Periódico Eletrônico "Fórum Ambiental da Alta Paulista"
Electronic Journal "Environmental Forum of Alta Paulista"

ISSN 1980-0827 – Volume 19, Number 5, Year 2023

Multitemporal land use and occupacion and morphometric analysis of the Aranha Stream watershed in Itapeva-SP

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ISSN 1980-0827 – Volume 19, Number 5, Year 2023

SUMMARY
From the beginning of the last century to the present day, Brazil has had a great migration of people from rural to urban areas. It resulted, many times, in a disorderly growth of cities and occupation of potentially floodable areas, which with the waterproofing of the soil potentiated such effects and, with the constant expansion of urban areas, tends to increase extreme events. The objective of the present work was to analyze the evolution of land use and occupation between the years 1991 and 2020, in addition to studying the morphometric parameters of the Aranha Stream watershed, in the municipality of Itapeva-SP. These analyzes were carried out with the aid of LANDSAT5 and LANDSAT8 satellite images, in addition to the SRTM digital elevation model, using the SPRING 5.4.3 software. The results indicated a growth of about 88% in the urban area within the basin throughout the study period, with a large part of this expansion in an area where floods were already observed, in the channeled part from the watercourse. Finally, the results from the morphometric analysis also showed medium to low tendencies to natural floods.

KEYWORDS: Morphometry. SPRING. Geographic Information System.

1 INTRODUCTION

The population increase and the growing Brazilian urbanization that has been taking place since the beginning of the last century have caused sudden changes in land use and occupation. Santos (2019) points out that only between the decades of 1990 to 2010, there was a population growth from 75,59% to 84,36%. This unplanned expansion in potentially problematic regions, coupled with canalization and rectification of waterways, can potentiate the occurrence of flooding in naturally floodable areas (FRITZEN; BINDA, 2011; BENTOS et al. 2021).

In this context, it is important to know the physical characteristics of the basin and its use and land occupation, which can help in the analysis of the natural tendency to flood (VILLELA; MATOS, 1975) and, consequently, in urban planning in order to minimize social and environmental impacts. Commonly in these studies, the use of geotechnologies and remote sensoring products is made for the analysis of morphometric parameters of watersheds and determination of land use and occupation (SILVA, 2018).

The dissemination of free terrain elevation data, especially those made available by the United States Geological Survey, from the Shuttle Radar Topography Mission (SRTM) (USGS, 2022), the Digital Elevation Models (DEM), added to the Georeferenced Information Systems (GIS) software, assist in obtaining morphometric information of watersheds. Satellite imaging, analyzed over a period of time, also helps understanding the transformation of land use and occupation and can indicate potential environmental risks in this growth and establish guidelines for the most appropriate urban expansion (RODRIGUES et al., 2020).

The Aranha Stream is located in the Upper Paranapanema Watershed (UGRHI 14), with source in the municipality of Itapeva, São Paulo, and mouth in the Pilão d'Água Stream. The study area receives runoff from a considerable urbanized part of the city. According to the Upper Paranapanema Basin Committee (CBHALPA, 2021) the watercourse is of class 4, which means it is intended for less demanding uses and landscape harmony.

Historically, the city developed on the left bank of the stream which, with urbanization was channeled. With the expansion of the urban area in recent decades, can be noticed the process of subdivision and soil sealing on the right bank of the stream, which historically presents floods in lower areas and areas with lower slope, occupied over the years, thus causing impacts to the residents of this region.

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Many studies have been developed, evaluating data from morphometric parameters and dynamics of land use and occupation, separately or integrated, to determine sensitive areas in basins and, especially in regions that suffer intense urbanization processes in recent decades, as shown in the studies of Oliveira, Acorsi and Smaniotto (2018), Miguel et al. (2013) and Souza and Félix (2017), given the importance of these analyses for the understanding of the impact generated by this phenomenon.

That said, there is a need for an analysis of land use and occupation over the last decades and of the morphometric characteristics of the Aranha Stream watershed in order to determine its morphometric parameters, analyze the susceptibility of the watershed to natural flooding events, and, based on the use and occupation maps, assist in urban expansion planning in order to reduce impacts in the region.

2 OBJECTIVES

The present study aims to determine the morphometric parameters of the Aranha Stream micro-basin, from its source to the meeting with the Mata Fome Stream, in the municipality of Itapeva, and to carry out a multitemporal analysis of the use and occupation of the soil in the region, with the help of geotechnologies.

3 METHODOLOGY

3.1 Study Area Definition

The study area comprises the micro-basin of the Aranha stream located between the UTM coordinates 714943 S 70338570 W and 721988 S 7348415 W, located in the 22S zone, and corresponds to a portion of the municipality of Itapeva, São Paulo, with an estimated population of approximately 95000 inhabitants (IBGE, 2021). The studied portion of the basin corresponds to its upper course and has an area of approximately 16.53 km² and had its outflow considered at the confluence of the Aranha and Mata-Fome streams.

