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VULNERABILIDAD SOCIAL: la propuesta de una metodología de matriz de datos geográficos en el municipio de Petrópolis, Río de Janeiro

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ABSTRACT

Land use and land cover expansion and intensification in Brazil, have significant environmental consequences and increase the associated hazards, including disasters related to extreme weather events. Hazard and risk management become indispensable to deal with this problem. This study proposes a Social Vulnerability Index aiming to identify vulnerable populations exposed to hazards associated with natural phenomena. This index was built based on social variables provided by the Instituto Brasileiro de Geografia e Estatística (IBGE) and was validated by fieldwork in the municipality of Petrópolis, with an emphasis on the first district, in the state of Rio de Janeiro. The results obtained revealed significant differences between populations classified at different vulnerability levels. Unfortunately, communities with high vulnerability, when compared to those with low vulnerability, are often overlooked by the government. This emphasizes the need for a more comprehensive and inclusive approach to risk management.

Keywords: Disasters. Risk exposure. Social indicator. Resilience.

RESUMO

A expansão e intensificação do uso e ocupação da terra no Brasil, traz consigo consequências ambientais significativas e aumenta os riscos associados, como desastres relacionados a fenômenos climáticos extremos. Para lidar com essa problemática, a gestão de riscos se torna indispensável. Diante desse cenário, o presente estudo propõe um Índice de Vulnerabilidade Social que tem como objetivo identificar as populações vulneráveis e expostas aos riscos dos fenômenos naturais. Esse índice foi construído com base em variáveis sociais fornecidas pelo Instituto Brasileiro de Geografia e Estatística (IBGE) e foi validado por meio de trabalho de campo no município de Petrópolis, com ênfase no primeiro distrito, no estado do Rio de Janeiro. Os resultados obtidos revelaram diferenças significativas entre as populações classificadas em diferentes níveis de vulnerabilidade. Infelizmente, comunidades com alta vulnerabilidade, quando comparadas às de baixa vulnerabilidade, muitas vezes são negligenciadas e ficam invisíveis para o poder público. Isso ressalta a necessidade de uma abordagem mais abrangente e inclusiva na gestão de riscos.

Palavras-chave: Desastres. Exposição ao risco. Indicador social. Resiliência.

RESUMEN

La expansión e intensificación del uso y ocupación de la tierra en Brasil tiene consecuencias ambientales significativas y aumenta los peligros asociados, incluyendo desastres relacionados con fenómenos climáticos extremos. La gestión de peligros y riesgos se vuelve indispensable para abordar este problema. Este estudio propone un Índice de Vulnerabilidad Social con el objetivo de identificar poblaciones vulnerables expuestas a peligros asociados con fenómenos naturales. Este índice fue construido con base en variables sociales proporcionadas por el Instituto Brasileiro de Geografia e Estatística (IBGE) y fue validado a través de trabajo de campo en el municipio de Petrópolis, con énfasis en el primer distrito, en el estado de Rio de Janeiro. Los resultados obtenidos revelaron diferencias significativas entre las poblaciones clasificadas en diferentes niveles de vulnerabilidad. Desafortunadamente, las comunidades con alta vulnerabilidad, en comparación con aquellas con baja vulnerabilidad, son frecuentemente pasadas por alto por el gobierno. Esto enfatiza la necesidad de un enfoque más completo e inclusivo para la gestión de riesgos.

Palabras Clave: Desastres. Exposición a riesgos. Indicador social. Resiliencia.

INTRODUCTION

In the last decades, there has been a significant increase in both the number of disaster occurrences and their intensity (DILLEY *et al*., 2005; BRAUCH, 2005; CARDONA, 2005). In Brazil, during the months from October to March, disasters arising from precipitation events are common. These events, due to their speed and duration, lead to injured populations, homelessness, loss of life, and economic damage (MARENGO, 2009).

To deal with disasters, it is essential to establish a theoretical-methodological framework that supports the management of natural risks. In this paper, the concept of social vulnerability is related to the social and economic impacts of disasters (TIMMERMAN, 1982; CUTTER, 1996; CUTTER, BORUFF & SHIRLEY, 2003; BARROS, CARVALHO & FRANCO, 2003). It is pivotal to understand that the effects of a natural phenomenon only become disasters when they occur in inhabited areas or areas occupied by economic and/or cultural activities. Vulnerability manifests only when there is exposure of people, properties, systems, and other elements in areas prone to hazards, resulting in potential harm to the individuals involved (CUTTER, BORUFF, e SHIRLEY, 2003; BARROS, CARVALHO & FRANCO, 2003; MIGUEZ, DI GREGÓRIO & VERÓL, 2018).

The definition of vulnerability is polysemic in nature and has different parameters in the proposition of the concept, as there is no uniform scientific language for the use of this term (JUPIASSU, 1976; WEICHSELGARTNER, 2001). Therefore, it is often confused with the concept of susceptibility, which refers to the physical propensity of an area or region to be impacted by adverse events (BITAR, 2014).

For the measurement of social vulnerability, there are different methodologies based on the selection of social variables according to specific topics and objectives. These approaches aim to assess the social and economic aspects that make certain populations more vulnerable. In the case of disasters, authors such as Koks *et al.* (2015), Tapsell *et al.* (2002), and Cutter *et al.* (2006) serve as a basis.

In Brazil, there are methodologies for measuring social vulnerability at a municipal level. These approaches seek to identify and understand the social factors and aspects that influence the vulnerability of communities. The Institute of Applied Economic Research (IPEA) has an index that can be applied to all instances and themes through the territorial division of Human Development Units (COSTA & MARGUTI, 2015). On the other hand, the National Water Agency (2014) has an index focused on floods, which categorizes areas susceptible to flooding considering the damage caused, but does not directly include social aspects that influence vulnerability.

There are also vulnerability indexes, such as the São Paulo Social Vulnerability Index by the SEADE Foundation, which was initially conceived as an income transfer indicator. However, over time, this index has become widely used by different governmental and non-governmental institutions as a management tool, without modifications to its variables.

Thus, measuring social vulnerability includes considering social, economic, and institutional aspects that influence the resilience capacity of a community, providing support for the planning of preventive measures, appropriate responses, and objective premises.

