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Application of a socio-environmental vulnerability index for disasters through a Geographic Information System (GIS): a case study in Blumenau (SC)

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Authors' notes'

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Abstract

Objective: To map and classify the socio-environmental vulnerability of regions in the municipality of Blumenau (SC) to socio-environmental disasters (floods and landslides) through the construction of a socio-environmental vulnerability index (SEVI) for the period 2000-2020.

Method: The SEVI map was developed from a multicriteria analysis with the aid of a geographic information system (GIS). For the SEVI to operate, it was necessary to prepare the indices of environmental susceptibility (ES) and social vulnerability (SV), which were then cross-referenced in an impact matrix.

Relevance: To develop a methodology for assessing the socio-environmental vulnerability to disasters, which considers issues related both to the local natural environment and to the ability of social groups to resist/respond to disasters.

Results: The results have indicated an increase in informal settlements in permanent preservation areas, environmental degradation, social inequality and consequently a population exposed to risk. In short, Blumenau presents a pattern of high susceptibility and an exacerbated increase in social vulnerability, which thereby configures a highly vulnerable scenario for socio-environmental disasters.

Contributions: Advances made in evaluation research and in formulating integrated management proposals for risk and resilience in the municipalities of Vale do Itajaí/SC/Brazil. In this context, it is essential to understand the scenarios with the greatest impact of socio-environmental disasters, as a tool for urban planning and disaster risk management in the municipality of Blumenau (SC).

Keywords: Socio-Environmental Vulnerability Index (SEVI), Geographic Information Systems (GIS), Social and Environmental Disasters, Blumenau (SC)

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Aplicação do índice de vulnerabilidade socioambiental a desastres por meio de Sistema de Informação Geográfica (SIG): estudo de caso do município de Blumenau (SC)

Resumo

Objetivo do Estudo: Mapear e classificar a vulnerabilidade socioambiental das regiões do município de Blumenau (SC) aos desastres socioambientais (inundações, enxurradas e deslizamentos de terra) por meio da construção de um índice de vulnerabilidade socioambiental (SEVI) para os anos de 2000 e 2020.

Metodologia: O mapa IVSA foi desenvolvido a partir de uma análise multicritério com auxílio de Sistema de Informação Geográfica (SIG). Para o funcionamento do IVSA foi necessário a confecção dos índices da suscetibilidade ambiental (SA) e vulnerabilidade social (VS) para os anos de 2000 e 2010, posteriormente projetados para o ano de 2020. Os índices de SA e VS são cruzados numa Matriz de Impacto. Assim, constituiu-se os Mapas de Vulnerabilidade Socioambiental comparativos para os anos de 2000 e 2020.

Originalidade/Relevância: Desenvolvimento de uma metodologia de avaliação de vulnerabilidade socioambiental a desastres, que considera as questões do meio-físico natural local e capacidade de grupos sociais em resistir/responder aos desastres.

Principais Resultados: Os resultados apontam um aumento das ocupações irregulares em áreas de preservação permanente (APP), da degradação ambiental, da desigualdade social e consequentemente da população exposta ao risco. Em suma, o município apresenta um padrão de alta suscetibilidade e um exacerbado aumento da vulnerabilidade social, o que configura um cenário altamente vulnerável aos desastres socioambientais.

Contribuições: 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 Blumenau (SC).

Palavras-chave: Índice de Vulnerabilidade Socioambiental (SEVI), Sistemas de Informações Geográficas (SIG), Desastres Socioambientais, Blumenau (SC)

Aplicación del índice de vulnerabilidad social y ambiental ante desastres a través del Sistema de Información Geográfica (SIG): estudio de caso del municipio de Blumenau (SC)

Resumen

Objetivo del Estudio: Mapear y clasificar la vulnerabilidad socioambiental de las regiones del municipio de Blumenau (SC) a los desastres socioambientales (inundaciones, aluviones y deslizamientos) a través de la construcción de un índice de vulnerabilidad socioambiental (IVSA) para periodo de 2000 e 2020.

Metodología: El mapa IVSA se elaboró a partir de un análisis multicriterio con la ayuda de un Sistema de Información Geográfica (SIG). Para el funcionamiento del SEVI fue necesario elaborar los índices de susceptibilidad ambiental (SA) y vulnerabilidad social (SV). Los índices SA y VS se cruzan en una Matriz de Impacto. Así, se crearon los Mapas de Vulnerabilidad Social y Ambiental.

Originalidad/Relevancia: Desarrollo de una metodología para la evaluación de la vulnerabilidad socioambiental a los desastres, que considera aspectos relacionados con el entorno natural local y la capacidad de los grupos sociales para resistir/responder a los desastres.

Principales Resultados: Los resultados apuntan a un aumento de las ocupaciones irregulares en las áreas de preservación permanente (APP), la degradación ambiental, la desigualdad social y consecuentemente la población expuesta a riesgo. En definitiva, el municipio presenta un patrón de alta susceptibilidad y un aumento exacerbado de la vulnerabilidad social, lo que configura un escenario de alta vulnerabilidad a los desastres socioambientales.

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Contribuciones: Avances en la investigación de evaluación y formulación de propuestas de gestión integral de riesgos y resiliencia en los municipios de Vale do Itajaí/SC/Brasil. En ese contexto, es importante comprender los escenarios de mayor impacto de desastres socioambientales, como herramienta para la planificación urbana y la gestión del riesgo de desastres en el municipio de Blumenau (SC).

Palabras clave: Índice de Vulnerabilidad Socioambiental (SEVI), Sistemas de Información Geográfica (SIG), Desastres Sociales y Ambientales, Blumenau (SC)

Introduction

Socio-environmental disasters are currently one of the most frequent and destructive phenomena (Tierney, 2020). Despite management efforts, losses from disasters have increased over the past three decades. Thus, the 2019 version of the Global Risks Report (WEF, 2019) indicated that socio-environmental disasters have increased both in terms of probability and impacts. This process seems to be associated with two main phenomena: a) the growing concentration of people, equipment and assets in risk areas and; b) the tendency for climate change to worsen. As a result, the loss of life (direct impacts) and economic damage (indirect impacts) have become a threat, especially to less developed regions (Guha-Sapir, 2013; Albala-Bertrand, 1993). Paradoxically, therefore, while management is becoming increasingly more necessary, it is always insufficient.

Quantitative data on invested resources also reveal that the problem in Brazil is becoming worse. Between 1995 and 2014, no less than 9 billion BRL (2.8 billion USD) was invested annually, with a total of 182.8 billion BRL (56.7 billion USD) over this 20-year period (UFSC, 2016). As a result, a growth in the recurrence of disasters and their magnitude have caused negative impacts that affect thousands of people. This signifies that socio-environmental disasters jeopardize the quality of people’s life and are a vector for increasing social inequality (Mattedi et al., 2018). This process occurs because disasters are very dynamic phenomena and

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it is necessary to be aware of the risk factors in advance in order to develop management strategies (IPEA, 2015). It may therefore be seen that identifying disaster-prone areas is a fundamental component in the process of appropriate management for socio-environmental disasters.

The case of the Itajaí Valley in general and the municipality of Blumenau (in the Brazilian state of Santa Catarina) in particular are no different. Despite a long history of living with disasters, the problem has yet to be adequately managed, especially since recent studies have indicated that conditions of risk will worsen (Mattedi et al., 2018). The disaster risk situation is accentuated by the population's exposure to areas of high geological and flood risk (Avila & Mattedi, 2017). Simultaneously, the populations in the most susceptible areas of Blumenau also present low levels of education, income, basic sanitation, and access to information. Thus, it may be understood that the risk of disasters in Blumenau is associated with socioeconomic and environmental factors. For efficient disaster risk management in the municipality, it is necessary to identify and classify the environmental and social vulnerabilities of the different land occupation models.

In this context, it is of vital importance to include the disaster risk management (DRM) strategy in an active and articulate manner on the agenda of local governments (Brazil, 2017). Disaster risk management is important because reducing the impacts of socio-environmental disasters involves understanding the complexity of the relationship between society and nature. Over the last 30 years, the concept of DRM has evolved significantly whereby some common points have remained in the concept while others have varied. This understanding may be improved using DRM, since models may: 1) simplify complex events; 2) make it possible to compare the real situation with a theoretical model; 3) allow for the quantification of disaster events; 4) establish a common basis of understanding for all the actors involved (Ludwig et al., 2018). The role of science and technology is primarily concerned with understanding socio-environmental disasters through risk assessments.

