Morphometric Study of the Jacuí River Watershed in João Monlevade (MG): A Geographic Perspective

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ABSTRACT

Knowledge of the characteristics of a watershed is fundamental to understanding the environmental dynamics of this planning unit. In this sense, the objective of this work was to characterize the morphometric aspects of the Córrego Jacuí watershed, located in the municipality of João Monlevade (MG), since this characterization makes it possible to understand the hydrological behaviour of the watershed and provide subsidies for its management. The bibliographic survey showed no morphometric studies available for the watershed studied. Considering the increasing urbanization of the basin, these first studies are important to understand its dynamics. The study used the Shuttle Radar Topographic Mission (SRTM) image with a resolution of 30 m and the digital elevation model (DEM) generated from it. The geoprocessing of the watershed information was carried out using tools from the free software Quantum Gis (QGIS). The morphometric parameters determined for the studied basin were area, perimeter, total length of tributary channels, compactness coefficient (Kc), shape factor (Kf), drainage density (Dd) and circularity index (Ic). The results indicate that the basin is elongated, with moderately developed dendritic drainage and a low to moderate propensity to flood under average annual rainfall conditions. It should be noted, however, that land use and occupation activity that interferes with the main channel can alter this trend by silting up the watercourse, making flooding more frequent than the morphometric characteristics of the watershed indicate.

Keywords: Watershed; morphometry; geoprocessing, urbanization

1. INTRODUCTION

According to Federal Law No. 9.433 of January 8, 1997,[1], river basins are considered territorial planning units and play important territorial roles as they constitute basic landscape units, as highlighted by [2]. Studies involving this unit can be developed taking into account physical, environmental, economic and population aspects related to land use and occupation, as well as the management of water resources in the basin, such as [3], [4] and [5].

According to [6] and [7], the characteristics of a watershed depend on factors that are interrelated with climate, geology and the environment and whose interaction promotes combinations that result in watersheds of different origins and physical conditions.These factors also act on various scales since a watershed can vary from a few hectares to millions of square kilometres.

The hydrological behaviour of a basin and the runoff depends, among other factors, on the physical characteristics, especially those associated with the relief, shape and drainage network, according to [8], [9], [10], [11], [12], [13] and [14].

[15] point out that in systemic studies of a basin, there are two approaches to analysis: the fractal relationships in the geometry of the network and the dimensions of the river system. These interactions of geomorphological and hydrological processes are dealt with in four (04) dimensions: 1) the longitudinal, which comprises upstream-downstream and tributary-stem relationships, 2) the lateral, which deals with slope-channel and channel-plain relationships, 3) the vertical, which includes flood levels and surface-subsurface interactions,

and 4) the temporal, which comprises magnitude, frequency and synchronism of water and sediment movement, disturbance regimes and patterns resulting from disturbances, with the morphometric characterization carried out here falling within dimension one.

According to [16], [17]and [18], the longitudinal analysis of the basin's morphometry represents the upstream-downstream and tributary-trunk relationships of the basin chosen for analysis and it makes it possible to verify the correlations between descriptive parameters of this basin and their correlation with surface hydrological behaviour.

These parameters include area and perimeter, shape, altimetric amplitude, total stream length, total channel length, number of rivers, drainage density, river density, bifurcation ratio, dissection index and roughness index ([19], [17]).

This analysis is currently easily carried out using technologies since obtaining morphometric properties using GIS is faster than traditional treatments and manually evaluating topographic maps. It even allows analysis to be incorporated over a given period, as highlighted by the works of [20], [21], [22], [5], [23], [24], [25] and [26], among others.

Considering the importance of knowing the characteristics of river basins to understand their hydrological behaviour, especially in an urban environment, where anthropogenic action rapidly modifies the environment, this work aimed to characterize the Jacuí RiverWatershed through its morphometric parameters, also as a subsidy for future hydrological and environmental analyses, since knowledge of the basin's physical characteristics is the starting point for its planning and occupation.