The region where the city is located has a predominance of soils of the type Latosol with occurrence of kandiudult soil and cambisol haplic, as pointed out by the classification of DATAGEO (2022), with an average annual temperature of approximately 19 °C (INMET, 2022) and Cfa climate (warm temperate climate), according to the Köppen-Geiger classification. Also, according to DATAGEO (2022), the municipality is located in a region where the Cerrado and Atlantic Forest biomes predominate. The average annual precipitation in the municipality is 1352.6 mm/year (EMBRAPA, 2012). Figure 1 shows the area of the micro-basin of Corrego do Aranha.

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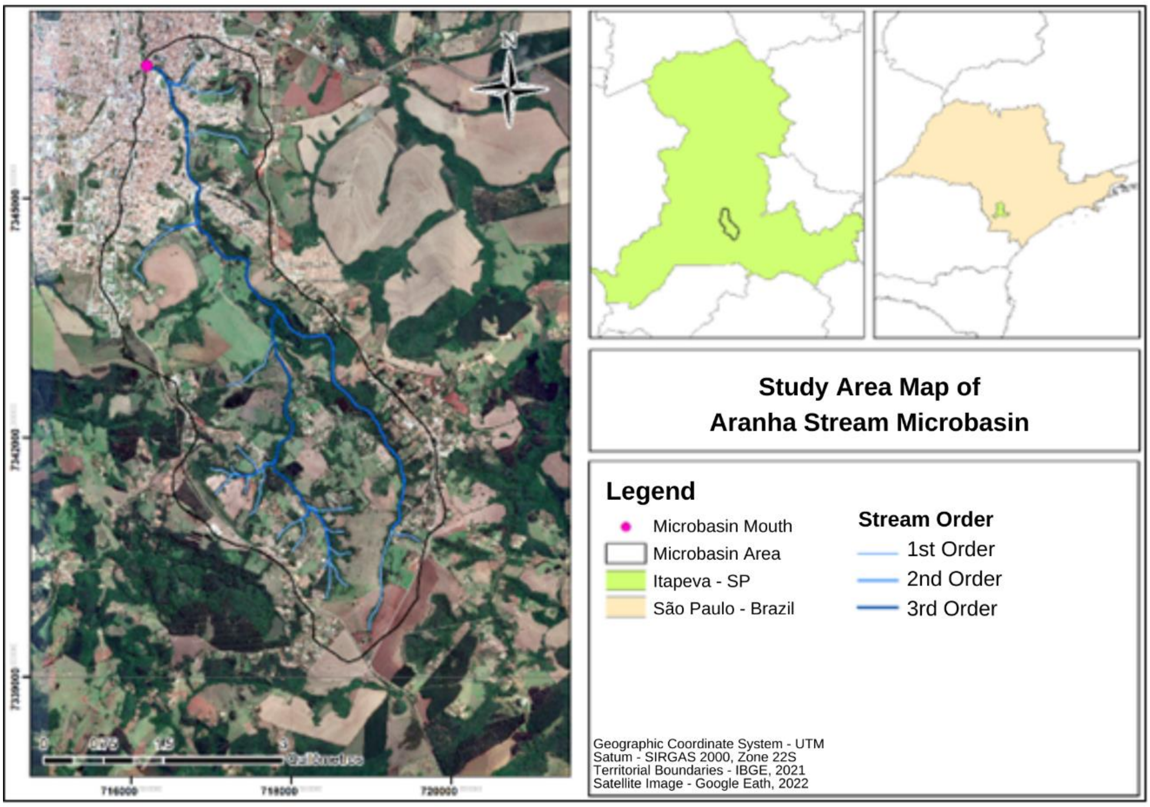
Figure 1 – Study area of the Aranha Stream micro-basin



Source: Elaborated by the author

3.2 Data Aquisition

For the study, terrain elevation data and satellite images were obtained to help delimit the basin and determine land use and occupation, respectively. A multitemporal analysis was carried out to evaluate the evolution of land cover over a period of approximately 30 years. In this context, the data were acquired:

- SRTM DEM with spatial resolution 30 m (USGS, 2022);
- LANDSAT5 images, Thematic Mapper (TM) sensor, bands 2, 3, 4 e 5 of 10/07/1991 e 17/08/2005 (INPE, 2022);
- LANDSAT8 images, Operacional Land Imager (OLI) sensor, bands 3, 4, 5 e 6 of 26/08/2020 (INPE, 2022).

It is noteworthy that for the imaging of the 1990s, the subsequent year of 1991 was used, due to the authors difficulty in finding a satellite image in which the cloud cover did not affect the study region. Figure 2 presents the satellite images used for the land use and land cover classification.

