Analysis of the road connectivity: A case study in the Tietê-Jacaré Hydrographic Basin – SP, Brazil

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Abstract

The structures and dimensions of anthropized areas undergo a growing process of modification, where man-made land spaces unevenly alter their nature and composition, requiring a new definition and understanding of their boundaries. This transformation is a consequence of established socio-environmental, economic, and cultural relations. This work contemplates the evaluation of road connectivity present in the territory of the Tietê-Jacaré Hydrographic Basin - SP, through the application of the Integration Space Syntax indices, with the objective of evaluating the dynamic and temporal process of the road infrastructures in 2007 and 2017. Geographic Information Systems (GIS) techniques were used using the integration theory to investigate the road connection, applying the “Groups” tool that showed the connections based on the “pixel” analysis of the images generated by the Overlay tool. The axial map was elaborated, consisting of the analysis of the road network connections, considering all possible straight segments (axial lines) allowing the understanding of the road network connectivity in the Tietê-Jacaré Hydrographic Basin. By updating the road network, growth from 9,450.43km from 2007 to 13,082.88km in 2017 was observed, totaling an increase of 38.43%. The watershed increased road network in all regions, which eventually led to changes in road integration patterns, increasing the number of road network connections by almost one third (from 67,125 to 81,895). These factors should be analyzed detailed, mainly related to the future and quality of urban resources and territorial planning, both municipal and regional.

Keywords: environmental planning, landscape analysis, landscape indices, landscape ecology

Resumo

As estruturas e dimensões das áreas antropizadas passam por um processo crescente de modificação, onde os espaços de terra feitos pelo homem alteram de forma desigual sua natureza e composição, exigindo uma nova definição e compreensão de seus limites. Essa transformação é consequência das relações socioambientais, econômicas e culturais estabelecidas. Este trabalho contempla a avaliação da conectividade rodoviária presente no território da Bacia Hidrográfica do Tietê-Jacaré - SP, por meio da aplicação dos índices de Sintaxe Espacial de Integração, com o objetivo de avaliar o processo dinâmico e temporal das infraestruturas rodoviárias nos anos de 2007 e 2017. Foram utilizadas técnicas de Sistemas de Informações Geográficas (SIG) utilizando a teoria da integração para investigar a ligação rodoviária, aplicando a ferramenta “Grupos” que apresentou as ligações com base na análise “pixel” das imagens geradas pela ferramenta Overlay. Foi elaborado o mapa axial, que consiste na análise das ligações da malha viária, considerando todos os trechos retos possíveis (linhas axiais) permitindo o entendimento da conectividade da malha viária na Bacia Hidrográfica do Tietê-Jacaré. Com a atualização da malha rodoviária, observou-se um crescimento de 9.450,43km de 2007 para 13.082,88km em 2017, totalizando um aumento de 38,43%. A bacia aumentou a malha viária em todas as regiões, o que acabou levando a mudanças nos padrões de integração viária, aumentando o número de ligações da malha viária em quase um terço (de 67.125 para 81.895). Esses fatores devem ser analisados detalhadamente no que diz respeito ao planejamento regional, principalmente relacionado ao futuro e à qualidade dos recursos urbanos e ao planejamento territorial, tanto municipal quanto regional.

Palavras-chave: planejamento ambiental, análise da paisagem, índices paisagísticos, ecologia da paisagem.

Resumen

Las estructuras y dimensiones de las áreas antropizadas experimentan un proceso creciente de modificación, donde los espacios terrestres creados por el hombre cambian de forma desigual su naturaleza y composición, lo que requiere una nueva definición y comprensión de sus límites. Esta transformación es consecuencia de las relaciones socioambientales, económicas y culturales establecidas. Este trabajo contempla la evaluación de la conectividad vial presente en el territorio de la Cuenca Hidrográfica Tietê-Jacaré - SP, a través de la aplicación de los Índices de Sintaxis Espacial de Integración, con el objetivo de evaluar el proceso dinámico y temporal de las infraestructuras viales en los años 2007. y 2017. Se utilizaron técnicas de Sistemas de Información Geográfica (SIG) utilizando la teoría de la integración para investigar el enlace vial, aplicando la herramienta "Grupos" que presentó los enlaces a partir del análisis "pixel" de las imágenes generadas por la herramienta Superposición . Se elaboró un mapa axial, que consiste en analizar las conexiones de la red vial, considerando todas las posibles secciones rectas (líneas axiales) que permitan comprender la conectividad de la red vial en la Cuenca Hidrográfica Tietê-Jacaré. Con la actualización de la red vial se pasó de 9.450,43 km del 2007 a 13.082,88 km en el 2017, totalizando un incremento del 38,43%. La cuenca incrementó la red vial en todas las regiones, lo que eventualmente condujo a cambios en los patrones de integración vial, aumentando el número de conexiones a la red vial en casi un tercio (de 67.125 a 81.895). Estos factores deben ser analizados en detalle en lo que respecta a la planificación regional, principalmente relacionados con el futuro y la calidad de los recursos urbanos y la planificación territorial, tanto municipal como regional.

Palabras clave: planificación ambiental, análisis del paisaje, índices de paisaje, ecología del paisaje.

