This is an Accepted Manuscript of an article published by Taylor & Francis in Journal of Risk Research on 14th of March, 2026 available at: https://doi.org/10.1080/13669877.2026.2636940

Methodological Solutions for Interactive Socio-Spatial Vulnerability Dashboards for Risk Governance

Aistė Balžekienė[a]* and Paulina Budrytė[a]

[a] *Civil Society and Sustainability Research group, Kaunas university of technology, Kaunas Lithuania*

*** email: aiste.balzekiene@ktu.lt*

Methodological Solutions for Interactive Socio-Spatial Vulnerability Dashboards for Risk Governance

The aim of this article is to systematically review and synthesise methodological solutions for interactive, open-access socio–spatial vulnerability dashboards at the national level, and to critically assess their features, comparability, and methodological rigour. A scoping review provides an inventory of the indicators, methodologies, features of interactivity and complexity, and visualisation elements used. Results identified that dashboards use a variety of methodological solutions, the most popular being the social vulnerability index SVI. Although most dashboards exhibit high visual complexity, interactivity levels are generally low. The review also reveals substantial methodological and visual inconsistency across dashboards, limiting cross-country comparability and longitudinal monitoring. The article concludes by highlighting the need for more policy-oriented, standardised methodological and visualisation approaches that focus on the multidimensional and intersectional representations of risk and social vulnerability.

Keywords: social vulnerability, risk governance, interactive dashboards, scoping review

1. Introduction

The number of natural disasters is increasing at unprecedented rates. For example, the yearly numbers of recorded natural disaster events globally have increased from the range 70 – 270 in the period from 1980 to 2000 to the range of 323-441 in the period from 2001 to 2023 (data fromEM-DAT, 2024). Due to advances in technologies such as early warning systems, geographical information systems (GIS), satellite navigation, and others (Krichen et al., 2024), there has been an increase in disaster preparedness and mitigation, resulting in fewer fatalities from natural disasters. The number of death rates from natural disasters has decreased from almost 100,000 annual average in the decade of 1970's to 38,000 annual average in the 2020's (EM-DAT, 2024).

However, there is a significant imbalance in the social impacts of natural disasters. They affect the most vulnerable populations, both in terms of cross-country vulnerability and social-structural vulnerability. Vulnerability is defined as a combination of physical, social, economic or political factors that increase the sensitivity of the social systems and individuals to the effects of hazards and risks (UNDRR, 2015). For example, social vulnerability, related to lower socio-economic status, minority status and the structure of the households, leads to lower disaster preparedness (Rao et al., 2023). Identifying the intersections of vulnerabilities is critically important, considering social, structural and infrastructural factors as well as cultural and political contexts. The synergetic effects may lead to reduced disaster preparedness and resilience, and a weaker response to crises. The key concept for analysing the intersection of different vulnerabilities with high-risk areas is *spatial vulnerability*. Spatial vulnerability analysis identifies spatially vulnerable zones (i.e. in the social, physical sense) that require responsible and targeted institutional attention (Raduszynski & Numada, 2023).

Over the past decade, governments in various countries have developed a range of tools for the spatial assessment of social vulnerability. These tools are important instruments for understanding and assessing spatial patterns of social vulnerability at the intersections with different types of hazards. Often, such tools are referred to as "dashboards"; they are open access and aimed at diverse stakeholder audiences, including national and local authorities, first responders, emergency managers, local communities, and others.

Roy & Blaschke (2015) note that there are no standard methodologies and models for assessing spatial vulnerabilities. Different countries may employ various methodologies to spatially evaluate and present social vulnerabilities. These differences often arise from the use of distinct data sources, unique sets of indicators, diverse index creation methods, and varying visualisation techniques. There is a growing body of systematic or scoping reviews about societal vulnerability and resilience (Atkinson, 2023; le Polain de Waroux et al., 2024; Schafer et al., 2024), dimensions of vulnerability and exposure to risks (Cardona et al., 2012); social vulnerability indicators and measurements (Asadzadeh et al., 2017; Mah et al., 2023) and else. However, there are no systematic or scoping reviews about open-access dashboards for spatial analysis of social vulnerabilities of national-level data in different countries. Our article aims to close this gap.

The aim of this article is to systematically review and synthesise methodological solutions for interactive, open-access socio–spatial vulnerability dashboards at the national level, and to critically assess their features, comparability, and methodological rigour. The specific objectives of the article are: to sample open-access interactive dashboards from different countries presenting data on the spatial distribution of social vulnerability; to identify and summarise the dimensions of social vulnerability that are used in spatial dashboards; to analyse the methodological solutions of social vulnerability assessment and visualisation in maps; and to provide recommendations on further development of spatial dashboards for risk governance.

Spatial dimensions of social vulnerability and its relevance to risk governance

Spatial resilience refers to the ability of a spatially defined system to recover lost functions after an unforeseen shock/crisis (Brunetta & Caldarice, 2020). The concept foresees the active role of societies and communities, and involves targeted actions(Steinberg & Steinberg, 2021). Vulnerability is defined as “the extent to which persons or things are likely to be affected” (Flanagan et al., 2011).

Researchers have proposed various approaches for measuring and visualising social vulnerability, including GIS-based mapping and interactive dashboards (Burton et al., 2018; Chen et al., 2024). The literature on social vulnerability mapping highlights the need for more robust theoretical frameworks and validation methods. Many studies lack explicit theoretical underpinnings (Kuhlicke et al., 2023), and there is a call for more rigorous methodologies and policy relevance in vulnerability assessments (Bukvic et al., 2020). Researchers emphasise the importance of comprehensive approaches that integrate multiple indicators, consider local contexts, and employ objective weighting methods (Ajtai et al., 2023). Efforts to improve vulnerability assessments include developing integrated frameworks (Thiault et al., 2021), focusing on spatial variability (Frigerio et al., 2019), and addressing validation demands (Fekete, 2019). However, debates persist regarding the validity and applicability of different vulnerability models, particularly in the context of specific hazard events (Flanagan et al., 2021).

There are several major methodological approaches to assessing social vulnerability. The main social vulnerability indices used in practice are SoVI and SVI. One of the most used methodologies for calculating social vulnerabilities is the social vulnerability index SoVI, proposed by Cutter et al. (2003). These authors were among the first to propose including spatial socio-economic and demographic data to construct an index to measure social vulnerability to environmental hazards. The values of SoVI are mapped using the standard deviation from the mean and presented in 5 categories (ranging from -1 to +1). SoVI was registered as a trademark in 2011 and started to be integrated into hazard and disaster reduction policies, for example, the National Risk Index and many states in the USA used SoVI for hazard identification and risk assessment (HIRA) (Cutter, 2024).

Another social vulnerability index (SVI) was proposed by Flanagan et al. (Flanagan et al., 2011) and developed by Centers for Disease Control and Prevention (CDS). The social vulnerability index (SVI) is calculated and presented in 4 themes: (1) Socioeconomic theme; (2) Housing Composition and Disability; (3) Minority Status and Language; and (3) Housing and Transportation. The overall index is then calculated from these four themes. The SVI methodology involves ranking census tracts for each variable (from highest to lowest) and calculating percentiles for each variable based on its ranking across all census tracts nationwide. Variables are then grouped into the four aforementioned themes. For each theme, a percentile rank is calculated, and the overall SVI is computed by summing the percentile ranks across all variables; values range from 0 (lowest vulnerability) to 1 (highest vulnerability) (Flanagan et al., 2011)

Main advantages of these social vulnerability indices are the mapping of vulnerabilities across different geographical scales, identifying high–risk areas, and aggregation of multiple socio-economic indicators for the broad measurement of social vulnerability (Arunachalam et al., 2023). The index has strong policy relevance, as it was widely used to inform policy and planning, especially in urban risk management and disaster preparedness (Arunachalam et al., 2023; Park & Xu, 2022).

