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Research Article

Detection of vulnerable areas to the occurrence of floods in tropical regions, from morphometric attributes

Detecção de áreas vulneráveis à ocorrência de inundações em regiões tropicais, a partir de atributos morfométricos

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Abstract: Floods are the principal natural disasters responsible for social, economic, and environmental damages in tropical and subtropical regions of Brazil. The objective of this research was to establish a procedure to remotely determine areas vulnerable to the occurrence of floods in a watershed using a geographic information system. Therefore, a morphometric analysis of the drainage network and the relief was performed in 170 hydrographic subbasins from the Alto Sapucaí watershed, Minas Gerais Southern and São Paulo Northeast states, Brazil. This study considered the following parameters: compactness coefficient, drainage density, stream frequency, roughness index, stream surface length and form factor or Gravelius´s shape index. Therefore, a cluster analysis was executed to identify similar characteristics in the 170 subbasins to discriminate those most susceptible to flooding due to the morphometric characteristics of the drainage, relief, and basins. It was possible to separate the subbasins into two groups. The first includes 85% of the area and did not present significant risks for floods. The second, which represents 15%, is classified as a risk zone. In the second group are the municipalities of Itajubá, Piranguinho, Santa Rita do Sapucaí, Piranguçu, and Delfim Moreira, which, according to the civil defense bulletins, suffer from recurrent floods. The diagnosis was followed by a list of suggestions for planning and managing areas subject to natural disasters. The procedure adopted was efficient and can be applied in other regions for the effective planning of public policies for the use and occupation of urban and rural areas, with lower financial costs and saving lives.

Keywords: Geoprocessing; Mantiqueira Range; Natural Disaster Management; Risk Analysis; Tropical Regions.

Resumo: As inundações são os principais desastres naturais responsáveis por danos sociais, econômicos e ambientais nas regiões tropicais e subtropicais do Brasil. O objetivo desta pesquisa foi estabelecer um procedimento para determinar remotamente áreas vulneráveis à ocorrência de inundações em uma bacia hidrográfica utilizando sistema de informações geográficas. Para tanto, foi realizada uma análise morfométrica da rede de drenagem e do relevo em 170 sub-bacias hidrográficas da bacia do Alto Sapucaí, Sul de Minas Gerais e Nordeste de São Paulo, Brasil. Este estudo considerou os seguintes parâmetros: coeficiente de compacidade, densidade de drenagem, frequência dos canais, índice de rugosidade, comprimento de superfície dos canais e fator forma ou índice de forma de Gravelius. Portanto, foi realizada uma análise de agrupamento para identificar características semelhantes nas 170 sub-bacias, objetivando discriminar aquelas mais suscetíveis a inundações devido às características morfométricas da drenagem, relevo e bacias. Foi possível separar as sub-bacias em dois grupos. O primeiro abrange 85% da área e não apresentou riscos significativos de inundações. O segundo, que representa 15%, é classificada como zona de risco. No segundo grupo estão os municípios de Itajubá, Piranguinho, Santa Rita do Sapucaí, Piranguçu e Delfim Moreira, que, segundo os boletins da Defesa Civil, sofrem com inundações recorrentes. O diagnóstico foi acompanhado de uma lista de sugestões para planejamento e gestão de áreas sujeitas a desastres naturais. O procedimento adotado foi eficiente e pode ser aplicado em outras regiões para o planejamento efetivo de políticas públicas de uso e ocupação de áreas urbanas e rurais, com menores custos financeiros e salvando vidas.

Palavras-chave: Análise de risco; Geoprocessamento; Gestão de Desastres Naturais; Regiões Tropicais; Serra da Mantiqueira.

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1. Introduction

Floods are phenomena that occur naturally due to surface dynamics, mainly in tropical and subtropical areas. However, the disordered use and occupation of the soil contribute to incremental loss of lives and material damage. As the most common natural disaster in Brazil, floods have resulting in losses worth billions of US dollars each year for both public and private capital (FERGUSON; FENNER, 2020). However, even though it is recurrent, there is practically no integrated plan for combating and preventing floods in Brazil (FERGUSON; FENNER, 2020).

Due to climatic and hydrological characteristics, Brazilian territory is highly prone to the occurrence of floods. The number of natural disasters has grown since 1960, which follows the current global trend. Atmospheric phenomena, such as prolonged or high-intensity rains over short periods, are some of the causes of floods and are also influenced by landscape morphometric and hydrological characteristics. However, underdeveloped countries, such as Brazil, are susceptible to this dangerous combination of factors, leading to catastrophic disasters (MEDHI; CHAKRAVARTTY; PATGIRI, 2017).