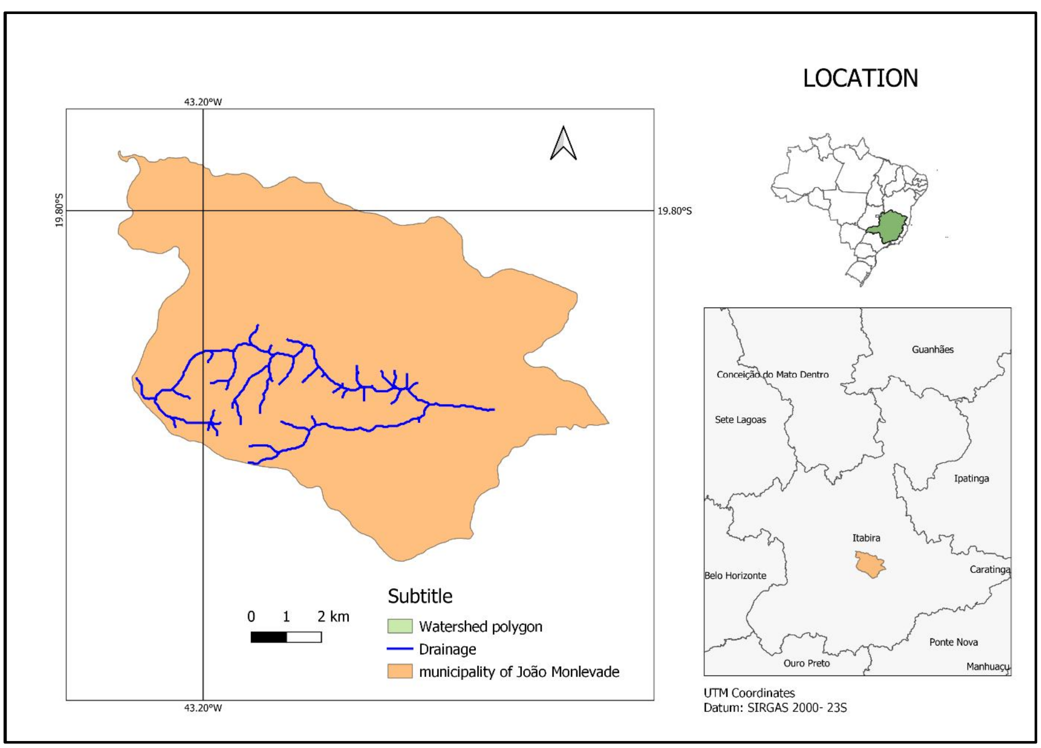
2. MATERIAL AND METHODS

2.1 Characterization of the study area

The municipality of João Monlevade, located in the central-eastern region of the state of Minas Gerais, has an area of 99.158 km² [27] and belongs to the Doce River basin. The sub-basins draining the municipality are the Santa Bárbara, Carneirinhos and Jacuí Rivers, according to [28].

The study looked at the Jacuí Riverwatershed, which covers an area of 28.82 km^2 and encompasses 23% (twenty-three percent) of the municipality's urban population. The basin's location in the municipality can be seen in Figure 1.

Figure 1- Location map of the region where the municipality of João Monlevade (MG) is located and the study basin



Source: Author (2023)

The municipality's natural vegetation cover consists of Atlantic Forest[29], but this has been partially replaced by urban occupation and pasture.

As for the physical aspects, the municipality has a relief formed by high hills and mountain ranges and secondarily by hills and low hills, according to [30] and the soils are mainly represented by dystrophic red latosols, according to [31].

The general geology is mainly made up of metagranites and metasyenogranites of alkaline affiliation, late to post-collisional and fine to oriented biotite granites with associated pegmatites, from the Borrachudos Suite with ages of 1.7 Ga, according to [32].

The municipality's climate is classified as Am (humid or sub-humid tropical climate) according to Köppen-Geiger, with an annual rainfall of around 1400 mm and two well-defined seasons, with a dry winter and minimum, maximum and average temperatures of 16.7oC, 26.5oC and 20.7^{o}C respectively ([29], [33]).

The hypsometric map (Figure 2) was made from a raster layer of the digital elevation model of the SRTM image and then rendered using a color scale that represents the variation in altitude in the area, ranging from 800m to 1300m, showing that the relief of the basin is made up of hills with altitudes between 1000 and 1300m and flatter areas where neighbourhoods such as Nova Monlevade, Tanquinho, Cruzeiro Celeste, Teresópolis and others have been established.

