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MAPPING OF AREAS SUSCEPTIBLE TO MASS MOVEMENTS IN THE TEJIPIÓ RIVER WATER BASIN, IN PERNAMBUCO

Mapeamento das áreas suscetíveis a movimentos de massa na bacia hidrográfica do rio Tejipió, em Pernambuco

Mapeo de las áreas susceptibles a movimientos en masa en la cuenca hidrográfica del rio Tejipió, en Pernambuco

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ABSTRACT

In several Brazilian cities, the phenomenon of urbanization was developed in an accelerated, intense, and unplanned manner, leading to the occupation of areas unsuitable for housing, such as steep slopes and soils with little stability. In addition to other consequences, this occupation regime, combined with adverse weather conditions, favors the occurrence of mass movements, causing property and environmental damage, in addition to the loss of human life. Therefore, this study aimed to map the areas susceptible to mass movements in the Tejipió river basin, in Pernambuco, due to the physical-natural characteristics and the significant urbanization rate presented in the region. The methodology was based on the integration, in a Geographic Information System (GIS) environment, of factors conditioning this type of process, namely: geology, geomorphology, pedology, land cover and use, slope, and rainfall. Then, weights were assigned to these factors, regarding the degree of potential for mass movements, so that the final product resulted in a thematic map of susceptibility to the aforementioned process. The main results revealed that 24.65 km² of the basin is represented by areas highly susceptible to mass movements, which is equivalent to 28.10% of the region and presents a combination of associated factors such as high hypsometry and slope and clayey soils. The mapping developed in this study comprises an important tool that aims to support planning and risk management for geological phenomena, allowing the definition of effective measures to prevent, protect, and mitigate negative impacts caused by mass movements.

Keywords: Slopes; Geological Phenomena; Geographic Information System.

RESUMO

Em diversas cidades brasileiras, o fenômeno da urbanização foi desenvolvido de maneira acelerada, intensa e não planejada, levando à ocupação de áreas inadequadas à habitação, como encostas declivosas e com solos de pouca estabilidade. Além de outras consequências, esse regime de ocupação, somado às condições climáticas adversas, favorecem a ocorrência de movimentos de massas, provocando danos patrimoniais e ambientais, além perdas de vidas humanas. Dessa forma, este estudo teve por objetivo mapear as áreas suscetíveis a movimentos de massa na bacia hidrográfica do rio Tejipió, em Pernambuco, devido às características físico-naturais e ao significativo índice de urbanização apresentados na região. A metodologia utilizada fundamentou-se na integração, em ambiente de Sistema de Informações Geográficas (SIG), de fatores condicionantes a esse tipo de processo, sendo eles: geologia, geomorfologia, pedologia, cobertura e uso da terra, declividade e pluviosidade. Em seguida, foram atribuídos pesos a estes fatores, quanto ao grau de potencialidade a movimentos de massa, de modo que o produto final resultou em um mapa temático de suscetibilidade ao supracitado processo. Os principais resultados revelaram que 24,65 km² da bacia é representada por áreas altamente suscetíveis aos movimentos de massa, o que equivale a 28,10% da região, as quais apresentam uma combinação de fatores associados como elevadas hipsometria e declividade e solos argilosos. O mapeamento desenvolvido neste estudo compreende uma importante ferramenta que visa subsidiar o planejamento e a gestão do risco a fenômenos geológicos, permitindo a definição de medidas eficazes à prevenção, proteção e mitigação dos impactos negativos causados por movimentos de massa.

Palavras-chave: Encostas; Fenômenos Geológicos; Sistema de Informações Geográficas.

RESUMEN

En varias ciudades brasileñas, el fenómeno de la urbanización se desarrolló de manera acelerada, intensa y no planificada, llevando a la ocupación de áreas no aptas para vivienda, como pendientes pronunciadas y suelos poco estables. Además de otras consecuencias, este régimen de ocupación, combinado con condiciones climáticas adversas, favorece la ocurrencia de movimientos masivos, provocando daños materiales y ambientales, además de la pérdida de vidas humanas. Por lo tanto, este estudio tuvo como objetivo mapear las áreas susceptibles a movimientos en masa en la cuenca del río Tejipió, en Pernambuco, debido a las características físico-naturales y al importante índice de urbanización que presenta la región. La metodología utilizada se basó en la integración, en un entorno de Sistema de Información Geográfica (SIG), de factores que condicionan este tipo de procesos, a saber: geología, geomorfología, edafología, cobertura y uso del suelo, pendiente y precipitaciones. Luego, se asignaron pesos a estos factores, en función del grado de potencial de movimientos de masas, de modo que el producto final resultó en un mapa temático de susceptibilidad al proceso antes mencionado. Los principales resultados revelaron que 24,65 km² de la región están representados por áreas altamente susceptibles a movimientos en masa, lo que equivale al 28,10% del territorio, que presenta una combinación de factores asociados como alta hipsometría y suelos de pendiente y arcillosos. El mapeo desarrollado en este estudio constituye una importante herramienta que tiene como objetivo apoyar la planificación y gestión de riesgos de fenómenos geológicos, permitiendo definir medidas efectivas para prevenir, proteger y mitigar los impactos negativos causados por los movimientos en masa.

Palabras clave: Pendientes; Fenómenos Geológicos; Sistema de información geográfica.

1 INTRODUCTION

The urbanization process occurred in Brazil intensely from the middle of the 20th century, when a significant part of the population migrated from the countryside to the city, driven by the opportunities arising from industrialization (Freitas; Robaina, 2019; LIMA et al., 2021; WU et al., 2021; Carvalho et al., 2022). However, in most large Brazilian centers, this process evolved in an unplanned manner, causing problems at social, economic, cultural, and environmental levels (Rocha; Schuler, 2016; Santos et al., 2020; Pereira; Sousa Júnior; Vieira, 2022).