In 2018, at least 2,500 people died, and more than 500 families were left homeless in Brazil due to the absence of efficient natural disaster prevention protocols. In addition to the lack of action protocols for catastrophic events, the unpreparedness of institutions and public policies related to the management of natural disaster risks is notable. The dispersal of information regarding such events in several databases makes risk analysis and management difficult (ALVALÁ et al., 2019).

The damage caused by floods is related to the advance of urbanization in fluvial areas (MIRANDA et al., 2018; LOUSADA; LOURES, 2020). The waterproofing of urban soils after removing the vegetation cover has a direct impact on the water balance in a watershed, modifying the natural drainage system and therefore intensifying the floods (LOUSADA et al., 2021; LOUSADA; GÓMEZ, 2022). The increase in the speed and volume of surface water enhances the peak of floods; that is, the surface runoff increases, promoting the rapid accumulation of water in wetland places in urban areas (ALMEIDA et al., 2017). This also occurs in occupied rural areas.

The occupation of areas vulnerable to flooding, such as floodplains of rivers or lower points of urban and rural areas where rainwater and fluvial waters tend to concentrate, is responsible for major losses of lives and economic resources. The mapping of these areas is part of the zoning process of municipal plans, but the oversight of these areas is inefficient, allowing the occurrence of precarious housing in inadequate locations (MEDHI; CHAKRAVARTTY; PATGIRI, 2017).

The advance of the removal of native vegetation cover in Brazil historically and, more specifically, in the Amazon rainforest has grown at an accelerated pace since the beginning of 2018, according to data from the Monitoring of Deforestation of the Brazilian Amazon Forest by Satellite (PRODES), carried out by the National

Institute for Space Research (INPE). The PRODES data from 2018 to 2019 show a 34% increase in deforestation in this biome (GRIFFITHS; JAKIMOW; HOSTERT, 2018).

In the Atlantic Forest biome, the situation is less worrisome, as pointed out by Ferreira et al. (2019). There was a redaction of the number of isolated forest fragments as a result of the extensive programs for the conservation of biodiversity. Additionally, according to Ferreira et al. (2019), this picture suggests the hypothesis that this biome is in a stage of stabilization and restoration. However, it is necessary to continue conservation programs so that they can reduce the impacts of climate change.

This significant increase in deforestation leads to a hydrological and climatic imbalance throughout Brazil, resulting in both intense short-term rain as well as prolonged intense rains, which can trigger flooding processes. This fact illustrates the relevance of exploring the relationship between climate change and the increase in natural disasters from external forces (MAURANO; ESCADA; RENNO, 2019).

In this context, the identification and mapping of areas vulnerable to floods is a tool that can be used for public policies that address the risk management of natural disasters (LOUSADA, 2020; SILVA et al., 2021). Therefore, this work aims to demonstrate the possibility of remote detection of such areas from the morphometric properties in tropical watersheds.

2. Materials and methods

The study area is the Alto Sapucaí Watershed, a tributary of the River Grande Watershed, in the Tropical Region of the Minas Gerais and São Paulo states, Brazil, with 2,813 km^2 and an average flow rate of 146 $m^3 s^{-1}$ (Figure 1). The waters are used for industrial, agriculture and energy production at the Furnas Hydroelectric Power Plant, as well as for human supply. Therefore, the study is strategic for regional socioeconomic development.

