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Morphometric characterization as a tool to control flood and landslide risks in a portion of the Manhuaçu River Basin, MG, Brazil

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ABSTRACT: This aims to evaluate the morphometric parameters of the Manhuaçu River watershed and their influence on erosive processes. The study was conducted upstream from the city of Manhuaçu, where the morphometric characterization of 23 sub-basins was made using relief. The morphometric parameters were submitted to Principal Component Analysis (PCA) to indicate the most significant. The hypsometric integral was applied to all sub-basins to analyze their stage of geological development. Among the 23 sub-basins evaluated, there was a variation of 1.32 to 243.94 km² of the basin area. The most significant morphometric parameters in the evaluation of ACP were: drainage intensity, basin axis, perimeter and altimetric amplitude. The Manhuaçu River sub-basin has a large difference in the value of the hypsometric integral, ranging from 0.23 to 0.78 for sub-basins 22 and 17 respectively. Among the sub-basins analyzed, sub-basins 9, 10 and 23 can be highlighted because they present the juvenile stage, high drainage network and altimetric amplitude. Finally, it can be concluded that this allows to subsidize the choice of priority sub-basins for management and effective for hydrological studies.

Key words: hydrology; hypsometric curve; principal component analysis; watershed

Caracterização morfométrica como ferramenta de controle de riscos de inundação e deslizamento em uma parte da bacia do Rio Manhuaçu, MG, Brasil

RESUMO: O objetivo deste trabalho é avaliar os parâmetros morfométricos da bacia do rio Manhuaçu e sua influência nos processos erosivos. O estudo foi realizado a montante da cidade de Manhuaçu, onde foi feita a caracterização morfométrica de 23 sub-bacias em relevo. Os parâmetros morfométricos foram submetidos à Análise de Componentes Principais (ACP) para indicar os mais significativos. A integral hipsométrica foi aplicada a todas as sub-bacias para analisar o estágio de desenvolvimento geológico das mesmas. Dentre as 23 sub-bacias avaliadas, Houve uma variação de 1,32 a 243,94 km² na área das 23 sub-bacias avaliadas. Os parâmetros morfométricos mais significativos na avaliação da ACP foram: intensidade de drenagem, eixo da bacia, perímetro e amplitude altimétrica. A bacia do rio Manhuaçu apresenta grande diferença no valor do hipsométrico integral, variando de 0,23 a 0,78 para as sub-bacias 22 e 17 respectivamente. Dentre as sub-bacias analisadas, pode-se destacar as sub-bacias 9, 10 e 23 por apresentarem o estágio juvenil, alta rede de drenagem e amplitude altimétrica. Pode-se concluir, por fim, que essa permite subsidiar a escolha de sub-bacias prioritárias para manejo e efetivas para estudos hidrológicos.

Palavras-chave: hidrologia; curva hipsométrica; análise de componentes principais; bacias hidrográficas

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Introduction

The physical characteristics of the basin are related to soil water infiltration and runoff velocity (Leal & Tonello, 2016). Morphometric analysis is a tool for watershed characterization, where pioneering studies by Horton (1932) demonstrated the importance of quantitative morphometric analysis for understanding hydrology and geomorphology in watersheds.

Thus, morphometric studies are fundamental in the characterization of watersheds, as well as in determining their limitations and potentials for land use, thus favoring the proper planning of activities to be developed (Santos et al., 2012; Singh et al., 2015; Farias et al., 2015).

In addition to morphometric characterization, the topographic profile and proportion of the basin to erosive processes are fundamental in management decisions (Dikpal et al., 2017). An analysis used for these processes is the hypsometric integral, a study of horizontal cross-sectional area distribution in relation to elevation (Strahler, 1952). Dikpal et al. (2017) observed from the hypsometric curves of the main basin and sub-basins in a mature stage of geomorphological development with the concavity facing upwards and in an S-shape, indicating an eroded basin.

The prioritization of sub-basins considering local morphometry and geomorphology is necessary for a better and more efficient management (Rahaman et al., 2015; Ahmed et al., 2018; Meshram & Sharma, 2018).

Recently, intense rains have caused great floods and landslides in the region of the Manhuaçu River watershed, causing great economic losses and six fatalities, resulting in a state of emergency declared by Minas Gerais state. The objectives proposed by this work were: (i) to evaluate and define the morphometric parameters that best explain the variation in the Manhuaçu River sub-basins; (ii) compare different hypsometric integrals for sediment yield potential and geological stage of sub-basins (iii) prioritize sub-basins for management based on morphometric parameters and hypsometric integral values.