Unplanned urban development causes considerable changes in land cover, use, and landscape patterns, causing severe damage to the environmental system such as material and property losses, loss of biodiversity, carbon emissions, water scarcity, extreme weather conditions, and polluted environment, threatening sustainability in general (Santos et al., 2021; Liang et al., 2022; Chao et al. 2023; Chen et al. 2023). Anthropogenic interventions, such as the removal of vegetation on slopes to expand impermeable areas, combined with adverse weather conditions intensify episodes of mass movements (Costa Junior; Cabral, 2019; Sant Ana et al., 2020). According to Silveira, Vettorazzi, and Valente (2014), mass movements occurring in urban areas, especially during rainy periods, result in economic and environmental damage, as well as the loss of human life.

These movements are processes whose main characteristic is the transport of rocky material and/or soil, with gravitational force as the fundamental triggering agent (HE et al., 2019; Kormann; Robaina, 2019). In view of the disturbances caused to society by mass movements, knowledge about the characteristics of methodologies that approach urbanization with mass movements becomes essential, being useful to coordinate the relationship with the environment in such an ecologically fragile area, highlighting a detailed study of the expansion of urban land in space and time (Costa Junior; Cabral, 2019; Tsagkis; Bakogiannis; Nikitas, 2023).

Geoprocessing, especially Geographic Information System (GIS) technology, allows the collection, storage, and processing of data and the performance of spatial analyses, resulting in the creation of thematic maps (Pessoa Neto; Silva; Barbosa, 2023). This versatility makes GIS essential in risk and disaster management, enabling the production of information that identifies regions with potential for mass movement (Amaya et al., 2021; Lima; Avanzi; Silva, 2021). The assessment of susceptibility to mass movements has been carried out in several studies that, together with GIS, encompass statistics, multi-criteria analysis, and/or machine learning (Rocha; Schuler, 2016; Meirelles; Dourado; Costa, 2018; He *et al.,* 2019; Vojteková; Vojtek, 2020; Devara; Tiwari; Dwivedi, 2021; Aslam *et al.,* 2022; Pessoa Neto *et al*., 2023).

The Tejipió river basin, located in the state of Pernambuco, faces profound changes in space due to the unplanned expansion of the urban network (Silva et al., 2017). According to Pessoa Neto, Silva, and Barbosa (2023), it is quite common to see problems in the region such as the irregular occupation of housing and the discharge of solid waste and untreated domestic effluents in inappropriate places, such as hillsides. These actions directly contribute to the increase in episodes of mass movements.

In addition to the considerable rate of urbanization, the Tejipió River basin has physical-natural characteristics that strongly condition it to present areas susceptible to the process of mass movements. From this perspective, the present work aimed to use geoprocessing techniques in a GIS environment to develop a susceptibility map to mass movements in the Tejipió river basin, in the state of Pernambuco.

2 LOCATION AND CHARACTERIZATION OF THE STUDY REGION

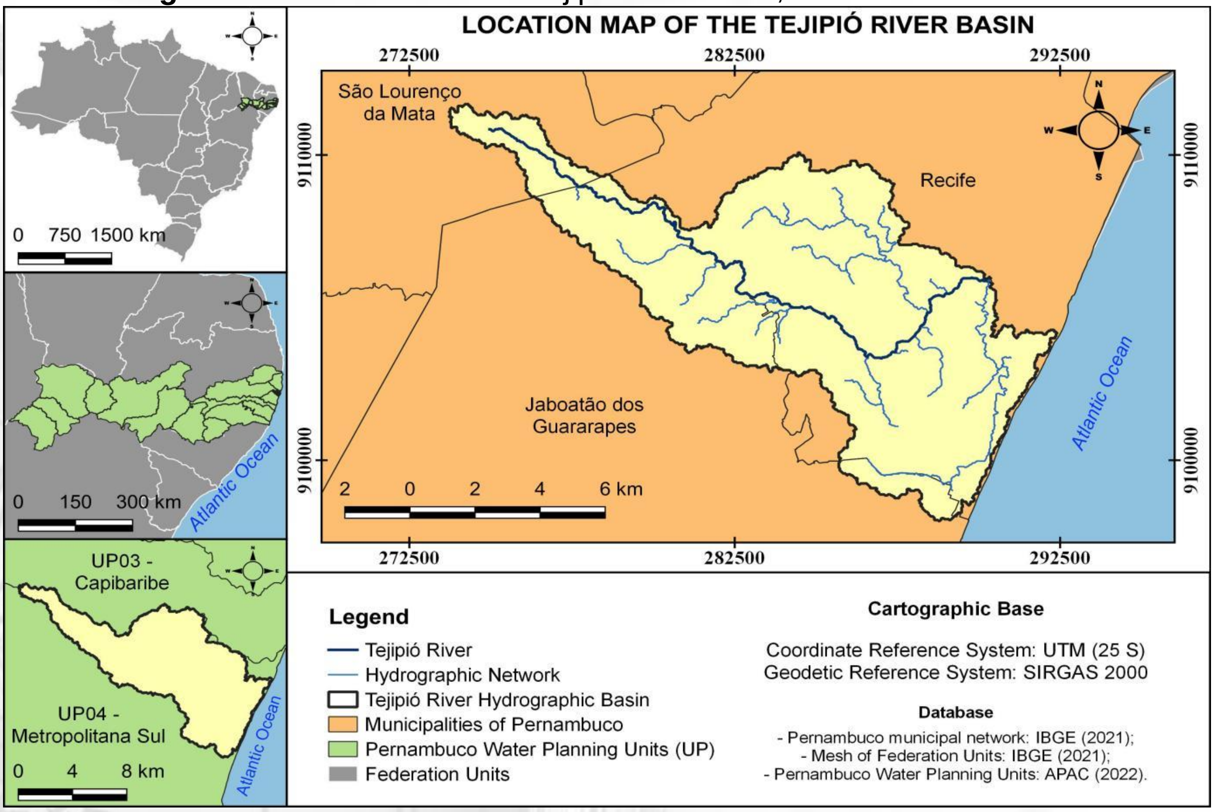
The Tejipió River basin is located entirely in the Recife Metropolitan Region (RMR), in Pernambuco. Between the UTM coordinates (25 S) 9,097,732,1422mN and 9,111,398,6828mN and 274,515,6117mE and 293,463,6738mE (Figure 01) and drains an area of approximately 90 km² (Silva *et al*., 2017).