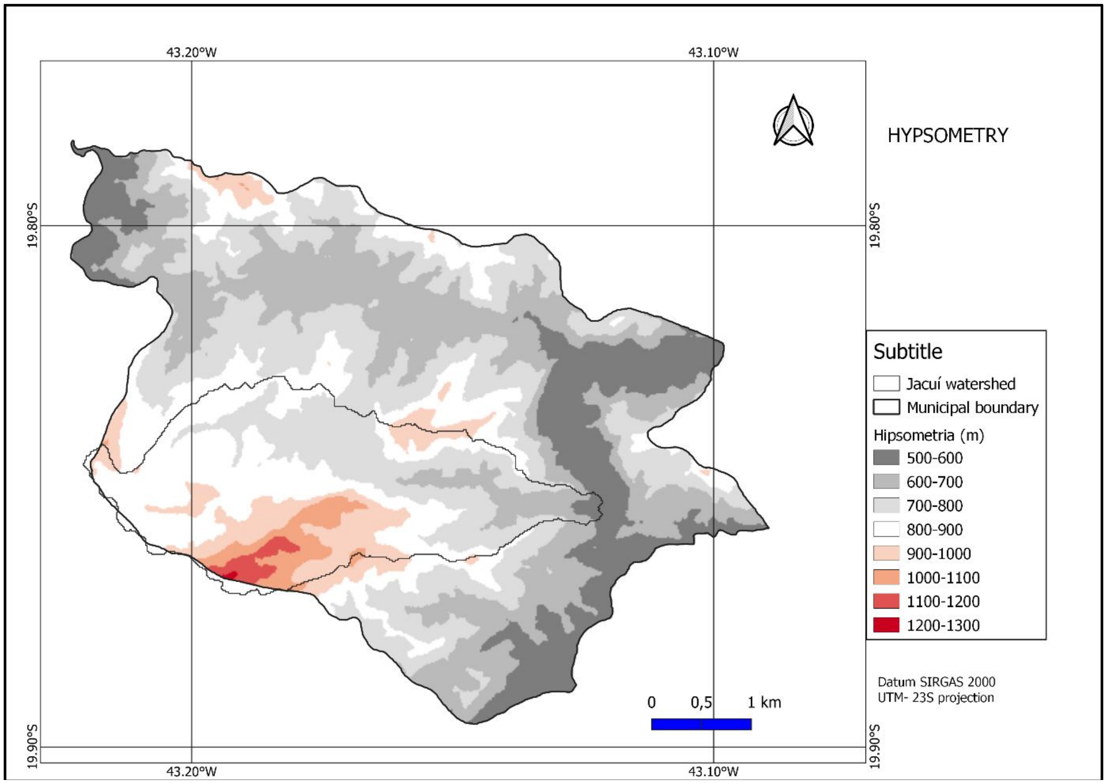


Figure 2 : Hypsometric map

Source: Author (2023)

2.2 Data acquisition and determination of morphometric parameters

To determine the morphometric parameters, an SRTM (Shuttle Radar Topographic Mission) image was first used, provided free of charge by the United States Geological Survey (USGS) with a spatial resolution of 30 meters. From the digital elevationmodel (DEM), the r.fill tool was used to generate a depressionless elevation map.

The basin was delimited, and the flow segments and drainage directions were obtained using the GRASS add-on in the Qgis software. For delineation, the r.watershed tool was used, in which the user indicates the location of the river or basin of interest and the program generates the river's area of influence based on the indicated exit point.

After delimitation, the drainage network was measured using the SRTM image and the morphometric parameters were calculated: drainage area, perimeter, circularity index, elongation ratio, shape factor, compactness coefficient and drainage density.

a) Drainage area (A) and basin perimeter (P)

The drainage area is the area drained by the entire river system between its topographic dividers, projected on a horizontal plane and is the basic element for calculating various morphometric indices. The perimeter (P) represents the total length of the line that delimits the basin through the watershed [34]. It is an important parameter because it influences the amount of water produced as runoff [35].

In addition to the area and perimeter, which are measures commonly used to describe a watershed, according to [7], the shape of the basins is analyzed using the circularity index (Ic), the compactness coefficient (Kc), the elongation ratio (Re) and the shape factor (Kf)).

b) Circularity index (Ic) and elongation ratio (Re)

Circularity is determined by the ratio between the area of the basin (A) and the area of a circle with a perimeter equal to the area of the basin (Ac), as expressed in Equation 1. When this index is below 0.4, the basin tends towards an elongated shape controlled mainly by the geological structure and the closer this value gets to one, the more circular the shape of the basin is, according to [7].

$$I_c = \frac{4.\pi.A}{P^2} \quad (1)$$

The elongation ratio, unlike the circularity index, expresses the relationship between catchment area and basin length (Lb) and can be obtained from Equation 2 ([36], [7]).

$$R_e = \frac{A^{0,5}}{L_b} \quad (2)$$

[37]proposes the classification of the river basin depending on the value of Re in:

Re < 0.7- elongated
Re between 0.7-0.8- less elongated
Re between 0.8-0.9- oval
Re >0.9- circular

c) Compactness coefficient (kc)

This coefficient, determined according to equation 3, based on the relationship between the basin's perimeter and area, associates the shape of the basin with that of a circle and the greater the irregularity of the basin, the greater the compactness coefficient will be, according to [5]. Thus, a circular basin has a coefficient close to or equal to one (unity), while larger coefficients represent less circular or elongated basins. Thus, the propensity to flooding is greater in basins with a Kc close to unity than for basins with a Kc greater than one (1.0) ([38]).

$$K_c = 0,28\frac{P}{\sqrt{A}} \quad (3)$$

Where: Kc - compactness coefficient, P - basin perimeter (m) and A - drainage area(m^2).

