



## Physiographic analysis of the Atibaia River Basin and flood susceptibility mapping in the municipality of Campinas-SP, Brazil

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Bruno de Souza Garcia<sup>1\*</sup>; Camila da Silva Dourado<sup>1,2</sup>  
Ana Maria Heuminski de Avila<sup>2</sup>

<sup>1</sup>Departamento de Engenharia Agrônômica. Centro Universitário Adventista de São Paulo (UNASP), Estrada Municipal Pastor Walter Boger, s/n, CEP: 13448-900, Engenheiro Coelho, SP, Brazil.

E-mail: camila.dourado@edu.unasp.br

<sup>2</sup>Centro de Pesquisas Meteorológicas e Climáticas Aplicadas à Agricultura. Universidade Estadual de Campinas (UNICAMP), Avenida André Tosello, n° 209, CEP: 13083-886, Campinas, SP, Brazil.

E-mail: camila.dourado@edu.unasp.br, avila@cpa.unicamp.br

\*Corresponding author. E-mail: bruno\_garcia@educadventista.org

### ABSTRACT

This study characterized and analyzed the physiographic factors of the Atibaia River Basin and their influence on flooding processes and evaluated the susceptibility to flooding in the municipality of Campinas during the years 1985 and 2019. At first, geoprocessing techniques and indices defined in the literature were used to provide a comprehensive understanding of the Atibaia River Basin regarding its geometric, relief, and drainage attributes and its influence on flooding processes, to provide decision-making support regarding preventive and mitigating actions for the socioeconomic and environmental impacts in the region. The pedogeomorphological characteristics and land use and occupation of Campinas were applied to the Analytic Hierarchy Process using geoprocessing techniques to generate the specific mapping of the municipality's susceptibility to flooding. The mapping allowed us to identify the critical sites of the municipality of Campinas, choosing priority areas for government action and programs regarding urban and environmental management. It can also guide new studies on the detail scale aiming to prevent and mitigate flooding events.

**Keywords:** hydrographic basin, spatial multi-criteria analysis, water risk.

### Análise fisiográfica da bacia do rio Atibaia e mapeamento de suscetibilidade à inundação no município de Campinas-SP, Brasil

### RESUMO

Este trabalho teve por objetivo a caracterização e análise dos fatores fisiográficos da bacia do rio Atibaia e sua influência nos processos de enchentes e inundações, além de avaliar a suscetibilidade a eventos de inundação para o município de Campinas, nos anos de 1985 e 2019. Em um primeiro momento, foram utilizadas técnicas de geoprocessamento e índices definidos na literatura a fim de proporcionar uma compreensão abrangente da bacia do rio Atibaia quanto a seus atributos geométricos, de relevo e drenagem e sua influência aos processos de inundação, com o intuito de fornecer suporte à tomada de decisão referente às ações preventivas e mitigadoras dos impactos socioeconômicos e ambientais na região. Em um segundo momento,



as características pedogeomorfológicas e de uso e ocupação da terra do município de Campinas foram processadas por meio de técnicas de geoprocessamento e aplicadas ao Processo Analítico Hierárquico com a finalidade de gerar o mapeamento específico do município quanto a sua suscetibilidade a inundações. O mapeamento permitiu conhecer os locais críticos do município de Campinas, elegendo áreas prioritárias às ações e programas governamentais no tocante à gestão urbana e ambiental, podendo orientar ainda a geração de novos estudos na escala de detalhe, com vistas à prevenção e contingência de possíveis impactos decorrentes dos processos de inundação.

**Palavras-chave:** análise espacial multicritério, bacia hidrográfica, risco hídrico.

## 1. INTRODUCTION

Floods are geoenvironmental problems arising from natural phenomena of a hydrometeorological or hydrological nature, which can be atmospheric, hydrological, or even oceanographic (UN-ISDR, 2009). Floods cause devastating impacts on society, being classified among the most dangerous disasters in the world (Bathrellos *et al.*, 2016).

Identifying and evaluating the potential and restrictions of basins, especially urban basins, contributes to the management of water resources, such as prediction of vulnerability to flooding, inundations, and erodibility (Villela and Mattos, 1975). Several indices were developed to determine these properties, considering as physiographic characteristics those which can be obtained from maps, aerial photographs, or satellite images (Souza *et al.*, 2018).

The municipality of Campinas has been characterized by significant urban and demographic growth since the 1970s (Caiado and Pires, 2006). It is a region that concentrates a high density of headwaters of rivers that are crucial for the hydrological balance of the state of São Paulo, including the Atibaia River Basin, with an extension of 2,814.59 km<sup>2</sup>. Thus, mapping and analyzing susceptibility to flooding in this municipality play important roles in guiding strategies to prevent and mitigate future water risks since they identify the most vulnerable areas based on the physical conditions that determine the propensity to flooding (Vojtek and Vojteková, 2019).

