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Mapping of Flood Susceptibility in the Urban Area of Vitória de Santo Antão, Pernambuco

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Mapeamento da Suscetibilidade a Alagamentos em Área Urbana de Vitória de Santo Antão–PE

RESUMO

Objetivo - Identificar e mapear as áreas suscetíveis a alagamentos em uma sub-bacia urbana localizada no município de Vitória de Santo Antão–PE, inserida na bacia do rio Tapacurá, por meio da análise integrada de critérios físicos e de uso e ocupação do solo, visando subsidiar o planejamento urbano e a gestão de riscos hidrológicos.

Metodologia - O estudo foi desenvolvido a partir de uma abordagem aplicada e exploratória, utilizando técnicas de geoprocessamento em ambiente de Sistema de Informações Geográficas (SIG). Foram empregados dados altimétricos do Modelo Digital do Terreno (MDT) do projeto Pernambuco 3D (PE3D), informações de uso e ocupação do solo do MapBiomas e ferramentas do QGIS e GRASS GIS para a delimitação da sub-bacia urbana, análise de declividade, fluxo acumulado e uso do solo. Os critérios foram reclassificados e integrados por meio de análise multicritério, permitindo a geração do mapa de susceptibilidade a alagamentos.

Originalidade/relevância - A originalidade do estudo reside na aplicação integrada de critérios físicos e antrópicos, com foco em uma sub-bacia urbana específica, frequentemente afetada por alagamentos, mas ainda pouco investigada sob a ótica da suscetibilidade espacial. A pesquisa contribui para o avanço das discussões acadêmicas sobre gestão de riscos hidrológicos em cidades de médio porte do Nordeste brasileiro.

Resultados - Os resultados evidenciaram a concentração de áreas com alta susceptibilidade a alagamentos ao longo da Avenida Mariana Amália e Henrique de Holanda, associadas principalmente à elevada impermeabilização do solo, baixos declives e maior acúmulo de fluxo superficial. O mapa final apresentou coerência com registros históricos e estudos anteriores, validando a metodologia adotada.

Contribuições teóricas/metodológicas - O trabalho contribui metodologicamente ao demonstrar a eficiência do uso de SIG e análise multicritério para a identificação de áreas suscetíveis a alagamentos sem a necessidade de modelagens hidrológicas complexas. Teoricamente, reforça a importância da integração entre fatores físicos e de uso do solo na análise de riscos urbanos.

Contribuições sociais e ambientais - Os achados oferecem subsídios técnicos para o planejamento urbano e a formulação de políticas públicas voltadas à mitigação de alagamentos, especialmente no que se refere à drenagem urbana. Além disso, o estudo contribui para a redução de impactos socioambientais associados a eventos extremos, promovendo maior segurança e resiliência urbana.

PALAVRAS-CHAVE: Alagamentos urbanos. Geoprocessamento. Drenagem urbana. Vitória de Santo Antão.

Mapping Flood Susceptibility in an Urban Area of Vitória de Santo Antão–PE

ABSTRACT

Objective – To identify and map areas susceptible to flooding in an urban sub-basin located in the municipality of Vitória de Santo Antão–PE, within the Tapacurá River basin, through the integrated analysis of physical criteria and land use and occupation, aiming to support urban planning and hydrological risk management.

Methodology – The study was developed using an applied and exploratory approach, employing geoprocessing techniques within a Geographic Information System (GIS) environment. Altimetric data from the Digital Terrain Model (DTM) of the Pernambuco 3D Project (PE3D), land use and land cover information from MapBiomas, and tools from QGIS and GRASS GIS were used for the delimitation of the urban sub-basin, slope analysis, flow accumulation, and land use assessment. The criteria were reclassified and integrated through multicriteria analysis, enabling the generation of a flood susceptibility map.

Originality/Relevance – The originality of this study lies in the integrated application of physical and anthropogenic criteria focused on a specific urban sub-basin frequently affected by flooding but still underexplored from a spatial susceptibility perspective. The research contributes to advancing academic discussions on hydrological risk management in medium-sized cities in northeastern Brazil.

Results – The results revealed a concentration of areas with high flood susceptibility along Avenida Mariana Amália and Avenida Henrique de Holanda, mainly associated with high soil impermeability, low slopes, and increased surface flow accumulation. The final map showed consistency with historical records and previous studies, validating the adopted methodology.

Theoretical/Methodological Contributions – Methodologically, the study demonstrates the effectiveness of GIS and multicriteria analysis in identifying flood-prone areas without the need for complex hydrological modeling. Theoretically, it reinforces the importance of integrating physical factors and land use in urban risk assessments.
Social and Environmental Contributions – The findings provide technical support for urban planning and the formulation of public policies aimed at flood mitigation, particularly regarding urban drainage. Additionally, the study contributes to reducing socio-environmental impacts associated with extreme events, promoting greater urban safety and resilience.

KEYWORDS: Urban flooding. Geoprocessing. Urban drainage. Vitória de Santo Antão.

Mapeo de la Susceptibilidad a Inundaciones en un Área Urbana de Vitória de Santo Antão–PE

RESUMEN
Objetivo – Identificar y mapear las áreas susceptibles a inundaciones en una subcuenca urbana ubicada en el municipio de Vitória de Santo Antão–PE, inserta en la cuenca del río Tapacurá, mediante el análisis integrado de criterios físicos y de uso y ocupación del suelo, con el fin de apoyar la planificación urbana y la gestión del riesgo hidrológico.
Metodología – El estudio se desarrolló a partir de un enfoque aplicado y exploratorio, utilizando técnicas de geoprocesamiento en un entorno de Sistema de Información Geográfica (SIG). Se emplearon datos altimétricos del Modelo Digital del Terreno (MDT) del proyecto Pernambuco 3D (PE3D), información de uso y cobertura del suelo de MapBiomas y herramientas de QGIS y GRASS GIS para la delimitación de la subcuenca urbana, el análisis de pendientes, la acumulación de flujo y el uso del suelo. Los criterios fueron reclasificados e integrados mediante análisis multicriterio, permitiendo la generación del mapa de susceptibilidad a inundaciones.
Originalidad/Relevancia – La originalidad del estudio radica en la aplicación integrada de criterios físicos y antrópicos, con enfoque en una subcuenca urbana específica, frecuentemente afectada por inundaciones, pero aún poco investigada desde la perspectiva de la susceptibilidad espacial. La investigación contribuye al avance de las discusiones académicas sobre la gestión del riesgo hidrológico en ciudades medianas del noreste brasileño.
Resultados – Los resultados evidenciaron la concentración de áreas con alta susceptibilidad a inundaciones a lo largo de las avenidas Mariana Amália y Henrique de Holanda, asociadas principalmente a la elevada impermeabilización del suelo, pendientes suaves y mayor acumulación de escorrentía superficial. El mapa final presentó coherencia con registros históricos y estudios previos, validando la metodología adoptada.
Contribuciones Teóricas/Metodológicas – Metodológicamente, el trabajo demuestra la eficiencia del uso de SIG y del análisis multicriterio para la identificación de áreas susceptibles a inundaciones sin necesidad de modelaciones hidrológicas complejas. Desde el punto de vista teórico, refuerza la importancia de la integración entre factores físicos y el uso del suelo en el análisis de riesgos urbanos.
Contribuciones Sociales y Ambientales – Los hallazgos ofrecen insumos técnicos para la planificación urbana y la formulación de políticas públicas orientadas a la mitigación de inundaciones, especialmente en lo referente al drenaje urbano. Además, el estudio contribuye a la reducción de los impactos socioambientales asociados a eventos extremos, promoviendo una mayor seguridad y resiliencia urbana.

