**Environmental Vulnerability Index: an evaluation of the water and the vegetation quality in a Brazilian Savanna and Seasonal Forest biome**

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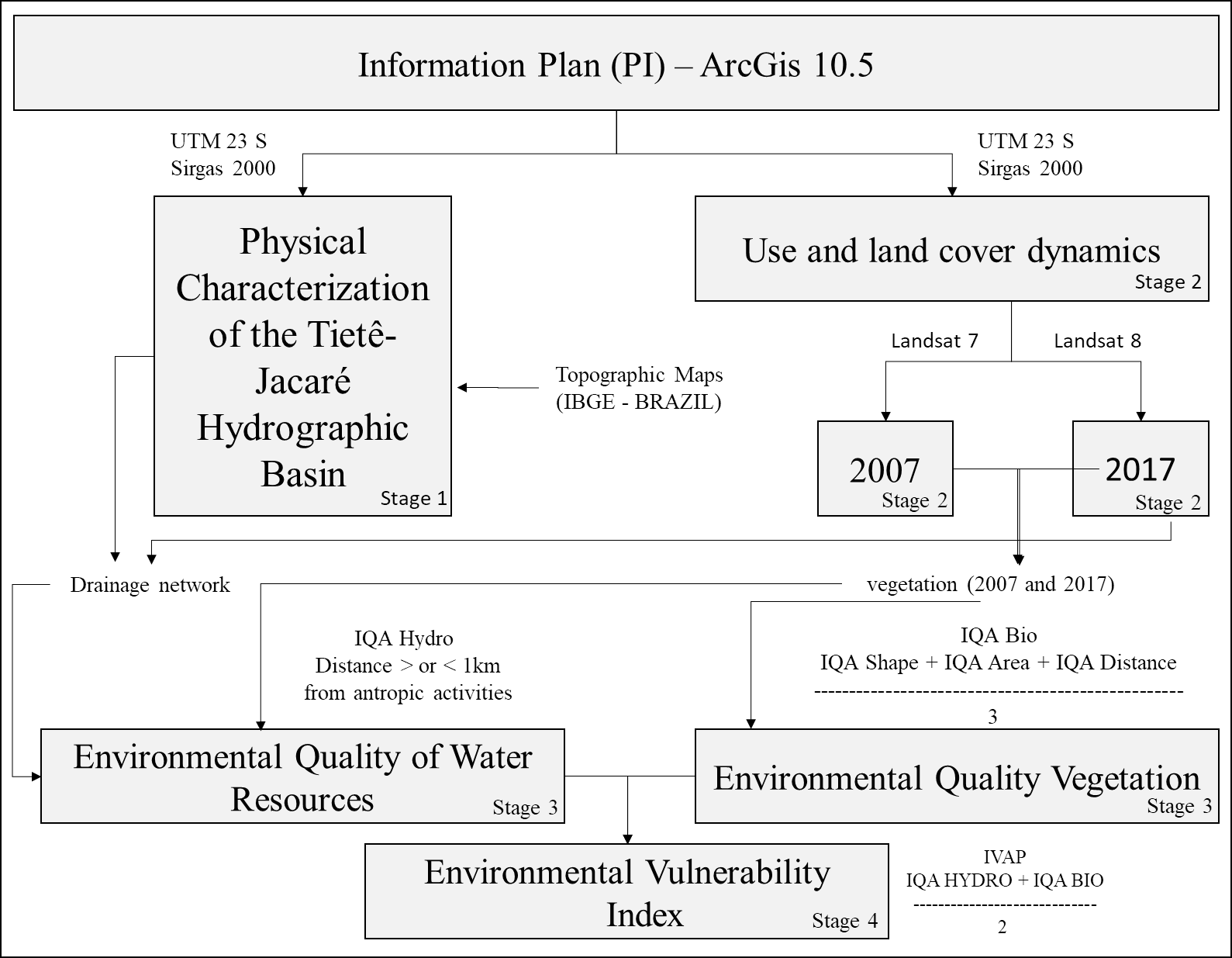
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**Highlights**

* Anthropic land uses are replacing Brazilian Savanna and Seasonal Forest
* Negatives impacts on natural landscapes have grown over time
* Landscape Indices could quantify the fragments environmental quality

**GRAPHICAL ABSTRACT**

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**ABSTRACT**

Landscapes constitute the manifestation of natural and anthropic elements and its structure is the result of physical, biological, political, economic and social interactions, fragmented or connected for different land uses. Drawing on this, our study aims to analyze the environmental landscape quality using ecological indices in the Tietê-Jacaré Hydrographic Basin – SP, Brazil between 2007 and 2017. A set of Environmental Quality Indices was used to analyze the susceptibility of the ecological components to the effects of human activities. The Environmental Quality Index of Vegetation, the Environmental Quality Index of Water Resources and the Environmental Vulnerability Index were used to assess the condition of ecological sustainability of the landscape. It was identified a reduction in the areas with native vegetation with a loss of 2.72%, representing over 32,149ha, an expansion of agricultural areas of 2.05% (24,507.53ha) and consequently a reduction of the environmental quality in the landscape. These impacts compromise the ecosystem structure and ecosystem services, per example, through the impacts on soils that support vegetation cover as the major sources of energy for terrestrial life. The observed intensification of anthropogenic activities and the corresponding reduction of natural areas often lead to the loss of biodiversity and the benefits that its ecosystem services provided to people.

**Keywords:** Environmental quality; Environmental planning; Landscape analysis; Landscape indices.

1. **Introduction**

Landscapes constitute the manifestation of natural and anthropic elements and its structure is the result of physical, biological, political, economic and social interactions, fragmented or connected for different land uses (Turner et al., 1998; Balmford et al., 2002; Goerl et al., 2011). The landscape analyses are fundamental in the environmental planning in order to designate a setting that corresponds to the spatial structure, contributing with the understanding of the anthropogenic change impacts in the natural processes (Gardner; O.'Neill, 1991; Chaichi; Daim, 2018).