[21] indicate that Kc can be used to indicate a tendency to flooding, according to the following ranges:

1.00 ≤Kc< 1.25 - basin with a high propensity to major flooding.
1.25 ≤ Kc< 1.50 - basin with a medium tendency to major flooding.
Kc≥1.50 - basin not prone to major flooding

d) Shape factor (Kf)

This is another measure of the relationship between catchment area and length and is calculated using Equation 4.

$$K_f = \frac{A}{L^2} \quad (4)$$

[38] point out that the lower the Kf of a watershed, the less prone it is to flooding. This is because a low Kf depends on a longer basin length, which shows that the basin is narrow. Thus, Kf values above 0.75 indicate basins with a high tendency to flood, while values below 0.50 reduce this tendency.

e) Drainage density (Dd)

Calculated according to Equation 5, this is the sum of the length of all the channels in the drainage network (L_t) by the drainage area (A) ([19]).

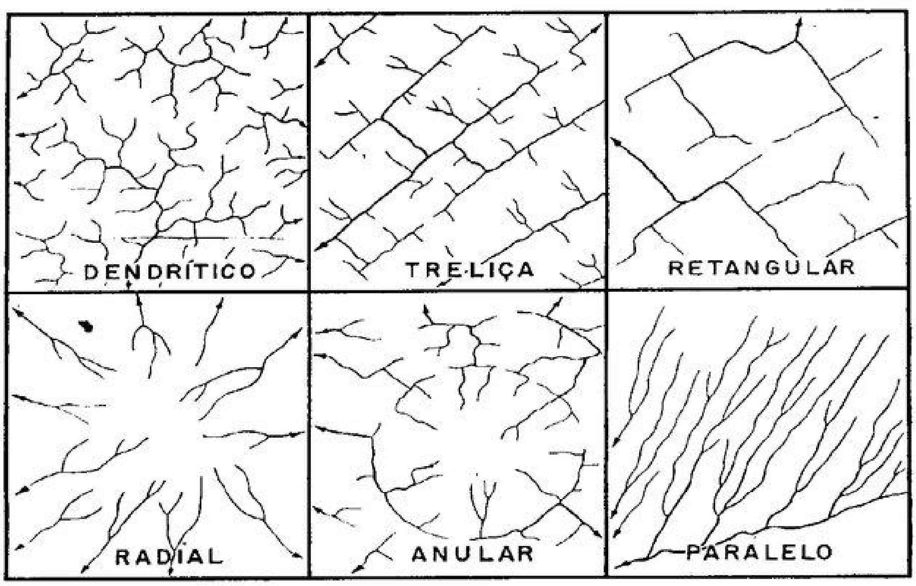
$$D_d = \frac{L_t}{A} \qquad (5)$$

[5] point out that drainage density is a parameter that expresses the development of a watershed's drainage system.

The drainage pattern provides information on the evolution of the drainage network and sediment input. [14]and [7] state that the drainage pattern is a product of the lithology and geological structures of a region and describes how the tributaries and the main river are connected (Figure 3). The dendritic pattern is the most common form and develops in areas where there is no structural control, and the tributaries join the main current drainage at angles of less than 90°. The lattice or parallel patterns show structural control, often with connection angles close to 90° (right angle) at the junction of the channels.

[12] points out that the Dd parameter varies from 0.55 to 2.09 km/km^2 in humid regions and is an important parameter in estimating water travel time of water.

Figure 3- Drainage patterns



Source: Fryis and Brierley (2013)

3. RESULTS AND DISCUSSION

The morphometric analysis of the Jacuí River watershed made it possible to recognize the hydrological conditions that operate in it and to provide input for future work. Studies on the morphometry of a watershed provide data and models that express the main characteristics and the most active processes in the area, contributing to the planning, organization and management of water resources.

The morphometric characteristics determined for the watershed under study were total area, perimeter, compactness coefficient, circularity index, shape factor, elongation ratio and drainage pattern, as shown in Table 1.

Table 1- Parameters and characteristics of the Jacuí Riverwatershed

PARAMETER VALUE	CLASSIFICATION

Area (km^2)	28,82
Perimeter (m)	24.575
Total length of main drainage (m)	9.693
Total length of channels -Lc (m)	41,880.62
Circularity index (Ic)	0,60
Compactness index (Kc)	1,28
Elongation ratio (Re)	0.55
Shape factor (Kf)	0.307
Drainage density (Dd)- km/km	1,68
Dendritic drainage pattern	Dendritic

Source: Author

The circularity index (Ic) of 0.60 and the elongation ratio (Re) show that the basin has an elongated shape, which can also be seen in Figure 1.