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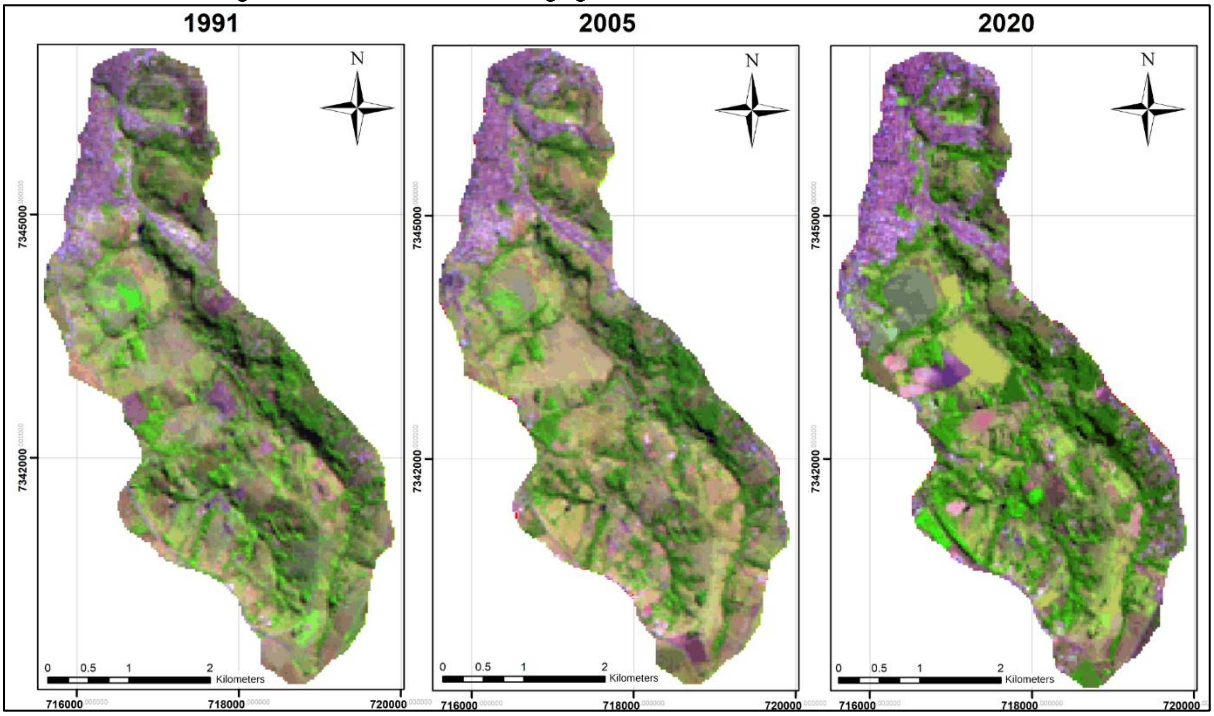
Figure 2 –LANDSAT5 satellite imaging in 1991 and 2005 and LANDSAT8 in 2020



Source: INPE, 2022; adapted by the author

3.3 Methods of Analysis

Initially, the LANDSAT images were imported into SPRING software (CAMARA et al., 1996), version 5.4.3, where the positioning of the images in relation to the coordinates was verified, with the help of Google Earth. For the scenes obtained from LANDSAT 5 (Sensor TM), from 1991 and 2005, it was necessary to register the images for correct geographical positioning of the elements, through the screen record, which was based on the image from LANDSAT8 (Sensor OLI).

Then followed the process for classification of land use and occupation, in which five classes were used to represent the region: water bodies, urban, exposed soil, low vegetation and dense vegetation. The pixel classification method was used, where, for the three scenarios the training of the classification software was performed and the composition of bands 3 (B), 4 (R), 5 (G) was used for the scenes obtained with LANDSAT5 and composition of bands 4 (B), 5 (R), 6 (G) for the LANDSAT8 scene. Table 1 presents the interpretation key with the five classes defined for land use determination.

