Analysis of hydrological connectivity in the Tietê-Jacaré hydrographic basin – São Paulo state, Brazil

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Abstract

The connectivity study is essential for the comprehension of various ecological processes, but it is poorly studied in aquatic environments, where hydrological connectivity is understood as the transfer of water, energy, and organisms from one part of the landscape to another. This work aims to analyze the hydrological connectivity present in the territory of the Tietê-Jacaré Hydrographic Basin - SP, through the application of the Hydrological Connectivity Index, to evaluate the dynamic and temporal process of these structures in 2007 and 2017. Geographic Information Systems (GIS) techniques were applied with the application of integration theory to investigate which rivers, wetlands, lakes, dams are connected. From 2007 to 2017, a reduction of 8,686.42 to 8,686.42 km was observed, totaling 208.35 km of the drainage network. There was also a loss of 163.77 km of springs (24.10%) and a reduction in the number of interactions between the hydrological network from 7,214 to 5,303. The updating of the information on the water resources extension complemented by the application of the indices, by expressing the state of landscape configuration, were important tools in the diagnosis of ecosystem conservation, enabling accurate analysis of the elements that compose them. The hydrographic basin showed a reduction in the drainage network in all regions, which consequently resulted in changes in the patterns of hydrological connectivity, reducing the number of connections by almost half. These factors must be analyzed in detail concerning the planning of the hydrographic basin, mainly related to the future of the quantity and quality of water resources.

Keywords: landscape analysis, landscape dynamics, hydrological network, drainage network.

Análise da conectividade hidrológica na bacia hidrográfica do Tietê-Jacaré – estado de São Paulo, Brasil

Resumo

O estudo da conectividade é essencial para a compreensão de vários processos ecológicos, mas é pouco estudado em ambientes aquáticos, onde a conectividade hidrológica é entendida como a transferência de água, energia e organismos de uma parte da paisagem para outra. Este trabalho tem como objetivo analisar a conectividade hidrológica presente no território da Bacia Hidrográfica do Tietê-Jacaré - SP, por meio da aplicação do Índice de Conectividade Hidrológica, para avaliar o processo dinâmico e temporal dessas estruturas nos anos de 2007 e 2017. Sistemas de Informação Geográfica (GIS) técnicas foram aplicadas com a aplicação da teoria da integração para investigar quais rios, pântanos, lagos, barragens estão conectados. De 2007 a 2017, foi observada uma redução de 8.686,42 para 8.686,42 km, totalizando 208,35 km da rede de drenagem. Também houve perda de 163,77 km de nascentes (24,10%) e redução do número de interações entre a rede hidrológica de 7.214 para 5.303. A atualização das informações sobre a extensão dos recursos hídricos complementada pela aplicação dos índices, ao expressarem o estado de configuração da paisagem, foram ferramentas importantes no diagnóstico da conservação dos ecossistemas, possibilitando análises precisas dos elementos que os compõem. A bacia hidrográfica apresentou redução da rede de drenagem em todas as regiões, o que consequentemente resultou em mudanças nos padrões de conectividade hidrológica, reduzindo o número de ligações quase pela metade. Esses fatores devem ser analisados detalhadamente no planejamento da bacia hidrográfica, principalmente em relação ao futuro da quantidade e qualidade dos recursos hídricos.

Palavras-chave: análise de paisagem, dinâmica da paisagem, rede hidrológica, rede de drenagem.

1. Introduction

Natural ecosystems are structured through the relationships between living beings and the environment, with human activities as the main responsible for their changes (Chapin III et al., 2002; Possamai; Gonçalves, 2018). In aquatic environments, especially in continental areas, events such as the transfer of matter and nutrients, the movement of organisms between compartments and the physical and chemical characteristics of a habitat depend on the patterns of hydrological connectivity in its various temporal and spatial scales (Soares et al ., 2010; Gooseff et al., 2017).

The floodplains are flooded areas during the rain period, having a complex structure due to the different succession stages between the water bodies, the flooded areas, and the terrestrial areas, reflecting in a mosaic resulting from the seasonal changes to a system is subjected periodically. Such areas are associated with the hydrological regime, which may cause the connection or fragmentation of aquatic landscapes (Ward et al., 2002; Belzen et al., 2017).

In this sense, the stability and consequently the resilience of aquatic ecosystems is important because floods can cause negative impacts, especially in small basins with inadequate spatial structure due to land use and coverage. In this way, land uses in different landscape structures can impact the ecological functions of ecosystems, requiring detailed knowledge of their structure and functioning (Izakovičová, 2010; Huang et al., 2017).

On a global scale, the effects of climate change interfere with the hydrological regime, due to periods of prolonged drought and the increased probability of events such as torrential rains (Sakamoto et al., 2007; Shenwen et al., 2017). Therefore, the approach of hydrological processes favors discussions about the importance of aquatic ecosystems and landscape protection in a hydrographic basin scale. These relationships between the elements of an ecosystem, such as the flows of energy, materials, and nutrients are affected by several factors, among them, the connectivity or fragmentation existing within an ecosystem or between different ecosystems (Crooks, 2006; Poulsen et al., 2015).

Hydrological connectivity is essential for understanding the various ecological processes, being understood as the transfer of water, matter, energy, and organisms from one part of the landscape to another (Wainwright, 2009; Soares et al., 2010; Gooseff et al., 2017). This is one of the main factors within a drainage network due to the unidirectional flow of water inside the network and this flow influences the physical characteristics and ecological processes of lotic and lentic ecosystems, being fundamental for the maintenance of its structure and functioning (Pringe, 2006; Lexartza-Artza; Wainwright, 2009).