The determination of methodologies to identify socially vulnerable areas is essential to support public policies. The development of vulnerability indicators plays a pivotal role in assisting decision-making by representative bodies and in diagnostics, especially in the theme being addressed here, disasters. It is essential to deepen studies on the different ways in which a population can be affected and to identify these vulnerable populations in order to work more efficiently in risk mitigation and prevention.

This article proposes a Social Vulnerability Index, at the census tract level, which, despite being applicable in different areas and themes, here has the premise of addressing, in Geography, the theme of risks related to disasters. To validate the methodology, the municipality of Petrópolis, located in the mountainous region of the state of Rio de Janeiro, was selected, with emphasis on the first district, known for presenting a significant frequency of disaster events

MATERIALS AND METHODS

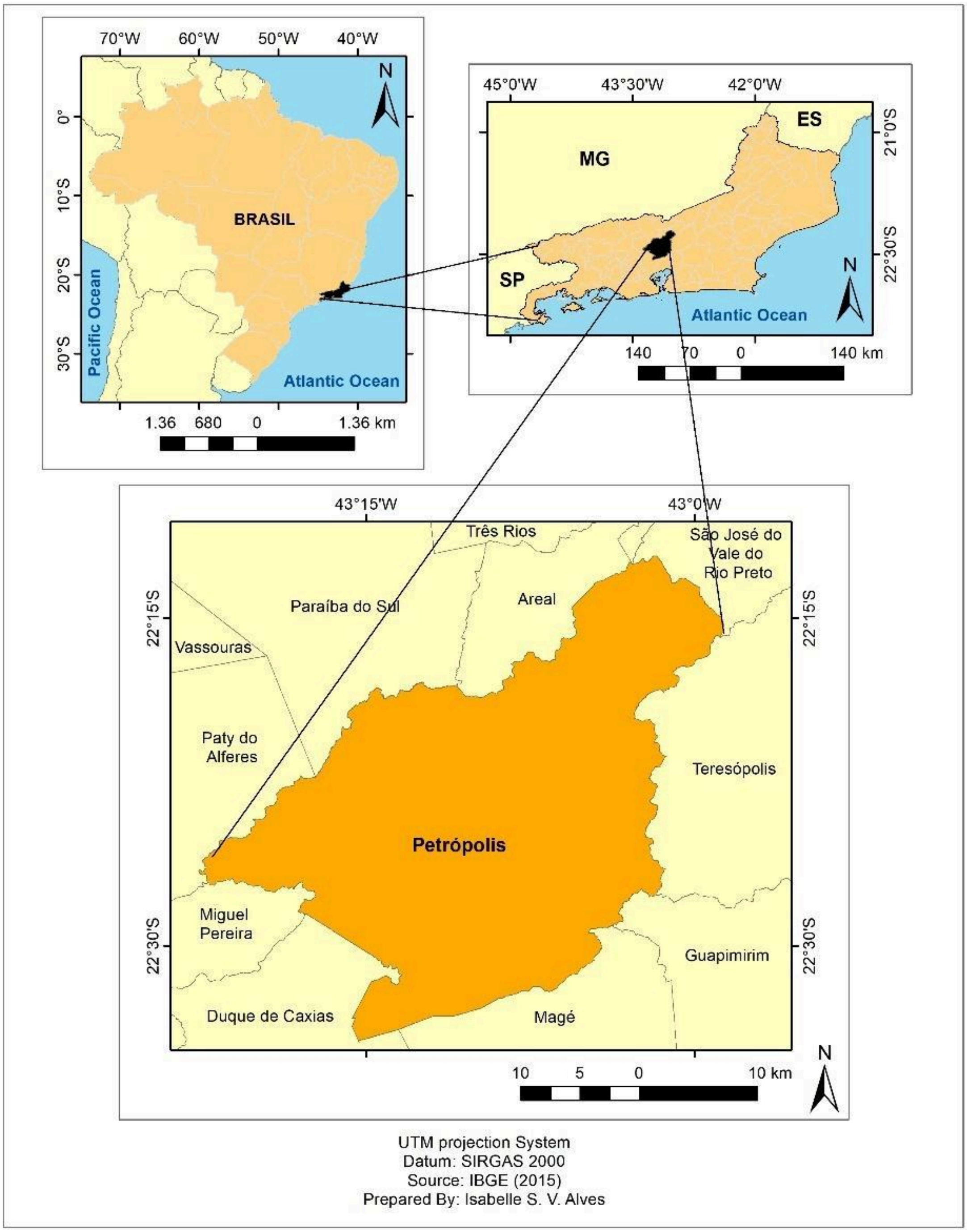
Field of Study

Petrópolis is a municipality located in the interior of the state of Rio de Janeiro, in the mountainous region (Figure 1), with five districts and a total area of approximately 793 km², and a total population of 278,881 inhabitants in 2022, according to the 2022 Census (IBGE CIDADES, 2023). In turn, the first district concentrates a large part of the urban areas and the majority of the inhabitants (WINTER, 2016). It is best known for recurring disasters, such as mass movements and floods, due to a rapid and disorderly urban expansion, resulting in the occupation of risk areas (GUERRA *et al*., 2007).

According to Alves, Manz and Amorim (2022), the Petrópolis region features a rough terrain, characterized by deeply incised valleys, steep escarpments, and soils that are more unstable and prone to mass movements. These areas are exposed to heavy rainfall due to the influence of the Atlantic Tropical mass and the South

Atlantic Convergence Zone (SACZ). Additionally, the altitude contributes to air turbulence, increasing the frequency of rainfall throughout the year.

Figure 1 – Map for Location of the Municipality of Petrópolis



Source: prepared by the authors.

The municipality faces two significant problems related to intense natural dynamics: mass movements and floods due to the depletion of the central area, especially the valley bottoms that have undergone channel rectification and complete occupation by residents. These issues are often associated with torrential rain events, with high volumes of precipitation occurring in short periods of time, such as the extreme precipitation event on 02/15/2022 (ALVES, MANZ & AMORIM, 2022).