PALABRAS CLAVE: Inundaciones urbanas. Geoprocesamiento. Drenaje urbano. Vitória de Santo Antão.

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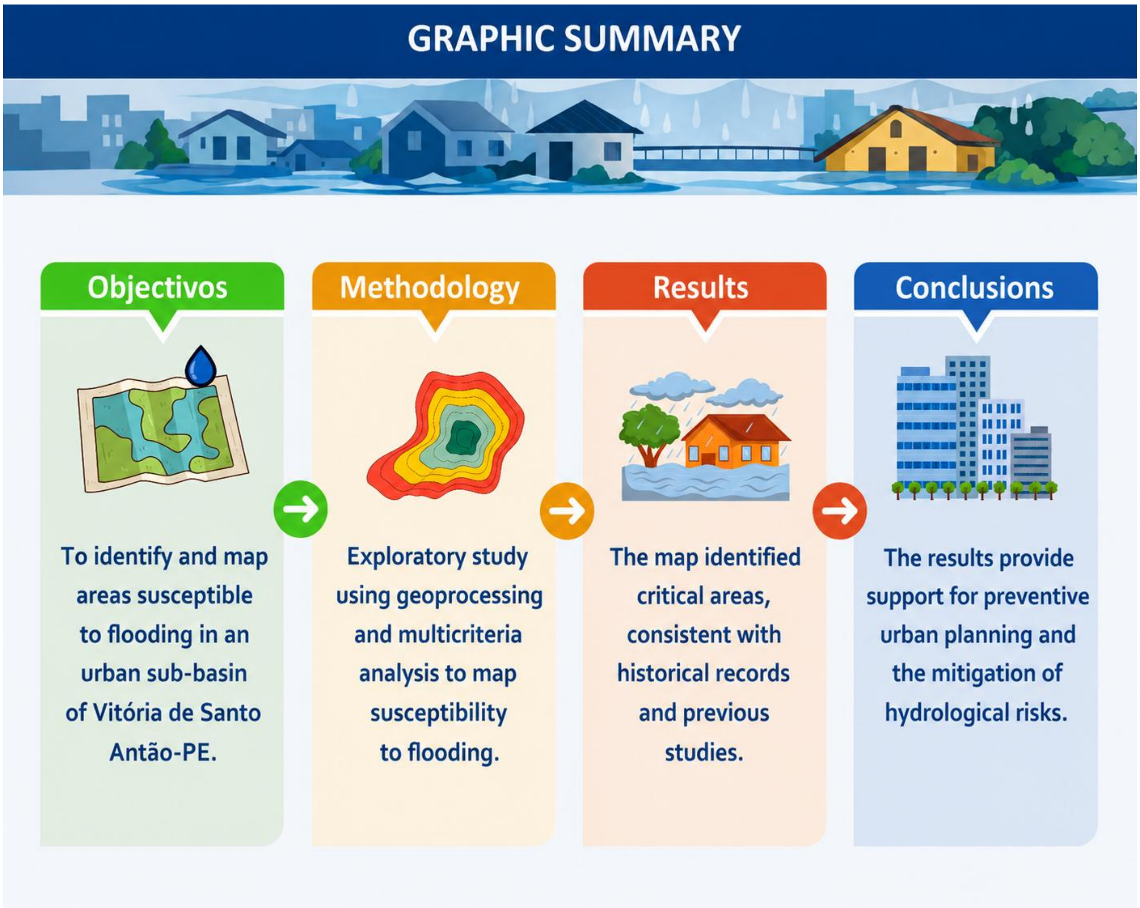
GRAPHICAL ABSTRACT



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1 INTRODUCTION

Rapid and poorly planned urbanization poses a significant obstacle to the promotion of urban sustainability. The expansion of the urban fabric—often detached from appropriate technical guidelines—has resulted in the occupation of environmentally vulnerable areas. Furthermore, the removal of native vegetation and the increase in impervious surfaces directly influence environmental systems, intensifying degradation processes (Salem; Tsurusaki, 2024).

In this context, adopting strategies for sustainable stormwater management has been identified as an alternative to minimize the impacts of urbanization. Solutions based on green infrastructure promote soil water infiltration, reduce surface runoff, and help mitigate urban flooding, thereby making cities more resilient to the challenges posed by urban growth and climate change (Borges, 2024).

The increasing frequency and magnitude of flood events in cities have led to significant economic, social, and environmental impacts. The intensification of these episodes is strongly linked to the inappropriate occupation of riparian zones, combined with deficient or non-existent urban drainage systems. This scenario increases socio-environmental vulnerability, compromising both ecosystem integrity and the safety of urban populations (Costa; Nascimento; Silva, 2020).

Concurrently, transformations associated with global climate change have caused significant shifts in rainfall patterns, characterized by a rise in extreme weather events. Notable examples include intense precipitation concentrated over short periods and prolonged dry spells—factors that exacerbate flooding in urbanized areas and heighten hydrological risks in cities (Awode et al., 2025). Developing countries are more vulnerable to flood-related impacts, experiencing more significant material and non-material losses compared to developed nations. This situation is linked to the increased frequency and intensity of these events—driven by climate change—combined with limited technical, financial, and institutional resources for implementing effective mitigation and adaptation measures (Razavi et al., 2020).

As climate change progresses, there is a trend toward more frequent compound extreme events, significantly increasing risks across various regions of the globe. According to the Intergovernmental Panel on Climate Change (IPCC), it is estimated that by the mid-21st century, over one billion people could be exposed to associated climate threats, such as the inundation of low-lying areas, erosion processes, and flood events (IPCC, 2021). Domestically, the municipality of Vitória de Santo Antão, located in the interior of Pernambuco state, stands out for the recurring occurrence of floods and inundations, highlighting its vulnerability to these phenomena.

Given this context, it is essential to strengthen urban planning guided by risk management and disaster prevention. Integrating territorial planning tools, public management, and social participation serves as a key mechanism for enhancing city resilience against extreme hydrological events, thereby reducing population vulnerability and promoting sustainable urban development (Inaba; Inaba, 2024).

