e-ISSN:2316-9834

GeAS

Revista de Gestão Ambiental e Sustentabilidade
Journal of Environmental Management & Sustainability

Received: 15 June 2022 - **Approved:** 24 Mayo 2023
Responsible Editor: Andreza Portella Ribeiro
Sections Editors: Cristiane Criscibene Pantaleão; Juliana Rodrigues Maróstica; Marco Antonio Casadei Teixeira
Evaluation Process: Double Blind Review
Special Edition: Mudanças climáticas e planejamento urbano: cenários e desafios
https://doi.org/10.5585/2023.22368

SOCIO-ENVIRONMENTAL VULNERABILITY TO DISASTERS: SCENARIOS AND CHALLENGES FOR THE MUNICIPALITY OF BRUSQUE (SC)

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Abstract

Objective: Since the beginning of this century, the municipality of Brusque has recorded a significant increase in landslide occurrences, which have caused both serious damage to the city's infrastructure and fatalities. This article aims to classify the socio-environmental vulnerability (SEV) of the municipality of Brusque, in the state of Santa Catarina (SC), to socio-environmental disasters (landslides).
Methodology: The SEV mapping was developed from a multi-criteria analysis with the aid of a geographic information system (GIS). In order for the SEV classification to function, it was necessary to calculate the propensity (Ivs) and exposure (VAT) indices. The indices were cross referenced in a social and environmental vulnerability matrix.
Originality/Relevance: The relevance of the study is justified by evaluating the methodology that not only considers the physical natural environment, but also the ability of the community to prevent, absorb, resist/respond and adapt to socio-environmental disasters.
Main Results: The results have classified Brusque as a municipality of high socio-environmental vulnerability to landslides. This classification indicates a pattern of high environmental susceptibility with an increased number of inhabitants living in risk areas.
Contributions: This article aims to contribute through advances in evaluation research and the formulation of integrated risk and resilience management proposals in the municipalities of Vale do Itajaí/SC/Brazil. In this context, it is important to understand scenarios with the greatest impact of socio-environmental disasters as a tool for urban planning and disaster risk management in the city of Brusque/SC

Keywords: socio-environmental disasters; environmental vulnerability; impact; mass movements; Brusque.

Cite as - American Psychological Association (APA)

Mello, B. J., Souza, C. M. M., Aumond, J. J., Silva, J. I. A. O., Langa, E. D. & Novaes, J. M. Special Edition, 2023). Socio-environmental vulnerability to disasters: scenarios and challenges for the municipality of Brusque (SC). *J. Environ. Manag. & Sust., 12*(2), 1-27, e22368. https://doi.org/10.5585/2023.22368

Special Edition Guest Editors - Mudanças climáticas e planejamento urbano: cenários e desafios

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A VULNERABILIDADE SOCIOAMBIENTAL A DESASTRES: CENÁRIOS E DESAFIOS PARA O MUNICÍPIO DE BRUSQUE (SC)

Resumo

Objetivo do Estudo: Desde o início deste século, o município de Brusque (SC) tem experimentado um aumento significativo nas ocorrências de movimentos de massa, resultando em danos graves à infraestrutura da cidade e perda de vidas. O artigo objetiva classificar a vulnerabilidade socioambiental (VSA) do município de Brusque (SC) aos desastres socioambientais (movimentos de massa).
Metodologia: O mapa de VSA foi desenvolvido a partir de uma análise multicritério com auxílio do Sistema de Informação Geográfica (SIG). Para o funcionamento da classificação de VSA foi necessária a constituição dos índices de propensão (Ivs) e exposição (Iva). Os índices foram cruzados numa Matriz de Vulnerabilidade Socioambiental e aplicados ao mapa de setores censitários do município de Brusque.
Originalidade/Relevância: A relevância do estudo se justifica pelo desenvolvimento de uma metodologia de avaliação de vulnerabilidade socioambiental a desastres, que considera não apenas as questões do meio-físico natural local, mas também a capacidade de determinados grupos sociais em prevenir, absorver, resistir/responder e se adaptar aos desastres socioambientais.
Principais Resultados: Os resultados classificam o município de Brusque como de alta vulnerabilidade socioambiental à movimentos de massa. A classificação aponta um padrão de alta suscetibilidade ambiental e um progressivo aumento da população em vulnerabilidade social, localizada em áreas de risco.
Contribuições: este artigo vem no sentido de contribuir por meio de avanços em pesquisas de avaliação e formulação de propostas de gestão integrada dos riscos e da resiliência nos municípios do Vale do Itajaí/SC/Brasil. Nesse contexto, é importante a compreensão dos cenários de maior impacto dos desastres socioambientais, como ferramenta de planejamento urbano e gestão dos riscos de desastres no município de Brusque/SC.

Palavras-chave: movimentos de massa; vulnerabilidade socioambiental; desastres socioambientais; impacto; Brusque.

VULNERABILIDAD SOCIOAMBIENTAL ANTE DESASTRES: ESCENARIOS Y DESAFÍOS PARA EL MUNICIPIO DE BRUSQUE (SC)

Resumen

Objetivo de estudio: Desde el comienzo de este siglo, el municipio de Brusque ha registrado un aumento significativo en las ocurrencias de movimientos de masa, que han causado graves daños a la infraestructura de la ciudad y han provocado muertes. El artículo tiene como objetivo clasificar la vulnerabilidad socioambiental (SAV) de los sectores censales de la ciudad de Brusque (SC) a los desastres socioambientales (movimientos en masa).
Metodología: El mapa VSA se desarrolló a partir de un análisis multicriterio con la ayuda del Sistema de Información Geográfica (SIG). Para el funcionamiento de la clasificación VSA, fue necesario realizar cálculos para la constitución de los índices de propensión (Ivs) y exposición (Iva). Los índices fueron cruzados en una Matriz de Vulnerabilidad Socioambiental y aplicados al mapa de sectores censales en el municipio de Brusque.
Originalidad/Relevancia: La relevancia del trabajo de estudio se justifica por el desarrollo de una configuración en el uso de nuevas metodologías para la evaluación de la vulnerabilidad socioambiental a los desastres, que consideran no solo las cuestiones del entorno natural local, s lugares, pero también la capacidad de ciertos grupos para prevenir, absorber, resistir/responder y adaptarse a los desastres socioambientales.
Principales Resultados: Los resultados clasifican al municipio de Brusque como de alta vulnerabilidad socioambiental a los movimientos masivos. Clasificación Los resultados

apuntan a un patrón de alta susceptibilidad ambiental y un aumento progresivo de la población en vulnerabilidad social, ubicada en áreas de riesgo. Estos resultados configuran al municipio como altamente vulnerable a los movimientos masivos.
Contribuciones: este artículo tiene como objetivo contribuir a través de avances en la investigación de evaluación y formulación de propuestas de gestión integrada de riesgos y resiliencia en los municipios de Vale do Itajaí/SC/Brasil. En este contexto, es importante comprender los escenarios y áreas con mayor impacto de desastres socioambientales, para su mapeo como herramienta para la planificación urbana y la gestión del riesgo de desastres en la ciudad de Brusque/SC.

