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Flood Risk Assessment: An Analysis Applied to the District of Ernesto Alves, Municipality of Santiago, RS

Lucas Storgatto Martins
Master's student in Architecture, Urbanism and Landscaping
Federal University of Santa Maria, Brazil
arqlucasstorgatto@gmail.com

Andrea Valli Nummer
PhD in Civil-Geotechnic Engineering
Federal University of Santa Maria, Brazil
a.nummer@gmail.com
ORCID iD: https://orcid.org/0000-0001-9271-442X

Romario Trentin
PhD in Geography
Federal University of Santa Maria, Brazil
romario.trentin@gmail.com
ORCID iD: https://orcid.org/0000-0002-0615-2801

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Cadastro do Risco à inundação: uma análise aplicada ao distrito de Ernesto Alves, Município de Santiago, RS

RESUMO

Objetivo - O presente artigo tem como objetivo elaborar o cadastro do risco à inundação no Distrito de Ernesto Alves, localizado no município de Santiago, Rio Grande do Sul, a partir da integração de variáveis físicas, ambientais e sociais, visando subsidiar ações de planejamento urbano e gestão de riscos.

Metodologia - A pesquisa possui abordagem quali-quantitativa, baseada em levantamento de dados primários e secundários, análise de registros históricos de eventos de inundação, trabalhos de campo e aplicação de geotecnologias. Foram elaborados mapas de suscetibilidade, perigo, vulnerabilidade e risco por meio de Sistema de Informações Geográficas (SIG).

Originalidade/relevância - O estudo contribui para o preenchimento de lacunas relacionadas ao mapeamento de risco à inundação em áreas urbanizadas de distritos de cidades pequenas, frequentemente carentes de instrumentos técnicos sistematizados para a gestão de riscos.

Resultados - Os resultados indicaram diferentes classes de risco à inundação, com uma edificação classificada como de risco muito alto, quatro como risco alto, trinta e nove como risco médio e dezenove como risco baixo.

Contribuições teóricas/metodológicas - O artigo reforça a aplicabilidade do conceito integrado de risco à inundação e demonstra a eficiência do uso de SIG como ferramenta metodológica para a espacialização e análise do risco.

Contribuições sociais e ambientais - O cadastro de risco elaborado pode subsidiar políticas públicas de ordenamento territorial, prevenção de desastres e mitigação de impactos socioambientais associados às inundações.

PALAVRAS-CHAVE: Inundações. Cadastro de risco. Vulnerabilidade.

Flood Risk Assessment: An Analysis Applied to the District of Ernesto Alves, Municipality of Santiago, RS

ABSTRACT

Objective – This paper aims to develop a flood risk inventory for the Ernesto Alves District, located in the municipality of Santiago, Rio Grande do Sul, by integrating physical, environmental, and social variables to support urban planning and risk management actions.

Methodology – The research adopts a qualitative-quantitative approach, based on the collection of primary and secondary data, analysis of historical records of flood events, fieldwork, and the application of geotechnologies. Susceptibility, hazard, vulnerability, and risk maps were produced using a Geographic Information System (GIS).

Originality/Relevance – The study helps fill gaps in flood risk mapping in urban districts of small cities, which often lack systematic technical risk management tools.

Results – Briefly outline the main results achieved.

Theoretical/Methodological Contributions – The paper reinforces the applicability of the integrated flood risk concept and demonstrates the efficiency of GIS as a methodological tool for spatializing and analyzing risk.

Social and Environmental Contributions – The risk inventory developed can support public policies related to land-use planning, disaster prevention, and the mitigation of socio-environmental impacts associated with flooding.

KEYWORDS: Urban floods. Risk inventory. Vulnerability.

Evaluación del riesgo de inundaciones: Un análisis aplicado al distrito de Ernesto Alves, municipio de Santiago, RS

RESUMEN

Objetivo - El presente artículo tiene como objetivo elaborar el inventario del riesgo de inundación en el Distrito de Ernesto Alves, ubicado en el municipio de Santiago, Rio Grande do Sul, a partir de la integración de variables físicas, ambientales y sociales, con el fin de apoyar acciones de planificación urbana y gestión de riesgos.

Metodología – La investigación adopta un enfoque cualitativo-cuantitativo, basado en la recopilación de datos primarios y secundarios, el análisis de registros históricos de eventos de inundación, trabajos de campo y la aplicación

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de geotecnologías. Se elaboraron mapas de susceptibilidad, peligro, vulnerabilidad y riesgo mediante un Sistema de Información Geográfica (SIG).

Originalidad/Relevancia – El estudio contribuye a cubrir vacíos relacionados con el mapeo del riesgo de inundación en distritos urbanos de pequeñas ciudades, que con frecuencia carecen de instrumentos técnicos sistematizados para la gestión de riesgos.

Resultados – Los resultados indicaron diferentes clases de riesgo de inundación, con una edificación clasificada como de riesgo muy alto, cuatro como riesgo alto, treinta y nueve como riesgo medio y diecinueve como riesgo bajo.

Contribuciones Teóricas/Metodológicas - El artículo refuerza la aplicabilidad del concepto integrado de riesgo de inundación y demuestra la eficiencia del uso de los SIG como herramienta metodológica para la espacialización y el análisis del riesgo.

Contribuciones Sociales y Ambientales – El inventario de riesgo elaborado puede servir de base para políticas públicas de ordenamiento territorial, prevención de desastres y mitigación de los impactos socioambientales asociados a las inundaciones.

PALABRAS CLAVE: Inundaciones urbanas. Inventario de riesgo. Vulnerabilidad.

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1 INTRODUCTION

Urban flooding is one of the main socio-environmental problems faced by contemporary cities, especially in countries marked by intense urbanization processes associated with socio-spatial inequality. Although floods are natural phenomena linked to the hydrological dynamics of river systems, their occurrence in urbanized areas assumes the character of a disaster due to the exposure of populations, infrastructures and economic activities to extreme events (Veyret, 2005; Alcántara-Ayala, 2002).

In Brazil, urban expansion occurred in a disorderly manner in most cities, dissociated from territorial planning, resulting in the occupation in areas naturally susceptible to flooding, such as alluvial plains and the banks of watercourses. This pattern of urban growth intensifies the impacts of hydrological events, as it promotes soil impermeabilization, the suppression of riparian vegetation, and the alteration of natural runoff regimes (Tucci, 2003; Santos, 2012).

Urbanization directly interferes with the hydrological cycle by reducing infiltration and increasing surface runoff, increasing both the frequency and magnitude of flooding. According to Tucci and Bertoni (2003), the increase in impermeable areas and the rectification of natural channels accelerate the flow of rainwater, reducing the concentration time and increasing flood peaks. These changes, combined with inadequate urban drainage infrastructure, make urban environments particularly vulnerable to flooding.