According to the Pernambuco Water and Climate Agency (APAC), the Tejipió river basin is included in the Water Planning Unit 04 - UP04, called Metropolitana Sul (APAC, 2022). The Tejipió River, which forms its main channel, has an approximate length of 25 km, has its source in the municipality of São Lourenço da Mata, and runs through the municipalities of Jaboatão dos Guararapes and Recife until its outlet, in the Pina basin (SILVA *et al* ., 2017).

According to Pessoa Neto, Silva, and Barbosa (2023), this river basin presented average maximum and minimum monthly rainfall of 333.53 mm and 29.85 mm and an annual average of 1,897.94 mm, for a period of 18 years, between January 1, 2004, and December 31, 2021. The maximum monthly precipitation rates generally occur in the region during the month of June, but can be exceeded in the event of extreme events, as occurred in may 28, 2022, where the accumulated rainfall for that day presented volumes exceeding

200 mm, which caused significant property, environmental and human damage, promoted by movements of mass and floods (Silva *et al*., 2023).

Figure 01 – Location of the Tejipió river basin, Pernambuco - Brazil



Source: Pessoa Neto, Silva and Barbosa, 2023.

Regarding geomorphology, the river basin has hills in its upper and middle courses and coastal plains in its lower course. In relation to land use and coverage, urbanization is the class that predominates in the location, equivalent to 67.40% of its total area; vegetation represents 22.50% of the basin, covering remnants of secondary Atlantic Forest; agriculture makes up 4.50% of the region, mainly covering the cultivation of sugar cane; mangroves cover an area that accounts for 5.20% of the territory; finally, 0.40% of the total area belongs to water bodies, especially bodies of water, such as dams and lakes (Silva et al., 2016; Silva et al., 2017).

The deposition of untreated solid waste and domestic effluents directly on slopes and the occupation of houses in inappropriate locations (Figure 02) increase episodes of mass movements in the region, which are aggravated during extreme precipitation events. This fact was proven during the extreme event that occurred in the region on May 28, 2022, which reached an accumulated precipitation rate of 292.80 mm, equivalent to 96.40% of the monthly average (APAC, 2022). In addition to mass movements, this extreme event also caused floods, resulting in considerable property and environmental damage, in addition to the loss of human life.

Figure 02 – Records of factors that increase the risk of mass movements in the Tejipió River basin

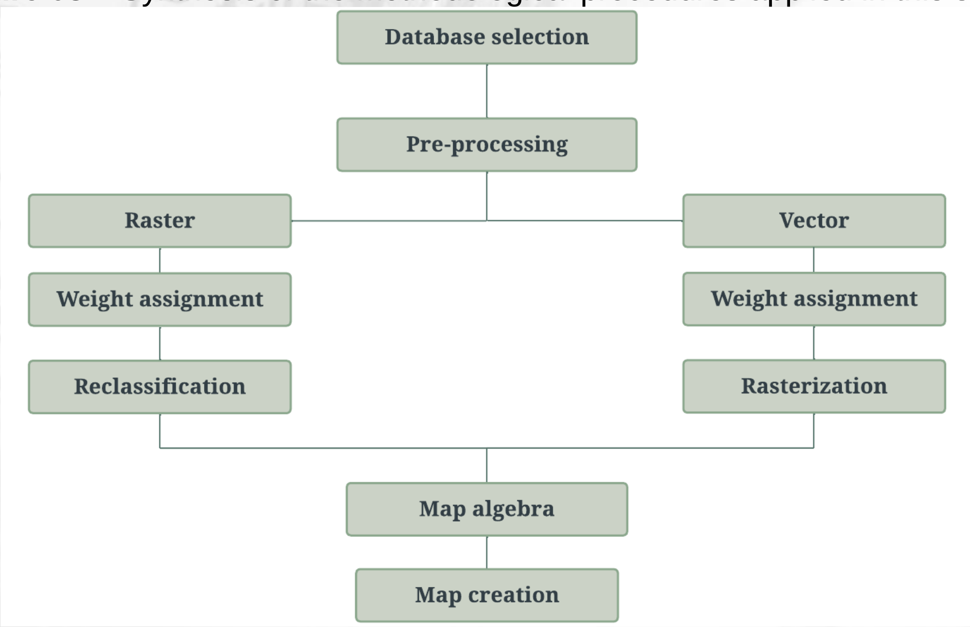
Image A: Deposit of construction waste on Tim Maia Street. Registration date: 12/2018
Image B: Deposition of solid waste on 1st Travessa Henrique Dias. Registration date: 04/2023
Image C: Discharge of untreated domestic effluent on Avenida Antônio Bezerra. Registration date: 12/2018

Source: Elaborated by the authors, 2023.

3 MATERIALS AND METHODS

The synthesis of the methodology applied in this study is in Figure 03. The susceptibility map to mass movements in the Tejipió river basin was produced based on the selection of factors that condition the region to this type of process, with these factors being predisposed by IBGE (2019).

Figure 03 – Synthesis of the methodological procedures applied in this study



Source: Elaborated by the authors, 2023.

Then, depending on the level of propensity for mass movements, values (weights) were assigned to the factors through the reclassification process. Finally, using map algebra, the reclassified spatial data were combined with a mathematical model defined by IBGE (2019) to generate the susceptibility map to mass movements.