Palabras clave: movimientos de masas; vulnerabilidad socioambiental; desastres socioambientales; impacto; brusco.

Introduction

Human interventions in nature over the past few centuries have steered the planet toward a serious unprecedented socio-environmental crisis. This socio-environmental crisis has primarily been driven by imbalances in the relationship between environment and society, in which human activities and global warming are leading the Earth into a planetary era of unknowns (Artaxo, 2014; Steffen et al. 2015; IPCC, 2021). What is being recorded, among other consequences, is an increase in extreme and unusual weather events that culminate in socio-environmental disasters (UN/ISDR, 2015; IPCC, 2021). Socio-environmental disasters are events that alter local normality and may reach different scales, simultaneously, thereby causing high numbers of deaths and economic losses (Tierney, 2020). The socio-environmental disasters that have caused the most negative impact in the world are climate-related, including climate change, with floods, landslides, droughts, and heat waves causing the most deaths since the beginning of the century. In 2022, the emergency event database EM-DAT (CRED, 2023), recorded 387 socio-environmental disasters worldwide resulting in an economic loss of $223.8 billion and a loss of 30,704 lives, which is 3 times higher than the deaths recorded from extreme events in 2021, above the average for the years between 2010 and 2020.

The concern with risk management is expressed in international protocols on disaster reduction. The Hyogo Frameworks 2005-2015 and the Sendai Framework 2015-2030 emphasize the importance of protecting communities by promoting a safety culture based on the reduction of vulnerabilities and on public officials and communities recognizing disaster risk(Shaw, 2020). Currently, the most relevant body for disaster risk management globally is the United Nations Office for Disaster Risk Reduction (UNDRR). The UNDRR works with governments, civil society organizations, the private sector, and other stakeholders to ensure that disaster risk reduction is integrated into development policies, programs, and projects. In Brazil, the roots of disaster risk management are in the National Policy for Protection and Civil

Defense, which was created in 1979. In 1988, the National Secretariat for Civil Defense was created with the objective of coordinating protection and civil defense actions throughout the national territory. Over the years, this structure has been upgraded and strengthened, until arriving at the current National System of Protection and Civil Defense (SINDPEC).

Historically, the Vale do Itajaí region, part of the Southern Brazilian state of Santa Catarina (SC), has been affected by hydro-meteorological disasters (floods, mass movements, mudslides, and drought). The largest disaster occurred in 2008 and left more than 135 people dead, 5,617 homeless, and 4.5 billion BRL in economic damages (World Bank, 2012). The major socio-environmental impacts, including recorded deaths and financial losses, were mainly caused by mass movements. After the 2008 disaster, Vale do Itajaí has registered: (i) an increase in the exposure of people and urban infrastructure in disaster risk areas (including new human settlements in environmental preservation areas); (ii) the lack of an efficient housing policy and (iii) the fragmentation of disaster risk governance (Jansen et. al, 2021). These factors combined with climate change-related impacts have directly affected the adaptive capacity and resilience of urban ecosystems in Vale do Itajaí.

The research problem focuses on the increased exposure of people and urban infrastructure in risk areas since the 2008 disaster. Thus, this paper aims to classify the socio-environmental vulnerability (VSA) of the municipality of Brusque (SC) in relation to socio-environmental disasters, especially mass movements. To this end, the impact classification methodology of Cutter (2011) is used. In this context, identifying the levels of impact on different social groups in situations of risk for mass movement may be an important tool to improve disaster risk management in the municipality, given the absence of such a tool. Therefore, in addition to this introduction, the article is structured as follows: a) theoretical background; b) characterization of the study area; c) methodology; d) results and discussion; and e) conclusion.

Theoretical background

Human activities, grounded in development models aimed solely at economic growth have fundamentally altered the ecological shape and functioning of the planet on a wide range of scales. This implies a period in which humanity has become a geological actor on biological soil (Dalby, 2015). The last century saw the mass production of automobiles and electronics, the large-scale conversion of land into urban and rural areas, and an increase in the global population from 1.6 billion in 1900 to over 7 billion in 2020 (MA, 2005; Steffen, Crutzen & Mcneill, 2007). It has been recorded that of the 64 million km² of existing forests in the world less than 15 million km² remain, i.e., around 24% (EMBRAPA, 2015). Added to this is the increase in planetary temperatures, which by 2100 may have risen by up to 4.8º due to greenhouse gas emissions (IPCC, 2018). Human activities have become so pervasive and profound that they rival the great forces of nature and are pushing Earth toward a planetary unknown.

Managing the impacts of human-induced pressures on the earth's life support system is the greatest challenge humanity has ever faced (Steffen, Crutzen & Mcneill, 2007). Currently, the world is threatened by considerable damage and/or loss of natural resources, including rivers, lakes, seas, and forests, as well as experiencing major reductions in biodiversity and the massive threat of global warming (Ostrom, 2009). Global warming, in turn, produces negative side effects, such as climate change (IPCC, 2018). Changes in climate are one of the foremost issues that humanity and governments all over the world are facing. The Framework Convention on Climate Change (FCCC) defines climate change as "changes attributed directly or indirectly to human activity that transform the composition of the global atmosphere and that add to natural climate variability over comparable periods." According to the IPCC (2018), if major countries do not act, planetary temperatures could increase by up to 4.8 degrees by the year 2100. If greenhouse gas emissions continue to grow at their current rates, the rise in the sea level could be up to 82 cm and cause major damage in most coastal regions of the globe (IPCC, 2018). In this context, climate change could cause intense socio-environmental conflicts, such as disasters, urban exodus, potentiating social and cultural inequalities, including in Brazil (Sttefen et al. 2015; Artaxo, 2014; IPCC, 2021).

In Brazil, the Intergovernmental Panel on Climate Change (2021) has forecasted that, by the end of this century, there could be a 40 to 50% decrease in rainfall distribution in the Caatinga biome, which is likely to significantly worsen water availability in this location. In addition, the report has also indicated an increase in the intensity of rainfall in the Southern region of the country over the coming decades. This climate unpredictability increases the vulnerability of the population, especially for those who reside in risk areas. According to Beck (2015, p.132), "climate change fundamentally induces changes in landscapes of social class and inequality". These generate consequences such as water scarcity, disease and contamination, problems in the infrastructure of cities, increased risks of socio-environmental disasters, etc.