The processes of the landscape occupation by human activities managed without the development of environmental planning have being produced great pressures on natural systems. The interaction between society and nature defines the types of land use and consequently the landscape spatial and structural patterns (Dos Santos 2011; Chaichi; Daim 2018). These human interferences in natural or anthropogenic landscapes have converted extensive and continuous areas with forest cover into forest fragments, compromising their environmental functions and consequently the services provided by ecosystems (Millennium Ecosystem Assessment 2005; Intergovernmental Panel on Climate Change 2017).

There is a need to analyze the landscape changes over time, caused by the anthropic activities to verify the main impacts within each landscape unit. The identification and quantification of these changes will allow the assessment of the dimensions of various environmental problems, such as deforestation, pollution, climate change and animal extinction (Intergovernmental Panel on Climate Change 2017).

The quantification of environmental properties such as land use and land cover, the status of conservation, and landscape recovery capacity plays a key role in environmental decision-making and urban policies. In recent years, there has been a growing demand for new ecological indices to direct conservation investments. The need for prompt solutions has drawn the attention to surrogate measures calculated on the basis of available or easily measurable indicators (De Leo; Levin, 1997; Dong; Hauschild, 2017).

This challenge searches to disseminate concepts and techniques of conservation and management that aim to reduce impacts on ecosystems, especially when referring to the landscapes recomposition and preservation. In the last decades, there has been an extensive search for new quantitative methods that can analyze patterns, determine the importance of spatial processes and develop models. The advance of methods for the quantification of that structure has been a prerequisite for understanding the relationships between the patterns and landscape processes (Turner; Gardner, 1991; Marino et al., 2015).

Several authors have been developing indices and descriptive measures of spatial landscape monitoring (Turner, 1987; O'Neill et al., 1988; Gustafsson; Parker, 1992; Mcgarigal; Marks, 1995; Schumaker, 1996; Moretti, 2007, Trevisan et al., 2016; Kuriqi et al., 2019). Such studies are often implanted in different environmental and social contexts, which contributes to the understanding of the changes in the natural landscapes, through the analysis of the interconnections of different impacts and contexts that act on the environment. Modeling is established as an excellent tool for obtaining knowledge and testing hypotheses in landscape ecology and population issues (Trevisan; 2015; Trevisan et al., 2017).

These measures are used to compare the composition and structure of different landscapes, to identify landscape changes over time and to explore the effects of different configurations imposed by practices of alternative management on the probability of disturbances occurrence (Franklin; Forman, 1987; Turner; Simard, 2017). Determining these changes will allow the assessment of various environmental problems and will lead to the implementation of international conventions, action programs, and local, regional and national policies.

Geographical Information Systems (GIS) have facilitated the characterization of the diagnostic analyses, the simulation of geographic space and its natural processes and the integration of spatial information (Ribeiro, 1999; O’Sullivan et al., 2018). An example is a study by Morelli et al., (2018) that aimed to explore the associations among the most common landscape metrics and diversity and community metrics calculated for bird assemblages in the Czech Republic. They used Generalized Linear Models and compared the strength and direction of these associations as well as their performance in three different environments.

In this context, the analysis of watersheds, as the main unit of the landscape, is of fundamental importance, because besides the management of water resources, they concentrate high richness and diversity of animal and plant species. Knowledge of the temporal behavior of hydrographic basins provides projects to prevent accidents such as floods, as well as maximizing the use of natural resources and ecosystem services in the supply of cities, agriculture, industrial activity and construction of hydroelectric plants (Hamilton, 2018).

In Brazil, one of the most effective ways to manage integrated regional planning is through the Water Resources Management Units (*Unidades de Gerenciamento de Recursos Hídricos*) and river basin committees. Over legislation, these corroborate with the physical and socioeconomic planning of the regions. In the country, planning is mostly done locally, where each municipality, despite respecting the legislative hierarchy, both state and federal, manages its territory locally, which in many cases it is insufficient, especially when this management is concerning with the conservation of natural resources.

Drawing on this, this, this study aims to analyze the environmental landscape quality using ecological indices in the Tietê-Jacaré Hydrographic Basin – SP, Brasil between 2007 and 2017, where it was identified a grown and a consolidation of agricultural activities without environmental planning (Trevisan, 2015; Trevisan et al., 2018), needing research to understand the impacts of these activities and how they have modified the landscape structure.

**2. Material and methods**

*2.1 Study area*

The State Law No. 9,034 regulates the management of water resources in São Paulo state, which is carried out through the Water Resources Management Units[[2]](#footnote-2) (CBH-SM, 2015). The state has 22 Water Resources Management Units, which were delimited from the concept of a river basin. Each unit encompasses the water resources that converge to a main body of water, necessitating a link between research, management, and application of innovations.

The Tietê-Jacaré Hydrographic Basin (Figure 1) is located in São Paulo state, Brazil, between 49º14' and 47º70' west and 21º62' and 22º79' south, with a population of 1,462.855 inhabitants and a total area of 1,181,090 hectares distributed in 37 municipalities. According to the classification of Köppen-Geiger, the climate of the Tietê-Jacaré Hydrographic Basin is between humid tropical climate (from October to March) and dry winter (from April to September). The surface is variable, with the highest point of altitude at 1,060m in São Carlos city (Tundisi et al., 2008; CBH – TJ, 2017).