1. Introduction

The structures and dimensions of anthropized areas undergo a growing process of modification, where the spaces occupied by anthropic activities change their nature, composition and requiring a new definition of their limits (Santos, 2008; Malcolm; Lehman, 2017). This transformation of spaces is a consequence of the socio-environmental, economic, and cultural relations established, where, society, through the development of techniques, modifies the organization of spatial elements, producing environmental impacts at the various scales (Millennium Ecosystem Assessment, 2005; Intergovernmental Panel On Climate Change, 2018).

The cities, because are spaces of concentration and produce the necessary conditions for the productions, develop as support territory for the various activities. However, the urbanization increase is not only a condition for industrial development, but it has also changed the character of cities, making them the management center and economy control, also subordinating agricultural production, which occurs in the countryside (Sposito, 2005; Thornhill, 2018), being able to support the technological and financial revolution that originated the contemporary industrial era.

Transport is one of the most important functions of a city, and the urban structure is affected by the flow of movement. Urban road networks, as carriers of human activities, have been studied in terms of structural and dynamic characteristics for decades (Wang et al., 2018). The road network structure and connection are essential in the organization of cities and contributes to increasing the movement of urban areas, attracting enterprises that seek population flow, with a strong association between the way of articulating the road network and the accessibility potentials found for each axis on a road distribution (Medeiros, 2006; Liang et al., 2017).

Thus, there is a need to analyze urban infrastructures in the landscape over time and verify the organization and consolidation of the infrastructures, in order to enhance connectivity and urban occupation, reducing the need to replace new green areas for local and regional growth. The main benefits related to the configuration analysis of the road network are related to the assessment of the concentration of movement in the different urban stretches, contributing to the planning of undertakings, aiming or not at increasing or decreasing flows, according to the association between the articulation form of the road network and the accessibility potentials found for each region (Başer; Kubat, 2007; Carvalho; Saboya, 2017). Determining such changes will make it possible to assess the size of the various urban infrastructures, leading the results to the application of national and international conventions and action programs (SMA, 1995; OECD, 2017).

For example, the study developed by Lupinetti et al., (2018) aimed to understand the relationship between roads and forest dynamics in fragments of the Atlantic Forest, the provide information for planning road infrastructure and restoration projects. As expected, a positive relation was found with the variable "Average slope" and the variable "Distance from roads", in which steep terrain hinders anthropogenic disturbance, which benefits the regeneration of the forest and the greater the distance from the roads, better the regeneration of fragments.

In this sense, the Spatial Syntax theory, formulated by Hillier and Hanson in 1984, is used to analyze the interactions and connections between society and space. This method seeks to evaluate spatial patterns by studying the road configuration of urban landscapes and how they are used and connected, trying to understand, through the use of computational techniques and models, the direction of the configuration of the road space, associating values and expressions for the analysis of urban geographic space (Carmo et al., 2012; Liang et al., 2017).

In view of these considerations, this work aims to analyze the road connectivity present in the territory of the Tietê-Jacaré Hydrographic Basin – SP, Brazil in order to assess the dynamic and temporal process of road infrastructures in the years 2007 and 2017, through the application Integration and Spatial Syntax indexes.

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 8,669.09km, 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).