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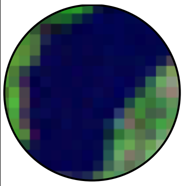
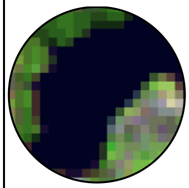
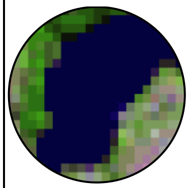
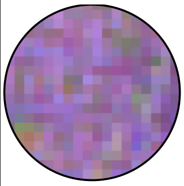
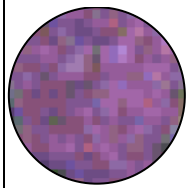
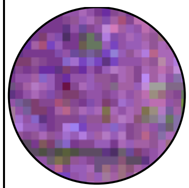
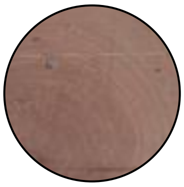
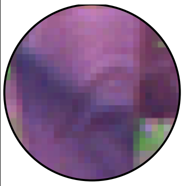
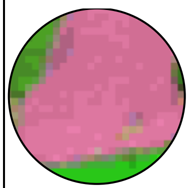
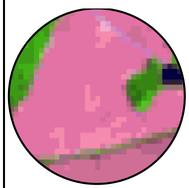
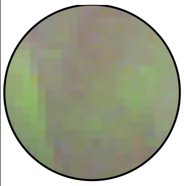
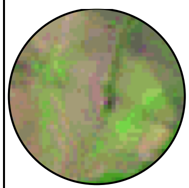
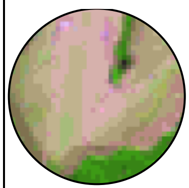
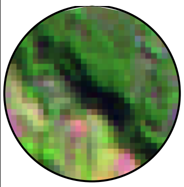
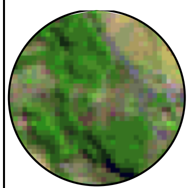
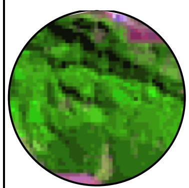
Chart 1 – Interpretation key for the land use determination

Classes	ID	Geographic Coordinates	Google Earth Image	LANDSAT 5 Year: 1991 3(B), 4(R), 5(G)	LANDSAT 5 Year: 2005 3(B), 4(R), 5(G)	LANDSAT 8 Year: 2020 4(B), 5(R), 6(G)
Water body		716814 E 7348150 S				
Urban		717191 E 7344834 S				
Exposed Soil		716560 E 7344051 S				
Ground Vegetation		716989 E 7344137 S				
Dense Vegetation		717224 E 7344355 S				

Source: Google Earth, 2022; INPE, 2022; Adapted by the author

The classification used the supervised method by pixel through the maximum likelihood algorithm, with an acceptance limit of 100%, since the post classification was done manually. The result of the classification was then analyzed and for some regions, where there was class confusion, matrix editing of the pixels was performed to better match the areas to the correct classes.

In addition to the LANDSAT satellite images, the SRTM Digital Elevation Model (DEM) was imported into the software, generating contour lines that helped in the manual extraction of the basin delineation for the study. Once the basin was delimited, the watercourses were then traced with the help of the LANDSAT8 image, in order to keep the watercourse tracing updated through vectorial editing, for later analysis of the morphometric parameters.

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From this, the main course of the river and its length, the order of each stretch according to Strahler's (1957) methodology, the total drainage length, the average slope of the main course, the drainage density and the average slope of the channel were defined, which also used the elevation data from the DEM.

Villela and Mattos (1975) point out two relevant parameters for knowledge of physical characteristics related to the basin shape (Coefficient of Compactness (Kc) and the Shape Factor (Ff)) and two other characteristics linked to the drainage system of the unit (Drainage Density and Sinuosity Index). Schumm (1956) also points out a third physical parameter for morphometric analysis, the Circularity Index (Ic).

Thus, the basin shape parameters calculated to determine flooding tendency as well as their formulas are described in Table 2.

Chart 2 – Morphometric parameters used on the study

Parameter	Equation
Coefficient of Compactness (Kc)	$Kc = 0{,}28 * \frac{P}{\sqrt{A}}$
Shape Factor (Ff)	$Kf = \frac{A}{L^2}$
Circularity Index (Ic)	$Ic = \frac{12{,}57 * A}{P^2}$
Drainage Density (Dd)	$Dd = \frac{\sum L}{A}$
Sinuosity Index (Is)	$Is = \frac{L}{L_t}$

Legend: A = Area (km), P = Perimeter (km), L = Main course length (km), L_t= Basin Length (km)
Source: VILLELA; MATTOS, 1975 and SCHUMM, 1956

4 RESULTS

The classification of the images resulted in three maps with the delimited areas for each class. The results of the classification are presented in Figure 3, with the five classes previously defined. Table 1 also shows the values corresponding to each of the areas in the years analyzed and their respective percentages.

Table 1 – LANDSAT image classification results

Classes	Area (km²)					
	1991	**%**	**2005**	**%**	**2020**	**%**
Water Body	0.01	0.08	0.02	0.11	0.01	0.06
Urban	1.98	11.95	2.92	17.63	3.73	22.57
Exposed Soil	2.36	14.29	1.11	6.70	0.94	5.69
Ground Vegetation	7.81	47.26	9.36	56.60	8.76	52.99
Dense Vegetation	4.37	26.41	3.14	18.97	3.09	18.69
Total	**16.53**	**100**	**16.53**	**100**	**16.53**	**100**