Global climate change aggravates this scenario by intensifying the occurrence of extreme hydrometeorological events, such as intense rainfall in short periods. International reports indicate that increased climate variability tends to heighten the risks associated with natural disasters, especially in urban areas with high social vulnerability (UN, 2004; UN, 2015). In this context, understanding and managing flood risks is fundamental to promoting urban safety and resilience.

The notion of risk adopted in this study comprises the interaction among natural hazards, the susceptibility of the physical environment, and the social and structural vulnerability of exposed populations. According to Wisner et al. (2003), disasters cannot be understood solely as natural events but as socially constructed processes in which socioeconomic conditions play a central role in defining impacts. Thus, areas occupied by low-income populations tend to be more vulnerable, increasing the damage from floods.

In Brazil's urban context, the occupation of risk areas is often associated with processes of social exclusion and the absence of effective public housing and territorial planning policies (Maricato, 2001; Jacobi, 2004). The permanence of these populations in susceptible areas underscores the need for technical tools to support preventive actions and risk mitigation strategies.

Despite recurrent flooding in small and medium-sized cities, a large share of studies and risk management investments is concentrated in large urban centers. Smaller municipalities, in turn, often lack systematized diagnoses and risk mapping that guide urban planning and civil defense performance (Wollmann, 2014). This gap contributes to the maintenance of inadequate patterns of land occupation and to the increase of socio-environmental vulnerability.

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The Ernesto Alves District, located in the municipality of Santiago, in the state of Rio Grande do Sul, is part of this context. The District's urban area has a recurrent history of flooding associated with the overflow of the Jaguarizinho River, with records of events that resulted in material damage and direct impacts on the local population. The repetition of these episodes highlights the need for studies aimed at identifying susceptible areas and characterizing the risk of flooding to support territorial planning and urban management.

In view of this scenario, this paper aims to present the flood risk register prepared for the District of Ernesto Alves, integrating physical, environmental, and social variables, by using geotechnologies and multicriteria analysis. The risk registry is a fundamental tool for identifying the most vulnerable areas, enabling the adoption of preventive measures, the orientation of land use and occupation, and strengthening disaster risk reduction strategies, in line with the guidelines established by international and national risk management organizations (UN, 2015; PAHO, 2014).

2 THEORETICAL FOUNDATION

Floods are natural phenomena inherent to the dynamics of river systems. They play a fundamental role in maintaining aquatic ecosystems and floodplains. However, when associated with urban occupation, these occurrences represent significant risks to the population and the built infrastructures, assuming the character of a disaster (Tucci, 2003; Amaral and Ribeiro, 2009).

The urbanization process promotes profound changes in natural systems by replacing permeable areas with impermeable surfaces, such as pavements and buildings. This transformation reduces the infiltration capacity of the soil and increases the volume and velocity of surface runoff, increasing the frequency and intensity of urban flooding (Tucci, 2005). In addition, interventions such as channeling and rectification of watercourses alter the river dynamics, reducing the capacity to dampen floods.

According to Kobiyama et al. (2006), the combination of disorderly urban growth, deficient drainage infrastructure, and occupation of riverside areas is one of the main factors responsible for the intensification of flooding events in urban areas. Goerl and Kobiyama (2013) point out that these processes are aggravated by the absence of integrated planning, especially in small municipalities.

The occupation of floodplains is often associated with processes of socio-spatial segregation; lower-income populations end up residing in areas more susceptible to extreme hydrological events. This relationship highlights the socio-environmental character of urban flooding, reinforcing the need for approaches that integrate physical and social aspects in the analysis of the phenomenon (Santos, 2012).

The analysis of flood risk is based on the integrated understanding of different concepts, widely discussed in the literature on natural disasters. The concept of susceptibility refers to the natural characteristics of the physical environment that favor the occurrence of a certain phenomenon, such as topography, slope, proximity to watercourses, and geomorphological characteristics (Thouret and D'Ercole, 1996).

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hazard is related to the probability of an adverse event occurring in a given location, considering its frequency and intensity. On the other hand, vulnerability is the degree of susceptibility of populations, buildings, and infrastructures to the impacts of the event, incorporating socioeconomic, constructive, and institutional aspects (Castro, 1998; Cutter, 2011).

Risk results from the interaction between hazard, susceptibility, and vulnerability, as presented in Figure 1. It is understood as the possibility of damage associated with adverse events (Wisner et al., 2003). This integrated approach allows for a more comprehensive analysis of disasters, recognizing that the impacts do not result exclusively from the magnitude of the natural event, but from preexisting social and territorial conditions (Busso, 2001; Ribeiro, 1995).

The delimitation of risk areas is crucial to detecting environmental vulnerabilities, serving as a guide for urban planning. This approach enables the adoption of strategies that minimize losses and prevent accidents, ensuring safer infrastructures and greater resilience for the population (Macêdo et al., 2019).

Figure 1 – Definition of the risk

Source: Adapted from Lenhard, 2022.

Socio-environmental vulnerability is one of the main factors that explain the different impacts of floods on urban populations. According to Aquino et al. (2017), vulnerability results from the combination of social, economic, and environmental weaknesses, and is intensified in contexts marked by housing precariousness and the absence of effective public policies.

Studies indicate that risk management should prioritize preventive and integrated actions, involving urban planning, environmental education, and institutional strengthening (Ayala-Carcedo, 2000; Bertone and Marinho, 2013). Thus, the flood risk registry is a strategic tool for identifying the most vulnerable areas and for guiding public policies aimed at disaster reduction.

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3 METHODOLOGY

The research is characterized as a study of applied nature, with a qualitative and quantitative approach, aimed at analyzing the risk of flooding in urban areas. From the point of view of the objectives, this is an exploratory and descriptive research, since it seeks to understand the dynamics of floods in the District of Ernesto Alves and to spatially describe the susceptible and vulnerable areas, supporting territorial planning and management actions (Marconi e Lakatos, 2010).

The methodological procedure adopted integrates physical, environmental, and social data in a Geographic Information System (GIS) environment. This approach is widely used in risk analysis studies, as it allows the spatialization of distinct variables and the integrated evaluation of factors that influence the occurrence and impacts of adverse events (Monteiro and Kobiyama, 2013; Marcelino, 2008).

3.1 Field of study

The study was developed in the Ernesto Alves District, located in the municipality of Santiago, the central-west region of the state of Rio Grande do Sul. The urban area of the District is located in the hydrographic basin of the Jaguarizinho River (Figure 2), a tributary of the Jaguari River, with a recurrent history of flooding associated with events of intense precipitation and the overflow of the main watercourse. In terms of population, the District has 1,211 inhabitants, of whom approximately 50 live in the village of Ernesto Alves.