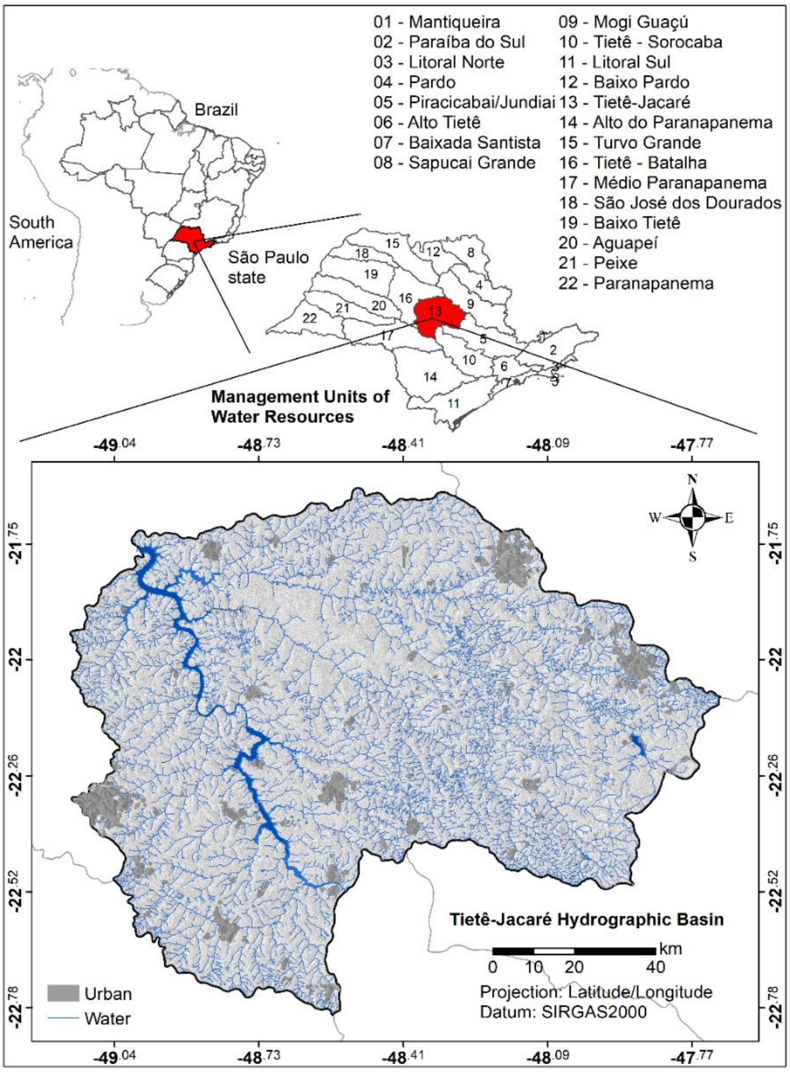

Figure 1. Tietê-Jacaré Hydrographic Basin - SP, Brazil. Source: Authors, 2022.

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.

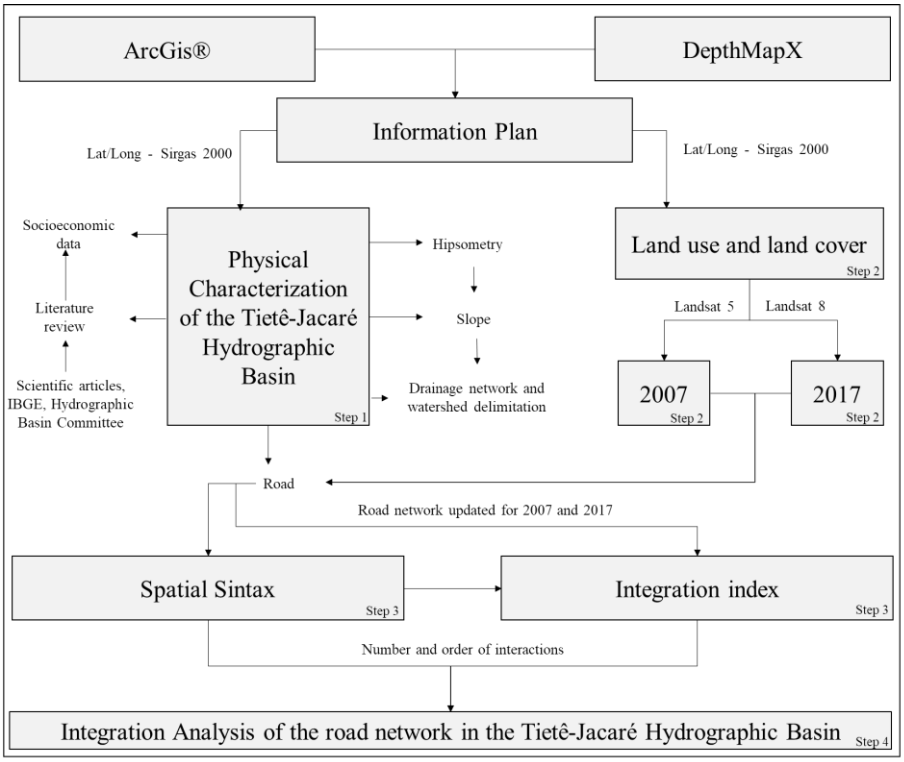

Figure 2. Work chart. Source: Authors, 2022.

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). The road network thematic map was obtained by screen digitizing based on the IBGE planialtimetric charts. The road network update for 2007 was carried out based on the 2007 Brazilian Digital Network prepared by IBGE, in the LandSat 5 images of April 21, 2007, and Digital Globe of July 14, 2007, acquired from Google Earth Pro 7.1 software, with 0.5m resolution. For 2017, the update was carried out based on the LandSat 8 image of March 11, 2017, and the World Street Map image of July 14, 2017, with 0.3m resolution.

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 Road network analysis of the Tietê-Jacaré Hydrographic Basin

For the road network analysis, the network integration methodology adapted by Weis et al., (2013) and Hillier's; Hanson (1984) Space Syntax theory were used in order to analyze the road connections in the Tietê-Jacaré Hydrographic Basin region. These methods evaluated the number of interactions, as well as the patterns and spatial configurations of urban landscapes and how they are connected. Seeking to understand through the use of computational techniques and models, the direction of the configuration of the road space, associating values, and expressions for the analysis of the urban geographic space of the study area (Carmo et al., 2012; Trornhill et al., 2017).

Several authors have been developing works related to network integration and Spatial Syntax, internationally (Ferguson, 2007; Kim et al., 2007; Başer; Kubat, 2007; Trornhill et al., 2017) and in Brazilian context (Barros, 2006; Jales, 2009, Carvalho; Saboya, 2017). The work developed by Kubat et al., (2007) used Spatial Syntax under the concept of pedestrian displacement, in addition to investigating the transport and traffic system flows, which differ from pedestrian movement. Therefore, in order to represent the road network for the movement of vehicles, a new map was created for Istanbul, demonstrating the dominant character of roads and their effects on land use and coverage and, thus, the possible orientation of expansion urban development in the region.