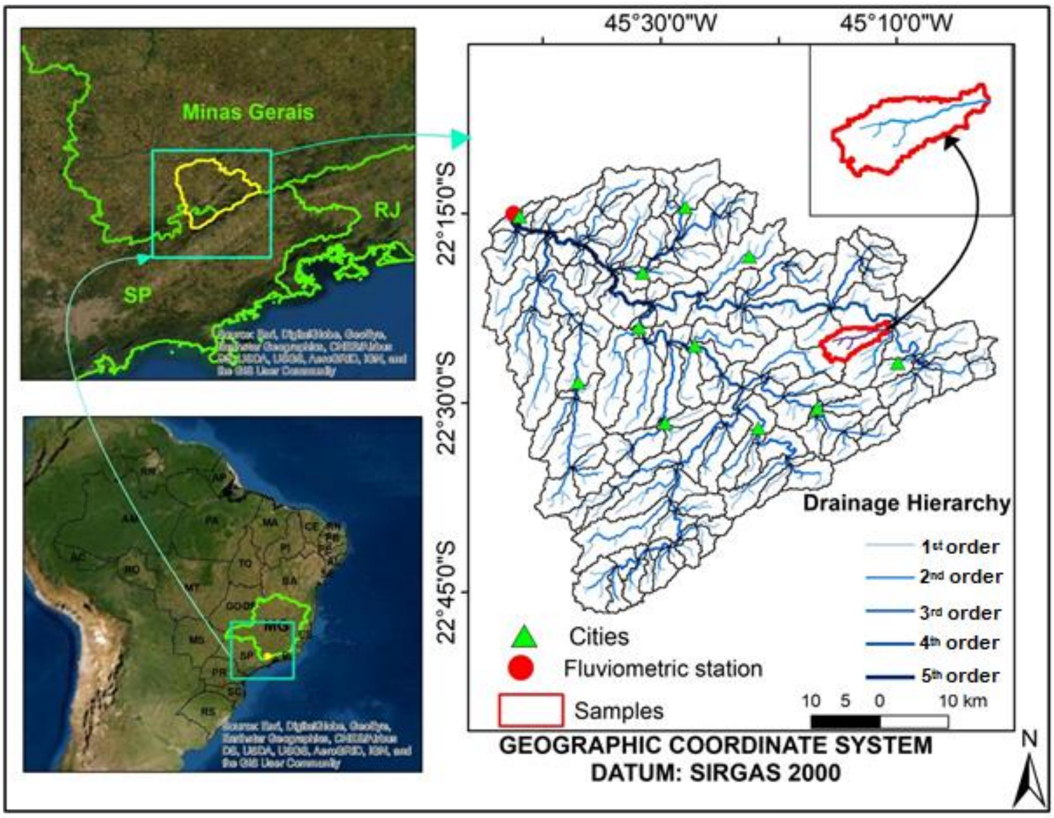

Figure 1. Map of the location of the Alto Sapucaí watershed, highlighting the areas of the sampling units.

According to the Köppen classification, the climate is tropical (Cwa and Cwb) and is characterized by hot and humid summers and cold and dry winters, with an average annual rainfall of 1,600 to 1,865 mm (SPAROVEK; JONG VAN LIER; DOURADO NETO, 2007; AQUINO et al., 2012). The Atlantic Forest is the prevailing morphoclimatic domain, although the seasonal semideciduous forest is mostly replaced by pastures and agriculture (SCOLFORO; MELLO; SILVA, 2008). The geological framework is predominantly composed of granitegneissic complexes from the Tocantins Orogenic System (CPRM, 1998). The geomorphology is dominated by denudational units of crystalline or metasedimentary rocks, with an altitude between 816 and 1,482 m. Regarding hydrography, the drainage pattern is dendritic, with 1st- and 2nd- order channels with a NNE–SSW orientation and 3rd-, 4th- and 5th- order channels with a NE–SW orientation (RIBEIRO et al., 2016).

Gupta, Gosh and Tripathi (2017) calculated the morphometric parameters using the digital elevation model (DEM) Shuttle Radar Topography Mission 2 (SRTM 2) with a pixel size of 1 arc-second (~30 m), which agrees with the study's scale criteria. The DEM was processed in a geographic information system (GIS) using the hydrology module of the Spatial Analyst Tools and the ArcHydro toolset. This stage was required to obtain a cartographic base containing declivity, altimetry, and hydrographic data. To remove pixels with null altimetry values and to reduce flaws and errors, the fill extension of ArcGIS 10.5 (ESRI, 2016) was used.

The automatic extraction of the drainage network was completed using the Hydrology extension of ArcGIS 10.5, from the processes of generating the following files: fill, flow direction, flow accumulation, con, stream to feature, and watershed definition (ESRI, 2016). Flow direction assesses the natural property of water to flow through the easiest path. Thus, the algorithm scans the DEM pixel by pixel, identifying valleys. Through flow direction, the most likely flow is mapped and used in the Flow Accumulation tool, which locates the possible sites of water accumulation. Then, the stream-to-features extension joined the water accumulation points with drainage areas, delimiting the river (ESRI, 2016).

From ArcHydro, it was possible to delimitate 170 subbasins in the Alto Sapucaí watershed, which followed the definition of the drainage hierarchy from Strahler (1957). Criteria of altimetry and slope and the areas of water flow and accumulation were used to identify the subbasins with precision. The morphometric parameters were calculated according to the authors mentioned in Table 1 for the 170 subbasins.

Table 1. Alto Sapucaí Watershed calculated morphometric parameters.