The above-mentioned spatial dashboards of social vulnerability have been used in various risk governance contexts, including disaster prevention, mitigation, emergency planning and risk communication. For example, social vulnerability assessment in Portugal was used to identify flood vulnerability hotspots of access to resources and ability to cope with hazards (Fernandez et al., 2016); SoVI was used in the Beijing-Tianjin-Hebei Region, China, to identify high vulnerability to natural hazards areas for the provision of targeted disaster mitigation and prevention policies (Huang et al., 2015); SVI was used during COVID-19 to identify the most vulnerable census locations in the USA to set additional testing centres, to introduce specialised tools for communication with disproportionally affected communities, and to plan vaccine allocation (ATSDR, 2024).

However, there are some limitations of these social vulnerability indices. The critique of SoVi and SVI is related to the lack of context-specific approaches, when representations of vulnerabilities should include place–based indicators, and not only replication of existing indices (Painter et al., 2024); data limitations related to data availability on some socio-economic indicators some countries that is used of social vulnerability indices (Rucińska et al., 2023); over-reliance on the quantitative data, mostly from the secondary sources, that does not capture the context of social vulnerability (Painter et al., 2024) or the lack of specificity on the local indicators that mostly contribute to vulnerability, which limits targeted policy–making (Park & Xu, 2022). These limitations have resulted in non-uniform national-level measures of social vulnerability across countries, complicating cross-national comparability. Countries have adopted diverse spatial representations of social vulnerability, employing indicators adapted to specific local contexts and policy needs. This article examines how interactive dashboards across countries present the spatial distribution of social vulnerabilities and discusses ways to improve them to enhance comparability and usability.

2. *Materials and methods*

A scoping review employing purposive criteria sampling was conducted to identify publicly available, interactive social vulnerability maps that incorporate national-scale spatial data. Scoping review methodologies start with the broad questions aimed at mapping available knowledge in an emerging, complex field and identifying the gaps (Munn et al., 2018). Our methodological design follows the guidelines of scoping review, defined by Arksey and O'Malley (2005). Because our study samples databases and not the body of available literature, some procedural steps required modification. In the stages of scoping review, we used “dashboards” instead of “studies”, originally proposed by Arksey and O'Malley (2005, p.22). The stages in the scoping review are presented in Figure 1.

Stage 1: identifying the research question	What are the indicators, methodological solutions and visualization methods used in open access spatial dashboards of social vulnerability?
Stage 2: identifying relevant dashboards	**Keywords**: “open access”, “national”, “social vulnerability”, “dashboards”, “maps” and “interactive” **Languages**: English, French, German, Portuguese, Spanish, Italian, Polish, Indonesian, Vietnamese, Russian, Swahili, and Zulu **Result**: 25 dashboards
Stage 3: dashboard selection	**Inclusion criteria**: availability, accessibility, interactivity, open-access, clarity of methodological approach, and representation of social vulnerability **Result:** 15 sampled dashboards
Stage 4: charting the data	**Coding scheme:** - General information about dashboards: country, data sources, - Dimensions of social vulnerability - Methods for calculating social vulnerability - Interactivity level - Complexity level - Visualisation of social vulnerability: number of categories and colour schemes
Stage 5: collating, summarising, and reporting the results	**Classification and summarising** the dashboards according the code and sub-code structure

Figure 1. Methodological design of scoping review

The scoping review is conducted by searching for keywords in a general search engine, since there are no existing summaries of global databases of dashboards on social vulnerabilities. The following keywords were used: “open access”, “national”, “social vulnerability”, “dashboards”, “maps” and “interactive”. These keywords were used in different languages: English, French, German, Portuguese, Spanish, Italian, and Polish. These languages are widely used in research, so it was expected that they would produce results. Other languages, such as Indonesian, Vietnamese, Russian, Swahili, and Zulu, were used for the search because they are among the most widely spoken languages worldwide; however, they yielded no meaningful results. The inclusion criteria for the sampling were: availability of information on data sources, accessibility, interactivity, and the spatial representation of social vulnerability. Sources that presented maps as static images, did not provide information on the data sources used to calculate social vulnerability indices, or did not present the spatial distribution of social vulnerabilities, were excluded from further coding. The list of selected dashboards is provided in Table 1.

Table 1. The list of spatial dashboards of social vulnerability sampled for the analysis

Name of dashboard*	**Title**	**Country**	**Link****
DB_Italy_1	Mappa dei rischi dei comuni italiani	Italy	https://gisportal.istat.it/mapparischi/index.html?extent=
DB_Austria_1	Örok Atlas	Austria	https://www.oerok-atlas.at/#indicator/75
DB_Austria_2	STATatlas	Austria	https://www.statistik.at/atlas/
DB_Norway_1	Integrated Vulnerability	Norway	https://folk.ntnu.no/opach/tools/viewexposed/
DB_USA_1	US Climate Resilience Map	USA	https://mappingresilience.onebillionresilient.org/explore?id=224553&indicator=52,31
DB_USA_2	The U.S. Climate Vulnerability Index	USA	https://map.climatevulnerabilityindex.org/map/health/usa?mapBoundaries=Tract&mapFilter=0&reportBoundaries=Tract&geoContext=State
DB_USA_3	Future Heat Events and Social Vulnerability 2018	USA	https://resilience.climate.gov/apps/3fbf36ad63c44cec96c405d92dfc4714/explore
DB_USA_4	Social Vulnerability	USA	https://www.atsdr.cdc.gov/placeandhealth/svi/interactive_map.html
DB_USA_5	Mapping Social Vulnerability to Climate Change in California	USA, California	https://www.ocf.berkeley.edu/~jbernstein/map/SOVI_map_red_v4.html

DB_Brasil_1	Índice de Vulnerabilidade Social – IVS	Brazil	https://ivs.ipea.gov.br/#/consulta-mapa
DB_Canada_1	Interactive Atlas of the Vulnerability of the Quebec Population to Climate Change for Local and Regional Actors	Canada, Quebec	https://ulaval.maps.arcgis.com/apps/webappviewer/index.html?id=d2c3ccbe069e4ab780308b8c501b0f8c
DB_France_1	Tableau de bord Vulnerability Management (PA)	France	https://iau-idf.maps.arcgis.com/apps/instant/portfolio/index.html?appid=ff73f22b99c74d009e0882aa2aff3149
DB_France_2	Adapter l'Île-de-France à la chaleur urbaine	France	https://www.observatoiredesfragilites.fr/portail/index.php/piloter-decider/cartographie-interactive/france-metropolitaine/
DB_Canada_2	SIG Grand Nord de l'observatoire des fragilités	Canada, Quebek	https://cartes.inspq.qc.ca/geoportail/?_gl=1*1tv7exa*_ga*MjQyNTA5MzAzLjE3MTM1MTk4MDA.*_ga_V5EL6F3WVC*MTcxMzUxOTgwMC4xLjEuMTcxMzUyMzAxNy42MC4wLjA.
DB_USA_6	Geoportal	USA	https://ruraldevelopment.maps.arcgis.com/apps/webappviewer/index.html?id=22660ea3cfd247b8928dcdb627096bec

*these names are created for the purpose of scoping review and used in this article. They are not official names of the databases

** The links were accessible on 08/02/2025. Accessibility may change depending on the funding schemes or administrative constraints of the institutions providing the dashboards.

Interactive maps and the methodologies were coded using a coding scheme. The code and sub-code scheme includes the type of risk, methods for calculating social vulnerability, levels of interactivity and complexity, types of data, data sources, and visualisation methods, including colour schemes and the number of categories. Explanation of codes and sub-codes is provided in Table 2.