In Brazil, Carvalho and Saboya (2017) aimed to investigate the configurational characteristics of the roads where the residential verticalization process took place in Florianópolis, Santa Catarina state. The results indicated that the location logic of vertical residential buildings in the city is mainly related to the measure of local choice, with a greater concentration on roads that channel flows used to reach other parts within a local system, making their location locally central.

For the study of the road network in the Tietê-Jacaré Hydrographic Basin with Spatial Syntax, an axiality map was drawn up, which consists of analyzing the connections of the road network, considering all possible straight-line segments (axial lines) and by crossing the axial lines between them. By the insertion of these data in the software DepthMapX 0.5 (UCL, 2019) and ArcGis 10.5, the degree of connectivity and ordering of urban network connections were evaluated (Medeiros, 2006; Liang et al., 2017).

The connectivity of each line was limited by the number of lines that intercept it, other quantitative values used were also measures of analysis properties, among them, the control, the depth, and the global and local integrations. The control measured the dependence in terms of spatial accessibility that a line has over the others connected to it. Connectivity and depth are related to global integration, which is the measure of the integration of a line with all lines in the system. Depth is the number of steps from one line to another or the number of steps from one point in relation to any other in the system, the greater the more intermediate spaces there are (Carmo et al., 2012; Trornhill et al., 2017).

The average depth (MD) of a given node in the system was obtained by adding the depths in relation to the other nodes (total depth), dividing by the number of spaces in the system, minus 1, according to the equation:

$$AD = \frac{Dr}{K-1}$$

Where:

AD: Average depth of the line in relation to the others;

TD: Total depth;

K: Number of spaces (lines or nodes) in the system.

The Relative Asymmetry (RA) variable indicates the levels of system integration, which in the Spatial Syntax theory, corresponds to the number of changes in direction, that is, change from one axial line to another subsequent one of the systems, necessary to arrive from one place to another. Such calculations resulted in the global integration map (Spatial Syntax), allowing an understanding of the connectivity of road networks in the watershed (Carmo et al., 2012; Trornhill et al., 2017) and the generation of the vector map with the axial lines. The values found for the depth were used to find the relative asymmetry (RA), given by the equation:

$$RA = \frac{2(AD-1)}{K-2}$$

Where:

RA: Relative asymmetry;

AD: Average depth of the line in relation to the others;

K: Number of spaces (lines or nodes) in the system.

The updated information from the 2007 and 2017 road networks (streets, roads, and highways) and analyzed by the Space Syntax were used to calculate the ordering and interactions of the road network in the Tietê-Jacaré River Basin. These files were converted and for the ArcGis 10.5 software and after the determination of each class, the information was converted into a raster format using the "Polygon To Raster" tool (Weis et al., 2013).

To analyze the number of road network connections in the analyzed periods, the "Groups" and "Region Group" tool was used to identify the existing connections, considering the entire road network together, through 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 by means of 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

The road network in the Tietê-Jacaré Hydrographic Basin has an extension of 13,082.88km (Figure 3 and Figure 4) and has thirty-three highways, six of which are major in length: Highway Washington Luís (SP-310), Comandante João Ribeiro de Barros Highway (SP-255), Engenheiro Paulo Nilo Romano Highway (BR-369; SP-225), Marechal Rondon Highway (SP-300), Deputado Leônidas Pacheco Ferreira Highway (SP-304) and Luís Augusto de Oliveira Highway (SP-215).