In most cases, the construction of reservoirs interrupts the natural flow of the river, changing the speed and quantity of water flows, changing the temperature, the water transport and the distribution of sediment and organic matter between the landscapes (Pringle, 2003; Gooseff et al., 2017). In Australia, studies have shown that an increase of 1 m^3 in the storage capacity of a reservoir resulted in a reduction of 1 to 2.4m3 in the annual flow of the river (Sinclair, 2000; Neal et al., 2001; Sayles et al., 2017). Although the existence of small and medium-sized reservoirs spread over large extensions promotes water distribution and also saves energy. The study developed by Malveira et al., (2012) highlights that the buildings without taking into account the dynamics of the landscapes have been causing interference in the dynamics of the water flow, increasing the risk of rupture of the dams and causing the breach of hydrological connectivity.

In other parts of the world, reservoir networks and hydrological connectivity have also been studied, as in Australia (Nathan et al., 2005), Romania (Rãdoane; Rãdoane, 2005), Spain (Mamede, 2008), China (Li; Wei, 2008), in South Africa (Boardman; Foster, 2011) and in the United States (Hudson et al., 2012; Huang et al., 2017). The analysis of the hydrographic networks and the connectivity of the drainage networks subsidize the studies related to the regions planning in many cases of the reconstruction and recovery of regions affected by natural or man-made disasters (Nascimento, 2016).

The restoration of regions affected by human activities requires the development and integration of actions involving the hydrographic basin and all its components (Caseri, 2009; Nascimento, 2016). The applications of remote sensing and Geographic Information Systems have contributed to these analyzes, both for their ease in interacting with the environment, and for their strategic importance (Martini et al., 2006; Sayles et al., 2017). Liu (2006) states that among the main applications of LandSat satellite images, is the monitoring of droughts and floods of water bodies. Given these considerations, the aim of this work is to analyze the hydrological connectivity in Tietê-Jacaré Hydrographic Basin (SP) - Brazil, through the Hydrological Connectivity Index, in order to evaluate the dynamic and temporal process in 2007 and 2017.

2. Materials and Methods

2.1 Study area

The State Laws n.7.663, of 12/30/91 (São Paulo, 1991) and 9.934 of 12/27/1994 (São Paulo, 1994) institute the management of water resources in São Paulo state, which has been carried out through the Water Resources Management Units (WRMU) (CBH-SM, 2015). The state currently has twenty-two (22) WRMU, which were delimited from the concept of a river basin, according to which each unit encompasses the water resources that converge to a mainstream, necessitating a link between research and management.

The Tietê-Jacaré Hydrographic Basin (Figure 1) is 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. With a drainage area of 8,669.09 km, the Tietê-Jacaré Hydrographic Basin contains three main rivers: the Tietê River, the Jacaré-Guaçu River, and the Jacaré-Pepira River. The climate by classification of Köppen-Geiger is between humid tropical climate (from October to March) and dry winter (from April to September) (Tundisi et al., 2008; CBH – TJ, 2017).

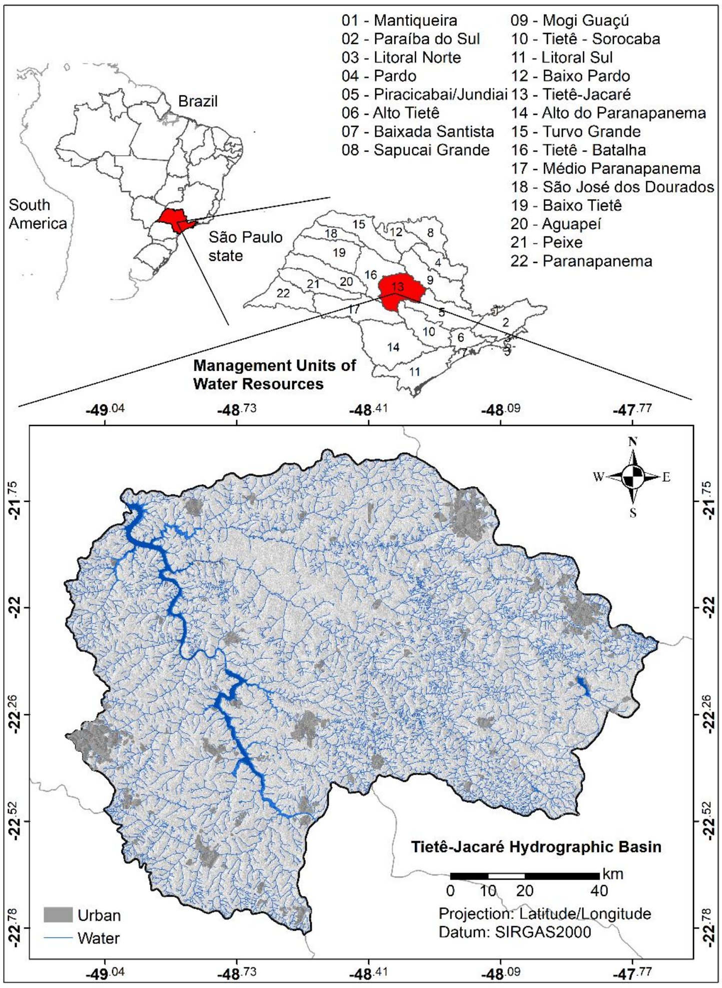


Figure 1. Tietê-Jacaré hydrographic basin – São Paulo State, Brazil.