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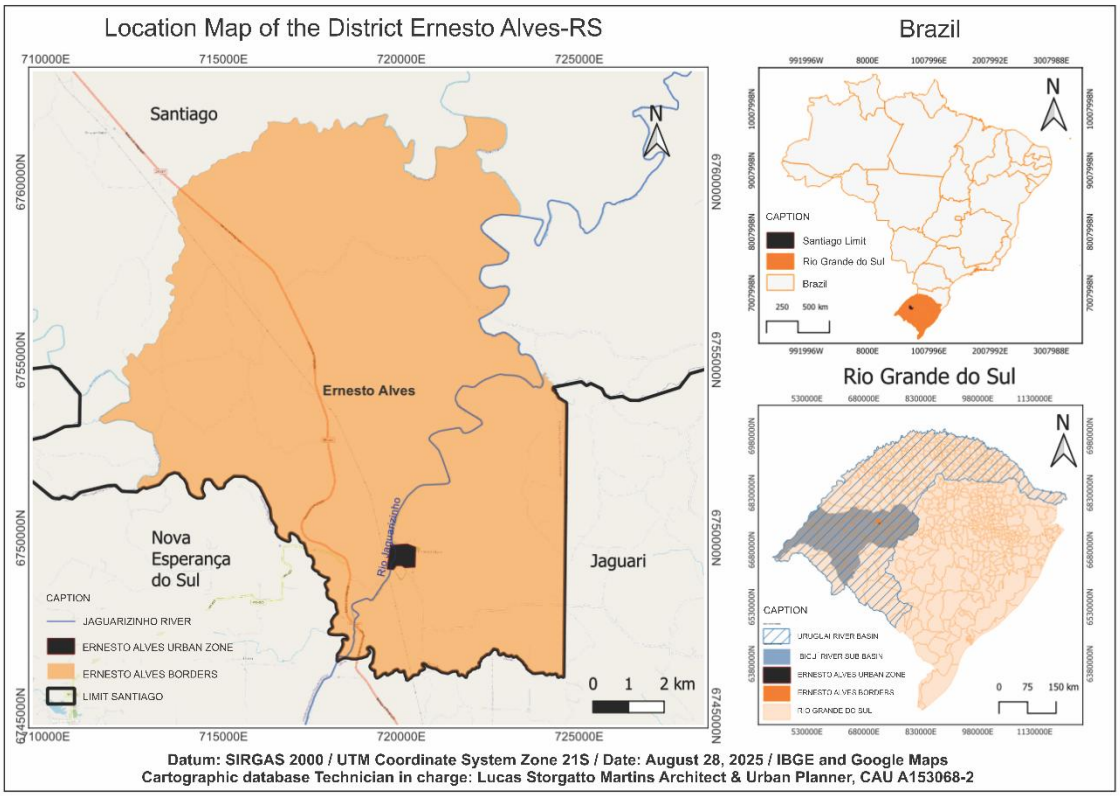
Figure 2 - Location of Ernesto Alves in the Jaguarizinho River Basin



Source: Authors, 2025.

3.2 Methodological procedures

The methodological procedures were structured in successive stages, as proposed by studies aimed at the analysis and registration of natural risks in urban areas (Robaina et al., 2010; Sebben et al., 2010). The stages included: data collection and organization, definition of analysis criteria, preparation of thematic maps, integration of variables, and classification of flood risk.

Initially, a survey of secondary data, including cartographic, hydrological, and socio-environmental information, obtained from official agencies and institutional databases, was carried out. These data were organized and processed in a GIS environment, enabling the standardization of scales and spatial reference systems.

Then, the criteria used in the analysis of susceptibility and vulnerability to flooding were defined. The selection of variables considered both the characteristics of the physical environment and the socioeconomic and constructive aspects, according to the recommendations of the specialized literature (Marcelino, 2008; Monteiro and Kobiyama, 2013).

3.3 Flood susceptibility analysis

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In order to characterize the study areas in detail and to assess the flood risk, the methodology employed a sequence of procedures that involve the aerial photogrammetric survey by Unmanned Aerial Vehicle (UAV), the elaboration of the Digital Terrain Model (DTM), and the calculation of the Return Period (RP) of the hydrological events.

The aerial photogrammetric survey was conducted using a DJI Mavic Air 2 UAV model, equipped with a GPS receiver, ensuring the capture of high-precision georeferenced data. The flight planning was carried out using the Dronelink software, where the height of 150 meters, the longitudinal and lateral overlap of 85%, the flight itinerary, and the estimated time of 60 minutes were parameterized. This setting made it possible to acquire approximately 400 images, essential for the accurate three-dimensional reconstruction of the terrain. The survey also included the use of demarcated control points in the area and was tracked with a dual-frequency GNSS receiver of the RUIDE R90 brand, with the data post-processed in the Brazilian Continuous Monitoring Network (IBGE, 2024).

From the images collected, the Digital Terrain Model (DTM) was elaborated. This process involved digital photogrammetry operations using Agisoft PhotoScan software, which enables the reconstruction of high-resolution three-dimensional models. Initially, a point cloud with planialtimetric coordinates was generated, which was later interpolated to create the Digital Surface Model (DSM) and, finally, the DTM, providing an accurate topographic basis for subsequent analyses.

In addition, the Return Period (RP) was calculated, a crucial statistical tool to estimate the frequency of extreme hydrological events. To this end, linimetric data from the Jaguarizinho River, available on the Hidroweb platform of the National Water and Basic Sanitation Agency (ANA), covering the period from 1958 to 2024 (67 years), together with the maximum monthly rainfall values recorded in the same time interval, were used. The methodology was based on the study by Menegon (2018), which applies Gumbel's distribution law. The results made it possible to prepare the susceptibility map and to classify the degrees of hazard (High, Medium, and Low) associated with different RTs and elevations, providing fundamental subsidies for delimitating areas susceptible to flooding.

3.4 Vulnerability analysis

The vulnerability analysis considered social, economic, and structural aspects of the district's urban areas, recognizing that the impacts of floods do not depend solely on the physical characteristics of the environment but also on the conditions of the exposed populations (Wisner et al., 2003; Cutter, 2011).

Feitosa and Monteiro (2012) propose an advanced, multidimensional conception of vulnerability, viewing it not as a static condition but as a dynamic process. This perspective results from the interaction among socioeconomic, environmental, and political variables, which continuously manifest and transform. Vulnerability, therefore, requires an analysis that contemplates its various interconnected facets, influenced by income disparities, access to education, ecosystem degradation, and deficiencies in governance and planning. This expanded understanding not only engages with diverse fields of knowledge but also fosters the

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development of innovative methodologies, such as simulation models and spatial analysis in Geographic Information Systems (GIS).

Among the vulnerability variables analyzed, the construction standard of the buildings, the number of floors, the finishing material, and the surrounding conditions stand out. This information was obtained through secondary data and field observations, making it possible to identify areas with greater fragility to flood events. Table 1 shows the assessment of vulnerability risks.