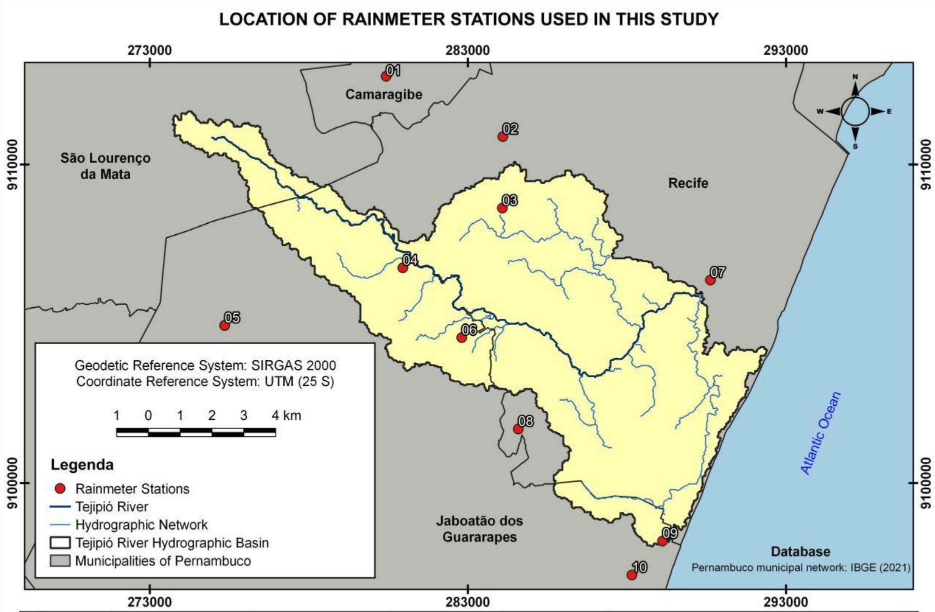
3.1 Selection, collection, and treatment of factors conditioning mass movements

The mapping of susceptibility to mass movements in the Tejipió river basin was prepared based on the selection of factors conditioning this process predisposed by IBGE (2019), which are: geology, geomorphology, pedology, land cover and use, slope, and rainfall. Spatial data was acquired through online websites from official bodies, and was collected and processed as follows:

- Geology and Geomorphology: Data relating to the geology and geomorphology of the Tejipió river basin were obtained in vector format (shapefile) through the Environmental Information Database (BDiA) platform, both at scale 1:250,000 (BDIA, 2019).
- Pedology: Through the Brazilian Agricultural Research Corporation (EMBRAPA) platform, a vector file (shapefile) was acquired, at a scale of 1:100,000, of the spatial distribution of soils in the state of Pernambuco (EMBRAPA, 2018).
- Land cover and use: The spatial data came from the Annual Mapping Project of Land Use and Cover in Brazil (MapBiomas) in matrix format (raster), at a resolution of 30 meters (MAPBIOMAS, 2021).
- Slope: The slope map was produced in raster format, in a regular grid, from a Digital Elevation Model (DEM) from the Pernambuco Tridimensional (PE3D) program, with a spatial resolution of 30 meters and from airborne laser profiling (LiDAR) (PE3D, 2013). The slope classes were defined in percentage format and grouped into six classes, according to the classification determined by EMBRAPA (2018).
- Rainfall: Historical monthly rainfall data from ten rainfall stations corresponding to a period of 18 years, from January 1, 2004, to December 31, 2021, were used. It is worth noting that this time interval was used in order to minimize the filling of gaps in the historical series of rainfall stations. In identifying flaws, to complement the absence of data, the regional weighting method was adopted, obtaining estimated data from measurements of at least three stations located in a climatic region similar to the station to be complemented. Of these stations, whose location can be seen in Figure 04, five are monitored by APAC, two by the Hidroweb Portal, one, by the National Water and Basic Sanitation Agency (ANA), one, by the National Institute of Meteorology (INMET)

and the others, by the National Center for Natural Disaster Monitoring and Alerts (CEMADEN).

Figure 04 – Map of the location of the rainmeter stations used in this study



ID	Code	Station name	Municipality	Coordinate X (mE)	Coordinate Y (mN)	Average Annual Precipitation (mm)	Monitoring agency
01	201	Camaragibe	Camaragibe	280429.9932	911277.3241	2004.61	APAC
02	30	Várzea	Recife	284099.6616	911087.318	2162.12	APAC
03	834007	Curado	Recife	284084.0568	910863.9328	2181.16	INMET
04	604	Cidade da Copa	Jaboatão dos Guararapes	280955.3949	9106755.209	2067.96	APAC
05	268	Barragem Duas Unas	Jaboatão dos Guararapes	275352.8671	9104946.521	1805.76	APAC
06	260790103A	Cavaleiro	Jaboatão dos Guararapes	282807.0963	9104562.903	1581.94	CEMADEN
07	834017	Afogados	Recife	290636.4783	910636.9773	1852.07	ANA
08	261160615A	Ibura	Recife	284584.7167	9101695.443	1847.21	CEMADEN
09	260790106A	Piedade	Jaboatão dos Guararapes	289120.764	9098177.428	1564.62	CEMADEN
10	202	Jaboatão dos Guararapes	Jaboatão dos Guararapes	288155.9125	9097110.939	1881.51	APAC

Source: Elaborated by the authors, 2023.

After obtaining and processing the historical series, the arithmetic method was used to determine the average annual precipitation for each station. Then, in QGIS (version 3.10.9), the “IDW Interpolation” tool was used to produce the precipitation spatialization map in the studied region.

All spatial data used in this work were processed in the free software QGIS (version 3.10.9), in UTM coordinates (Spindle 25 S), and in the Geocentric Reference System for the Americas (SIRGAS 2000).

Despite the importance of the factors conditioning mass movements used in this study, it is worth highlighting that some others could be verified in similar works (Aslam *et al*., 2022; Bhagya *et al*., 2023; Öcül; Şişman, 2023; Pessoa Neto *et al*., 2023), such as orientation and shape of slopes, seismic intensity, distance between water bodies, proximity to highways, accumulated water flow and the Normalized Difference Vegetation Index (NDVI).

In general, studies that adopt the theme of mapping areas susceptible to mass movements are prepared depending on the objective of the work, the methodology used, and the focus of the application, which allows addressing different combinations of environmental, physical, and/or socioeconomic characteristics of the region under study (Meena; Mishra; Piralilou, 2019; Vojtek; Vojteková, 2020; Pessoa Neto *et al*., 2023).

3.2 Reclassification of factors regarding susceptibility to mass movements

The process of reclassifying the factors listed in the previous stage was carried out according to a hierarchization technique of its variables (classes). This hierarchy was based on the correspondence between the potential of the variables for the process of mass movements to integer values (notes) between one and tenand determined by IBGE (2019), with the unit value being represented by the variables least favorable to the occurrence of mass movements and the value ten, the variables most prone to this type of process. Table 01 presents the association of notes made in this hierarchization process for consequent reclassification.