The main economic activities are related to agroindustry (sugar, alcohol, and citrus processing). In the largest municipalities such as Bauru, São Carlos, Araraquara, and Jaú, other sectors of the industry such as paper, beverages, footwear, and metalworking also stand out (Tundisi et al., 2008; CBH – TJ, 2017). The region of the Tietê-Jacaré Hydrographic Basin is inserted in the biomes of the Atlantic Forest (23%) and Brazilian Savanna (Cerrado) (77%), considered biodiversity hotspots.

For presenting consolidated development characteristics, which integrate several municipalities with a high degree of urbanization and industrial and agricultural potential, and inserted in important regions of natural ecosystems, the Tietê-Jacaré Hydrographic Basin becomes a potential area for analyzing the connectivity relationships between the landscape compartments and their interrelationships with anthropic development and natural areas, assessing how they influence the conservation of ecosystems.

2.2 Methodology

The information was analyzed in Geographic Information Systems (GIS), using the ArcGis 10.5 and DepthMapX 0.5 software (Figure 2). For the landscape characterization, a georeferenced database of the Tietê-Jacaré Hydrographic Basin was prepared in the geographic projection latitude/longitude, datum SIRGAS2000 for the entire information plan. The delimitation of the Tietê-Jacaré Hydrographic Basin was obtained from the digital database of the Brazilian Institute of Geography and Statistics (IBGE), version 2015.

The files were imported into the Geographic Information System, which enabled the analysis and digital processing of the vector file, using the IBGE planialtimetric charts, acquired in an analog form on the 1:50,000 scale (IBGE, 1971). Through the digitalization on-screen, drainage lines were obtained, and the delineation of hydrographic sub-basins was obtained, acquired through the digitalization of territorial limits, determined and directed by the elevations of the land, present in the hypsometric classes.

The update of the drainage network for 2007 was based on the LandSat 5 images of April 21, 2007, and Digital Globe of July 14, 2007, acquired from Google Earth Pro 7.1 software, with 0.5-meter resolution. For 2017, the update was based on the LandSat 8 images of March 11, 2017, the Digital Globe of July 14, 2017, acquired from the Google Earth Pro 7.1 software, with 0.5-meter resolution and the Project of Ecological Restoration of the Permanent Preservation Areas of the Tietê-Jacaré Hydrographic Basin (Attanasio et al., 2014).

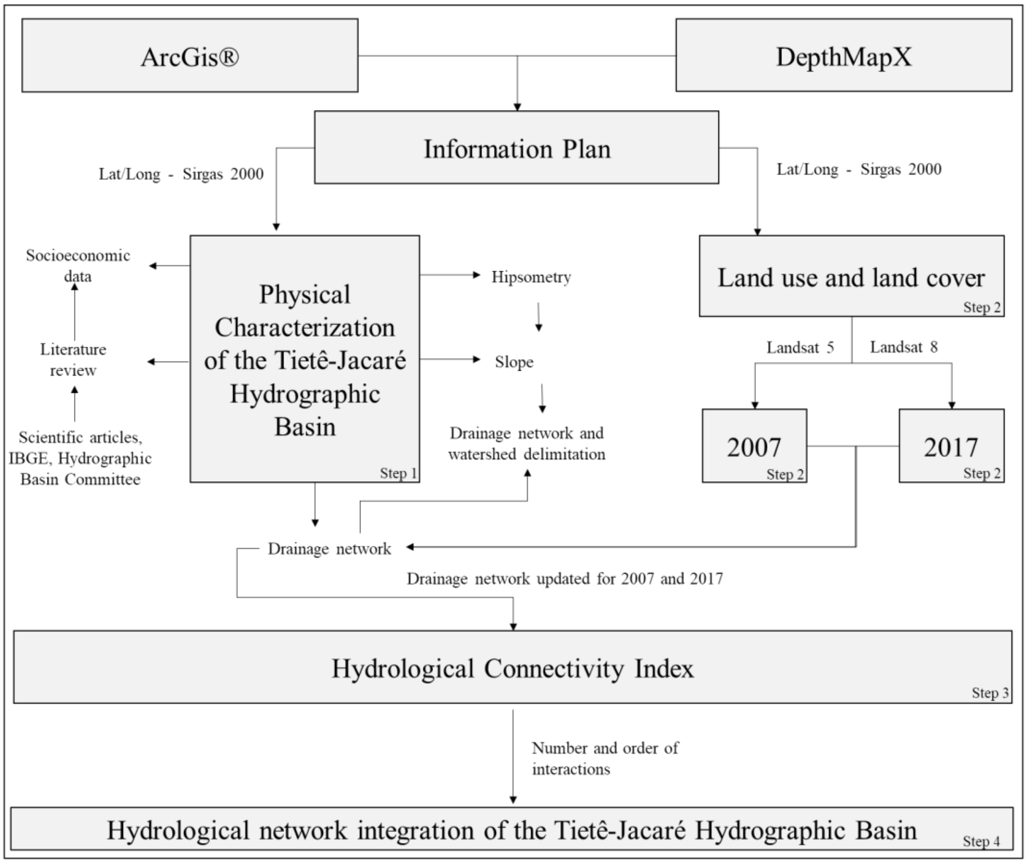


Figure 2. Work chart.

The use of different satellite scenes (USGS, 2017) occurred due to the unavailability of images by a single satellite during the study period, where the images used for this study had the same spatial resolution of 30 meters. The dates were selected according to the work schedule to be carried out, where the periods of March and April, due to the seasonality of the agricultural practices prevalent in the region. The 10-year difference between the images made it possible to study the temporal patterns of the landscape, essential in directing regional planning, which considered the current growth and development aspects.