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Table 1 - Variables selected for the vulnerability assessment

Variable	Rationale
Building use	The function attributed to construction interferes with the dynamics of occupation and with the permanence of individuals. Leisure use may imply the absence of residents at critical moments; mixed and commercial use generate variable flows of people; residential use implies greater continuous exposure to risk.
Typology of residents	The predominant age group interferes with autonomy and the ability to respond in emergencies. Children and the elderly have less autonomy, which makes evacuation difficult and increases social vulnerability.
Number of floors	The height of the building can serve as an alternative form of protection in cases of flooding. Buildings with more floors offer vertical shelter, reducing direct exposure to water. Single-story residences are more exposed.
Finishing material	The type of material determines the building's resistance to water. Masonry has greater resistance to moisture and water flow. Wood and mixed structures, especially those that are poorly maintained, are more susceptible to damage.
Condition of the building	The state of conservation reflects the structural stability and the property's protection capacity. Properties in good condition offer greater protection. Precarious workers are at increased risk of collapse and exacerbate the effects of flooding.
Conditions of the Surroundings	It refers to the state of conservation and cleanliness of the space around the residence and the public road, especially considering the presence or absence of garbage, debris, or materials that may obstruct drainage and aggravate the risk of flooding.

Source: Adapted from Pessoto, 2020

Each variable analyzed was assigned a score reflecting its relevance to the assessment of social vulnerability, taking into account the specific characteristics of the population. This means that the most significant variables for the local situation received higher scores and weights, allowing a more accurate analysis of social vulnerability in the region studied. It should be noted that the weights are attributed based on local characteristics and theoretical references, so these variables may not represent other locations. Table 2 presents the weights and grades assigned to the variables analyzed in the field.

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Table 2 - Weights and grades for mapping social vulnerability

Variable	Classification	Note
Use of the Building	Residential	2
	Mixed	1
	Leisure	0
Typology of Residents	Children	2
	Elderly	1
	Adults	0
Number of floors	Ground floor	2
	Two	1
	>2	0
Finishing material	Mixed Wood	2
	Masonry	1
		0
Conservation Status	Bad	2
	Average	1
	Good	0
Conditions of the Surroundings	Very dirty	2
	Dirty	1
	Clean	0

Source: Adapted from Pessoto, 2020.

After data collection, all collected information was entered into the QGIS application, where the Vulnerability Index was calculated by combining variables using assigned grades and weights (Table 3). Based on this index, each building was classified according to three vulnerability categories.

Table 3 - Degrees of vulnerability according to notes

Weight of Vulnerability	Vulnerability Category
0 to 2	High Vulnerability
3 to 5	Medium Vulnerability
6 to 9	Low Vulnerability

Source: Author, 2025.

The flood risk map was prepared by integrating the hazard and vulnerability maps, with four risk categories: low, medium, high, and very high (Table 4).

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Table 4 – Obtaining the degrees of risk considering the hazard and vulnerability

	Low Vulnerability	Medium Vulnerability	High Vulnerability
Low hazard	R-1	R-1	R-2
Medium hazard	R-2	R-2	R-3
High hazard	R-3	R-3	R-4

Source: Author, 2025.

There are specific characteristics for each risk category that differentiate it from the others. These characteristics may include the intensity of the hazard, the level of social vulnerability, and the interaction between these elements, as Table 1 shows.

Table 1 - Characteristics of the risk category

RISK CATEGORY	DEFINITION
R-4 – Very High Risk	Defined for situations in which the houses present High Vulnerability and are subject to High hazard.
R-3 – High Risk	Medium hazard and High Vulnerability housing are defined as this risk level. High Risk is also defined for homes with High hazard in situations of Low and Medium Vulnerability.
R-2 – Medium Risk	Defined for homes with Low hazard, where flooding processes cause damage to streets, but the Vulnerability is High. Medium Risk is also defined for homes with Medium hazard, where flooding processes cause relatively more significant damage, affecting streets and houses. In this condition, the Vulnerability is Low or Medium.
R-1 – Low Risk	Defined as houses in Low hazard, flooding situations in which the street is affected without damage to the houses. Vulnerability set to Low and in some cases, may be Medium.

Source: Author, 2024.

The map obtained was configured in a flood risk register, which gathers spatial and descriptive information for each building in the analyzed area. This document is a tool to support urban planning and risk management, supporting preventive actions, guiding the use and occupation of the land, and the performance of public agencies, such as civil defense, in dealing with flood events (IPT, 2007; PAHO, 2014).

4 RESULTS AND DISCUSSION

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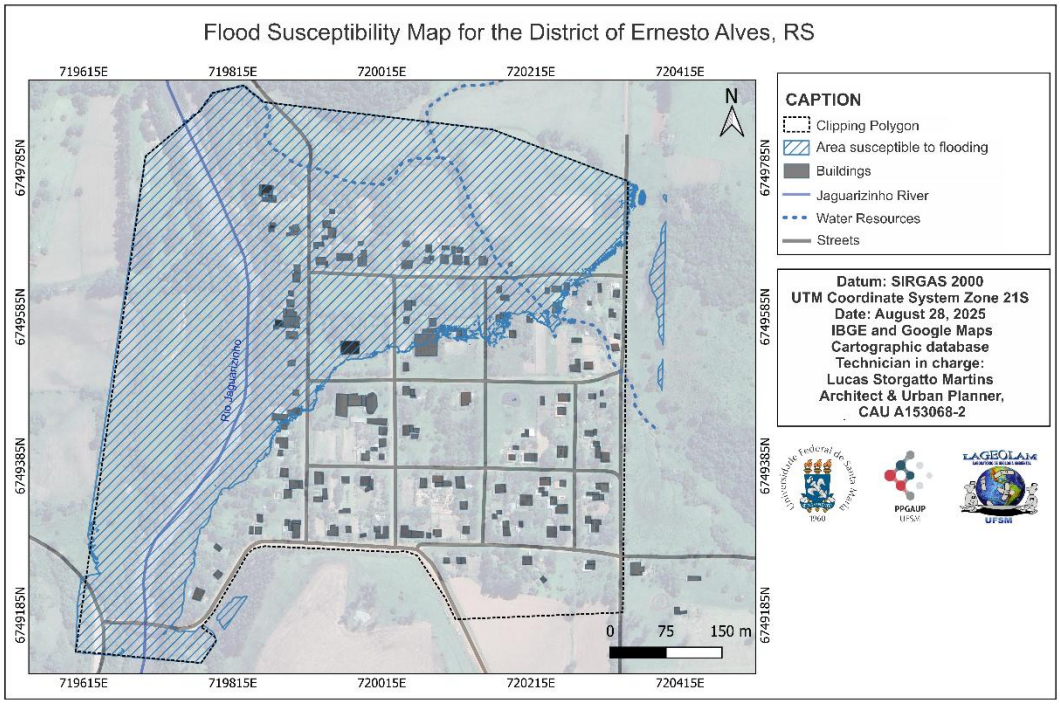
4.1 Flood susceptibility analysis

The results of the flood susceptibility analysis (Figure 3) show a concentration of the most susceptible areas in the lower portions of the Ernesto Alves District, especially in the main course of the Jaguarizinho River. This spatial setting confirms the strong influence of geomorphological and altimetric characteristics on the dynamics of urban flooding, as pointed out by Souza Robaina et al. (2010) and Fujimoto, Dias, and Bombardelli (2010).

