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Unveiling social vulnerability to natural hazards in the EEA and UK: A systematic review with insights for enhanced emergency planning and risk reduction

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ABSTRACT

The interaction between natural hazards and the socio-economic environment implies multidisciplinary assessments that aim to integrate the physical and the socio-economic features of the affected territories. The quantification and mapping of social vulnerability, coupled with hazard assessment, could be a useful approach to support risk management strategies.

With this aim, we carried on a systematic review on the role of social vulnerability in the natural hazard literature in the European Economic Area (EEA) and United Kingdom (UK) over the last twenty years. The various definitions, measurements and mapping of social vulnerability were studied, providing an instrument for conducting hazard assessment and demonstrating the relevance of multidisciplinary approach in disasters research.

The PRISMA methodology and frequency analysis were used to extract and analyze the literature.

According to our selection criteria, 95 papers were included in the final analysis. Results revealed that: i) 53 % of papers focuses on social vulnerability related to flood hazard, ii) 61 % of case studies include hazard assessment, while the rest only investigate the socio-economic component of vulnerability, iii) Portugal and Italy are the most investigated countries, iv) 51,6 % of papers carry out an integrated approach. The review underlines a pronounced perception of the scientific community to the more recurrent events (floods) rather than to the number of deaths (heat waves), leading to a discussion on the effected of climate change and suggestions for emergency planning in highly developed countries. Finally, a scheme of data integration between hazard, vulnerability and exposure is proposed.

1. Introduction

It is generally accepted that disasters are not "natural" events but depends on the interaction between humans and the environment [1]. Disasters are considered as serious disruptions of the functioning of a community or a society at any scale due to hazardous events interacting with conditions of exposure, vulnerability and capacity and leading to one or more of the following: human, material,

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economic and environmental losses and impacts [2].

Hurricane Katrina, the tropical cyclone that struck the southeastern United States in August 2005, represents one of the most relevant examples of disasters, since at every phase (causes, preparedness, response, damage and reconstruction), the contours of disaster and the difference between who lived and who died was to a greater or lesser extent also a social calculus [3]. Katrina destroyed the entire region in the proximity of the Gulf of Mexico, killing more than 1,500, leaving hundreds of thousands homeless and producing $108 billion in damage (.).

The development of hazards into disasters is caused by the impact of significant natural events on the vulnerable elements exposed that cause damage of properties and loss of lives. According to the United Nations Office for Disaster Risk Reduction, risk is described as the product of hazard, exposure, and vulnerability [4]. Hazard is defined as “the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation” [5,6].

Exposure refers to the inventory of elements (human beings, livelihoods and assets) in an area in which hazardous events can occur [4,7]. Vulnerability is explained as the susceptibility of exposed elements to the impact of hazards [8]. Disaster risk depends thus on the severity of hazard, the number of people or assets exposed and the susceptibility of people and economic assets to suffer loss and damage. Since losses vary geographically over time and among different element groups, vulnerability differs over time and space [9] including social, physical, economic, environmental and institutional features [10]. For this reason, vulnerability can be described as a spatio-temporal multidimensional component of risk which is guided by theories, methodologies, and standard measurements derived from different schools of thought: (i) the political-economy; (ii) the social-ecology and more recently (iii) the hazard and disaster risk reduction research and (iv) the climate change research on adaptation. Particularly, the disaster risk management community is oriented towards humanitarian assistance and uses a “people-centered” approach, whereas, the “climate change" ones has developed its concept of vulnerability on the basis of natural sciences that focusses on quantitative findings and looks at projections of impacts in the future considering the capacities of people and communities to cope with hazards and adapt to them [11]. Example of conceptual frameworks deriving from different schools are: the “Human Adjustment to Natural Hazards” [12], The “Hazards-of-Place model of vulnerability” [9], the “Disaster Pressure and Release Model” [13], “The climate change system” (IPCC, 2012), “The MOVE framework” [14] and “The BBC framework [15,16].

Within the risk reduction community, the introduction of the *Yokohama Strategy* [17] marked the beginning of a significant change in the development of risk reduction strategies which until then were largely influenced by purely technical and scientific approaches. From the 1990s onwards, in fact, the analysis of socioeconomic vulnerability becomes crucial in the study of natural risks and one of the approaches to identify vulnerable people is the definition of a tailored vulnerability index [10]. A social vulnerability index is defined as an aggregated or composite measurement of selected vulnerability indicators that results in a numerical value of the social vulnerability of a given geographical unit [18]. Nowadays, within the social science community, there is a general consensus on the main factors that influence a community’s social vulnerability to natural hazards such as lack of access to resources (information, knowledge and technology); the limited access to political power and delegation, social capital, social networks and links; belief and habits; the building stock and its age; vulnerable and/or physically limited individuals; the typology and the density of infrastructures [19].

