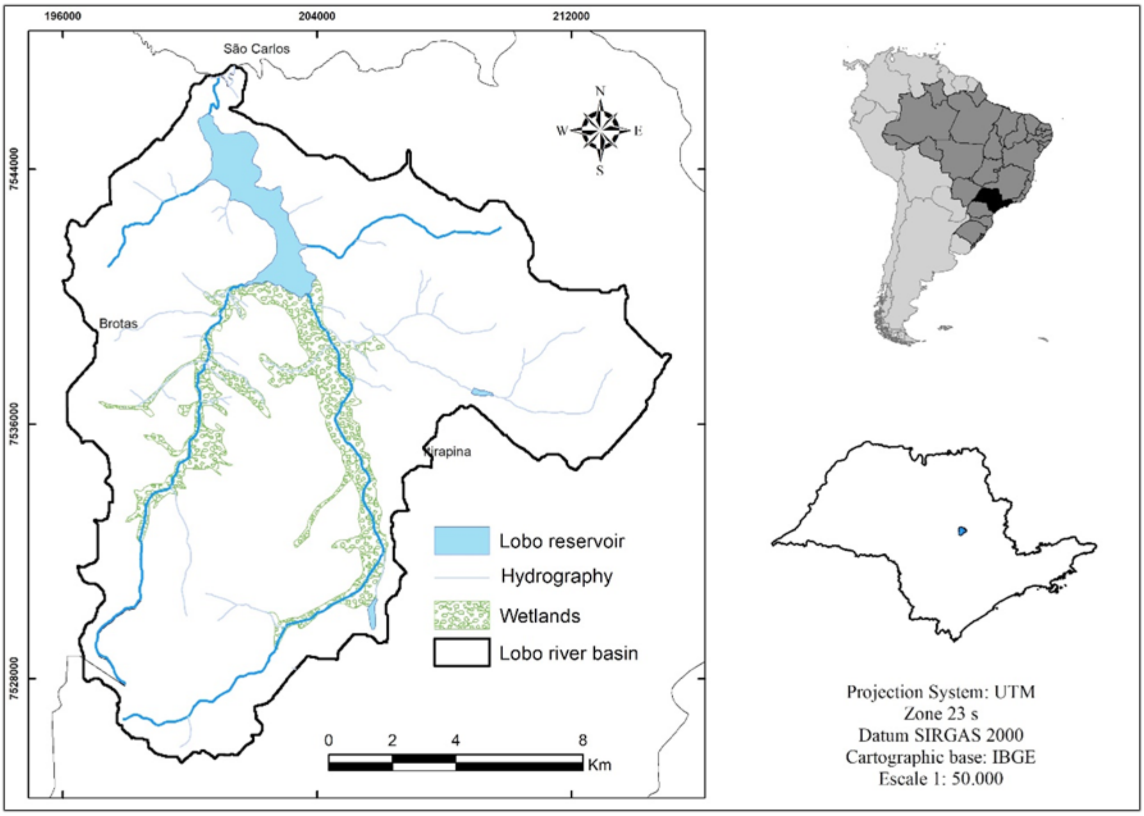
2.1 Study area

The study was developed in the LSDB (Figure 1), located at 22° 9' S latitude and 47° 49' W longitude, in South America, Brazil, São Paulo state. It covers an approximate drainage area of 221.5 km^2, between the municipalities of Brotas and Itirapina.

The LSDB is formed by four main rivers: Geraldo, Perdizes, Itaqueri and Lobo, which flows towards the Lobo reservoir, and then, to Jacaré-Guaçu river. The most representative rivers for water resources in the basin are Itaqueri and Lobo, corresponding together to 85% of the total water volume that discharges in the Lobo reservoir (TUNDISI; MATSUMURA-TUNDISI; RODRIGUES, 2003). The two rivers springs elevation are at 940 and 900 meters, runs 20.21 and 24.6 kilometers and have average flow rate of 3.11 and 0.99 m^3 s^{-1}, respectively. About the water quality, these two rivers are classified as class 2 according to the Environmental National Council (Conselho Nacional do Meio Ambiente - CONAMA) Resolution (BRASIL, 2005).

The region rainfall regime, according to Köppen climate classification, is characterized as hot climate and dry winter (Cwa), corresponding to tropical climate of altitude (CENTRO DE PESQUISAS METEOROLÓGICAS E CLIMÁTICAS APLICADA À AGRICULTURA, 2017). Annual rainfall is 1,500 mm and temperature vary between 15°C and 17°C in winter and between 21°C and 23°C in summer. The summer rainfall and intense wind

Figure 1 - Lobo Stream Drainage Basin



in winter, controlled by the equatorial and tropical air masses, favor the material input into the water systems, both by surface runoff and by precipitation (TUNDISI; MATSUMURA-TUNDISI, 2013).

The basin geology is composed by São Bento group, represented by the Piramboia, Botucatu and Serra Geral formations, and Bauru group, outcropping areas of Marília or Itaqueri, and by recent alluvial sediment (NISHIYAMA, 1991). The geomorphology is characterized by the Basaltic Cuestas, located between plateaus and depressions (ALMEIDA, 1964). The relief has no significant variation in altitude, in average between 50 and 300 meters in some points of the basin (GUERRA; CUNHA, 1996). The maximum altitude is 940 meters and slope 0.00575 m m^{-1} (TUNDISI; MATSUMURA-TUNDISI; RODRIGUES, 2003).