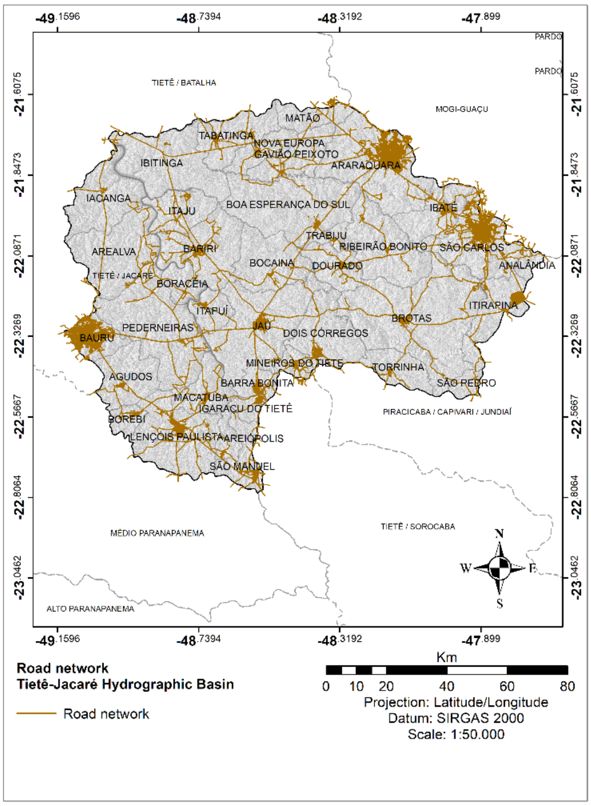

Figure 3. Road network of the Tietê-Jacaré Hydrographic Basin

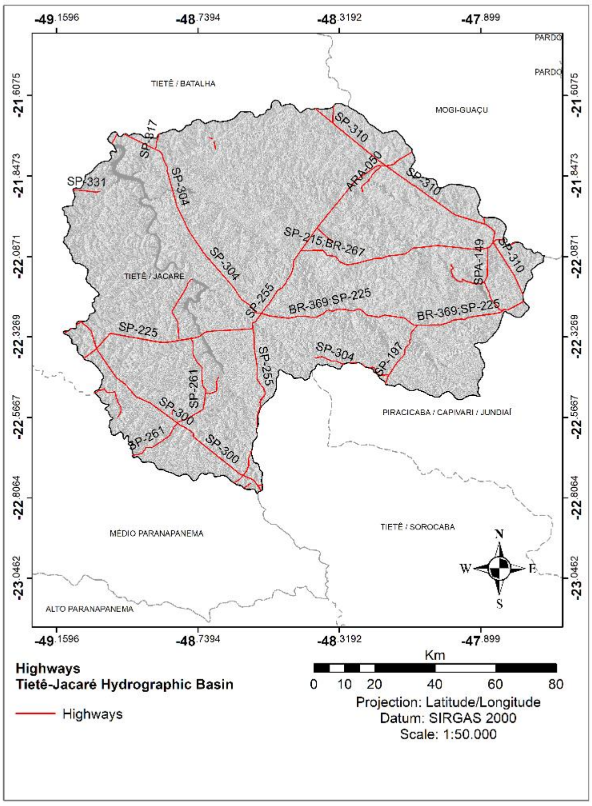

Figure 4. Main highways of the Tietê-Jacaré Hydrographic Basin. Source: Authors, 2022.

According to Castro (2008), this road extension expanded mainly between 1870 and 1930, where the process of territorial occupation took place in the region, through the urban network was structured, in addition to consolidating the transport infrastructure with highways, railways, and waterways. The hydrographic basin (Table 1) presents the Washington Luiz Highway (SP-310) as the main access route, starting at kilometer (Km) 145 of the Highway Anhanguera (SP-330) and has its route from the Northwest direction to North, passing through the municipalities of Araraquara, São Carlos and Ibaté (Alberto, 2003; DER, 2019).

In the East-West direction, the SP-331 (Hilário Spuri Jorge Highway) stands out, which goes to the Northwest of the hydrographic basin, passing through Ibitinga municipality. Another important access is the Marechal Rondon Highway (SP-300), which runs through the region along its southern in São Manuel municipality, heading north-west and crossing Bauru municipality (Alberto, 2003; DER, 2019).

Table 1. Distribution of highways in the Tietê-Jacaré Hydrographic Basin.

Name	Reference	km
Highway António Machado Sant'Anna	SP-255	15.49
Highway Brigadeiro Faria Lima	SP-326	11.76
Highway Carlos Aravechia	-	1.16
Highway César Augusto Sgavioli	-	22.26
Highway Cezário José de Castilho	SP-321	3.78
Highway Chico Landi	SP-251	2.80
Highway Comandante João Ribeiro de Barros	SP-255	174.61
Highway da Amizade	BRI-002	16.01
Highway of Access SP-331	-	2.86
Highway Deputado Amauri Barroso de Sousa	SP-304	19.85
Highway Deputado João Lázaro de Almeida Prado	SP-255	39.32
Highway Deputado Leônidas Pacheco Ferreira	SP-304	76.49
Highway Domingos Innocentini	SPA-149/215	28.64
Highway Dr Antônio Piva	SP-197	22.45
Highway Dr Maurício Antunes Ferraz	SP-317	5.11
Highway Dr. Paulo Lauro	SP-215; BR-267	5.17
Highway Engenheiro João Baptista Cabral Rennó	SP-225	4.43
Highway Engenheiro Paulo Nilo Romano	BR-369; SP-225	171.66
Highway Engenheiro Thales de Lorena Peixoto Juni	SP-318	2.21
Highway Geraldo de Barros	SP-191	1.43
Highway Hilário Spuri Jorge	SP-331	8.28
Highway João Schmidt	-	6.57
Highway João Mellão	SP-255	3.77
Highway Lauro Peragolli	MTB-020	8.30
Highway Luís Augusto de Oliveira	SP-215; BR-267	64.85
Highway Macatuba / Usina São José	LEP-060	1.82
Highway Marechal Rondon	SP-300	159.90
Highway Municipal Ayrton Senna	SPA-097/225	11.39
Highway Municipal Domintini	SPA-149/215	0.08
Highway Osni Mateus	SP-261	52.25
Highway Otavio Pacheco de Almeida Prado	-	6.61
Highway Vicinal Abílio Augusto Corréa	ARA-050	10.89
Highway Washington Luís	SP-310	184.45

Source: Authors, 2022.

Also, the SP-225 (Antônio Machado Sant'Anna Highway) crosses the hydrographic basin in the West-East direction, passing through the municipalities of Bauru, Pederneiras, Jaú, Brotas, and Itirapina. The SP-215 highway crosses the region from Northeast to South, passing through the municipalities of Araraquara, Boa Esperança do Sul, Jaú, Barra Bonita, Igaraçu do Tietê and São Manuel. The SP-304 (Deputado Leônidas Pacheco Ferreira Highway) runs through the Northwest to South basin, passing through the municipalities of Ibitinga, Bariri, Jaú, Dois Córregos and Torrinha (Alberto, 2003; DER, 2019).