Table 01 – Reclassification of factor variables, regarding susceptibility to mass movements

Factors	Variables (Classes)	Notes
Geology (Structural Subprovinces)	Barriers	1
	Indiscriminate Cenozoic Cover	1
	Continental Body of Water	1
	Coastal Cenozoic Sedimentary Deposits	1
	Pernambuco-Alagoas	8
	Transverse Zone	8
Geomorphology (Geomorphological Units)	Eastern Northeastern Coast	1
	Eastern Tablelands of the Northeast (Dc41)	6
	Eastern Tablelands of the Northeast (Dc51)	6
	Eastern Tablelands of the Northeast (Dc52)	7
Pedology (Soil Types)	Urban Area	10
	Red-Yellow Argisol	7
	Gleisol Haplico	6
	Yellow Latosol	3
	Fluvic Neosol	1
	Soils Mangrove	2
	River	1
Land Cover and Use	Agricultural Area	9
	Artificial Area	10
	Water Body	1

	Mangrove	2
	Exposed Soil	5
	Countryside Vegetation	2
	Forest vegetation	1
Slope (%)	0 – 3	1
	3 – 8	3
	8 – 20	5
	20 – 45	8
	45 – 75	9
	> 75	10
Rainfall (mm)	1.500 - 2.000	8
	2.000 - 2.500	9

Source: Elaborated by the authors, from IBGE (2019)

The reclassification of spatial data, according to the attribution of grades presented in Table 01, was carried out using QGIS (version 3.10.9). The files represented in vector format were converted to matrix format for this procedure.

3.3 Map algebra and verification of mapping efficiency regarding susceptibility to mass movements

Map algebra was applied by correlating the layers reclassified in the previous stage with weights determined by IBGE (2019). As support for this stage, the mathematical model presented in Equation 1 was developed. According to IBGE (2019), the susceptibility calculation was carried out by integrating thematic information and developing an algorithm for the respective calculation. The weights were defined according to simulations carried out and evaluated by the technical-scientific knowledge of the team that makes up the institution, so that those that presented abnormal data were excluded and the others preserved. In addition, through a process of elimination, the set of weights was defined which best represented the condition of susceptibility to mass movements (IBGE, 2019).

$$\mathrm{M} = 0{,}15 \times \mathrm{GL} + 0{,}20 \times \mathrm{GM} + 0{,}15 \times \mathrm{PE} + 0{,}10 \times \mathrm{UT} + 0{,}35 \times \mathrm{DE} + 0{,}05 \times \mathrm{PL} \qquad (1)$$

Where: M = Map of susceptibility to mass movements, GL = Geology, GM = Geomorphology, PE = Pedology, UT = Land cover and use, DE = Slope, PL = Rainfall.

Finally, the mass movement susceptibility map, produced by map algebra, was reclassified according to the criteria presented in Table 02.

Table 02 – Criteria for reclassifying the susceptibility map to mass movements

Pixel Value	Reclassification Value	Susceptibility Level
0 - 3,50	1	Muito baixa
3,51 - 4,50	2	Baixa
4,51 - 5,50	3	Média
5,51 - 6,50	4	Alta
6,51 - 10	5	Muito alta

Source: Elaborated by the authors, from IBGE (2019).

Intending to verify the efficiency of the methodology applied in this study, the susceptibility map to mass movements in the Tejipió river basin was validated through the spatialization of 361 occurrences carried out at the Civil Defense Secretariat of Jaboatão dos Guararapes (SEDC) in the period of 28 from May 2022 to June 2, 2022, which were recorded directly in a spreadsheet obtained from the agency.

These occurrences reflected the extreme precipitation event that occurred in the region on May 28, 2022. The meteorological event that occurred on that date resulted from Eastern Wave Disturbances, presenting rainfall volumes exceeding 200 mm, with these high volumes of precipitation associated with disasters such as floods, landslides, and economic losses (Silva *et al*., 2023).

For this type of validation, points of occurrence that coincided with being located in areas identified in the mapping as highly susceptible to mass movements were considered as assertive, which defined their level of accuracy. Complementing the validation stage, a comparison of the mapping of susceptibility to mass movements was carried out with six photographic records, dated from June 3, 2022, to July 14, 2022, which portrayed episodes of this type of process that occurred in the region.

It is worth noting that although the Tejipió river basin also covers the municipalities of Recife and São Lourenço da Mata, it was not possible to obtain information regarding mass movements in these regions, such as those originating in the municipality of Jaboatão dos Guararapes, as the institutions responsible for the information did not respond to requests in a timely manner.

4 RESULTS AND DISCUSSION

With the help of GIS, the maps that represent the behavior of the Tejipió river basin in terms of the factors that affect susceptibility to mass movements selected for this study were prepared, as shown in Figure 04, being: geology (A), geomorphology (B), pedology (C), land cover and use (D), slope (E) and rainfall (F).