According to the Brazilian Soils Classification, the basin pedology is formed by the soil types: Purple Latosol, Red Latosol, Red Yellow Latosol, Red Yellow Argisol, Litholic Neosol, Nitosol, Quartzarenic Neosol and Gleysol (INSTITUTO AGRONÔMICO DE CAMPINAS, 1981). The most representative classes are the Quartzarenic Neosol and Red-yellow Latosol, present mainly in the Lobo and Itaqueri river floodplain areas.

The natural vegetation that occurs is fragments of Brazilian Cerrado, where most of which are covered by open physiognomies characterized by *campo sujo* (shrub savanna), *campo úmido* (wet savanna), *campo cerrado* (savanna woodland) and *campo limpo* (grassland), complemented by fragments of *cerrado stricto sensu* (woodland), riverine forests and *cerradão* (tall woodland) (INSTITUTO FLORESTAL DO ESTADO DE SÃO PAULO, 2006). These areas are found in Corumbataí-Botucatu-Tejupá Environmental Protection Area and, part in the Itirapina Ecological Station (São Paulo state), playing a fundamental role in the preservation of the phytophysiognomies and the fauna-flora genetic patrimony.

The predominant landscape configures in agricultural activities, urbanized areas and native vegetation fragments. According to Tundisi et al. (2003), the pollutant loads generated by these activities get in the aquatic systems by diffuse forms and are characterized by high concentration of phosphorus and nitrogen.

2.2 Map data collection

The spatial data used in this study were obtained from the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE) and the United States Geological Survey (USGS). For the cartographic base were used:

- Topographic maps of the Itirapina city (SF-23-M-1-3) and São Carlos city (SF-23-Y-A-1) in 1:50,000 scale (IBGE, 1969; 1971) and;
- Images from the Landsat 5 satellite for the year 1985 and from the Landsat 8 for the year 2017, available on USGS.

All the cartographic information was inserted, processed and analyzed in Geographic Information System (GIS) environment, using ArcGis 10.3 software. The geodetic reference system adopted was SIRGAS 2000, Universal Transversa de Mercator (UTM), South 23 Zone.

2.3 Study area drainage network and delimitation

The limit of the study area was obtained in the Paulista Environmental System (Sistema Ambiental Paulista - DataGeo). The drainage network was drawn from the vectorization of the topographic maps of the municipalities of Itirapina (SF-23-M-1-3) and São Carlos (SF-23-YAI-1), within the area of the LSDB.

2.4 Land use

For the land use map elaboration, it was used the sensors images: (i) Thematic Mapper (TM) and Enhanced Thematic Mapper (EMT) (Landsat 5) with seven spectral bands, dated July 9, 1985; (ii) and Operational Land Imager (OLI) and Thermal InfraRed Sensor (TIRS) (Landsat 8), with ten spectral bands of 30 meters spatial resolution and one spectral band of 15 meters spatial resolution (OLI panchromatic band 8), dated July 15, 2017.

The land use characterization was generated from manual digitizing in GIS environment, where the satellite images were read to identify the elements in terrestrial surface. To do so, the reference of land use classes was taken from the Land Use Technical Manual of the Brazilian Institute of Geography and Statistics (INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA, 2013). This system classifies the land use in 3 levels, being the first level (level I) more general and the level III more detailed.

2.5 Environmental Quality Index of Water Resources

The EQI-Hydro index reflects the water resources vulnerability front to the impactful sources of pollution from anthropic activities on the landscape (MOSCHINI, 2008). In this case, the Euclidean distance between the water bodies and the pollution sources (land use types) are analyzed, and the closer the water body is to the pollution sources, greater the contamination risk. For this analysis, the drainage network and pollution sources were identified, reclassified and processed using the ArcMap 10.3 distance module.

Afterwards, the generated data were again scaled, using the linear function type [y = f (x)] by means of the fuzzy logic, with values from zero to one (MARRO et al., 2010). This procedure was performed through the ArcMap 10.3 Fuzzy Membership tool.

The pollution potential determination varies within zero to one scale, indicating the environmental quality level. Thus, areas with zero values (EQI-Hydro = 0) or close to zero, represent a minimum degree of environmental quality, indicating the proximity between pollution sources and water bodies. While, areas with values one (EQI-Hydro = 1) or close to one, represent a maximum degree of environmental quality, indicating the gradual distance between pollution sources and water bodies. Subsequently, the data were reclassified into five categories, according to the water pollution risks (Table 1).

Table 1 - The water resources vulnerability classification front to the impactful sources of pollution

Fuzzy logic values	EQI-Hydro
0.0 – 0.20	Very High
0.20 – 0.40	High
0.40 – 0.60	Medium
0.60 – 0.80	Low
0.80 – 1.00	Very Low

3 Results and Discussion

At first, the changes in land use from spatial-time analysis in the LSDB between 1985 and 2017, leads to discussion on the anthropic activities impacts in water bodies. Then, the changes in EQI-Hydro were analyzed and compared with the observed alterations.