According to the Digital Atlas of Disasters in Brazil, the municipality of Vitória de Santo Antão (Pernambuco) ranks fifth among the state's municipalities for the highest number of people left homeless or displaced due to extreme hydrological events, underscoring its high vulnerability to flooding (MDR, 2022). This scenario underscores the need for technical tools

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capable of supporting prevention and harm-reduction measures, particularly in urban settings prone to recurring extreme events linked to hydrological dynamics.

In this context, flood hazard mapping is a crucial step in formulating risk mitigation and management strategies, as highlighted by Namara et al. (2022). Accordingly, this study proposes the development of a flood risk map for the municipality of Vitória de Santo Antão using geoprocessing techniques; the aim is to identify susceptible areas and produce thematic maps showing hazard indices, thereby contributing to urban planning and risk management in Northeast Brazil.

2 OBJECTIVES

The general objective of this study is to identify and map areas susceptible to flooding within the urbanized region of the Tapacurá River sub-basin, located in the municipality of Vitória de Santo Antão, in the state of Pernambuco. Initially, the urban sub-basin will be delimited and characterized—taking into account physical aspects as well as land use and occupation—to understand the spatial dynamics associated with flooding events.

Subsequently, the study proposes identifying and analyzing critical flooding points within the urban perimeter using geoprocessing and spatial analysis techniques. This approach will enable the identification of the most vulnerable areas and the physical factors that foster recurrent flooding, particularly those linked to existing urban infrastructure.

Finally, the study aims to provide technical input to support the formulation and improvement of public policies for flood mitigation in the municipality, focusing on measures related to urban infrastructure and drainage systems. Identifying critical areas is intended to contribute to urban planning and the reduction of socio-environmental impacts associated with flooding events in Vitória de Santo Antão.

3. METHODOLOGY

3.1 Study área

The study area comprises the municipality of Vitória de Santo Antão, located in the state of Pernambuco, within the Mata Pernambucana mesoregion and the Vitória de Santo Antão microregion. The municipality shares borders with Glória de Goitá and Chã de Alegria to the north, Primavera and Escada to the south, Moreno, Cabo de Santo Agostinho, and São Lourenço da Mata to the east, and Pombos to the west (Miranda, 2015), as illustrated in Figure 1. This spatial configuration places the municipality in a transition zone between urbanized areas and regions of intense agricultural activity, influencing its socio-spatial and environmental dynamics.

Vitória de Santo Antão is located approximately 46 km from the state capital, Recife, covering a land area of 373.3 km². According to population estimates by the Brazilian Institute of Geography and Statistics (IBGE), the municipality had a population of approximately 143,799 inhabitants in 2024 (IBGE, 2025). The continuous population growth observed in recent decades is linked to its role as a regional economic hub and its proximity to the Recife Metropolitan Area. This process of urban expansion has direct implications for land use and the demand for

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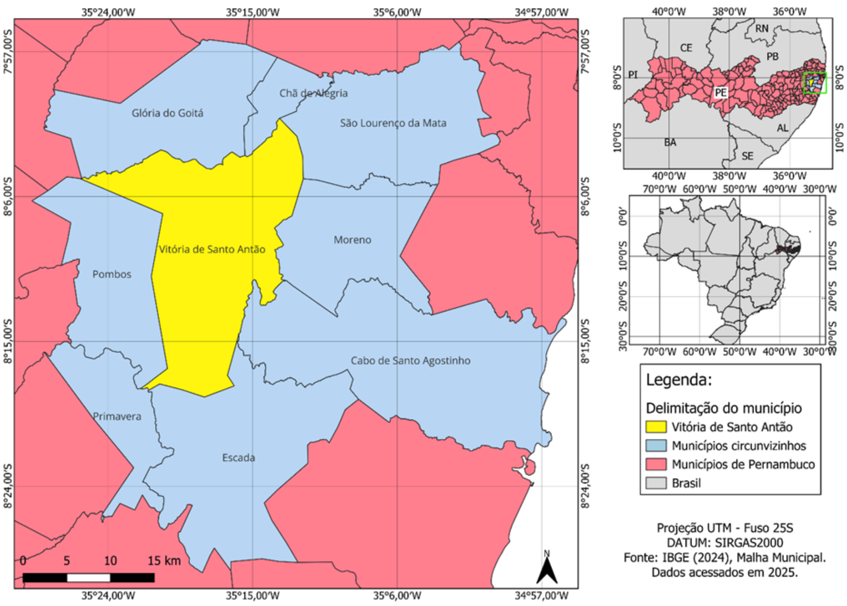
infrastructure—factors relevant to analyzing areas within the municipality that are susceptible to flooding.

Figure 1 – Delimitation of the municipality of Vitória de Santo Antão, PE.



Source: Authors (2026).

The Tapacurá River basin is located in the state of Pernambuco and has an approximate drainage area of 471 km², encompassing municipalities such as Vitória de Santo Antão, Pombos, Chã Grande, and São Lourenço da Mata, while also directly influencing areas within the Recife Metropolitan Region. Situated within the Capibaribe River basin, the Tapacurá River plays a significant role in regional water dynamics, serving as a crucial element for water supply, flow regulation, and flood mitigation, particularly in urban contexts (APAC, 2025; Miranda, 2015).

3.2 Land use and land cover map

Land use and land cover mapping for the municipality of Vitória de Santo Antão (PE) was conducted using QGIS software, based on data provided by the MapBiomas project (2025). The geospatial data, made available in GeoTIFF format, were obtained from the official MapBiomas platform and subsequently subjected to spatial clipping procedures to restrict the analysis to the area within the administrative boundaries of the municipality under study.

3.3 Delineation of the urban sub-basin

The delineation of the sub-watershed of interest and the definition of the outlet point were carried out using a Digital Terrain Model (DTM) obtained via the OpenTopography DEM extension in QGIS software. The SRTM model was used—featuring a 30 m spatial resolution and the EPSG:4674 (SIRGAS 2000) geographic reference system—which represents the terrain surface excluding elements such as buildings or vegetation cover.

The DTM was initially clipped to the administrative boundaries of the municipality of Vitória de Santo Antão to restrict the analysis to the area of interest. Subsequently, the

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topographic surface was processed using the r.fill.dir tool from the GRASS GIS plugin to eliminate artificial depressions and correct surface runoff direction, resulting in a hydrologically consistent Digital Elevation Model (DEM).

Using the corrected DEM, the r.watershed tool was applied to determine flow direction, contributing areas, and drainage divides. The parameter for the minimum basin size was set to 100, a value established through empirical testing to ensure an accurate representation of urban sub-watersheds. The primary outputs generated included layers for drainage direction, flow segments, and sub-basins.

Based on these results, a flow segment associated with a tributary of the Tapacurá River—located in an urban area with a history of recurring flooding—was selected. The corresponding sub-watershed was then delineated using the r.water.outlet tool, utilizing the drainage direction layer and the geographic coordinates of the outlet point, defined at the confluence of the tributary and the main river.