Since floods result from multidimensional phenomena with spatial and temporal aspects, the delimitation of risk areas to these hydrological processes can be analyzed based on a multicriteria methodology. Among the methods developed in the Multicriteria Decision Analysis (MCDA) environment, the Analytic Hierarchy Process (AHP) stands out (Saaty, 1990). This method is based on the creation of an importance scale by assigning weights between the evaluated parameters to determine the proportion of influence of each factor in the possible flooding of the analyzed area (Saaty, 1987; 1990).

The determination and analysis of physiographic factors, also applied to the AHP method, has been used by several authors at municipal or hydrographic basin scales (Lorenzon *et al.*, 2015; Souza and Sobreira, 2017; Caldas *et al.*, 2018; Souza *et al.*, 2018; Cezar *et al.*, 2019; Vajtek and Vojteková, 2019; Silva *et al.*, 2020), especially combined with geoprocessing techniques, for assessing the impacts of continuous territorial changes and the zoning of areas susceptible to possible natural disasters.

Given the above, the assessment of flooding risk plays an important role in territorial planning, especially as an indication of limitations and potential in future projections of urban occupation. In this context, this study aimed to characterize and analyze the physiographic factors of the Atibaia River Basin and its influence on the inundation and flooding processes, and evaluate the susceptibility to flooding events for the municipality of Campinas, in the years 1985 and 2019, using the AHP method and geoprocessing techniques, to provide support for decision-making regarding preventive and mitigating actions of socioeconomic and

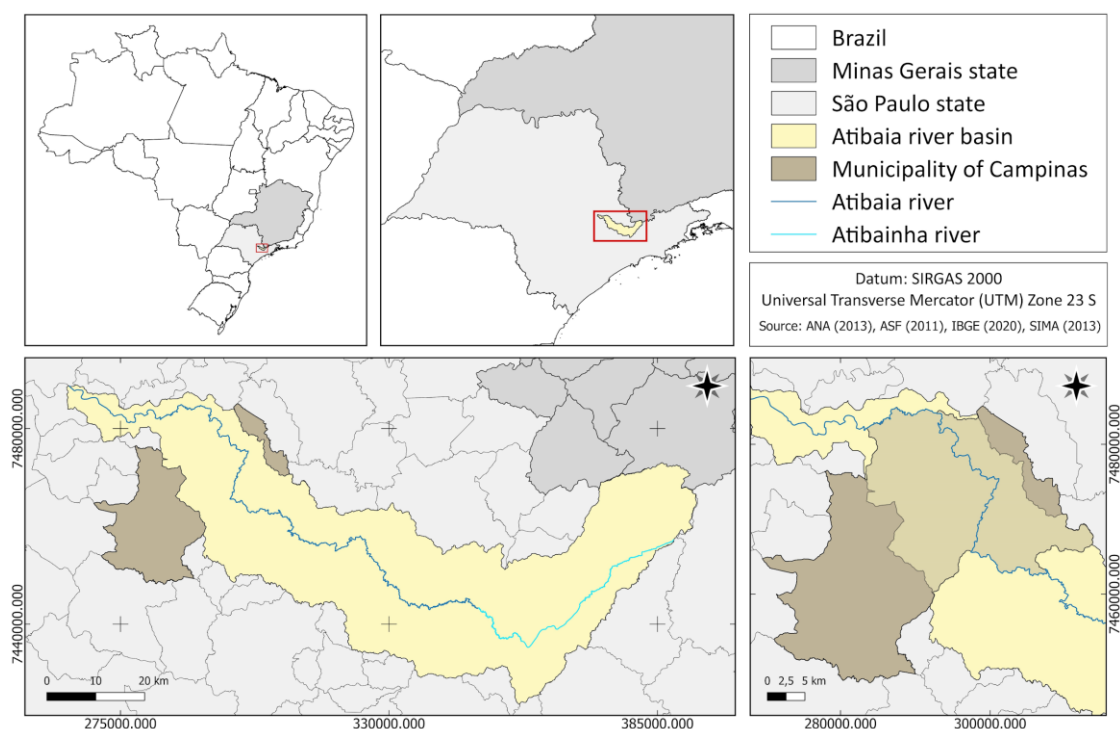
environmental impacts in the region.

## 2. MATERIAL AND METHODS

The physiographic factors were first characterized and the concentration times in the entire Basin of the Atibaia River were determined to provide a comprehensive understanding of the basin regarding its geometric attributes, relief, and drainage and its relationship to flooding processes. Subsequently, the study was limited to the municipality of Campinas, specifying its pedogeomorphological characteristics, land use and occupation to analyze in more detail the influence between the natural and anthropic aspects in attributing risk to flooding processes in the municipality.

### 2.1. Characterization of the study area

The Atibaia River Basin, located between coordinates 22°40' and 23°20' south and 47°20' and 46°00' west, covers, total or partially, 16 municipalities in the state of São Paulo and one in the state of Minas Gerais, in the Southeast region of Brazil (Figure 1). Due to its location, the Atibaia River Basin shows a contrast between relatively preserved natural environments and extremely urbanized areas. Its basin is directly related to the Campinas metropolitan area with an extension of 2,814.59 km<sup>2</sup>. Among the many peculiarities of this basin, its insertion in a region with wide urban expansion and a vast and diversified industrial park, besides an important technological center in the national scenario, stands out (Demanboro *et al.*, 2013a; 2013b).