Source: Elaborated by the author

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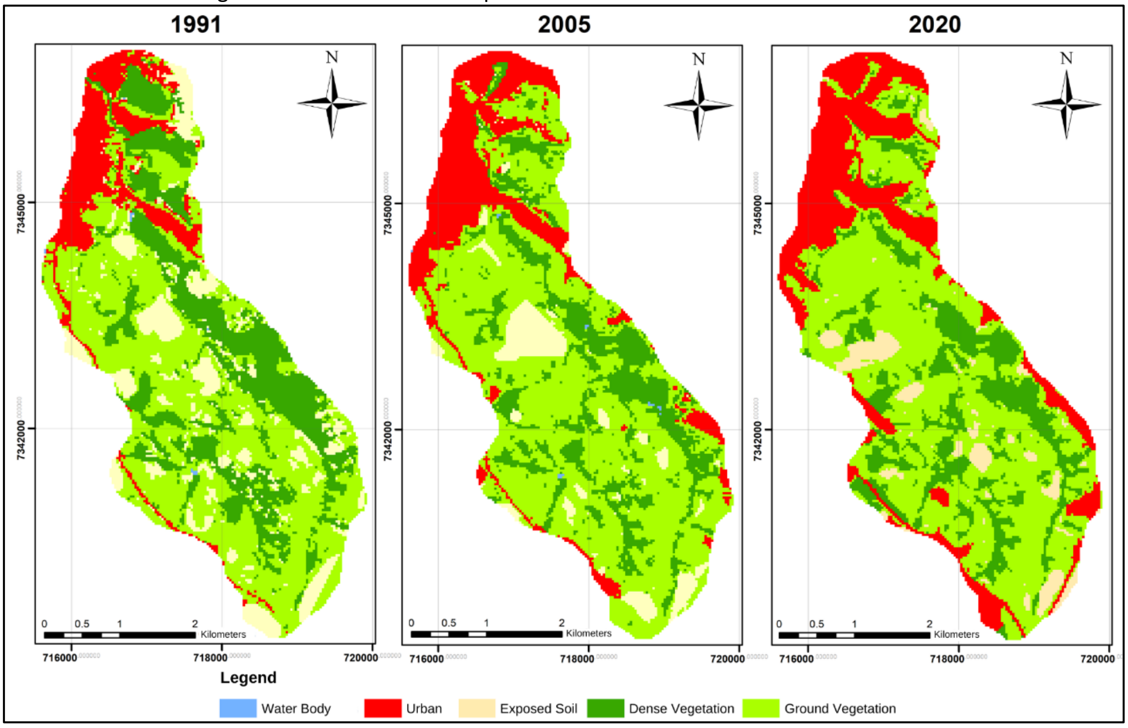
Figure 3 – Land use and occupation of soil classification on Aranha Stream



Source: Elaborated by the author

A small area classified as hydric bodies was observed, since it was not possible to identify a large quantity of water courses in the classification because of their low order. Thus, the total areas of this class that could be identified correspond to small dams reservoirs.

It was also observed that the urban area had an increase of about 48% between 1991 and 2005, and about 27% between 2005 and 2020. This points to the rapid expansion of impermeable areas in the last three decades, representing a total of 88% growth over this period. The main regions that suffered from urbanization were in the lower course of the basin, in the satellite regions where built-up areas were already observed in the 1990s, corresponding to the city center. It is also pointed out that it is in this region of urban expansion that the greatest problems with flooding are observed.

Over the three-decade study period, it was also observed that there was a suppression of dense vegetation in the area of about 29%, and a 60% decrease in exposed soil, comparing the years 1991 and 2020. This fact can be explained, besides urbanization, by the planting in this region, which has several rural properties.

A cross-tabulation table of the 1991 and 2020 classifications was also made, where the regions that have changed the most over the years were analyzed. The result is presented in Table 2.

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Table 2 – Cross tabulation with the 1991 and 2020 images classification

Areas (km²)		2020					
		Water Body	Urban	Exposed Soil	Dense Vegetation	Ground Vegetatoin	Total
1991	Water Body	0.00	0.00	0.00	0.00	0.01	0.01
	Urban	0.00	1.70	0.01	0.02	0.25	1.98
	Exposed Soil	0.00	0.36	0.28	0.22	1.50	2.36
	Dense Vegetation	0.00	0.40	0.00	2.10	1.87	4.37
	Ground Vegetation	0.01	1.27	0.65	0.75	5.13	7.81
Total		0.01	3.73	0.94	3.09	8.76	16.53

Source: Elaborated by the author

From the classification, it is observed that about 48% of the original dense vegetation was maintained over the 30 years studied. The municipality of Itapeva is in a region where the Cerrado and Atlantic Forest biomes can be observed, which, over the years, have undergone major changes. It is estimated that only 7% of the original area of the Atlantic Forest is still preserved (RIBEIRO, 2007). The Cerrado is also pointed out as an area of significant deforestation, since it was considered an alternative region to the Amazon for exploitation (Conservation International et al., 1999).