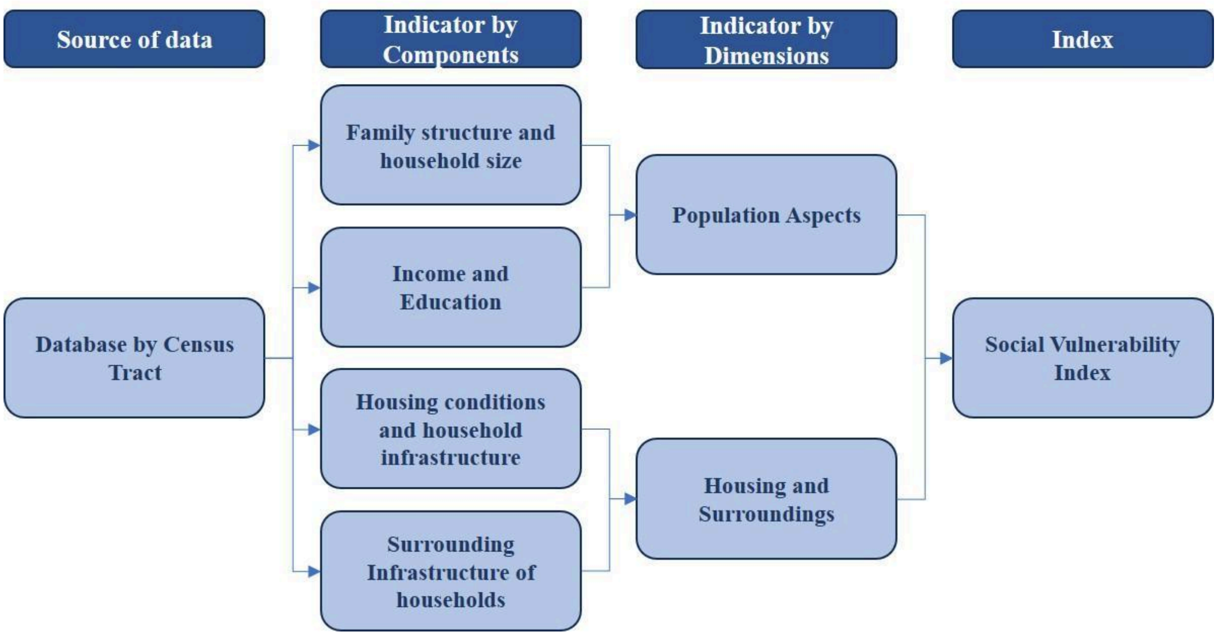
Mass movements in Petrópolis are influenced by factors such as slope characteristics, terrain, surface water flow patterns, as well as disorderly land use and occupation. Irregular occupation along riverbanks and slopes, along with the occupation of unstable and illegal areas without adequate supervision, are elements that contribute to the occurrence of disasters (ALVES, MANZ & AMORIM, 2022).

Procedures for Social Vulnerability Index Methodology

The implementation of the social vulnerability methodology applied to disasters, based on the determination of a multidimensional indicator, includes the grouping of selected variables from the 2010 Demographic Census of the Brazilian Institute of Geography and Statistics (IBGE), <https://censo2010.ibge.gov.br/>, into dimensions, components, and variables.

The dimensions “Population Aspects” and “Housing and Surroundings” are separated, each divided into two components (Figure 2).

Figure 2 - Summary of the Social Vulnerability Index



Source: prepared by the authors.

These components, in turn, encompass variables that were selected from ten data spreadsheets per census tract[1]. For the most accurate determination of the index, statistical techniques, spatial analysis, and factorial analysis were used for the smallest area of spatial representation of the national territory: the census tract.

Population Aspects

The Population Aspects dimension is intrinsically linked to the representation of characteristics that define the vulnerability of Brazilian families exposed to risks. It covers key variables such as gender, education, income, and age group, separated into components: “Family Structure and Household Size” and “Income and Education,” as shown in Table 1.

Table 1 - Variables composing the “Population Aspects” dimension in the Social Vulnerability Index for census tracts

Size	
Components	Variable
Family Structure and Household Size	Proportion of child with 0 – 12 years old
	Proportion of elderly with 60 years old and older
	Proportion of elderly household heads
	Proportion of female household heads
	Proportion of household heads in working age
	Proportion of household with > 4 residents
Income and Education	Proportion of household heads with nominal monthly income up to 1 minimum wage
	Proportion of female household heads with no nominal monthly income
	Proportion of households with no income
	Private households with nominal monthly per capita income up to 1/4 minimum wage
	Proportion of literate children and adolescents
	Proportion of literate individuals in working age
	Proportion of literate female household heads

Source: prepared by the authors.

Upon considering these characteristics, it is possible to better understand the dynamics of families exposed to disasters, directing risk management strategies and appropriate public policies, as these factors have a negative impact on social vulnerability. This contributes to the reduction of vulnerability and the strengthening of resilience of these families in the face of adverse natural events.

Within this dimension, it is essential to consider income dynamics, as they are directly proportional to household size. Additionally, the number of dependents has a significant influence on social vulnerability, with an expected increase in vulnerability as the number of dependents in the same household increases

[1] Household01, Household02, HouseholdIncome, Surroundings03, Surroundings04, Person01, Person13, Provider01, Provider02, and IncomeProvider.

(CUTTER, BORUFF & SHIRLEY, 2003). Thus, investigating the population's income is important because it reveals the financial capacity to resist and cope with disaster situations and natural hazards.

Gender also plays an important role, as it influences the distribution of roles, employability, and responsibilities between men and women, contributing to the inequalities and challenges faced by each group. Cutter, Boruff and Shirley (2003) highlight that women face greater difficulty in disaster recovery due to lower wages and family responsibilities.

Education and age are related to gender and income issues. Education reflects access to education, which impacts employability, the distribution of wages between men and women, and household responsibilities. Often, women are forced to interrupt their studies to take care of their families. Additionally, many families are headed by single mothers.

Access to education and the level of knowledge acquired are factors that influence lifetime earnings, while low levels of education can hinder the assimilation of warning systems, access to information, and disaster recovery (CUTTER, BORUFF & SHIRLEY, 2003).

Finally, the age range of family members also plays a pivotal role, as different age groups may present distinct needs and vulnerabilities in the face of risks. Barros, Carvalho and Franco (2003) argue that the presence of children and the elderly increases the vulnerability of families since greater costs are required for maintaining basic needs, security conditions, adequate nutrition, and medical care for these individuals.