Materials and Methods

Description of the study area

The Manhuaçu River Basin is located in the eastern center of the Doce River Basin, Minas Gerais state, Brazil. It has its source in the Seritinga mountain range, in the municipality of São João do Manhuaçu and its mouth in the municipality of Aimorés in the Rio Doce. The site evaluated in the present study limited the mouth upstream of the Manhuaçu municipality headquarters, thus assessing the southwest portion of the Manhuaçu River Basin (Figure 1).

The region was chosen because it is upstream from the main and largest city in the basin where the Manhuaçu River passes through the urban perimeter. The occurrence of floods is frequent and causes great damage and environmental impacts.

The average precipitation was 1,169 mm year-1 in the period between 1961-1990 and 924 mm year-1 between 1981-2010 according to climatological normal data for the city of Aimorés, located at the mouth of the Manhuaçu River (INMET, 2022). The municipalities of São João do Manhuaçu and Luisburgo have the entire territorial area inserted in the basin, and the municipality of Manhuaçu has 41.61% of its territory within the area considered by the study.

Data processing

The delimitation of the Manhuaçu River basin was through the use of the database of contour lines, graded points (IEDE, 2022) and mapped hydrography (IBGE, 2022), both on the scale 1:50,000. Data were redesigned and used to

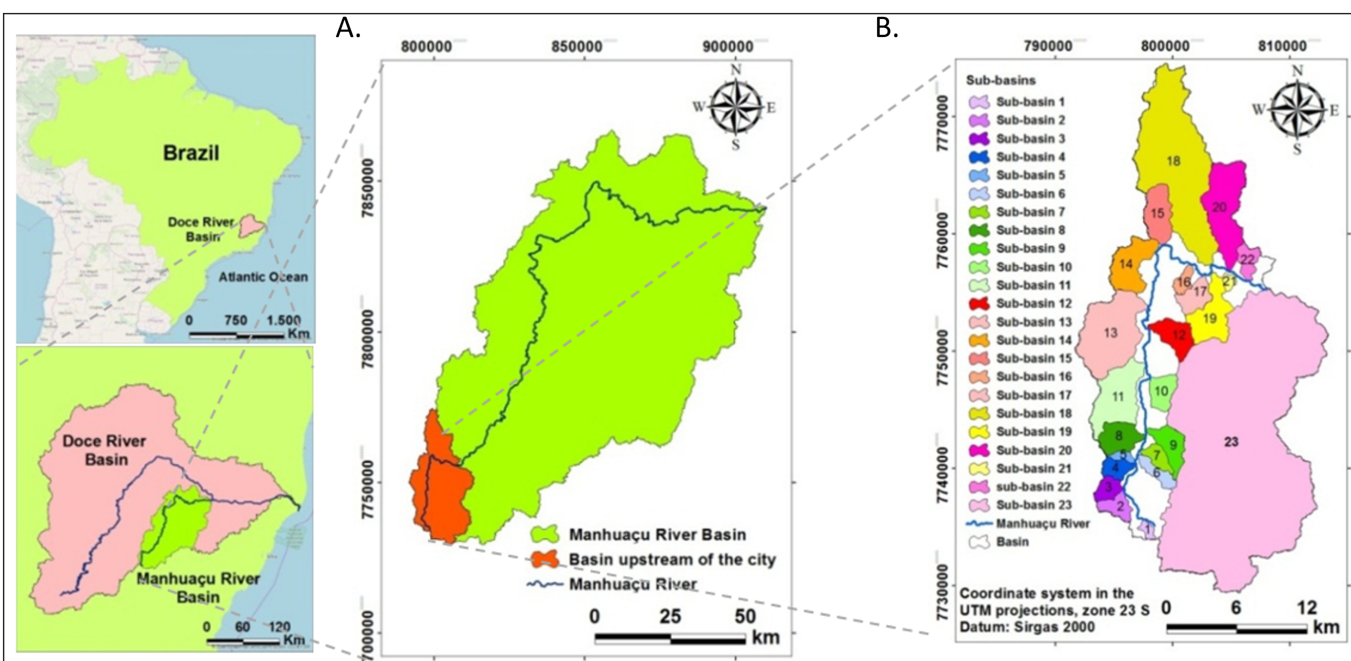

Figure 1. Location of the Manhuaçu River Basin (A) and upstream basin to the city of Manhuaçu, MG, Brazil (B).

generate a Hydrologically Consistent Elevation Digital Model (MDEHC). An MDEHC is characterized by having a marked coincidence between numerical hydrography (raster) and mapped hydrography (vector). Data processing and analysis were performed in a Geographic Information System (GIS) environment, ArcGIS 10.2.2 software.

Areal parameters of the basin, linear parameters and relief characteristics were obtained using spatial analysis tools. Only basins with channel ordering higher than 3rd order (Strahler, 1964) were selected, totaling 23 sub-basins.