3.1 Temporal analysis of land use and occupation

The different classes of land use and the respective areas and percentages for the years 1985 and 2017 are presented in Table 2. Thirteen land use classes for the analyzed period were identified and are spatially distributed in Figure 2.

The data presented in Table 2 shows that the activities of agriculture, sugarcane, citrus culture, pasture and planted forest increased together 15.20 km^2 during the analyzed period, representing 6.86% of the basin total area. Currently, these activities occupy approximately 65% of the basin total area and are responsible for changes in the landscape. These changes modify the floodplain regions and native vegetation, in this form, increasing the risk of impact on water bodies.

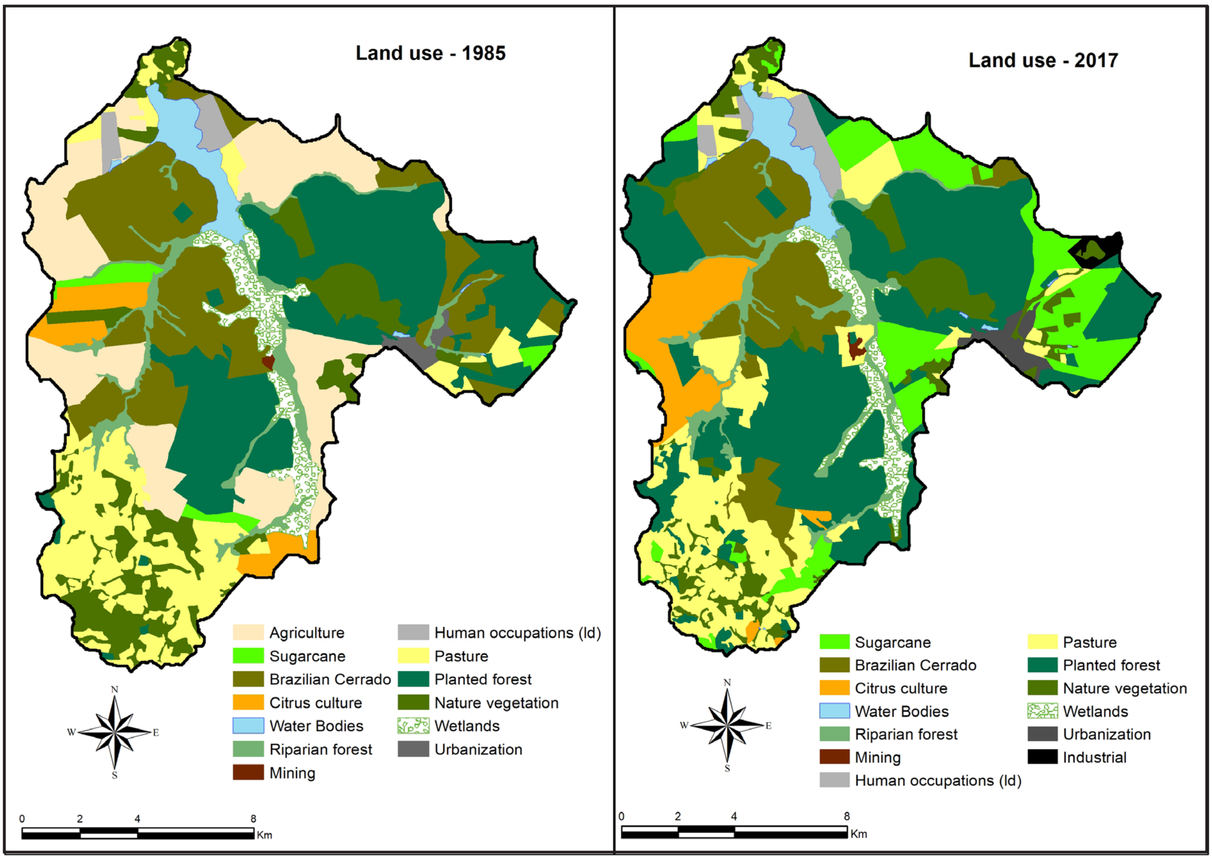
The most representative activity is planted forest, which is the largest occupation area for the two years analyzed, with approximately 50 km^2 in 1985 and 73 km^2 in 2017, corresponding to an increase of more than 10%. Currently, this activity occupies more than 33% of the basin total area. The expressive presence of planted forest activity occurs mainly in the protected area of the Itirapina Experimental Station, managed by the Forest Institute of São Paulo State. The activities are focused on forest production, nature conservation, serving as well as study area for scientific research. (INSTITUTO FLORESTAL DO ESTADO DE SÃO PAULO, 2006).