The areas classified as highly susceptible correspond predominantly to flat-relief sectors with low elevations and reduced natural drainage capacity. This pattern favors the accumulation of water during intense precipitation events, increasing the probability of overflows and prolonged flooding, as discussed by Tucci (2003; 2005).

Figure 3 – Map of susceptibility to flooding in Ernesto Alves



Source: Author, 2025.

The urban perimeter of Ernesto Alves, delimited via drone-based aerial photogrammetric survey for this study, totals 462,333.04 m². Of this extension, 248,489.52 m² are classified as areas with flooding susceptibility, representing 53.75% of the urban area analyzed. In these areas, 63 buildings are predominantly intended for residential and leisure use. Although the Jaguarizinho River is the primary vector of flood events, the tributary watercourses are recognized as a factor that contributes to enhancing the volume of water directed to the main river through intensified surface runoff, aggravating the risk of flooding in the region.

4.2 Hazard Assessment

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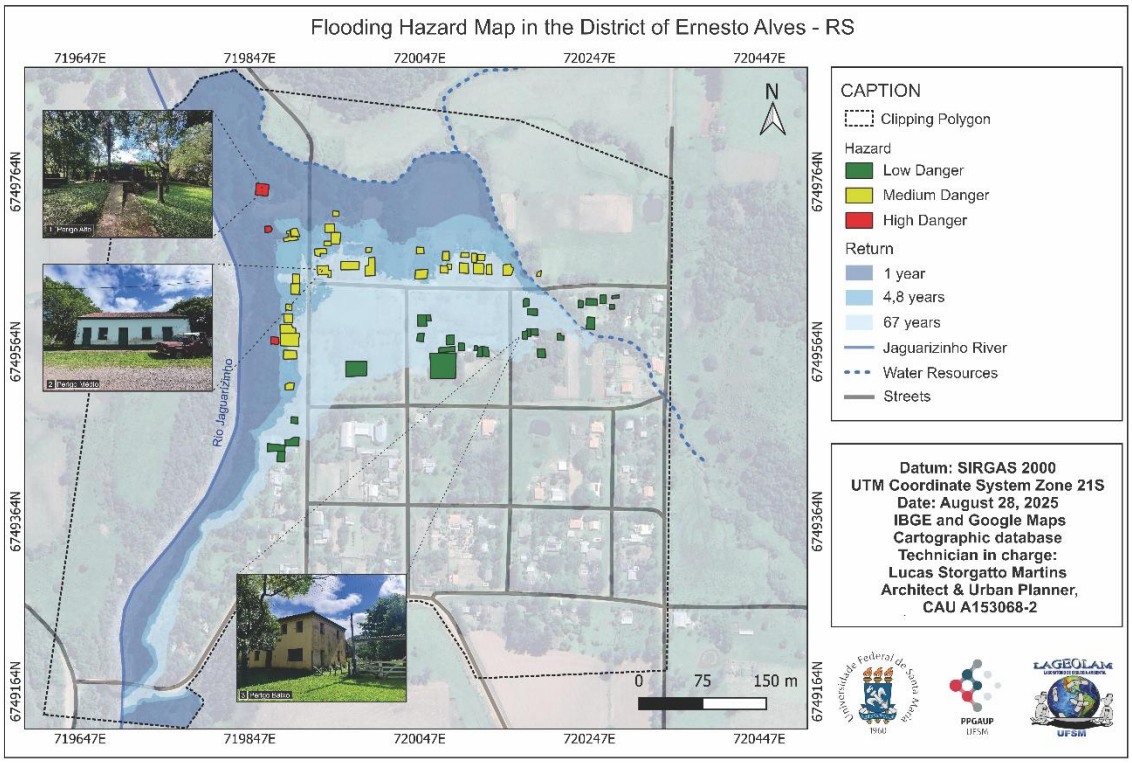
Based on analyses of return period and the spatial distribution of buildings, three hazard classes were delimited for the District of Ernesto Alves (Figure 4). The Low Hazard category, at elevations between 131-134 m, covers residences located in more remote areas, exposed only to extreme events or not yet recorded. The Medium Hazard, with elevations between 129 and 131 m, corresponds to the houses affected by more recent flooding episodes, such as those in 2015 and 2024. Finally, the High Hazard class, with elevations between 119 and 129 m, corresponds to buildings located at critical points that suffer recurrent flooding and, consequently, accumulate significant losses over time.

Figure 4 – Hazard map



Source: Author, 2025.

The areas classified as Low hazard concentrate 28 residences (44.44%), where, despite the absence of overflows in certain stretches, factors such as unfavorable relief and deficiency in the drainage system contribute to occasional flooding and erosive processes. The Medium hazard covers 32 residences (50.79%), mainly on Guilherme Muller and Rosário streets, areas already affected by previous flooding events, indicating a high level of population exposure. High hazard corresponds to 3 buildings (4.77%) located near the Jaguarizinho River, characterizing critical areas with recurrent structural damage and impacts on daily dynamics, requiring priority interventions.