It is estimated that in the municipality of Itapeva between the years 2001 and 2020 alone, there was suppression of 21.48 km² regarding the Cerrado areas (TerraBrasilis, 2022). It is also pointed out that the region is a producer of *Pinus sp*. and *Eucalyptus sp*., used for industrial purposes, which end up taking space of the original vegetation and are pointed out as a threat to native species (Secretaria do Meio Ambiente de São Paulo, 2018). According to MapBiomas (2022) of the areas that underwent coverage transition, considering the period from 1990 to 2020, there was a change of 21.30% of forest areas for agricultural use in the municipality of Itapeva-SP.

There is also a great divergence in the classifications between exposed soil and ground vegetation, since in the regions outside the urban area plantations are observed, the fact being explained, therefore, by the inter-harvest period, which can cause such changes. Finally, it can be said that among the regions that have suffered most from urbanization over the years, the one with low vegetation stands out.

Once the soil classification analyses were completed, it was then proceeded to the morphometric classification, with the results of the calculated parameters being presented in Table 3.

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Table 3 – Physical characteristics and morphometric parameter results of the Aranha Stream Basin

Parameter	Results
Stream Order	3rd Order
Drainage Pattern	Dendritic
Basin Area (A)	16.53 km²
Basin Perimeter (P)	20.09 km
Main Course Length (L)	8.88 km
Basin Length (Lt)	7.89 km
Total Streams Length (∑L)	23.24 km
Average Basin Width(B)	2.03 km
Main Course Initial Altitude	837.00 m
Main Course Final Altitude	646.00 m
Main Course Average Slope	0.0215 m/m
Coefficient of Compactness (Kc)	1.38
Shape Factor (Kf)	0.21
Circularity Index (Ic)	0.51
Sinuosity Index (Is)	12.55 %
Drainage Density (Dd)	1.41 km/km²

Source: Elaborated by the author

The Coefficient of Compactness (Kc) showed a value of 1.38, which suggests, according to Silva and Mello (2008) that the basin has an average tendency to major flooding, since the coefficient is between 1.25 and 1.50. As for the Form factor (Ff), a value of 0.21 was observed. The result indicates that the tendency to major floods analyzing this parameter is low since, according to the interval indicated by Rodrigues et al. (2015), they are not close to 1, which would indicate greater tendencies to flooding. Finally, the Circularity Index (Ic) resulted in a value of 0.51, which, according to Schumm (1956) indicates a small probability of rapid flooding and moderate runoff in the basin.

Regarding the factor Sinuosity Index (Is), this is considered low according to the classification of Romero, Formiga, and Marcuzzo (2017), since it is equal to 12.55%, and can be considered as a very rectilinear course. Although the basin has sinuosity considered low, it is observed a large amount of first-order courses and the Drainage Density (Dd) whose value is 1.41 km/km². According to Villela and Mattos (1975) this coefficient can vary from 0.5 km/km² to 3.5 km/km², which indicates, therefore, a regular drainage density for the basin since it has an intermediate value.

Next, an analysis of the slope of the terrain in the study region was performed, according to the Lepsch (1991) methodology. Table 4 shows the classification of the terrain according to its slope and their respective areas, Table 5 shows the areas corresponding to the slicing of the hypsometry and Figure 4 shows a representation of the slope and hypsometry of the region.