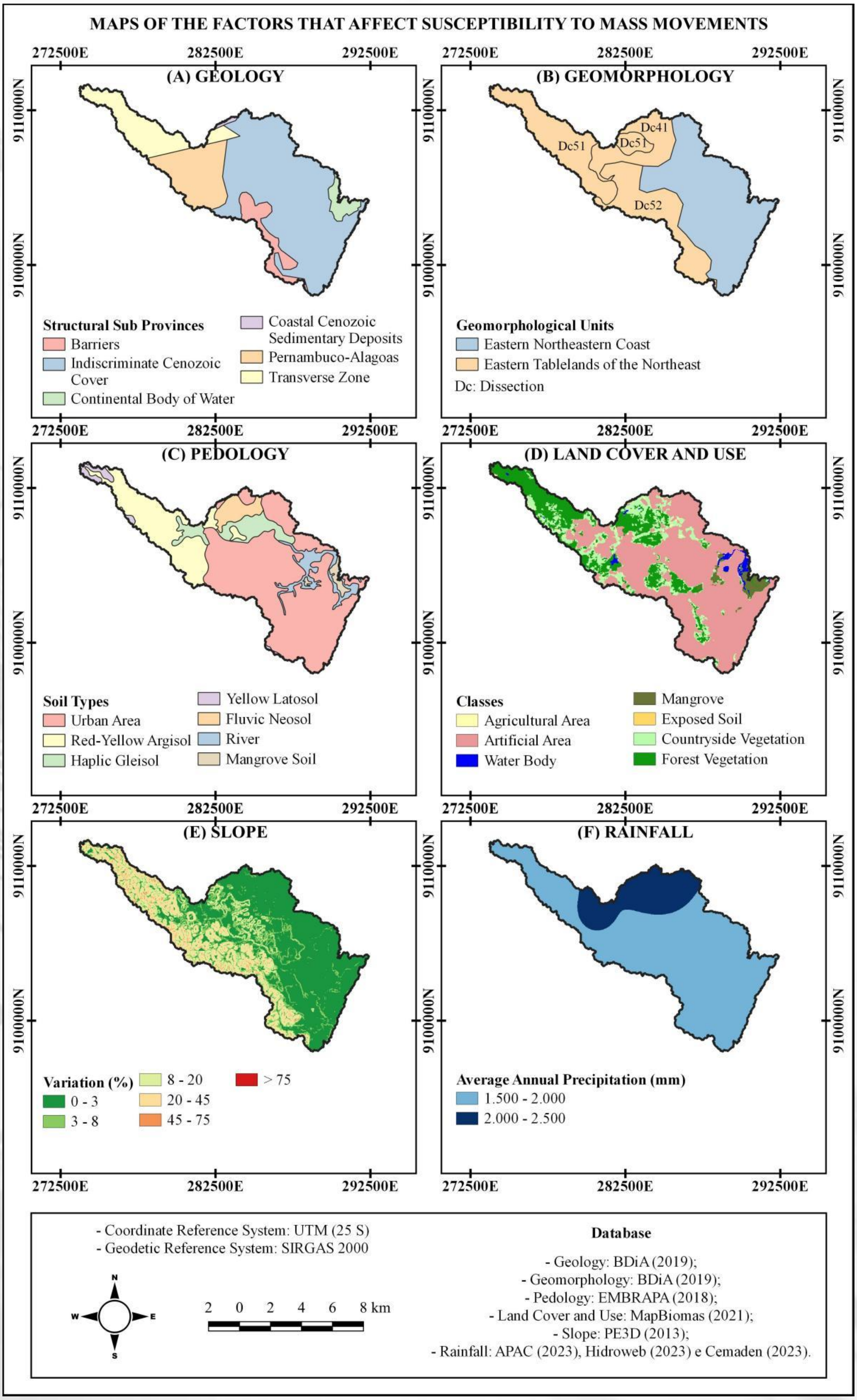
Analyzing Figure 05, it can be seen that in terms of geology (A), the structural sub provinces referring to the Cenozoic covers are the majority on the studied territory; the Pernambuco-Alagoas and Zona Transversal sub provinces, which favor susceptibility to mass movements, are located in the northern portion of the region; and those relating to Barriers, Continental Water Bodies and Coastal Cenozoic Sedimentary Deposits appear in small quantities. According to Meena, Mishra, and Piralilou (2019), geology represents a considerable factor when it comes to addressing mass movements, as geological units present varying levels of resistance, permeability, and propensity to failure.

In relation to geomorphology (B), the region comprises two relief units: the Northeastern Eastern Litoral, which covers the coastal plains, and the Eastern Tablelands of the Northeast, located in the western part of the region, consisting of tabular forms and with minimum and maximum elevation levels of 30 and 130 meters, respectively. Areas with higher altitudes generally have greater propensities for the process of mass movements (Vojtek; Vojteková, 2020).

As for pedology (C), the urban area prevails in the basin, especially in its coastal part. The Red-Yellow Argisol and the Haplic Gleisol, which are more clayey soils, are found, respectively, in the western and central-northern portions of the region. The sandiest soils, the Yellow Oxisol and the Fluvic Neosol are identified to the northwest and north, respectively. According to Aslam et al. (2022), clay soils are more susceptible to mass movements, due to their high-water absorption capacity. This process increases the weight of the soil layer and contributes to the failure of the slopes.

Regarding the coverage and use of land (D) of the Tejipió river basin, the class of artificial area, which favors mass movements, the coastal and central parts of the territory predominate. The forest formation, which represents the class that least affects the process of mass movements, covers, above all, the northwestern portion, in the upper reaches of the basin. The conversion of vegetated areas into impermeable areas accelerates the process of mass movements, as vegetation is responsible for stabilizing slopes, since the root system has the function of filling voids in the soil, delaying the process of rainwater infiltration. (Silveira; Vettorazzi; Valente, 2014; Jazouli; Barakat; Khellouk, 2019).

Figure 05 – Maps of the factors, selected for this study, that affect susceptibility to mass movements.



Source: Elaborated by the authors, 2023.

Regarding topography, the different slope classes (E) are distributed across the territory so that the flat regions encompass the eastern part of the basin, which is filled, above all, by urbanized areas. The steepest regions are found in the northwest of the basin. According to Meirelles, Dourado, and Costa (2018), the greater the region's slope, the greater its instability, which increases mass movements.

Regarding the variability of average annual precipitation, the highest rainfall rates (F) observed (greater than 2,000 mm) are present in the central-northern part of the region. Precipitation is the main element of the hydrological cycle of water input into a river basin. Extreme precipitation events result in soil saturation and, consequently, in the process of mass movement, as, under these conditions, the slopes have difficulty absorbing excess water.