Monitoring vulnerability to disasters has been the subject of many studies (Cutter, 2006; Phillips et al., 2010; Bankoff et al., 2007). An attentive look at these challenges indicates that one of the emerging strategies is continuous risk monitoring. Thus, a tool used to identify and classify which areas are most prone to impacts from extreme weather events is the Socio-Environmental Vulnerability Index (SEVI). The SEVI is based on the use of geographic information system (GIS) technologies and by cross-referencing demographic and cartographic data, environmental susceptibility and social vulnerability, key elements for the SEVI, may be mapped. Given its flexibility and the possibility of integrating different types of data, the SEVI has been applied to various areas of knowledge, such as health (Malta et al., 2017) and geography (Kuhlick et al., 2013).

Essentially, climate change is able to change the risk of disasters both by increasing vulnerability and decreasing resilience, since it a) intensifies the occurrence of the event, and b) reduces the capacity to manage the impacts.

Since the publication in 2012 of the IPCC report Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation, the global average annual precipitation is expected to increase by the end of the century, although changes in the amount and intensity of precipitation vary significantly by class. Therefore, the worsening impacts of disasters revealed by both the 2017 Annual Report and the Final Report of the 2016-17 Biennium Work Programme (UNISDR, 2018) and the 2017 Annual Disaster Statistical Review seem to express the materialization of climate change. Taking these factors into account indicates the need to adapt local plans, programmes and projects to the effects of climate change.

Therefore, since climate change modifies the pattern of vulnerability, it consequently increases the destructive potential of natural disasters. Hence, by considering the relationship between climate change and disasters globally, it is possible to identify four main trends:

a) there is an annual increase in the number of disasters;

b) there is an increase in the number of people affected by disasters;

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c) losses are becoming more costly;

d) the poorest regions are the most affected.

This signifies, as mentioned above, that disaster management is paradoxical in that it is becoming increasingly more necessary but is constantly insufficient.

Blumenau is an emblematic case study for the development and application of the SEVI. Throughout its process of urban formation and economic development, the municipality has suffered more than 68 floods and numerous cases of landslides (Kormann, Robaina & Mattedi, 2021). Although both structural and non-structural strategies for managing the problem have been introduced, there has been a strong tendency for socio-environmental impacts to worsen over recent years. Locally, there have been two general trends in Blumenau: a) hydrometeorological phenomena are becoming more random, and b) a population concentration in floodplain and hillside areas. This thereby indicates the need to develop new cognitive interpretation tools and social management devices that enable people to learn to live with risk. Therefore, the case of Blumenau presents both a theoretical and practical interest for the application of SEVI.

With these factors in mind, the aim of this article is to map the socio-environmental vulnerability of regions in the municipality of Blumenau to socio-environmental disasters. More precisely, this article aims to develop a SEVI and classify the socio-environmental vulnerability of the municipality of Blumenau in two time frames - 2000 and 2020. Studying these two scenarios has enabled a comparative analysis so as to understand the socio-environmental dynamics of vulnerability. In order to develop this argument, the text has been divided into five sections, including this brief contextualization. Section two reviews the literature on the relationship between socio-environmental disasters and SEVI. Section three characterises the case study and

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section four explains the methodological strategies used to produce the data. The fifth section presents the results of applying the Blumenau SEVI.

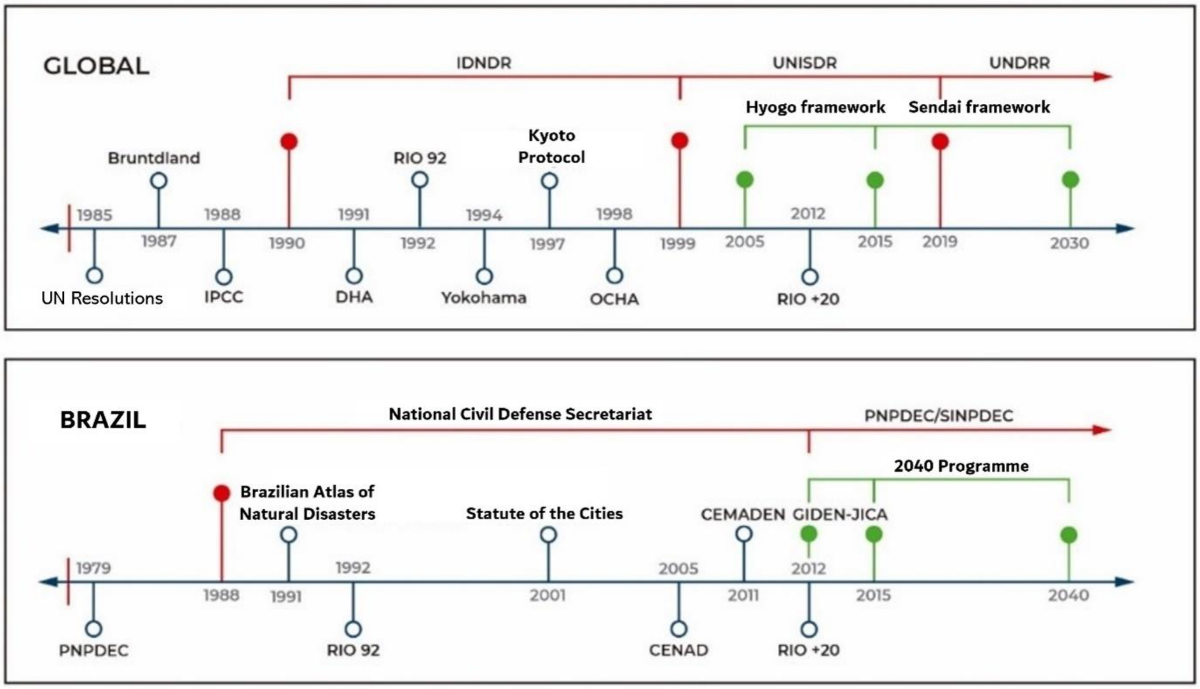
Natural disasters as emerging effects of socio-environmental relations

The study of natural disasters has been the subject of many theoretical and methodological controversies (Alexander, 1993; Stallings, 2002; Tobin, Montz, 1997, Quarantelli 1998; Prery and Quarantelli, 2005). In general, it may be said that natural disasters are unexpected consequences of the prevailing pattern of interactions between society and nature. The various theoretical strategies differ according to the emphasis placed on natural and social factors (Mattedi & Butzke, 2001). Therefore, it is possible to differentiate between two main strategies for addressing natural disasters: a) Hazard Paradigms: centred on the geographical approach (physical event); b) Vulnerability Paradigms: centred on the sociological approach (social impact). This may therefore be characterized as the emerging effect of the process of dissolving the socio-technical networks that symbolically and materially link the natural world to the social world (Mattedi, 2017).

Natural disasters are the subject of a truly comprehensive set of integrated management actions. This concern is expressed in international disaster management protocols. The Hyogo Framework for Action 2005-2015 emphasizes an international strategic vision that ratifies preparedness, prevention and mitigation as fundamental goals for nations to protect communities (Santos, 2011), in order to promote a culture of security based on reducing vulnerabilities, recognition and awareness of disaster risk on the part of public agents and communities (Soriano, 2009). The Sendai Framework 2015-2030 established four priorities: a) Understanding disaster risk; b) Strengthening disaster risk governance; c) Investing in disaster risk reduction for resilience; and d) Improving disaster preparedness in order to provide an effective response and better reconstruction (Sendai Framework, 2015).

Figure 1

Timeline of Disaster Risk Reduction actions (1985-2019)



Source: Own elaboration, adapted from Shaw (2020, p. 3).

According to Figure 1, one of the most relevant bodies for disaster risk management worldwide is the United Nations Office for Disaster Risk Reduction (UNDRR). The UNDRR works with governments, civil society organisations, the private sector and other stakeholders to ensure that disaster risk reduction is integrated into development policies, programmes and projects. In Brazil, disaster risk management has its roots in the National Civil Protection and Defence Policy, which was created in 1979. In 1988, the National Civil Defence Secretariat was created to coordinate civil protection and defence actions throughout the country. Over the years, this structure has been improved and strengthened, until it became the current National Civil Protection and Defence System (SINDPEC). One of the main institutions that makes up SINDPEC is the National Centre for Monitoring and Warning of Natural Disasters (CEMADEN), which monitors, prevents and warns of natural disasters throughout Brazil.