As for the propensity to flooding, analyzed based on the shape factors (kf) and compactness index (kc), this watershed is classified as having a low to medium tendency to the hydrological phenomena of flooding and inundation.

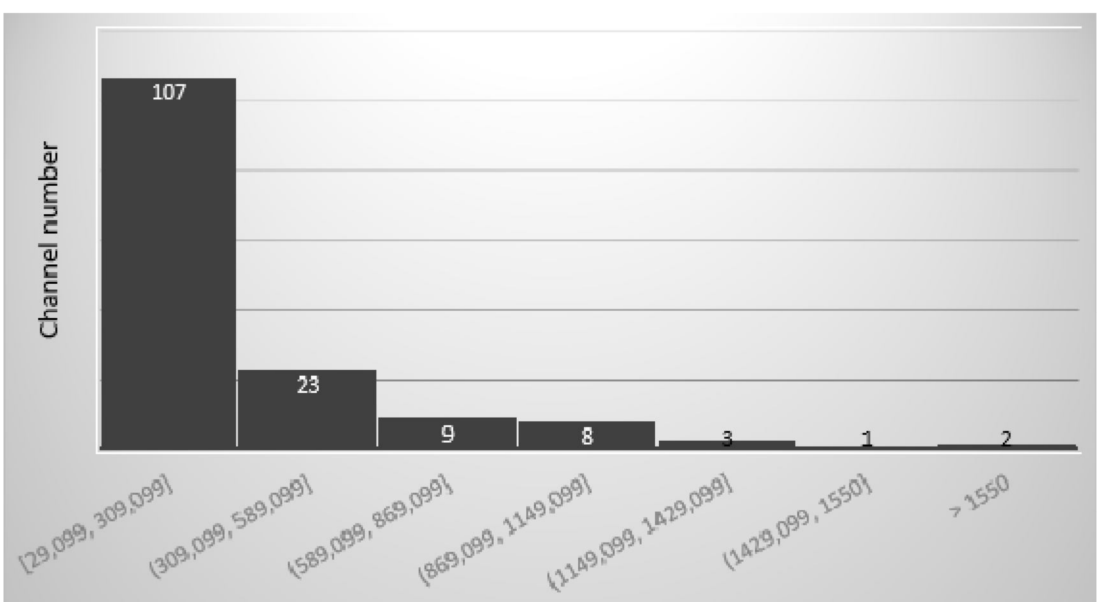
In a basin with an elongated and narrow shape, with a low form factor, there is an increase in the concentration-time of the flow and so the possibility of intense rainfall simultaneously covering the entire length of the basin and generating floods is lower.

However, the occurrence of this phenomenon depends not only on the geometry of the basin but also on the use and occupation of the land. Thus, considering that about 30% of the study area is in an urban expansion area according to [40], there are still areas that will be used for housing and that will change the use and occupation of the land in the areas occupied by forests in the next few years.

The main impact of urbanization on a drainage system is the increase in peak flood flow, the anticipation in time of this maximum flow and the increase in the volume of surface runoff, which can result in floods that harm the surrounding population ([39]). Thus, urbanization and other anthropogenic changes tend to alter surface hydrological conditions, and so maintaining the trend of low to medium propensity to flooding is only confirmed if the other characteristics of the basin remain constant.

Regarding the lengths of the drainages obtained by Qgis, a histogram was created to observe the distribution of these channels and their lengths, and it observed that channels with lengths between 29.0 and 309.9 m predominate in the study area (Figure 4), representing 1st and 2nd-order drainages.This result is similar to that of [41]López-Ramos (2023), in which channels of 1st and 2nd order represent the majority of the drainage, with those of order 1, as they are smaller and shorter in length than the others, prevail in areas where there is find the steepest slopes.

Figure 4- Length of drainage channels in the Jacuí River watershed



Source: Author (2023)

According to [18], drainage density (Dd) values of less than 0.5 km/km^2 represent basins with low drainage density and values between 0.5 and 3.5 km/km^2 classify the basin as having medium drainage density.

The Dd value obtained for the Jacuí River watershed shows a medium drainage density, with values compatible with those expected for tropical climates and regions with relatively homogeneous terrain, represented locally by sandy to sandy-clay soils and granitic rocks that make up its geological substrate. Rocks and soils (especially those covered with vegetation) with greater porosity and permeability tend to infiltrate water from rainfall, reducing the amount of surface runoff and thus the drainage density of a given geographic region.

The soils that occur in the micro-basin are mainly red latosols, evolved soils with good drainage and sandy loam to silty loam texture. The predominant dendritic pattern found in the drainage network, according to [42], indicates a diversity of structure types and is generally found in mountainous areas**.**

4. CONCLUSION

Analysis of the data and results obtained for the Jacuí Riverwatershed led to the conclusion that this watershed has an elongated shape, with shape and circularity indices that show a low to medium tendency to flood under normal annual rainfall conditions.