**Figure 1.** Location of the study area.

Recent studies conducted by Young and Papini (2020) indicate a scenario of more than 5,000 people exposed to the risks of flooding disasters associated with a part of the Atibaia River Basin covering the municipality of Campinas in response to urban sprawl that has already reached flood-prone areas, as well as intense agricultural activities and degraded pastures in the locality. A portrait of use and occupation was identified throughout the territorial extension of the municipality of Campinas.

The municipality of Campinas, partially inserted into the Atibaia River Basin, is in the east-central part of the state of São Paulo, between the coordinates 22°53'20" south and 47°04'40" west. Its territory covers an area of approximately 794.6 km<sup>2</sup> and has a population of 1,223,137 inhabitants (IBGE, 2021), being the third most populous city in the state of São Paulo and the fourteenth in Brazil. Its climate is humid tropical (Cwa, according to the Köppen-Geiger classification), expressed as mild winters and hot, wetter summers (Beck *et al.*, 2018).

## 2.2. Physiographic characterization of the Atibaia River Basin

For the characterization of the physiographic aspects and determination of the time of concentration of the Atibaia River Basin, the factors and indexes referring to the geometry of the basin, the relief characteristics, and its drainage network were evaluated. The analyses were performed using geographic, vector, and matrix information referring to the drainage sections of the Ottocodified Hydrographic Database of the Tietê River Basin (ANA, 2013) and to the sub-basins of the state of São Paulo (São Paulo, 2013), both in a 1:50,000 scale, in addition to the information from images from the ALOS PALSAR radar sensor satellite with 12.5 meters of spatial resolution, provided by Alaska Satellite Facility (ASF DAAC, 2020) Figure 1.

In the analysis of the basin's geometric variables, the area, perimeter, and axial length of the basin were evaluated. According to the equations described by Cezar *et al.* (2019), the shape factor (Sf), the compactness coefficient (Cc), and the circularity index (Ci) of the basin were also calculated since they determine the shape of the basin from geometric shapes. These indices allow estimating the tendency of flooding in a basin, as Table 1 indicates, since the shape of the basin directly influences surface runoff (Collischonn and Dornelles, 2013).

**Table 1.** Values and interpretation of shape factor (Sf), circularity index (Ci) and compactness coefficient (Cc).

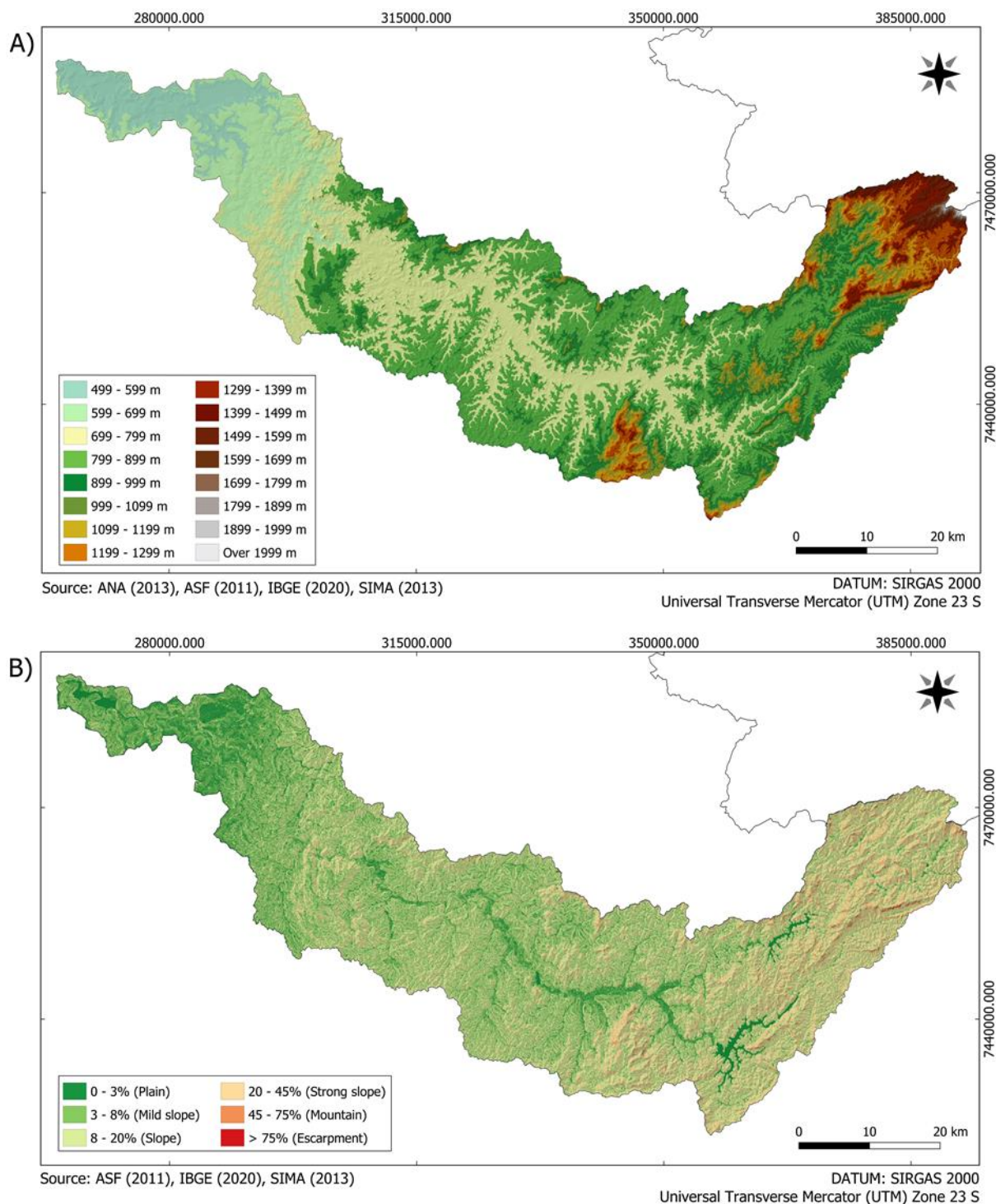
Sf	Ci	Cc	Basin shape	Basin characteristics
1.00 – 0.75	1.00 – 0.8	1.00 – 1.24	Circular	Great tendency to flooding
0.75 – 0.50	0.8 – 0.6	1.25 – 1.50	Oval	Average tendency to flooding
0.50 – 0.30	0.6 – 0.4	1.50 – 1.70	Oblong	Low tendency to flooding
< 0.30	< 0.4	> 1.70	Elongated	Tendency of conservation