The region is located in the Peripheral Depression of the São Paulo state, where the Bauru, Serra Geral, and Botucatu aquifers are located. The watershed is formed by soils of deep to moderate quartz sands and in smaller occurrences of latosols (Tundisi et al., 2008; CBH – TJ, 2017). The main economic activities are related to agroindustry (sugar, alcohol and citrus processing) (Tundisi et al., 2008; CBH – TJ, 2017). In the largest municipalities, for example, Bauru, São Carlos, Araraquara and Jaú, other sectors of the industry such as paper, beverages, footwear, and metalworking also exist.

The region of the Tietê-Jacaré Hydrographic Basin is the Atlantic Forest (23%) and *Cerrado* (Brazilian Savanna) (77%) biomes, considered biodiversity hotspots. The Atlantic Forest consists of a set of forest formations and associated ecosystems such a~~s~~ altitude fields, which are distributed in the central region of the watershed, between the regions of Barra Bonita, Bariri, and Iacanga. The *Cerrado* (Brazilian Savanna) is characterized especially by the savanna biome, the seasonal forest, and field, which are distributed throughout the watershed region, between the regions of Lençóis Paulistas, Bocaina and São Carlos.

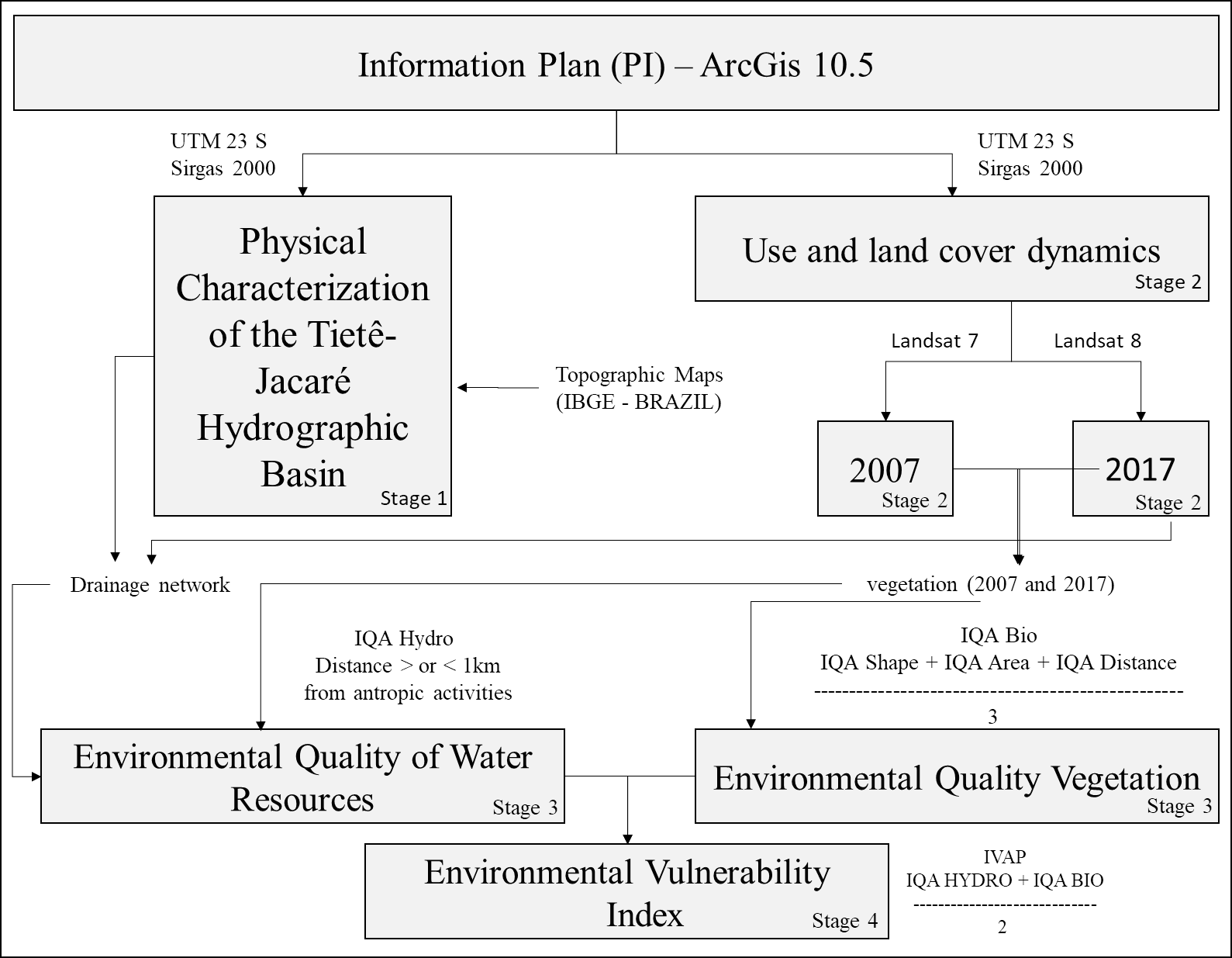


**Fig. 1:**  Tietê-Jacaré Hydrographic Basin, Brazil

Because of this agricultural predominance and consolidated development characteristics, that includes municipalities with high urbanization and industrial and agricultural potential, requiring an integrated road network and consequently a hydrological network that supports all this development. The Tietê-Jacaré Hydrographic Basin becomes a potential area for analysis of the temporal changes in the landscape environmental quality due to the land use and land cover changes over time, regarding the interrelationship of anthropic, agricultural development and natural ecosystems, assessing how they influence the landscape environmental quality, the conservation of ecosystems and their respective services.

*2.2 Methodology*

The Data analysis (Figure 2) was done with a Geographic Information Systems (GIS), using ArcGIS 10.5 software using the geographical Universal Transverse Mercator projection, Zone 23 South, datum SIRGAS 2000. The Tietê-Jacaré Hydrographic Basin data were purchased from the Brazilian Institute of Geography and Statistics and planialtimetric charts (IBGE, 1971) in analog form on a 1:50.000 scale. All the data resolution used in this study was 30 meters or 1:50.000, utilized because it was the best resolution available on the Brazilian governmental databases.

