

**Evaluation of areas with environmental vulnerability in the Rio Claro hydrographic basin, SP – Brazil****Avaliação de áreas com vulnerabilidade ambiental na bacia hidrográfica do Rio Claro, SP - Brasil**

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**ABSTRACT**

The environmental vulnerability study is one of the most important ways to analyze the anthropic pressures that occur in the physical and biological environment. In this context, the aim of this work is to evaluate the areas with environmental vulnerability in the Rio Claro Hydrographic Basin in 2001 and 2017, using physical and biological factors. The hydrographic basin has 251.91km<sup>2</sup> and is localized in the Santa Rita do Passa Quatro (SP). The analysis was carried out addressing the physical attributes (slope, geology, unconsolidated materials, and aquifer units) and biological attributes with use and land cover for 2001 and 2017. The methodology was based on the environmental characterization and standardization of the information through the Fuzzy logic, processed in ArcGIS 10.5 software. The data were classified into five levels of environmental vulnerability (very low, low, medium, high and very high). For both periods, the most evident levels were the low, medium and high vulnerability, occupying over 70%. The method employed in this work allowed the evaluation of the environmental vulnerability in the Rio Claro Hydrographic Basin and made possible the definition of the regions that suffered interference due to the influence of the anthropic activities in the physical and biological environment, as well as of the different activities that occurred in the region.

**Keywords:** Anthropogenic Activities, Environmental planning, Fragility, Fuzzy Logic, GIS.

**RESUMO**

O estudo de vulnerabilidade ambiental é uma das formas mais importantes para analisar as pressões antrópicas que ocorrem no ambiente físico e biológico. Nesse contexto, o objetivo deste trabalho é avaliar as áreas com vulnerabilidade ambiental na Bacia Hidrográfica de Rio Claro em 2001 e 2017, utilizando fatores físicos e biológicos. A bacia hidrográfica possui 251,91 km<sup>2</sup> e está localizada em

Santa Rita do Passa Quatro (SP). A análise foi realizada abordando os atributos físicos (declividade, geologia, materiais não consolidados e unidades aquíferas) e atributos biológicos, com uso e cobertura do solo para 2001 e 2017. A metodologia baseou-se na caracterização e padronização ambiental das informações por meio da Lógica Fuzzy, processada no software ArcGis 10.5. Os dados foram classificados em cinco níveis de vulnerabilidade ambiental (muito baixa, baixa, média, alta e muito alta). Para ambos os períodos, os níveis mais evidentes foram a baixa, média e alta vulnerabilidade, ocupando mais de 70%. O método empregado neste trabalho permitiu a avaliação da vulnerabilidade ambiental na Bacia Hidrográfica Rio Claro e possibilitou a definição das regiões que sofreram interferências devido à influência das atividades antrópicas no ambiente físico e biológico, bem como das diferentes atividades que ocorreram na região.

**Palavras-chave:** Atividades antrópicas, Planejamento ambiental, Fragilidade, Lógica Difusa, SIG

## 1 INTRODUCTION

Land use has been changed by anthropogenic influences as good manufacturing and urbanization process (DEFRIES; FOLEY; ASNER, 2004; NEWBOLD, 2015). The planning actions without management focused in decrease the damage transformation on the landscape could modify important ecological functions, such as water resources quality, biodiversity sustainability, maintenance of soil fertility (LEE et al., 2009; ZHAO et al., 2015). Hence, ecological zoning is used for land use and land cover planning to show landscape fragility and it is potential (FURLAN; BONOTTO; GUMIERE, 2011; Li, 2017).

According to the Brazilian Ministry of the Environment (MMA, 2017), the concept of environmental vulnerability is defined as the susceptibility degree in which an attribute of the environment, between a set of components and a landscape, offers a response to a certain type of anthropogenic action. In this method, investigations about ecological systems are aimed, where environmental planning and management need to be considered in a multidisciplinary aspect with the objective of sustainable development.

The common impacts of land use in a catchment basin are erosion and soil loss (GESSESSE; BEWKET; BRÄUNING, 2015), caused mainly by deforestation. Also, water resources contamination by fertilization and agricultural defensives are recurrent (CONNOLLY et al., 2015). The environmental vulnerability in these areas must consider some attributes like soil characteristics, permeability, erosion susceptibility and the distance of water sources and groundwater in relation to possible agricultural or urban developed practices.