The drainage density and the dendritic pattern show that it has a medium degree of development over relatively homogeneous terrain, represented by soils formed from granitoid rocks.

As pointed out by [43], the physical conditions of the basin are fundamental in the process of water movement in the basin, influencing surface runoff and infiltration, processes that depend on the basin substrate, rainfall patterns, and relief**.**

Considering that the local relief is mountainous, there is a greater tendency for surface runoff and although the morphometric characteristics indicate a low to medium tendency for flooding problems, changes in the use and occupation of the basin will certainly contribute to an increase in these flows, as is the case in another watershed in the municipality, the Carneirinhos River basin, which is constantly flooded.In that regard, according to[44] the hydrographic network and its characteristics are part of the landscape and present a dynamic aspect in which geology, geomorphology, vegetation and structure correlate. They also emphasize that understanding the shape and density of the watercourses in a watershed, as well as their gradient, plays an important role in understanding the hydrological phenomena in an area**.**

The study also showed that the use of remote sensing data to analyze morphometric parameters can be carried out quickly and reliably, as well as allowing thematic maps to be drawn up, such as maps of land use, vegetation cover, and the relief of the area, which are part of the physical characterization of river basins.

Although the morphometric parameters indicate a low to medium trend in the occurrence of hydrological processes such as flooding, it is important to note that urbanization and deforestation tend to increase the flow of surface water, causing this initial indication to change over time. The processes of environmental degradation and changes in land use therefore reinforce the need to know the characteristics of the watershed to better manage its use and occupation.

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REFERENCES

[1] BRAZIL. Law No. 9,433, of January 8, 1997: Establishes the National Water Resources Policy, creates the National Water Resources Management System, regulates item XIX of art. 21 of the Federal Constitution, and amends art. 1st of Law No. 8,001, of March 13, 1990, which modified Law No. 7,990, of December 28, 1989. http://www.planalto.gov.br/ccivil_03/LEIS/L9433.htm

[2] Mattos JB et al. Geoenvironmental diagnosis of the Una River watershed, Southern Bahia: morphometry, vegetation and land use. Ambiência, Guarapuava (PR), 2017; 13(1); 13 – 29. DOI:10.5935/ambiencia.2017.01.01

[3]. Carvalho ATF. Watershed as a planning unit: Discussion on the impacts of social production on water resources management in Brazil. Caderno Prudentino De Geografia, 2020; 1(42): 140–161. Accessed 10 January 2023. Available: https://revista.fct.unesp.br/index.php/cpg/article/view/6953

[4] Menezes JPC., Franco C., Oliveira, LFC, Bittencourt, RP, Farias, MS, Fia R. Morphometry and evolution of land use and maximum flow in an urban watershed. Brazilian Journal of Geomorphology, São Paulo, 2014; 15(4): 659-672

[5] Mioto CL., Ribeiro VO; Souza, DM. de Q.; PereiraTV.; Anache JAA.; Paranhos FilhoAC. Morphometry of Hydrographic Basins Using Free and Free GIS. Yearbook of the Institute of Geosciences – UFRJ, 2014; 37(2):16-22

[6] Naiman RJ., Lonzarich DG.; Beechie TJ.; Ralph SC. General principles of classification and the assessment of conservation potential in rivers. In: Boon, P.J., Calow, P. and Petts, G.E. River Conservation and Management. John Wiley and Sons, Chichester. 1992: 93-123.

[7] Fryirs KA.; Brierley GJ. Geomorphic Analysis of River Systems: An Approach to Reading the Landscape. 2013, First Edition Blackwell Publishing Ltd.

[8] FERREIRA, C. W. S et al. Morphometric characterization of the Cachoeira II Reservoir Hydrographic Basin, in the municipality of Serra Talhada-PE, Brazil. VI Latin American Seminar on Physical Geography II Ibero American Seminar on Physical Geography, University of Coimbra.2010. Accessed 20 December 2023. Available: https://www.uc.pt/fluc/cegot/VISLAGF/actas/tema2/clarisse

[9] Leal MS, Tonello K.C. Analysis of morphometry and soil and land cover of the Córrego Ipaneminha de Baixo Microbasin, Sorocaba, SP.

Revista Floresta, Curitiba, PR, 2016; 46(4): 439 - 446. DOI: 10.5380/rf.v46i3.45809

[10] Tonello KC. et al. Morphometry of the Cachoeira das Pombas watershed, Guanhães – MG. Revista Árvore, Viçosa-MG; 2006, 4 (8): 156-168. Accessed 03 October 2022. Availlable https://www.redalyc.org/pdf/488/48853019.pdf

[11] Cigagna C., Jimenez-Rueda J., Bonotto D. Morphostructural analysis of the Itanhaém River Basin/SP. Geosciences. 2022;.41(3): 633-341. Accessed 16 January 2024. Available at https://www.periodicos.rc.biblioteca.unesp.br/index.php/geociencias/article/view/16310.