In this context, there is a strong correlation between the indicators of poverty and the exposure of some populations to risks from their environment. As many environmental justice researchers have emphasized, environmental inequality is undoubtedly one of the expressions of social inequality (Herculano, 2002; Acselrad, 2018). In this context, poorer populations tend to be more affected by risks arising from the place where they live (UN/ISDR, 2015). Hence, the focus of socio-environmental disasters emerges from within the scope of this inequality.

Disasters constitute one of the most frequent and most destructive phenomena occurring today (Tierney, 2020). Disaster signifies an event that affects the normality of social functioning and, by extension, causes damage and harm to society, thereby affecting the economy, ecosystems, basic structure, and human development (UN/ISDR, 2017). It is understood that [...] "we employ the term "socio-environmental disaster" rather than "natural disaster" because we understand that disasters are socially constructed" (Mattedi et al., 2009, p.15). Risk is a human construction in the face of uncertain events with damaging consequences (Almeida, 2014). Worldwide, socio-environmental disasters are increasingly frequent in everyday life and, in the main, impact the most socially vulnerable populations.

According to a report from the UN Office on Disaster Risk Reduction (UN/ISDR, 2015), approximately 89% of deaths occurring in the world, in extreme weather events, involve people in conditions of social vulnerability, chiefly in the so-called developing countries. During the period 1995-2015, climate change was responsible for 90% of the major socio-environmental disasters (UN/ISDR, 2017). According to the report "The Human Cost of Disasters 2000-2019," drawn up by the current UN Office for Disaster Risk Reduction (UNDRR, 2019), 7,348 socio-environmental disasters occurred during this period, resulting in almost 1.5 million fatalities.

In Brazil, the most frequent disasters are hydro-meteorological, i.e., those involving either an excess or scarcity of rainfall (floods, mass movements, floods, droughts, and droughts). Of the abovementioned extreme events, mass movements and floods are among those with the highest rates of mortality in Brazil (Carmo & Anazawa, 2014). Mass movements are gravitational movements responsible for the mobilization of soil, sediment, vegetation or rock downhill, and may include debris from homes and/or urban infrastructure. On the other hand, torrents are large amounts of water that flow violently as a result of heavy rainfall. In addition, these events have led to major disasters on a national scale, such as the Petrópolis tragedy in 2022 with 178 deaths, the disaster in the mountainous region of Rio de Janeiro in 2011 causing 918 deaths, and the 2008 disaster in Santa Catarina with 135 deaths (World Bank, 2012).

Despite efforts to reduce disaster risks, losses have increased over recent decades. Thus, the 2021 version of the Global Risk Report (WEF, 2021) indicated that socio-environmental disasters have increased both in terms of probability of occurrence and impact. The report further states that between 1995 and 2015 disasters cost the global economy around $2.97 trillion, while in Brazil, during the same period, disasters cost R$182.8 billion (UFSC, 2016). This increase seems to be associated with two main phenomena: a) the increasing process of concentrating people, equipment and assets in risk areas and; b) the tendential process of worsening climate change and; c) political and land management processes (Albala-Bertrand, 1993; Guha-Sapir, 2013).

While it is important to understand the natural systems and processes that give rise to risks and hazards, it is not possible to fully understand them.

> [...]This is because it is only from a combined study that a more comprehensive understanding about the circumstances that put people and the places where they live at risk is possible. Above all, to the hazards and factors that increase or reduce the ability of populations, physical-natural systems or infrastructure to respond and recover from environmental and social threats in different disaster risk scenarios (Cutter, 2011, p.59).

Against this background, for the study of disasters, such as mass movements, it is necessary to understand the relationship of social vulnerability (propensity) and socio-environmental susceptibility (exposure). Social vulnerability or risk propensity corresponds to the "potential for loss" (Cutter, 2011). According to this author, social vulnerability includes both the "elements of risk exposure" and the "factors of propensity to circumstances that increase or reduce the capacities of the population, infrastructure, or physical systems to respond to and recover from environmental threats". Risk exposure refers to the predispositions of a particular region, which has a human settlement, to be impacted by a particular physical event. This is the type of vulnerability that is usually studied by geographers, who tend to be concerned with the vulnerability of place. From the symbiotic relationship (propensity and exposure), the so-called socio-environmental vulnerability (Cutter, 2011) emerges.

It may thus be stated that socio-environmental vulnerability reflects the complexity of socio-environmental problems. It presents not only the probability of the place and its potential for material and human loss in case of a climatic event, but also indicates the social problems that potentiate them. The study of socio-environmental vulnerability is based on statistical analysis and methodologies of census data and on the study of population distribution and the material goods exposed to dangerous events, offering a broader perception of the pre-impact phase, which is essential for actions that minimize problems. In order to map and classify socio-environmental vulnerability, it is necessary to combine the mapping of risk exposure and risk propensity. The combination of these two factors, or other associated elements, gives light to the approach of socio-environmental disaster risk assessment (Cutter, 2011).

The city of Brusque (SC)