Parameter	**Estimator**	**Variables**	**Meaning**	**References**
Stream frequency (Dh)	$Dh = \frac{n}{A}$	n = Number of channels A = Basin area in km^2	Expresses the number of existing channels per unit area, indicating the water potential of the region	Gupta, Gosh and Tripathi (2017)
Drainage density (Dd)	$Dd = \frac{C}{A}$	C = Channels total length in km A = Basin area in km^2	Expresses the influence of the supply and transport of dendritic material. Indicates the degree of the anthropization of the channels	Taofik et al. (2017)
Relief ratio (Rr)	$Rr = \frac{\Delta a}{L}$	Δa = Altimetric amplitude of the basin in km L = Chanel length in km	Relationship between altimetric amplitude and the length of the main channel	Kuntamalla et al. (2018)
Roughness index (Ir)	$Ir = Hm \times Dd$	Hm = Altimetric amplitude of the basin in km Dd = Drainage density in km km^{-2}	Represents the slope relationship with the channel lengths. Indicates the degree of dissection of the watershed	Kuntamalla et al. (2018)
Compactness coefficient (Kc)	$Kc = 0.28\frac{P}{\sqrt{A}}$	P = Basin perimeter in km A = Basin area in km^2	Indicates the highest or lowest occurrence of floods	Taofik et al. (2017)
Form fator or Gravelius´s shape index (Kf)	$Kf = \frac{A}{G^2}$	A = Basin area in km^2 G = Basin axial length in km	Lower values indicate that the basin is less prone to flooding	Horton (1945); Taofik et al. 2017)
Stream surface length (Eps)	$EPS = \frac{1}{2.Dd}$	Dd = Drainage density in km km^{-2}	Indicates the average length traveled by the flow to the drainage channel	Kuntamalla et al. (2018)

To identify groups of subbasins according to similar morphometric characteristics, multivariate cluster analysis was used (FERREIRA, 2009).

Student's t test was applied when the assumptions were not violated. When a violation did occur, the Mann–Whitney nonparametric test was used (FERREIRA, 2009). The maximum error of 5% for rejection of the null hypothesis was considered, which shows a nondifference between the groups ($p < 0.005$). The data were processed and analyzed with the support of the statistical package R (R CORE TEAM, 2020).

The results of the cluster analysis were synthesized in ArcGIS 10.5, generating maps with groupings of subbasins with similar morphometric characteristics. The data were systematized to represent the areas vulnerable to floods from the interpretation of these data. Afterward, historical information about floods in the Alto watershed was obtained from the Civil Defense and the Integrated Disaster Information System Natural (S2iD) database (DEFESA CIVIL, 2020; S2iD, 2020), which was used to validate the model. The validation of the cluster analysis was conducted through a visual comparison of the map of risk areas to floods with empirical data obtained by Defesa Civil (2020), and the overlap in both mappings was considered as an indicator of quality.

The Civil Defense is responsible for actions to prevent floods in Brazil. Such information contributed to the discussion regarding the mapping of vulnerable areas and predictive planning for natural disasters.

Finally, measures to prevent losses caused by floods and a model for natural disaster management for the municipalities in the watershed, as established by the Civil Defense (DEFESA CIVIL, 2020), were suggested.

3. Results

The morphometric parameters calculated for the 170 subbasins are illustrated in Figure 2A, showing the Dd, with the darkest areas having high values and accompanying the river stretches with higher stream channels.

The Dh (Figure 2B) has the highest concentration of values in the northeast and east sectors of the watershed, which can be explained by the rugged relief of the Mantiqueira Mountains. Native vegetation must be maintained in areas with high Dr to sustain the quantity and quality of water and the hydrological balance, reduce the amount of rainwater, and mitigate the impacts downstream (PUROHIT; PARMAR, 2017).

The rock directly influences the hydrographic density. Massive rocks, without many fractures, make it difficult for water to infiltrate, resulting in greater surface runoff and river development and providing a high Dh. However, sedimentary rocks, or rocks with very fracture planes, provide greater water infiltration, resulting in a less dense drainage network, with fewer rivers providing a low Dh and more runoff than infiltration (FEITOSA et al., 2008).

Basin sectors with higher Dh indicate the occurrence of thinner surface flow, while very low Dh indicates the occurrence of deep aquifers. Generally, the water accumulation areas are in higher-order channels in the middle and lower reaches, with exceptions in the upper reaches (FEITOSA et al., 2008).

Higher stream surface length (Eps) values can be found in areas of lower river hierarchy, mainly 1st- and 2nd-order channels (Figure 2C). The distribution of the Ir values (Figure 2D) is along the main channel, which indicates that the Alto Sapucaí watershed has the potential for modeling the relief and influences the entire geomorphological dynamics of the area. This dynamic generates characteristics that directly impact flooding downstream areas (SIDDARAJU et al., 2017). The Rr expressed in Figure 2E is concentrated upstream and is consistent with the rugged relief of the Mantiqueira Mountain Range.