Housing and Surroundings

The Housing and Surroundings dimension consists of two components: "Housing Conditions and Household Infrastructure" and "Surrounding Infrastructure of Households." Table 2 details the variables, with the same variables adopted for both urban and rural sectors in the former component. However, for the latter, there was differentiation in selection: six variables for urban sectors and two for rural sectors[2]. This is due to the fact that rural areas may lack access to basic conditions such as public lighting, paving, drains, and others.

[2] For rural census tracts, only two variables were considered: Proportion of residents in permanent private households – No afforestation; and Proportion of residents in permanent private households without garbage collection.

Table 2 – Variables composing the Housing and Surroundings dimension of the Social Vulnerability Index for census tracts

Size	
Component	**Variable**
Housing conditions and household infrastructure	Proportion of residents in permanent private households without access to piped water supply
	Proportion of residents in permanent private households with a bathroom exclusively for residents' use or a toilet and sanitary drainage system that does not have a general sewer or storm water system
	Proportion of residents in permanent private households with electricity supply
	Proportion of residents in non-owned households
	Proportion of residents in inadequate permanent private households
Surrounding Infrastructure of households	Proportion of residents in permanent private households - No public lighting
	Proportion of residents in permanent private households - No pavement
	Proportion of residents in permanent private households - No storm drain / manholes
	Proportion of residents in permanent private households - No afforestation
	Proportion of residents in permanent private households - No wheelchair ramp
	Proportion of residents in permanent private households without garbage collection

Source: prepared by the authors.

Housing conditions play a pivotal role in the quality of life of a family, as they are directly linked to health conditions (BARROS, CARVALHO & FRANCO, 2003). An inadequate housing environment, with a lack of basic sanitation, poor infrastructure, and exposure to risks, can have negative impacts on the physical and mental health of residents.

On the other hand, a safe housing environment, with access to basic health services, adequate ventilation, and basic sanitation, contributes to a better quality of life and well-being. It is essential to consider housing conditions when analyzing social vulnerability and developing risk management strategies and public policies aimed at improving the living conditions of families. Additionally, the infrastructure situation in inadequate housing areas can trigger risks such as contamination of the physical environment and even exacerbate mass movements and floods (DAVIS, 2006).

For this reason, variables indicating the presence or absence of infrastructure have been adopted, such as water supply, sanitation, and the presence of manholes, which are indications of drainage works for directing surface water runoff.

The existence of infrastructure such as paving, public lighting, and electricity also provides the population with resources to resist natural hazards and ensures better conditions for coping when disasters occur. Accessibility is directly related to the degree of organization of occupation in areas susceptible to natural phenomena. Thus, the observation of these variables encourages good conditions for resilience to vulnerability (BLAIKIE *et al.*, 2014).

In conclusion, the presence of afforestation and garbage collection is related to social, public health, and environmental susceptibility factors. The existence of green areas, represented by afforestation, may imply permeable zones that help reduce surface water runoff and delay the occurrence of floods in drainage systems. On the other hand, proper garbage collection is linked to its correct disposal, preventing it from being discarded in the environment and contributing to the prevention of floods and contamination of soil and water. These aspects have a direct impact on the well-being of the local population (DAVIS, 2006).

Representation of Social Vulnerability

After establishing the relevant dimensions, components, and variables, a spatial analysis was conducted to compile, process, and transform the variables into a Social Vulnerability Index. This process was carried out with the assistance of factor analysis, which allowed for the identification of underlying patterns in the data, and utilized census tracts as reference units for projecting the results.

Subsequently, the proportion of variables for each tract was calculated, enabling a localized pre-assessment of social vulnerability. This data normalization procedure ensures that all variables are considered on the same scale, ranging from 0 to 1. Such normalization is essential, as it is not possible to correlate absolute data expressing different aspects, such as gender and income, without placing them on a comparable scale. However, further steps were necessary to develop the Social Vulnerability Index, as the data were not categorized.

In this context, factor analysis was used due to the proportions of the variables being ranged between 0 and 1. To avoid the removal of random variations and to consider trends in the results, measures of central tendency such as the arithmetic mean were not used.

Instead, data analysis was conducted using quartiles, which divide the sample into regular ranges. The first quartile corresponds to the 25th percentile, and the third quartile corresponds to the 75th percentile. These percentiles are values that divide the distribution, allowing for the identification of "low," "medium," and "high" indicator classes based on the quartile values. The calculation of the quartile positions can be expressed as follows (Equation 1):

$$P = \{P_{1,} P_{2,} P_{3,} \dots P_n\} | \eta \in^{+*}$$

Equation 1

Thus, the position of the first and third quartiles can be calculated according to Equations 2 and 3, with the treatment depending on the size of the database.

$$Q_1 = \frac{n+1}{4}$$

Equation 2

$$Q_3 \frac{3(n+1)}{4}$$

Equation 3

Subsequent to this, each variable was analyzed within its dataset by area of analysis using the quartile method. This method divides the dataset into four parts: 1 to 25, 26 to 50, 51 to 75, and 76 to 100. Then, the data was divided into three classes: low (= 1 to 25), medium (= 26 to 75), and high (= 76 to 100).