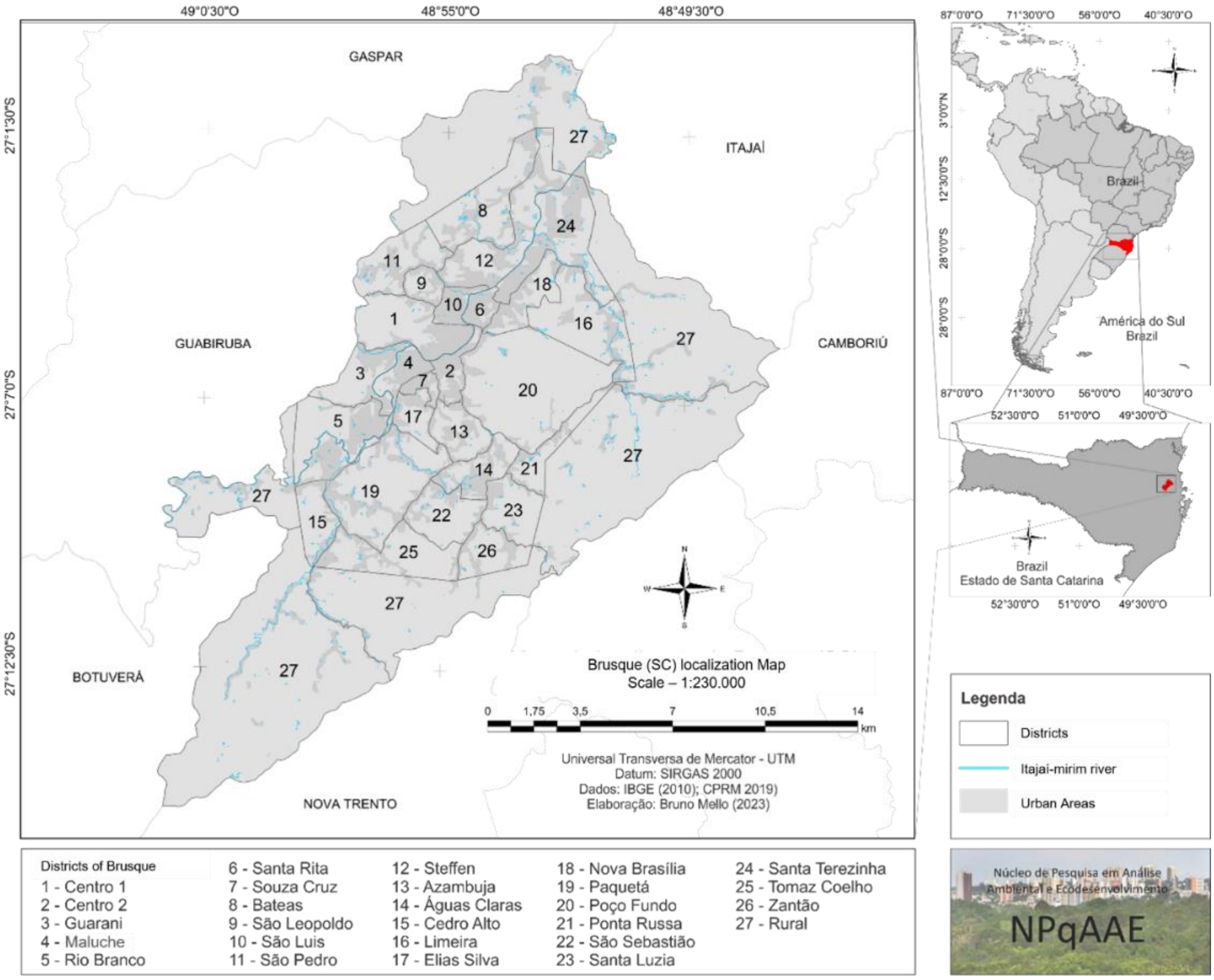
Brusque is a municipality located in the southern Brazilian state of Santa Catarina, precisely in the Itajaí Valley (Figure 1). The city was colonized in the middle of the nineteenth century by German immigrants. It has an estimated population of 140,597 (Brazilian Institute of Geography and Statistics - IBGE, 2021), 96% of whom live in the urban area. Its total area corresponds to 284.675 km². Brusque's gross domestic product per capita in 2018 reached 45,676 BRL and its human development index of 0.795, was considered very high (IBGE, 2018a; UNDP, 2010). According to IBGE (2010), in Brusque, approximately 7,000 people live in areas of high risk to socio-environmental disasters.

Since its colonization, the municipality has been hit by disasters (floods, mass movements, mudslides, and erosion) triggered by excessive rainwater (hydro-meteorological disasters). In 1983, an estimated 22,000 people were made homeless by intense flooding. In 2008, the most serious social and environmental disaster in the history of the city occurred, causing one fatality and more than 3,000 occurrences, including 1,500 mass movements, 200 collapsed power poles, 18 destroyed bridges. An estimated 8 thousand people were displaced, 3,500 were made homeless, 66 were injured, and one death was recorded (World Bank, 2012).

According to IBGE (2018b), in Brusque, approximately 8,000 people live in areas of high risk to mass movements. Under these circumstances, it is important to highlight the accelerated population increase that occurred between the years 2000 and 2022, in which the population of the municipality more than doubled, from 76 thousand inhabitants to approximately 140 thousand (IBGE, 2000; 2021). In addition, the actions of the local real estate sector (valorizing areas with lower disaster risk) combined with the increase in social vulnerability in the second half of the 2010s, expanded the occupation of peripheral hillside areas. The Mineral Resources Research Company report (CPRM 2019) revealed that in Brusque there are 630 points classified as risk areas to mass movements, which catalogues registered settlements (CPRM, 2011).

Figure 1

Localization map of the city of Brusque (SC)



Source: Own elaboration, based on vector data from IBGE (2010); CPRM (2019).

Thus, Brusque presents a significant indicator that the risks of disasters related to mass movements are worsening, whereby it combines: (a) the trend of increasingly unpredictable weather events with a greater magnitude (high rainfall) (IPCC, 2021; INMET, 2022); (b) an increase in the population living in situations of social vulnerability, in high risk areas of mass movements (IBGE, 2000; 2010; CPRM, 2019) and; (c) the undemocratic model of urban and risk management (including land use and occupation, master plans, housing planning, works code, basin plans, municipal sanitation plans, etc.) between the population and government institutions (Jansen, 2020). Therefore, a disaster may impact the population in different ways (with varying degrees of intensity depending on their social, economic, territorial, and cultural conditions).