In the Rio Claro Hydrographic Basin (RCW), as São Paulo state as a whole, there is a high predominance of agricultural activities, mainly by sugarcane, being the largest producer of sugarcane in Brazil (NATALE NETTO, 2007; Martini et al., 2018). However, there no information

about the impacts of these advances on natural ecosystems, as well as on the environmental quality of these regions, their potentials, and vulnerabilities.

In Brazil, one of the most effective ways to manage integrated regional planning is through the Water Resources Management Units (WRMU) and river basin committees and the environmental vulnerability based on watersheds is widely used (FURLAN; BONOTTO; GUMIERE, 2011; LIU et al., 2015). These areas have important ecosystem functions being a transition between terrestrial and aquatic systems (GREGORY et al., 1991; PETER, 2012). They also act on nutrient cycling conservation and landscape connection (ŞEKERCIOĞLU, 2015).

Several authors have been developing indices and descriptive measures of landscape spatial monitoring and environmental vulnerability (MORETTI, 2007, TREVISAN et al., 2016; REGO et al., 2018). The work of Nghyen and Liou (2019) presented the first global-scale map of quantified eco-environmental vulnerability by integrating remote sensing. The showed on a global scale, a small fraction of the globe (10.1%) is strongly (high and very high vulnerability) affected by influential factors. Among continents, the largest fraction of a very high vulnerability level is attributed to Asia (74.6%) followed by Africa (19.6%).

Remote Sensing and Geographic Information System (GIS) technologies have been improving the acquisition and the quality of the information on river basins facilitating water resources management and creating guidelines for proper management of land use (SMA, 2005; SAVIOUR, 2012; REICHERT et al., 2016). GIS approaches that contemplate ecological and social aspects have been used in different localities (DE FREITAS; TAGLIANI, 2009; HUNKE et al., 2015).

In this context, the aim of this work is to evaluate the areas with environmental vulnerability in the Rio Claro Hydrographic Basin in 2001 and 2017, using physical and biological factors.

## **2 MATERIAL AND METHODS**

### **2.1 STUDY AREA**

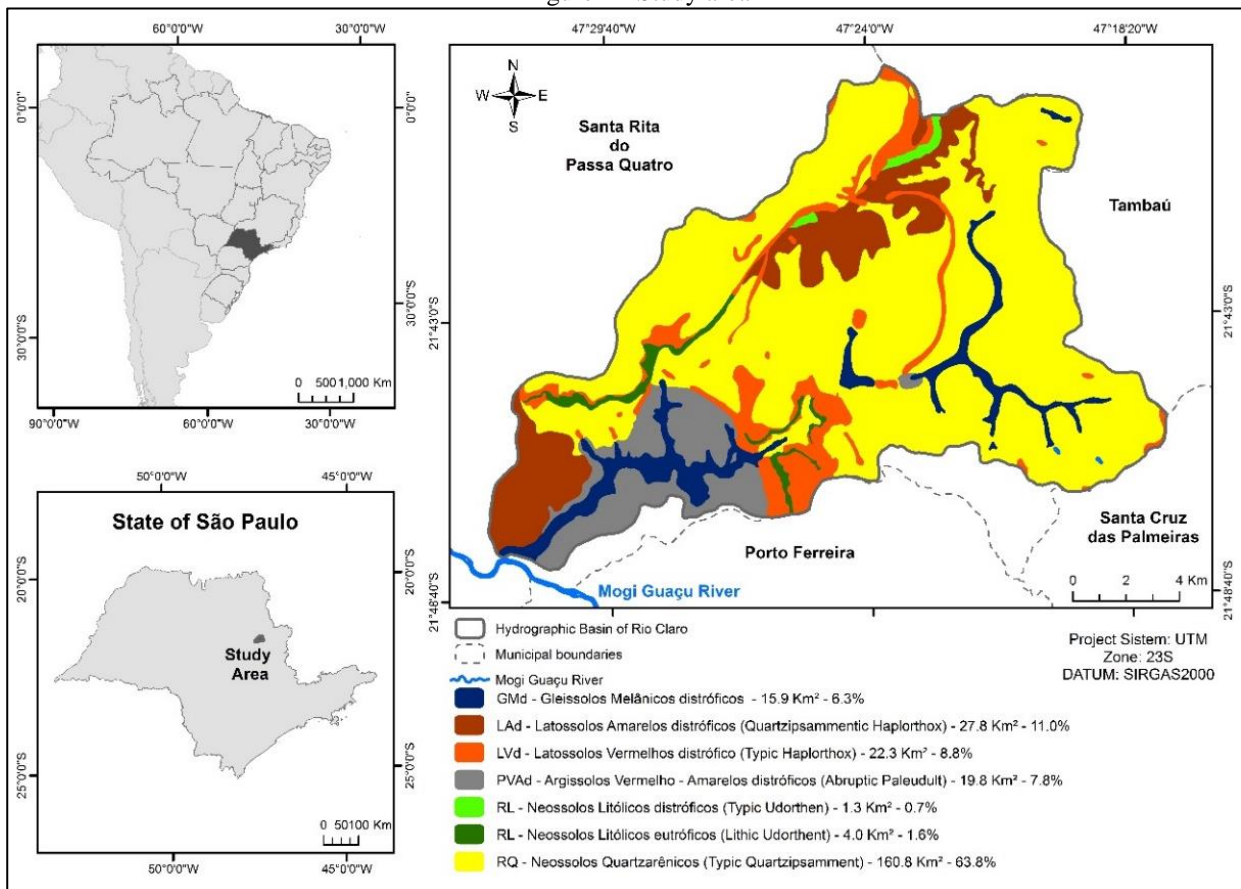
The RCW is located in the Santa Rita do Passa Quatro municipality between the coordinates 47,538946 - 47,292626 west longitude and 21,800682 - 21,632093 south latitude, at São Paulo State, Brazil (Figure 1). The Rio Claro River presents an average to a high density of drainage patterns and is classified as a fifth-order watershed (STRAHLER, 1952; MARQUEZOLA et al., 2016).