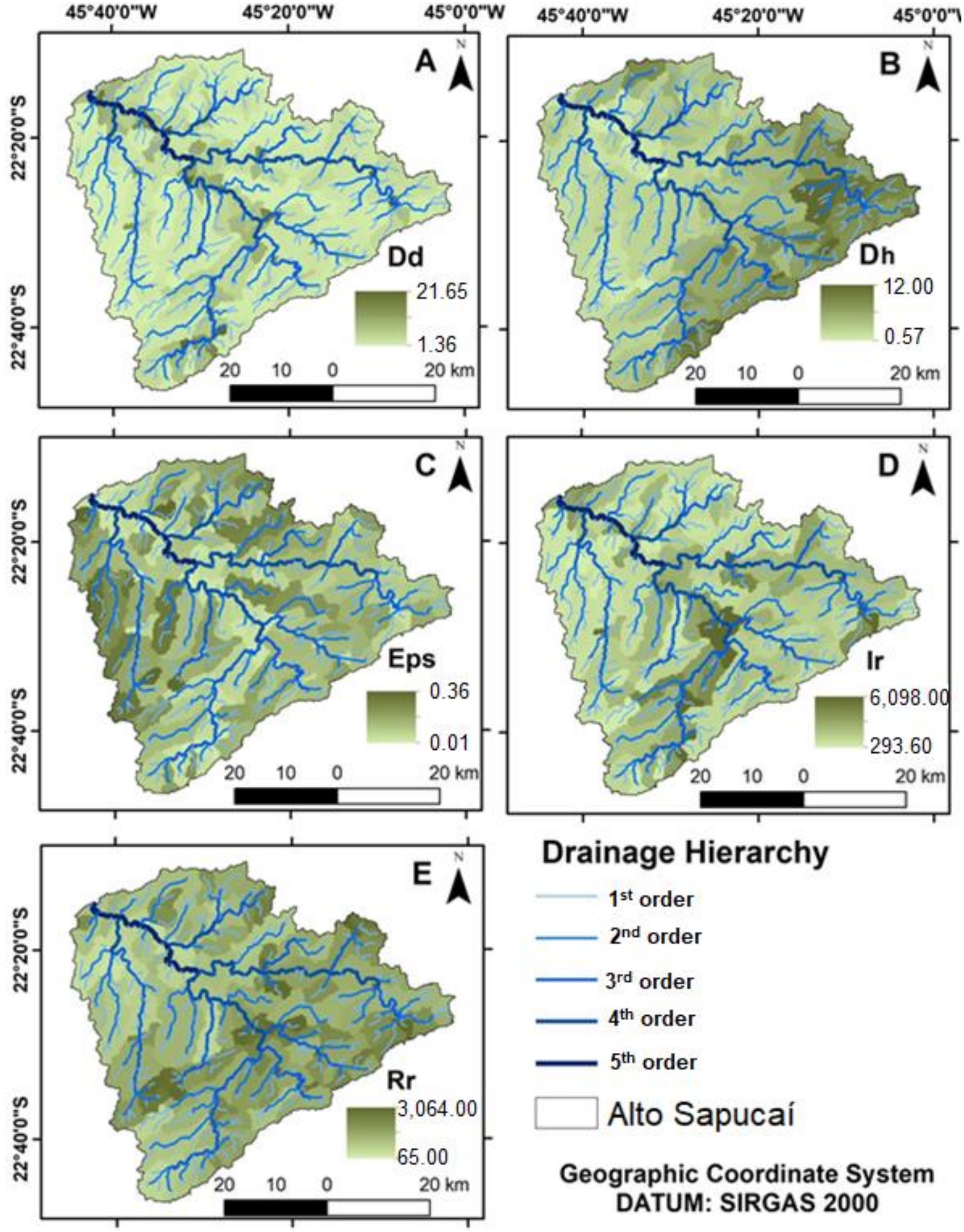

Figure 2. Maps of the spatial distribution of the morphometric indices calculated for the Alto Sapucaí watershed. (A) Dd: Drainage density; (B) Dh: Stream frequency; (C) Eps: Stream surface length; (D) Ir: Roughness index; (E) Rr: Relief ratio.

The analysis of the regionalized parameters (Figure 2) allowed the grouping of similar characteristics and the discrimination of two distinct areas, a "safe area" (Cluster 1), which was less susceptible to the occurrence of floods, and a "risk area" (Cluster 2), which was more susceptible (Table 2).

In Table 2, the high Dd values for the risk area indicate that it has the potential for the accumulation of surface water from rapid, intense, or prolonged rains. The obtained Kf suggests a rounded shape for the studied watershed. This parameter, along with the high Dd values, indicates that the area is susceptible to the occurrence of periodic floods, which is in agreement with Taofik et al. (2017).

Table 2. Watershed, according to morphometric characteristics and parameter values. Alto Sapucaí Watershed - Minas Gerais Southern, 05/10/2020.