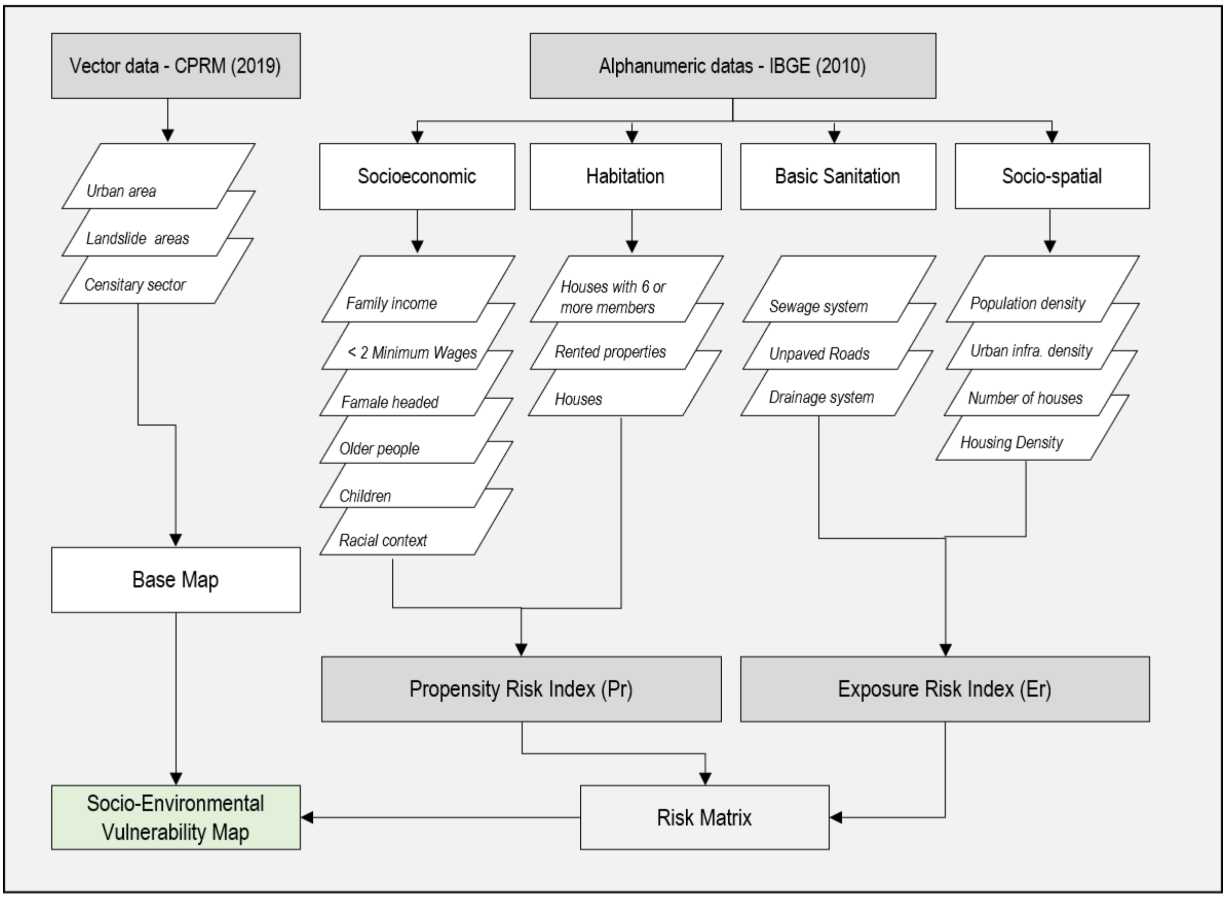
It is important to emphasize that the community of Brusque has previously demonstrated a certain resilience in relation to historical disasters, such as floods. Currently, however, risk managers and researchers are concerned about the destructive impact of mass movements in the municipality. The Municipal Civil Defense (MCD) in Brusque is the main entity responsible for disaster risk management in the region, and has its own headquarters for inspecting and monitoring risk areas. The MCD website provides freely available information regarding flood and rainfall quotas, as well as 19 shelters distributed mainly in churches. The MCD also runs educational activities in schools and evacuation simulations. Although the MCD also provides geological risk and flood susceptibility maps, there is however, no map that considers the impact and damage potential of extreme events. Hence, it is important to understand the areas with the greatest impact from socio-environmental disasters in order to map them as a tool for urban planning and disaster risk management in the municipality.

Methodology

This is a qualitative-quantitative explanatory study that culminates in the classification and mapping of socio-environmental vulnerability to mass movements in the municipality of Brusque (SC), based on the methodology of Cutter (2011). The research addressed the urban area of the municipality of Brusque (SC) with specific focus on areas at risk of mass movement. In this context, all neighborhoods of the municipality were analyzed with a special focus on susceptibility sectors to mass movements mapped by CPRM (2019). Quantitative research aims to quantify the information in order to analyze it. Qualitative research seeks to describe the relationship between the world and the subject. The qualitative analysis in this study emerges from the evaluation of the visual and descriptive aspects presented, as well as an understanding of the context in which these elements were created. Lastly, the explanatory portion seeks to answer the causes of the events, facts, physical or social phenomena found in the research universe, describing the concepts of the phenomena or the establishment of relationships between the concepts (Jansen, 2020).

Figure 2

Methodology for the construction of the socio-environmental vulnerability map of Brusque



Source: Own elaboration.

Against this background, the study was conducted through an analysis and grouping of several environmental, socioeconomic and urban infrastructure variables. The purpose was to classify the impact of mass movements in different contexts of the city of Brusque (SC). The variables were arranged into two risk dimensions: i) propensity and ii) exposure. Subsequently, from the indices obtained, for each of the dimensions, the results were cross referenced in a risk matrix (Cutter; 2011), culminating in an impact mapping with the aid of the geographic information systems (GIS) Esri Arcmap 10.8 ©.

Indicators

For Cutter (2011) the components that increase the propensity (Ivs) to risk are: i) populations with special needs, older people and children: mobility issues; requiring special care; greater intransigence; ii) socioeconomic status: ability to absorb damage and recover; bearer of material assets to lose (family income); iii) race and ethnicity: language and cultural barriers; lack of access to post-disaster resources; tendency to occupy high hazard zones; iv) gender: jobs with high rate women contractors may be affected; mothers head of household; lower wages; care-giving tasks and; v) housing type and urban infrastructure: often tenants are neither insured nor invest in the community; housing type and construction; lack of sanitation. In this respect, based on the definition of conceptualized assets (CUTTER, 2011) variables and dimensions were used to design the propensity scores. The risk exposure (Iva) aims to quantify the number of people (potential loss of life) and the amount of material, i.e., urban infrastructure (potential economic losses) in disaster risk areas. This step is challenging since the existing data for the census sectors only quantify the number of households. Thus, the number of urban roads, urban equipment such as schools, hospitals, health clinics, industries, shops, parks, squares, sports courts, etc., have not been identified. Hence, the variables used to measure the population's exposure to risk were made available by IBGE (2010) and CPRM (2019) (Table 1).

Table 1

Variables that increase the propensity and exposure to landslide hazards

Indicator	Code	Variable
Propensity	V1	Average family income
	V2	% of population with up to 2 minimum wages
	V3	% of single mothers
	V4	% of older people (those aged 60)
	V5	% of child population (up to 12 years old)
	V6	% of Black, mixed-race, or indigenous populations
	V7	% of permanent private households with 6 or more residents
	V8	% of rented households
	V9	% of households of the house type
	V10	% of households with no adequate sewage system
	V11	% of unpaved roads
	V12	% of roads with no urban drainage
Exposure	V13	Population density (people/há)
	V14	Population in the Census Tract
	V15	Urban infrastructure density (buildings/ha)
	V16	Number of households in the Census Tract

Source: Own elaboration with data from the 2010 Census (IBGE, 2010; CPRM, 2019).