2.3 Analysis of the hydrological network of the Tietê-Jacaré Hydrographic Basin

The methodology adopted by Weis et al (2013) was used for the hydrological connectivity analysis in 2007 and 2017, based on several authors who have been developing works related to hydrological connectivity in hydrographic basins (Caseri, 2009; Carvalho; Bin, 2012; Weis et al., 2013; Toledo, 2013; Muniz et al., 2017; Shenwen et al., 2017).

For example, the study by Caseri (2009) showed the hydrological topology of the Corumbataí River Basin - SP, evaluating the river segments, contribution areas, and dams that caused the break in connectivity, in addition to the construction of contribution areas, calculating the favorable flow and the distances within the drainage network, where the results were useful for the establishment of aquatic biodiversity conservation strategies in the region. The updated information on the drainage network (rivers, lagoons, dams) from 2007 and 2017 was used and these files were converted and worked in the DepthMapX 0.5 and ArcGis 10.5 software, being classified into rivers, lakes, and dams (as they are water bodies, they were analyzed together). After determining each class, the information was converted into a raster format using the “Polygon To Raster” and “Polyline To Raster” tools (Weis et al., 2013).

To analyze the number of connections of the water network in the analyzed periods, the tool "Groups" and "Region Group" was used, which identified the existing connections, considering the entire road network together, by means of the "pixel" analysis of the generated images by the “Overlay” tool, allowing the quantification and ordering of road connectivity in the hydrographic basin (Caseri, 2009; Weis et al., 2013).

This classification was performed using the “Eight” functions that define the connectivity between cells of the same value if they are within the immediate vicinity of each other (including right, left, above or diagonal) and “Within” that tests the connectivity between equal input values in the same zone, where the only cells that can be grouped are cells of the same value that meet the specified spatial connectivity requirements).

3. Results and Discussion

3.1 Drainage network of the Tietê-Jacaré Hydrographic Basin

The hydrography (drainage network) of the Tietê-Jacaré Hydrographic Basin (UGRHI 13) has an extension of 8,686.42 km and 23,123.28 ha of wetlands, bordering the Northeast with UGRHI 9 - Mogi-Guaçu, to the Southeast with UGRHI 5 - Piracicaba / Capivari / Jundiaí, to the South with UGRHI 10 - Médio Tietê-Sorocaba, to the Southwest with UGRHI 17- Médio Paranapanema and to the Northwest with UGRHI 16 - Tietê-Batalha (Comitê PCJ, 2007; CBH-TJ, 2017). It consists of 34 municipalities with headquarters in the UGRHI itself and another 3 municipalities with headquarters in other UGRHIs (Analândia, Matão and São Pedro) (Comitê PCJ, 2007; CBH-TJ, 2017). The Tietê-Jacaré Hydrographic Basin Committee (CBH-TJ) was created on 11/10/95 and officially installed on 10/09/1996, following the context of Art. 4 of the transitional provisions of Law No. 7663/91, where:

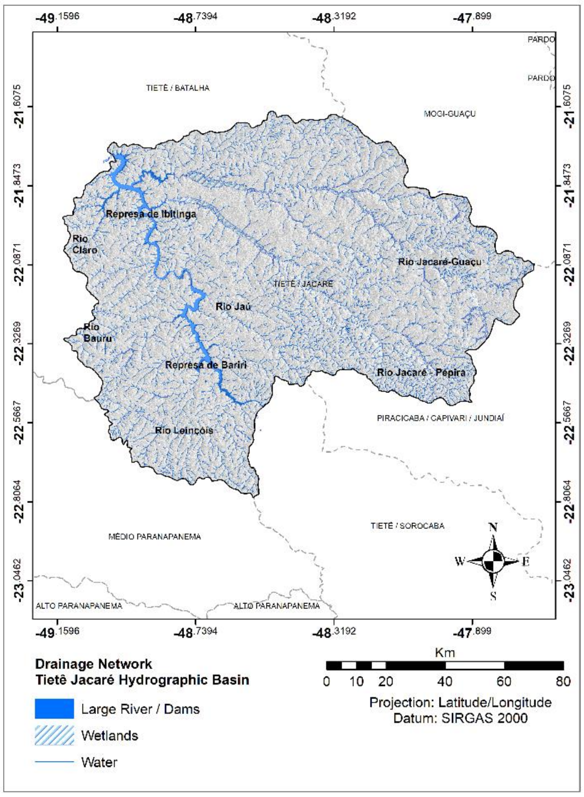
> Article 4 - Through the Integrated Management System - SIRGH, the State will ensure financial and institutional means to meet the provisions of Articles 205 to 213 of the State Constitution and especially for:
>
> I - rational use of water, surface and underground resources, ensuring priority use for supplying populations;
>
> II - maximization of the economic and social benefits resulting from the multiple uses of water resources;
>
> III - protection of water against actions that may compromise its current and future use;
>
> IV - defense against critical hydrological events, which offer risks to public health and safety, as well as economic and social losses;
>
> V - development of waterway transport and its economic use;
>
> VI - development of permanent groundwater conservation and protection programs against pollution and over-exploitation;
>
> VII - prevention of soil erosion in urban and rural areas, with a view to protecting against physical pollution and the silting up of water bodies.