		Morphometric Characteristics						
Area	**Obs**	**Kc[1]**	**Dd[2]**	**Dr[2]**	**Ir[2]**	**Rr[1]**	**Eps[2]**	**Kf[1]**
Safe	109	1.93	3.53	2.00	2.,117.76	2,265.16	0.14	0.36
Risk	66	1.13	21.65	2.12	6,928.39	2,444.41	0.02	0.78
P value	-	0.0040	0.001	0.1617	0.0001	0.3286	0.0001	0.0001
		*	**	**	**	*	**	*

Note: number of observations; Kc: compactness coefficient; Dd: drainage density; Dr: stream frequency; Ir: roughness index; Rr: relief ratio; Eps: stream surface length; Kf[1]: form factor; [1]Average; [2]Median; * Student's t test; ** Mann–Whitney test.

The results obtained in this research demonstrate that areas with Kf values of 0.36 are areas close to the basin's outlet, a region of water accumulation, so they are more prone to flooding, and such information allows the monitoring of inappropriate land occupation. Therefore, it can support land use and occupation public policies and help to reduce flood damage since it allows the automation of the delimitation of areas at risk (TAOFIK et al., 2017; SERVIDONI et al., 2019).

The cluster analysis allowed the mapping of areas naturally vulnerable to the occurrence of flooding in the Alto Sapucaí watershed, considering the relief and drainage network's morphometric characteristics, as shown in Figure 3.

The municipalities of Santa Rita do Sapucaí and Itajubá, located close to the outlet of the Alto Sapucaí Watershed, are in a flat relief region bathed by 5th- order channels. Therefore, as shown in Figure 3, it is an area naturally prone to flooding. On the Official Civil Defense Bulletin No. 118 of April 27, 2020, Santa Rita do Sapucaí, Delfim Moreira, Itajubá, Piranguinho, and Piranguçu Municipalities decreed a state of emergency because of the extreme rains and floods that affected the region of the Alto Sapucaí Watershed (DEFESA CIVIL, 2020).

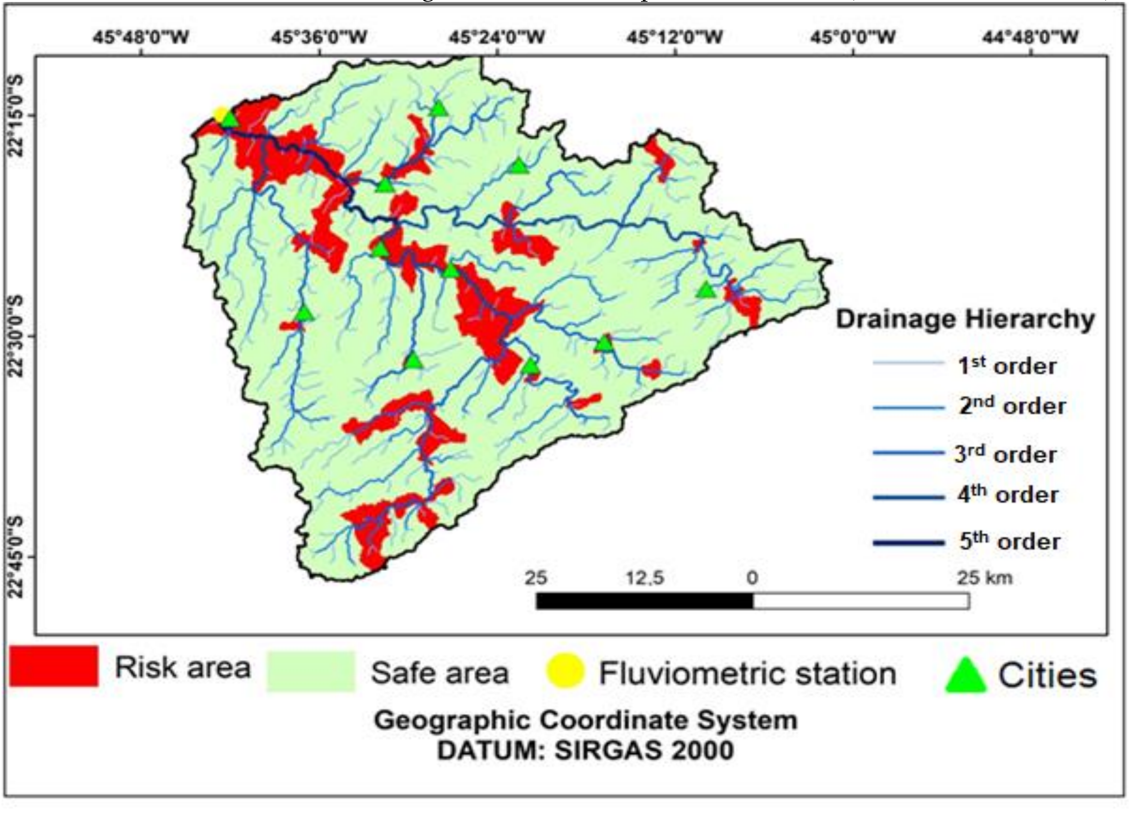

Figure 3. Map of areas at risk of floods in the Alto Sapucaí Watershed.