The characterization of all 89 sub-basins would be difficult to present in this paper, justifying the choice of characterizing only those higher than order 3. The description of the parameters can be described in Table 1.

Principal component analysis

Principal component analysis (PCA) was applied to the morphometric parameters dataset of all sub-basins to verify the inter-correlated variables and summarize the information, highlighting the most influential or explanatory parameters of these data.

Data were processed in Excel and analysis was performed using the software R v.3.5 (R Core Team, 2018).

Hypsometric curve

The hypsometric curve was performed to evaluate the relationship between horizontal transverse area and elevation, representing the relief of the watershed. In the generation of the hypsometric curve (HC), the function related to relative elevation with the relative area was considered. HC can be considered as a cumulative elevation probability distribution function, so HC can be represented by a continuous polynomial function of the Equation 1:

$$f(x) = a0 + a1x + a2x^2 + \ldots + anx^n \quad (1)$$

where: F (x) is the polynomial function of HC by regression and a0, a1, a2, ... an are the coefficients.

For the total representation of the watershed, the area of HC can be called the Hypsometric Integral, which represents the relative fraction of land surface that remains above the base plane, calculated by the integral of F (x) between the boundaries of the area. This integral can be solved as follows (Equation 2):

$$HI = \iint R\,dx\,dy = \int_0^1 f(x)\,dx = \sum_1^{10} \frac{ak}{K+1} \quad (2)$$

where: F(x) is the unit value defined by the area and altitude axis, R is the total representation of the area, and K is the average value of the elevation.

The curve is created by plotting the ratio of the total basin height (h/H = relative height) to the ratio of the total basin area (a/A = relative area). The shape of the hypsometric curve is related to the stage of the geomorphic development of the basin. The convex hypsometric curves are typical of a young stage, the S-shaped curves are related to a maturity stage, and the concave curves are indicative of a high erosion stage, presenting isolated mountains with a slightly sloping region (Strahler, 1952).

Table 1. Morphometric parameters analyzed in the sub-basins of Rio Manhuaçu, MG, Brazil.

Morphometric parameters	Symbol	Methods	References
Areal parameters			
Shaft lengh	Lb	#	Horton (1945)
Perimeter (km)	P	#	#
Area (km²)	A	#	#
Form Factor	Ff	$Ff = A / Lb^2$	Horton (1932)
Elongation ratio	Re	$Re = 1{,}128\ A^{0{,}5}/Lb$	Schumm (1956)
Circularity ratio	Rc	$Rc = 4\pi A/P^2$	Miller (1953)
Compactness coefficient	Cc	Cc = P/2(πA)0,5	Gravelius (1941)
Liner parameters			
Stream order	U	Hierarchical rank	Strahler (1964)
Stream number	Nu	Nu= N1+N2+...Nn,	Horton (1945)
Stream lenght (km)	Lu	Lu= L1+L2+...Ln	Horton (1945)
Mean stream lengh (km)	Lm	Lm = Lu/Nu	Strahler (1964)
Bifurcation ratio	Rb	Rb= Nu/Nu+1	Horton (1945)
Mean bifurcation ratio	Rbm	Rbm=∑Rb/n	Strahler (1964)
Channel frequency (km^{-1})	Fs	Fs = Nu/A	Horton (1945)
Drainage density (km/km²)	Dd	Dd = Lu/A	Horton (1932)
Drainage intensity	Di	Di = Fs/ Dd	Faniran (1968)
Relief characteristics			
Height of basin outlet (m)	Emin	#	#
Maximum height of basin (m)	Emax	#	#
Total basin relief	H	H=emax-emin	Strahler (1952)
Relief ratio	Rr	Rr = H/Lb	Melton (1957)
Ruggedness number	Rn	Rn = H x Dd	Strahler (1964)
Orientation	-	Presentation face from the mouth to one of the cardinal directions	Tonello et al. (2006)

Results and Discussion

Principal component analysis

The Principal Component Analysis identified four components to explain 80.13% of the total variation in morphometric parameters of the 23 sub-basins. The first component (Dim.1) explained 33.76% of the total variation, whose variables with significant weights were Rc, Re, Ff, Fs, Di, Dd, Lm, Lu, A, H and Cc. The second component (Dim.2) represented 19.57% of the total variation and had Di, Fs, Lu, A and Lm with significant weights.

The prioritization of sub-basins for management through the analysis of morphometric main components has been used by several authors (Rahaman et al., 2015; Choudhari et al., 2018; Mesham & Sharma, 2018). Farias et al. (2015) made a morphometric and land use analysis in 26 sub-basins of the Arroio Candiota-RS basin and, through the analysis of the main components, the most important characteristics were highlighted, allowing more precise recommendations.