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**Fig. 2:**  Flow chart of the work

The Landsat satellite images (USGS, 2017) were used (Table 1) that correspond to 220/75, 220/76, 221/75 and 221/76 path/row, with overpass dates of April 30th, 2007, and September 21st, 2017. For 2007, Landsat 5 TM, bands 5/4/3 were utilized, and for 2017 Landsat 8 OLI/TIRS, bands 6/5/4 were utilized. The application of images from different satellites was necessary due to the long study period, however, the scenes applied in the study have the same spatial resolution of 30 meters. The periods of April and September were chosen due to the seasonality of the prevailing agricultural practices in the region and the time gap of ten years between the images allowed the study of the temporal patterns of the landscape.

**Table 1**

Satellites and images used in the study

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Satellite** | **Overpass** | **Orbit** | **Bands** | **Resolution** |
| Landsat 5 | April 30th, 2007 | 220/75 | 5/4/3 | 30m |
| Landsat 5 | April 30th, 2007 | 220/76 | 5/4/3 | 30m |
| Landsat 5 | April 30th, 2007 | 221/75 | 5/4/3 | 30m |
| Landsat 5 | April 30th, 2007 | 221/76 | 5/4/3 | 30m |
| Landsat 8 | September 21st, 2017 | 220/75 | 6/5/4 | 30m |
| Landsat 8 | September 21st, 2017 | 220/76 | 6/5/4 | 30m |
| Landsat 8 | September 21st, 2017 | 221/75 | 6/5/4 | 30m |
| Landsat 8 | September 21st, 2017 | 221/76 | 6/5/4 | 30m |

By visual on-screen digitizing the land use and land cover was based on the multi-level classification system proposed by the Land Use Technical Manual from IBGE (IBGE, 2013). In the primary level, four classes were included that indicate the principal land use categories. The secondary level analyzed the types of land uses that were included in the first level and the tertiary level explained the land uses themselves (Table 2).

**Table 2**

Description of land use and land cover classes.

|  |  |  |
| --- | --- | --- |
| **Class (I)** | **Type (II)** | **Description (III)** |
| Anthropogenic and not agricultural areas | Urban areas | Dense urban area and areas with rural developments (industrial and household) |
| Anthropogenic- agricultural areas | Sugarcane | Cultivation area of *Saccharum* *officinarum L*. |
| Citrus | Cultivation area of *Citrus sinensis*. |
| Pastures | An area with a predominance of herbaceous vegetation (native or exotic), used for extensive livestock farming. |
| Silviculture | Cultivation area of Eucalyptus *spp* or *Pinus spp*. |
| Soil exposed | Soil fallow area for *Saccharum officinarum L*. cultivation |
| Vegetation | Natural vegetation | An area with a predominance of tree vegetation, with vegetation types of semi-deciduous forest and *Cerrado.* |
| Water | Water | Large rivers, lakes, ponds, and reservoirs. |

*2.2.1 Landscape indices*

Landscape indices were used to describe the landscape temporal pattern resulting from the influence of anthropogenic land use and land cover processes in the Tietê-Jacaré Hydrographic Basin for 2007 and 2017. This approach assumes that the relevance of the environmental impacts of land use and land cover is associated with the vulnerability and sensitivity of environmental components. The indices in this work were adapted from O’Neill et al., (1988); Canter (1996); Eastman (1997); Bojórquez-Tapia et al., (2002); Wrbka et al., (2004) and Fritzsons et al., (2004). Some authors such as Fushita et al., (2013), Bueno (2014) and Trevisan; Moschini (2017) also have developed and tested indices in the Brazilian context.

The information used for the integrated analysis of the environment has different natures. Thus, it was necessary to standardize the criteria using comparability adjustments where appropriate. To understand the application of the landscape indices, the fuzzy logic method was used for the analyses of the indices. This method is an extension of Boolean logic which allows intermediate membership values between false (0) and true (1), for example, the value could be 0.5. This allows intermediate states to be treated by control devices (Fisher; Wood, 1998; Marro et al., 2013).

A set of Environmental Quality Indices (EQI) was used to analyze the susceptibility of the ecological components to the effects of human activities. The Environmental Quality Index of Vegetation (EQI Bio) reflects the sensitivity of the landscape to the biodiversity loss and habitat fragmentation resulting from the condition of native vegetation class (Canter, 1996; Moschini, 2008; Trevisan, 2015). The EQI Bio was obtained based on the analysis of the area (EQI Area), shape (EQI Shape) and distance (EQI Distance) between fragments of native vegetation, defined by the expression (Equation 1):

|  |  |  |
| --- | --- | --- |
|  |  | (1) |

The information on the native vegetation class was used to estimate the EQI area (Eastman, 1997; Trevisan, 2015), where the bigger the area of a fragment, the greater is the environmental quality in relation to biodiversity. The vegetation fragments with areas equivalent to 1 hectare (ha) were considered of minimum quality (EQI Area = 0) and fragments with areas higher than 1,000 ha were considered of maximum quality (EQI Area = 1).

The information on the native vegetation class was also used to estimate EQI-Shape, the perim function was used to calculate the perimeter (P) of each fragment (Eastman, 1997; Trevisan, 2015). The shape index (SI = 0.25\*P / √A) was applied using the image calculator module. This model was proposed by Valente (2001) and Trevisan (2015) and results in a thematic map where each fragment showed a value related to their shape. Thus, fragments with values near to 1, had a lower edge effect and increased environmental quality (EQI shape = 1), while fragments with indices near to 0, showed lower environmental quality (EQI shape = 0).