[12] Mahala A. The significance of morphometric analysis to understand the hydrological and morphological characteristics in two different morpho-climatic settings. Applied Water Science, 2020;10:33. https://doi.org/10.1007/s13201-019-1118-2

[13] Alves WS, Scopel IAP, Martins, AP, Morais WA. Morphometric analysis of the Ribeirão das Abóboras Basin- Rio Verde (GO). Geosciences.2016; 35(4): 652-667.Accessed 20 January 2024. Available at https://www.periodicos.rc.biblioteca.unesp.br/index.php/geociencias/article/view/12007/7986.

[14] Charlton Ro. Fundamentals of fluvial geomorphology. New York: Routledge, 2007. 234 p.

[15] Marçal MS, LimaRNS. Contemporary Conceptual Approaches in Fluvial Geomorphology. Espaço Aberto Magazine, PPGG – UFRJ.2016; 6(1):17-33. https://doi.org/10.36403/ESPACOABERTO.2016.5236

[16]. Domingues GF. et al. Morphometric characterization and hydrological behavior of the Rio Pardo watershed. Rev Ifesciência. 2020; 6(2):03-16., DOI: 10.36524/ric. v6i2.502

[17] Schiavetti A; Camargo AFM. River basin concepts: theories and applications. Ilhéus, Ba: Editus, 2002, 293p.

[18] Arantes LT, Silva D.C.C., Lourenço, R.W. Subsidies of morphometric indicators in territorial management. Scientia Plena. 2022; 18(11). DOI: 10.14808/sci.plena.2022.111701

[19]. Tucci, CEM (org). Hydrology: science and application. Porto Alegre: Publisher of the Federal University of Rio Grande do Sul: Brazilian Water Resources Association, 2004, 3rd ed.

[20] Moraes MEBA, Lorandi R.(eds). Methods and techniques for research in river basins [online]. Ilhéus, BA: Editus, 2016, 283p. ISBN 978-85-7455-443-3. SciELO Books<http://books.scielo.org>.

[21] Souza CF. de et al. Morphometric characterization of the Ivaí-Paraná River Hydrographic Basin. Online Geoenvironment: Goiânia. 2017; 29. DOI: 10.5216/revgeoamb.v0i29.50602.

[22] Santos LL, Ribeiro VO, DiodatoJO. Morphometric analysis of the river basins covering the urban perimeter of the municipality of Dourados – MS. Proceedings of the 7th Geotechnology Symposium in the Pantanal, Jardim, MS, 20 to 24/10/2018. Embrapa Informática Agropecuária/INPE, p. 220-229, Available https://www.geopantanal.cnptia.embrapa.br/Anais-Geopantanal/pdfs/p36.pdf

[23] Reis DR. et al. Physical characterization of a watershed through GIS: a study in the Schmidt stream, Brazil. Brazilian. Journal of Biology, 2015; 75(4), suppl. 2: S16-S29. https://doi.org/10.1590/1519-6984.01313suppl

[24] Shekar PR, Mathew A. Morphometric analysis for prioritizing sub-watersheds of Murredu River basin, Telangana State, India, using a geographical information system. Journal of Engineering and Applied Science, 2022:69:44, https://doi.org/10.1186/s44147-022-00094-4

[25] Mani A., Kumari M., Badola R. Morphometric Analysis of Suswa River Basin Using Geospatial Techniques. Engineering Proceedings. 2022, 27, 65. https://doi.org/10.3390/ecsa-9-13225

[26] Gonçalves A. K. (2016). Environmental and morphometric analysis of the Córrego Santo Antônio-São Francisco Xavier Hydrographic Basin (SP). Botucatu. 2016, 81

f.Dissertation (Master’s in Agronomy/Energy in Agriculture) – Faculty of Agricultural Sciences, Universidade Estadual Paulista

[27] IBGE. Brazilian Institute of Geography and Statistics. Data from the municipality of João Monlevade, 2021. Accessed 18 August 2022. Available at https://cidades.ibge.gov.br/brasil/mg/joao-monlevade/panorama

[28] Silva JJR et al. Influence of urban expansion combined with morphometric characteristics on flood occurrences: case study in the municipality of João Monlevade-MG. Research, Society and Development, 2020; 9(2): DOI: http://dx.doi.org/10.33448/rsd-v9i2.2101