Considering the most explanatory variables in the first component, the sub-basins with the greatest potential for response to management would be those that presented the best values for the morphometric parameters: Rc, Re, Ff, Fs, Di, Dd, Lm, Lu, A, H and Cc. Each of these variables will be discussed in subsequent topics.

Areal parameters

The Manhuaçu River Basin has an area of 550.03 km² and a perimeter of 187.47 km to the mouth, up to the headquarters of the Manhuaçu, MG, Brazil. Among the 23 sub-basins evaluated, there was a variation of 1.32 to 243.94 km² of the basin area, corresponding to 86.24% of the total evaluated basin area, where the remaining area (13,76%) corresponds to the sub-basins that did not satisfy the selection criteria. These previous area parameters and other shape indices are shown in Table 2.

The form factor (Ff) is a parameter defined by the ratio between the basin area and the area of a square (Horton, 1932), the dimensionless value approaching the unit indicates a more uniformly shaped basin and the farther from this value indicates a longer-shaped basin with less susceptibility to flooding. Among the sub-basins evaluated, 9 and 10 had the highest values of the form factor 0.60 and 0.55, respectively. Rahaman et al. (2015) observed a low form factor (0.22) for the river Kallar, indicated along the shape and low risk of flooding.

The elongation ratio (Re) is the relationship between the diameter of a circle of equal area of the basin and length of the basin axis. When the ratio tends to unity (Re = 1.0) it indicates that the basin has a tends circular shape, which in turn favors flooding and rapid flooding (Dikpal et al., 2017). Among the sub-basins analyzed, the highest values for de Re were 0.87 and 0.84 for sub-basins 9 and 10, respectively.

The circularity ratio (Rc) is the ratio between the basin area and the area of a circle equal to the basin perimeter. Sub-basin 5, 6 and 18 had a lower circularity index (0.52), indicating a longer basin, with a lower risk of high flow peaks, with lower risk of sudden flooding. Santos et al. (2012) observed low flood risk for the Córrego Perdizes and Forjo sub-basins that presented low circularity index values, 0.27 and 0.29 respectively.

Table 2. Geometric parameters of the 23 sub-basins of the Manhuaçu River Basin, MG, Brazil.

Areal parameters							
Sub-basin	Lb	P	A	Ff	Re	Rc	Cc
1	1.96	5.64	1.35	0.35	0.67	0.53	1.37
2	2.86	10.37	4.24	0.53	0.82	0.5	1.42
3	2.6	8	3.64	0.54	0.83	0.71	1.18
4	4.17	8.64	3.72	0.41	0.72	0.63	1.26
5	2.49	6.02	1.33	0.21	0.52	0.46	1.47
6	2.6	10.45	3.67	0.21	0.52	0.42	1.54
7	3.79	8.95	3.45	0.29	0.61	0.54	1.36
8	4.1	12.36	7.84	0.47	0.77	0.64	1.24
9	5.11	13.61	6.94	0.6	0.87	0.47	1.46
10	7.47	9.98	5.62	0.55	0.84	0.71	1.19
11	5.19	22.3	18.21	0.31	0.63	0.46	1.47
12	4.24	12.82	7.6	0.47	0.77	0.58	1.31
13	7.6	24.29	29.42	0.51	0.81	0.63	1.26
14	5.11	17.75	12.13	0.46	0.77	0.48	1.44
15	5.19	13.76	9.59	0.36	0.67	0.64	1.25
16	2.76	7.53	2.59	0.34	0.66	0.57	1.32
17	3.79	11.53	5.86	0.41	0.72	0.55	1.34
18	17.56	49.61	64.63	0.21	0.52	0.33	1.74
19	6.22	20.17	12.73	0.33	0.65	0.39	1.59
20	9.33	25.12	21.82	0.25	0.56	0.43	1.52
21	1.66	4.73	1.31	0.48	0.78	0.74	1.17
22	3.31	9.87	4.02	0.37	0.68	0.52	1.39
23	26.01	86.87	242.94	0.36	0.68	0.4	1.57

Lb - Shaft lengh; P - Perimeter (km); A - Area (km²); Ff - Form factor; Re - Elongation ratio; Rc - Circularity ratio; Cc - Compactness coefficient.

The compactness coefficient (Cc) relates the shape of the basin to that of a circle. The lowest values were for sub-basins 10 and 21 with 1.19 and 1.17, respectively, indicating the most concentric form, increasing flood risks. Leal & Tonello (2016) verified, for the Ipaneminha de Baixo basin, a coefficient of compactness of 1.25, circularity ratio of 0.63 and form factor of 0.34, where analyzed together indicate oblong/oval shape.