The overlap in both mappings for the municipalities of Itajubá, Piranguinho, Santa Rita do Sapucaí, Piranguçu, and Delfim Moreira confirms that the cluster analysis proved to be efficient in identifying regions prone to flooding, suggesting that this procedure can be applied in other areas.

4. Discussion

As pointed out by Kuntamalla et al. (2018), the values obtained for Kc in the risk areas suggest that these areas are prone to the occurrence of intense floods. The morphometric parameters obtained were similar to previous analyses in the Rio Machado watershed, which belongs to the Rio Grande watershed (SERVIDONI et al., 2019). Thus, both have similar morphometric characteristics and hydrological behavior.

The data regarding the morphometric parameters of the drainage network and the relief of the Alto Sapucaí watershed are consistent (SANGMA; BALAMURUGAN, 2017). The authors found similar outcomes for the Kakoi River Basin in India, which has relief and hydrological behavior comparable to the study area.

The inference that areas classified as "at-risk" are more susceptible to floods is due to their morphometric characteristics (LOUSADA et al., 2021). In addition to the high Dd values, the Kc and Kf values indicate destructive hydrological behavior and rapid flooding caused by the rounded shape of the subbasins. This behavior suggests that the river has great potential to cause loss of life and material.

In this scenario, Quintal et al. (2021) also used morphometric parameters that helped to determine the probability of flooding in the Machico River basin in Portugal. They obtained convergent results for a low probability of occurrence of floods, due to the elongated shape of the basin.

Taofik et al. (2017) compared the morphometric parameters of the drainage network and the relief of two watersheds in a tropical region of Nigeria, both with climatic, geological, and geomorphological attributes similar to the Alto Sapucaí Watershed. The results of this work corroborate Taofik et al. (2017) because the authors achieved a Kf of 0.85 for a low flood tendency basin and 0.36 for one with high vulnerability.

The survey of municipalities in an emergency in the Minas Gerais state carried out by S2iD for the years 2003 and 2016 pointed out that there is a seasonality factor, which can be explained by the variability of the region's climate. Moreover, there was a notable increasing trend of municipalities in an emergency, which reinforces the impacts resulting from local and global climate changes causing intense rain more frequently (S2iD, 2020).

Data from the Minas Gerais State Secretariat for the Environment and Sustainable Development (SEMAD) classify the Alto Sapucaí region as a critical zone due to material damage and loss of lives caused by flooding (MINAS GERAIS, 2013).

Both the impact and the frequency of these events are considered high by SEMAD, which increases the vulnerability of the area, as highlighted in the Bulletin (DEFESA CIVIL, 2020) by the state of the calamity of the municipalities of Itajubá, Piranguinho, Santa Rita do Sapucaí, Delfim Moreira and Piranguçu.

The mapping of the characteristics of the population at risk of disasters in Brazil carried out by Alvalá et al. (2019) made it possible to define a profile of those who suffer from floods in an intense way. Alvalá et al. (2019) found that in 2010, 16% of the small-town populations were at risk, but only 8% were in large cities. In Brazil, people from small and medium-sized towns are more vulnerable to flooding than those from regional and metropolitan centers due to both the lower degree of technical and operational infrastructure and the lack of consolidated proposals for land use and occupation planning in municipal zoning.

The National Policy to Civil Protection and Social Defense established by law 12.608 (BRASIL, 2012) provides that civil defense must carry out actions aimed at disaster management and that these actions must pursue the following parameters: prevention, mitigation, preparation, and response to recovery. Each parameter addressed requires specific responsibilities and skills to compose a continuous, integrated, permanent, and interdependent management system amid various sectors of civil service and the population vulnerable to risk.

Data from the Civil Defense Bulletin of Minas Gerais reinforce the demand for a contingency plan for small and medium-sized towns in the state. The report made available by the Civil Defense pointed out that 271 municipalities declared an emergency in the rainy season of 2020. The political incapacity of Brazilian cities to manage actions to prevent natural disasters reinforces the need for investments in strategies to fight against impacts caused by short-, medium-, and long-term natural disasters (DEFESA CIVIL, 2020). Therefore, procedures and analyses, such as those presented here, allow the identification of areas naturally vulnerable to the occurrence of floods, contributing to information for zoning and risk management.

The Civil Defense has a history of identifying and mapping areas subject to flooding. Thus, this is empirical knowledge based on the occurrence of floods in previous years. However, they do not use a method that allows the identification of such areas before the occurrence of floods. However, the method proposed by this research allows the previous identification of areas subject to floods, avoiding loss of life and material. Therefore, our proposal presents a method of prognostication of areas subject to flooding and not just a diagnosis of areas already flooded in previous events.