The pasture activity also stood out as the second largest anthropized area in the analyzed periods, with approximately 30 km^2 in 1985, increasing its territory by 1% by the year 2017. Currently, this activity occupies almost 15% of the total study area. The pasture in the region is characterized by extensive cattle ranching with the use of undergrowth, mostly grasses. Considering the geographical distribution of this activity, the pasture areas are present in the Itaqueri and Lobo rivers spring areas, probably negatively impacting the quality of the

Table 2 - Changes in land use between the years 1985 and 2017, in the Lobo watershed

Land use	1985		2017		Change
	(km²)	(%)	(km²)	(%)	(%)
Agriculture	38.28	17.28	-	-	- 17.28
Industry	-	-	1.13	0.51	+ 0.51
Wetland	8.99	4.06	7.57	3.42	- 0.64
Urbanization	1.58	0.71	2.72	1.23	+ 0.52
Sugarcane	3.33	1.50	25.36	11.45	+ 9.95
Brazilian *Cerrado*	40.15	18.13	27.84	12.57	- 5.55
Citrus culture	7.06	3.19	13.33	6.02	+ 2.83
Water Bodies	5.95	2.68	5.95	2.7	+ 0.02
Riparian forest	9.56	4.32	9.95	4.49	+ 0.18
Mining	0.15	0.07	0.29	0.13	+ 0.06
Human occupations (ld*)	2.73	1.23	4.22	1.90	+ 0.67
Pasture	29.86	13.48	32.14	14.51	+ 1.03
Planted forest	50.44	22.77	73.34	33.11	+ 10.39
Nature vegetation	23.42	10.57	17.61	7.95	- 2.62

Figure 2 - Changes in land use between the years 1985 and 2017, in the Lobo watershed



*ld = low density

water, due to the intensification of sediment production (JUNIOR, 2013) and nutrient concentration (ANJINHO, 2019).

In the land use maps (Figure 2) of the analyzed years, the sugarcane activity expansion was verified in the east portion of the LSDB, in the Itaqueri river right bank and near the Lobo reservoir. This activity, in 1985, was restricted to small fragments scattered in the LSDB, however, there was an increase of almost 10% until the year 2017. Currently, sugarcane is developed in more than 11% of the LSDB. The land use change to this activity can cause impacts on water bodies, through inadequate use of fertilizers and agricultural inputs (LOPES SOARES; PORTO, 2007; MAHVI et al., 2005; BRUNINI et al., 2017), which can reach the water bodies.

During the analyzed period, it was observed an increase in citrus production, which doubled the occupation area. This increase occurred mainly in the proximity of the Itaqueri river springs and in the Lobo river left bank (Figure 2), occupying more than 6% of the total study area. According to Argenton (2004), orange cultivation in the region requires a considerable quantity of agrochemicals, which, in turn, end up being carried out to the aquatic environment through soil leaching.

The human occupations of low density are installed in the areas surrounding the Lobo reservoir, which can negatively influence water quality due to diffuse pollution. Part of this area is characterized as one of the main tourist attractions of the region (Balneário Santo Antônio), and it is estimated that approximately 35 thousand people are received during some holidays (QUEIROZ, 2000). Although it covers a small area in the LSDB (almost 2% in 2017), this occupation can cause negative impacts on water resources, mainly on the Lobo reservoir, as already reported in several studies (QUEIROZ, 2000; TUNDISI et al., 2003).

The urban area corresponds to Itirapina city, located in the east region of the LSDB, near the Itirapina Experimental Station. This occupation type is characterized as the main pollution source of the LSDB, due to the point source pollution originated from the sewage treatment station that releases effluents in the Água Branca stream, which in turn flows into the Itaqueri river and by sequence to the Lobo reservoir. Over the years, several studies have highlighted the negative effects of the treatment station effluents on waters quality of the LSDB (MATHEUS; TUNDISI, 1988; ARGENTON, 2004; JUNIOR, 2013; ANJINHO, 2019).

The industrial activity can only be observed in the year 2017, since there is an automobile factory in installation phase. It is important to emphasize that the economic characteristic of the region are rural and touristic activities, however, gradually other types of activity are being installed in the LSDB.

The mining activity installed in the Itaqueri river floodplain is characterized by sand extraction for use in metallurgy and civil construction. This activity has direct negative impacts on the Itaqueri river quality and, consequently, in the Lobo reservoir. According to Argenton (2004), mining is related to the contamination of water and sediment by toxic substances and silting process of the Itaqueri river mouth. In addition, environmental impacts on river dynamics may also occur (PADMALAL et al., 2007; RINALDI et al., 2005; LUSIAGUSTIN; KUSRATMOKO, 2017).

The natural areas characterized by wetlands, Brazilian Cerrado, riparian forest and natural vegetation, together lost more than 19 km^2 in the analyzed period, which corresponds to almost 9%. Currently, natural areas occupy approximately 28.5% of the LSDB. These areas are fragments in the Itaqueri and Lobo rivers spring, and in the Ecological Station of Itirapina region, which plays a fundamental role in the region environmental preservation. According to Tundisi and Matsumura-Tundisi (2016), the mosaic of natural vegetation fragments, and other natural areas of this region, are important for nutrients and other pollutants control that are deposited in the Lobo reservoir and are, therefore, essential for the water quality maintenance of the whole watershed.

3.2 Analysis of changes in EQI-Hydro

The spatial distribution of EQI-Hydro classes in the LSDB is presented in Figure 3, and Table 3 shows the quantified area of each class. The results show that the EQI-Hydro classes high and very high are the largest areas of the LSDB. These classes increased more than 7% during the analyzed period, which corresponds to an area of 15.83 km^2. In 2017, the EQI-Hydro classes high and very high occupied 57% of LSDB and occur near riparian regions of the water courses. These classes represent areas where distances between impacting sources and water bodies are minimal or non-existent. The main human activities responsible for these classes, and that can alter the water quality of the LSDB, are agricultural activities, especially the sugarcane crops located in the eastern portion of the LSDB, in places with low natural vegetation cover, where the water courses are more vulnerable to pollution.