The river is a tributary of the Mogi-Guaçu River in the Paraná Basin, and it drains part of the south of Brazil. Mogi-Guaçu Watershed is a Unit for Water Resources Management - UGRHI 9 (in Portuguese) defined in 1994 by the State Law No. 9.034 of 12/27/1994 (SÃO PAULO, 1994).

The UGRHI is governed by the Mogi-Guaçu River Basin Committee (CBH-MOGI), installed on June 05/04/1996.

Santa Rita do Passa Quatro has a population of 26.397 and an extension of 251,91km<sup>2</sup> (IBGE, 2019). The regional climate is classified as Cwa (Köppen), with dry winter, between October and April, and moist summer, among May and September. The temperature ranges from 17.5°C to 23.5°C and the annual rainfall is 1506mm. The RCW is situated in one of the most important water source zones, the Guarani and the Serra Geral groundwater (CEPAGRI, 2018).

Figure 1 - Study area



Source: The authors

RCW morphology (Table 1) is in the peripheral depression of the Mogi-Guaçu River zone and is sculpted almost entirely by the Paleo-Mesozoic sediments of the basin (MARQUEZOLA, 2016). It is composed of hills with broad tabular tops, slope shapes average of 5 and 10% and dominant elevation between 500 e 650m. RCW land use is related to agribusiness activities like sugarcane, silviculture, and pastures. The development of these activities has replaced the natural land-cover, Brazilian semideciduous seasonal forests, Savannah (Cerrado), which has been increased the deforestation rate (MARQUEZOLA et al. 2016).

Table 1 - Geologic Formation of the Rio Claro Hydrographic Basin

Group Unit	Era Period	Description
Alluvial deposits (Qa)	Cenozoic; Holocene	They are represented by plains that occur along the Ribeirão do Meio valley and Taquari and Invernada stream. They are alluvial and colluvial sediments of sandy texture due to the contribution of the adjacent lithologies. It is common for the presence of organic matter in the superficial layers.
Piraçununga (Qdi_p) and Santa Rita do Passa Quatro (Qdi_sr) formations	Cenozoic; Pleistocene	Consisting of unconfined sandy sediments of continental origin, non-stratified and without structure, vertically homogeneous, overlapping indifferently to the earliest formations, on the basis of which pebble lines have sometimes been found. In terms of thickness, the Piraçununga formations reach 5m, while the Santa Rita do Passa Quatro thickness up to 20m.
São Bento; Basic Tabular Intrusives (Kδsg)	Mesozoic Cretaceous	They are regionally constituted of sills and dikes, presenting intensely fractured and dense appearance. In aerial photographs, they have dark gray shades, abrupt slopes, and preferential distribution. In the study area, they present dikes associated with normal faults in the western portion, while in the east they present themselves in the form of extensive sills.
São Bento; Botucatu formation (JKbt)	Mesozoic Jura/ Cretaceous	It is consisting of winding sandstones attributed to deposits in a desert environment, with fine to medium granulation particles and essentially quartzous composition (80%), the thickness varies between 20 and 280m. It has a large number of interconnected pores and a high capacity to store and supply water. In aerial photos, they present characteristics similar to those of the Pirambóia Formation.
São Bento; Pirambóia formation (PTp)	Mesozoic Triassic	Composed of fluvial whitish, yellowish and pinkish sandstones, medium to fine, sometimes quite clayey, due to stratigraphic positioning. In aerial photographs, they have light gray to white shades, with an underdeveloped drainage system with a dendritic pattern.
Passa Dois; Corumbataí formation (PTc)	Paleozoic Permian	Composed, regionally, by variegated shales, being positioned between Irati (lower) and Pirambóia (upper) formations. In aerial photographs, print dark gray tones and high drainage density with a punctured pattern. The most expressive outcrops are found in the study area, distributed to the west and southwest of Pirassununga (SP).