**Source:** Nardini *et al.* (2013, adapted by the authors, 2022).

The characterization of the relief of the basin was performed by remote sensing techniques applied to the Digital Elevation Model provided by the Alaska Satellite Facility, previously mentioned, enabling the preparation of the hypsometric and slope maps of the basin (Figure 2), from which altitude and maximum, medium, and minimum slope information were extracted, as well as the altimetric amplitude (Hm). The relief ratio (Rr) was also determined, indicated by the ratio between the altimetric range and the extension of the main channel (Cezar *et al.*, 2019). According to Nardini *et al.* (2013), Rr allows comparing altimetry between different regions, demonstrating that the higher its values, the more uneven is the predominant relief in the analyzed region, classified into three classes: low (0 to 0.1), medium (0.11 to 0.30), and high (0.31 to 0.60). The slope of the main river was defined from the longitudinal profile of the thalweg and the area of the curve was calculated, obtaining a right triangle of equivalent area, with a base equal to the length of the watercourse, as equated by Lorenzon *et al.* (2015). The creation of the longitudinal profile also made defining the maximum, average, and minimum height of the main river possible, as well as its altimetric range.

To evaluate the basin drainage network, the order of the channels, the total number and length of the drainage, and the real and vector length of the main river were analyzed. The drainage network was organized according to the methodology proposed by Strahler (1957).

Drainage density (Dd) and sinuosity index (Si) were determined using the method of Cezar *et al.* (2019). Drainage density represents a parameter indicative of the drainage efficiency of a basin: as its numerical value increases, the capacity of the basin to perform rapid drainage at the outlet also increases (Villela and Mattos, 1975). Thus, Dd values above 2.5 mean good drainage of the basin, whereas values between 1.5 and 2.5 represent average drainage, and subsequently, values below 1.5 mean low drainage of the basin (Nardini *et al.*, 2013). In turn, the sinuosity index describes the flow velocity of the main channel; the smaller the sinuosity, the less difficulty the water courses encounter in reaching the outlet (Cezar *et al.*, 2019).



**Figure 2.** Characterization of the relief of the Atibaia River Basin by its A) hypsometric map and B) slope map.

In addition to the physical aspects of the basin, the knowledge of its concentration time plays a decisive role in estimating the maximum flows since it defines the time the water takes to travel the entire length of the basin until contributing to the flow in its outlet (Collischonn and Dornelles, 2013). Thus, to estimate the time of concentration, the methods of Giandotti, Johnstone-Cross, Temez, and the Corps of Engineers, developed for basins with similar physical characteristics to the Atibaia Basin, were used as described by Zahraei *et al.* (2021).