The composition of its plenary takes place with the participation of twelve representatives of organized civil society, twelve representatives of the state and twelve representatives of the municipalities and its board is composed of a president, a vice president, an executive secretary, and an assistant executive secretary, that meet the demands of the hydrographic basin (SIGRH, 2016). Like the hydrographic basin, the basin committee is also the target of studies such as the one elaborated by Prota (2011), which analyzed the committee's participatory process and its implication in the implementation of water resources management instruments within the scope of the basin. The results pointed to the need to review the committee's statute in view of state and federal legislation, in addition to the need for greater disclosure of water resources issues in the hydrographic basin and in the state as a whole.

UGRHI 13 is sub-divided into 6 sub-basins: the Jacaré-Guaçu River sub-basin and Tietê River tributaries; the Jacaré-Pepira River Sub-Basin and tributaries of the Tietê River; the Rio Jaú Sub-Basin - Ribeirão da Ave Maria - Ribeirão do Sapé and direct tributaries of the Tietê River; the Lençóis River Sub-Basin - Ribeirão dos Patos and tributaries of the Tietê River; the Bauru River Sub-Basin - Ribeirão Grande - Ribeirão Pederneiras and tributaries of the

Rio Tietê and the Rio Claro Sub-Basin - Ribeirão Bonito - Ribeirão do Veado - Ribeirão da Água Limpa and tributaries of the Rio Tietê (Figures 3 and 4 and Table 1).

The two main sub-basins of the Tietê-Jacaré Hydrographic Basin are the Jacaré-Pepira and Jacaré-Guaçu River sub-basins. The sub-basin of the Jacaré-Pepira River rises at the border of the municipalities of Brotas and São Pedro (in the Serra de Itaqueri) and travels approximately 174 km to the right bank of the Tietê River, in the municipality of Ibitinga, being used for tourism purposes, economic development of the region (Comitê PCJ, 2007; CBH-TJ, 2017).



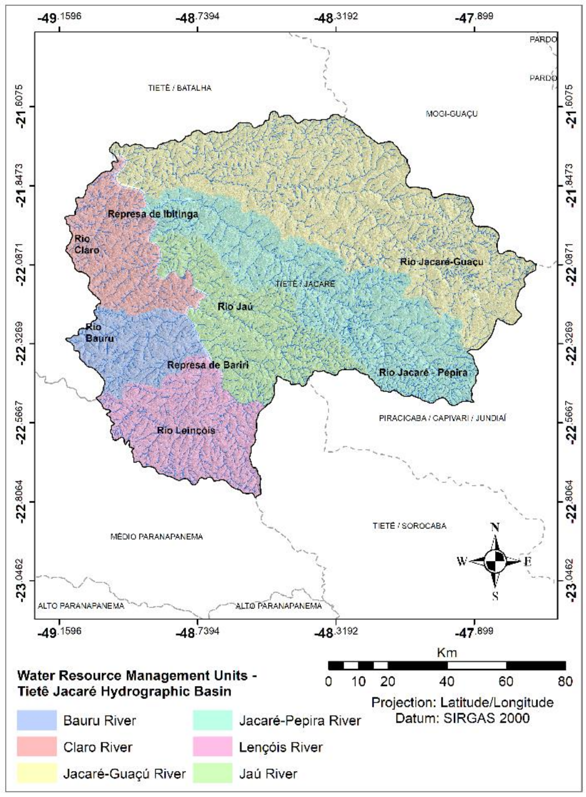


Figure 3. Drainage network of the Tietê-Jacaré hydrographic basin, and Figure 4. Distribution of Water Resource Management Units in the Tietê-Jacaré Hydrographic Basin.

The Jacaré-Guaçu River is a tributary north of the Tietê River and has eleven tributaries which are born at the confluence of Ribeirão Feijão and the Lobo River below the dam of the Represa do Broa on the border between the municipalities of Itirapina and São Carlos. The Jacaré-Guaçu River runs through the municipalities of Itirapina, São Carlos, Ribeirão Bonito, Araraquara, Gavião Peixoto, Nova Europa and flows into the right bank of the Tietê River within the municipality of Ibitinga.

Table 1. Distribution of Water Resource Management Units in the Tietê-Jacaré Hydrographic Basin in 2007 e 2017.

Sub-basin	**Area (ha)**	**%**	**2007**	**2007**	**Reduction**	**%**
Bauru River	83,195.00	7.04	619.10	589.84	29.26	4.73
Claro River	116,893.00	9.90	908.87	850.87	58.00	6.38
Jacaré-Guaçu River	418,920.00	35.46	2,940.59	2,908.15	32.44	1.10
Jacaré-Pepira River	266,157.00	22.53	2,163.30	2,119.34	45.96	2.03
Jaú River	153,582.00	13.00	1,148.27	1,132.72	15.55	1.35
Lençóis River	142,343.00	12.06	1,112.67	1,085.50	27.17	2.44
Total	**1,181,090.00**	**100.00**	**8,894.77**	**8,686.42**	**208.35**	**2.34**

According to the Water Resources Availability Report (São Paulo, 2017; CBH-TJ, 2017) the region has been critical in terms of surface water availability, with a probability of scarcity in the future due to the high demand in irrigation that contributes to the risk of groundwater pollution. As described by Kaiser (2006) and later by DAEE (2017) “in the main cities of the hydrographic basin such as Araraquara and São Carlos, the surface catchment represents 40 to 50% of the total catchment of the public network, generally destined to the population supply.

In most smaller cities, urban supply is preferably through wells, where since the 1970s, there has been an increase in the exploitation of underground water sources as a result of the water availability of the Bauru and Botucatu aquifers, combined with facilities in transport and treatment mainly because groundwater represents approximately 98% of the available fresh water suitable for human consumption (Kaiser, 2006; Tanajura, 2017).