3.1. Road connectivity in the Tietê-Jacaré Hydrographic Basin

By updating the road network using satellite images, it was observed an increase from 9,450.43km in 2007 to 13,082.88km in 2017, totaling an increase of 38.43% or 3,632.45km (Table 2 and Figure 5). This growth is mainly correlated with the expansion of urban areas in the municipalities (data obtained through the analysis of land use and land cover in 2007 and 2017, pointed a growth of 7,832.67ha), with the highways and roads already had been consolidated since 1971, as noted in the IBGE planialtimetric charts.

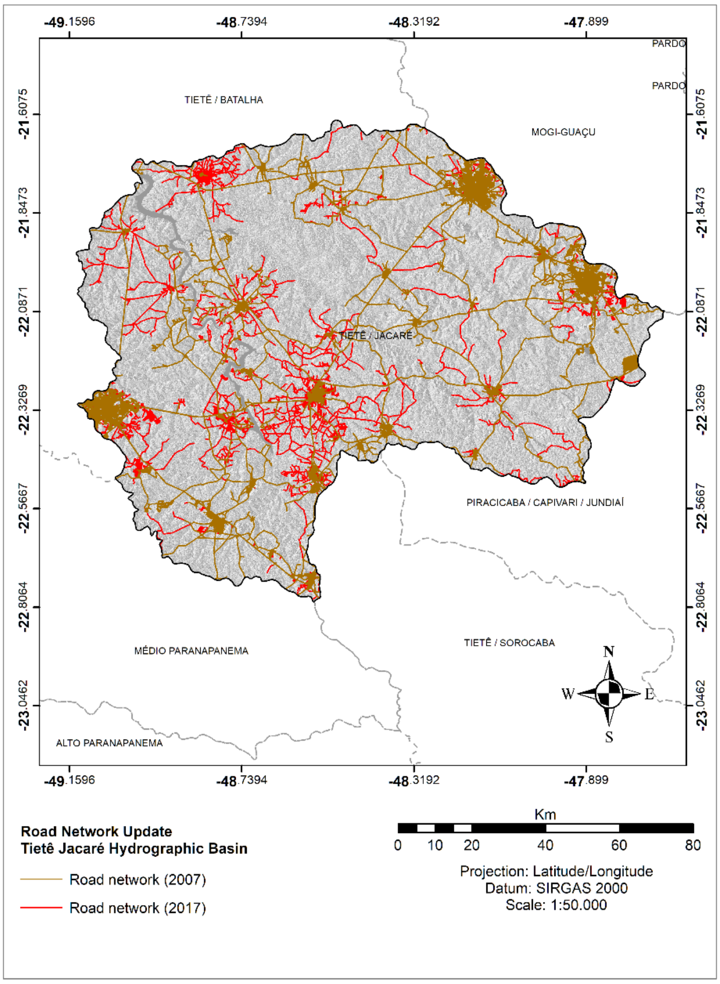

Figure 5. Update of the road network of the Tietê-Jacaré Hydrographic Basin in 2007 and 2017. Source: Authors, 2022.

The growth of the road network is observed in all municipalities, but it is mainly correlated to larger cities, such as Jaú and Bauru, with an increase of 86.69% in the Jaú sub-basin region and in the Rio Claro sub-basin with an increase of 121.88%.

Table 2. Growth of the road network in the Tietê-Jacaré Watershed in 2007 and 2017.

Sub-basin	Area (ha)	%	Road (2007)	Road (2007)	Increase	%
Bauru River	83,195.00	7.04	1,708.85	2,379.00	670.00	39.20
Claro River	116,893.00	9.90	263.37	584.36	321.00	121.88
Jacaré-Guaçu River	418,920.00	35.46	4,112.03	4,993.00	881.00	21.42
Jacaré-Pepira River	266,157.00	22.53	776.65	1,149.83	373.00	48.05
Jaú River	153,582.00	13.00	1,296.74	2,420.91	1,120.00	86.69
Lençóis River	142,343.00	12.06	1,292.79	1,555.78	267.45	20.36
Total	**1,181,090.00**	**100.00**	**9,450.43**	**13,082.88**	**3,632.45**	**38.43**

Source: Authors, 2022.

The structure of this growth was observed by the Spatial Syntax Index (Figure 6), which demonstrated that the configuration of the road network in the Tietê-Jacaré Hydrographic Basin, between 2007 and 2017, underwent few structural changes in the connection between the municipalities, with the growth of the road network mainly related to urban expansion within each municipality.