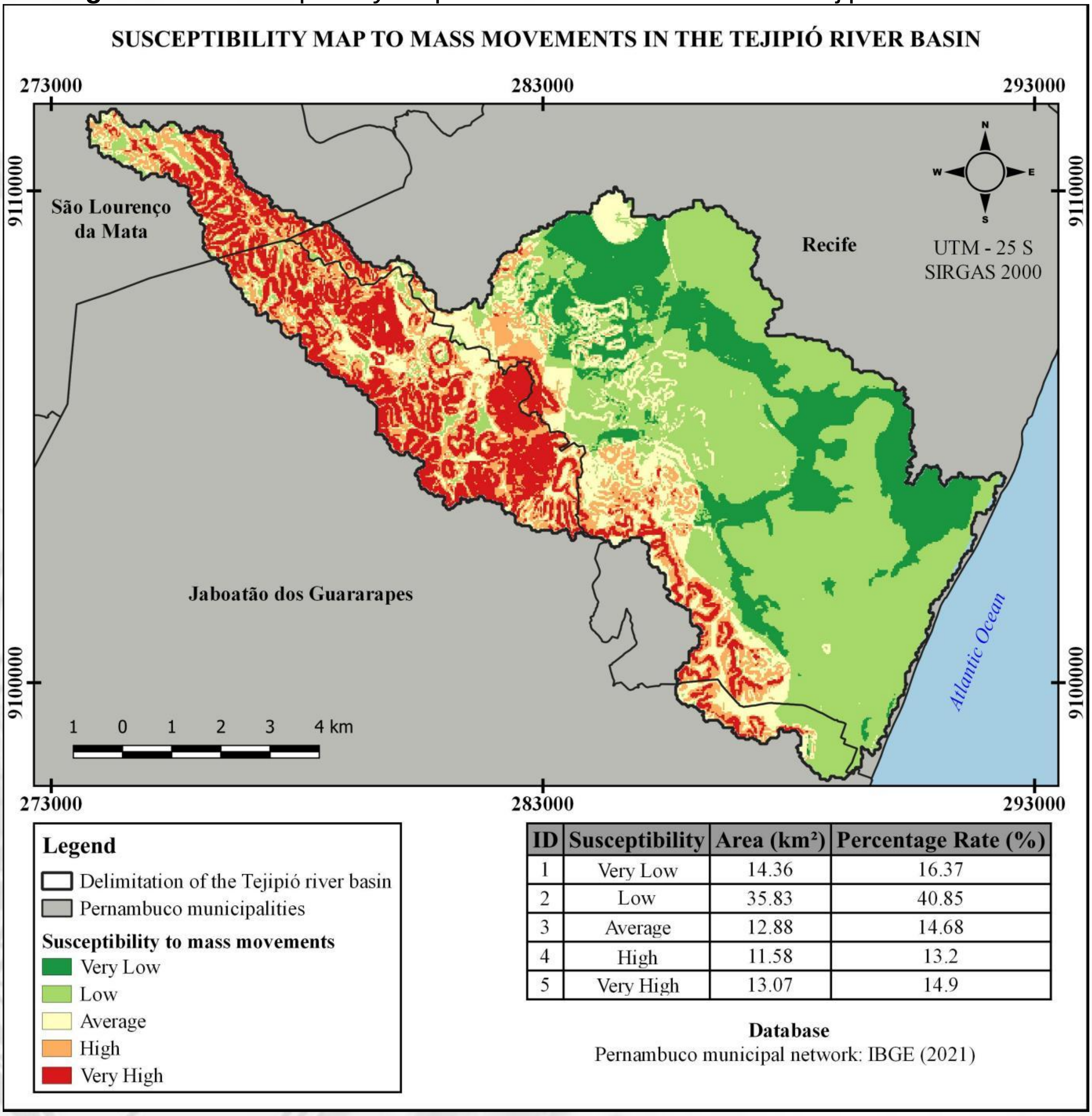
Figure 06 presents the susceptibility map to mass movements resulting from the reclassification of the conditioning factors, obtained by map algebra.

By mapping the region under study regarding susceptibility to mass movements, it is possible to verify that the classes with lower propensity to the process total 50.19 km², which is equivalent to 57.22% of the territory. The areas belonging to this class are located in the municipality of Recife and represent flat regions with lower elevations. The areas that are most susceptible to mass movements, represented by the upper and very upper classes, cover 28.10% of the basin and are generally distributed in the municipalities of Jaboatão dos Guararapes and São Lourenço da Mata, representing the steepest regions, with the greatest altitudes and which have more clayey soils.

According to Xavier, Listo, and Nery (2022), the areas most favorable to mass movements in the RMR are characterized by accelerated urban expansion in lands of Cenozoic sedimentation, which are more prone to this type of process. Still, according to the aforementioned authors, a large part of this type of occupation is consolidated in a location with precarious infrastructure, which contributes to the instability of slopes, especially steep slopes, characterized by the accumulation of glacis of the Barreiras Formation.

Based on bibliographic analysis, interviews, and field surveys, Silva et al. (2017) found that the occurrence of mass movements in the Tejipió river basin is related to the following factors: climatic and geomorphological dynamics favorable to the process, rectifications in river courses and occupations on steep and sparsely vegetated slopes.

Figure 06 – Susceptibility map to mass movements in the Tejipió river basin.



ID	Susceptibility	Area (km²)	Percentage Rate (%)
1	Very Low	14.36	16.37
2	Low	35.83	40.85
3	Average	12.88	14.68
4	High	11.58	13.2
5	Very High	13.07	14.9