Finally, the delineated sub-watershed was converted from raster to vector format, enabling easier manipulation within the GIS environment. A geometric simplification process was also applied to smooth the polygon boundaries and optimize subsequent spatial analyses, without compromising the representativeness of the delimited area.

3.4 Identification of areas susceptible to flooding

The identification of areas susceptible to flooding was carried out through a multi-criteria analysis using a Geographic Information System (GIS) environment. The criteria considered were land use and land cover, slope, and accumulated flow, in accordance with the parameters defined in Table 1.

Table 1 – Spatial parameters and values for reclassifying images according to susceptibility to inundação.

Class	Parameter	Land Use and Land Cover	Slope (%)	Flow Accumulation
1-	Very Low	Forest cover	>20	0-2000
2-	Low	Regenerating forest cover	8-20	2000-4000
3-	Moderate	Degraded forest cover	3-8	4000-8000
4-	High	No forest cover	0-3	>8000

Source: Adaptado de Vinhal; Oliveira; Giongo (2023), com base em Korah; López (2015).

To clarify the methodological process adopted in developing the flood risk map, a flowchart was created to summarize all stages of the multicriteria analysis. This flowchart sequentially organizes the phases of data acquisition, criterion selection, variable standardization, weight application, and final result integration, providing an objective and structured visualization of the procedure. Thus, the flowchart helps facilitate understanding of the process and ensures the transparency and reproducibility of the methodology employed (Figure 2).

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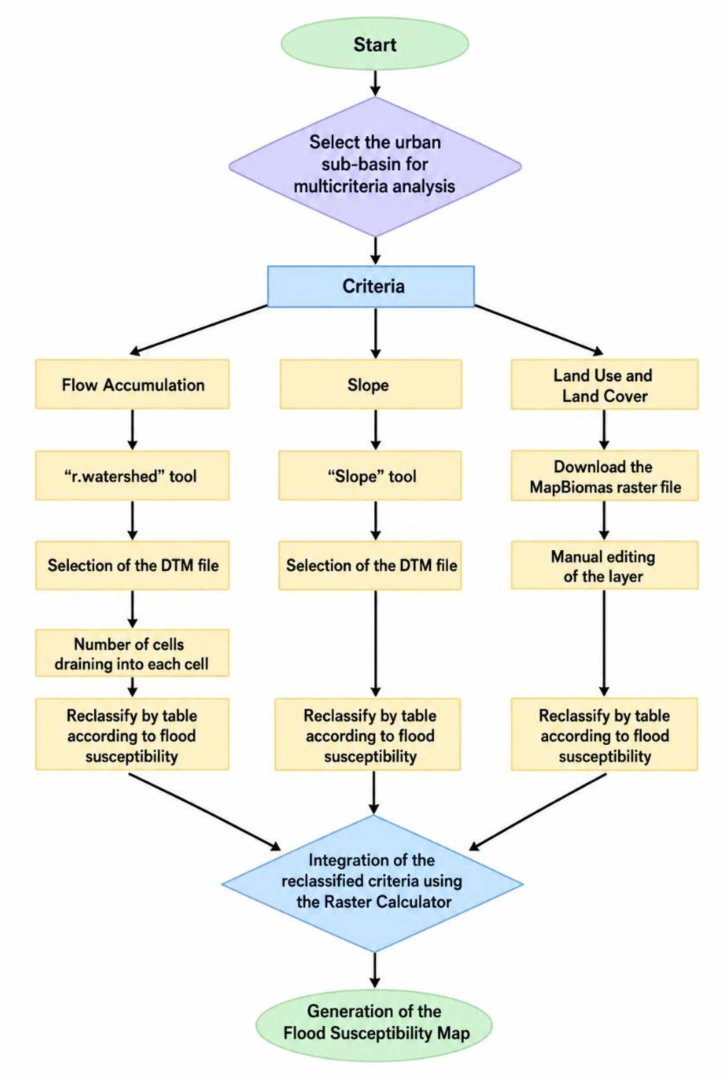
Figure 2 – Flowchart for generating the urban sub-basin flood risk map.



Source: Authors (2026).

3.4.1 Generation of accumulated flow

Accumulated flow was derived using the *r.watershed* algorithm available in GRASS GIS, with the Digital Terrain Model (DTM) from the PE3D project (Digital Territory Modeling Program of the State of Pernambuco)—specifically element MDT-SC-25-V-A-II-1-NE-F-III—serving as the input. A minimum basin size of 100 was adopted for the analysis.

The output selected was the option representing the number of cells contributing to runoff for each cell, resulting in an accumulated flow raster. This layer was subsequently clipped to the boundaries of the sub-basin under study. Next, the "Reclassify by Table" tool was applied using the accumulated flow raster as input, following the parameters defined in Table 1 and setting the output data type to Int16. This procedure generated a layer reclassified into four classes, representing different levels of flooding risk.

3.4.2 Slope calculation and reclassification

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The slope analysis was conducted using the Digital Terrain Model from the PE3D project and the Slope tool in QGIS, with values expressed as percentages. The resulting layer was subsequently clipped to the boundaries of the sub-basin under analysis.

Next, the slope data were reclassified using the "Reclassify by Table" tool, based on the intervals defined in Table 1. This process enabled the variable to be categorized into four distinct classes—ranging from 1 to 4—corresponding to different levels of flooding risk.

3.4.3 Adjustment and reclassification of land use and occupancy

Land use and land cover data were obtained from MapBiomas but showed inconsistencies within the study area, such as generalized classification as urban areas. Consequently, the dataset was manually adjusted to reflect local conditions. After clipping the data to the sub-basin, the layer was reclassified using the "Reclassify by Table" tool—as shown in Table 1—resulting in four flood risk classes (1 to 4).

3.4.4 Multi-criteria integration and generation of the flood risk map

Finally, the integration of the three previously reclassified criteria was performed using the Raster Calculator tool in QGIS software. For this step, specific weights were assigned to each thematic layer based on the methodology proposed by Vinhal, Oliveira, and Giongo (2023): 40% for land use and land cover, 25% for slope, and 35% for accumulated flow. The assignment of these weights was based on established international literature in which similar approaches were used for flood susceptibility analysis, such as the studies conducted by Korah and López (2015), Ouma and Tateishi (2014), Rincón et al. (2018), Popa et al. (2019), and Azua et al. (2019).

4. RESULTS AND DISCUSSION

4.1 Spatial analysis of land use and land cover

Interpretation of the land use and land cover map (Figure 3) reveals the predominance of agricultural and livestock activities within the territory of Vitória de Santo Antão, with the greatest spatial extent found in the central and southern parts of the municipality. These areas are characterized primarily by extensive sugarcane plantations and livestock farming, establishing a dominant rural land-use pattern. Forest formations occur in a fragmented and discontinuous manner, distributed in small patches, particularly in the municipality's peripheral areas. The urban fabric, depicted in red on the map, is concentrated in the central region, defining the main urban core and highlighting the city's expansion toward the surrounding rural areas.