If quartiles Q_1 or Q_3 are not whole numbers, interpolation is necessary to determine their precise values. This includes calculating the proportional advancement between the suggested position and the next number (ROGERSON, 2012). Thus, for Q_i non-integer with a decimal value equal to 0.25, we have (Equation 4):

$$Q_i = \left[\frac{(P_{n+1} - P_n)}{4}\right] + P_n$$

Equation 4

For Q_i non-integer with a decimal value equal to 0.5, we have (Equation 5):

$$Q_i = \left[\frac{(P_{n+1} - P_n)}{2}\right] + P_n$$

Equation 5

For Q_i non-integer with a decimal value equal to 0.75, we have (Equation 6):

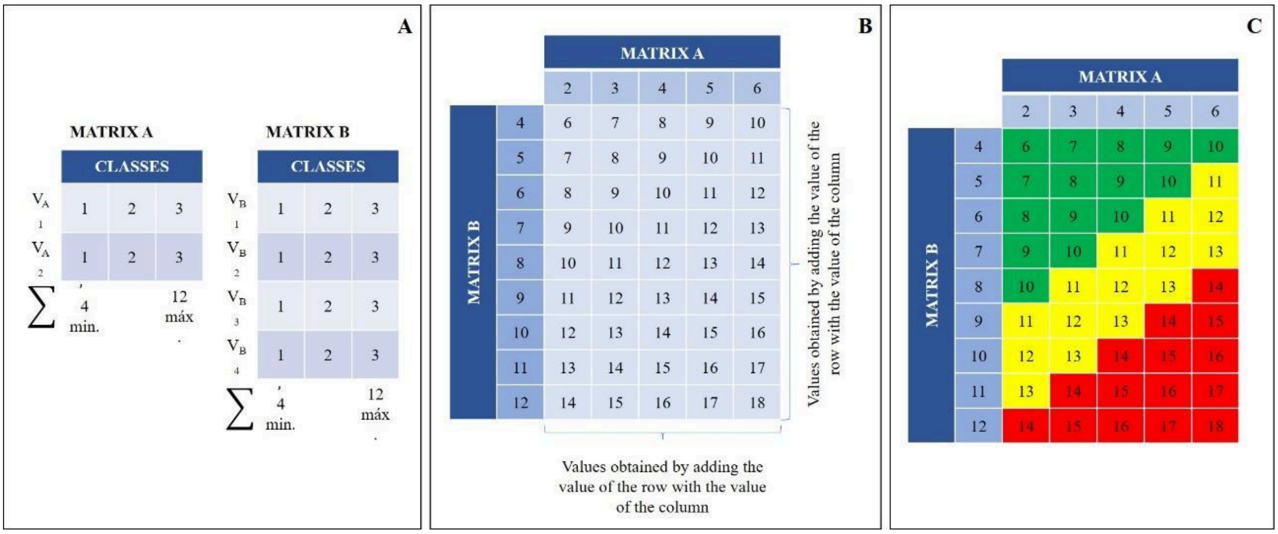
$$Q_i = \left[\frac{3(P_{n+1} - P_n)}{4}\right] + P_n$$

Equation 6

The interquartile range is used to classify the data based on their actual occurrence, allowing for a harmonious division into three classes (low = 1, medium = 2, and high = 3), related to the dimensions, “Population Aspects” and “Housing and Surroundings.” These classes are obtained through the sum and reclassification of the previous results using the *Geographic Data Matrix* proposed by Berry (1964) for the spatialization of the Social Vulnerability Index.

By summing the result matrices, new values emerge, which need to be reclassified. For example, the sum of a 2x4 matrix tends to present 12 different values, ranging from 6 (minimum value) to 18 (maximum value). To categorize these results into three classes, the interquartile ranges are used. Values from 6 to 10 are classified as 1 (low), values from 11 to 13 as 2 (medium), and values from 14 to 18 as 3 (high) (Figure 3).

Figure 3 – A – Possible values obtained for each variable, considering categorization by classes (1 - low class; 2 - medium class; and 3 - high class); B – Sum of matrices from different components, indicating minimum and maximum values obtained for each class; C - Distribution of matrix classes, after reclassification, with green (class 1 - low), yellow (class 2 - medium), and red (class 3 - high).



Source: prepared by the authors.

To identify the classification ranges, a set of equations was used as presented in Table 3. This procedure is repeated for all components and dimensions throughout the process of summing the variables that compose them to achieve the Social Vulnerability Index. The set of equations used allows for the harmonious classification of the data into three ranges: low (1), medium (2), and high (3), providing a comprehensive and detailed analysis of each element contributing to the final index.

Table 3 - Equations for categorizing the values obtained in the sum of matrices.

Phases	Equations	Example
A - Determination of the number of variables in the geographic matrix	$N = x_{máx} - x_{min}$	$N = 18 - 6$ $N = 12$
B - Determination of the number of variables that will compose the extreme classes (low and high)	$i = \frac{N}{C}$	$i = \frac{12}{3}$ $i = 4$
C - Determination of the ranges constituting each class in the geographic matrix	Low Class:	
	$L_B = x_{min} + i$	$L_{B=}6 + 4$ $L_B = 10$
	$C_B = x_{min} \dashv L_B$	$C_B = 4 \dashv 10$
	Medium Class:	
	$L_{M(\min)} = L_B + 1$	$L_{M(\min)} = 10 + 1$ $L_{M(\min)} = 11$
	$L_{M(\max)} = L_A - 1$	$L_{M(\max)} = 14 - 1$ $L_{M(\max)} = 13$
	$C_M = (L_{M(min)} \dashv L_{M\,(\max)})$	$C_M = (11 \dashv 13)$
	High Class:	
	$L_{A=}\, x_{max} - i$	$L_{A=}\, 18 - 4$ $L_{A=}\, 14$
	$C_A = L_A \dashv x_{max}$	$C_A = 14 \dashv 18$

Reference

N = number of variables x_{max} = largest variable determined in the geographic matrix x_{min} = smallest variable determined in the geographic matrix i = number of variables that will compose the extreme classes of the geographic matrix C = number of classes L_B = Upper limit of the low class	L_A = Lower limit of the high class $L_{M(min)}$ = Minimum limit of the medium class $L_{M\,(\max)}$ = Maximum limit of the medium class C_B = Range of variables composing the low class C_M = Range of variables composing the medium class C_A = Range of variables composing the high class

Source: prepared by the authors.

Fieldwork

The methodology was validated through data collection in 12 representative locations with different levels of social vulnerability. This ensured the accuracy and reliability of the Social Vulnerability Index.

The fieldwork occurred in two phases: the first on March 26 and 27, 2022, about 39 days after the disaster that resulted in 242 deaths on February 15, 2022. The second phase was conducted from March 16 to 19, 2023, one year after the disaster. This temporal approach allowed for the validation of the indicator developed by the authors, observing the social and environmental conditions of the affected areas.