Table 2. Analytical codes and sub-codes for social vulnerability spatial dashboard analysis

Code	**Sub-code**	**Description**
Risk type	Environmental risks Social risks Economic risks Technological risks Geopolitical risks	Types of risks: World Economic Forum classification.
Methods applied to evaluate social vulnerability	SVI methods Weights (Weighted indicators vs. not weighted indicators	SVI/ SoVI/ other Weighted: different weights are assigned for indicators in the final social vulnerability index . Not weighted: all indicators have the same weight towards the final social vulnerability index.
Interactively level	High Medium Low	High: The user/viewer of the map could zoom to different scales and choose which indicators and risk types should be considered and how they are represented in the map. The representation could be changed to adapt to certain visual conditions (e.g. colour blindness). The zoom-in-zoom-out function will represent administrative units of different scales. Low: The map shows just one indicator or criterion at a time. There are very few opportunities to examine the lowest administrative units. The list of available information is short and very basic.
Complexity level	High Medium Low	High: The methodology includes diverse indicators provided by different institutions/organisations. Indicators are weighted. The final result is presented at the lowest administrative unit or on a large-

Code	Sub-code	Description
		scale map. It was observed that social vulnerability varies with the selection of different indicators or risk types. Low: basic census information is used, the methodology is simplified, and the social vulnerability index (if calculated) represents just one certain type of risk.
Data	Basic statistics (census data) Spatial data	The data used to create the maps could be from general census data (e.g. unemployment rate, median of citizens in the map unit, etc.) to very peculiar data on certain risks (e.g. flood depth, landslide zones, etc.).)
Visualisation methods	Colour schemes Number of categories for the measurement of social vulnerability	Colour schemes range from saturated to hue based. The number of categories is numeric.

In the coding scheme, the classification of risks by the World Economic Forum (2020) was used to classify the social vulnerability indicators.

Inter-coder agreement and consensus discussions enhanced the methodological rigour of the review. Most of the codes did not require subjective judgment, as there were clear distinctions among the subcategories. The article provides links to all dashboards to ensure replicability and transparency. The analysed dashboards were available for open access in the spring of 2025; however, because not all of them have sustainable funding and digital object identifiers (DOIs), the open access might not be permanent.

Further, the results of the scoping review are presented, discussing findings from the scoping review of national-level spatial dashboards of social vulnerabilities.

The scoping review created the inventory of open-access social vulnerability dashboards presented further in the results section.

3. *Results*

3.1. Inventory of social vulnerability dashboards at the national level

Recent research has focused on developing frameworks and tools for mapping social vulnerability to natural hazards and public health emergencies. These studies emphasise the importance of integrating social vulnerability indices with physical risk assessments to create comprehensive risk maps and dashboards (Coelho et al., 2022; Hou et al., 2022; Roy et al., 2024). Click or tap here to enter text.

Further, we discuss the results of the scoping review according to the main dimensions of the coding scheme: types of risk included in the dashboards, measurement methods of social vulnerability, levels of interactivity and complexity, and the visual elements.

An investigation of available open-source online maps that present social vulnerability revealed a number of indicators that could be used for evaluation. The dimensions of social vulnerability indicators in the reviewed dashboards are presented in Table 3.

Table 3. Dimensions and subdimensions for social vulnerability mapping and calculations

Name	**Dimensions of indicators**	**Sub-dimensions of indicators**
DB_Italy_1	Economic Social	Ec: income S: age; education; housing; well-being
DB_Austria_1	Economic Environmental Political/Geopolitical Social: Technological	Ec: unemployment; income; dependency ratio; economic activity En: extreme weather events; green spaces; land cover; temperature; P/G: country's financial context; local governance S: age; gender; migration; housing; population; well-being T: infrastructure

Name	Dimensions of indicators	Sub-dimensions of indicators
DB_Austria_2	Economic Environmental Political/Geopolitical Social Technological	Ec: economic activity; income; unemployment En: extreme weather event; land cover P/G: country's financial situation; local governance S: age; health; housing; migration; population; rase T: infrastructure
DB_Norway_1	Economic Political/Geopolitical Social	Ec: income; unemployment P/G: country's financial situation; local governance; voting S: age; education; gender; housing; migration; well-being
DB_USA_1	Economic Social	Ec: income; unemployment S: health; housing; migration; race; single parents
DB_USA_2	Economic Environmental Political/Geopolitical Social Technological	Ec: income En: extreme weather events; floods; land cover; pollution; hazard; temperature P/G: country's financial situation, local governance S: health; housing; population; race; well-being T: Infrastructure
DB_USA_3	Economic Environmental Political/Geopolitical Social Technological	Ec: income En: extreme weather events; floods; land cover; pollution; hazard; temperature P/G: country's financial situation, local governance S: health; housing; population; race; well-being T: Infrastructure
DB_USA_4	Economic Environmental Political/Geopolitical Social Technological	Ec: income En: extreme weather events; floods; land cover; pollution; hazard; temperature P/G: country's financial situation, local governance S: health; housing; population; race; well-being T: Infrastructure
DB_USA_5	Economic Environmental Social	Ec: income; unemployment En: land cover S: age; education; migration; race
DB_USA_6	Unclear	Unclear

Name	Dimensions of indicators	Sub-dimensions of indicators
DB_Brasil_1	Economic Environmental Social	Ec: income En: quality of urban environment S: age, education; gender; housing; migration
DB_Canada_1	Economic Social	Ec: income; unemployment S: accessibility to critical infrastructure, education, family structure; housing; migration; population
DB_Canada_2	Economic Social	Ec: income; unemployment S: age; education; family structure; housing; migration; population
DB_France_1	Economic Environmental Political/Geopolitical Social Technological	Ec: income; unemployment En: extreme weather events; green spaces; quality of urban environment S: accessibility to critical infrastructure; age; family structure; housing; population T: infrastructure
DB_France_2	Economic Environmental Social Technological	Ec: income P/G: country's financial situation S: accessibility to critical infrastructure; age; health; housing; well-being T: infrastructure

The selection of indicators is highly context-specific. As shown in the table above, even dashboards from the same country differ in terms of which indicators are included or excluded. As a result, meaningful comparison is challenging. For example, under the subdimension "income", the used indicators are: "*per capita income NOK 1000*", *"% households earning more than NOK 500,000*" (DB_Norway_1) or "*single household*[1]" (DB_Austria_1), or "*Median after-tax personal income*" (DB_France_2), just to name a few examples. Although the possibility of a context-specific assessment is highly insightful, it also prevents cross-country comparisons.

[1] Hereinafter translations from none-English languages are done by using online vocabularies and AI-based translators

The most frequently used indicators refer to the economic issues. They are included in every dashboard and are usually linked to income and unemployment. Yet the indicators within the economic dimension are highly varied and context-specific. For example, both Austrian dashboards use multiple indicators to assess social housing and the broader housing context. (like " *per cent of households, which experiences shortcomings and which consist of a higher number of elderly people*"). Additionally, the economic income dimension captures how structural income-related constraints shape the possibilities for individuals to leave the dangerous situations independently ("*households with automobile*"); such concern was included in DB_Austria_2, DB_USA_1, DB_USA_5. This index in the USA dashboards has a different expression; DB_USA_1 evaluates "*Households without a vehicle*"; meanwhile, DB_USA_5 uses "*percentage of households with no vehicle*". Moreover, amongst economic income subdimensions, there is a variety of indicators. For example, DB_Austria_1 has six indicators: "*Number of jobs (employed at the place of work) per 100 inhabitants*"; "*Total unemployment rates by gender*", "*Suspension rates (a suspenders in % of the employed persons at their place of residence*", "*Employed persons (at the place of residence/job) by gender",* "*Share of part-time employees in total employees*" and "*Change in the number of unemployed persons in % - annually* ". Here, the main concern is directed at unemployment. It is analysed using several dimensions: comparisons between employed and unemployed by total population size or working hours, employment type, and gender inequality. Meanwhile, in Brazil, the economic income indicators are quite different – "*People aged 15 to 24 who do not study and do not work*", "*People with per capita household income up to 1/2 minimum wage*", "*Single living people with per capita household income of up to 1/2 minimum wage*", "*Income difference in households headed by women and men*". These examples illustrate the measurement of intersectional vulnerabilities, in which gender and income, or age and low income, have compounding effects. The intersectional vulnerabilities are country – specific and provide policy insights into the local contexts, however the spatial distributions are not comparable across countries.