4.3 Vulnerability analysis

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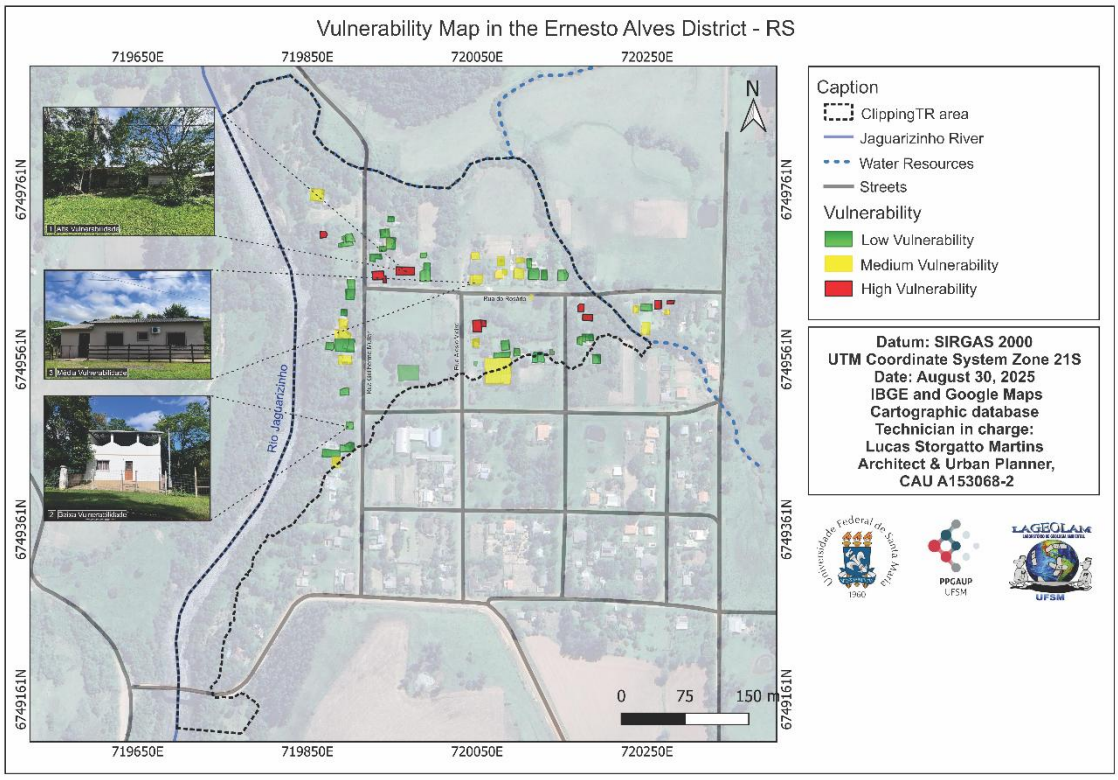
The highest flood hazard areas largely coincide with urban sectors characterized by greater social and constructive fragility. Most buildings located in these areas have simple construction patterns, less access to urban infrastructure, and higher occupancy density, factors that amplify the potential impacts of flood events (Figure 5).

Figure 5 – Vulnerability map



Source: Author, 2025.

High Vulnerability comprises 9 households (14.28%), located mainly on Guilherme Muller and Rosário streets, and are characterized by precarious infrastructure, which exacerbates flood damage. The Medium Vulnerability class encompasses 18 households (28.57%) distributed across Guilherme Muller, Rosário, and Alesio Vieiro streets, which present better construction and urban infrastructure standards, conferring them greater resilience capacity. Low Vulnerability corresponds to 36 households (57.14%), comprising dwellings with higher construction standards and better infrastructure indicators, located in less exposed areas, factors that significantly reduce the damage associated with flood events.

Studies conducted in other municipalities in Rio Grande do Sul point to similar patterns, in which urban riverside areas concentrate socially vulnerable populations, thereby amplifying the adverse effects of floods (Righi and Robaina, 2012; Saueressig and Robaina, 2015). Thus, the results obtained reinforce the importance of integrating social indicators into risk analyses, overcoming exclusively physical approaches.

4.4 Integration and risk registration

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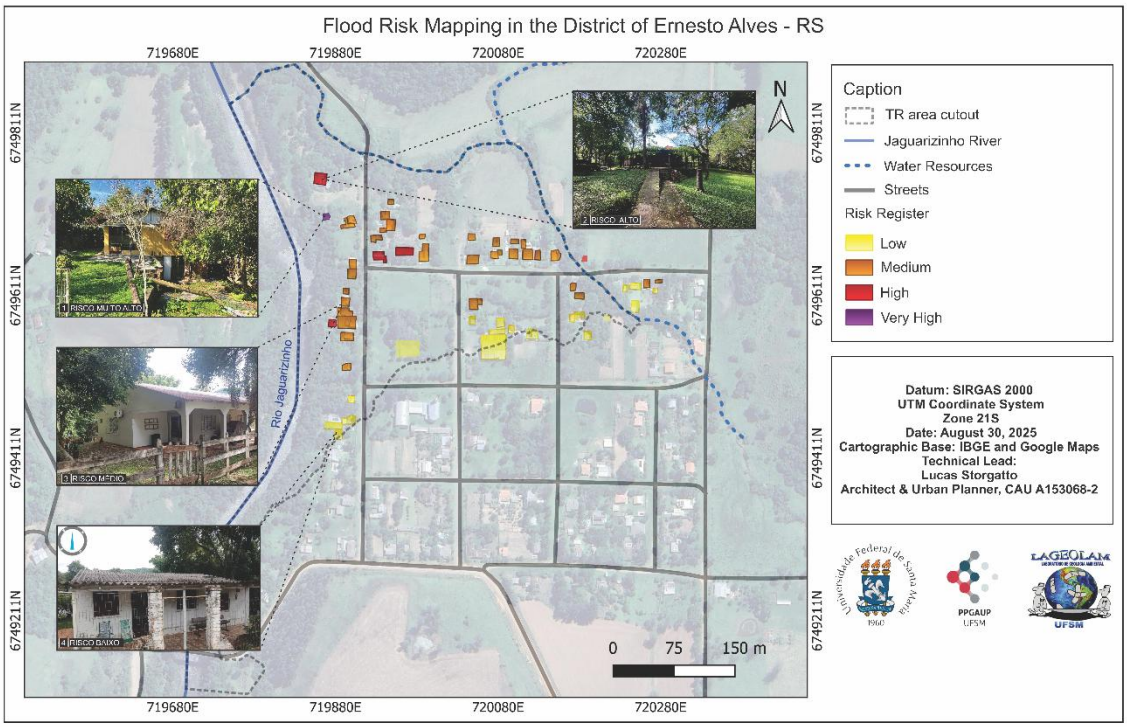
The integration of the Hazard and Vulnerability maps made it possible to identify the areas of greatest flooding risk in the District of Ernesto Alves. It allowed households to be classified into four levels — low, medium, high, and very high — based on the buildings' physical characteristics, exposure to hydrological events, and conditions of urban infrastructure, such as the presence or absence of drainage, sanitation, and paving.

The households classified as high risk are mainly concentrated along the banks of the Jaguarizinho River and in urbanized sectors in low-altitude areas, where human occupation is consolidated (Figure 6).

Figure 6 – Map of Flood Risk Registration in Ernesto Alves



Source: Author, 2025.

The survey identified different levels of flood risk among the households analyzed, with a predominance of Medium Risk, which covers 61.90% of the residences, located in areas already affected by previous events and with moderate to high vulnerability. The areas classified as Low Risk account for 30.16% of households, located in sectors farther from the river and less susceptible to flooding, although they can still be affected in extreme events.

The High and Very High Risk levels represent 6.35% and 1.59% of the residences, respectively, and include the most critical situations, especially in the vicinity of the Jaguarizinho River, where the frequency of flooding is higher, the infrastructure is precarious, and the constructional fragility is greater. The case classified as Very High Risk stands out: a single residence in an area of recurrent flooding that has sustained significant damage to the building's structure and the surrounding infrastructure.