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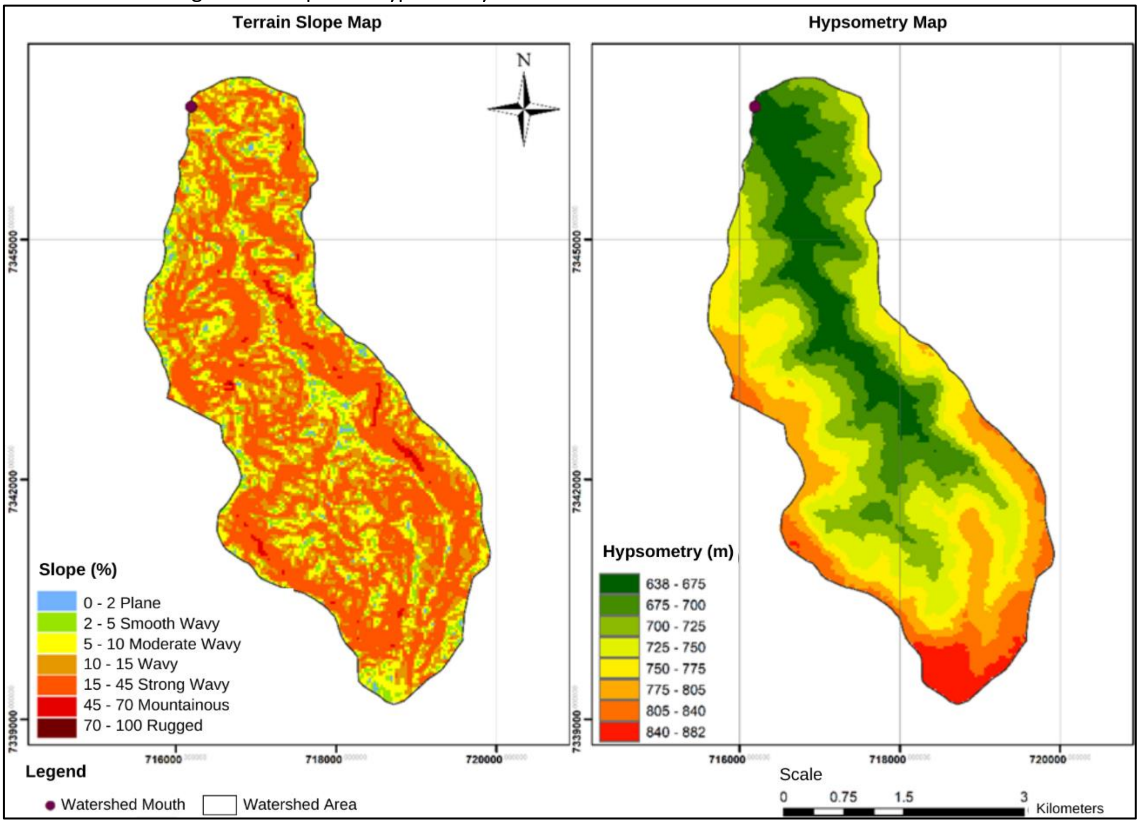
Figure 4 – Slope and hypsometry classification of the Aranha Stream basin terrain



Source: Elaborated by the author

Table 4 – Slope classification of the Aranha Stream basin terrain

Classes	Slope (%)	Area (km²)
Plane	0 - 2	0,18
Smooth Wavy	2 - 5	1,01
Moderate Wavy	5 - 10	3,35
Wavy	10 - 15	4,44
Strong Wavy	15 - 45	7,37
Montainous	45 - 70	0,16
Rugged	70 - 100	0,01

Source: Lepsch, 1991, adapted by the author

Table 5 – Hypsometry classification of the Aranha Stream basin terrain

Hypsometry (m)	Area (km²)
638 - 675	2.04
675 - 700	2.49
700 - 725	2.90
725 - 750	3.06
750 - 775	2.37
775 - 805	2.12
805 - 840	1.01
840 - 882	0.54
Total	16.53

Source: Elaborated by the author

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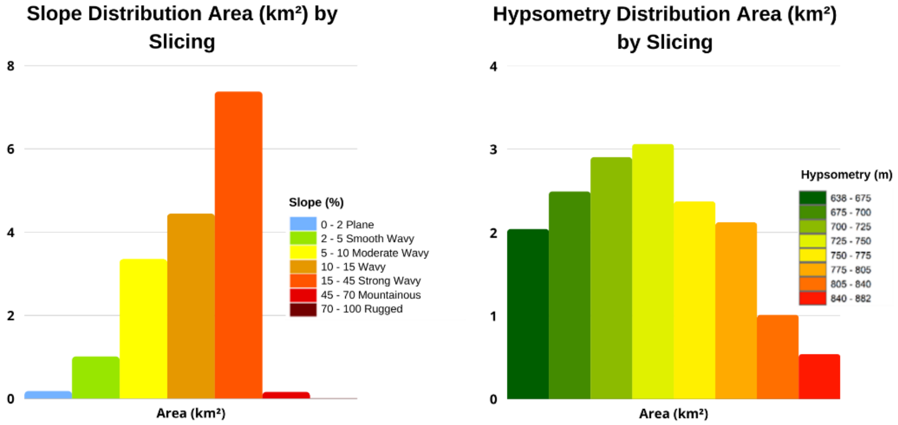
Figure 5 shows the graph corresponding to the areas by slicing the slope and hypsometry classifications of the basin.

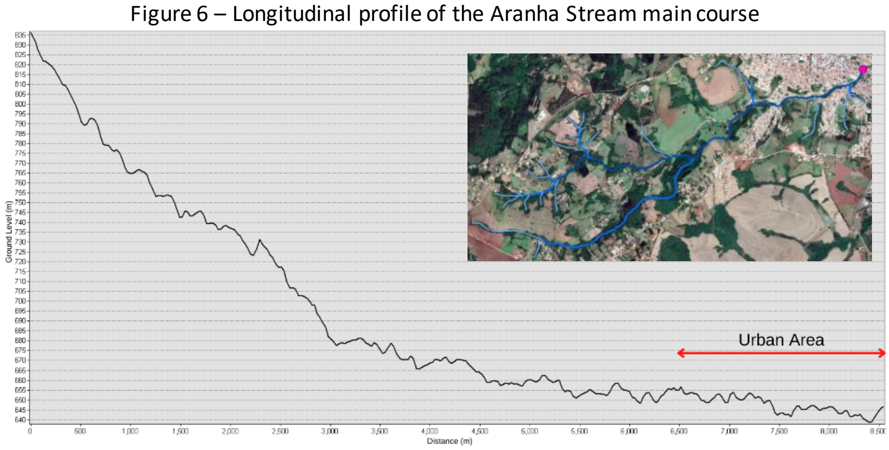
Figure 5 – Slope and Hypsometry areas by slices from the Aranha Stream Basin