Having defined the alphanumeric data of the census sectors for propensity and exposure, the next step was to standardize the variables using the methodology of Reis, Ribeiro and Silva (2020), with adaptations. The reference values were extracted from the fraction between the occurrence of the variable in the census sector in relation to the total number of households or people in the respective sector. In this case, it was necessary to use maximum and minimum parameters in each variable to also transform it into a standardized variable, with values ranging from 0 to 1. Hence, 0 corresponds to the ideal, or desirable, situation, and 1 corresponds to the worst situation. The Risk Propensity and Exposure variables were calculated separately using Equations (1) and (2):

$$Ips = \frac{Is - Imin}{Imax - Imix} . p \qquad (1)$$

$$Ips = \frac{Is - Imax}{Imin - Imax} . p \qquad (2)$$

Considering the geographic clippings of IBGE census sectors: 1) the variable Ips corresponds to the standardized value of the indicator (I) (Reis, Ribeiro & Silva, 2020); 2) Is is equivalent to the original value of the indicator (I); 3) Imax and Imin are, respectively, the maximum and minimum value of the indicator (I) within the universe of census sectors; and 4) (p) matches the weight applied to each variable. For indicators with a direct relation to vulnerability (the lower the indicator value, the lower the vulnerability), Equation (1) was used. With regard to the indicators with an indirect relationship with vulnerability (the lower the indicator, the higher the vulnerability), Equation (2) was used (V1 - family income). The IVs for propensity and IVa for exposure were then calculated from Equation (3).

$$IVx = \sum_{i}^{n} = 1 \text{ Ips} \qquad (3)$$

The IVx corresponds to the propensity index (IVs) and/or exposure index (IVa) in the census sector of the municipality, and the variable "n" corresponds to the total of variables selected by dimension (Reis, Ribeiro & Silva, 2020). With obtaining the separate Propensity and Exposure indices, in alphanumeric form using Microsoft Excel, it was possible to cross reference IVs and Iva in a risk matrix, culminating in the VSA classification.

Risk Matrix

Impact or risk matrices are two-dimensional techniques that relate actions to environmental factors. Impact matrices are basically identification methods (Calvalcante & Leite, 2016), although they can incorporate assessment parameters. These matrices can be simple or complex, depending on the amount of information being worked with (IBAMA, 2001). The Impact or Risk Matrix may present a major deficiency by not considering temporal aspects in its analysis or by taking into account only the direct impacts of the project (Fogliatti et al., 2004). On the other hand, according to Costa et al. (2005), the method, besides allowing for results that are easy to understand, addresses the relationship between the biophysical and social variables. By cross referencing the indexes obtained in propensity and exposure in the risk/impact matrix (Table 2) it was possible to classify the socio-environmental vulnerability of each census sector exposed to mass movements in Brusque.

Thus, the classification of socio-environmental vulnerability is determined by cross-referencing the indicators in the risk matrix (Table 2): VL – Very Low; L – Low; ML – Medium Low; M – Average; MH – High Average; A - High; VH – Very High. Thus, this map may contribute both to understanding the geolocation of populations most exposed to socio-environmental risks and to identifying the level of impact of landslides. Furthermore, it was also possible to analyze the most critical areas of the municipality of Itajaí and thereby map out scenarios.

Table 2

Impact matrix or risk matrix

		Propensity (Pr)									
Exposure (Er)		0 - 0.099	0.100 - 0.199	0.200 - 0.299	0.300 - 0.399	0.400 - 0.499	0.500 - 0.599	0.600 - 0.699	0.700 - 0.799	0.800 - 0.899	0.900 -1
	1 – 0.900	M	M	MH	MH	H	H	VH	VH	VH	VH
	0.800 - 0.899	M	M	M	MH	MH	H	H	VH	VH	VH
	0.700 - 0.799	ML	M	M	M	MH	MH	H	H	VH	VH
	0.600 - 0.699	ML	ML	M	M	M	MH	MH	H	H	VH
	0.500 - 0.599	L	ML	ML	M	M	M	MH	MH	H	H
	0.400 - 0.499	L	L	ML	ML	M	M	M	MH	MH	H
	0.300 - 0.399	L	L	L	ML	ML	M	M	M	MH	MH
	0.200 - 0.299	VL	L	L	L	ML	ML	M	M	M	MH
	0.100 - 0.199	VL	VL	L	L	L	ML	ML	M	M	M
	0 – 0.099	VL	VL	VL	L	L	L	ML	ML	M	M

Source: Own elaboration, adapted from Cutter (2011).

Elaboration of the Socio-environmental Vulnerability Classification Map (IVSA)

There are several ways to expose the intersection of physical and social environment vulnerability, the most advantageous being spatial cartography (Cutter, Mitchell & Scott, 2000; O'Brien et al., 2004; Zahran et al., 2008; Cutter; 2011). The development of the socio-environmental vulnerability map made use of GIS-based technologies, in this case Esri Arcmap 10.8©. In order to construct the socio-environmental vulnerability map, three processes were implemented: i) constructing the base map; ii) applying Cutter's (2011) risk/impact matrix; and iii) including the alphanumeric results in the base map, generating the VSA classification map.