Geometric parameters are important for verifying flow variation in watersheds. Arulbalaji & Gurugnanam (2017) using SRTM data and geospatial tools for the morphometric analysis of the Sarabanga basin, Cauvery River, India, observed a form factor of 0.23 and a circularity ratio of 0.36, indicating an elongated shape, favoring a larger shape concentration-time after precipitation.

Linear parameters

The linear parameters referring to the drainage network of each sub-basin are presented in Table 3.

The order of watercourses (U) represents the degree of branching of the basin drainage system. By Strahler's system (Strahler, 1964), channels without tributaries are considered first-order; from the confluence of two first-order channels arise the second-order channels, and so on, with the order of the river basin corresponding to the value of the highest-order channel. Sub-basin 23 has the highest order, being sixth order (Table 3).

The stream number (Nu), stream length (Lu) and average stream length (Lm) inform about the drainage of the basin. The sub-basins of order 3, 4, 5 and 6 presented an average of 20.1, 51.6, 181 and 1099 Nu and 12.6, 33.9, 127.6 and 584.6 km for Lu, respectively. Nu follows geometric projection (law of stream numbers) and the pattern of bifurcation of flows occurs independently of geological controls, in turn, Lu can be limited by geological controls (Horton, 1945), as well as Lm. basins with lower Lm values are usually present on steeper slopes and fine-textured soils (Strahler, 1964), with the lowest Lm for sub-basin 21 (0.41) and the highest values for sub-basins 7 and 8 (0.86 and 0.85), respectively.

The average bifurcation ratio (Rbm) expresses the relationship between the number of channels of an order and the number of channels of the next higher order (Strahler, 1964). Sub-basin 13 presented the largest Rbm (6.81) indicating some geological control and may produce a low peak flow, but longer than a low Rbm, which tends to have a high peak flow.

The channel frequency (Fs) expresses a relationship with soil permeability, being able to conclude on the generation of floods in a watershed, since high Fs infer the existence of impermeable soils, such as rocky outcrops, more susceptible to flooding (Biswas et al., 2014; Odiji et al., 2021). Sub-basins 21, 10 and 5 show greater susceptibility to flooding with Fs of 6.07, 5.51 and 5.25 km^{-1}, respectively, with the lowest Fs for sub-basin 7 with 2.6 km^{-1}.

The drainage density (Dd) proposed by Horton (1932) correlates the total length of the channels with the watershed area, indicating the proximity between channels. The studied sub-basins have drainage density, with values between 1.81 km km^{-2} (sub-basin 20) and 2.80 km km^{-2} (sub-basin 10). The frequency of channels presented values between 2.60 and 6.07 channels km^{-2} in the sub-basins. Fraga et al. (2014) found

Table 3. Drainage network parameters of the 23 sub-basins of the Manhuaçu River Basin, MG, Brazil.

	Linear Parameters							
Sub-basin	**U**	**Nu**	**Lu**	**Lm**	**Rbm**	**Fs**	**Dd**	**Di**
1	3	7	3.29	0.47	2	5.17	2.43	2.12
2	3	15	7.68	0.51	2.2	3.73	1.91	1.95
3	3	11	8.42	0.77	1.75	3.02	2.31	1.31
4	3	17	9.98	0.59	2.25	4.57	2.68	1.7
5	3	7	3.52	0.5	2	5.25	2.64	1.99
6	3	13	8.65	0.67	1.7	3.49	2.32	1.5
7	3	9	7.77	0.86	2.33	2.6	2.25	1.16
8	4	25	21.37	0.85	2.43	3.19	2.73	1.17
9	3	27	18	0.67	1.71	3.89	2.59	1.5
10	3	31	15.77	0.51	1.64	5.51	2.8	1.97
11	4	56	41.13	0.73	1.78	3.07	2.26	1.36
12	4	31	18.81	0.61	1.89	4.08	2.48	1.65
13	4	99	63.19	0.64	6.81	3.36	2.15	1.57
14	4	47	24.87	0.53	1.67	3.87	2.05	1.89
15	3	29	19.67	0.68	1.57	3.02	2.05	1.47
16	3	13	6.89	0.53	2	5.02	2.66	1.89
17	3	19	12.3	0.65	2.46	3.24	2.1	1.54
18	5	181	127.64	0.71	2.12	2.8	1.97	1.42
19	3	41	28.36	0.69	1.74	3.22	2.23	1.45
20	3	59	39.54	0.67	1.54	2.7	1.81	1.49
21	3	8	3.33	0.42	2.25	6.07	2.52	2.4
22	3	15	7.68	0.51	2.2	3.73	1.91	1.95
23	6	1099	584.61	0.53	1.87	4.51	2.4	1.88

U - Stream order; Nu - Stream number; Lu - Stream length (km); Lm - Average stream length (km); Rbm - Average bifurcation ratio; Fs - Channel frequency; Dd - Drainage density (km km^{-2}); Di - Drainage intensity.

low density (0.34 km km^{-2}), indicating low susceptibility to flooding of the basin.