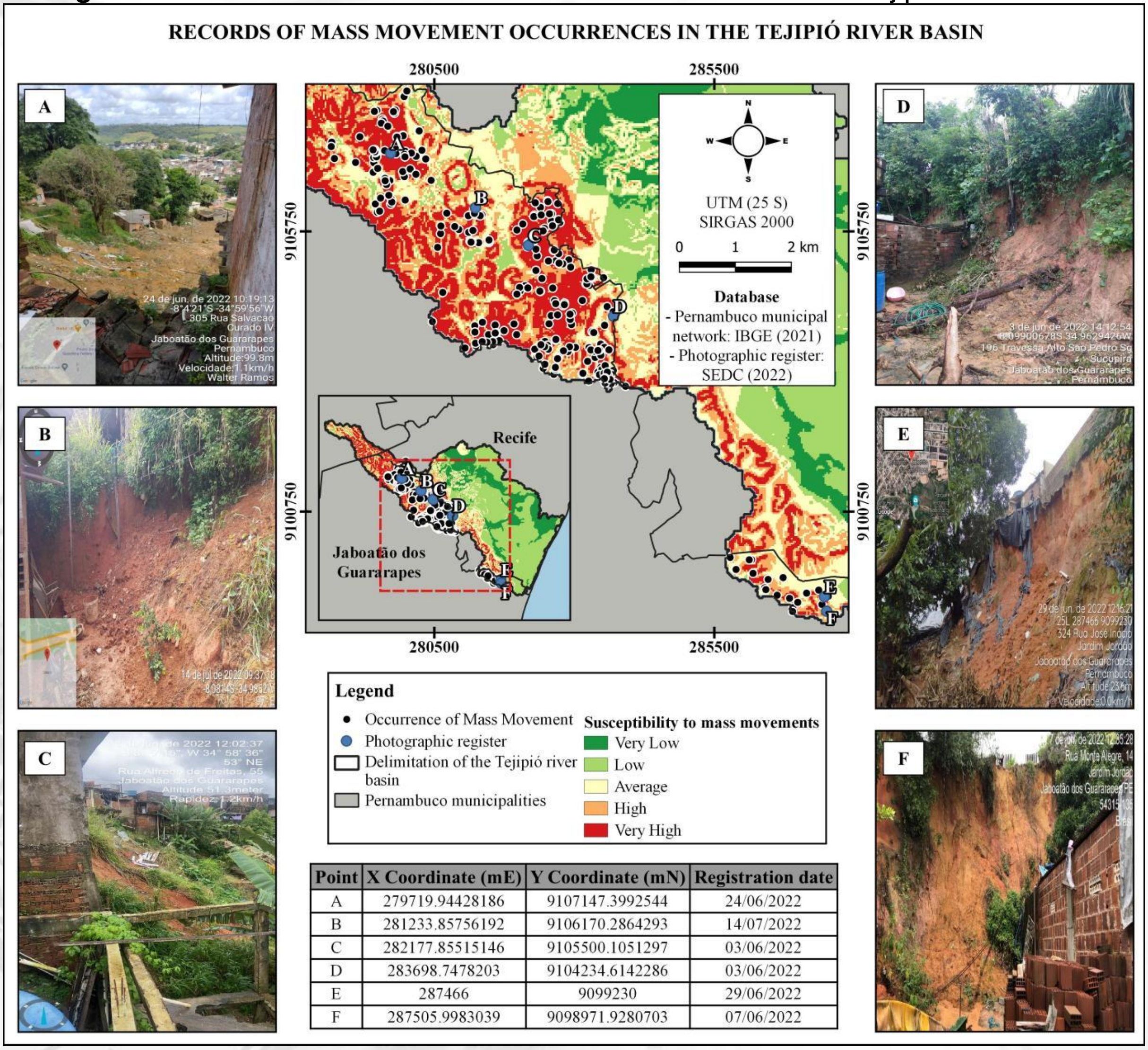
Database
Pernambuco municipal network: IBGE (2021)

Source: Elaborated by the authors, 2023.

In other regions, covering characteristics similar to those observed in the Tejipió river basin, similar results were observed. As the study by Rodríguez, Flores and Santana (2021) found that the areas most favorable to mass movements in the municipality of Angangueo, Mexico, have a fragile geological substrate and soils prone to erosion. Soares Júnior, Barradas, and Franchi (2022) found that the areas of the municipality of Mairiporã, in São Paulo, where susceptibility to mass movements is increased, are those with high slopes and lack of vegetation cover, these characteristics are similar to those observed in the area of study.

Figure 07 was prepared from 361 records of mass movement episodes in the region under study, provided by SEDC. The photographic records (identified by the letters A, B, C, D, E, and F) portrayed the adversities caused by mass movement processes resulting from the extreme precipitation event occurred on May 28, 2022, at the study site.

Figure 07 – Records of mass movement occurrences in the Tejipió river basin.



Point	X Coordinate (mE)	Y Coordinate (mN)	Registration date
A	279719.94428186	9107147.3992544	24/06/2022
B	281233.85756192	9106170.2864293	14/07/2022
C	282177.85515146	9105500.1051297	03/06/2022
D	283698.7478203	9104234.6142286	03/06/2022
E	287466	9099230	29/06/2022
F	287505.9983039	9098971.9280703	07/06/2022

Source: Elaborated by the authors, 2023.

From the findings presented in Figure 07, it was observed that of the 361 occurrences of mass movements, 72 are located in areas classified by mapping as highly susceptible and 257, in areas of very high susceptibility (Table 03). This analysis gives the mapping a level of reliability (accuracy) greater than 91.00%, verifying high consistency in the method used. Regarding the six photographic records taken into consideration, it was verified that they all coincide in being located in areas defined by the mapping as having very high susceptibility to the process.

Table 03 – Level of reliability of mapping areas susceptible to mass movements, according to occurrences registered with SEDC during the months of May and June 2022

Level of susceptibility to mass movements defined by mapping Number of occurrences	Number of occurrences
Very Low	zero
Low	1
Average	31
High	72
Very High	257
Total	**361**
Accuracy	**91,14%**

Source: Elaborated by the authors, 2023.

5 FINAL CONSIDERATIONS

Through the results, it was verified that a portion of 12.88 km² of the region under study is represented by areas of moderate susceptibility to mass movements, which is equivalent to 14.68% of the area. Those with low and high propensities correspond, respectively, to 57.22% and 28.10% of the territory. The regions categorized by mapping as having a high propensity for mass movements are those that have a combination of correlated factors, such as high altitude and slope and more clayey soils.

The methodology used in this work regarding mapping susceptibility to mass movements represents a viable alternative in terms of efficiency and applicability, enabling managers and/or professionals in the field to make more assertive decisions. This viability is granted, mainly, by the ease of access, storage, and manipulation of spatial information, which allows a wide combination of procedures and applications. Thus, it is possible to base planning and preventive and mitigating measures regarding mass movements, reducing the negative impacts caused by this process.

Consistent mapping regarding susceptibility to mass movements can be considered an important instrument that supports planning and risk management for geological phenomena, which enables the development of effective measures to prevent, protect, and mitigate the negative impacts caused by this phenomenon.

Finally, it is worth highlighting that mass movement processes in the study area can be minimized by actions aimed at conserving the natural conditions of the environment, such as maintaining native vegetation, promoting adequate land use and coverage.

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