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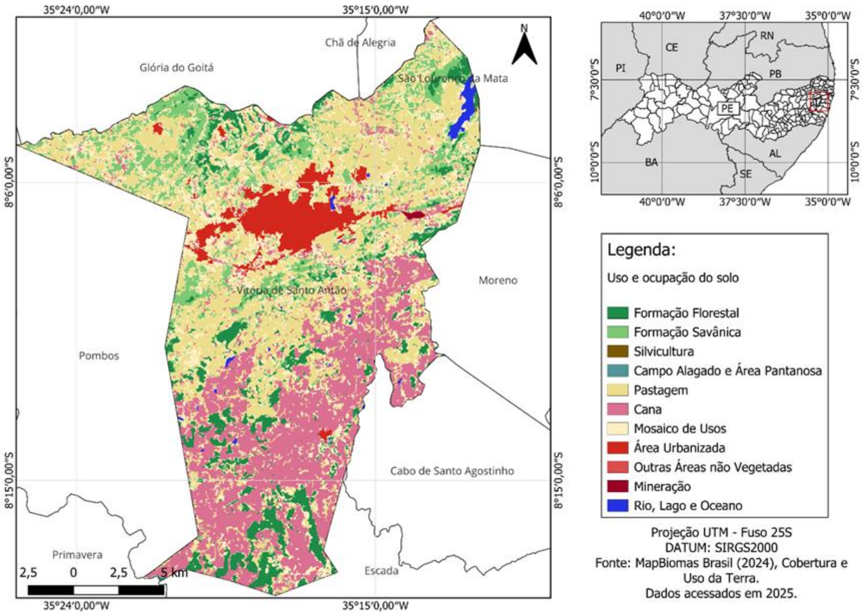
Figure 3 – Land use and land cover map of the municipality of Vitória de Santo Antão, Pernambuco, 2024.

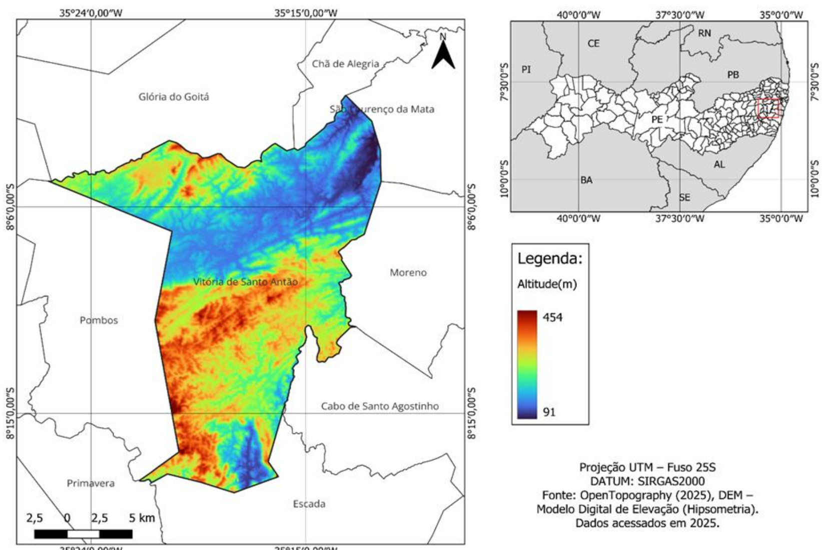


Source: Authors (2026).

4.2 Delineation of the urban sub-basin and location of the outlet

Processing the Digital Terrain Model (DTM) derived from the PE3D dataset resulted in the product shown in Figure 4, in which the model was clipped to the municipality's territorial boundaries. This spatial clipping enabled a more detailed representation of local topographic features, contributing to a better understanding of the study area's relief. This procedure was fundamental for delineating the drainage network and served as the basis for subsequent stages of the hydrological analysis.

Figure 4 – Hypsometry of the municipality of Vitória de Santo Antão, Pernambuco.



Source: Authors (2026).

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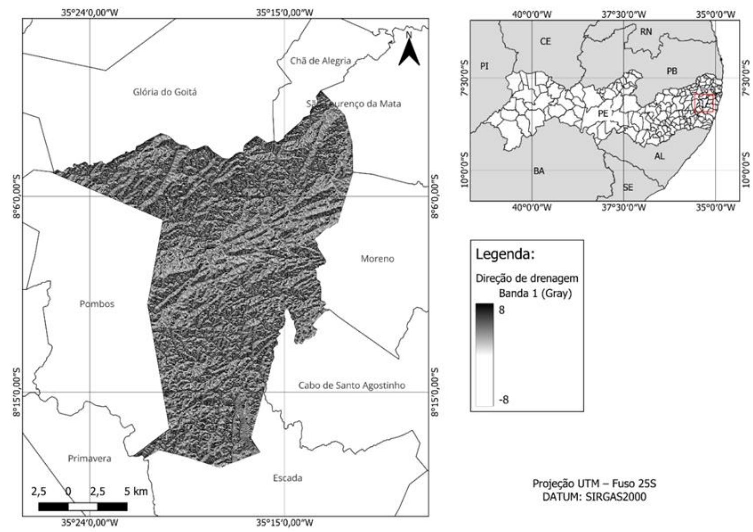
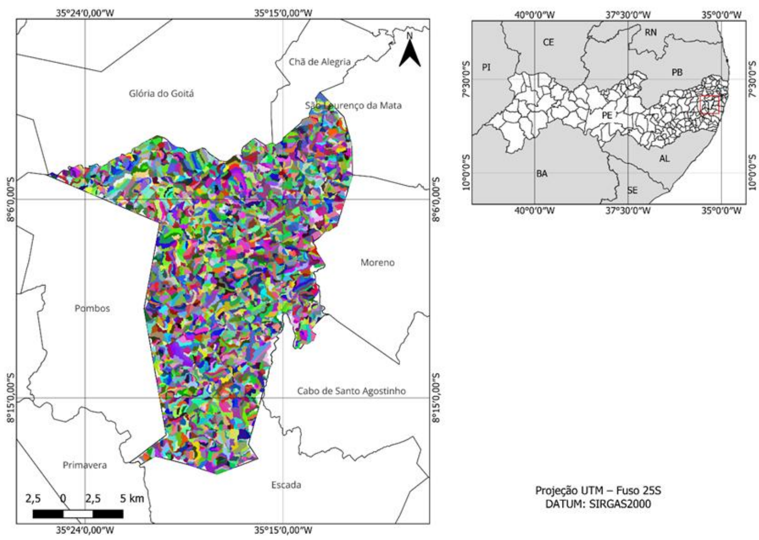
Data processing within the GRASS GIS environment—integrated with QGIS—enabled the generation of Drainage Direction (Figure 5), Micro-basin (Figure 6), and Flow Segment (Figure 7) layers. These products form the technical basis for delineating the hydrographic sub-basins located within the municipality's urban area. This information allowed for a more precise identification of areas most prone to flooding, providing a foundation for hydrological analysis and guiding sustainable planning and impact mitigation efforts.