A contingency plan, which is the product of this management system, must be prepared with the definition of procedures, actions, and decisions to be made concerning disasters. This plan contains eight stages in Table 3. (BRASIL, 2017). However, we suggest that a new stage must be provided, which consists of a center for organizing, training, and disseminating knowledge accessible to communities located in areas at risk of flooding. This new stage makes it possible for people affected by disasters to respond quickly and efficiently (STOLERIU; URZICA; MIHU-PINTILIE, 2020; SCHOBER; HAUER; HABERSACK, 2020).

This methodological proposal aims to act as the first stage of the contingency plan, providing areas that, due to their morphometric and hydrological characteristics, are subject to flooding. Thus, it would encourage the preventative actions by public agencies and victims, optimizing the use of resources to fight floods, and promoting an instrument that directly helps in the occupation of the urban and rural land to reduce or eliminate risks of losses of life and materials.

Lousada and Castanho (2021) agree with these considerations by emphasizing the importance of integrating geometric data from the relief and the drainage system for the elaboration of contingency plans. For the authors, such data evidence and explain the need for human intervention for the construction of river hydraulic infrastructure and the implementation of mitigating measures (LOUSADA; CASTANHO, 2021).

Currently, government agencies have taken measures to contain floods as a direct consequence of inappropriate land use and occupation. If the occupations of the areas were based on their physical and hydrological attributes, then contingency plans would be improved. Therefore, our proposal, if implemented, would avoid new tragedies by adopting simple and low-cost procedures.

Table 3. Synthesis of procedures for preparing the contingency plan. Source: Brasil (2017).

Contingency Plan Design	Description
1st Stage: Risk perception	Reflects the perception of the local risk. It varies depending on the physiographic and demographic characteristics of a given area. Stage of identification of the zones with the highest potential for natural disasters.
2nd Stage: Team building	Working group establishment according to the risks identified in the 1st Stage. The involvement and responsibility for preparation and response actions are criteria for the selection of the team members.
3rd Stage: Analysis of the risk scenario	This stage is for identifying and mapping the risk scenarios. Locations where disasters use to occur, as well as their communities, should be detailed.
4th Stage: Definition of actions and procedures	Establishment of viable strategies for the execution of procedures to mitigate the risks and impacts of disasters.
5th Stage: Approval	The approval must be with a Public Hearing, which should happen for each new assent in the Plan. Then, the institutions responsible for the execution must validate it.
6th Stage: Disclosure of the Contingency Plan	The final document of the Contingency Plan must have language accessible and widely disseminated to the community.
7th Stage: Operationalization	Operationalization occurs at each simulation of alerts, alarms or even in a real disaster situation. In this case, the actions suggested in the previous stages must be applied.
8th Stage: Review	The Contingency Plan must be constantly reviewed and updated due to the unpredictability of natural disasters.

The risk of flooding increases due to the seasonal characteristics of the region's tropical climate and the influence of La Niña and El Niño. Well, it concentrates the rains from October to March. Seasonality is, in general, ignored by public managers. This lack of action creates insecurity in the population of areas subject to the risk of flooding, as seen in several Brazilian cities between 2020 and 2021. In addition, climate change coupled with the lack of planning is responsible for the recurring tragedies that could be avoided through the adaptation of customary planning practices for the use and occupation of land, investments in infrastructure, and technical training of society to promote the security of citizens against natural events that could be catastrophic.

5. Conclusions

The protocol of morphometric analysis of the Alto Sapucaí watershed, together with the cluster analysis, allowed us to discriminate areas at risk of floods. Thus, this protocol is efficient for assessing areas susceptible to flooding in the Brazilian territory and supporting public management and the minimization of natural disasters. Based on the morphometric characteristics of the watershed, the cluster analysis allowed the identification of two groups in the studied location: safe and risk areas.

The watershed has an area of 85% without a significant risk of flooding; thus, it is a safe area for occupation, which corresponds to 6 municipalities. Therefore, the risk area corresponds to 15% and 5 municipalities.

The overlap in both mappings for the municipalities of Itajubá, Piranguinho, Santa Rita do Sapucaí, Piranguçu, and Delfim Moreira confirms that the cluster analysis proved to be efficient in identifying regions prone to flooding, suggesting that this procedure can be applied in other areas. Thus, these maps can be an instrument for monitoring and protecting risk areas.

Municipalities in risk areas must jointly prepare contingency plans that follow defined risk maps and civil defense procedures. Thus, public managers must incorporate science and techniques into decision-making to reduce or minimize the loss of life and material. Similarly, it is possible to identify areas susceptible to flooding in advance.

It is important to emphasize that the use of scientific knowledge about morphometric attributes is essential to avoid tragedies with human and material losses associated with floods. The protocol applied is configured as an essential tool for the development of public policies for planning and regional land use.

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