### 2.3. Flood susceptibility mapping in the Municipality of Campinas

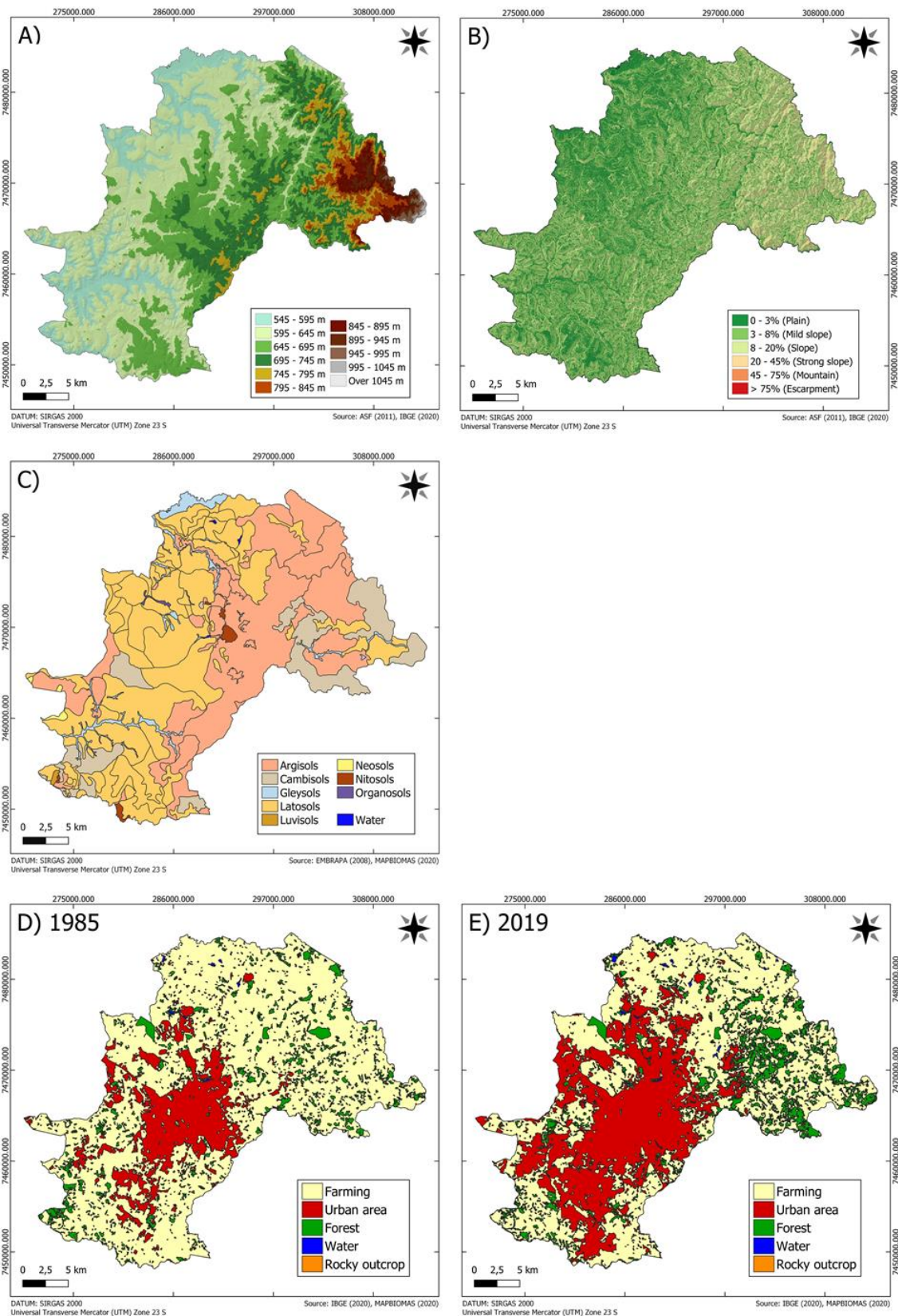
In this stage, the city of Campinas was emphasized, aiming at mapping the risks of flooding in the location for the years 1985 and 2019. Based on the literature review and vulnerability to water risks, four factors conditioning floods were selected: altitude, slope, pedology, and land use and cover. According to Tucci and Bertoni (2003), the main natural conditions for the occurrence of floods are relief, due to the accumulation of water in the lower regions due to the action of the force of gravity, and the drainage capacity, since sandy soils provide greater infiltration and percolation of water, whereas clay soils produce greater surface runoff. Likewise, the artificial characterization of the physical environment due to the increase in the density of occupation and urban infrastructure, directly impacts the increase of impermeable areas, promoting greater accumulation of water on the surface than in soils with vegetation cover, since they are less compacted.

The cartographic base used consisted of: vector and matrix products referring to the mesh of municipal units in the state of São Paulo (IBGE, 2020), from which the limit of the municipality of Campinas was extracted; image information from the ALOS PALSAR radar sensor satellite with 12.5 meters of spatial resolution (ASF DAAC, 2020), for the delimitation of altimetric and slope variables of the study area; the Semi-Detailed Pedological Map of the municipality of Campinas, on a scale of 1:50,000, prepared by Embrapa in 2008 (Campinas, 2021a), identifying the soil classes of the municipality; and the fifth collection of land use and occupation maps made available by the Mappiomas Project (2021), with 30 meters of spatial resolution, for the years 1985 and 2019. The Datum Geocentric Reference System for the Americas 2000 (SIRGAS 2000) and the Universal Transverse Mercator plane projection in the 23 S zone were used. As validation of the final map, records of critical points of flooding and inundation in the municipality of Campinas were also used, prepared in 2018 and provided by the City Hall of Campinas (Campinas, 2021b; 2021c).