The distance module (Eastman, 1997; Trevisan, 2015) was used to estimate the Quality Score related to distance (EQI Distance). The lowest degree of environmental quality was assigned when the fragments presented distances greater than 1,000 meters between them (EQI Distance = 0), while the highest level of environmental quality was assigned when the distance between the fragments was approximately zero (EQI Distance = 1).

The susceptibility of water resources to land use and land cover impacts was quantified by the Environmental Quality Index of Water Resources (EQI Hydro). This index considers the impacts of pollutants, the effects of pesticides, the transport of solid waste, and other factors resulting from human activities (Canter, 1996; Bojórquez-Tapia et al., 2002; Trevisan, 2015).

The EQI Hydro was determined based on the overlap of the agricultural thematic maps, obtained by reclassifying land use and land cover and the drainage network. The spatial representation was developed based on the use of the distance module on ArcGIS 10.5 software (Eastman, 1997; Trevisan, 2015) and staggered based on fuzzy logic. This analysis represents the distance of water resources in relation to impacting sources, considering the minimum quality degree (EQI Hydro = 0) rivers with a distance from the impacted areas closed to zero and the maximum degree of quality (EQI Hydro = 1) corresponded to rivers with a distance from the impacted areas greater than 1,000 meters.

The Environmental Landscape Vulnerability Index (ELV) determines the degree of susceptibility to degradation by environmental impacts, expressing the landscape potential to absorb or be disturbed by human activities (Canter, 1996; Trevisan, 2015). Vulnerability and resilience are closely related, as the term vulnerability refers to the propensity to damage due to the lack of protection or at risk of being affected by a negative impact, in other words when the vulnerability is high, the resilience is considered low (Steffen et al., 2004; Trevisan, 2015).

The ELV was obtained (Equation 2) from the mean of EQI Hydro and EQI Bio indices based on the application of the “Image Calculator Module” (Eastman, 1997; Trevisan, 2015). The lowest degree of the environmental vulnerability index of the landscape (ELV = 0) was ascribed to a state most susceptible to impacts, per example, small fragments that present low area, small distance from anthropogenic land use and low connectivity with other vegetation fragments, while the greatest degree of environmental vulnerability index of the landscape (ELV = 1) is assigned to a condition with the largest capability to absorb impacts (high resilience), per example, fragments of vegetation that have high representativity, in the amount of area, distance from anthropogenic land use and connectivity with other vegetation fragments.

|  |  |  |
| --- | --- | --- |
|  |  | (2) |

**3. Results and discussions**

The citrus, diverse cultures (by satellite image resolution, some regions such as corn, coffee, and rice were grouped in the same land use), exposed soil, pasture, sugarcane, silviculture, vegetation, and water were classified (Figure 3), showing an expansion of agricultural activities with an increase of 24,507.53ha (2.05% of the total area), mainly by sugar cane cultivation.



Fig. 3: Land use and land cover of the Tietê-Jacaré Basin Hydrographic Basin for 2007 and 2017

Considering the size of the region, the land use and land cover transition are minimum, however, this change between the landscape uses explains the consolidation state of the anthropic activities, where regions whose agricultural activities occur are already predefined and delimited. In 2007, approximately 72% of the area showed a predominance of agricultural activities, being 542,114.00ha occupied by sugarcane, 122,046.00ha by exposed soil, 76,817.59ha by pasture, 62,121.90ha by citrus, 49,272.60ha by silviculture and 1,315.71ha by diverse cultures (Table 3).

The exposed soil areas are associated with agricultural harvest period (122,046ha), as they refer to the fallow period and soil preparation for the next crop and the pasture areas arise in small parcels, being a subsistence or small-scale production activity. The sugarcane is predominant in practically all municipalities, but in some regions, other types of agricultural cultures are present, such as citrus cultivation in the Araraquara, Nova Europa and Gavião Peixoto region, and forestry in the Agudos, Pederneiras, Brotas and Itirapina region.

Table 3

Distribution of land use and land cover classes in the Tietê-Jacaré Basin in 2007 and 2017.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Classes** | **Land use 2007** | | **Land use 2017** | |
| **Area (ha)** | **%** | **Area (ha)** | **%** |
| Vegetation | 274,288.00 | 23.22 | 242,139.00 | 20.50↓ |
| Water | 16,955.80 | 1.44 | 16,764.60 | 1.42↓ |
| Pastures | 76,817.59 | 6.50 | 51,564.90 | 4.37↓ |
| Silviculture | 49,272.60 | 4.17 | 58,258.00 | 4.93↑ |
| Citriculture | 62,121.90 | 5.26 | 38,198.80 | 3.23↓ |
| Diverse cultures | 13,15.71 | 0.11 | 13,82.63 | 0.12↑ |
| Exposed soil | 122,046.00 | 10.33 | 121,346.00 | 10.27↓ |
| Sugarcane | 542,124.00 | 45.90 | 607,455.00 | 51.43↑ |
| Urban area | 36,148.40 | 3.06 | 43,981.07 | 3.72↑ |
| **Total** | **1,181,090.00** | **100.00** | **1,181,090.00** | **100,00** |

In 2017, approximately 74% of the was used for agricultural activities, being 607,455ha occupied by sugarcane, 121,346ha by exposed soil, 58,258ha by silviculture, 51,564.9ha by pastures, 38,198.80ha by citriculture and 1,382.63ha by diverse cultures. It was observed the growth of 65,331ha of sugarcane areas, where zones of other agricultural uses were converted, contributing to the predominance of this crop in the region.

The urban areas had a growth of 7,832.67ha (36,148.40ha in 2007 and 43,981.07ha in 2017) and the increase was more noticeable in medium to large municipalities, such as Jaú, Bauru, São Carlos, and Araraquara, while small municipalities such as Torrinha, Ibaté, and Brotas, still maintain their structures mainly focusing on activities related to the agricultural sector with industrial support from the larger municipalities.