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However, recent climate change has altered the pattern of how natural disasters occur (IPCC, 2012), because rising temperatures are intensifying droughts, forest fires, and heatwaves, as well as floods, landslides and tropical cyclones. Therefore, alterations in the state of the climate have ultimately changed the frequency, intensity, extent and duration of climatic events. These changes have been detected by considering the average variations in climate properties over a period of time. The variations are caused by both natural internal processes and anthropogenic external processes. With the development of climate science over recent years, it has been discovered that temperature and precipitation are very important predictors of the impacts caused by disasters. The combined effect of these phenomena will have profound impacts on the health, food, security, infrastructure and economy of various regions (Mora et al., 2018). Therefore, with climate change it is likely thata natural disasters will become more frequent and more intense.

On the one hand, for a socio-environmental disaster to occur, there must be a triggering physical event. The biophysical and climatic conditions of a given territory may have characteristics that expose its population to risk, i.e. the place is susceptible. Thus, susceptibility is the measure of whether a given phenomenon is likely to occur, irrespective of social factors, although with society as an element of interference that may either accelerate it or delay it (Freitas & Cunha, 2013). Here, the human element enhances susceptibility, and analysing it indicates an understanding of the likelihood of a harmful event occurring to the population living in a given location. If certain territories have physical characteristics that pose a risk to human life, this signifies that a certain region is predisposed to the incidence of a certain phenomenon (physical event) (Burton et al., 1993).

On the other hand, to understand environmental disasters, it is also necessary to consider the social characteristics of the population. Hence, the concept of vulnerability corresponds to the "potential for loss" (Cutter, 2011). According to Cutter, vulnerability includes both the elements of risk exposure and the factors of propensity to circumstances that increase

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or reduce the capacities of the population, infrastructures or physical systems to respond to and recover from environmental threats. Despite this understanding, the study of vulnerability is considered to be a product of exposure to hazardous processes and predisposing factors. In these studies, the social vulnerability of residents is accentuated by the risk to which the population is exposed as a result of living in disaster-prone areas (Avila & Mattedi, 2017). Consideration of vulnerability therefore involves the socio-economic influences on space.

Based on these factors, environmental susceptibility may be differentiated from social vulnerability. Environmental susceptibility refers to the predispositions of a given region to be impacted by a given physical event (spatial propensity), and social vulnerability refers to the degree to which a population is exposed to social impacts (community exposure). The relationship between these two sets of variables allows us to establish a SEVI analytical matrix. Thus, SEVI refers to both the probability of losing an element or a set of elements and is based on: a) the possibility of damage from a risk situation and; b) the result of exposure to risk (Ludwig & Mattedi, 2018). This signifies that the SEVI captures the dynamics that shape a given spatiality, seeking to circumscribe its scale, i.e., a region, city or neighbourhood, in order to identify the risks of a place.

Figure 2 demonstrates that the relationship between susceptibility and vulnerability makes it possible to build the operational elements for applying the SEVI. More precisely, it is possible to establish causal links between the probability of a physical event occurring and the probability of this event generating a social impact. This signifies that the emerging effects triggered by a natural disaster depend jointly on disposition (physical characteristics of the region) and exposure (pattern of social organisation). However, it should also be noted that the relationship between these two dimensions is not linear. In fact, it depends on the calibration of two contextual factors: a) climate change has altered the recurrence of hydrometeorological regimes; and b) the pattern of occupation and development concentrates populations in risk

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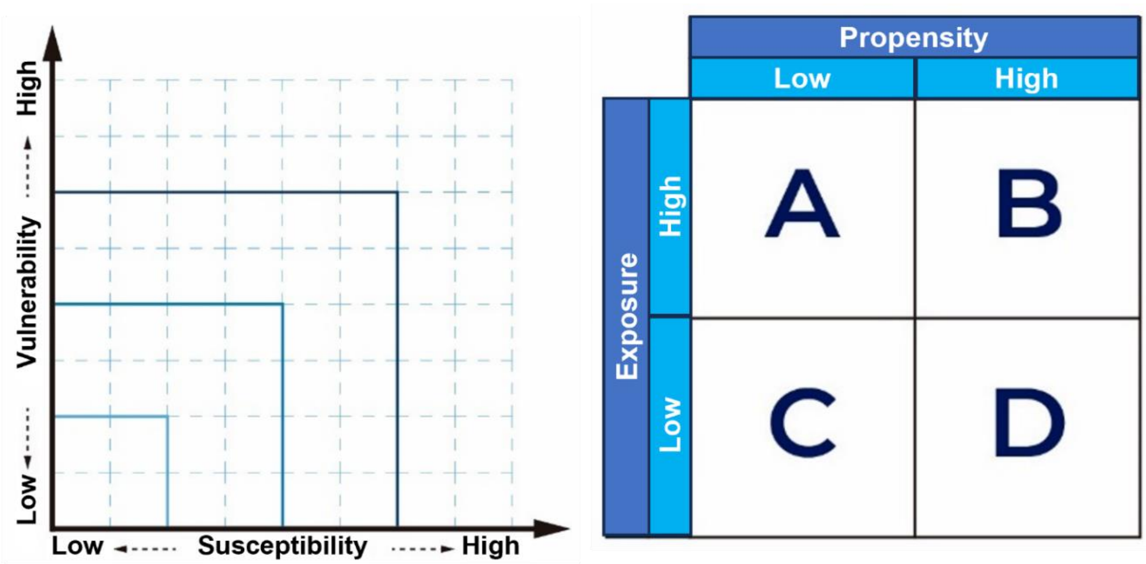
areas. The combined effect makes it possible to create an analytical matrix for establishing hypothetical SEVI scenarios.

Figure 2

The relationship between the scales of vulnerability, disposition and exposure



Source: Own elaboration (2022)

- **SCENARIO A (safe):** establishes a relationship between a condition of low susceptibility and low vulnerability (areas with no risk and with protection capacity);

- **SCENARIO B (potentially safe):** a relationship between low susceptibility and high vulnerability (areas with no risk and with high protection capacity);

- **SCENARIO C (potentially unsafe):** relates low susceptibility to high vulnerability (areas with no risk, but with little protection capacity);

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- **SCENARIO D (unsafe):** establishes a relationship between high susceptibility and high vulnerability (areas with a very high level of risk and no ability to react).

From this relationship between disposition and exposure, it is possible to establish socio-environmental vulnerability. In other words, this is the convergence of limit situations and "explosive" spectra that involve the occurrence of numerous natural and man-made stressful situations within the same timeframe and space. Thus, by crossing and interacting, these vulnerabilities produce harmful results for a given population and the surrounding environment. This is a relationship that leads to the idea of the simultaneous existence of: 1) Background problems: limited access to electricity, structures, resources and political and economic systems; 2) Dynamic pressures: lack of local institutions, training, investment, urbanisation, excessive deforestation and declining soil productivity; 3) Unsafe conditions: dangerous locations, buildings and infrastructures, low income levels, lack of public actions and institutions and; 4) Hazardous events: earthquakes, floods, drought, viruses and so on (Wisner et al., 2004).