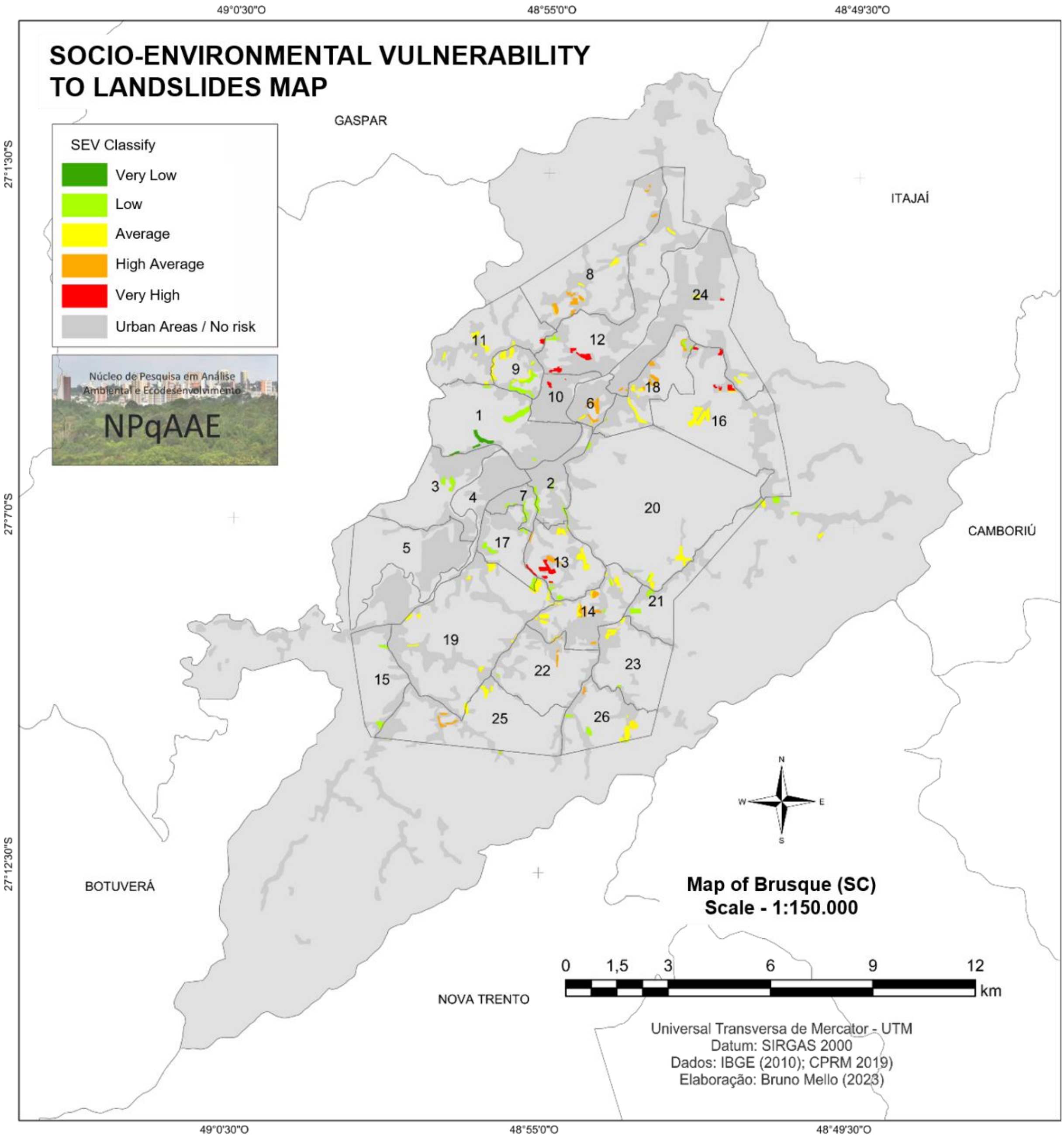
To build the base map, the vectors of the IBGE census sectors (2010) were used. This cartography is essential, since the alphanumeric census data may only be applied in mapping through this vector. The Brusque vector data (areas of high susceptibility to mass movement and the built-up urban area and municipal boundaries) were made available by the Mineral Resources Research Company (CPRM, 2019) by means of CDs (Compact Disk). By using the geographic information systems (GIS) Esri Arcgis 10.8©, the map of areas susceptible to mass movements was intersected with a map of the urban area and a map of the IBGE census sectors (2010), in order to delimit the urban areas that may be affected by the event. Thus, the base map was obtained to receive the intersected indices of propensity (IVs) risk (IVa) and exposure to risk through the Cutter matrix (2011) (Table 2).

Results and Discussion

The results of the mapping and classification of socio-environmental vulnerability (Figure 3) in Brusque indicate a worsening trend in the impact of disasters caused by mass movements. Two hundred and sixty five mass movement risk sectors registered by CPRM (2019) were identified, whereby 8 sectors were classified as very low socio-environmental vulnerability, mostly located in the neighborhoods Centro 1, Centro 2 and Santa Luzia; 45 sectors as low socio-environmental vulnerability, mainly in the neighborhoods Centro 1, São Leopoldo, Azambuja, Poço Fundo, Ponta Russa and Loteamento Elias Silva; 111 sectors as medium socio-environmental vulnerability, present in 20 neighborhoods; 89 sectors as high socio-environmental vulnerability, located mainly in the neighborhoods Água Claras, Azambuja, Bateas, Nova Brasília, Zantão and Tomas Coelho; and 23 sectors classified as very high socio-environmental vulnerability, occurring in the neighborhoods Bateas, Steffen, Azambuja, Águas Claras and Limeira.

Figure 3

Map of socio-environmental vulnerability to landslide impacts



Source: Own elaboration with data from the 2010 Census (IBGE, 2010; CPRM, 2019).

Among the risk sectors identified in the research, 73, classified as high and very high socio-environmental vulnerability, are particularly outstanding and deserve special attention. Of these: 9 are located in the Azambuja neighborhood, where the severest conditions are observed in the vicinity of Luiz Machado (Figure 4A), Florêncio Day and João Vanolli streets; 7 sectors in the Steffen neighborhood, where the most concerning conditions are in the vicinity of the SF-34, Olga Day de Souza (Figure 4B) and SF-006 streets; 8 sectors in the Água Claras neighborhood, with the highest risks on Adelina Ziercke (Figure 4C), Anna Wiedecker, Eduardo Wiedecker, José Ramiro Dias and Valdir Gerarti streets. The Brusque Civil Defense estimates that in these areas, 1,800 people in 500 residences are exposed to the risk of landslides. There are also 12 risk sectors in the Bateias neighborhood, with significant loss potentials on Bertoldo Todt (Figure 4D), Ana Duarte and Beto Duarte Hill, where approximately one thousand people are exposed to risk. Another 9 risk sectors are in the São Sebastião neighborhood, with a similar landscape to the Steffen neighborhood, and 11 sectors in the Limeira and Nova Brasilia neighborhoods, with worse conditions on Rotary and Carlos Boos streets. Lastly, the Zantão neighborhood presents 4 risk sectors, where approximately 1.1 thousand people in 300 residences are exposed to the risk of mass movements, according to the CPRM (2011).

Figure 4

Sectors of high socio-environmental vulnerability to landslides in Brusque (SC)

Legenda: (A) Bairro Azambuja; (B) Vista para as ruas Olga Day de Souza e SF-034 – Steffen; (C) Rua Adelina Ziercke – Águas Claras; (D) Rua Bertoldo Todt – Bateas.

Source: Own elaboration.