The second most listed dimension is the social dimension. Here, a large variety of subdimensions and indicators can be identified. For example, within the age subcategory, there are more than 20 indicators. In Norway, the *"% population 5 years or younger*" and *"% population 67 years or older*" indicators are used. In Austria's dashboards, changes within society (e.g. "*Change in population total in % - 10-year cohorts*") and future predictions (e.g. "*Population forecast 2021-2051*") are considered. Indicators, related to youth populations, are present in many dashboards (e.g. "*youth aged 15-29 proportion in education and work*" DB_Italy_1; "*percentage of the population aged 14 and under*" DB_Canada_2). Most indicators regarding the older generation are included in the French dashboard (DB_France_2): "*New pensioners*", "*Minimum old-age pension*", "*Survivor's pension*", etc. The next common sub-category amongst the social dimension is health related. Few examples include "*Infectious disease*", "*Chronic disease*" (DB_USA_2) , "*Insured 16-25 years-old population*", "*Insured on sick leave > 45/60/90 days*" (DB_France_2) , "*Fraction of children who are overweight or obese*" DB_USA_5). Furthermore, within the housing sub-dimension, indicators often examine housing conditions, such as renting, crowding, ownership, and occupied housing characteristics (building age, renovations, available services, etc.), among others. In the social dimension, other sub-dimensions are education (e.g., "*Proportion of people without certificate, diploma or degree*" DB_Canada_1; *"% with 4 years or more in tertiary education*" DB_Norway_1; "*Illiteracy rate of 15 years or older*" DB_Brasil_1, etc.), family structure (e.g., "*Proportion of single-parent household*" DB_Canada_1, DB_Canada_2, DB_France_1; "*Percentage of families with 2 or more children*" DB_Canada_2), gender (e.g., "*Women from 14 to 17 who had children*" DB_Brasil_1, "*Gender inequality index*" DB_Norway_1), migration (e.g., "*Migration saldo*" DB_Austria_2; "*Foreign born*" DB_USA_5; "*Percentage of migrants who moved 5 years previously/total population*" DB_Canada_2), race (e.g., "*Population by national groups*" DB_Austria_2, "*Racial and Ethnic minority status*" DB_USA_2) and well-being (e.g., "*Social stressors*" DB_USA_2, "*Availability of public transportation*" DB_Austria_1). Although various tools can inform decision-making and policy development, including race as a factor in vulnerability assessments may raise legal concerns. (Schiavinato & Payne, 2015). Spatial mapping should consider potential harms and benefits to vulnerable communities (Wise, 2024), as the identification of "hot spots" of high vulnerability can stigmatise local communities or groups of individuals.

The next dimension of the dashboards is technological. Available indicators cover mainly issues of energy, traffic and mobile coverage, like "*Traffic networks*", "*Energy consumption*" (DB_Austria_1), "*Power from photovoltaic systems to 1000 inhabitants*" (DB_Austria_2) or "*areas covered by 4G*" (DB_France_2). Although infrastructure is critical in crises preparedness and response, relevant indicators rarely appear on the dashboards.

The political dimension is not often used. The indicators focus on the condition of the municipality or country and are most often expressed as growth rates, measured through comparisons with well-developed neighbouring countries or through successful participation in various funding schemes. Only the Norwegian dashboard (DB_Norway_1) includes the voting index *(% electorate voting in the local elections*).

The last dimension is the environmental. Here, the indicators best represent the local context; hence, the list of indicators is among the longest for this dimension. "*Land cover*" index is included most often. In some countries, however, these indicators are further disaggregated into more detailed evaluations, such as "Forested area" in DB_Austria_1, "Treeless area" and "Land covered by tree canopy" in DB_USA_5, and "*Field vegetable cultivation*" in BD_Austria_2. Additionally, extreme weather events are included in the environmental dimension. They measure for example "*Precipitation*" in DB_USA_2 and heat-related indicators, like "*Tropical night climate projections*" and "*Very strong or strong exposure to heat during the day and/or at night during a heat period/wave in %*"(DB _Austria_1, DB_Austria_2) and "*the 'heat wave' hazard via its amplification by the UHI effect*" (DB_France_1). The Austrian dashboard (DB_Austria_1) is the only dashboard that includes future projections ("*Climate projections regarding precipitation*"). The inclusion of indicators that enable modelling of future predictions for vulnerable locations would be highly important for emergency planners.

Several dashboards place significant emphasis on urban environmental quality. These indicators are included in DB_France_1, DB_Brasil_1, and DB_UAS_5. The most explicit amongst them is DB_France_1, which has more than ten indices on this dimension. These indicators include, for example, "*Soil sealing*", "*Presence of water in the neighbourhood*", "*Proximity of the neighbourhood to the river or body of water*" or "*Lack of trees in the neighbourhood*", etc. Yet the pollution dimension is quite rare and was found just in two dashboards (DB_USA_2; DB_France_1).

To conclude, even where methodologies are described in considerable detail, differences in indicator selection and construction across dashboards and countries substantially reduce comparability.

We present a summary of social vulnerability indicators in the reviewed spatial dashboards (see Figure 2), which are systematised across five dimensions (social, economic, political, technological, and environmental), with sub-dimensions identified.

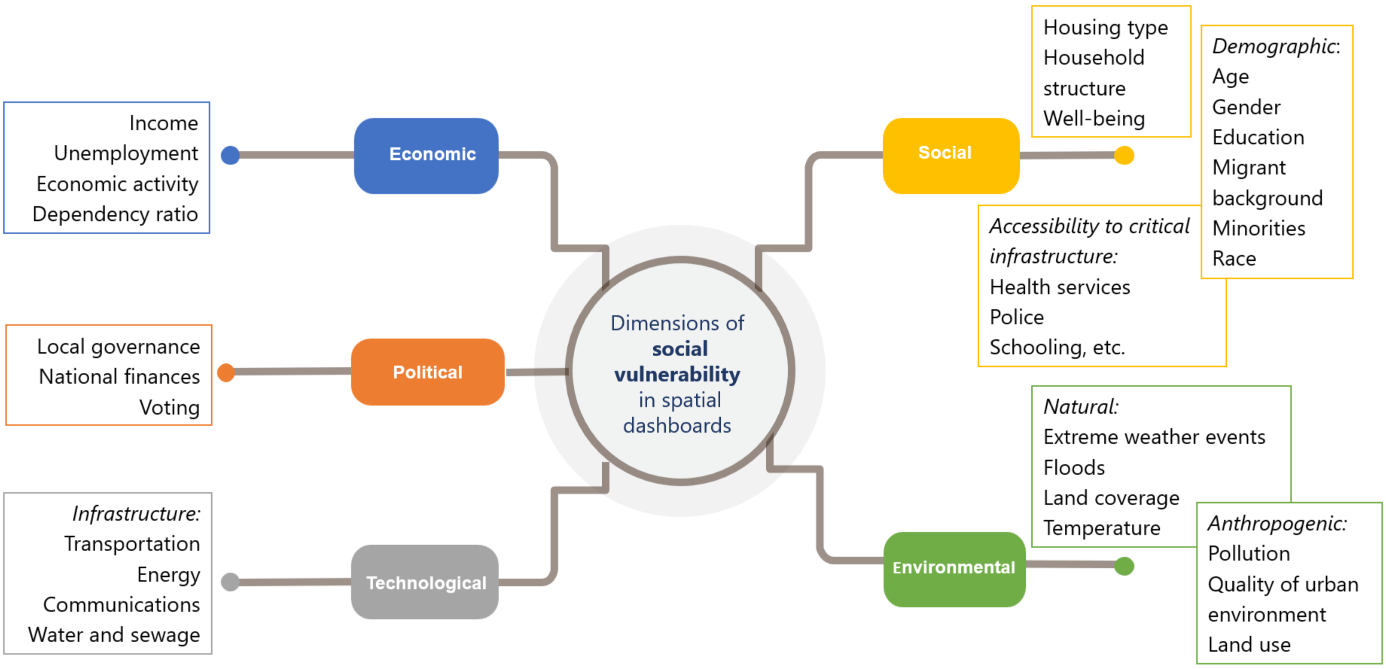


Figure 2. *Dimensions of social vulnerability in analysed spatial dashboard*

Most sub-dimensions fall under social risks, with indicator sub-dimensions including demographic characteristics, access to critical infrastructure, and housing type. Economic dimensions include indicators that are often available from census data, such as unemployment or economic activity. For the environmental indicators, two sub-dimensions are natural and anthropogenic sources of hazards; the technological dimension is primarily related to infrastructure networks; and the political dimension is primarily represented by voting data but is rarely presented in spatial dashboards.