This predominance of sugarcane coincides with the characteristics of the São Paulo state, mainly in the interior, which is the largest producer of sugarcane in Brazil. This, as well as in the Tietê-Jacaré Hydrographic Basin, is due to the conditions favorable to its cultivation, such as the existence of fertile soils that lead the average productivity to be higher than in other regions (Natale Netto, 2007; Martini et al., 2018).

In the case of the Tietê-Jacaré Hydrographic Basin, the expansion of sugarcane cultivation areas, it is similar to studies carried out with this theme and different regions (Rudorff et al., 2010; Moraes et al., 2013). Ferreira et al., (2019) mapped land use and land cover and the spatial evolution of sugarcane in 1,000km2 in the Brilhante River Hydrographic Basin in Mato Grosso do Sul, Brazil, using remote sensing techniques associated with fieldwork. It was observed the predominance of agricultural activities, occupying 85% of the area and the growth of sugarcane areas from 50,000 250,000ha between 2004 and 2015, totaling an increase of 500%.

The native vegetation in the Tietê-Jacaré Hydrographic Basin is fragmented along the study area, presenting a loss of approximately 2.7% in ten years (32,149ha). These fragments are immersed in the agricultural matrix and mostly associated with water. These natural remnants are located near the Tietê-Jacaré River, in the municipalities of Itajú, Bariri, Ibitinga, and Bocaina, near the Jacaré-Guaçu River in the municipalities of Ribeirão Bonito, São Carlos, Ibaté and Itirapina, near the Jacaré-Pepira River in the municipalities of Dourado and Brotas and near the Jaú River, in the municipalities of Jaú and Mineiros do Tietê.

This loss was similar to the studies conducted by Moraes (2013) and Mello (2014), which analyzed the vegetation types of *Cerrado* (Brazilian Savanna) and Seasonal Semideciduous Forest (vegetation types present in the study area). They also evidenced the process of fragmentation in the landscape due to anthropic actions. Other regions in the country present the same results, as the work developed by Rego et al., (2018) that reveals a loss of vegetation in São Luis Municipality - Maranhão, which is highly urbanized. The Atlantic Forest and the Cerrado are two hotspots of biodiversity and it is necessary to plan in order to avoid the fragmentation process of the landscape due to the advancement of anthropic activities (Moraes et al., 2013).

These negative impacts compromise all environmental structures and services (Bertoni; Lombardi Neto, 2008; Hernandez et al., 2015) and the uncontrolled land use occupation and inadequate soil management have led to several environmental problems, such as soil compaction, decreases the infiltration of rainwater and increased runoff. This set of factors favors the intensification of the water erosion process, which can evolve to the laminar, groove or ravine form (Silva, 2001; Medrano; Recaman, 2018).

In this way, the analysis of the EQI of vegetation showed the degradation of the landscape's environmental quality over time (Figure 4 and Table 4). It was observed an increase in the number of fragments with low environmental attributes (+6.39% in the EQI Bio = 0.0 to 0.4), while the fragments with intermediate qualities decreased (-3.96% in the EQI Bio = 0.4 to 0.6). The fragments with high environmental quality decreased (-2.43% in the EQI Bio = 0.6 to 1) and the remaining was maintained mainly due to their vicinity to water and steep slopes preventing agricultural land use and are related mainly to the principal rivers in the region as Jacaré-Pepira, Jacaré-Guaçu and Jáu River.



**Fig 4**: EQI Bio in the Tietê-Jacaré Hydrographic Basin for 2007 and 2017

The region, in addition to losing areas of natural vegetation (Figure 5), loses the environmental quality of the remnants over time. The loss of 32,149ha of native vegetation between 2007 and 2017, is similar to findings from other areas (Cintra, 2004; Moschini, 2005; Moraes, 2013; Mello, 2014) which also identified the occurrence of fragmented landscapes due to unplanned land use and the consequent increase in the level of environmental vulnerability.

**Table 4**

EQI Bio values in the Tietê-Jacaré Hydrographic Basin for 2007 and 2017

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **EQI BIO** | **2003** | | **2013** | |
| **Area (ha)** | **(%)** | **Area (ha)** | **(%)** |
| **0.0 – 0.2** | 110,484.14 | 40.28 | 112,027.16 | 46.27↑ |
| **0.2 – 0.4** | 81,707.34 | 29.79 | 73,111.66 | 30.19↑ |
| **0.4 – 0.6** | 48,899.34 | 17.83 | 33,592.26 | 13.87↓ |
| **0.6 – 0.8** | 18,744.74 | 6.83 | 9,534.8 | 3.94↓ |
| **0.8 – 1.0** | 14,452.44 | 5.27 | 13,873.12 | 5.73↑ |
| **TOTAL** | **274,288.00** | **100.00** | **242,139.00** | **100.00** |

The changes in the vegetation also impacted the fragmentation. In 2007 the region presented 2.190 fragments, which 35 had areas superior to 1,000ha. In 2017 the number of fragments increased to 2.231 but the number of fragments with areas superior to 1,000ha decreased to 28. This pattern explains that the increase of fragments refers to the fragmentation of big fragments in small fragments.

**Fig. 5:** Variation of the EQI Bio values for 2007 and 2017

Some studies published for other Brazilian regions (Moschini 2005, Dos Santos, 2011; Moraes et al., 2013; Junior; Hamada, 2015) also showed the loss of areas of natural vegetation and the increase in anthropic impacts on the studied landscapes. Behera et al., (2018) documented a decrease in natural fragments in Mahanadi and the Brahmaputra River Basin in India. They used digital interpretation from Landsat images at three decadal and have observed a decrease in forest classes (20%) and an increase in built-up, cropland classes (15%) in both the river basins.