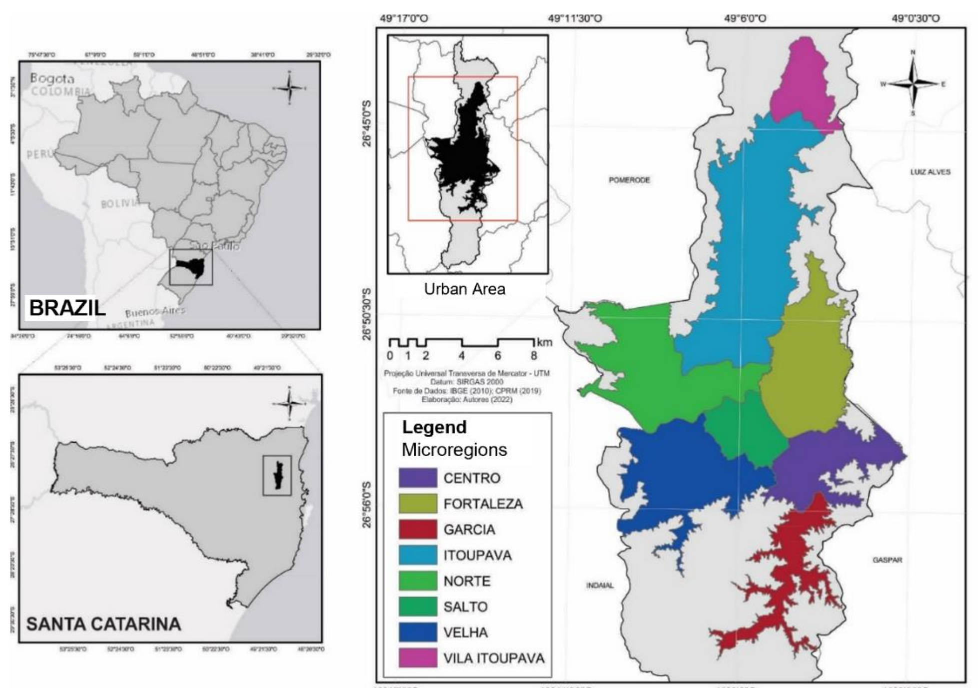
It may therefore be stated that socio-environmental vulnerability reflects the complexity of socio-environmental problems. It shows not only the probability of the place and its potential for the loss of things and people in the event of a climatic event, but also the social problems that potentialize them. The study of socio-environmental vulnerability is based on statistical analyses and methodologies of census data and the study of the distribution of the population and material goods exposed to hazardous events. This provides a broader perception of the pre-impact phase, which is essential for actions to minimise the problem. In order to map and classify socio-environmental vulnerability, it is necessary to combine the mapping of environmental susceptibility and social vulnerability. The combination of these two factors and other associated elements sheds light onto socio-environmental disasters.

The production of socio-environmental disasters in Blumenau (SC)

Blumenau is a municipality located in the southern region of Brazil, in the state of Santa Catarina (Figure 3). It is the seat of the Itajaí Valley mesoregion and is the region's most important economic centre. It was founded in the mid-nineteenth century by immigrants of German origin. The population is approximately 350,000 inhabitants (The Brazilian Institute for Geography and Statistics - IBGE, 2010), delimited by an area of 519,000 km², with more than 90% of the population living in urban areas. The Human Development Index is 0.806, considered very high (UNDP, 2010). Ever since it's colonization, the municipality has faced socio-environmental disasters, triggered by extreme climatic events such as excessive rainfall, which causes flooding, flash floods, erosion and landslides. This is an historical problem and has become worse over time.

Figure 3

Localization Map of Blumenau (SC)



Source: Own elaboration (2022)

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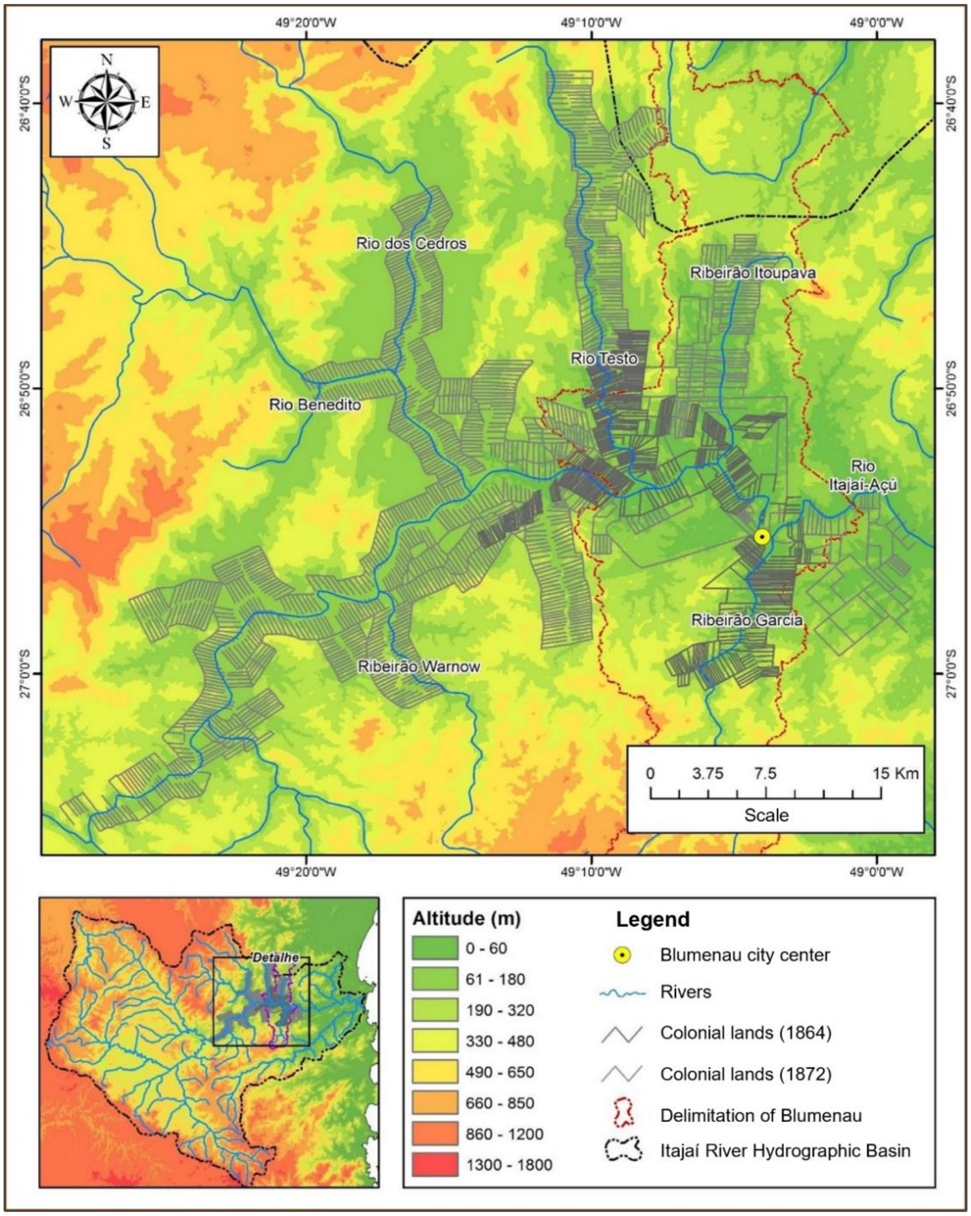
The development process of Blumenau has been accompanied by the problem of disasters and during its 160-year history, the municipality has recorded 68 floods (Mattedi et al., 2009). The first major flood occurred in 1880, reaching a flood level of more than 17 metres. "In 1983 and 1984, floods of more than 15 metres affected 70% of the urban network. In 1990, a flood caused the death of 22 people" (Siebert, 2012, p. 7. Our translation). In 2008, the most serious socio-environmental disaster in the history of the municipality took place, leaving 24 dead - 21 of whom were buried in mudslides and 3 drowned, hundreds were injured, and 25,000 people were forced to leave their homes, causing losses of hundreds of millions of Brazilian Reals (CEPED, 2016). For Siebert (2012), the recurrent occurrence of major socio-environmental disasters is the result of an urbanisation process based on constant conflict with the natural environment, with attempts to adapt it to human needs. The occupation that has developed on the river plains has structured the process of occupation, strongly marked by water resources (Figure 4).

Figure 4

Agricultural plots depicting the colonial occupation of Blumenau



Source: Kormann, 2014.