[29] ENGECORPS/ANA. Review and Update of the Integrated Water Resources Plan for the Rio Doce Basin (PIRH Doce), Including its Respective Master Plans forWater Resources (PDRHs)/Water Resources Action Plans (PARHs),and Proposal for Classifying the Basin’s Water Bodies into Classesaccording to the Predominant Uses and Update of the Framework ofWatercourses of the Piracicaba River Basin. 2021. Accessed 20 December 2022. Available at https://www.cbhdoce.org.br/wp-content/uploads/2022/01/1454-ANA-01-RH-RT-0001-R0_18-11-21.pdf

[30] CPRM- Mineral Resources Research Company. Chart of susceptibility to gravitational and mass movements and flooding - Municipality of João Monlevade, scale 1:30,000, 2014. Accessed 12 October 2023. Available at https://rigeo.cprm.gov.br/xmlui/handle/doc/14934

[31] Amaral FCS do et al (org). Soil mapping and agricultural suitability of lands in the State of Minas Gerais. Rio de Janeiro: Embrapa Solos.2004, 95 p. - Embrapa Solos. Research and Development Bulletin; n. 63

[32.] Padilha AC., VieiraVS; BrunoEM. Itabira geological chart SE.23-Z-D-IV,scale 1:100,000. CPRM, Geological Survey of Brazil, 2000

[33] Sá Junior A.. Application of the Köppen classification to the climate zoning of the state of Minas Gerais. Thesis (master’s degree in Agricultural Engineering/Water and Soil Engineering) – Federal University of Lavras, 2009, 101 p. Accessed 13 October 2022. Available http://repositorio.ufla.br/jspui/handle/1/3076.

[34] Tonello KC. Hydro-environmental analysis of the Cachoeira das Pombas Hydrographic Basin, Guanhães-MG. Dissertation (master's degree) presented to the Department of Forestry Sciences of the Federal University of Viçosa-Viçosa (MG), 2005, 69 p.

[35] Santos AM, Targa MS, BatistaGT, DiasNW. Morphometric analysis of the Perdizes and Fojo sub-basins in the municipality of Campos do Jordão, SP, Brazil. Ambi-Água, Taubaté. 2012; 7(3): 195-211. http://dx.doi.org/10.4136/ambi-agua.945

[36] Sousa JAP et al. Modeling to identify sub-basins susceptible to soil erosion using the weighted sum approach. Brazilian Journal of Physical Geography.2021; 14(5):2685-2699. https://periodicos.ufpe.br/revistas/rbgfe/article/viewFile/244603/39490

[37] Sukristiyanti S, Maria R., Lestiana M. Watershed-based Morphometric Analysis: A Review. IOP Conf. Series: Earth and Environmental Science, 2018. DOI:10.1088/1755-1315/118/1/012028.

[38] Cardoso CA., Teixeira HC, SoaresCPB, MartinsSV.Morphometric characterization of the Debossian River Basin, Nova Friburgo, RJ. Revista Árvore, Viçosa-MG. 2006; 30(2):.241-248. https://doi.org/10.1590/S0100-67622006000200011

[39] Vendrame IF.; Lopes, WAB. Analysis of urban growth and its effects on changing surface runoff dynamics in the Pararangaba basin - Anais XII Brazilian Symposium on Remote Sensing. Goiânia, INPE, 2005

[40]MUNICIPALITY OF JOÃO MONLEVADE. Master Plan 01/2018. Accessed 05 October 2022. Available at https://pmjm.mg.gov.br/publicacoesView/?id=499

[41]López-Ramos, A.;Medrano-Barboza, J.P.;Martínez-Acosta, L.; Acuña, G.J.; Remolina López, J.F.;López-Lambraño, A.A. Assessment of Morphometric Parameters as the Basis for Hydrological Inferences in Water Resource Management: A Case Study from the Sinú River Basin in

Colombia. ISPRS Int. J. Geo-Inf. 2022 (11), 459. https://doi.org/10.3390/ijgi11090459

[42] Franco ACV, SantoMAD. Contributions of morphometry to the study of floods in the Luis Alves/SC River sub-basin. Rev Mercator. 2015; 14(3): 151-167, Sept./Dec. 2015. DOI: 10.4215/RM2015.1403.0009

[43] Dias AA, AquinoCM, SantosFD.Environmental Characterization and Morphometric Analysis of the Itaueira River Basin, Piauí, Brazil. Geosaberes [Online]. 2020; 11:265-276 https://repositorio.ufc.br/bitstream/riufc/53549/1/2020_art_aadias.pdf

[44] Shekar PR, Mathew A.Morphometric analysis of watersheds: A comprehensive review of data sources, quality, and geospatial techniques. Watershed Ecology and the Environment,2024 (6):13–25. https://doi.org/10.1016/j.wsee.2023.12.001