RESULTS AND DISCUSSIONS

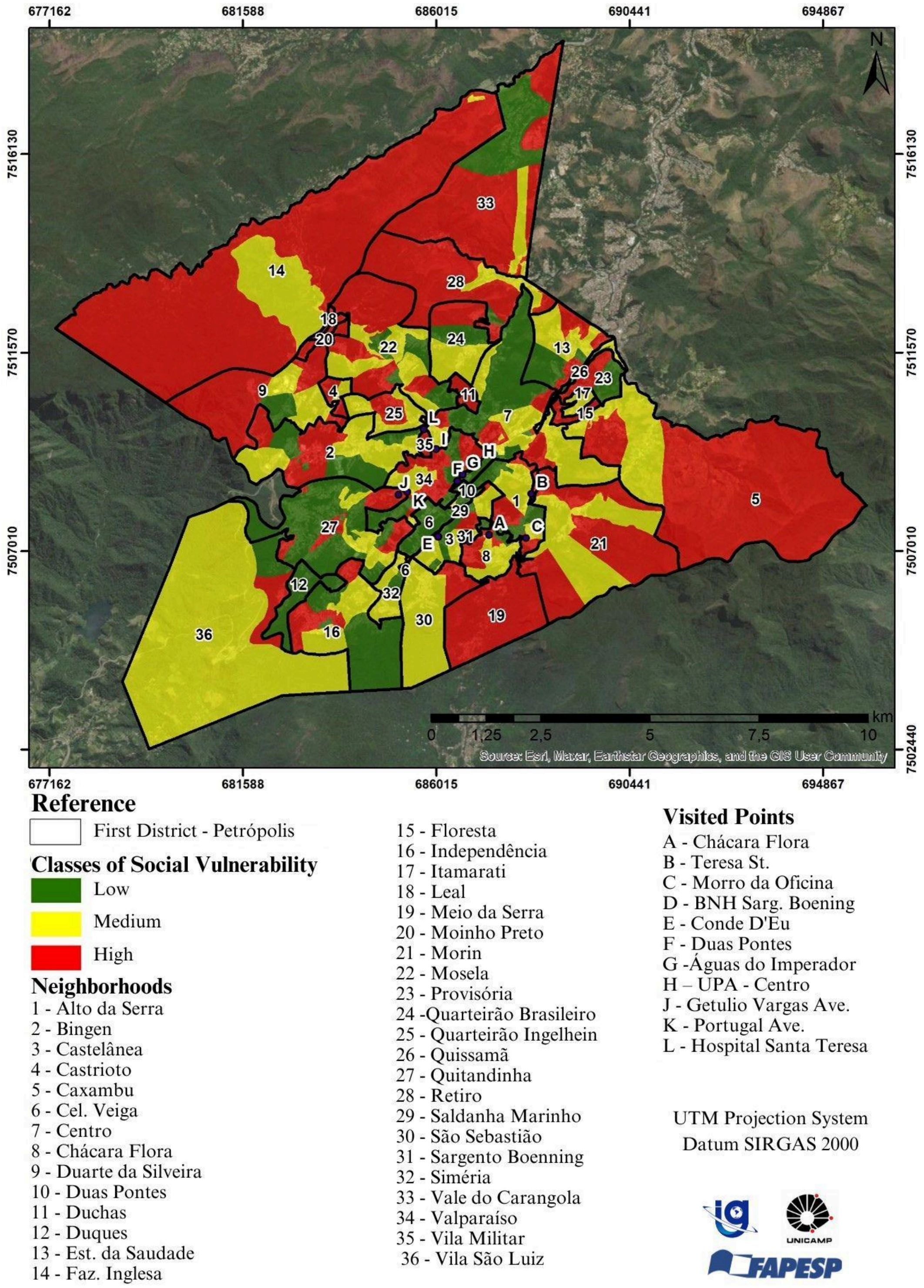
Social vulnerability refers to the fragility in which certain groups or individuals find themselves in a society due to structural inequalities and unfavorable conditions. Although not directly associated with poverty, individuals belonging to lower social classes suffer more from the consequences of disasters due to their limited access to income, often resulting from low wages, and the concentration of their assets in a residence (BLAIKIE *et al.*, 1994).

The social vulnerability indicator allows us to understand geographically vulnerable areas or population groups, especially in disaster situations, by observing their capacity for response and resilience in recovery. This serves as a complementary foundation for the development of intervention strategies and targeted public policies.

The analysis of this indicator reveals its effectiveness in providing relevant social data for assessment and planning, covering measures of protection, prevention, mitigation, and response. Unlike environmental susceptibility, which refers to the propensity of an area to be affected by natural phenomena (BITAR, 2014; LOURENÇO and AMARO, 2018; GIRÃO, RABELO & ZANELLA, 2018; MIGUEZ, DI GREGÓRIO & VERÓL, 2018), social vulnerability considers socioeconomic and demographic factors that influence communities' capacity to face and recover from adverse events. Thus, socially vulnerable areas are not necessarily susceptible to disasters.

The projection of the results (Figure 4), along with the neighborhood boundaries, happened because these are units for disaster planning and prevention in the municipality. Despite the different levels of social vulnerability in neighborhoods, the distribution of census tracts masks and generalizes urban and social elements and infrastructures. This highlights the geographic scale paradigm, as census tracts, although the smallest area of analysis, do not encompass all the dynamics of the territory to reflect reality more accurately (FERREIRA, 2017).

Figure 4 - Distribution of Social Vulnerability in Relation to Neighborhoods in the First District of Petrópolis



Source: prepared by the authors.

When including the boundaries of neighborhoods in the cartographic representation, a direct connection was established between the analyzed areas and their corresponding neighborhoods. For instance, the Centro and Quitandinha neighborhoods (Figure 4) are predominantly characterized by low social vulnerability due to the presence of tourist spots, events, cultural exhibitions, and essential services. Hence, these neighborhoods have more resilient infrastructures and a population with higher purchasing power, attributed to the valued location of the area and real estate speculation. Therefore, due to their low social vulnerability, these neighborhoods have a quick capacity for response and resilience in the face of disasters.

On the other hand, neighborhoods like Chácara Flora and Alto da Serra (Figure 4) present a predominance of medium and high social vulnerability. Due to social, demographic, and urban infrastructure characteristics, when affected by disasters, they lack a quick capacity for response and resilience. However, considering these characteristics, it is noticeable on the map (Figure 4) that some neighborhoods may have census tracts with low social vulnerability. This can be explained by the presence of residential condominiums that have specific census tracts with adverse characteristics of the population and the surroundings.