The natural constraints of this process are mainly the Itajaí-Açu river and its tributaries, such as the Velha, Garcia and Itoupava streams, and the hills and slopes. The terrain of the city is extremely rugged, and its flattest parts are located close to the watercourses, corresponding to the flood plains of the Itajaí-Açu River and its main tributaries. These areas, which

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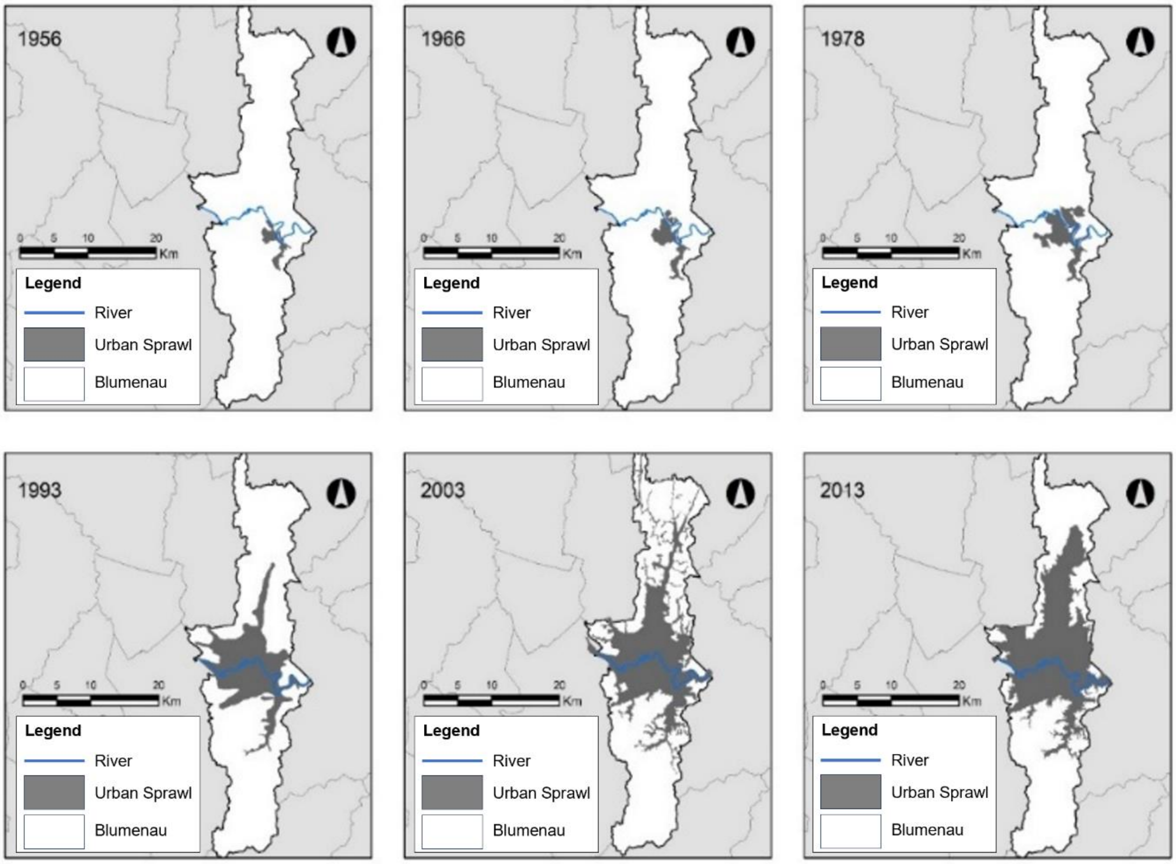
correspond to Quaternary lithology, are the most recent, and are highly susceptible to flooding and inundation. Another part of the population occupies the slopes of the hills, which basically have lithology from two major formations: a) the Itajaí Group; and b) the Santa Catarina Granulite Complex. The Itajaí Group is a more fragile lithology, corresponding to a steeper relief that is extremely susceptible to landslides. The Santa Catarina Granulite Complex is an older, and therefore, more altered geology, less rugged and more stable, but nonetheless, landslides occur in regions with high slopes.

In Blumenau, the process of urban development was conditioned by the pattern of land occupation resulting from the fragmentation of the old colonial plots. With industrialisation, the urban development process triggered a double concentration: the population concentrated near the industries and also along the banks of the rivers. With the intensification of disasters in recent decades, the effect of this process has been: a) the verticalization of floodplain areas (gentrification by the middle class) and; b) the occupation of hillsides (the lower class). Reproduction may also be observed, with areas regularised by the city council (good urban infrastructure on the floodplain) inaccessible to the poorest who occupy the hillsides. Hence, the middle class is impacted by floods and the less well-off communities by landslides and torrents. Figure 5 shows the urban evolutionary process in the municipality of Blumenau.

Figure 5

Urban development in the municipality of Blumenau (1956-2013)



Source: Own elaboration with the Blumenau City Hall (PMB) database (2013).

The process of strengthening disaster risk management (DRM) in the region began with the implementation of dams on the tributaries of the Itajaí-Açu River during the second half of the twentieth century, with the aim of minimising the impact of recurrent floods that interfered with industrial and agricultural development. After the great floods of 1983/1984, the Crisis Project and the Operational Centre for the Itajaí-Açu River Basin Warning System (CEOPS) were implemented. In 1986, the JICA Project was drawn up, presented to the state of Santa Catarina by the Japan International Cooperation Agency (JICA), and was responsible for creating disaster warning and prevention systems, as well as structuring the municipal civil defence. The Blumenau Municipal Civil Defence was established in 1989. After the 2008

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disaster, the municipal DRM set up a warning and communication system for climatic events called ALERTABLU in 2013. According to Jansen et al. (2021), the score of the intitutional organisational structuring index (IEOI) for the Blumenau civil defence is aover 0.80, which is considered very developed.

Within this context, the communities and the municipal civil defence are only prepared to deal with extreme weather events up to a certain extent. However, the biggest problem lies in the lack of preparation to deal with increasingly serious situations that combine increased social vulnerability and exposure to the risk of landslides and floods, which have become increasingly frequent. According to the IBGE (2018), Blumenau has 31 subnormal settlements and 78,371 inhabitants living in vulnerable areas, which represents 25 per cent of the population. Blumenau ranks as the seventh municipality with inhabitants living in flood and landslide areas.

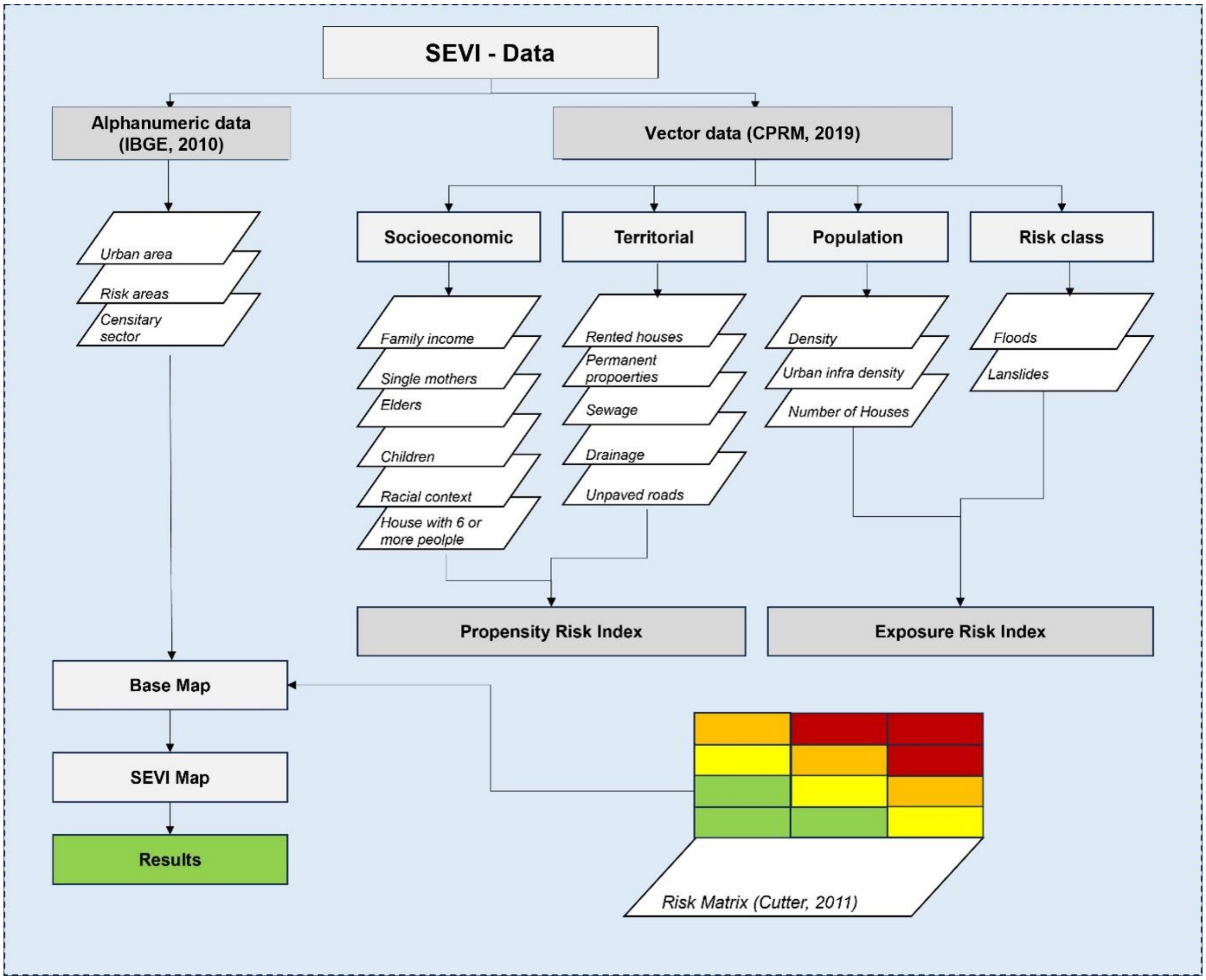
Considering these aspects, we argue that the problem of socio-environmental disasters in Blumenau is progressively moving from a **SCENARIO B** toward a **SCENARIO D** (Figure 2). More precisely, this worsening trend indicates that Blumenau is progressively losing its ability to control the disaster problem, which signifies that the effects of climate change associated with the predominant pattern of development in the region are transforming the local risk level. In other words, Blumenau is moving from being a city characterised by High Susceptibility and Low Vulnerability to a city with High Susceptibility and High Vulnerability. The reason for this is because risk-free areas and the protection capacity are decreasing, i.e., **the more intense the vulnerabilization process, triggered by climate change, and a higher concentration of the population in risk areas, the lower the local capacity to react and recover.**