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The house has a mixed construction typology, with a lower floor in uncoated basalt stone masonry and an upper floor in wood, distributed over two floors, frequently affected by floods. The proximity to the river reduces response time to rising water levels, increasing exposure to impacts. Thus, the combination of geographic location and construction typology is a determinant of the building's high vulnerability, showing that more resistant materials are not enough to mitigate damage in areas of high exposure to flooding.

5 CONCLUSION

The analysis of flooding susceptibility showed that the most critical areas are associated with flat relief, low elevations, and proximity to the Jaguarizinho River, conditions that favor water accumulation during intense precipitation events. These findings confirm the relevance of geomorphological and hydrological constraints in the occurrence of urban flooding, as widely discussed in the specialized literature (Tucci, 2003; Kobiyama et al., 2006; Souza Robaina et al., 2010).

By integrating the dimensions of hazard and Vulnerability, it was possible to show that the highest levels of risk are concentrated in areas where physical susceptibility coincides with social and constructive weaknesses. This result reinforces the understanding of risk as a socially produced phenomenon, resulting from the interaction between natural hazard and social vulnerability, as defended by Wisner et al. (2003), Cutter (2011), and Veyret (2005). Thus, even in a small district, recurrent patterns are observed in Brazilian cities, in which more vulnerable populations tend to occupy more environmentally fragile areas.

From a methodological perspective, the study demonstrated the effectiveness of integrating geoprocessing techniques for flood risk mapping at the urban scale. The approach adopted proved compatible with methodologies used in other municipalities in Rio Grande do Sul, enabling regional comparisons and replicability of the method in similar contexts (Eckhardt, 2008; Freitas, 2017; Knierin, 2022). Thus, the study contributes to advancing applied studies on risk management in small and medium-sized cities, which are often less considered in academic research.

In the field of urban planning and public management, the registration of risk areas can guide land use and occupation policies, support the performance of civil defense, and contribute to the preparation of contingency plans and preventive actions, as recommended by national and international disaster reduction guidelines (Brasil/IPT, 2007; PAHO, 2014; UN, 2015).

Finally, the research has limitations related to the availability and level of detail of the data used, especially regarding social variables and historical hydrological series. As future referrals, it is recommended to incorporate more detailed hydrological and hydraulic modeling, to analyze climate change scenarios, and to strengthen participatory approaches that involve the local population in the risk management process. Such advances can improve prevention strategies and help build safer, more resilient cities in the face of natural disasters.

The results obtained show that the risk of flooding in the District of Ernesto Alves does not arise exclusively from the natural characteristics of the physical environment, but, above all, from the way in which the urbanization process has historically been established in naturally

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susceptible areas. This scenario aligns with studies conducted in other Brazilian municipalities, such as Assú, where disorderly urban growth led to the consolidation of areas subject to flooding, aggravated by the absence of territorial planning compatible with the environmental reality. In this context, the outdated Master Plan and the lack of specific zoning for risk areas reinforce the need to review urban planning tools, incorporating the mapping of susceptible areas and the elaboration of a Risk Management Plan (Frutuoso et al., 2020). Measures of this nature are essential to guide the occupation of the territory, reduce the population's vulnerability, and minimize the impacts of extreme hydrological events, thereby promoting greater safety for people, property, and the environment.

REFERENCES

AMARAL, R. d.; RIBEIRO, R. **Inundações e enchentes**: Desastres naturais: Conhecer pra previnir. 1. ed. São Paulo, Brasil: (Org.) Tominaga, Lídia Keiko and Santoro, Jair and Amaral, Rosangela. Instituto Geólogico, 2009.

ALCÁNTARA-AYALA, I. Geomorphology, Natural Hazards, Vulnerability and Prevention of Natural Disasters in Developing Countries. **Geomorphology**, v. 47, p. 107–124, 2002.

AQUINO, A. et al. **Vulnerabilidade ambiental**. Editora Edgard Blücher Ltda., 2017.

BERTONE, P.; MARINHO, C. **Gestão de riscos e resposta a desastres naturais: a visão do planejamento.** VI Congresso de Gestão Pública - CONSAD. Centro de Convenções Ulysses Guimarães, Brasília/DF – 16, 17 e 18 de abril de 2013, p. 24.

BUSSO, G. Vulnerabilidad social: Nociones e implicancias de políticas para latinoamerica e inicios del siglo xxi. In: **Seminario Internacional - Las Diferentes expresiones de la vulnerabilidad sociel en América Latina y el Caribe**. [S.l.: s.n.], 2001.

CASTRO, A. L. C. d. **Glossário da Defesa Civil: Estudos de riscos e medicina dos desastres.** 5. ed. Brasília, Brasil: Ministério da Integração Nacional. Secretaria Nacional de Defesa Civil, 1998. p. 19

ECKHARDT, R. R. **Geração de modelo cartográfico aplicado ao mapeamento das áreas sujeitas às inundações urbanas na cidade de Lajeado/RS**. 116 p. Dissertação (Mestrado em Sensoriamento Remoto) — Universidade Federal do Rio Grande do Sul, Porto Alegre, Brasil, 2008.

FEITOSA, F. da F.; MONTEIRO, A. M. V. Vulnerabilidade e modelos de simulação como estratégias mediadoras: contribuição ao debate das mudanças climáticas e ambientais. **Geografia**, v. 37, n. 2, p. 289–305, Maio/Agosto 2012.

FRUTUOSO, Gilciane Kariny da Costa; GRIGIO, Alfredo Marcelo; NETA BARROS, Terezinha Cabral de Albuquerque. Inundações urbanas: um olhar para o planejamento urbano na revisão do plano diretor de Assú – RN, Brasil. **Revista Nacional de Gerenciamento de Cidades**, [S. l.], v. 8, n. 61, 2020. DOI: 10.17271/2318847286120202431. Available at: https://publicacoes.amigosdanatureza.org.br/index.php/gerenciamento_de_cidades/article/view/2431. Accessed on: 9 Jul. 2026.

FUJIMOTO, N. S. V. M.; DIAS, T. S.; BOMBARDELLI, G. F. **Análise da suscetibilidade à inundação na bacia hidrográfica do Arroio do Salso – Porto Alegre/RS**. XVI Encontro Nacional dos Geógrafos. Realizado de 25 a 31 de julho de 2010. Porto Alegre - RS, 2010.

GOERL, R. F.; KOBIYAMA, M. Redução dos desastres naturais: desafio dos geógrafos Natural disaster reduction: the challenge of geographers. **AMBIÊNCIA**, v. 9, n. 1, p. 145–172, 1 abr. 2013.