Drainage intensity (Di) indicates the ratio between channel frequency and drainage density. Sub-basin 21 presented greater drainage intensity among the evaluated sub-basins (2,4) indicating a high drainage basin. Farhan et al. (2016) observed average drainage intensity 1.1 to 43 sub-basins above 4 ° Waves of the Zerqa River, Jordan.

Relief parameters

The parameters referring to the relief characteristics of each sub-basin are presented in Table 4.

The altimetric amplitude (H) represents the difference between the basin's maximum altitude (Emax) and its lowest altitude at the mouth (Emin). The H was 1,124.88 m in the Manhuaçu River Basin, with the maximum variation occurring in the sub-basin 23 (Table 4). In larger basins, the presence of higher altitudes occurs more frequently (Farias et al., 2015).

The orientation of the basin interferes with sun exposure, promoting greater water conservation in south-north oriented basins (Tonello et al., 2006). Among the sub-basins of the present study, 61% are northeast oriented. Leal & Tonello (2016) verified favorable physical characteristics for north-oriented water conservation, with 88 m of altimetric amplitude in the Ipaneminha de Baixo watershed.

The relief ratio (Rr) represents the variation in altitude in a unit of area relative to the local base level. It measures the overall declivity of the river basin and indicates the intensity of the erosion processes operating on the watershed slopes. Because they are steeper, smaller sub-basins tend to exhibit a greater intensity of erosion processes of the main watercourse. Sub-basin 1 and 5 presented the highest relief ratio values, 0.29 and 0.25 respectively, indicating steepest, requiring the adoption of water conservation techniques. Arulbalaji & Gurugnanam (2017) observed a relief ratio (0.02) for the Sarabanga Basin, Cauvery River, India, resulting in low sediment yield per unit area.

Roughness number (Nr) is the product of the altimetric amplitude with the drainage density, this is a useful index to indicate the flood potential (Arulbalaji & Gurugnanam, 2017). Sub-basin 14 had the lowest value (0.53) and the largest was for sub-basin 23 (2.68), indicating greater susceptibility to erosion in sub-basin 23 and to present peak flow in less time concentration.

The drainage network has a SO-NE oriented escarpment relief, with a strong predominance of the dissected relief, influencing the peak flow of the watercourses (Noce et al., 2007; Machado & Silva, 2010).

The basin is inserted into the geomorphological unit of the mountain range of the forest zone, characterized by the presence of strongly undulating relief, rectilinear saws and northeast orientation (Gatto et al., 1983). About 70% of the basin has undulating to strongly undulating relief and over 20% of the basin is mountainous and strongly mountainous, which aggravates the risk of erosion and flooding in the region second (Embrapa, 1979) (Figure 2c). The spatial variation of slope gradients influences runoff and erosion in the Thamirabarani River basin (Kaliraj et al., 2015).

Hypsometric curve

The Manhuaçu River basin has a large difference in the value of the hypsometric integral between the sub-basins, ranging from 0.20 to 0.78 for sub-basins 14 and 7 respectively (Figure 3).

Table 4. Relief characteristics parameters of the 23 sub-basins of the Manhuaçu River Basin, MG, Brazil.

Relief Characteristics						
Sub-basin	**Emin**	**Emax**	**H**	**Rr**	**Nr**	**Orientation**
1	921.35	1,499.04	577.69	0.29	1.4	Northwest
2	830.43	1,169.43	339	0.12	0.73	Northeast
3	830.61	1,234.78	404.17	0.15	0.93	Northeast
4	821.78	1,437.63	615.85	0.2	1.65	East
5	822.41	1,433.35	610.94	0.24	1.61	East
6	817.85	1,623.85	806	0.19	1.87	Southeast
7	817.91	1,611.41	793.5	0.23	1.78	Northwest
8	811.25	1,597.23	785.98	0.19	2.14	East
9	810.37	1,623.85	813.48	0.16	2.1	Northwest
10	804.54	1,340.95	536.41	0.17	1.5	Northwest
11	802.04	1,584.07	782.03	0.1	1.76	Northeast
12	792.33	1,580.38	788.05	0.18	1.95	Northwest
13	784.35	1,401.70	617.35	0.08	1.32	Northeast
14	758.51	1,019.21	260.7	0.05	0.53	Northeast
15	756.93	1,242.94	486.01	0.09	0.99	South
16	699.73	1,323.82	624.09	0.22	1.66	Northeast
17	691.60	1,498.27	806.67	0.21	1.69	Northeast
18	673.43	1,628.5	955.07	0.05	1.88	Southeast
19	677.76	1,587.67	909.91	0.07	2.03	Northeast
20	667.23	1,239.79	572.56	0.17	1.03	South
21	660.62	892.96	232.34	0.14	0.58	Northeast
22	635.64	1,008.45	372.81	0.11	0.71	Southeast
23	617.89	1,737.77	1,119.88	0.04	2.68	North