3.2 Hydrological Connectivity of the Tietê-Jacaré Watershed

By updating the water bodies, was observed a reduction from 8,818.09 km to 8,686.42 Km from 2007 to 2017, totaling 208.35 km (2.34%) of the drainage network (Figure 5), where 163.77 km refer to the reduction of springs, with the most significant losses in the sub-basins of Rio Claro (-58 km), Jacaré-Pepira (-45.86 km) and Jacaré-Guaçu (-32.44 km).

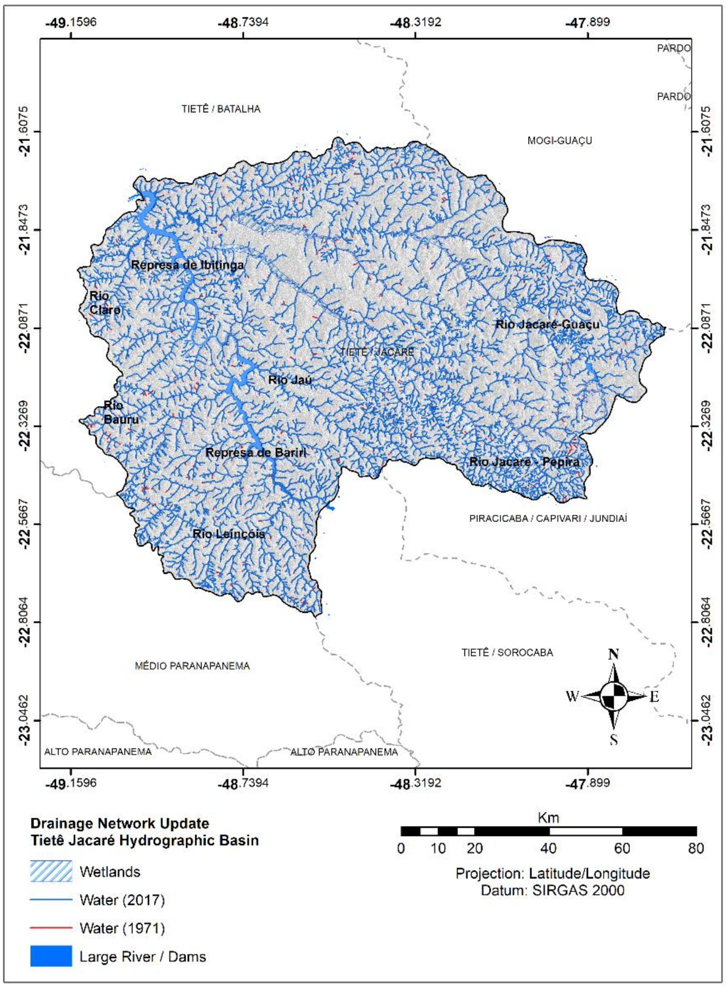


Figure 5. Update of the Tietê-Jacaré Hydrographic Basin drainage network in 2007 and 2017.

This reduction is noticeable throughout all territory, but in some regions, such as the municipalities of Ribeirão Bonito, Boa Esperança do Sul, Bocaina and Araraquara, these changes are more significant, mainly caused by the advances of human activities over natural landscapes, which occurred even in tourist-sized municipalities, such as Brotas.

According to the Hydrological Connectivity Index (Figure 6), the decrease in the drainage network, between 2007 and 2017, did not change the structural configuration of the hydrographic basin, where the main connectivities are related to the main drainage zones and their respective dominant rivers that they name the sub-basins (Bauru and Lençóis River of

4th order, Claro and Jaú of 5th order and Jacaré-Guaçu and Jacaré-Pepira River of 6th order), with the central decrease in hydrography being related to primary connectivities, that is, the springs.

The regions of the Jacaré-Guaçu and Jacaré-Pepira sub-basins have the greatest complexities and connections, mainly because they are, in the territory, the largest in the hydrographic basin, followed by the sub-basins of the Lençóis, Jaú, Claro and Bauru River, being the executory and the biggest connectivity in the region of the Ibitinga Reservoir in the Northwest direction of the basin, where the connection of the Tietê-Jacaré Hydrographic Basin with the Tietê -Batalha Hydrographic Basin begins (UGRH 16).

The reduction in the drainage network contributed to the decrease in connections between the interactions of the drainage network in the hydrographic basin, which showed an average reduction of 25.85%, considering rivers, dams, and lakes (Tables 2, 3 and 4). In 2007, dams and lakes showed a group of 873 interactions, falling to 661 in 2017, for rivers, the interactions dropped from 6,341 to 4,642 and added the interactions dropped from 7,214 to 5,303, totaling a decrease of 26.49%.