As indicated by the mapping of the conditioning factors for inundation (Figure 3), the city of Campinas presents an altimetric range of 537 m, with altitudes that vary between 545 to 1082 m. It has diversified reliefs, with an average slope of 11.4%, classified as wavy relief (Embrapa, 1979). Regarding pedology, eight orders of soils were identified in the municipality, highlighting the predominance of soils classified as Argisols and Latosols, characterized by high clay content and pedogenetic development (Santos *et al.*, 2018). Pedological portions are also directly associated with the marginal regions of water courses, classified as Gleysoils and Organosols, which have a strong propensity to hydromorphism and a restricted drainage rate (Santos *et al.*, 2018). Concerning land use and cover, of the five classes established, between the years 1985 and 2019, municipal urban infrastructure increased 96.51%, water bodies, 82.44%, forest areas, 52.07%, and rocky outcrops, 8.38%. In turn, areas of agricultural use decreased by 26.02%. In 2019, among the 794.57 km<sup>2</sup> of the municipality of Campinas, 446.98 km<sup>2</sup> represented areas of agricultural use, 251.79 km<sup>2</sup> of urban infrastructure, 91.2 km<sup>2</sup> of forests, 4.58 km<sup>2</sup> of bodies of water and 0.01 km<sup>2</sup> of rocky outcrop.

In this study, an analysis based on matrix data was used. In this sense, the conditioning factor referring to pedology was converted to raster format with a cell size of 12.5 m resolution. As a method of comparing the conditioning factors, the classes of the evaluated information levels received scores from one to five according to the level of susceptibility to flooding, with

Grade 1 (very low), Grade 2 (low), Grade 3 (moderate), Grade 4 (high), and Grade 5 (very high).



**Figure 3.** Information levels adopted in the analysis of susceptibility to flooding in Campinas, referring to A) hypsometric map, B) slope map, C) pedological map and maps of land use and land cover in the years D) 1985 and E) 2019.

The application of the AHP method was carried out from the comparative judgment between the conditioning factors by the Paired Comparison Matrix. To this end, the fundamental scale of weights defined by Saaty (1990) was used to measure the intensity of the relationship between the variables analyzed in terms of flooding processes, as Table 2 shows:

**Table 2.** Fundamental criteria judgment scale.

Importance Values	Reciprocal Importance Values	Importance
1	1	Equal importance
3	1/3	Weak importance of one over another
5	1/5	Essential or strong importance
7	1/7	Very strong importance
9	1/9	Absolute importance
2, 4, 6, 8	1/2, 1/4, 1/6, 1/8	Intermediate values between adjacent importance intensities

**Source:** Saaty (1990, adapted by the authors, 2022).

Since the greater the number of comparisons analyzed, the greater the tendency towards uncertain results, Equations 1, 2, and 3 were applied, referring to the calculation of the Consistency Index (CI) and the Consistency Ratio (CR), to validate the results obtained by the paired matrix.

$$CR = \frac{CI}{RI} \quad (1)$$

$$CI = \frac{(\lambda_{max} - n)}{n - 1} \quad (2)$$

$$\lambda_{max} = \frac{1}{n} \sum_{j=1}^n \frac{[AW]_i}{w_i} \quad (3)$$

Where:

CR = Consistency ratio

RI = Random index

CI = Consistency index

n = number of factors evaluated (number of columns or rows)

$\lambda_{max}$  = Eigenvector

$[AW]_i$  = matrix resulting from the product of the comparison matrix  $[AW]_i$  by the calculated weights ( $w_i$ )

( $w_i$ ) = calculated weights

In turn, the zoning of areas susceptible to flooding was obtained from the joint sum of each criterion of the matrix data by the *raster calculator* tool of the QGIS 3.16 software. The resulting flood susceptibility map was divided into five classes according to their probability of flooding, namely: very low, low, moderate, high, and very high risk.



### 3. RESULTS AND DISCUSSION

#### 3.1. Physiographic aspects of the Atibaia River Basin

Table 3 shows 26 physiographic parameters of the Atibaia River Basin established by the proposed methodology.