Emin - Height of basin outlet (m); Emax - Maximum height of basin (m); H - Total basin relief; Rr - Relief ratio; Nr - Ruggedness number; Orientation - Basin orientation.

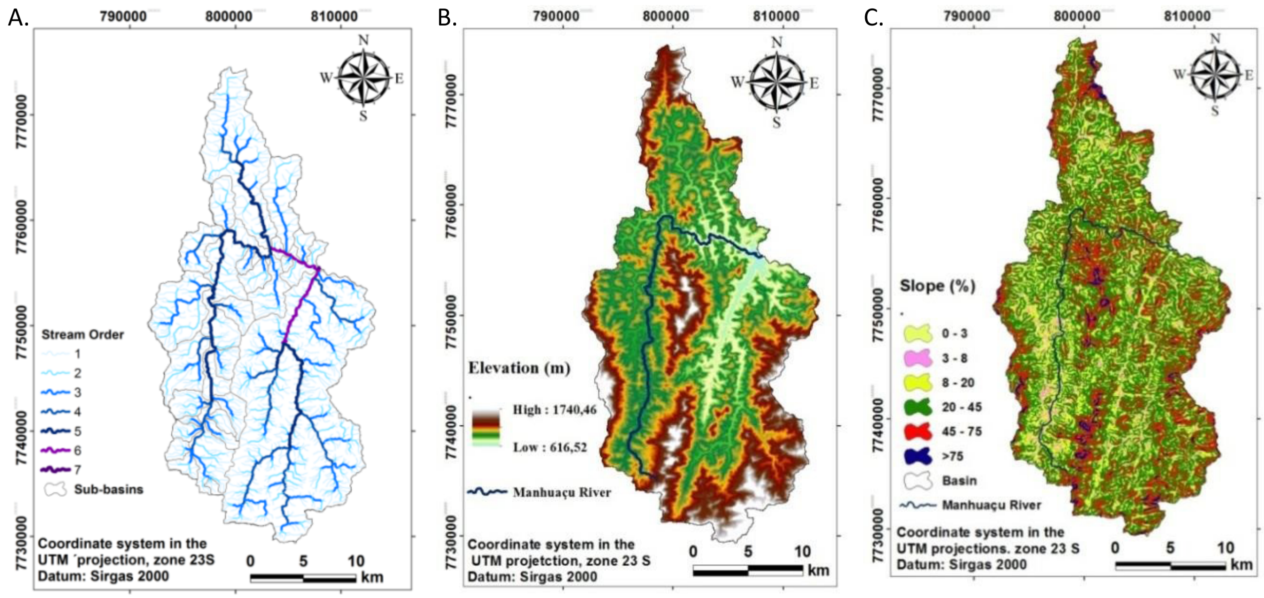

Figure 2. Fluvial hierarchy (A), elevation maps (B), and declivity class map (C) in the Manhuaçu River Basin, MG, Brazil.