3.2. Methodological solutions and characteristics of the spatial dashboards of social vulnerability

The summary of the characteristics in spatial dashboards is provided in Table 4. Dashboards often include additional features beyond maps, therefore the way information is presented, and the degree of user interaction are particularly important.

Table 4. *Summary of the characteristics of the spatial dashboards*

Category	**Sub-category**	**Dashboards**	**No. of dashboards**
Interactivity	High	DB_Austria_2; DB_Norway_1; DB_USA_1; DB_USA_2; DB_USA_3; DB_USA_4	6
	Average	DB_Italy_1; DB_Brasil_1; DB_France_1	3
	Low	DB_Austria_1; DB_USA_5; DB_USA_6; BD_Canada_1; BD_Canada_2; DB_France_2	6
Complexity	High	DB_Italy_1; DB_Austria_2; DB_Norway_1; DB_USA_1; DB_USA_2; DB_USA_3; DB_USA_4; DB_Brasil_1; DB_Canada_2; DB_France_1	10
	Average	DB_USA_5; DB_Canada_1; DB_France_2	3
	Low	DB_Austria_1; DB_USA_6	2
Map grains	Smallest NUTS	DB_Italy_1; DB_Austris_1; DB_Austria_2; DB_Norway_1; DB_USA_1; DB_USA_2; DB_USA_3; DB_USA_4; DB_USA_5; DB_Brasil_1; DB_Canada_1; DB_Canada_2; DB_France_2	13
	Unique areas	DB_USA_6; DB_France_1	2
Language	English	DB_Austria_2; DB_Norway_1; DB_USA_1; DB_USA_2; DB_USA_3; DB_USA_4; DB_USA_5; DB_USA_6	8
	French	DB_Canada_1; DB_Canada_2; DB_France_1; DB_France_2	4
	Portuguese	DB_Brasil_1	1
	German	DB_Austria_1; DB_Austria_2	2
	Italian	DB_Italy_1	1
Colour scheme	1 colour	DB_USA_6	1
	4 colours	DB_Italy_1; DB_Austria_1; DB_Canada_2	3
	5 colours	DB_USA_4; DB_Brasil_1; DB_France_2	4
	6 colours	DB_Austria_2; DB_Norway_1; DB_Canada_1	2
	7 colours	DB_USA_5	1
	8 colours	DB_France_1	1
	10 colours	DB_USA_2	1
	Unique colour schemes for every indicator	DB_Italy_1; DB_USA_3;	2
	5x5 matrix	DB_USA_1	1

Our scoping review results identified different levels of interactivity. A high level of interactivity in dashboards enables users to select scales for analysis, adapt visualisations, intersect variables, and retrieve statistical summaries for the administrative units of interest. Additionally, these interfaces enable comparison of vulnerability levels across small administrative units and larger ones, such as regional or national levels. Only six dashboards in our analysis feature a high level of interactivity. For example, in DB_Norway_1 map, comparisons among indices, and the table of all municipalities are presented on the same page. The viewer can explore the map and investigate a specific index and its value in a particular municipality or across the country. The most interactive map is DB_USA_1. Here, various indicators and their interactions can be explored, and results are presented in a 5x5 matrix.

Low interactivity in the dashboards means limited possibilities for users in terms of visualisations; they are usually restricted to a single variable and do not provide opportunities to visualise intersecting vulnerabilities or compare the statistics of small units in reference to larger scales (for example, national level). Six of the fifteen dashboards were characterised by low interactivity levels. For example, DB_Austria_1 presents the entire country in four colours to indicate different vulnerability levels; viewers can only click on municipalities, and a pop-up menu then presents basic information for that municipality. Here, viewers cannot explore primary indicators or compare two or more areas.

Another characteristic analysed in the scoping review refers to the level of complexity. Ten out of fifteen dashboards in our sample exhibited a high level of complexity, characterised by the use of diverse indicators to construct social vulnerability indices, the application of weights, and the availability of small-scale units for analysis. For low-complexity dashboards, maps do not include representations of derivative social vulnerability indices. Two dashboards present information with a low level of complexity (DB_Austria_1; DB_USA_6).

Analysed national dashboards used different approaches for the calculation of social vulnerability indices and variables. Most dashboards use Social Vulnerability Index (SoVi or SVI) for the assessment of social vulnerability (for example, Db_USA_3, DB_USA_4, DB_USA_6 use SVI, DB_USA_5 use SoVi). As discussed in the introduction, these two methods are well-grounded in the practice of emergency and disaster management. These methods employ multiple indicators to construct composite indices of social vulnerability.

SoVi is based on the standardisation of variables using z-scores, which is the measurement of an observation's distance from the average. However, criticism towards the use of z-scores is related to the fact that, as z-scores allow only for relative comparison, they are based on the means and in a time series, every new data point has a new mean (Santos et al., 2022). The recently developed method using Maziotta Paretto index allows for data comparison across time and space. It is a composite index of a set of indicators that are assumed not to be fully substitutable (ibid.). This method is used in the Italian dashboard (DB_Italy_1).

Many dashboards do not present derivative social vulnerability indices; instead, they present individual social vulnerability variables. For example, dashboards from Brazil (DB_Brasil_1), Austria (DB_Austria_2) and Canada (DB_Canada_2) present maps of separate variables classified into 5 or 6 intervals.

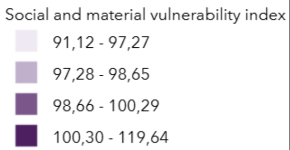
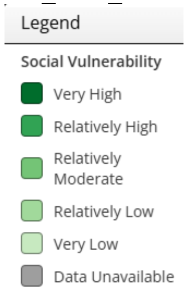
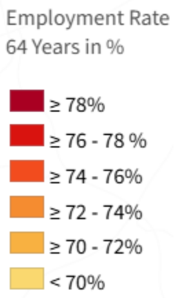
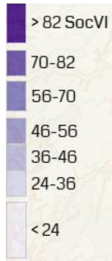
An important methodological aspect is the weight of individual indicators in the calculation of the social vulnerability index. Most of the dashboards analysed in this review assign an equal weight to the indicators of social vulnerability. Just the

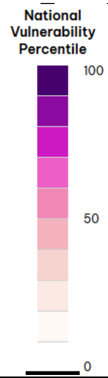
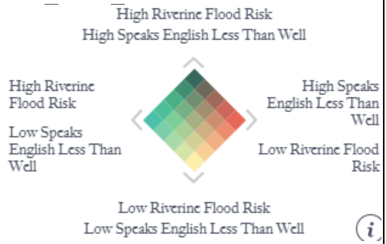
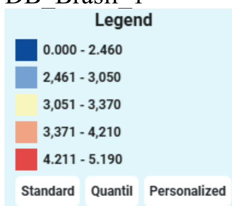
Norwegian dashboard uses weighted indices for social vulnerability. The use of weights in the social vulnerability index may reduce the dominance of specific indicators relative to the overall SoVI. For example, Park & Xu, (2022) found that high social vulnerability in suburban areas in Houston, USA, is largely driven by a single principal component correlated with the percentage of mobile homes. The local context might require assigning different weights for the indicators of the social vulnerability index. For example, Burton et al. (2018) applied a hierarchical model using expert-derived weights that performed better than the inductive models, where the vulnerability profiling approach had the strongest statistical association with the observed outcomes.

3.3. Visual presentation of social vulnerability indices

The reviewed dashboards employ a variety of approaches to present social vulnerability and its indices. The review of the number of categories used to represent vulnerabilities in dashboards is presented in Table 5. Results indicate no consistency across all dashboards in the number of categories or colour schemes.