The areas classified as medium water pollution risk (EQI-Hydro = medium) are found in small portions in the LSDB, located near the watershed dividers and in the Itaqueri river and Lobo river high lands. This class had an increase of 3.41 km^2 from 1985 to 2017, which corresponds to 1.54% of the LSDB. In 2017, 8.83% of the LSDB area was classified as medium risk to water pollution. The main anthropogenic activities that occur in these areas are silviculture, sugarcane, and citrus crop.

The very low and low class represents the greatest distances between anthropic activities and water bodies. These classes are in the Itaqueri river and Lobo river high lands of the two analyzed years, near the district of Itaqueri da Serra. The results show a decrease of 0.05% between 1985 and 2017, which corresponds to 0.11 km^2. In 2017, the areas classified as very low and low water pollution risk occupied a small area in the LSDB (7.44 km^2), representing almost 3.5% of the LSDB. The land uses occurring in these areas are silviculture and pasture, which are activities with low potential for water pollution compared to agricultural crops.

Figure 3 - Changes in the EQI-Hydro spatial setting in the years 1985 and 2017, in the Lobo watershed

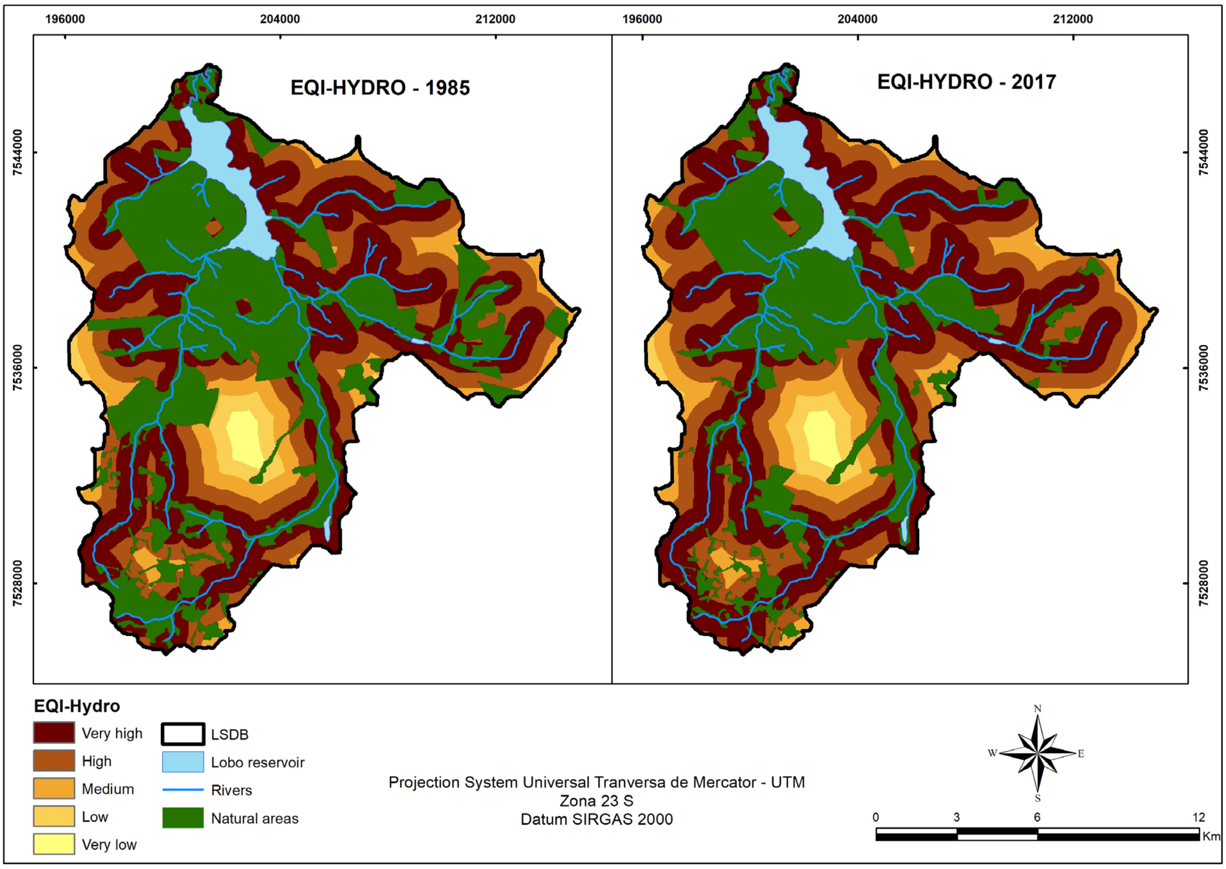


Table 3 - EQI-Hydro percentage values in the years 1985, 2017 and the changes in the period, in the Lobo watershed

EQI-Hydro Classification	1985 (%)	2017 (%)	Change (%)
Very low	0.96	0.94	- 0.01
Low	2.45	2.42	- 0.03
Medium	7.29	8,83	+ 1.54
High	20.01	22.57	+ 2.56
Very high	29.53	34.12	+ 4.59
Natural areas	37.08	28.44	- 8.65
Water Bodies	2.69	2.69	0

The results of this work showed that the LSDB still presents an appropriate condition for water conservation when compared to other sites near LSDB. Most studies found in the literature that used the same method of this study found a worrying situation regarding the risk of pollution of water resources, indicating high vulnerability due to the proximity to the sources of pollution (MOSCHINI, 2008; DA SILVA et al., 2017; DE SOUZA, 2017).