Source: Adapted from IBGE (1998)

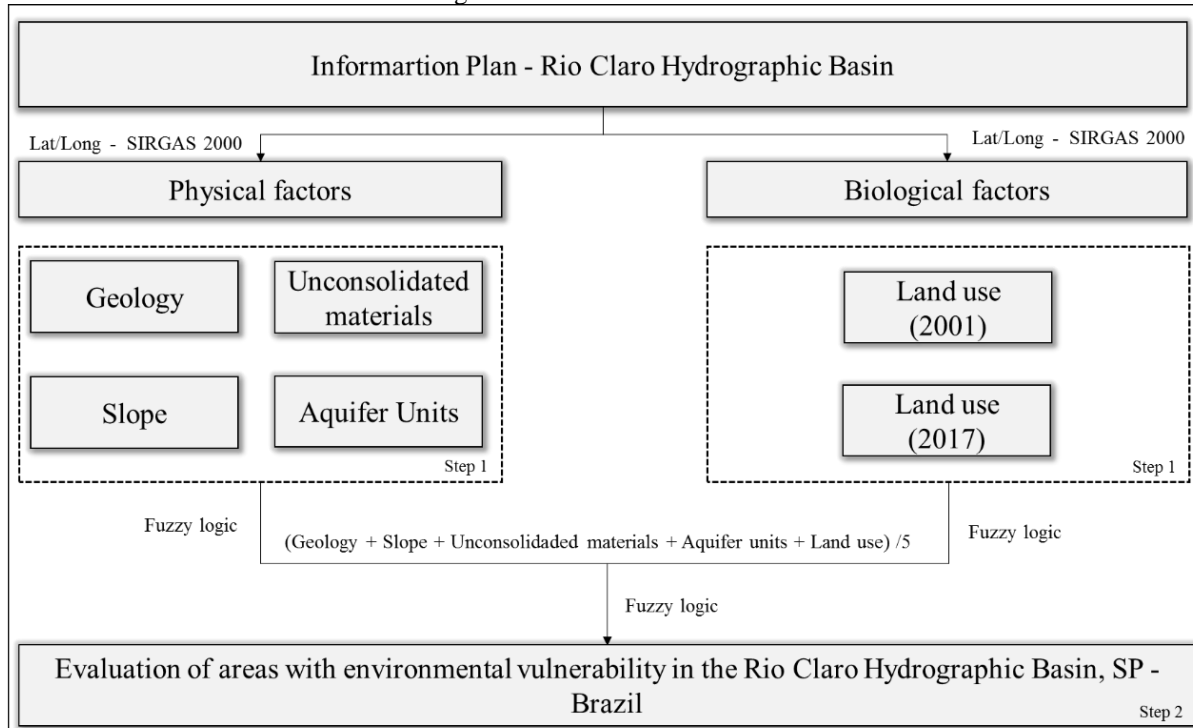
## 2.2 METHODOLOGY

Physical and biological attributes (Figure 2) were used to evaluate the areas with environmental vulnerability in the Rio Claro Hydrographic Basin. The data was performed with



ArcGIS 10.5, using the datum SIRGAS2000 and the Universal Transverse Mercator (UTM 23S) projection for all information plan, divided into two stages.

Figure 2 - Flowchart of activities



Source: The authors

In the first stage (Table 2), the acquisition of the database was made with physics aspects (aquifer units, slope shapes, soils, geological formation) and biological (use and land cover from 2001 and 2017).

Table 2 - Geo-environmental attributes/sources.