Table 5 Visualisation of vulnerabilities in the analysed dashboards: examples

<table>
<tr><td>Number of categories in the visualisation</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>10</td><td>5x5 matrix</td></tr>
<tr><td>Principle of visualisation and examples from national dashboards</td>
<td>The value of the vulnerability index is presented in 4 categories DB_Italy_1

</td>
<td>Five categories of social vulnerability (not quantified in the legend) DB_USA_4

</td>
<td>The values of separate indicators are visualised in six categories DB_Austria_2

</td>
<td>Social vulnerability index (1-100_ visualised in 7 categories) DB_Norway_1

</td>
<td>Eight classes of vulnerability DB_France_1

</td>
<td>Percentiles of vulnerability index DB_USA_2

</td>
<td>Five categories of vulnerability vs five categories of risk DB_USA_1

</td></tr>
<tr><td></td><td></td>
<td>Five categories of separate vulnerability indicators DB_Brasil_1

</td>
<td>The integrated vulnerability index (value is in the range from 0 to 100) is visualised in six categories DB_Norway_1</td>
<td></td><td></td><td></td><td></td></tr>
</table>

			> 85 IntVI 68-85 50-68 32-50 14-32 < 14				
			Six categories of vulnerability (not quantified in the legend) DB_Canada_1 Très faible vulnérabilité Faible vulnérabilité Vulnérabilité modérée Vulnérabilité moyenne Forte vulnérabilité Très forte vulnérabilité Données manquantes				

The number of categories in the visual representation of vulnerabilities ranges from 4 to 10. Most dashboards use five or six categories for mapping vulnerabilities. It should be noted that both odd- and even-numbered categories are used. Most of the dashboards use numeric intervals for the categories of vulnerabilities; just a few dashboards (DB_USA_4; DB_Canada_1) do not quantify the legend and use verbal names for categories from “very low vulnerability” to very high vulnerability”. Such a variety of visualisation categories not only complicates cross-national comparisons of vulnerabilities but also creates confusion for emergency planners in identifying high- and low-vulnerability areas.

There is a difference in the colour schemes used to represent social vulnerability. They include at least three types of representation: (1) variation in the saturation of colour: red (for example, Db_Austria_2), violet/ purple (DB_Italy_1); DB_USA_2) and green (DB_USA_4); (2) variation in the hue of colour: green – red scale (DB_Norway_1. DB_Canada_1) and blue- red scheme (Db_Brasil_1) and (3) bivariate map of two variables, including both saturation of green and red and hue of green- red (DB_USA_1). The use of hue colour scheme is recommended for the categorical data; however, for the continuous data, the transition in colours could be interpreted as a sharp transition in data, which is not the case (Borland and Taylor 2007, cited in Kaye et al., 2012). The social vulnerability data is usually continuous, and there is no sharp distinction between the intervals. (Borland & Taylor, 2007) consider “rainbow colour” mapping confusing and prone to misinterpretation and should be used only for nominal data. Therefore, it is advisable to use the saturated colour schemes in the dashboards, but not the hue colour schemes.

4. Discussion

Open spatial dashboards at the national level are important in multiple ways. One of the main practical implications of dashboards for risk governance is the help for emergency and disaster planners, officials and policy makers to identify and communicate with the most vulnerable communities. Dashboards also help identify areas where high social vulnerabilities intersect with infrastructure gaps or with high exposures to various hazards, informing the planning of targeted investments.

The United Nations encourages governments to open the data for citizen engagement and provided the principles of governmental open data in a 2013 report (UN, 2013). Open government data is defined by Sebastopol principles that were defined in 2007 and include the principles that data must be complete, be primary (not aggregated), be timely, be accessible, be machine processable, be non-discriminatory (everyone should have the right to access it), among others (Tauberer, 2014).

The open-access spatial dashboards in different countries that were reviewed in this article aim to provide access to the wider network of stakeholders and citizens and contribute significantly to the disaster risk reduction efforts. Yet, not all principles of open government data are fully met in the analysed spatial dashboards. For example, the principle of timely data means that data should be available as quickly as possible. However, many dashboards are created using data from specific years, and the data is not updated annually. Presumably, many dashboards are created for specific projects that do not anticipate sustainable funding for the continuous renewal of the data; consequently, their longevity and relevance are questionable. Another principle of open government data is that data should be primary; however, not all dashboards have access to the primary data or attribute tables and instead use aggregate data to visualise vulnerability categories. Full methodological designs are also not always available, which interferes with this principle. Digital infrastructures to support national-level spatial dashboards require political will and sustainable funding. Our inventory indicates that dashboards are predominantly available in high-income countries, with limited or no analyses for low-income countries. Spatial dashboards for assessing social vulnerability would benefit from closer alignment with international open government data principles.

The integration of hazard assessment with social vulnerability analysis is crucial for effective risk management (Lapietra et al., 2024). Dashboards have emerged as valuable tools for visualising and communicating vulnerability data. Researchers have also explored the interplay between vulnerability, resilience, and adaptation, highlighting the need for multidisciplinary approaches and context-specific indicators (Azzimonti et al., 2020; Frigerio et al., 2019). Our review has summarised and systematised the social vulnerability indicators used in spatial dashboards. Most often, economic indicators are derived from census data, and least frequently, indicators from the political dimension are visualised in dashboards. One of the methodological challenges for spatial dashboards is that some important data for measuring vulnerability are not spatial. For example, disinformation and fake news are important factors for increased vulnerability (Gelado-Marcos et al., 2022), however it is not possible to have spatial data for the spread of disinformation. Advancing methodologies for developing spatial dashboards could involve integrating spatial and non-spatial data (e.g., from public opinion surveys). Public opinion surveys can indicate factors contributing to increased vulnerability (for example, studies show that older people are more vulnerable to disinformation, ibid), and the weight of these factors can be incorporated into the calculation of spatial indicators of vulnerability. Public opinion survey data can also be geolocated and contribute significantly to the analysis of the spatial distribution of vulnerabilities, however there are ethical concerns regarding spatial data at the individual level. The use of geospatial data often includes sensitive personal information and can raise privacy concerns. Open access to GIS data at the individual level should be subject to strict standards for data accuracy, privacy, and validation (Blatt, 2012) to avoid misuse or stigmatisation of vulnerable groups.

Despite the growing body of research on social vulnerability, resilience, and adaptation, a systematic review by Kuhlicke et al. (2023) revealed that about 90% of studies lack explicit theoretical underpinnings. To address this gap, some researchers have proposed frameworks that incorporate both physical and social vulnerability in risk assessments (Enderami et al., 2022) Of the dashboards analysed in our scoping review, only one from the USA provides an integrated visualisation of the risk–vulnerability nexus within a single spatial layer. Other dashboards enable the visualisation of the layers of vulnerabilities and risks as separate indicators. As cascading crises intensify, policymakers need tools to identify and address intersecting and compound vulnerabilities. Compound vulnerabilities are shaped by multiple stressors, including poverty, political instability, limited access to food, and natural hazards such as drought and floods, among others (UNDRR, 2022). Therefore, spatial dashboards should integrate physical risks and social vulnerabilities into a single layer, enabling the identification of "hot spots" with high levels of risk and vulnerability for targeted policy measures. Another important further development should focus on multivariate visualisations of social vulnerability indices. Strode et al. (2020) used multivariate visualisation techniques to analyse the relationships between the dimensions of the social vulnerability index SVI. The results of this approach provide a more nuanced understanding of intersecting vulnerabilities and support well-informed planning.

A scoping review of the dashboards has revealed inconsistencies in the number of categories and colour schemes used to visualise social vulnerabilities. The use of different numbers of categories (both odd and even) has several implications. First, there is no possibility for cross-country comparison even for the same risks such as climate change or air pollution. Second, the use of a large number of intervals (e.g., 9 or 10) complicates the perception of dominant trends on the map. A standardised approach to visualising social vulnerability would improve comparability across dashboards and provide a more robust evidence base for policymaking. The national dashboards could use the example of the global map of vulnerabilities created by Disaster Risk Management Centre of European Commission INFORM. "The INFORM Risk Index is a global, open-source risk assessment for humanitarian crises and disasters" (European Commission, 2024). It provides an analysis of vulnerability and classifies it across 5 dimensions (ranging from very low to very high). The data in this index is provided at the aggregated country level. The use of the same number of categories in national dashboards would allow not only cross–national comparability but also would give more insight into the transboundary risk management. Another recommendation from our study is related to colour schemes in the vulnerability maps. Saturated colour schemes are preferable to hue-based colour schemes, because the transition between categories is a matter of definition of intervals, and hue colour schemes place a strong emphasis on the differences between vulnerability categories. Standardising colour schemes, the number and labelling of categories, and methodological approaches across national dashboards would enable better transboundary comparability, improved monitoring of compound vulnerabilities, and more efficient emergency planning. The field faces challenges in incorporating future projections, characterising uncertainty, and engaging with policymakers (De Sherbinin et al., 2019). This article identified key limitations, including the absence of future projections, insufficient uncertainty characterisation, challenges in validation, and limited engagement with policy audiences. Further research should focus on the systemising of methodological principles of social vulnerability index calculations and visualisations, and providing standardised solutions for better usability and compatibility with open access data.