3.3 Method evaluation

In this work, we use a simple method to assess the risk to water pollution, by analyzing the distance between impacting sources and the LSDB drainage network. The use of this method made it possible to identify areas of greater risk for water pollution due to the proximity of pollution sources, quantified through the map of land use. However, some limitations were observed in the use of EQI-Hydro.

The approach used in the determination of EQI-Hydro considers only the land use to analyze the vulnerability of water resources to environmental pollution. Although the change in land use is an relevant factor that can alter the quality of the water resources (SIMEDO et al., 2018; JAMES et al., 2019; PETLUŠOVÁ et al., 2019), it is important to emphasize that other variables are also fundamental in the process, such as the hydrological and biophysical characteristics of the region of interest (ALILOU et al., 2019).

In addition, the sources of pollution identified through land use do not have the same potential to pollute water resources. Areas of sugarcane cultivation, for example, may present a greater risk of water degradation when compared to areas of silviculture or pasture, due to intensive use of machinery and agricultural inputs. The distinction between the polluting potential of the classes of land use, similar to the approach of Mazzuco and Lorandi (2018), is important to improve the EQI-Hydro method.

Although considering the limitations described above, the methodology was consistent with the current state of the LSDB. Compared with other regions of the state of São Paulo, the LSDB still presents an expressive percentage of natural vegetation areas, approximately 30%, as shown by the results of 2017. The basin is inserted within the limits of the Environmental Protection Area of Corumbataí-Botucatu-Tejupá, and covers the Ecological Station of Itirapina, an important reserve destined to preserve the Cerrado biome in the state of São Paulo (INSTITUTO FLORESTAL DO ESTADO DE SÃO PAULO, 2006). Very low to medium EQI-Hydro areas, which represent a lower risk to water quality, correspond to about 12% (2017), which summed up with the natural areas represent 40% of the LSDB, indicating a situation favorable to the conservation of the water resources. A recent study by Anjinho (2019) showed that the waters of the basin are little impacted by anthropic activities, where most of the analyzed parameters were within the reference values established by Conama Resolution 357/2005 for rivers of class 2. The author also evaluated the trophic state of the LSDB main hydrography and most of the analyzed sections were classified in intermediate classes of trophy.

4 Final Considerations

The spatial analysis developed in this work, through geoprocessing tools, proved to be an easy and simple tool to identify high risk areas for water pollution, assisting the implementation of strategies and actions for water resources management.

The analysis of land use over time has shown an intensification in anthropic activities in the LSDB, mainly in the silviculture and sugarcane areas. The sugarcane expansion follows the same tendency in other regions of the state of São Paulo, which, since the 1970 decade, with the advent of the PRÓALCOOL program, has been progressively increased over the years.

EQI-Hydro has made it possible to perform a rapid diagnosis of the vulnerability of water resources to impacting sources. The analysis showed that the basin is altered by human activities, and approximately 57% of the study area is in the highest risk classes for water pollution (high and very high EQI-Hydro). The Itaqueri River and Água Branca Stream are the most vulnerable of the LSDB due to their proximity to urban areas and sugarcane crops.

Despite the limitations of the methodology used, it can be concluded that the results generated were satisfactory for the LSDB. The results presented in this study can support the selection of priority areas for monitoring water quality, by means of identificating the areas that presents the greatest risk to environmental pollution, therefore optimizing the available financial resources. Since this methodology have the low data requirements and simple operation, it can be replicated in any drainage basin, especially in non-instrumented watershed or with low data availability.

Acknowledgment

To National Council of Scientific and Technological Development (CNPq) and Coordination for the Improvement of Higher Education Personne (CAPES) for granting scholarships to authors, and the Center of Water Resources and Environmental Studies (CRHEA), University of São Paulo, for the structure offered.

References

ALMEIDA, F.F.M. Fundamentos geológicos do relevo paulista. Boletim do Instituo Geográfico e Geológico, n.41, São Paulo, 1964.

ALILOU, H et al. A novel approach for selecting sampling points locations to river water quality monitoring in data-scarce regions. **Journal of Hydrology**, v. 573, p. 109-122, 2019.

ANJINHO, P. S. Modelagem distribuída da poluição pontual e difusa dos sistemas hídricos da bacia hidrográfica do ribeirão do Lobo, Itirapina-SP. Dissertação (Mestrado). Universidade de São Paulo, São Carlos, 135 p, 2019.

ARGENTON, É C. Limnologia, balneabilidade e impactos ambientais: uma análise temporal e espacial na represa do Lobo (Broa), Itirapina/Brotas-SP. Dissertação (Mestrado). Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos, 159 p, 2004.

ARNOLD, J. G. et al. Large area hydrologic modeling and assessment part I: model development 1. JAWRA **Journal of the American Water Resources Association**, v. 34, n. 1, p. 73-89, 1998.