Source: Elaborated by the author

From these results, it can be observed that the region has a predominance of undulating and strongly undulating terrain corresponding, respectively, to 27% and 44.5% of the total basin area. Thus, it can be said that due to the topography of the terrain, there is a tendency to a runoff with higher velocity, which coupled with other parameters such as regular drainage and compactness coefficient indicating low probability of flash floods, makes the site prone to flooding. The longitudinal profile of the terrain was then drawn to analyze the slope of the river's main course. Figure 6 shows the longitudinal profile of the main course of the basin, the Aranha Stream.

Figure 6 – Longitudinal profile of the Aranha Stream main course



Source: Elaborated by the author

It was observed that the studied stretch has a pronounced average slope with a value of approximately 0.0215 m/m. As Christofoletti (1980) points out, channels with higher slope tend to be more rectilinear, which can also be observed with the Sinuosity Index. Furthermore, it can be seen that the highest slope is found in the headwaters of the basin, which results in rapid water runoff near the springs and has lower slopes near the urban area, a factor that can directly contribute to flooding

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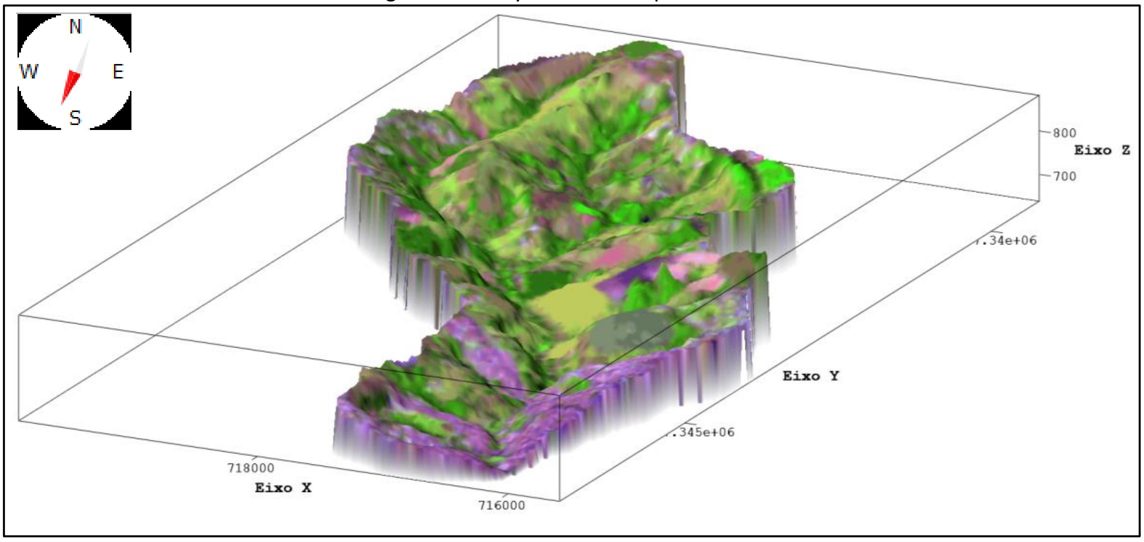
in the lower part of the basin. Figure 6 shows the visualization of the basin in 3D model, using the SRTM DEM and the 2020 imagery from the LANDSAT8 satellite.

Figure 7 – Study area in 3D representation



Source: Elaborated by the author

It is also worth mentioning that the stream has been channelized and occupied along its banks, besides undergoing a strong urbanization over the years. Such factors end up contributing to increasingly extreme scenarios of flooding of the channel, increasingly affecting the population living on the banks of the stream. Therefore, a cautious analysis of the region is necessary for the construction of new neighborhoods and urban expansion.

5 CONCLUSIONS

The urban area increased by 88%, mainly in the lower part of the basin, where flooding is already observed. At the same time, it was observed a suppression of dense vegetation, a decrease in exposed soil and an increase in ground vegetation.

In spite of presenting some parameters of low tendencies of flooding, the compactness coefficient pointed out an average tendency to these events. We also noticed that the drainage density is regular, with 1.41 km/km² and the main stream has low sinuosity and high slope, especially in the headwaters.

The soil sealing associated with the parameters and the channelization of the lower course can collaborate in the potentialization of extreme events. In this aspect, this work can serve as a help for future actions in the region.

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