Data	Description	Source	Scale
Hydrography	Rivers	Topography charts (IBGE, 1971)	1:50.000
Aquifer units	Delimitation of the aquifer units	Aquifer Units Applied to Geo-Environmental Zoning (LORANDI et al., 2016)	
Slope shapes	Classes of slope	Topography charts (IBGE, 1971)	
Geology	Geological formations	Geology charts (LORANDI et al., 2016)	
Soils	Classes of soils	GUERRERO et al (2016)	
Land use - 2017	Classes of land use	Landsat 8 - sensor OLI/TIRS, bands 6/5/4. Orbit/point 220/75. Orbit/point 220/75. (USGS, 2017) April 23, 2017.	

Land use - 2001	Classes of land use	Landsat 5 - sensor TM, bands 5/4/3. Orbit/point 220/75. (USGS, 2017) March 23, 2017.	
Geomorphology	Relief forms	Geomorphometric database (TOPODATA, 2008)	1:250.000

Source: Authors

Land use was classified based on a multilevel system (IBGE, 2013) (Table 3). In the primary hierarchical level I four classes were included that indicate the main use and land cover categories. The secondary hierarchical level II analyzed the types of land uses that were included in the first level. The tertiary hierarchical level III explained the land uses themselves.

The periods of March and April were chosen due to the seasonality of the prevailing agricultural practices in the region. The time gap of 10 years between the images allowed the study of the temporal patterns of the landscape. The use of different satellite scenes occurred due to the unavailability of images by a single satellite during the study period. The scenes used for this study were worked in the same spatial resolution of 30 meters.

Table 3 - Land use hierarchical level.

Hierarchical level	Type	Description
Human activities non-agricultural	Urbanized zones	Area of urban densification and areas with rural facilities (industrial and domiciliary)
	Sugarcane	<i>Saccharum officinarum</i> L. tillage
Agriculture human activities	Citriculture and miscellaneous cultures	<i>Citros sinensis</i> , <i>Zea mays</i> , <i>Coffea arabica</i> L. e <i>Oryza sativa</i> . cultivation areas
	Cattle pastures	Areas with a predominance of grassy vegetation (native or exotic), used for extensive cattle
	Forestry	<i>Eucalyptus spp</i> or <i>Pinus spp</i> . cultivation areas
	Soil exposed	Areas between <i>Saccharum officinarum</i> L. plantation
Natural land-cover	Native land-cover	<i>Cerrado</i> (seasonal semideciduous forest) area.
Water	Water resources	Broad rivers, lakes, pond, and dams.

Source: Authors

In the second stage, the physical and biological variables were classified in accordance with their degree of vulnerability to anthropic intervention (Table 4), where all the environmental attributes received hierarchical weights in a 1 to 5 scale based on the study area knowledge.



Table 4 - Geo-environmental attributes/sources.

Attributes	Weights				
	Very high	High	Medium	Low	Very low
Aquifer units	Aluvial	Piraçununga Santa Rita do Passa Quatro	Botucatu Piramboia	Intrusivas básicas	Corumbataí
Slope	>30	20-30	12-20	6-12	0-6
Unconsolidated materials	Qa < 2m - Média Qa < 2m - Sandy Qa 2 a 5m - Sandy Qdi_p > 10m - Sandy PTp > 10m - Sandy Qdi_sr > 10m - Sandy	PTp - 5 a 10 m - Sandy Qdi_sr - 5 a 10 m - Sandy	JKbt < 2m - Sandy JKbt 5 a 10m - Sandy Kdsg - 2 a 5m - Medium Kdsg - 5 a 10m - Sandy	PTc 2 a 5m - Clay Kdsg < 2m - Medium Kdsg - 2 a 5m - Clay	PTc < 2m - Clay Kdsg < 2m - Clay
Geological Formation	Quaternário- Qa	Formação Santa Rita do Passa Quatro - Qdi_sr Piraçununga Formation - Qdip	Botucatu Formation - JKbt	Botucatu Formation - Ptp	Intrusivas básicas tabulares - Kdsg Corumbataí Formation - PTc
Land use (2001 and 2017)	Dams Vegetation	Urbanized rural area	Coffe / Silviculture Citriculture Pasture	Sugar cane	Mining Exposed soil Urban area

Source: Authors

The variables collected had different natures. Thus, to obtain comparability and adjustment of the data to a common scale of work, it was necessary to standardize the criteria. In this way, the spatial representation of the values obtained from the application of the proposed indexes was scaled based on fuzzy logic (FUZZY), of linear type  $[y = f(x)]$ , with values from zero (0) to one (1).