Construction Methodology of the SEVI

The study examined the urban area of the municipality of Blumenau (SC) focussing specifically on areas at risk of mass movement. It was a qualitative-quantitative explanatory study that has culminated in the classification and mapping of socio-environmental vulnerability to hydrometeorological disasters, based on Cutter's methodology (2011), during the years 2000 and 2020. Quantitative research aims to quantify information in order to analyse it, while qualitative research seeks to describe the relationship between the world and the subject. The explanatory portion ultimately 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 establishing relationships between the concepts (Jansen, 2020). Within this context, the study was carried out by analysing and grouping various environmental, socioeconomic and urban infrastructure variables in order to classify the impact of natural disasters in the different contexts of the municipality of Blumenau (SC). The variables were arranged into two dimensions: Propensity and Exposure to risk. Later, after obtaining the indices through calculations for each of the dimensions, these were cross-refenced in a Risk Matrix (Cutter, 2011) culminating in a mapping and classification of socio-environmental vulnerability for the years 2000 and 2020, with the aid of geographic information systems (GIS). Figure 6 presents a flowchart of this methodology.

Figure 6

Flowchart of the methodological path of this study



Source: Authors (2022).

Indicators

For Cutter (2011) the components that increase the propensity to risk are: i) special needs populations and older people: this affects mobility; requires special care; and greater intransigence; ii) the socioeconomic status: the ability to absorb damage and recover; more 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 areas; iv) gender: jobs with high rates of feminisation may be affected; mothers as heads of household; lower wages; caregiving tasks and; v) type of housing and urban infrastructure: tenants often lack insurance and invest in the community; type of housing and construction; lack of basic sanitation. In this context, based on the definition of assets conceptualised by Cutter (2011), indicators and dimensions were proposed to design the propensity indices (Table 1).

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Table 1

Variables that increase risk propensity (2000-2010)

Variable	Description
Average family income	Income is one of the fundamental factors in controlling the population's susceptibility to disaster risk. According to IBGE (2010), a monthly household income of up to 3 minimum wages constitutes a situation of social vulnerability.
% of single mothers who are heads of household	A high occurrence of single mothers in a particular area is characterized as a factor of social vulnerability.
% of older population (60 years and older)	An excess of older people in a sector constitutes vulnerability due to factors such as greater resistance to change, cognition, knowledge, and difficulty in mobility during emergencies.
% of child population (up to 12 years)	Children and adolescents are vulnerable to environmental and social situations. An excess of children in a sector constitutes vulnerability due to a lower capacity to respond to danger (cognitive, understanding the problem, decision-making, among others).
% of Black, brown, or indigenous population	The Black, brown, or indigenous population constitutes groups with a higher number of individuals in situations of social vulnerability with a greater tendency to occupy risk areas – environmental racism.
% of permanent private households with 6 or more residents	The population density in residences increases vulnerability, meaning more people may be impacted by risks.
% of rented households	Population in rented homes tends to lack a connection with the location – reducing knowledge, response, and engagement in management – as well as having a lower capacity to invest in the property to absorb the impact.
% of oermanent households, house type	Houses, especially single-storied, tend to have fewer structural possibilities to absorb impacts, making them more exposed to damage caused by floods, mass movements, and flash floods.
% of households without adequate sanitation	The lack of adequate sanitation implies that the impact of climatic events is aggravated, not only in environmental degradation but also in the emergence of diseases and difficulty in recovering the affected area.
% of unpaved roads	One of the major problems found in both urban centres and rural areas is the deficiency in maintaining urban roads. Although unpaved roads contribute to drainage, the lack of maintenance has a direct impact on emergency mobility.
% of urban roads with no drainage	The lack of urban drainage has a direct impact on exacerbating floods and mass movements.

Source: Own preparation with data from the 2000; 2010 Census (IBGE, 2000; 2010).

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Risk exposure aims to quantify the number of people (potential loss of life) and the number of materials, i.e. urban infrastructure (potential economic loss) in disaster risk areas. This stage is difficult to pin down, as the existing data for census sectors only quantifies the number of households. Therefore, the number of urban roads, urban facilities such as schools, hospitals, health centres, industries, shops, parks, squares, sports courts and others were not identified. In this context, the variables used to measure the population's exposure to risk were provided by IBGE (2010) and the Mineral Resources Research Company - CPRM (2019).

Table 2

Variables that increase exposure to risks (2000-2010)

Variable	Description
Population Density (people/ha) (IBGE, 2010)	The higher the concentration of people in risk-prone areas, the higher the potential for victims.
Urban Infrastructure Density (Residence units/ha) (IBGE, 2010)	In addition to increasing the risk of death, since the concept of mass movements also considers debris from residences, the potential for material losses is increased, complicating recovery and expanding the cost of the disaster. Indirect impact is also increased, affecting the normality of the entire community (e.g., damage to roads affecting mobility, electricity grid, water supply, garbage collection, health, and education services, etc.).
Number of households in the census sector (IBGE, 2010)	The more households there are in a sector, the greater the urban infrastructure exposed to the direct and indirect impacts of disasters.
Susceptibility Classification (CPRM, 2019)	Observance of susceptibility classification to mass movement and floods (High, Medium, and Low).

Source: Own preparation with data from the 2000; 2010 Census (IBGE, 2000; 2010).

With the alphanumeric data from the census sectors for propensity and exposure tabulated, the next step was to normalise the variables using the methodology by Reis, Ribeiro and Silva (2020), with adaptations. This adjustment makes it possible to apply the index and

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thus characterise the vulnerability of Blumenau. The reference values are 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 for each variable to transform it into a standardised variable with values ranging from 0 to 1. In other words, 0 corresponds to the ideal or desirable situation and 1 corresponds to the worst situation. Thus, the risk propensity and exposure variables were calculated separately using Equations (1) and (2):

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

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

According to Reis, Ribeiro and Silva (2020), the variable *Ips* corresponds to the standardised value of the indicator (I) in the census tract (s). It is equivalent to the original value of indicator (I) in census tract (s), and Imax and Imin are, respectively, the maximum and minimum value of indicator (I) within the universe of census tracts, and (p) refers to the weight applied to each variable. Equation (1) was used for indicators with a direct relationship to vulnerability (the lower the value of the indicator, the lower the vulnerability). For indicators with an indirect relationship to 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 using Equation (3).