Figure 5 – Drainage direction of the municipality of Vitória de Santo Antão, PE.



Source: Authors (2026).

Figure 6 – Micro-watersheds of the municipality of Vitória de Santo Antão, PE.



Source: Authors (2026).

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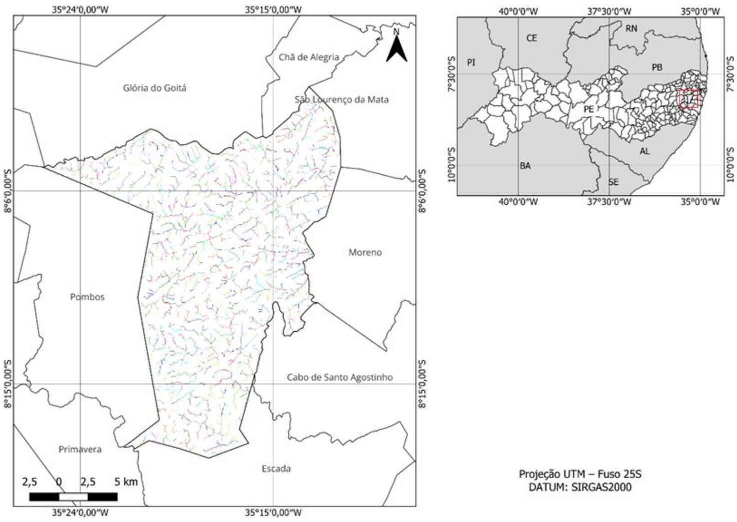
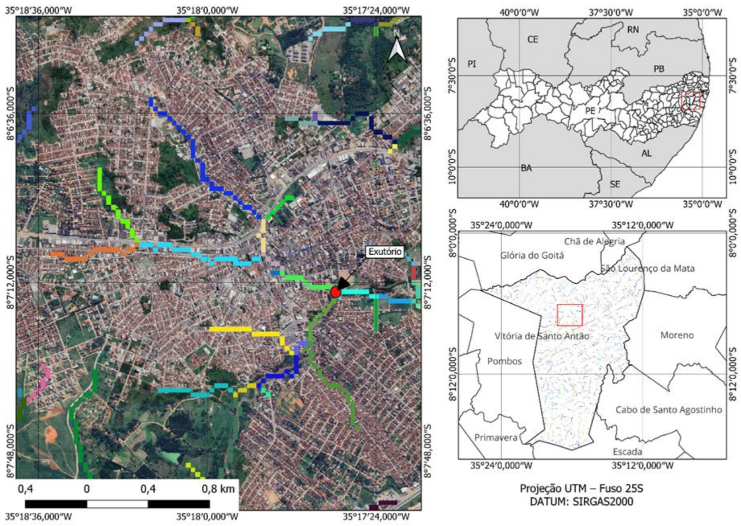
Figure 7 – Flow segments of the municipality of Vitória de Santo Antão, PE.



Source: Authors (2026).

After identifying the urban footprint from the land use and land cover map, the outlet point of the urban sub-basin was defined. The outlet was established at the confluence of the drainage channel and the main channel of the Tapacurá River, representing the natural exit point for the sub-basin's surface runoff. This point, indicated graphically by a red marker (Figure 8), was adopted as the reference for the automated delineation of the associated drainage area using spatial analysis tools within a Geographic Information System (GIS) environment.

Figure 8 – Location of the urban sub-basin outlet in Vitória de Santo Antão, PE.



Source: Authors (2026).

The processing resulted in the generation of a raster corresponding to the hydrological contributing area associated with the defined outlet, which was subsequently converted to vector format. This procedure enabled the creation of a polygon that more accurately represents the boundaries of the drainage sub-basin, highlighted in blue in Figure 9.

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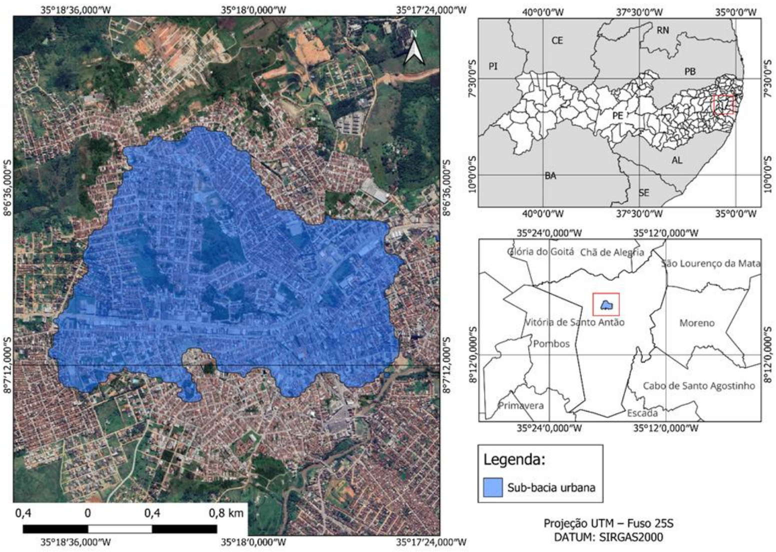
Figure 9 – Delineation of an urban sub-basin in Vitória de Santo Antão, PE.

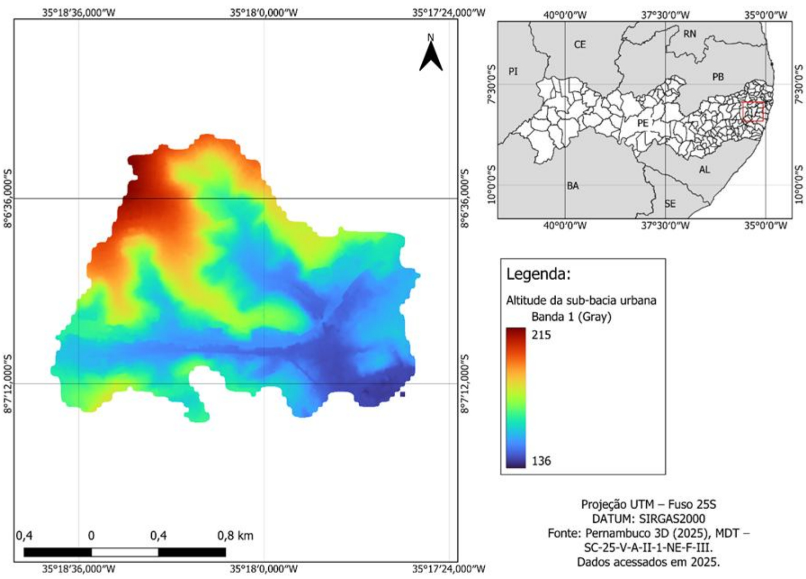


Source: Authors (2026).