The study was carried out on a multi-criteria evaluation (JIANG; EASTMAN, 2000) to describe relevance areas for ecological conservation and human activities at the watershed scale, in this way degree of vulnerability to anthropic intervention, considering the equation;

$$EV = \frac{(Geology + Slope + Unconsolidated materials + Aquifer units + Land use)}{5}$$

### 3 RESULTS AND DISCUSSIONS

The physical and biological attributes (slope, geology, soils, aquifer units and land use and occupation) are presented in Figure 3. The low, medium and high vulnerability classes present more frequency for the two periods, occupying a percentage of 73.5% for 2001 and 78.4% for 2017 (Figure 4). The principal attribute that caused changes in the charts was the use and land cover since

it is the only factor that demonstrates considerable modifications in the study area for a long time. Table 3 presents the percentage of area occupied by each type of use and land cover mapped.

In the 16-year period, it is possible to notice the growth of the urban area and the sugar cane plantation, where the areas of the exposed soil also related. In addition, the pasture present greater evidence for 2017 (10.4%) compared to 2001 (3.2%).

Figure 3 – Physical and biological attributes for the RCW

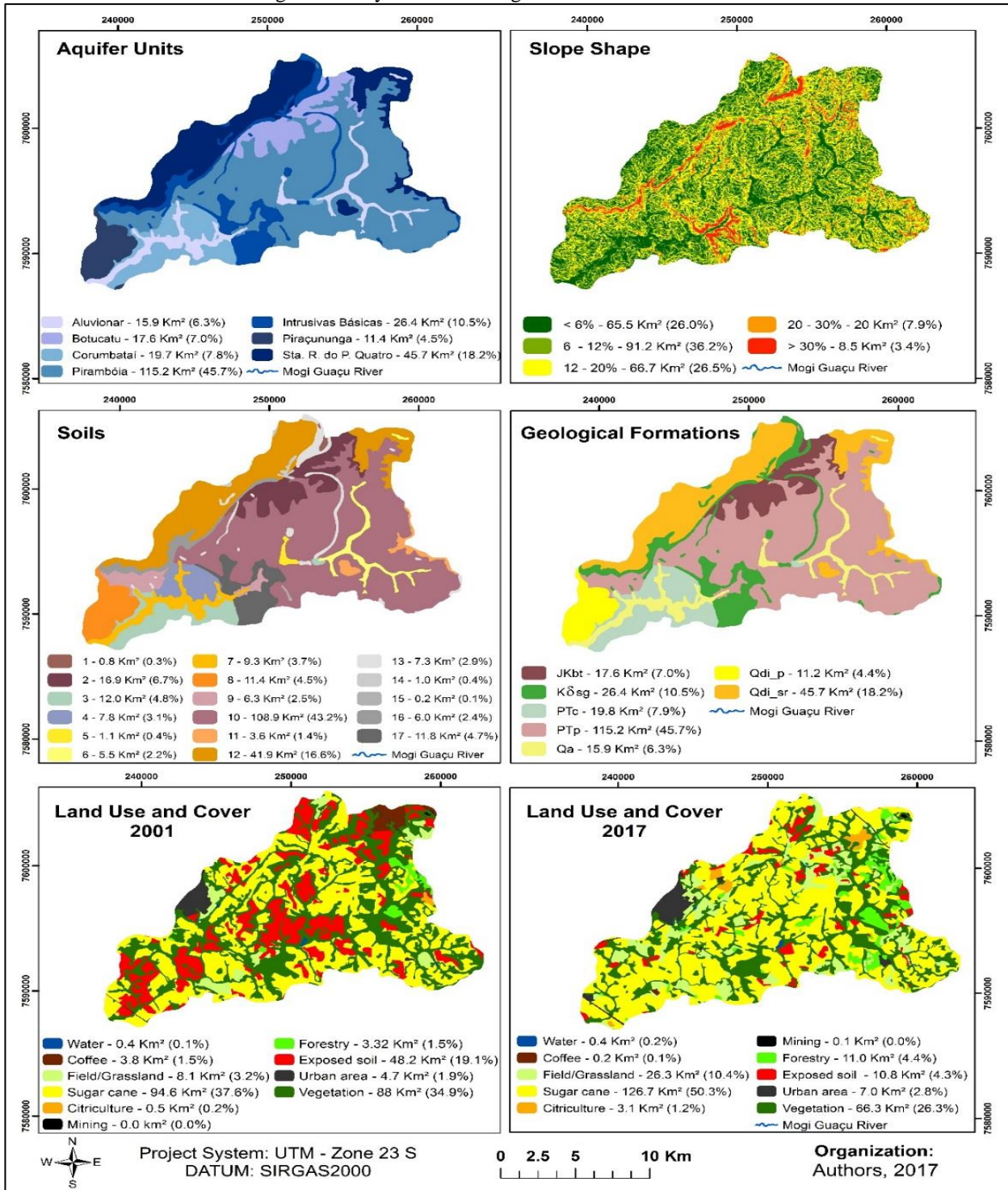
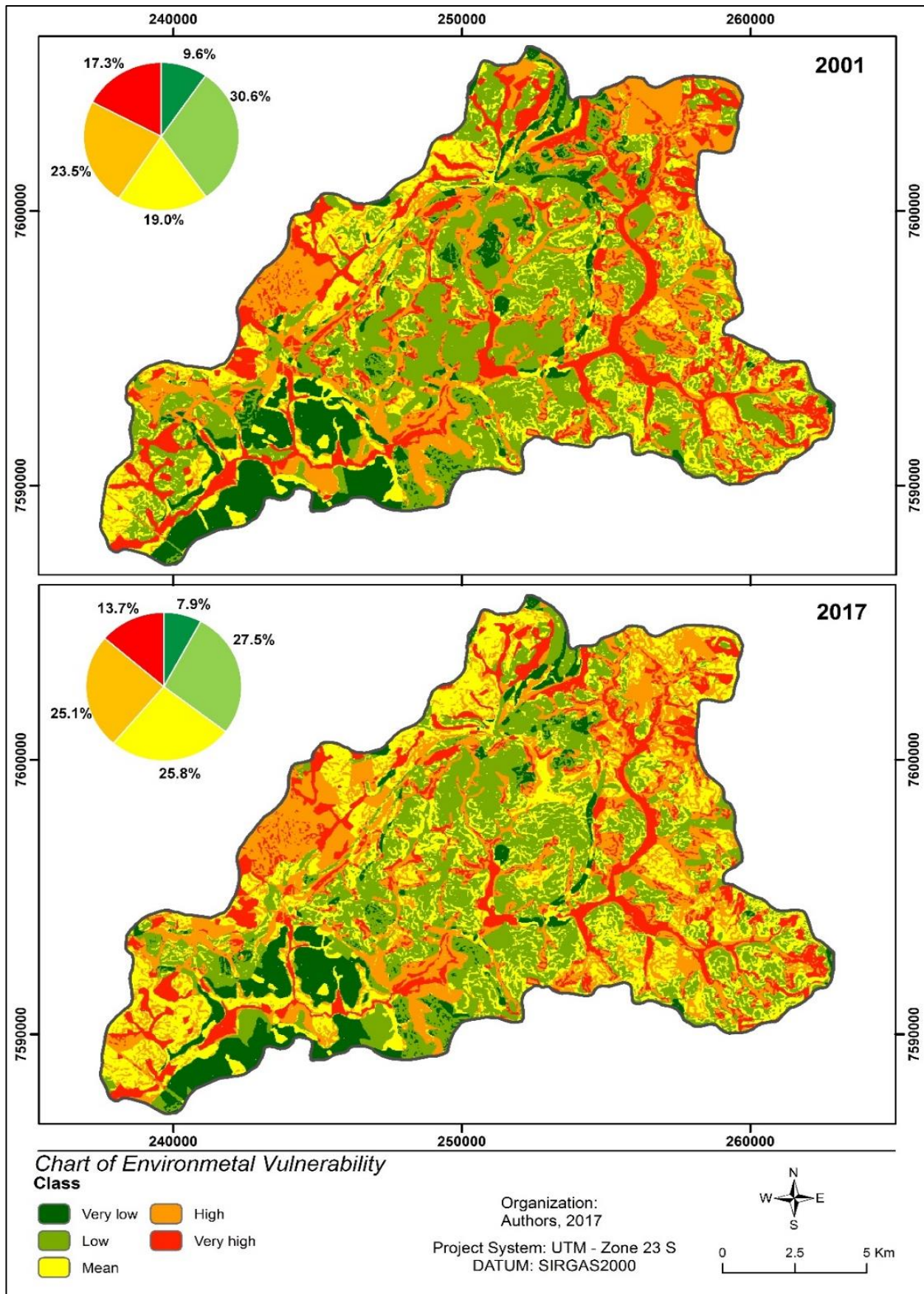


Figure 4 - Chart of Environmental Vulnerability.