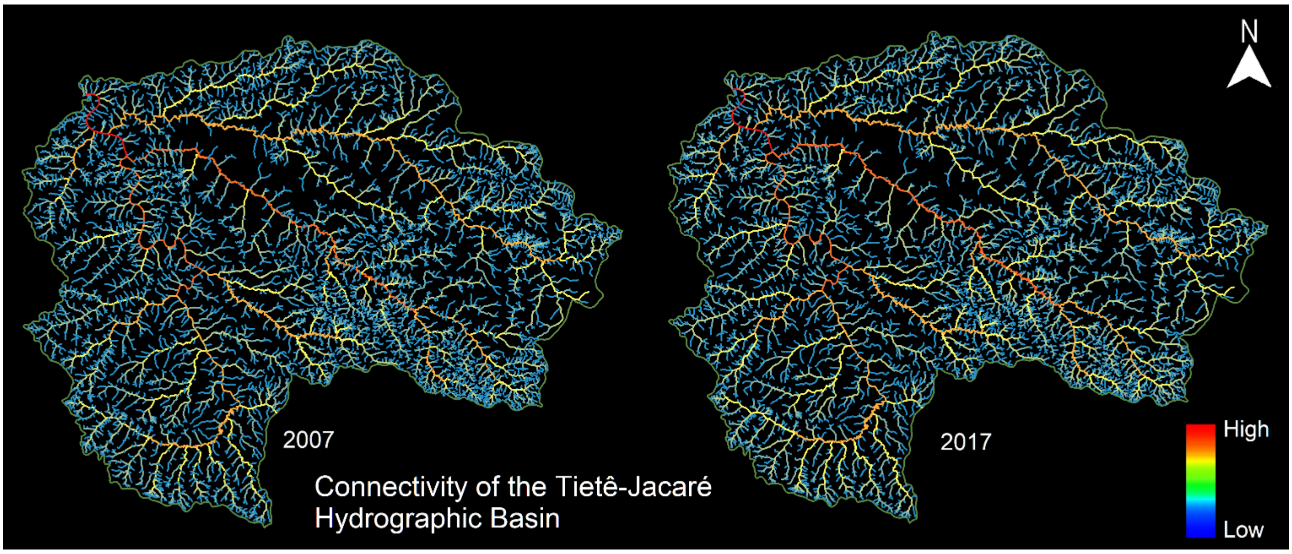


Figure 6. Hydrological Connectivity of the Tietê-Jacaré Hydrographic Basin in 2007 and 2017.

This decrease was similar in all regions of the hydrographic basin (Figure 3.7), with the Jacaré-Guaçu River sub-basin, where the municipalities of São Carlos, Araraquara, Ibaté, Matão, among others, presented the biggest reductions between interactions, areas that also suffered the biggest reductions in water, as seen in the update by satellite images. The Bauru River sub-basin is the region that obtained the worst results in terms of losses in the number of water resources, with a decrease of 33.26% of the interactions, a result to be considered, considering the fact that the region has since 2007, the lowest water availability among the sub-basins.

Table 2. Distribution of the number of interactions between dams and lakes in the Tietê-Jacaré Hydrographic Basin in 2007 and 2017.

Sub-basin	**Connection groups**				
	2007	**%**	**2017**	**%**	**Reduction (%)**
Bauru River	54	6.19	35	5.30	35.19
Claro River	112	12.83	88	13.31	21.43
Jacaré-Guaçu River	332	38.03	254	38.43	23.49
Jacaré-Pepira River	201	23.02	142	21.48	29.35
Jaú River	84	9.62	71	10.74	15.48
Lençóis River	90	10.31	71	10.74	21.11
Total	**873**	**100.00**	**661**	**100.00**	**24.28**

This reduction was also observed in other regions, as in the work developed by Gomes et al., (2018), which aimed to identify the degree of environmental degradation of water resources in the Tocantins Araguaia Hydrographic Region, through the Rapid Assessment Protocol for Ecological Integrity. The results showed that about 50% of the hydrographic basin presented environmental changes and 16% with impacted regions, presenting medium and great intensity of alteration of the natural conditions of the watercourses.

Table 3. Distribution of the number of interactions between rivers in the Tietê-Jacaré Hydrographic Basin in 2007 and 2017.

Sub-basin	**Connection groups**				
	2007	**%**	**2017**	**%**	**Reduction (%)**
Bauru River	421	6.64	282	6.07	33.02
Claro River	648	10.22	474	10.21	26.85
Jacaré-Guaçu River	1,961	30.93	1,483	31.95	24.37
Jacaré-Pepira River	1,744	27.50	1,317	28.37	24.44
Jaú River	778	12.27	545	11.74	29.95
Lençóis River	789	12.44	541	11.65	31.43
Total	**6,341**	**100.00**	**4,642**	**100.00**	**26.79**

The reduction of these water resources, in some cases, is associated with the natural regime of the water bodies as changes in the hydrological regime, however in the case of the Tietê-Jacaré watershed, in many regions, in addition to the reduction of water bodies, there is a modification in the flow of these by anthropic actions such as grounding in rural areas or the creation of channels in urban areas, as observed in São Carlos, which has channels in water resources that pass through the central region of the urban area.

Table 4. Distribution of the number of interactions between dams, lakes, and rivers in the Tietê-Jacaré Basin in 2007 and 2017.

Sub-basin	**Connection groups**				
	2007	**%**	**2017**	**%**	**Reduction (%)**
Bauru River	475	6.58	317	5.98	33.26
Claro River	760	10.54	562	10.60	26.05
Jacaré-Guaçu River	2,293	31.79	1,737	32.76	24.25
Jacaré-Pepira River	1,945	26.96	1,459	27.51	24.99
Jaú River	862	11.95	616	11.62	28.54
Lençóis River	879	12.18	612	11.54	30.38
Total	**7,214**	**100.00**	**5,303**	**100.00**	**26.49**

These data corroborate with the recent discussions about the possible water crisis in the 21st century, related much more to the lack of adequate management than to the real crisis of scarcity and stress (ROGERS et al., 2006). However, for other specialists, it is the result of a set of environmental problems aggravated by other problems related to the economy and social development (Gleick, 2000; Pellenz et al., 2018). The aggravation and complexity of the water crisis, mainly in the last few years, are due to real problems of availability, increased demand, a management process still sectorial and definitive response to crises and problems without a predictive attitude and a systemic approach (Somlyody; Varis, 2006; Pellenz et al., 2018).