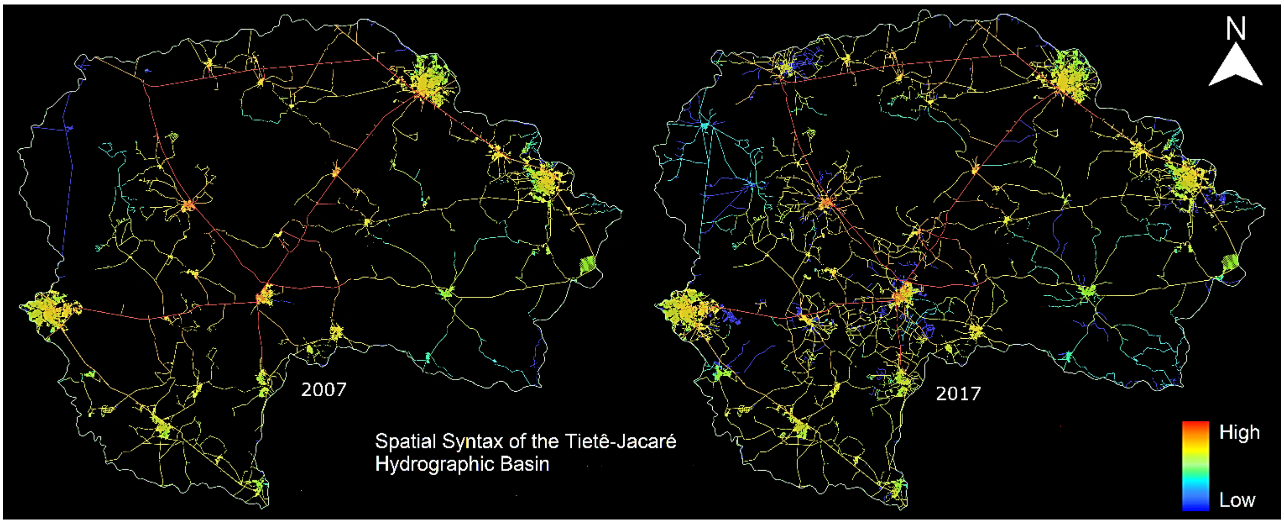

Figure 6. Spatial Syntax of the Tietê-Jacaré Hydrographic Basin in 2007 and 2017. Source: Authors, 2022.

In 2007, about 2.75% of the road network (260km) had little or no connectivity and in 2017 this number increased to 5.02% (654km) and the areas with high connections went from 6,953km to 9,213km. In both periods, the main highways, that connecting the municipalities in the region are SP - 310 (Washington Luiz), SP - 304 (Luiz de Queiroz Highway), SP - 255 (António Machado Sant'Anna Highway), SP - 300 (Marechal Rondon Highway) and SP - 2015 (Municipal Domintini Highway), which make connections towards the main municipalities in the region and their sub-regions, being Bauru, São Carlos, Araraquara, Jaú, and Lençóis Paulistas.

The regions that showed greater isolation from the others are Arealva and Iacanga at the end of the Rio Claro sub-basin (their connection is low due to the presence of the Ibitinga dam) and in Torrinha and Águas de São Pedro (low connection due to environmental characteristics regions, such as mountain ranges and slopes), at the extreme of the Jacaré-Guaçu River sub-basin.

The growth of the road contributed to the increase in the number of interactions of the network in the hydrographic basin, which showed an average growth of 45% (Table 3). In 2007, the total number of connections was 67,125, rising to 81,895 in 2017, totaling an increase of 14,770 interactions or 22%. The region has six orders of streets, with secondary streets as predominant, with 58,439 or 87.06% in 2007 and 69,864 or 85.31% in 2017.

This growth was similar in all the regions of the hydrographic basin (Figure 7), with the regions of the Jacaré-Guaçu River sub-basin, where the municipalities of São Carlos, Araraquara, Ibaté, Matão, among others are located, presented the greater number of interactions, totaling 40% of the entire road network. The Rio Claro sub-basin is the region that had the highest growth in the period studied, with the growth of 150%, however, this is associated with the fact that the region has, since 2007, had the lowest road availability among the sub-basins.

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

Sub-basin	**Interactions 2007**	**%**	**Interactions 2017**	**%**	**Increase %**
Bauru River	16,552	24.66	21,098	25.76	27.46
Claro River	588	0.88	1,472	1.80	150.34
Jacaré-Guaçu River	29,715	44.27	33,024	40.32	11.14
Jacaré-Pepira River	3,071	4.58	3,775	4.61	22.92
Jaú River	8,408	12.53	12,835	15.67	52.65
Lençóis River	8,791	13.10	9,691	11.83	10.24
Total	**67,125**	**100.00**	**81,895**	**100.00**	**22.00**

Source: Authors, 2022.

Such growth was also observed in the work developed by Leite et al., (2012), which aimed to carry out the temporal assessment of urban growth, by supervised classification of images from the LandSat 5 satellite between 1975 and 2010 in the Reserva da Biosfera do Cinturão Verde, located in the Metropolitan Region of São Paulo - SP. The authors found areas that had suppressed forest-sized vegetation fragments and brought an interpretation of urban growth that was characterized by assuming a radial shape, following the axes of the main highways, which expanded the possibilities of connections and propagation of its impacts to more peripheral areas of the studied region.

This development corroborates with the information provided by the São Paulo State Highway Department (DER, 2019) which shows that the total road network in the São Paulo state in 1988 was 24,548mkm, moving to a projection of 42,000 km in 2020, being the largest state road transport system in Brazil. With the city of São Paulo as its center, the main highways that connect the surrounding regions were built in the 50s and 60s and doubled from the 70s.