Therefore, it is evident that resilience to disasters is associated with social vulnerability and vice versa (KLEIN, NICHOLLS, and THOMALLA 2003; CUTTER *et al.* 2008; BURTON, 2015). However, this particularity is connected to the paradigm of geographic scale (FERREIRA, 2017), which can be overcome in fieldwork, allowing the validation of the methodology proposed in this article and a more detailed analysis of social vulnerability related to disasters in the municipality.

Fieldwork

Considering the logic of the relationship between vulnerability and resilience, strategic points were visited to identify social vulnerability, such as the neighborhoods of Centro, Chácara Flora, Alto da Serra, and others (Table 4 and Figure 4). Although the social vulnerability indicator is based on 2010 census data, it is argued that the timeframe of these data still provides a significant representation of population vulnerability due to the contradictions in socio-economic and political relations that intersect the evolution of territorial infrastructure and social development.

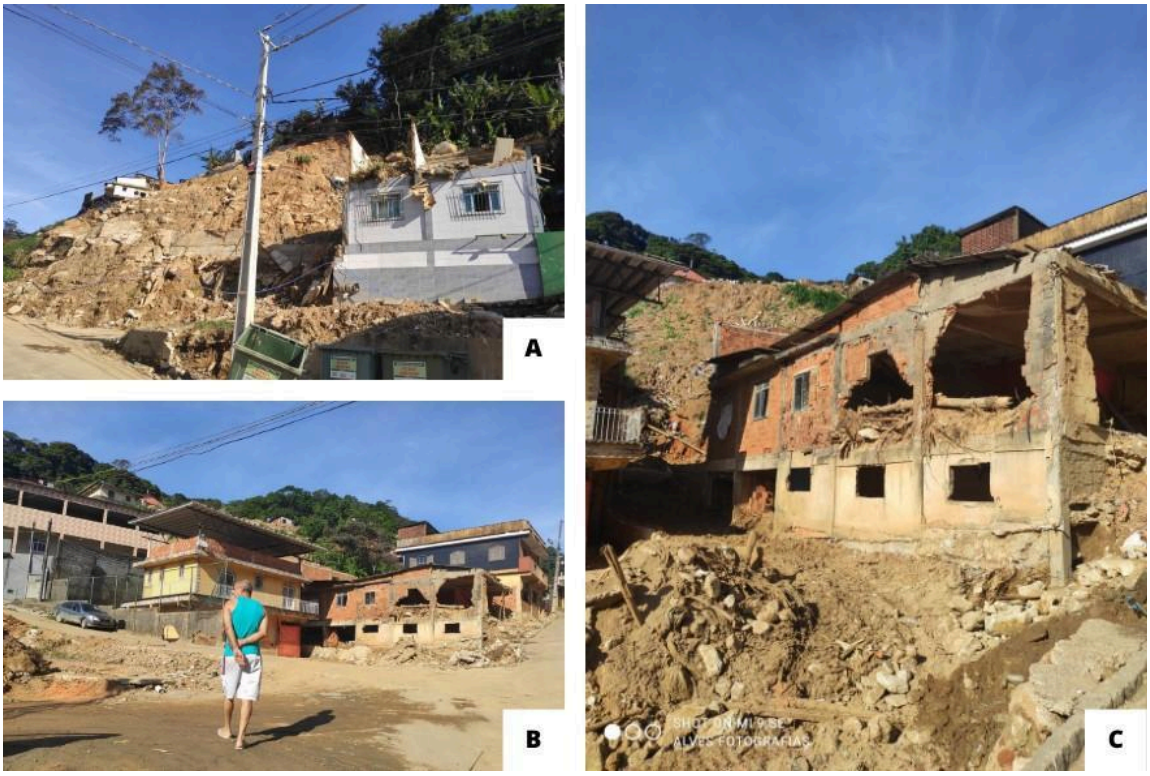
Table 4 - Classification of Social Vulnerability, according to Fieldwork Points

	Name	Social Vulnerability Class
A	Chácara Flora	High
B	R. Teresa	Medium
C	Morro da Oficina	High
-	BNH Sargento Boenning	Low
E	Conde D'Eu	Low
F	Duas Pontes	Low
G	Águas do Imperador	Low
H	UPA – Centro	Low
I	Comunidade Oswaldo Cruz	High
J	Av. Getúlio Vargas	High
K	Av. Portugal	Medium
L	Hosp. Sta. Teresa	Low

Source: prepared by the authors.

In other words, in areas characterized by high vulnerability, there is a noticeable lack of significant changes over the years or even when comparing between disasters. This consistency is evident in Figures 5 and 6. This indicates the persistence of factors contributing to vulnerability in these regions.

Figure 5 – Chácara Flora, 39 days after the disaster on 15 February, 2022 (26/03/2022). A) Destroyed houses hanging on the slope; B) Destroyed houses near Centro de Educação Infantil Deise Elói Gomes; C) House affected at the base of the slope.



Source: prepared by the authors.

Figure 6 – Chácara Flora, 01 year after the disaster of 15 February, 2022 (18/02/2023). A) Destroyed houses hanging on the slope; B) Destroyed houses near Centro de Educação Infantil Deise Elói Gomes; C) House affected at the base of the slope

Source: prepared by the authors.

Upon analyzing Figure 5, it is possible to notice the impact of the disaster on Chácara Flora in March 2022, where the capacity for emergency response and assistance was virtually nonexistent, with only the removal of soil and debris from the main road to allow residents access to public transportation. A year later, it was observed that there were no significant changes in the landscape, except for the construction of a wall. This measure may have been taken to prevent burglaries, as many houses were targeted by break-ins after the disaster (Figure 6[3]).

The relationship between social vulnerability and resilience, as evidenced by the index, can also be observed in other neighborhoods of the municipality, such as the Morro da Oficina, which presents high vulnerability. It’s important to note that this locality was severely affected by the disaster on 15 February, 2022, resulting in 242 deaths, 93 of which were in the community (DE SOUZA, 2022). Unlike Chácara Flora, the visit to the Morro da Oficina community took place only one year after the disaster, respecting the residents and the sensitivity of the situation. Therefore, in the first stage of fieldwork, the observation was conducted from a distance (Figure 7).