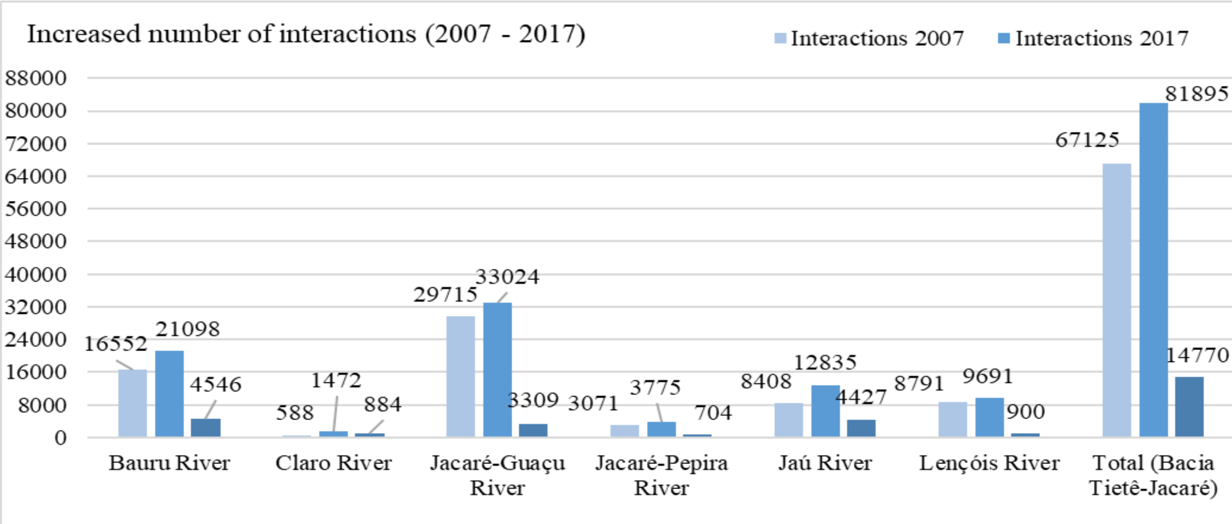


Figure 7. Number of interactions of the drainage network of the Tietê-Jacaré Hydrographic Basin in 2007 and 2017.

The volume and diversity of inland and surface water resources in Brazil are high, which provides the country with conditions for the use and multiple uses of water resources and, at the same time, increases the need for conservation, management and recovery programs for lakes, dams, rivers, swamps, coastal lagoons, and other inland waters. The set of inland waters in Brazil is, therefore, a complex system with great potential for use (Tundisi et al. 2006, Ribeiro, 2018).

The natural and anthropic aspects of river basins have direct and indirect consequences on their water system. The quality of the water in springs that make up a hydrographic basin is related to the amount of rain, land use in the basin, and the degree of control over the sources of pollution. Changes in water quality are directly related to changes that occur in the hydrographic basin, such as vegetation and soil (Santos; Pereira Filho, 2017).

There are several impacts related to the reduction of the drainage network, such as the modification of the hydrological cycle by decreasing the infiltration of the soil and replacement of ground and surface water or the appearance of floods in large and medium cities by the advance of runoff due to the channeling of water bodies. Numerous authors have been discussing the impacts on water resources, such as Arai (2012), Cruz (2015) and Silva et al., (2016), who debate the challenges of water resource management.

Peixoto et al., (2019) discuss the importance of integrated water resources management, which has the potential to develop effective solutions to various water problems, such as floods, floods and loss and reduction of water quality and quantity, with the ability to integrate between water resource policies and land use and coverage. The authors also emphasize that at the institutional level, in the Brazilian case, the main challenge is to articulate the interests of the various agents of society in land use policies with regional, state, or national water resources plans.

4. Conclusions

The hydrographic basin showed a reduction in the drainage network in all regions, which consequently resulted in changes in the hydrological connectivity pattern, reducing the number of connections by almost half. These factors must be analyzed in detail with regard to the planning of the hydrographic basin, mainly related to the future with regard to the quantity and quality of water resources, in surface and underground context.

Discussions related to the conservation of water resources are of great relevance and prominence in modern studies, since their lack of conservation is reflected in the reduction of quality and availability for the population. The importance of preservation areas in protecting and conserving water resources is increasingly emphasized since such regions act as a barrier and natural filters, mitigating the action of agricultural and industrial pollution.

Planning actions are fundamental not only in the scope of the hydrographic basin but in all Brazilian regions, in search of a set of strategic studies on the various topics related to water resources, such as water resources and energy, water resources and the economy, water and human health, water and global changes, water quality, in order to promote long-term visions and scenarios that encourage consolidated public policies (Tundisi, 2008; Pellenz et al., 2018).

The updating of the information on the extension of water resources complemented by the application of integration indexes, when expressing the state of landscape configuration, presented themselves as important tools in the diagnosis aimed at the conservation of ecosystems, enabling precise analysis of the elements that compose them. Such indexes allowed the temporal comparison of the studied region, allowing a projection on the impacts generated, which is essential in regional planning, as in the case of hydrographic basins. However, it is emphasized that the analysis of fragmentation and connectivity must always be contextualized, and its discussions based on the scale of analysis used, as this can imply changes in the observation of studies.

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Diego Peruchi Trevisan: conception and design, data acquisition, data analysis and interpretation, article writing and content review, and final approval of the version to be published and Luiz Eduardo Moschini: conception and design, data analysis and interpretation, article writing and content review, and final approval of the version to be published

7. Conflicts of Interest

No conflicts of interest.

8. Ethics Approval

Not applicable.

9. References

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