For example, Anhanguera Highway (SP-330) that crosses the Campinas Region; Dutra (BR-116) which passes through the Paraíba Valley towards Rio de Janeiro; the Raposo Tavares Highway (SP-270) in the west direction, crossing the Sorocaba region; and the Anchieta Highway (SP-150) that connects the capital to the port of Santos (SEADE, 2019). In the 1970s and 1980s, other large highways were built in parallel to those already existing. These are the cases of the Ayrton Senna / Carvalho Pinto system (SP-070), parallel to Via Dutra, from Imigrantes (SP-160), next to Anchieta, and the Bandeirantes Highway (SP-348), which follows alongside Anhanguera (SEADE, 2019).

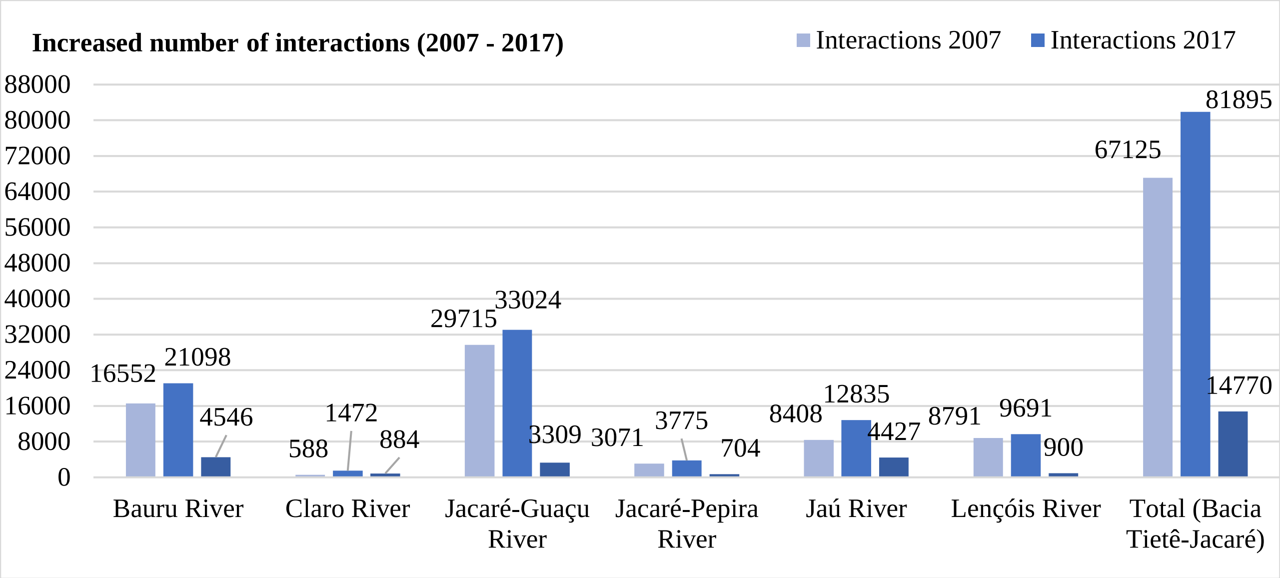

Figure 7. Number of interactions of the road network of the Tietê-Jacaré Hydrographic Basin in 2007 and 2017. Source: Authors, 2022.

Although this study does not have the objective of evaluating the environmental impact of the expansion of the road network over the analyzed period, it is important to emphasize that such development needs a planning process, since there are several impacts caused by urban expansion under different ecosystems. Such as suppression of vegetation and terrestrial and transient environments, barriers for animal movement and scavenging of fauna, the proliferation of vectors and reservoirs of diseases and accumulation of residues, alteration of the geomorphological surface, erosion, silting and flooding, alteration of parameters physical and chemical properties of the soil, changes in the quality of surface and groundwater.

The work developed by Felipe Junior; Pinheiro (2019), discusses the importance and impacts of urban and road expansions, carrying out an analysis of road transport in the state of Sergipe, considering the economic reflexes, state planning, public and private investments, and the existing bottlenecks. According to the authors, investments in transport infrastructure were and continue to be important for economic development, territorial ordering, with impacts on circulation, spatial interactions, productive activity, the tertiary sector, and others.

4. Conclusions

The road network grew in all hydrographic basin, which consequently culminated in changes in the patterns of road integration, increasing the number of connections between the road network by almost a third. These factors must be analyzed in detail about regional planning, mainly related to the future and quality of urban resources and territorial planning, both municipal and regional.

The debate on urban spatial planning, the extension of the road network, and its impact on society generate great repercussions, affecting various sectors of management, such as transport, security, health, and ecosystems conservation. The 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 themes related to territorial planning and urban growth, such as urban growth and energy, territorial planning and economy, transport and quality of life, urban pollution and global changes, in order to promote long-term visions and scenarios that encourage consolidated public policies (Tundisi, 2008; Pellenz et al., 2018).

The update of the information on the extension of the road network complemented by the application of the Integration and Spatial Syntax indexes, when expressing the state of landscape configuration, presented themselves as important tools in the diagnosis of spatial planning, essential for the development of conservation actions of both urban and environmental ecosystems, enabling precise analysis of the elements that compose them. Such indices 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 noted that structural analyzes should always be contextualized and their discussions based on the scale of analysis used, as this may imply changes in the observation of studies.

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