[3] The letters shown in Figure 4 represent the same letters present in Figure 3.

Figure 7 - Morro da Oficina, 39 days after the disaster on 15 February, 2022: distance reconnaissance (26/03/2022)

Source: prepared by the authors.

Despite the difficulties in accessing the community, it's possible to clearly observe the extent of the damage caused by the disaster. The landscape shows damaged structures, debris, and evidence of mass movements. Upon returning to the area one year later, on 18 March, 2023, it becomes evident that the community confirms the relationship between vulnerability and resilience. Unfortunately, the lack of action by the responsible authorities is visible, as the streets are not being cleaned (Figure 8 - A and B) and no containment or reconstruction measures have been implemented, considering there are still loose debris upstream of the slope (Figure 8 - C and D) and people living exposed to risk (Figure 8 - E and F).

These images highlight the urgency of effective interventions by the responsible authorities, aiming to ensure the basic needs of the affected population are met and to promote community reconstruction and resilience. It is essential to implement public policies of support, investments in infrastructure, and social assistance to reverse the situation of abandonment and vulnerability faced by residents exposed to risk.

Figure 8 - Morro da Oficina one year after the disaster of 15 February, 2022 (18/03/2023): A and B) Abandoned streets, without cleaning and reconstruction efforts; C and D) Materials without upstream retention works on the slope; E and F) Homes still occupied by residents

Source: prepared by the authors.

On the other hand, in areas of low vulnerability, such as those along Rua Washington Luiz, located in the central region of the municipality, there was an emergency response time of one month for the same disaster that occurred in the previously mentioned areas. In Figure 9 – A and B, it is possible to notice that the authorities isolated the affected area, and in the following year, in Figure 9 – C and D, the reconstruction of these areas was already completed.

Figure 9 – R. Washington Luiz: A and B) 39 days after the disaster on 15 February, 2022 (26/03/2022); C and D) one year after the disaster (18/03/2023).

Source: prepared by the authors.

These examples confirm the discrepancies between areas of high and low vulnerability, highlighting socio-spatial inequality and how different communities are affected by disasters. While high vulnerability areas face neglect from authorities, lack of adequate infrastructure, and difficulties in reconstruction, low vulnerability areas receive a quicker and more efficient response, restoring normal conditions in a short period of time.

Therefore, the Social Vulnerability Map of the First District of Petrópolis, built based on the index methodology, offers a visual and clear representation of the most vulnerable areas. Fieldwork tends to strengthen the methodology and reliability of the index.

FINAL CONSIDERATIONS

This article established a Social Vulnerability Index at the census tract level. Although the social data is limited as it is from 2010, it managed to represent the territory dynamics, which could be further detailed with the updating of census tracts as spatial vectors and social data. As an alternative, fieldwork was a temporal validation action associated with a resilience and response capacity approach of the population exposed to risk, thus validating the methodology of this paper.

Another limitation imposed on the index development is associated with the application of concepts involving social vulnerability. In order to avoid subjectivities, a note of observation of the concepts was elaborated at the end of the article. Furthermore, data manipulation for index development and associated factorial statistics are other limitations, as they require the user to have prior knowledge of spatial analysis and/or programming. For the purpose of replicating and disseminating the index, a free online data repository <10.17632/j85dj6p4z8.2> was established, where it is possible to obtain the data and results used.

Additionally, it is evident that the Social Vulnerability Index developed by the authors is applicable for use throughout the national territory, given its database and availability with open access.

Finally, it was observed that localities and populations in high vulnerability are suffering from lack of assistance from government authorities, deprived of basic rights such as housing, food, health, and water. These areas are being neglected, and their needs are being ignored, resulting in a situation of abandonment and invisibility.

Therefore, this study emphasizes the need for attention and action by authorities to address social vulnerability in areas affected by disasters. It is essential to adopt appropriate policies and measures to meet the needs of vulnerable populations, ensuring access to basic rights and promoting community resilience. The continuity of research in this area, with data updates and the inclusion of recent information, will be essential to enhance risk mitigation strategies and improve the quality of life of populations affected by social vulnerability.

NOTE

Disaster is the term used to describe the negative effects arising from risk events affecting a society or specific region. This concept is similar to the concept of “catastrophe” in Portugal, as mentioned by Lourenço and Amaro (2018). Disasters are characterized by natural phenomena that, when impacting a population, result in significant damages, as pointed out by Fontes (1998).

Risk is a term referring to any process, whether natural or induced, that poses a threat to a certain area or population, as cited by Fontes (1998) and Keller and Blodget (2004). However, it is pivotal to emphasize that risk is constructed over history due to human actions, as highlighted by Braga, Oliveira and Givisiez (2006).

Vulnerability is understood as the potential loss of a social group or element in a particular area, facing the possibility of being affected by a natural phenomenon (CUTTER, 1996). This perspective underscores the importance of considering not only the characteristics of the phenomenon itself but also the social, economic, and environmental conditions influencing a community's ability to cope with its impacts. Vulnerability can vary according to factors such as access to resources, adequate infrastructure, socioeconomic status, response capacity, and resilience.

Susceptibility represents the predisposition of a location to the occurrence of a specific phenomenon, as indicated by Bitar (2014), Lourenço and Amaro (2018), Girão, Rabelo, and Zanella (2018), and Miguez, Di Gregório and Veról (2018). In other words, it refers to the propensity or sensitivity of an area regarding the occurrence of a specific event, taking into account geological and environmental factors.

Resilience is a concept that involves the capacity for resistance, adaptation, absorption, and recovery in the face of a disaster, aiming to return to a state of normalcy, as mentioned by Cardona (2004) and Bitar (2014).

Exposure to risk refers to the situation in which the population and their assets are subject to the occurrence of a hazardous phenomenon, as highlighted by Alves (2006), Braga, Oliveira, and Givisiez (2006), Licco (2013), and Lourenço and Amaro (2018). In this context, people and infrastructure are exposed to the adverse effects of natural or induced events, such as landslides, floods, fires, among others.

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