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

Thus, IVx corresponds to the propensity index (IVs) and/or exposure index (IVa) in the census sector of the municipality, and variable n corresponds to the total number of variables selected by dimension (Reis; Medeiros & Silva, 2020). Once the separate propensity and exposure indices were obtained, in alphanumeric form using Microsoft Excel, it was possible to cross-reference IVs and IVa in a risk matrix, culminating in the VSA classification. Once the IVs and IVa of the Blumenau census sectors had been calculated for the years 2000 and 2010, it was possible, by means of an integral calculation, to prospect the results for the year 2020 using Equations (4) and (5).

$$ka = \frac{\Delta ivx}{\Delta t} \quad (4)$$

$$Ivxt = Ivo + Kax\,(t - to) \quad (5)$$

In this context, the coefficient Ka signifies the variation of the intermediate index (SEVI of 2010) and the initial index (SEVI of 2000) (∆ivx) divided by the variation of the intermediate time (2010) and the initial time (2000) (∆t) (Equation 4). Next, the arithmetic projection is calculated taking into account Ivxt, which is the index for 2020, Ivo is the initial index, Ka is the coefficient found from equation (4), and finally t, which is relative to the end time (2020) and to the initial time (2000). By cross-referencing the indices obtained for propensity (IVs) and exposure (IVa) in a risk/impact matrix (Table 3), it was possible to classify the socio-environmental vulnerability of each census tract exposed to disaster risks in Blumenau in 2000 and 2020.

Impact or risk matrices are two-dimensional techniques that relate actions to environmental factors. Although they can incorporate evaluation parameters, they are basically identification methods. Matrices may be simple or complex, depending on the amount of information you are working with (Brazilian Institute of Environment and Renewable Natural Resources - IBAMA, 2001). The impact or risk matrix may be very deficient because it does not consider temporal aspects in its analysis and only takes into account the direct impacts of the project (Fogliatti et al., 2004). On the other hand, according to Costa et al. (2005), in addition to making the results easy to understand, the method addresses the relationship between biophysical and social variables.

Table 3

Impact matrix or risk matrix

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

Source: Own preparation, adapted from Cutter (2011)

Thus, the socio-environmental vulnerability classification, obtained in alphanumeric form, was related to the base map, thus developing the SEVI maps of Blumenau (2000 and 2020). On the map, each census tract in the municipality was classified according to the cross-referencing of the indices: (Table 3): White - no significant risk; L - Low risk - in green; M - Medium risk - in yellow; H – High risk - in orange; and VH - Very High risk - in red. This map may contribute both to understanding the geolocation of the most-exposed populations to socio-environmental risks and to identifying the impact level of extreme hydrometeorological events. It was also possible to analyse the most critical areas in the municipality and to project scenarios.

Preparation of the Socio-environmental Vulnerability Map

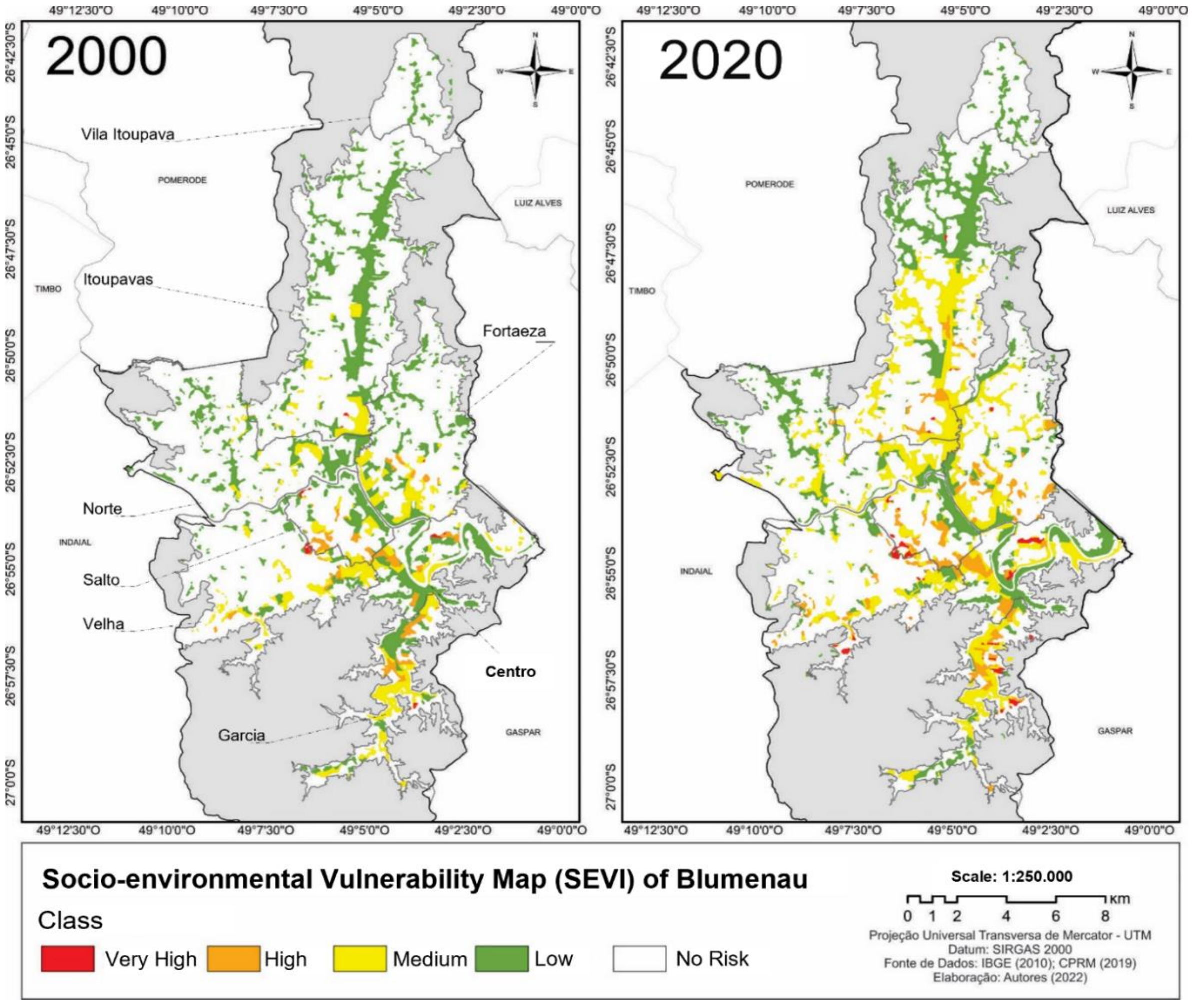
While there are various ways of showing the intersection of physical and social vulnerability, the most advantageous is spatial mapping (Cutter; Mitchell; Scott; 2000; O'Brien et al., 2004; Zahran et al., 2008; Cutter; 2011). The socio-environmental vulnerability map was developed using GIS-based technologies, in this case Esri Arcmap 10.8©. To build the base maps, we used geospatial data containing the location of the IBGE (2010) census sectors, which is essential, since alphanumeric census data can only be applied to mapping using this vector. Vector data for areas of high environmental susceptibility and built-up urban areas were obtained from the IBGE map portal (2000 and 2020) and administrative boundaries were made available by CPRM (2019) via compact disks. Using Esri Arcgis 10.8© GIS, the areas susceptible to mass movements were spatially cross-referenced with the urban area and the IBGE census sectors (2010), so as to delimit only those occupied areas that could be affected by the event. Lastly, the socio-environmental vulnerability classification was applied in alphanumeric form (excel) to each census tract already delimited by its disaster risk area.

Classifying socio-environmental vulnerability in Blumenau (SC)

Figure 7 presents the socio-environmental vulnerability map (SEVI) of Blumenau. The study identified 258 high-risk areas for mass movements and flooding, as registered by the CPRM (2015). The SEVI map identified 50 areas of low socio-environmental vulnerability, mostly located in the central and northern areas of the municipality, 184 areas of medium socio-environmental vulnerability, in all the municipal neighbourhoods, and 19 areas of high socio-environmental vulnerability, mainly in the south and north of Blumenau.

Figure 7

The SEVI maps of Blumenau (SC)



Source: Own elaboration (2022).