BRASIL. Conselho Nacional do Meio Ambiente (CONAMA). Resolução Nº 357 de 17 de março de 2005. Dispõe sobre a classificação dos corpos de água e diretrizes ambientais para o seu enquadramento, bem como estabelece as condições e parâmetros de lançamento de efluentes, e dá outras providências. Diário Oficial da União, DF, 19/03/2005.

BOJÓRQUEZ-TAPIA, L. A.; JUÁREZ, L.; CRUZ-BELLO, G. Integrating fuzzy logic, optmization and GIS fpr ecological impact assessments. **Environmental Management**, v. 30, p. 418-433, 2002.

BRUNINI, R. G.; DA SILVA, M. C.; PISSARRA, T. C. T. Efeito do Sistema de Produção de Cana-de-Açúcar na Qualidade da Água em Bacias Hidrográficas. **Agrarian**, v. 10, n. 36, p. 170-180, 2017.

CALIJURI, M. L. et al. Impact of land use/land cover changes on water quality and hydrological behavior of an agricultural subwatershed. **Environmental Earth Sciences**, v. 74, n. 6, p. 5373–5382, 1 set. 2015.

CANTER, L. W. **Environmental Impact Assessment.** 2d. ed. [s.l.] McGraw-Hill International Editions, New York, 1996.

CENTRO DE PESQUISAS METEOROLÓGICAS E CLIMÁTICAS APLICADA À AGRICULTURA (CEPAGRI). Universidade Estadual de Campinas. Disponível em: http://www.cepagri.unicamp.br/. Acesso em: 27 out. 2017.

DA SILVA, F. L et al. Naturalidade da Paisagem Verificada por Meio de Indicadores Ambientais: Manancial do Rio Monjolinho, São Carlos-SP. **Revista Brasileira de Geografia Física**, v. 10, n. 3, p. 970-980, 2017.

DE SOUZA, B. F et al. Avaliação da qualidade dos corpos hídricos frente ás ações antrópicas no município de Santa Lúcia-SP (Quality assessment of water corpuses front the anthropic actions in the municipality of Santa Lucia-SP). **Revista Brasileira de Geografia Física**, v. 10, n. 1, p. 317-331.

GUERRA, A. J. T.; CUNHA, S. B. Geomorfologia e meio ambiente. Bertrand, Brasil, Rio de Janeiro, 1996.

HUANG, J.; HONG, H. Comparative study of two models to simulate diffuse nitrogen and phosphorus pollution in a medium-sized watershed, southeast China. Estuarine, **Coastal and Shelf Science**, v. 86, n. 3, p. 387-394, 2010.

INSTITUTO AGRONÔMICO DE CAMPINAS (IAC). Carta pedológica da quadrícula de São Carlos (SF-23-Y-A-1). 1981. 1:100000.

INSTITUTO FLORESTAL DO ESTADO DE SÃO PAULO (IF). Plano de Manejo Integrado das Estações Ecológica e Experimetnal de Itirapina/SP, 2006.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). Folha Topográfca de Itirapina (SF-23-M-1-3). 1969. Escala 1:50000.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). Folha Topográfca de São Carlos (SF-23-Y-A-I-1). 1971. Escala 1:50000.

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). Manual Técnico de Uso da Terra. 3ª ed. Rio de Janeiro: Diretoria de Geociências, 2013.

JAMES, J. N et al. Land use change alters the radiocarbon age and composition of soil and water-soluble organic matter in the Brazilian Cerrado. **Geoderma**, v. 345, p. 38-50, 2019.

JUNIOR, A. P. P. **Avaliação da produção e transporte de sedimentos na bacia hidrográfica do rio Itaqueri, municípios de Itirapina e Brotas-SP**. USP. Dissertação (Mestrado). Escola de Engenharia de São Carlos. Universidade de São Paulo, São Carlos, 112 p, 2013.

LI, H.; WU, J. Use and misuse of landscape indices. **Landscape ecology**, v. 19, n. 4, p. 389-399, 2004.

LOPES SOARES, W.; PORTO, M. F. Atividade agrícola e externalidade ambiental: uma análise a partir do uso de agrotóxicos no cerrado brasileiro. **Ciência & Saúde Coletiva**, v. 12, n. 1, 2007.

LUSIAGUSTIN, V.; KUSRATMOKO, E. Impact of sand mining activities on the environmental condition of the Komering river, South Sumatera. In: AIP Conference Proceedings. AIP Publishing, 2017. p. 030198.

MAHVI, A. H.; NOURI, J.; BABAEI, A. A.; NABIZADEH, R. Agricultural Activities Impact on Groundwater Nitrate Pollution. **International Journal of Environmental Science & Technology**, v. 2, n. 1, p. 41–47, 1 mar. 2005.

MARRO, A. A et al. Lógica fuzzy: conceitos e aplicações. Natal: Universidade Federal do Rio Grande do Norte (UFRN), p. 1-23, 2010.

MATHEUS, C. E.; TUNDISI, J. G. Estudo físico químico e ecológico dos rios da bacia hidrográfica do Ribeirão e represa do Lobo. Limnologia e Ecologia de Represas. (JG Tundisi, ed.). ACIESP, p. 419–472, 1988.