**Table 3.** Physiographic characteristics of the Atibaia River Basin – SP.

	Physical Characteristics	Units	Results
Geometric Characteristics	Drainage area	km <sup>2</sup>	2,814.59
	Perimeter	km	579.71
	Axial length	km	131.27
	Shape factor (Sf)	Dimensionless	0.16
	Compactness coefficient (Cc)	Dimensionless	3.06
	Circularity index (Ci)	Dimensionless	0.11
Relief Characteristics	Minimum basin altitude	m	499
	Average basin altitude	m	850.3
	Maximum basin altitude	m	2,026
	Altimetric range	m	1,527
	Minimum basin slope	%	0
	Average basin slope	%	20.2
	Maximum basin slope	%	279.60
	Relief ratio (Rr)	Dimensionless	0.029
	Minimum altitude of the main river	m	504
	Average altitude of the main river	m	708.69
	Maximum altitude of the main river	m	802
	Altimetric range of the main river	m	1,306
Slope of the main river	%	0.021	
Drainage Network Characteristics	Basin order	-	7th
	Total number of channels	-	12,365
	Total length of drainage	km	6,599.48
	Length of the main river	km	257.48
	Vector length of the main river	km	127.56
	Drainage density (Dd)	km/km <sup>2</sup>	2.34
	Sinuosity index (Si)	Dimensionless	2.02

The analysis of the physiographic factors made determining and understanding important variables to aid in the planning and environmental management of the region possible. Regarding the shape of the basin, the values obtained for the shape factor ( $Sf = 0.16$ ), compactness coefficient ( $Cc = 3.06$ ), and circularity index ( $Ci = 0.11$ ) give the Atibaia Basin a more elongated shape (Nardini *et al.*, 2013; Villela and Mattos, 1975). This indicates a low tendency to flooding in the locality since rainfall over the basin is concentrated at different points, helping to mitigate the influence of rainfall intensity (Villela and Mattos, 1975).

Regarding relief, the low value of the relief ratio indicates a lower general slope of the Atibaia River Basin, confirmed by the average slope of the basin in the order of 20.2%, thus, classified as strong-wavy relief (Lepsch *et al.*, 2001). This relief class presents moderate fragility to erosion and environmental degradation and has limitations to agricultural mechanization, recommended in the use of semi-intensive agriculture (Lepsch *et al.*, 2001).

The shape and relief of the basin also affect the time of concentration (Collischonn and Dornelles, 2013). The results obtained for the time of concentration by the different formulas

show a variability of values for the Atibaia Basin, as indicated by Table 4. In this study, the mean value between the results was adopted as an indication of the time of concentration of the basin.

**Table 4.** Time of concentration of the Atibaia River Basin – SP.

Method	Time of concentration (hours)
Giandotti	52.29
Johnstone-Cross	61.9
Temez	102.27
Corps of Engineers	65.11
Mean	70.39

Thus, the high time of concentration calculated for the study area reflects the elongated shape of the basin and its mostly undulating relief.

The characteristics of the drainage network, in turn, reveal the drainage density of the basin and the sinuosity index of the main river. The calculated value of drainage density (Dd) indicates the Atibaia Basin shows medium drainage, allowing us to infer a moderate permeability and infiltration of water in the locality (Nardini *et al.*, 2013). In turn, the main river presented a sinuosity index (Si) of 2.02, classified as a winding watercourse (Cezar *et al.*, 2019).

### 3.2. Flood susceptibility mapping in the Municipality of Campinas

Based on Saaty's (1990) fundamental scale, the pairwise comparison matrix resulted in a square matrix of order four. The values assigned to the matrix represent the intensity of importance of the parameters evaluated between them for the susceptibility to flooding; the main diagonal represents the comparison between the same criteria, while whereas the elements arranged above and below the diagonal represent the judgment of importance between the different criteria (Table 5).

**Table 5.** Paired comparison matrix of the analyzed criteria.

	Pedology	Land use and cover	Altitude	Slope
Pedology	1	1/3	1/5	1/7
Land use and cover	3	1	1/3	1/5
Altitude	5	3	1	1/3
Slope	7	5	3	1

The values assigned to the matrix allowed the calculation of the statistical weights of each analyzed variable by the quotient between the sum of the n elements of each variable in the matrix and the total of the respective sums. Thus, the calculated weights ( $w_i$ ) defined the importance between the conditioning factors, in a range from 0 to 1, where the predominance of one criterion over another is larger as  $w_i$  approaches 1, as shown in Table 6.

**Table 6.** Priority and consistency values of the resulting matrix.

Analyzed criteria	$w_i$	$[Aw]_i$	$\lambda_{max}$	CI	CR
Slope	0.558	2.356	4.118	0.039	0.044
Altitude	0.263	1.099			
Land use and cover	0.122	0.492			
Pedology	0.057	0.229			

The information levels that most influenced the susceptibility map were slope and hypsometry, given the occurrence of low slope and general altimetric range in the municipality, followed by land use and occupation, and finally, acting to a lesser extent in the results, pedology.

According to the dimensions of the matrix, the tabulated value of 0.90 was adopted to express the Random Index, according to Saaty (1987). In turn, the judgment of the analyzed variables, by the validation of the assigned weights, as outlined in Equations 1, 2, and 3, presented satisfactory statistical conditions, whereas the calculation of the consistency ratio of the matrix elements did not exceed the indicated value of 0.10, which demonstrated coherence (CI) and reliability (CR) of the generated data (Saaty, 1987).