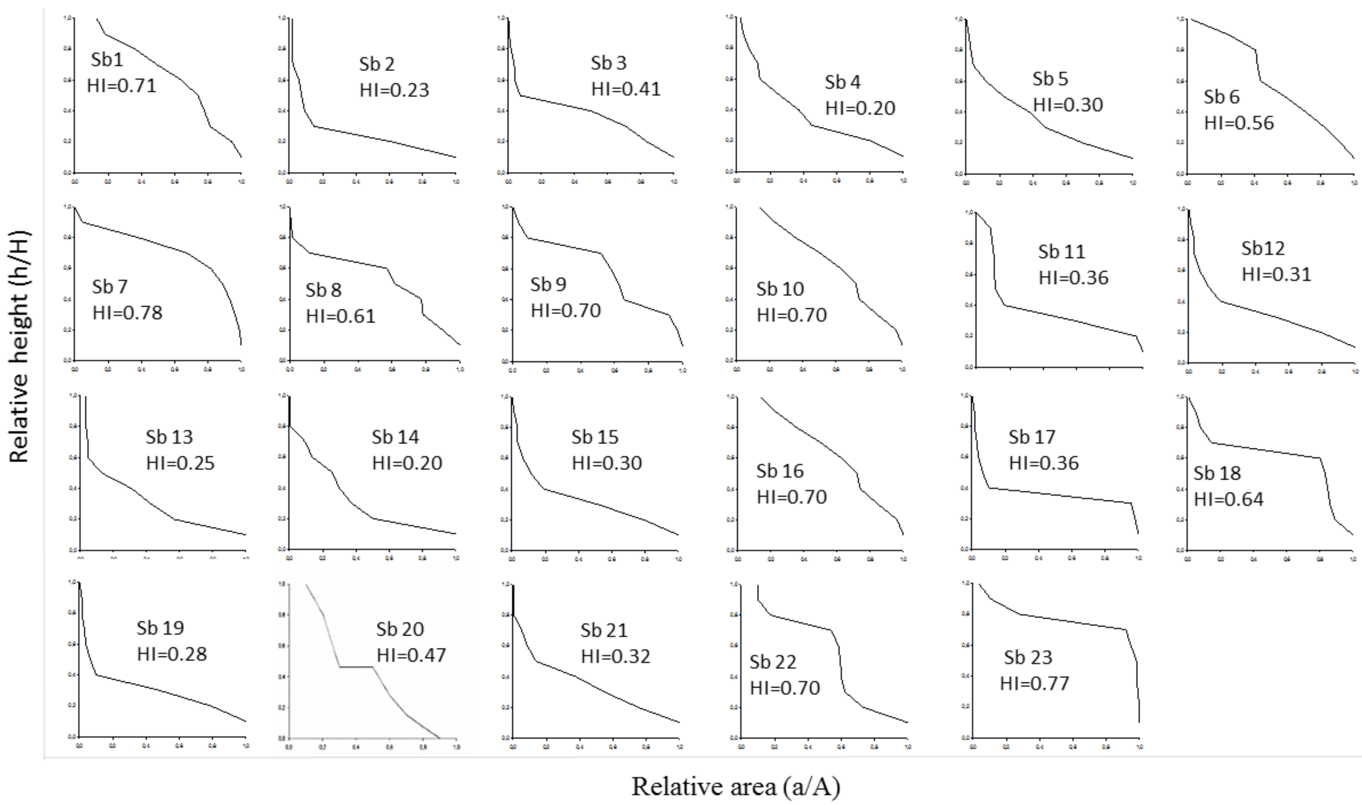

Figure 3. Median height and area distribution by elevation and hypsometric curve of the sub-basins of the Manhuaçu River, MG, Brazil.

Sub-basin 23 has a high hypsometric integral value (0.77) with convex shape, indicating a juvenile stage basin, ie 77% of the original rock mass is still present in the basin (Figure 3). Kaliraj et al. (2015) found that the Thamirabani River sub-basin, India has a convex hypsometric curve, with a value of 0.49, and has a drainage network strongly influenced by the geological and geomorphologic structures of the area causing a loss. of 65 t/km²/year of soil.

The morphometric and hypsometric analysis of basins assist in the determination of basins that have greater potential for water and soil loss, supporting the choice for application of priority sites (Dikpal et al., 2017; Balasubramanian et al., 2017; Mesham & Sharma, 2018).

Among the sub-basins analyzed, we can highlight the sub-basins 7, 9, 10 and 23 for presenting the juvenile stage, high drainage network, and high altimetric amplitude. Priority management sub-basin analysis allows the River Basin

Committee and public agencies to appropriately allocate resources for watershed management activities such as reforestation, spring protection, and the construction and maintenance of catchments for the purpose of increasing infiltration, reducing the risk of flooding, recurrent in the region.

Conclusions

The morphometric parameters of the Circularity Index, Elongation Ratio, Form Factor, Drainage Density and Channel Length were the most significant morphometric parameters.

There was great variation in the hypsometric curve between the evaluated sub-basins, where the youngest were the sub-basins 7, 23 and 1 with values of 0.78, 0.77 and 0.71 respectively, presenting higher erosion risk.

Sub-basins 7, 9, 10 and 23 were considered priorities for management after joint analysis of morphometric characteristics and principal component analysis.

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Compliance with Ethical Standards

Author contributions: Conceptualization: RAB, AGS, HCTD; Data curation: RAB, AGS, LJS; Formal analysis: RAB, AGS; Funding acquisition: RAB, HCTD; Investigation: RAB, AGS, LJS, SGB; Methodology: RAB, HCTD, ASL, KCT; Project administration: RAB, HCTD; Supervision: HCTD; Validation: RAB, AGS, LJS, SGB, HCTD; Visualization: RAB, AGS; Writing – original draft: RAB, AGS, Writing - review & editing: RAB, AGS, LJS, SGB, HCTD, ASL, KCT.

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