5. Limitations

We would like to acknowledge some limitations of this scoping review. The keyword search was limited to the major languages; therefore, some national dashboards might have been omitted from the scoping review. To understand the methods of the calculations of social vulnerability indicators, the translation tools from some languages (Portuguese, Italian and French) were used, as the authors do not have the operational knowledge of these languages. Some dashboards had limited access to the methodology, which complicated the completeness of the inventory of the dashboards.

6. Conclusions

This article presents a scoping review of open-access national-level spatial dashboards for social vulnerability and provides an inventory of available dashboards, summarising the indicators used, social vulnerability measurement methods, interactivity, complexity, and the features of visual elements. Results indicate that economic and social indicators are most frequently used to create social vulnerability indices, whereas indicators from the political dimension are used less frequently in the dashboards. Most dashboards are highly complex, but many offer low interactivity. Dashboards lack the possibility for multivariate geovisualisation of social vulnerability, which is important for understanding compound vulnerabilities. Additionally, most dashboards do not support visualising the intersections between risks and vulnerabilities, a critical feature for emergency planning. Scoping results also indicate a lack of coherence in the methodological approaches to social vulnerability assessment, the number of categories used to visualise social vulnerabilities, and the principles governing colour usage, which complicate cross-country comparisons and monitoring of change. Further discussions should focus on the policy-oriented use of open-access dashboards, with the aim of reducing inconsistencies in methodological approaches and visualisation solutions, and on standardised solutions to improve comparability and the sustainability of the dashboards.

Funding

This work was supported by the Research Council of Lithuania (LMTLT), research project "Socio-spatial determinants of societal vulnerability and resilience to crises and strengthening the crisis response potential of communities" (SERENITY), grant n. no. S-VIS-23-21.

Disclosure

The authors report there are no competing interests to declare.

References

Ajtai, I., Ștefănie, H., Maloș, C., Botezan, C., Radovici, A., Bizău-Cârstea, M., & Baciu, C. (2023). Mapping social vulnerability to floods. A comprehensive framework using a vulnerability index approach and PCA analysis. *Ecological Indicators*, *154*, 110838.

Arksey, H., & O'Malley, L. (2005). Scoping studies: Towards a methodological framework. *International Journal of Social Research Methodology: Theory and Practice*, *8*(1), 19–32. https://doi.org/10.1080/1364557032000119616

Arunachalam, M., Saravanavel, J., & Joseph Kochuparampil, A. (2023). PCA-based approach for mapping social vulnerability to hazards in the Chennai metropolitan area, east coast of India. *Annals of GIS*, *29*(4), 529–552. https://doi.org/10.1080/19475683.2023.2226189

Asadzadeh, A., Kötter, T., Salehi, P., & Birkmann, J. (2017). Operationalizing a concept: The systematic review of composite indicator building for measuring community disaster resilience. *International Journal of Disaster Risk Reduction*, *25*(May), 147–162. https://doi.org/10.1016/j.ijdrr.2017.09.015

Atkinson, C. L. (2023). Research Trends in Resilience and Vulnerability Studies. *Encyclopedia*, *3*(4), 1208–1222. https://doi.org/10.3390/encyclopedia3040088

ATSDR. (2024). *Innovative Uses of SVI During COVID-19 | Place and Health - Geospatial Research, Analysis, and Services Program (GRASP) | ATSDR*. https://www.atsdr.cdc.gov/place-health/php/covid19response/innovative-uses-of-svi-during-covid-19.html

Azzimonti, O. L., Colleoni, M., De Amicis, M., & Frigerio, I. (2020). Combining hazard, social vulnerability and resilience to provide a proposal for seismic risk assessment. *Journal of Risk Research*, *23*(9), 1225–1241.

Blatt, A. J. (2012). Ethics and privacy issues in the use of GIS. *Journal of Map and Geography Libraries*, *8*(1), 80–84. https://doi.org/10.1080/15420353.2011.627109

Borland, D., & Taylor, R. M. (2007). Rainbow color map (still) considered harmful. *IEEE Computer Graphics and Applications*, *27*(2), 14–17. https://doi.org/10.1109/MCG.2007.323435

Brunetta, G., & Caldarice, O. (2020). *Spatial Resilience in Planning: Meanings, Challenges, and Perspectives for Urban Transition*. 628–640. https://doi.org/10.1007/978-3-319-95717-3_28

Bukvic, A., Rohat, G., Apotsos, A., & de Sherbinin, A. (2020). A systematic review of coastal vulnerability mapping. *Sustainability*, *12*(7), 2822.

Burton, C., Rufat, S., & Tate, E. (2018). Social vulnerability. *Vulnerability and Resilience to Natural Hazards*, *53*.

Cardona, O. D., Van Aalst, M. K., Birkmann, J., Fordham, M., Mc Gregor, G., Rosa, P., Pulwarty, R. S., Schipper, E. L. F., Sinh, B. T., Décamps, H., Keim, M., Davis, I., Ebi, K. L., Lavell, A., Mechler, R., Murray, V., Pelling, M., Pohl, J., Smith, A. O., & Thomalla, F. (2012). Determinants of risk: Exposure and vulnerability. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*, *9781107025*, 65–108. https://doi.org/10.1017/CBO9781139177245.005

Chen, L., Li, Y., & Hui, P. (2024). *VulnerabilityMap: An Open Framework for Mapping Vulnerability among Urban Disadvantaged Populations in the United States*.

Coelho, D., Gupta, N., Papenhausen, E., & Mueller, K. (2022). Patterns of social vulnerability-an interactive dashboard to explore risks to public health on the us county level. *2022 Workshop on Visual Analytics in Healthcare (VAHC)*, 1–9.

Cutter, S. L. (2024). The origin and diffusion of the social vulnerability index (SoVI). *International Journal of Disaster Risk Reduction*, *109*(April), 104576. https://doi.org/10.1016/j.ijdrr.2024.104576

Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2003). Social Vulnerability to Environmental Hazards*. *Social Science Quarterly*, *84*(2), 242–261. https://doi.org/10.1111/1540-6237.8402002

De Sherbinin, A., Bukvic, A., Rohat, G., Gall, M., McCusker, B., Preston, B., Apotsos, A., Fish, C., Kienberger, S., & Muhonda, P. (2019). Climate vulnerability mapping: A systematic review and future prospects. *Wiley Interdisciplinary Reviews: Climate Change*, *10*(5), e600.

EM-DAT, C. / L. with major processing by O. W. in Data. (2024). *"Global reported natural disasters by type – EM-DAT" [dataset]*.

Enderami, S. A., Mazumder, R. K., & Sutley, E. J. (2022). Framework for Incorporating Community Social Vulnerability in the Assessment of Hurricane-Induced Wind Risk to Residential Buildings. *ArXiv Preprint ArXiv:2207.14206*.

European Commission. (2024). *INFORM Risk - Results and data*. https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk/Results-and-data

Fekete, A. (2019). Social vulnerability (re-) assessment in context to natural hazards: Review of the usefulness of the spatial indicator approach and investigations of validation demands. *International Journal of Disaster Risk Science*, *10*, 220–232.