Teixeira et al., (2017) discuss the soil losses related to changes in land use in São Francisco - Minas Gerais state, located in the vicinity of natural drainage systems. In addition, they observed that the greatest probabilities of occurrence of soil loss in the regions where their uses are most intense, whose main degradation practices are agricultural. Rezende et al. (2018) discuss the impacts of agriculture on the use of water for irrigation and its return to the environment with pesticides and fertilizers. The authors analyzed a stretch of the Tietê River located between the Bariri and Ibitinga dams and observed the relevance of anthropic activities in land uses and hydrography along with the degradation of the landscape.

The EQI of Water Resources follows the same trend as the EQI Bio, which also identified a decline in environmental quality from 2007 to 2017. Figure 6andTable 5 show a increasing number of fragments with low quality (+1.42% in the EQI HYDRO = 0.0 to 0.4) and fragments of intermediate quality (+1.27% in the EQI HYDRO = 0.4 to 0.6) while the fragments of high quality decreased (-2.72% in the EQI HYDRO 0.6 to 1.0). The landscape had fragments with very low quality converted to low quality, in the same way, very high quality became in medium or low quality, whereas some fragments with high quality exist in both scenarios.

Besides losing areas of natural vegetation, the region also witnessed a loss of the quality of the remnants that remained and the replacement of natural areas by agricultural and urban land uses contributes to the deterioration of the quality of its water resources through negative effects such as loss of riparian vegetation, sedimentation, and disposal of waste and pollution.

In the case of water resources management, the issue of declining water quality for domestic supply is due to the pollution caused by different sources such as household, industrial, urban and agricultural effluents. The contamination through industrial effluents is due to the raw materials and industrial processes used and may be complex concerning the nature, concentration, and volume of the waste produced. The degradation of the water sources mainly occurs because of the increase of the nitrogen and phosphorus from farming and animal production (Merten; Minella, 2002; Musharafi et al., 2014).



**Fig. 6:** EQI HYDRO in the Tietê-Jacaré Hydrographic Basin for 2007 and 2017

The growth of algae and plants reduces the availability of dissolved oxygen in the water, adversely affecting the aquatic ecosystem and sometimes causing fish mortality. In addition to the impacts to aquatic ecosystems, increasing nutrient levels in water may jeopardize their use for domestic supply on account of changes in the taste and odor of water or the presence of toxins released by the flowering of some types of algae (Souza, 2005; Musharafi et al., 2014).

**Table 5**

EQI Hydro values in the Tietê-Jacaré Hydrographic Basin for 2007 and 2017

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **EQI HYDRO** | **2007** | | **2017** | |
| **Area (ha)** | **(%)** | **Area (ha)** | **(%)** |
| **0.0 – 0.2** | 761,902.00 | 64.51 | 724,410.90 | 61.33↓ |
| **0.2 – 0.4** | 125,158.00 | 10.60 | 179,837.00 | 15.23↑ |
| **0.4 – 0.6** | 14,975.5 | 1.27 | 30,013.70 | 2.54↑ |
| **0.6 – 0.8** | 2,769.15 | 0.23 | 4,160.40 | 0.35↑ |
| **0.8 – 1.0** | 276,285.35 | 23.39 | 242,668.00 | 20.55↓ |
| **TOTAL** | **1,181,090.00** | **100.00** | **1,181,090.00** | **100.00** |

Another direct impact is related to the reduction of water resources, which is in some cases associated with the natural water balance through modifications of the hydrological regime. In many cases, the change in river flow is caused by anthropogenic actions such as the creation of canals in urban areas. For the Tietê-Jacaré Hydrographic Basin, through the update of water bodies, from 2007 to 2017, it was observed a reduction of water from 10,601km to 8,686.42km, totaling 1,914.58km or 18.60% of the drainage network and also a loss of 1,324.74km of springs, totaling 24.10%.

These data (Figure 7) corroborate recent discussions about the water crisis in the 21st century, largely related to a lack of adequate management rather than to the real crisis of water scarcity and water stress. However, for some, it is the result of a set of environmental problems aggravated by other problems related to the economy and social development (Rogers, 2006; Wang, 2018).

**Fig. 7:** Variation of the EQI Hydro values for 2007 and 2017

The Water Resources Status Report (CBHTJ, 2017) provided by the Tietê-Jacaré Hydrographic Basin Committee indicates the contamination of surface waters such as household or industrial and agricultural waste. The groundwater analyzes showed that the most worrying parameter of all is the nitrate that has an exogenous origin, coming from the decomposition of organic matter, that reaches the aquifers of the region through artesian wells.

There are several impacts related to the reduction of the drainage network, such as the modification of the hydrological cycle due to the reduction of soil infiltration and the replacement of groundwater and surface water or the appearance of floods in large and medium cities. Numerous authors such as Arai (2012) and Silva et. al, (2016) have discussed the challenges of water resource management. Martins (2017) identified the need for the implementation and planning of the National Water Resources Information System in Brazil, focusing on the public responsible for its design and maintenance and representatives of civil society present at the National Water Resources Council.

As a result of the environmental changes, the determination of environmental spatial vulnerability is essential and required to identify areas that need actions for improvement and are crucial for the ecological sustainability of the landscape and the Environmental Landscape Vulnerability Index (ELV) considers the direct drivers of landscape change (Figure 8).



**Fig. 8:** ELV in the Tietê-Jacaré Hydrographic Basin for 2007 and 2017

The lower ELV values represent areas with higher vulnerabilities to impacts, that increased from 2007 to 2017 (+6.68% in the ELV = 0.0 to 0.4), the intermediate ELV values decreased (-0.64% in the ELV = 0.4 to 0.6) and the higher ELV values decreased (-6.15% in the ELV = 0.6 to 1.0) from 2007 to 2017 (Table 6). Fragments were lost over time, particularly vulnerable fragments in 2007, were being converted for other land uses until 2017. The low degree of vulnerability remained high for the two periods studied, especially in the vicinity of water, where the rivers and streams remain the most vulnerable areas of the region, because of the proximity to human activities, especially agriculture activities.