The Garcia micro-region of Blumenau presents environmental conditions that are extremely susceptible to floods, torrents and landslides. In recent years, there has been an increase in the number of informal settlements located in peripheral areas, in areas classified with very high socio-environmental vulnerability: Rua Araranguá, Rua Carlos Spliter, Rua Arnoldo Zimmermann, Rua Grevsmuehl and others. These are areas occupied by people of low socioeconomic status, located in areas most susceptible to landslides and flooding at the

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headwaters of the drainage system. Most of the housing occupies flood plains with medium and high socio-environmental vulnerability.

The neighbourhoods of the Centro micro-region are, in the main, highly exposed to flooding. In general, the data for this micro-region shows an increase in population density and in the number of facilities and urban infrastructure. Occupations in areas susceptible to mass movements are less common. In this context, the communities with very high socio-environmental vulnerability are Morro da Pedreira and Pedro Krauss. Since this is the main commercial and institutional centre of the municipality, the area has been provided with infrastructure, urban planning, prevention systems and training for the population regarding this type of event.

The neighbourhoods of the Velha and Salto micro-regions are classified with low and medium socio-environmental vulnerability in their regularised urban areas, since these areas suffer less frequently from the impact of disasters. Although the socio-economic level of the population, for the most part, demonstrates a good family income, adaptation to environmental conditions (homes, urban infrastructure and risk perception) is limited and reduces the capacity to withstand extreme weather events. The communities with very high socio-environmental vulnerability are: Coripós, Morro da Dona Edith, Morro da Figueira, Vila Bromberg, Vila Feliz and some areas on Rua Bahia along the banks of the Itajaí-Açu River. The northern micro-region has seen a population increase and, at the same time, a decrease in socio-economic conditions and infrastructure, however, the region has very low environmental susceptibility.

In the Fortaleza micro-region there are many settlements in areas susceptible to landslides and flooding. The areas of very high socio-environmental vulnerability are: Toca da Onça, Nova Esperança and Morro da Laguna. Currently, 52 per cent of the Itoupava micro-region is classified as medium and 32 per cent as medium-low socio-environmental vulnerability. At various points, the region is susceptible to flooding and landslides, such as Rua

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Gustavo Zeck and Vila União. The Vila Itoupava micro-region presents good socio-economic conditions and infrastructure, resulting in low socio-environmental vulnerability.

It may be said that there was a dramatic increase in socio-environmental vulnerability in Blumenau between 2000 and 2020. This dynamic reflects the increased urbanisation in areas susceptible to floods, torrents and landslides. The growth of these settlements is due to the high price of land in less environmentally susceptible areas, in parallel with an increase in unemployment and the precarious socio-economic conditions of the population. Lastly, it may be stated that the population in the municipality of Blumenau is highly vulnerable to socio-environmental disasters.

Final Considerations

Applying the SEVI to the case of Blumenau has revealed a worsening trend in the problem of disasters between 2000 and 2020. It has indicated, on the one hand, that the transition from Scenario B to Scenario D implies a progressive decrease in the effectiveness of the predominant pattern of disaster management in Blumenau (concentrating protection in central areas and generalising risks to the peripheral areas); and, on the other hand, that the main vector is the intensification of urbanisation dynamics (a concentration of populations in risk areas). While the combined effects of this process make disaster management ever more necessary, it is nonetheless always insufficient. This is why, despite growing investment in forecasting and response strategies, the impacts are becoming worse. The study used geospatial tools and technologies to measure and map exposure to risk (physical vulnerability) and census data on people's propensity to risk (social vulnerability) in order to create analyses based on Blumenau. The intersection of physical and social vulnerability created the landscape of risks (hazardscape), which has demonstrated that the municipality of Blumenau presents a catastrophic scenario.

The combined study of exposure and vulnerability is of great importance for understanding disasters, since these two dimensions are fundamental for analysing the ability of a community to cope with adverse events. This study may provide a theoretical contribution to the development of studies that focus on proactivity in relation to disasters, and that are not only limited to a response in situations of action and reaction. Furthermore, there are few methods available that aim to quantify the relationship between socio-economic and environmental factors in terms of aggravating the risks of socio-environmental disasters. The use of Cutter's (2011) concepts would seem to be a more suitable approach for Brazil because of her vision of social vulnerability and exposure, which, in Brazil, are emerging factors. In this context, the present article contributes to urban studies with new methods for analysing disaster risk, taking into account urban expansion in territory susceptible to extreme weather events and the increase in the population's social vulnerability.

The practical contribution of this study stems from the fact that mapping socio-environmental vulnerability may be an important tool for risk management, since it enables the identification of areas, which are most vulnerable to socio-environmental disasters, as well as the population groups with the greatest potential for impact. Based on this information, authorities may implement more effective plans and actions for prevention and mitigation, ensuring that financial resources are better spent on the places and populations that are in most need. In addition, mapping socio-environmental vulnerability can help raise awareness among the population and the authorities regarding the importance of risk management and the adoption of preventive plans and actions. It may also contribute to territorial planning and decision-making in different locations, addressing issues such as building more resilient infrastructure and developing more effective public policies to protect vulnerable populations. Thus, mapping socio-environmental vulnerability is an important tool for disaster risk management. The method is based on widely available geospatial tools and technologies, and the multidisciplinary approach allows the method to be adapted to different types of risks and socioeconomic and environmental contexts.

The use of place-based analyses and the intersection of physical and social vulnerability also enables a more precise, localised understanding of risk and disaster issues, which is useful for risk and disaster planning and management at a local level. However, it is vital to remember that the replicability of the method may depend on the availability of accurate, up-to-date geospatial and socioeconomic data, as well as the ability to gather and integrate information from different disciplines. Future studies should not only just observe one municipality, but also include areas in the Itajaí Valley region, such as the Itajaí-mirim river sub-basin. Moreover, the study should extend further into analysing the risk perception of populations exposed to floods and landslides.

The main limitation of this study is the 2010 census database. To overcome this problem, a projection method was used. The projection method takes into account Itajaí's population growth between the years 2000, 2010 and 2020. However, this may lead to distortions, especially in socio-economic data, given the likely increase in social vulnerability within the Blumenau landscape. In other words, the vulnerability reflected in the city's landscape may apparently be greater than that presented by the results of this article. It will only be possible to crosscheck information and assess the effectiveness of the method applied, with the results of the new census. However, the use of projection models has been shown to be effective according to Ayhan (2018), Daci (2016) and Miller (2006). In addition, an observational field study was carried out to minimise serious distortions of socio-spatial reality. Risk equation models are another factor to be considered for this study.

In relation to Sustainable Development Goal 11, which aims to "make cities [and human settlements] inclusive, safe, resilient and sustainable", the study highlights the importance of multidisciplinary integration of social sciences, natural sciences and engineering and urban planning, which can promote collaboration between different sectors and disciplines in implementing actions to achieve this goal. By identifying the critical points of vulnerability in cities and human settlements, strategies may be planned and implemented to reduce the risks and increase the resilience of these areas, ensuring that they are inclusive, safe and sustainable. Finally, at a regional level, the study highlights the need for place-based analyses to address disaster risk issues that directly affect local sustainable development.

Lastly, it is essential to improve a risk governance model that strengthens local resilience, not only to guarantee the rapid reconstruction of degraded areas after a crisis, but also to strengthen the population's perception of risk, thereby increasing their autonomy, and guaranteeing conditions so that they are able to respond more independently, minimising loss of life. Final suggestions would be: 1) to improve communication regarding risk; 2) to encourage the population to learn about signs of risk in the environment, as well as government warning systems; 3) to monitor/prevent new occupations in risk areas; 4) to increase the capacity to absorb impacts by implementing safety structures that are adapted to the local physical environment; 5) to create a community support network in each risk community; 6) to provide education on urban planning and safe, sustainable forms of construction; 7) to relocate residents, in extremely necessary cases, in a sustainable, socially just manner; 8) to foster social participation in decision-making, thereby increasing the sense of belonging; 9) to produce a housing plan that is effective in mitigating the perpetuation of risk; and 10) to provide universal basic sanitation. These actions, combined with those already in existence, should be aimed at mitigating the perpetuation of risks, through the development of more sustainable occupation alternatives and accept that certain areas should not be occupied.

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