For a detailed analysis of the Environmental Vulnerability, each of the five classes was described, considering the environmental attributes adopted.

Table 3 - Use and land cover in Rio Claro Hydrographic Basin for 2001 and 2017.

Land Use	2001 (%)	2017 (%)
Water	0,20	0,20
Urban	1,90	2,80
Coffe	1,50	0,10
Sugarcane	37,60	50,30
Pasture	3,20	10,40
Citriculture	0,20	1,20
Silviculture	1,30	4,40
Exposed soil	19,10	4,30
Vegetation	35,00	26,30

Source: Authors

Very low environmental vulnerability: this class is distributed in the extreme south of the hydrographic basin, the environmental attributes that define this classification are the soils originating from the Corumbataí Formation, with thicknesses that vary below 2m and can reach up to 5m. Geology is composed of variegated shales. The very low vulnerability is also found in the central region of the basin with soils from Basic Tabular Intrusives, which are characteristic of clayey texture. In addition, it is a shallow soil with a thickness that can reach up to 2m. The slope present in these regions ranges from < 6% to 20%.

It can be noticed that from the year 2001 to 2017 there was a decrease in the class very low environmental vulnerability. Since 2001, the exposed soil was more presented, however, in 2017, these areas were occupied by sugar cane or other activities.

Low environmental vulnerability: this is the vulnerability class with the greatest predominance in 2001 and 2017. It is spatialized throughout the hydrographic basin, mainly in the central region, whose soil comes from the Piramboia Formation presenting > 10m of thick and sandy texture.

This class is more concentrated where the relief has smooth undulating and interflowing flattened. There was a small decrease in the area occupied by this class in the river basin due to changes in land use and occupation. Since 2001, this class occupied a percentage of 30.6%, while in 2017 fell to 27.5%.

Medium environmental vulnerability: this class is distributed among all the study area. There was an increase from 2017 (25.8%) in relation to 2001 (19%). This is also a reflection of the

use and land cover. It is worth noting that the region where coffee was occupied in 2001 was exchanged for sugar cane, once an area considered to be highly vulnerable, currently characterized as being of medium environmental vulnerability.

This class is associated with regions that present mainly soils of the Santa Rita do Passa Quatro and Piraçununga formation, present thickness  $> 10\text{m}$  and sandy texture. It is located to the north and northwest of the hydrographic basin. On the northeast are soils of the Piramboia Formation with thickness  $> 10\text{m}$  with a sandy texture. In the southern region there are soils originating from the Quaternary Formation whose thickness varies from 2 to 5m, presents sandy texture. The slope ranges from  $< 6\%$  to 20%.

High environmental vulnerability: There was a change in 2001 of 23.5% to 25.1% in 2017. This classification is associated with the soils originating from the Piramboia and Santa Rita do Passa Quatro Formations, which have a thickness  $> 10\text{m}$ , and sandy texture. On the southern, presents soils originating from Basic Tabular Intrusives with a thickness of 5 to 10m, and medium texture.

Very high environmental vulnerability: these classes are associated with the natural vegetation, dams and exposed soil. This class is spatialized along the hydrographical basin, presents regions with a slope from  $< 6\%$  to 20%.

In this way, it is evident the tendency of loss of the environmental quality present in the region, caused by the expansion of the agricultural and urban frontiers without environmental planning, interfering in the conservation and maintenance of the environmental services provided by the ecosystems.

This scenario is also observed in other studies (PINATTI et.al, 2013; Trevisan; Moschini, 2015), which demonstrate the loss of environmental quality due to the expansion of agricultural frontiers, evidencing the expansion of sugarcane cultivation and the suppression of areas of native vegetation and the substitution of other agricultural practices.

#### **4 CONCLUSIONS**

The method employed in this work allowed the evaluation of the environmental vulnerability in the Rio Claro Hydrographic Basin and made possible the definition of the regions that suffered interference due to the anthropic activities in the physical and biological environment.

The use of the Geographic Information System was important for the elaboration of the results since it is an instrument that presents resources to analyze a series of data and cartographic

information through map algebra, aiming to obtain an integrated knowledge to understand the environmental dynamics.

The results will allow guiding the public managers in the decision making, aiming at strategic planning in order to mitigate socio-environmental problems that can occur in the regions of greater environmental vulnerability; besides, it serves as contribute to helping future occupations to consider socioeconomic development together with environmental preservation.

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