Fernandez, P., Mourato, S., & Moreira, M. (2016). Social vulnerability assessment of flood risk using GIS-based multicriteria decision analysis. A case study of Vila Nova de Gaia. *Geomatics, Natural Hazards and Risk*, *7*(4), 1367–1389. https://doi.org/10.1080/19475705.2015.1052021

Flanagan, B. E., Gregory, E. W., Hallisey, E. J., Heitgerd, J. L., & Lewis, B. (2011). A Social Vulnerability Index for Disaster Management. *Journal of Homeland Security and Emergency Management*, *8*(1). https://doi.org/10.2202/1547-7355.1792

Flanagan, B., Hallisey, E., Sharpe, J. D., Mertzlufft, C. E., & Grossman, M. (2021). On the validity of validation: A commentary on Rufat, Tate, Emrich, and Antolini's "how valid are social vulnerability models?" *Annals of the American Association of Geographers*, *111*(4), em--i.

Frigerio, I., Zanini, F., Mattavelli, M., & De Amicis, M. (2019). Understanding the interacting factors that influence social vulnerability: A case study of the 2016 central Italy earthquake. *Disasters*, *43*(4), 867–890.

Gelado-Marcos, R., Moreno-Felices, P., & Puebla-Martínez, B. (2022). Disinformation as a Widespread Problem and Vulnerability Factors Toward it: Evidence From a Quasi-Experimental Survey in Spain. *International Journal of Communication*, *16*, 3599–3625.

Hou, X., Stewart, B. P., Tariverdi, M., Pambudi, E. S., Harimurti, P., Nagpal, S., Jia, W., Vicencio, J. M., Görgens, M., & Garrett, K. P. (2022). *Vulnerability Map for Response to the COVID-19 Epidemic: A Case Study on Indonesia*.

Huang, J., Su, F., & Zhang, P. (2015). Measuring social vulnerability to natural hazards in Beijing-Tianjin-Hebei Region, China. *Chinese Geographical Science*, *25*(4), 472–485. https://doi.org/10.1007/s11769-015-0769-7

Kaye, N. R., Hartley, A., & Hemming, D. (2012). Mapping the climate: Guidance on appropriate techniques to map climate variables and their uncertainty. *Geoscientific Model Development*, *5*(1), 245–256. https://doi.org/10.5194/gmd-5-245-2012

Krichen, M. , M. S. Abdalzaher, M. Elwekeil, and M. M. Fouda. (2024). "Managing natural disasters: An analysis of technological advancements, opportunities, and challenges." *Internet of Things AND Cyber-Physical Systems* 4: 99–109. 10.1016/j.iotcps.2023.09.002.

Kuhlicke, C., de Brito, M. M., Bartkowski, B., Botzen, W., Doğulu, C., Han, S., Hudson, P., Karanci, A. N., Klassert, C. J., & Otto, D. (2023). Spinning in circles? A systematic review on the role of theory in social vulnerability, resilience and adaptation research. *Global Environmental Change*, *80*, 102672.

Lapietra, I., Colacicco, R., Capolongo, D., La Salandra, M., Rinaldi, A., & Dellino, P. (2024). Unveiling Social Vulnerability to Natural Hazards in the EEA and UK: A Systematic Review with Insights for Enhanced Emergency Planning and Risk Reduction. *International Journal of Disaster Risk Reduction*, 104507.

le Polain de Waroux, Y., Carignan, M. C., del Giorgio, O., Díaz, L., Enrico, L., Jaureguiberry, P., Lipoma, M. L., Mazzini, F., & Díaz, S. (2024). How do we study resilience? A systematic review. *People and Nature*, *6*(2), 474–489. https://doi.org/10.1002/pan3.10603

Mah, J. C., Penwarden, J. L., Pott, H., Theou, O., & Andrew, M. K. (2023). Social vulnerability indices: a scoping review. *BMC Public Health*, *23*(1), 1253. https://doi.org/10.1186/S12889-023-16097-6

Munn, Z., Peters, M. D. J., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology 2018 18:1*, *18*(1), 143-. https://doi.org/10.1186/s12874-018-0611-x

Painter, M. A., Shah, S. H., Damestoit, G. C., Khalid, F., Prudencio, W., Chisty, M. A., Tormos-Aponte, F., & Wilhelmi, O. (2024). A systematic scoping review of the Social Vulnerability Index as applied to natural hazards. *Natural Hazards 2024 120:8*, *120*(8), 7265–7356. https://doi.org/10.1007/S11069-023-06378-Z

Park, G., & Xu, Z. (2022). The constituent components and local indicator variables of social vulnerability index. *Natural Hazards*, *110*(1), 95–120. https://doi.org/10.1007/s11069-021-04938-9

Raduszynski, T., & Numada, M. (2023). Measure and spatial identification of social vulnerability, exposure and risk to natural hazards in Japan using open data. *Scientific Reports*, *13*(1), 1–13. https://doi.org/10.1038/s41598-023-27831-w

Rao, S., Doherty, F. C., Teixeira, S., Takeuchi, D. T., & Pandey, S. (2023). Social and structural vulnerabilities: Associations with disaster readiness. *Global Environmental Change*, *78*(January), 102638. https://doi.org/10.1016/j.gloenvcha.2023.102638

Roy, D. C., & Blaschke, T. (2015). Spatial vulnerability assessment of floods in the coastal regions of Bangladesh. *Geomatics, Natural Hazards and Risk*, *6*(1), 21–44. https://doi.org/10.1080/19475705.2013.816785

Roy, S., Majumder, S., Bose, A., & Chowdhury, I. R. (2024). Mapping the vulnerable: A framework for analyzing urban social vulnerability and its societal impact. *Societal Impacts*, *3*, 100049.

Rucińska, D., Adinolfi, G., Frigerio, I., Gavinelli, D., Zanolin, G., Werner, W., Rauscher, N., Jaczewska, B., & Gręda, Ł. (2023). Case study in Poland: Understanding spatial diversity of social vulnerability to natural hazards based on local level assessments within the European Union. *International Journal of Disaster Risk Reduction*, *96*, 103941. https://doi.org/10.1016/j.ijdrr.2023.103941

Santos, P. P., Zêzere, J. L., Pereira, S., Rocha, J., & Tavares, A. O. (2022). A Novel Approach to Measuring Spatiotemporal Changes in Social Vulnerability at the Local Level in Portugal. *International Journal of Disaster Risk Science*, *13*(6), 842–861. https://doi.org/10.1007/s13753-022-00455-w

Schafer, S. K., Supke, M., Kausmann, C., Schaubruch, L. M., & Lieb, K. (2024). A systematic review of individual , social , and societal resilience factors in response to societal challenges and crises. *Communications Psychology*. https://doi.org/10.1038/s44271-024-00138-w

Schiavinato, L., & Payne, H. (2015). Mapping coastal risks and social vulnerability: current tools and legal risks. *North Carolina Sea Grant, Spring*.

Steinberg, S. L., & Steinberg, S. J. (2021). Conceptualizing spatial resilience. In *Resilient Communities across Geographies* (pp. 1–16). Esri Press.

Strode, G., Mesev, V., Bleisch, S., Ziewitz, K., Reed, F., & Morgan, J. D. (2020). Exploratory bivariate and multivariate geovisualizations of a social vulnerability index. *Cartographic Perspectives*, (95), 5–23.
Tauberer, J. (2014). *Open Government Data Definition: The 8 Principles of Open Government Data*. https://opengovdata.io/2014/8-principles/
Thiault, L., Jupiter, S. D., Johnson, J. E., Cinner, J. E., Jarvis, R. M., Heron, S. F., Maina, J. M., Marshall, N. A., Marshall, P. A., & Claudet, J. (2021). *Harnessing the potential of vulnerability assessments for managing social-ecological systems*.
UN. (2013). *Guidelines on open government data for citizen engagement*
UNDRR. (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030 | UNDRR*. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030
UNDRR. (2022). *Systemic Risks Emerging from Compound Vulnerabilities*. https://www.undrr.org/publication/systemic-risks-emerging-compound-vulnerabilities
Wise, N. (2024). "Research Ethics in Geography." *Ethics in Social Science Research: Current Insights and Practical Strategies* 179–189. https://doi.org/10.1007/978-981-97-9881-0_14
World Economic Forum. (2020). WEF Global Risks Report 2020.