ISSN 2318-8472, v. 14, n. 92, 2026

IBGE – INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA. **Rede Brasileira de Monitoramento Contínuo dos Sistemas GNSS - RBMC**. Rio de Janeiro: IBGE, 2024. Available at: https://www.ibge.gov.br/geociencias/informacoes-sobre-posicionamento-geodesico/rede-geodesica/16258-rede-brasileira-de-monitoramento-continuo-dos-sistemas-gnss-rbmc.html. Accessed on: October 2024.

JACOBI, P. **Impactos Socioambientais Urbanos - do risco à busca de sustentabilidade:** impactos socioambientais urbanos. Curitiba, Brasil: (Org) Francisco Mendonç. RiMa Editora, 2004.

KOBIYAMA, M.; MENDONÇA, M.; MORENO, D.A.; MARCELINO, I.P.V.O.; MARCELINO, E.V.; GONÇALVES, E.F.; BRAZETTI, L.L.P.; GOERL, R.F.; MOLLERI, G.; RUDORFF, F. **Prevenção de desastres naturais:** conceitos básicos**.** Florianópolis: Ed. Organic Trading, 2006. 122p.

MACÊDO, Francisca Ranielly de Brito; GRIGIO, Alfredo Marcelo; SILVA, Márcia Regina Farias da. Zoneamento de áreas de risco: uma visão para a Agenda 2030. **Revista Nacional de Gerenciamento de Cidades**, [S. l.], v. 7, n. 51, 2019. DOI: 10.17271/2318847275120192151. Available at: https://publicacoes.amigosdanatureza.org.br/index.php/gerenciamento_de_cidades/article/view/2151. Accessed on: July 9, 2026.

MARCONI, M.A.; LAKATOS, E.M. **Fundamentos da metodologia científica.** São Paulo: Altas, 320 p. 2010.

MARCELINO, Emerson V. **Desastres naturais e geotecnologias: conceitos básicos**. Santa Maria: CRS/INPE (Centro Regional Sul), 2008. 40 p.

MARICATO, E. **Brasil Cidades:** alternativas para a crise urbana. 2ªed. Petrópolis: Vozes, 2001. 204p.

MENEGON, B. S. **Estudo de Mapeamento dos Tempos de Retorno a Inundação no Perímetro Urbano de Dom Pedrito:**. [S.l.], 2018.

ONU, O. ao das Nações U. **Living with risk: a global review of disaster reduction iniciatives.** Genebra, Suíça: Agency Secretariat of the International Strategy for Disasters Reduction, 2004.

ONU - Organização das Nações Unidas. **Marco de Sendai para la Reducción del Riesgo de Desastres 2015- 2030**. Genebra: UNISDR. 2015. Available at: https://www.unisdr.org/files/43291_spanishsendaiframeworkfordisasterri.pdf. Accessed on: August 2, 2025.

OPAS. Organização Pan-Americana da Saúde (OMS). Ministério da Saúde. **Desastres Naturais e Saúde no Brasil. Brasília, DF**: OPAS, Ministério da Saúde, 2014. 49 p:. il. (Série Desenvolvimento Sustentável e Saúde, 2).

RIGHI, E.; ROBAINA, L. E. S. **Risco à inundação no médio curso do rio Uruguai: estudo de caso no município de São Borja - RS.** Revista Brasileira de Geomorfologia, v. 13, p. 279-286, 2012.

SANTOS, K. R. Inundações urbanas: um passeio pela literatura. **Revista de Geo. UEG - Goiânia**, v. 1, n. 1, jun. 2012.

SEBEN, E.; TEN CATEN, A.; ROBAINA, A. D.; MOREIRA, A. L. L.; PELLEGRINI, G. C. **Fundamentos de Cartografia e o Sistema de Posicionamente Global GPS.** Editora da UFSM: Santa Maria – RS, 2010.

SOUSA, L. F. N. M. de. **Metodologia para o mapeamento de cheias em zonas de risco. Aplicação a um troço de um rio no Norte de Portugal**. 133 p. Dissertação (Mestrado em Engenharia Civil. Especialização em Hidráulica) — Universidade do Porto, Porto, Portugal, 2012.

SAUERESSIG, S. R.; ROBAINA, L. E. S. **Zoneamento das áreas de risco a inundação da área urbana de Itaqui-RS.** Boletim Gaúcho de Geografia, v. 42, p. 673-688, 2015.

TUCCI, C.E.M **Gestão de inundações urbanas.** Ministério das Cidades – Água Global Parceria - Banco Mundial – Unesco 2005.

ISSN 2318-8472, v. 14, n. 92, 2026

TUCCI, C.E.M; BERTONI, J.C. **Inundações urbanas na América do Sul**. Porto Alegre, 1ª edição: 2003, ISBN: 85-88686-07-4, 156 p. Available at: http://www.eclac.cl/samtac/noticias/documentosdetrabajo/5/23335/InBr02803.pdf. Accessed on: August 27, 2024.

THOURET, J.-C.; D'ERCOLE, R. Vulnérabilité aux risques naturels en milieu urbain : effets, facteurs et réponses sociales. **Cahiers des sciences humaines. ORSTOM**, v. 32, n. 2, p. 407–422, 1996.

VEYRET, Y. **Os riscos: o homem como agressor e vítima do meio ambiente.** 1. ed. São Paulo: Contexto, 2005.

WISNER, B. et al. **At Risk: natural hazards, peoples vulnerability and disasters.** 2. ed. Reino Unido: Routledge, 2003.

WOLLMANN, C. A. Enchentes No Rio Grande Do Sul Do Século XXI. **Mercator - Revista de Geografia da UFC**, v. 13, n. 1, p. 79–91, 2014.

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STATEMENTS

CONTRIBUTION OF EACH AUTHOR

Conception and Design of the Study: Lucas Storgatto Martins and Andrea Valli Nummer
Data Curation: Lucas Storgatto Martins and Andrea Valli Nummer
Formal Analysis: Lucas Storgatto Martins, Andrea Valli Nummer and Romario Trentin
Research: Lucas Storgatto Martins and Andrea Valli Nummer
Methodology: Lucas Storgatto Martins, Andrea Valli Nummer and Romario Trentin
Writing - Initial Draft: Lucas Storgatto Martins
Writing - Critical Review: Andrea Valli Nummer and Romário Trentin
Revision and Final Editing: Lucas Storgatto Martins, Andrea Valli Nummer and Romário Trentin
Supervision: Andrea Valli Nummer - PhD in Civil Engineering-Geotechnics

DECLARATION OF CONFLICTS OF INTEREST

We, Lucas Storgatto Martins, Andrea Valli Nummer, and Romário Trentin, declare that the manuscript entitled " Flood Risk Register: an analysis applied to the district of Ernesto Alves, Municipality of Santiago, RS",

1. **Financial Ties**: Has no financial ties that could influence the results or interpretation of the work.
2. **Professional Relationships**: No professional relationship relevant to the content of this manuscript has been established.
3. **Personal Conflicts**: Has no personal conflicts of interest related to the content of the manuscript.