**Table 6**

ELV values in the Tietê-Jacaré Hydrographic Basin for 2007 and 2017

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **ELV** | **2007** | | **2017** | |
| **Area (ha)** | **(%)** | **Area (ha)** | **(%)** |
| **0.0 – 0.2** | 54,072.49 | 19.71 | 61,688.28 | 25.48↑ |
| **0.2 – 0.4** | 20,209.59 | 7.37 | 20,037.48 | 8.28↑ |
| **0.4 – 0.6** | 138,393.29 | 50.46 | 120,878.58 | 49.92↓ |
| **0.6 – 0.8** | 48,373.39 | 17.64 | 26,133.68 | 10.79↓ |
| **0.8 – 1.0** | 13,239.20 | 4.83 | 13,400.97 | 5.53↑ |
| **TOTAL** | **274,288.00** | **100.00** | **242,139.00** | **100.00** |

The areas with higher vulnerability (ELV = 0.0 to 0.6) (Figure 9) are most environmentally susceptible to disturbances and have lower resilience. The entire landscape of Tietê-Jacaré Hydrographic Basin needs special attention in regional planning, as 85% of the native vegetation area is in the ELV interval of 0.0 to 0.6. Virtually, all green areas are highly vulnerable to land use impacts, and the need for restoration and conservation of native vegetation areas is evident in order to reduce the degree of environmental vulnerability.

The ELV shows a trend of expansion of anthropogenic processes in the landscape due to the reduction of vegetation fragments over time. Some of the remaining vegetation fragments, although preserving ecological value, mostly become insufficient for biodiversity protection, serving only as ecological corridors, because of the conditions they appear in the landscape, per example, small fragments isolated and merged on the agricultural or urban matrix. But, it is important to register, for ecosystems conservation is crucial to maintain these fragments, even in this conditions, then lose all, unfortunately, the tendency of the scenario is if another study came 10 years later, there is a high chance of these fragments disappear and be converted in other land use and land cover.

**Figure 9:** Variation of the ELV values for 2007 and 2017

Very small fragments were converted to other land uses, and few of these have been grouped with other fragments, which would be ideal for environmental restoration of the landscape. In the Brazilian context, the importance of the areas with permanent conservation was legally supported by the Brazilian Forest Code of 1934 by Decree nº 23,793 and later in 1965 by Law nº 4,771/65 and currently by Law nº 12,561/12. The law defines that the riparian forest has the environmental function of preserving water resources, landscape character, geological stability, and biodiversity, gene flow of fauna and flora, as well as soil, to ensure the wellbeing of human populations.

Despite the increase of human impacts on riparian ecosystems, in 2012 Brazil discussed whether to change the Forest Code of 1965 in order to reduce the restrictions and penalties imposed by it, through the Law Project nº 1,876, 1999. It generated the new laws nº 12,561 of 25 May 2012 and nº 12,727 of 17 October 2012, thus revoking the previous Forest Code of 1965. The new Forest Code proposes changes regarding the calculation of environmental reserves within rural properties, decreases in permanent conservation areas (riverbanks, hills, and mountains), decreases in the penalties imposed on those who deforest and cultivate agricultural crops in these properties (Observatório do Código Florestal, 2015).

Studies conducted by the Institute of Applied Economic Research (IPEA, 2011) predict the possibility of about 79 million hectares loss of natural vegetation or 30% of the current legal reserve in the country. Considering the permanent conservation areas, this number would rise to hundreds of millions of hectares. The removal of these areas makes agriculture unsustainable in the short term (Tundisi, Matsumura-Tundisi, 2010; Comino et al., 2016), impairing economic activity.

According to IPEA (2011), approximately 76% of the productive land (436,047,761ha of the 571,740,440ha) is owned by only 10% of landowners. In the short term, this inequality will cause irreversible damage to water quantity and quality thus endanger human health and food production (SINGH et al., 2017). It should be noted that environmental protection cannot be the exclusive task of the São Paulo state, either through the executive branch institutes or through the judiciary, but should be backed by everyone’s commitment, involving individuals, companies and civil society. A balanced environment must be guaranteed for the present and future generations (Pinto, 2009; Fushita et al., 2013).

**4. Conclusions**

As expected, the presence or absence of native vegetation is directly related to the landscape’s environmental quality. The loss of 32,149ha (2.72%) of native vegetation between 2007 and 2017 in the Tietê-Jacaré Hydrographic Basin, resulted in the growth of the vulnerability degree, where 85% percent of the region is in the interval of low to medium degree of environmental quality. The Tietê-Jacaré Hydrographic Basin region requires an immediate plan aimed at maintaining the remnants of native vegetation, giving priority to the conservation and restoration of these areas, considering not only the current state of the region but the developmental trend which has been following this.

The growth of human activities and the loss of natural areas can compromise the biodiversity present in the study area, resulting in the loss of environmental functions and consequently the benefits they provide, considering that these areas serve as support for maintenance of urban and agricultural activities generally. The strengthening of participation spaces, through the mobilization of the population and its representative councils, should be a premise of the municipal administration, for the formulation, execution, and follow-up of urban development plans, programs, and projects, adapting to the local reality and thus fulfilling its objectives, proposing, then, an integrated management between government and civil society.

The Indices used were presented as important tools for the diagnosis aimed at the conservation of ecosystems. They enabled accurate analysis of each fragment related to the interconnections observed between the environmental qualities of the different landscape compartments, where the loss of natural areas directly involves loss of quality of several compartments, which are interconnected.

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