Digital image processing was used to prepare the flood susceptibility maps by weighted combination of established hierarchical data, allowing the estimation of the territorial susceptibility of Campinas to flooding processes, using the matrix data calculator expressed in the form of Equation 4:

$$SF = 0.057PE + 0.122LUC + 0.263AL + 0.558SL \tag{4}$$

Where:

SF = Susceptibility to flooding

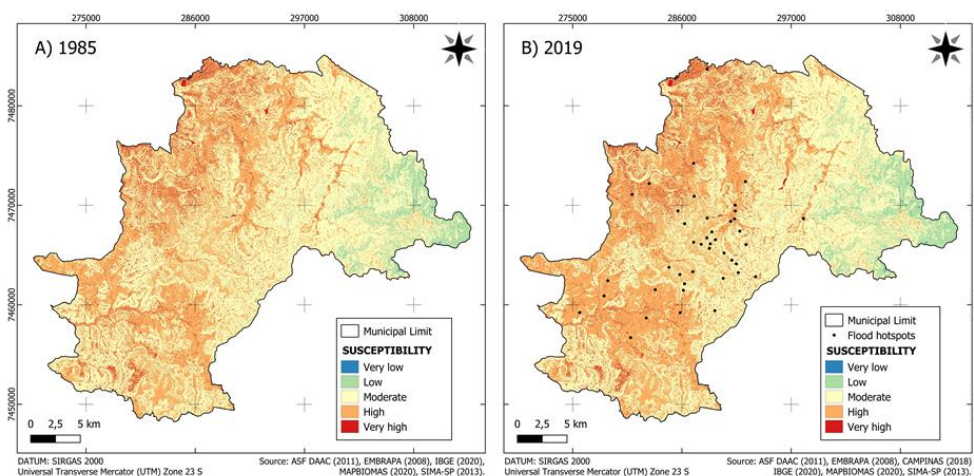
PE = Pedology

LUC = Land use and cover

AL = Altitude

SL = Slope

Figure 4 shows that, in 1985, the municipality of Campinas presented mainly areas of moderate and high risk of flooding, equivalent to 393.70 km<sup>2</sup> and 324.42 km<sup>2</sup>, or 49.96% and 41.17% of the total area, respectively. The very low risk, low risk, and very high risk areas covered, in this order, areas of 0.19 km<sup>2</sup> (0.02%), 41.53 km<sup>2</sup> (5.27%), and 28.18 km<sup>2</sup> (3.58%). Compared with the flood susceptibility mapping for the year 2019, very low risk, low risk, high risk, and very high risk areas increased, respectively, to 0.28 km<sup>2</sup> (0.03%), 44.9 km<sup>2</sup> (5.70%), 349 km<sup>2</sup> (44.29%), and 28.98 km<sup>2</sup> (3.68%), and moderate risk areas decreased to 364.84 km<sup>2</sup> (46.30%).



**Figure 4.** Flood susceptibility maps of Campinas – SP, for the years of A) 1985 and B) 2019.

The areas classified with the highest degree of susceptibility are directly related to the

marginal edges of rivers and streams since they present the smallest slope intervals and soils with a greater tendency to hydromorphism or low infiltration capacity. This risk is potentiated, as observed in the past 35 years, by urban expansion to areas close to water courses, resulting in potential areas vulnerable to problems arising from the reach of hydrological processes, especially in the event of critical rainfall. For 2019, among the 48 critical flood points established by the City Hall of Campinas, 37 points are in areas of high and very high susceptibility to flooding, whereas the remaining 11 points are in areas of moderate susceptibility.

#### 4. CONCLUSIONS

The characterization of the Atibaia Hydrographic Basin regarding its physical aspects and concentration time is fundamental to a better understanding of the hydrogeomorphological processes occurring in the basin, besides adding auxiliary information to future studies regarding diagnosis, planning, and environmental management in the locality.

For the municipality of Campinas, based on this study, the mapping of areas susceptible to flooding identified critical zones of the territory, defining priority areas for government action and programs regarding urban and environmental management, which may guide new studies on a more detailed scale, aiming to prevent and mitigate possible impacts resulting from the flooding processes.

In addition, when comparing the flood susceptibility map for 2019 with the records of floods in 2018, we have found agreement between the zones of susceptibility and critical flooding points recorded, of which 77.1% coincided with areas of high and very high susceptibility levels, thus confirming the effectiveness of the adopted methodology.

Furthermore, due to being a qualitative method, the importance of correctly defining the grades and weights assigned to the analyzed variables, as well as the necessary rigor regarding the scales and quality of the data used is emphasized since they can result in over- or underestimated mappings. In this sense, despite possible variations in the result of the consistency index value, within the acceptable limit, it is valid to apply this methodology as a basis for preliminary studies and to guide decision-making in the management and prevention of flooding processes.

#### 5. ACKNOWLEDGEMENTS

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