The areas classified as low and very low socio-environmental vulnerability indicate locations with a low population density, high socioeconomic status and a high risk of mass movement. The excess of points classified as medium socioenvironmental vulnerability is justified by three factors: i) most of the population in Brusque is considered middle class (IBGE, 2020); ii) there is a tendency for the population of higher social vulnerability to occupy slope areas, thus providing, in many cases, areas of low exposure and high propensity and; iii) on the other hand, areas of high risk exposure are located mainly in the central areas of the city where the population has a higher socioeconomic status. The points of high and very high socio-environmental vulnerability represent a small portion of the invisible population, which presents a condition of high social vulnerability and high risk exposure.

Given this scenario, the southern and northern regions of Brusque may be the most affected areas, both directly and indirectly, with regard to the occurrence of mass movements. Therefore, it is crucial that disaster risk management sets out to prioritize these areas. However, we observe that investments in flood protection are made in more valorized areas of the municipality, such as those for the construction of an avenue along the Itajaí-Mirim River and storm water drainage works in the central zone. This demonstrates a situation of injustice of risk materialized within the city landscape, where areas with the highest risk of death are occupied by the poorest population, while areas of controlled risk are occupied by the middle and upper classes. Moreover, disaster-free areas are occupied by the wealthy. Lastly, an extreme weather event of high rainfall in Brusque could be catastrophic due to the following trends:

i) an intense incubation period of vulnerabilities: an exponential population increase followed by an amplification of social vulnerability, which consequently expanded the exposure of the population and urban infrastructures to the risk of mass movements. Also, the strengthening of real estate speculation, especially in safe areas, the lack of investments and the lack of an efficient housing plan increase the probability of the impact of extreme weather events. These conditions have made the urban infrastructure and people unable to respond, absorb and recover from the impacts of this event;

ii) Prolongation of the crisis: the crisis becomes economically more costly because there are more people, businesses, housing, and urban infrastructures in risk areas that may be affected by mass movements. In other words, a greater potential for loss. An exit becomes more time-consuming due to the increased population in situations of social vulnerability in risk areas (the inability to recover without state aid) (FGV, 2018; Avila & Mattedi, 2017). Added to this, since 2014, there have been fewer investments in disaster prevention (*Folha de São Paulo*, 2020).

iii) Perpetuation of risk: inefficient/inexistent housing plans, the mentality of rapid reconstruction in risk areas, a lack of enforcement, growth in the number of dwellings in environmental preservation areas, lack of sustainable strategies/solutions for housing construction, real estate speculation among other factors prepares the municipality for the next disaster. With this context, it is therefore necessary to consider a model that will strengthen local resilience to mass movements, although not only in terms of the rapid reconstruction of degraded areas. But rather, in a model that may improve the operational response, provide a faster and less costly exit from the crisis, and mitigate the perpetuation of risk, developing more sustainable alternatives for occupation and accepting that certain areas should not be occupied (Siebert, 2020; The Kresge Foundation, 2015).

From the conditions presented in Brusque, a long and/or intense period of rainfall, such as that of 2008 (489 mm of rainfall in two days - 30-year return period), could directly or indirectly affect more than 100 thousand people, and could leave 7 to 10 thousand people homeless (considering that the population increased from 100 thousand inhabitants in 2008 to 140 thousand in 2021). Deaths may show a tendency to increase, especially in peripheral areas (of high social vulnerability and difficult access). The economic impacts will also be greater, considering that the urban infrastructure has increased by approximately 13% (IBGE, 2021). Thus, the municipality is heading for an even more costly disaster, difficult to escape and slow to recover from, demanding more public resources and more community efforts.

Final Considerations

The present article has sought to study aspects of the socio-environmental vulnerability that underlie the links between social inequalities and socio-environmental disasters. The application of this methodology to the case of Brusque/SC reveals the tendency for the problem of disasters to become worse during recent decades. If, on the one hand, there has been a progressive decrease in the effectiveness of the prevailing pattern of disaster management in Brusque (concentrating protection in central areas and generalizing risk to peripheral areas susceptible to mass movements), on the other, the main vector is an intensification in the dynamics of urbanization. It may be stated, therefore, that socioenvironmental disasters cause the socioenvironmental problems of a region to materialize. Thus, the classification of socioenvironmental vulnerability has signaled the progressive loss of control over the phenomenon of socioenvironmental disasters in Brusque.

It is therefore necessary to introduce an improved risk governance model that strengthens local resilience, not only to ensure the rapid reconstruction of degraded areas after a crisis, but also to strengthen the perception of the population regarding the risk, increasing their autonomy, ensuring the conditions for them to respond more independently, thereby minimizing the loss of life. Lastly, the following suggestions are put forward: i) to invest in resilient infrastructure, capable of absorbing the impact of extreme disaster events; ii) to improve contingency plans; iii) to conduct regular training programs for the population; iv) to improve the coordination between government agencies; v) to promote public awareness and risk communication; vi) to invest in technology: new technologies, such as monitoring sensors and early warning systems; vii) to conduct vulnerability studies; viii) to prevent new human settlements in risk areas; ix) to invest in basic sanitation; ; x) to relocate residents, in cases of extreme necessity, in a sustainable and socially just manner; xi) to develop more effective public policies such as an efficient housing plan and; xii) to foster social participation in decision making, thereby encouraging a sense of belonging.

This study has the potential to contribute theoretically to the development of research that focuses on identifying the impact of disasters, going beyond a response to action and reaction situations. Furthermore, there are few methods available that seek to quantify the relationship between socioeconomic and environmental factors that exacerbate socioenvironmental disaster risks. The use of the concepts proposed by Cutter (2011) seems to be a more suitable approach for Brazil, due to his views on social vulnerability and exposure, which are emerging factors in Brazil. The practical contribution of this study lies in the fact that mapping socio-environmental vulnerability may be a valuable tool for risk management, since it enables the identification of the most vulnerable areas to socio-environmental disasters and the population groups with the greatest potential for impact. Based on this information, the authorities may implement more effective preventive and mitigation plans and actions.

The method used is based on widely available geospatial tools and technologies, allowing the method to be adapted to different types of risks and socioeconomic and environmental contexts. Furthermore, the measurement and mapping of social and physical vulnerability may be adapted to different geographic scales, from local communities to entire countries and regions. However, it is vital to remember that the replicability of the method may depend on the availability of accurate and up-to-date geospatial and socioeconomic data, as well as the ability to gather and integrate information from different disciplines. The main limitation of this study is the 2010 Census database. In using data from the IBGE (2010) database, it is essential to point out that over the last decade the demographic density of the municipality of Brusque has increased considerably, and the wage income, as well as the consumption power, have undergone relevant changes. To circumvent this problem, an observational field study was conducted to minimize serious distortions of the socio-spatial reality. In this context, the vulnerability that is reflected in the city's landscape may be apparently greater than that presented by the results of this article.

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