4.3 Hypsometric delimitation of the urban sub-basin

Using the Digital Terrain Model (DTM) from the PE3D project, the hypsometric layer corresponding to the boundary of the previously delineated urban sub-basin was extracted (Figure 10). This subsetting enabled a detailed analysis of elevation variations within the area of interest in a GIS environment, supporting the multi-criteria integration phase for the creation of the flood susceptibility map.

Figure 10 – Hypsometry of an urban sub-basin in Vitória de Santo Antão, Pernambuco.



Source: Authors (2026).

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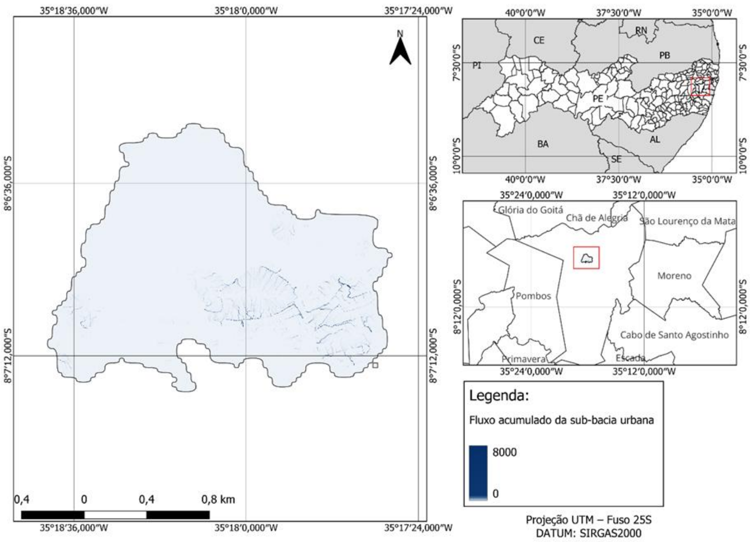
4.4 Accumulated flow of the urban sub-basin

Analysis of the accumulated flow map for the urban sub-basin reveals the surface drainage structure and areas with the highest runoff concentration. The highest accumulated flow values—represented by darker shades of blue—are concentrated primarily near Mariana Amália Avenue, indicating a convergence of large volumes of surface water in this sector. Intense accumulated flows are also observed in the vicinity of Henrique de Holanda Avenue, reinforcing the influence of major road corridors on surface runoff routing. This pattern is linked to both topographic characteristics and the high degree of urban soil impermeabilization (Zheng et al., 2025). In the remaining areas of the sub-basin, lower accumulated flow values predominate, corresponding to sectors with less direct hydrological contribution. These results highlight critical urban drainage areas and support the identification of zones with a higher potential for flooding.

Figure 11 – Accumulated flow of an urban sub-basin in Vitória de Santo Antão, PE.



Source: Authors (2026).

4.5 Urban sub-basin slope

The slope map of the urban sub-basin (Figure 12), derived from the PE3D Digital Terrain Model (DTM), reveals a predominantly gently to moderately undulating terrain, with slope values expressed as percentages ranging from 1% to 100%. It is observed that the gentlest slopes are concentrated in lower-lying areas near drainage channels, whereas the steepest slopes occur in isolated spots associated with hillsides and the sub-basin's higher elevations. This topographic configuration tends to reduce surface runoff velocity in areas with gentler slopes, contributing to water accumulation and, consequently, increasing susceptibility to flooding. Following reclassification based on the criteria in Table 1, the slope data were integrated into the final flood risk susceptibility map, highlighting the slope's influence on the spatial distribution of the most vulnerable areas within the urban sub-basin.

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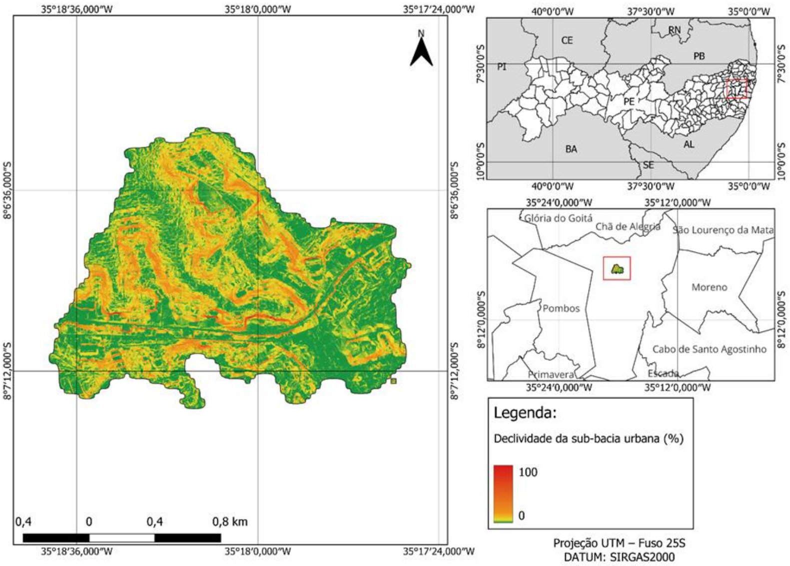
Figure 12 – Slope of an urban sub-basin in Vitória de Santo Antão, PE.



Source: Authors (2026).

4.6 Land use and land cover map of the urban sub-basin

The land use and land cover map of the urban sub-basin (Figure 13) highlights the significant predominance of urban areas—which occupy the majority of the analyzed territory—reflecting a high degree of surface impermeability. This condition promotes increased surface runoff and reduces soil water infiltration, acting as a key factor in intensifying flooding processes. Areas classified as vegetation appear fragmented and discontinuous, concentrated mainly in the sub-basin's interior sectors, whereas open areas occur sporadically and to a lesser extent.

Following the application of the criteria defined in Table 1, the land use and land cover layer was incorporated into the integrated analysis used to generate the flood susceptibility map, playing a significant role in identifying and mapping areas of high hydrological vulnerability within the sub-basin.