MAZZUCO, G. G.; LORANDI, R. Impactos ambientais negativos das atividades antrópicas na qualidade das águas superficiais da sub-bacia do ribeirão dos toledos: aplicação do IQA-Hidro. 8º Congresso Luso –Brasileiro para o planejamento urbano, regional, integrado e sustentável, Coimbra, Portugal, 2018.

MOSCHINI, L. M. **Zoneamento Ambiental da Bacia Hidrográfica do Médio Mogi-Guaçu Superior.** UFSCar. Tese de Doutorado. Universidade Federal de São Carlos, São Carlos, 149 p, 2008.

MISHRA, V. N.; RAI, P. K. A remote sensing aided multi-layer perceptron-Markov chain analysis for land use and land cover change prediction in Patna district (Bihar), **India. Arabian Journal of Geosciences**, v. 9, n. 4, p. 249, 24 mar. 2016.

NISHIYAMA, L. **Mapeamento geotécnico preliminar da quadrícula de São Carlos, SP.** Dissertação (Mestrado). Geotecnia, EESC/USP, São Carlos. 228 p, 1991.

O'NEILL, R. V et al. Indices of landscape pattern. Landscape Ecology, v. 1, n. 3, p. 153-162, 1988.

PADMALAL, D. et al. Environmental effects of river sand mining: a case from the river catchments of Vembanad lake, Southwest coast of India. Environmental geology, v. 54, n. 4, p. 879-889, 2008.

PETLUŠOVÁ, V et al. Effect of Landscape Use on Water Quality of the Žitava River. Ekológia (Bratislava), v. 38, n. 1, p. 11-24, 2019.

QUEIROZ, O. T. M. M. Impactos das atividades turísticas em área de reservatório: uma avaliação sócio-ambiental do uso e da ocupação na área da Represa do Lobo, município de Itirapina, SP. 2000. Tese (Doutorado). Escola de Engenharia de São Carlos. Universidade de São Paulo, São Carlos, 2000.

RINALDI, M.; WYŻGA, B.; SURIAN, N. Sediment mining in alluvial channels: physical effects and management perspectives. River research and applications, v. 21, n. 7, p. 805-828, 2005.

SCHUMAKER, N. H. Using Landscape índices to predict habitat connectivity. Ecology, v. 77, n. 4, p. 1210-1225, 1996.

SIMEDO, M. B. L et al. Effect of watershed land use on water quality: a case study in Córrego da Olaria Basin, São Paulo State, Brazil. Brazilian Journal of Biology, v. 78, n. 4, p. 625-635, 2018.

TREVISAN, D. P.; MOSCHINI, L. E. Dinâmica de Uso e Cobertura da Terra em Paisagem no Interior do Estado de São Paulo: Subsídios para o planejamento. Fronteiras: Journal of Social, Technological and Environmental Science, v. 4, n. 3, p. 16, 20 dez. 2015.

TREVISAN, D. P.; MOSCHINI, L. E. Avaliação da sustentabilidade ecológica do município de São Carlos, São Paulo. Boletim de Geografia, v. 35, n. 1, p. 95-111, 2017.

TREVISAN, D. P.; MOSCHINI, L. E.; GUERRERO, J. V. R. Dinâmica Temporal do Uso e Cobertura da terra no município de Brotas-SP entre os anos de 1988 e 2016. pdf. Fronteiras: Journal of Social, Technological and Environmental Science, Edição Especial. v. 06, n. 04, p. 204–219, 2017.

TUNDISI, J.; MATSUMURA-TUNDISI, T.; RODRIGUES, S. Gerenciamento e Recuperação das Bacias Hidrográficas dos Rios Itaqueri e do Lobo e da UHE Carlos Botelho (Lobo-Broa) -Municípios de Itirapina e de Brotas. São Carlos: Rima Artes e Textos, 2003.

TUNDISI, J. G.; MATSUMURA-TUNDISI, T. The ecology of UHE Carlos Botelho (Lobo-Broa Reservoir) and its watershed, São Paulo, Brazil. Freshwater Reviews, v. 6, n. 2, p. 75–91, 1 dez. 2013.

TUNDISI, J. G.; TUNDISI, T. M. Integrating ecohydrology, water management, and watershed economy: Case studies from Brazil. Ecohydrology & Hydrobiology, v. 16, n. 2, p. 83-91, 2016.

TURNER, M. G. Spatial simulation of landscape changes in Georgia: a comparison of 3 transition models. Landscape Ecology, v. 1, n. 1, p. 29-36, 1987.

TURNER, M. G.; GARDNER, R. H. Quantitative methods in landscape ecology. New York, NY: Springer Verlag, New York, NY, USA, 1991.

UNITED STATES GEOLOGICAL SURVEY (USGS). Imagens LANDSAT 5. http://earthexplorer.usgs.gov/. Accessed: 17 Oct 2017.

UNITED STATES GEOLOGICAL SURVEY (USGS). Imagens LANDSAT 5. http://earthexplorer.usgs.gov/. Accessed: 17 Oct 2017.

XIANG, C.; WANG, Y.; LIU, H. A scientometrics review on nonpoint source pollution research. Ecological Engineering, v. 99, p. 400-408, 2017.