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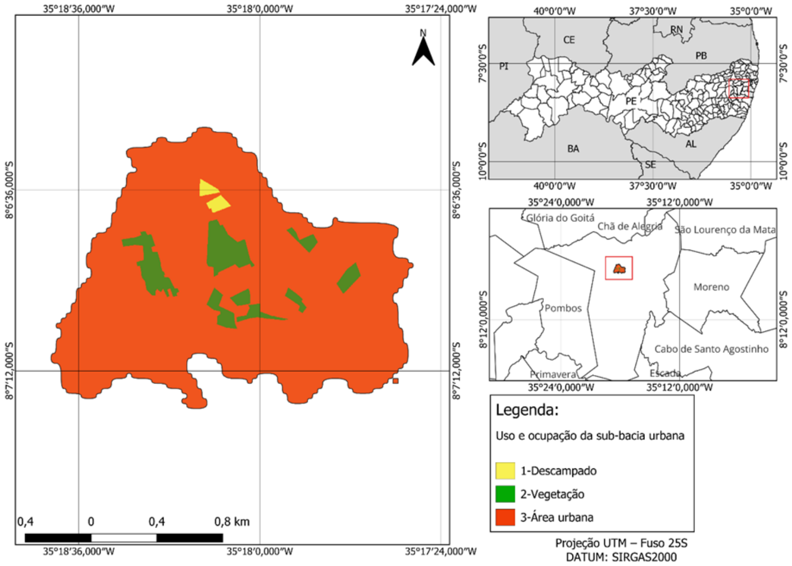
Figure 13 – Land use and occupation of an urban sub-basin in Vitória de Santo Antão, Pernambuco.

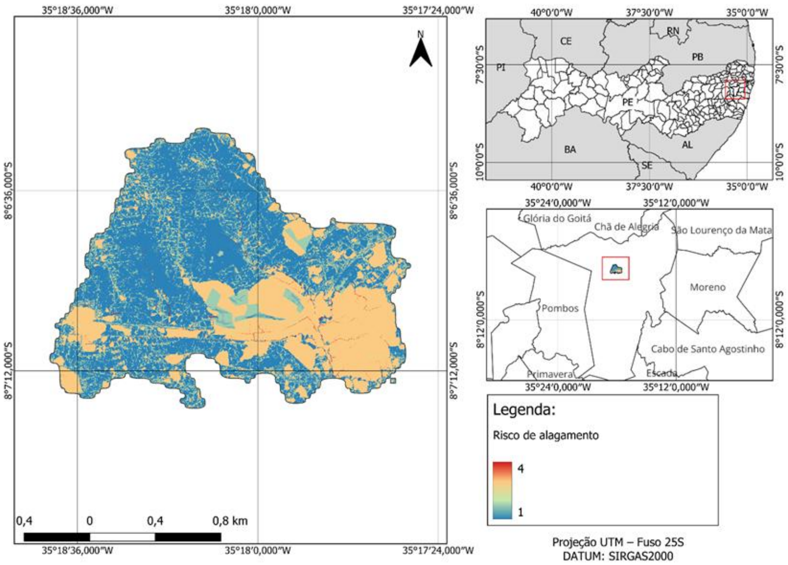


Source: Authors (2026).

4.7 Multi-criteria integration and generation of the flood risk map

The flood susceptibility map, derived from integrating the criteria presented in Table 1, illustrates the spatial distribution of varying risk levels within the urban sub-basin located in the municipality of Vitória de Santo Antão, Pernambuco. A predominance of areas classified as low to medium risk—represented by classes 1 and 2—is observed, concentrated primarily in sections with steeper slopes and minimal human alteration. Conversely, areas of higher susceptibility (classes 3 and 4) are associated with flatter, intensely urbanized zones near drainage channels, reflecting the combined influence of land use and cover, topography, and surface runoff accumulation. These results confirm the effectiveness of the multicriteria approach employed, enabling the identification of priority areas for urban planning, drainage management, and flood mitigation, thereby constituting the study's primary output and contribution.

Figure 14 – Flooding susceptibility map of an urban sub-basin in Vitória de Santo Antão, PE.



Source: Authors (2026).

The results obtained in this study align with evidence previously reported in the literature. Miranda et al. (2017) note that the area has a history of recurring flooding, primarily associated with urban drainage system failures and a high degree of soil impermeabilization. Similarly, Chaves (2023) identified this same region as a major flooding hotspot within the municipality—particularly during heavy rainfall—due to limited surface runoff capacity and the presence of low-lying areas that facilitate water accumulation.

When compared with the risk map developed in this study, these earlier works reinforce the robustness of the findings, indicating that the area is highly susceptible to flooding. This condition is fully consistent with patterns identified in previous investigations, confirming the recurring and persistent nature of hydrological vulnerability in this urban sector.

5. CONCLUSIONS

The results obtained in this study enabled the identification and spatial mapping of areas most susceptible to flooding within an urban sub-basin in the municipality of Vitória de Santo Antão (PE), demonstrating the effectiveness of an approach based on geoprocessing and multicriteria analysis within a Geographic Information System (GIS) environment. Integrating criteria such as accumulated flow, slope, and land use and cover allowed for the creation of a synthesis map that consistently represents the spatial variability of hydrological risk, highlighting urban sectors most vulnerable to surface water accumulation.

Analysis of the results revealed that areas classified as having the highest susceptibility are concentrated primarily in urbanized sections characterized by high soil impermeability, low slopes, and greater surface flow convergence—notably in regions near Mariana Amália and Henrique de Holanda avenues. These findings align strongly with historical records and previous studies conducted in the municipality, reinforcing the reliability of the method used and confirming the recurrence of flooding in areas already identified as critical in technical literature.

Thus, the generated susceptibility map serves as a valuable tool for urban planning and risk management, capable of informing public policies aimed at improving drainage infrastructure and mitigating impacts associated with extreme rainfall events. Furthermore, the adopted methodology is replicable in other urban areas with similar characteristics, contributing to the strengthening of preventive strategies and the promotion of urban development that is more resilient to hydrological risks.

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STATEMENTS

Author Contributions

When describing each author's contribution to the manuscript, use the following criteria:

- **Study Conception and Design**: Diego Deyvison dos Santos
- **Data Curation**: Autores
- **Formal Analysis**: Diego Deyvison dos Santos
- **Securing Financing**: Autores
- **Investigation**: Diego Deyvison dos Santos
- **Methodology**: Diego Deyvison dos Santos
- **Drafting – Initial Draft:** Diego Deyvison dos Santos
- **Drafting – Critical Review:**Erika Alves de Meneses
- **Review and Final Editing:**Erika Alves de Meneses e Edevaldo Miguel Alves
- **Supervision:** Diogo Henrique Fernandes da Paz e Edevaldo Miguel Alves

DECLARATION OF CONFLICTS OF INTEREST

We, Diego Deyvison dos Santos, Diogo Henrique Fernandes da Paz, and Erika Alves de Meneses, declare that the manuscript titled "Mapping Flood Susceptibility in the Urban Area of Vitória de Santo Antão, PE":

Financial Ties: No financial ties that could influence the results or interpretation of the work. No funding institution or entity was involved in the development of this study.

1. **Professional Relationships:** Does not have/has professional relationships that could impact the analysis, interpretation, or presentation of the results. No professional relationships relevant to the content of this manuscript have been established.
2. **Personal Conflicts:** Does not have/has personal conflicts of interest related to the content of the manuscript. No personal conflicts related to the content were identified.