Over the last years, several studies were proposed to measure social vulnerability to natural disasters in different countries such as Poland [20], China [21], United States of America [22], Croatia [23]; Australia (Wang et al., 2016), Indonesia [24], India (Vitta et al., 2020), Italy [25] and Germany [26]. However, only the integration between social vulnerability and the physical components of natural hazards could be a useful development tool for quantifying and mapping the most exposed population that need special attentions in natural disaster emergency planning and management. This implies the application of a challenging multidisciplinary approach in disaster studies, which requires competences belonging to Earth Sciences for hazard assessment, Social Sciences and Engineering for vulnerability evaluation. In fact, one of the greatest challenges of the scientific community that deals with risk analysis, is the method of integration of hazard and vulnerability assessment. Hazard assessments are critical at identifying areas at risk in the preparation and mitigation strategies and require technical competencies (Earth Sciences), whereas vulnerability include different components (physical, social, environmental and institutional) that involve knowledges of Engineering, Social and Environmental sciences. Therefore, risk analysis could be described as a multidisciplinary point of view where society, environment and natural hazard interact.

Moreover, since the 60’s onwards, the growth of industrialization led to significant changes in the land use of the European Economic Area (EEA) and United Kingdom (UK) increasing the impact of natural disasters. In particular, the fragility and vulnerability of the territory have interacted with the man-made environment, resulting in an imbalance that too often leads to tragic outcomes and that still require vulnerability and hazard investigation [27].

In this study, after collecting data about natural disasters, we conducted a systematic review of social vulnerability to natural hazards studies in the EEA and UK from 2000 to 2023. The main aims of the review are: (i) exploring the various techniques of measuring and mapping social vulnerability, (ii) providing instruments and tools to conduct hazard assessment (iii) suggesting methods of integration for future disaster studies.

Despite the high number of past reviews on social vulnerability assessments, theories and indicators [10,11,28–38] systematic evaluations on methodological integration procedures are still lacking, especially in European countries. The review examines the approach whereby integration is employed as a methodological process. This process encompasses the amalgamation of social vulnerability with additional components of vulnerability, hazards, exposure, or other elements pertinent to risk analysis. The main focus is to synthesize, by means of classificatory schemes, the various approaches proposed for the analysis of social vulnerability and hazard estimation in the literature. Finally, a scheme of data integration is also suggested for helping the development of multidisciplinary studies toward mitigation of natural disasters.

The review is made of 5 sections. The following section (1.1) provides information about the EEA and UK with a particular look at the disaster scenario in the last twenty years. Section 2 describes the analysis framework of the review. Section 3 focuses on the results linked to hazard assessment, vulnerability evaluation and integration methodologies. Section 4 provides a critical analysis of the results in the context of climate change and multidisciplinary studies. Lastly, an outlook for emergency planning and risk reduction coupled with research limitations are also considered in the conclusion section (section 5).

1.1. The EEA and UK

The European Economic Area (EEA) was established on the January 1, 1994 to strengthen trade and economic relations between the contracting parties. The EEA unites the EU Member States and the three EEA European Free Trade Association States (Iceland, Liechtenstein, and Norway) into an Internal Market governed by the same economic basic rules. The EEA is based on four main pillars: the free movement of goods, people, services and capital. Other policies included in the agreement are social, environmental and consumer protection policies. The EEA Agreement focuses on cooperation in flanking areas such as research, social policy, tourism, public health and environment (). The choice to focus on the EEA is linked to two main reasons. Firstly, the EEA is characterized by similar socio-economic features (Fig. 1) which are strictly correlated to social vulnerability analysis. Secondly, the countries belonging to the EEA are included within the European Civil Protection which represents the mechanism that provide preparedness and prevention actions to catastrophes. Indeed, a well-coordinated response at European level avoids duplication of relief efforts and ensures that assistance meets the real needs of the affected region (). In this context, the comparison among studies conducted on social vulnerability provide a useful support to civil protection response, economic and environmental dynamism and logistic and service capacity [39].

In terms of socio-economic characteristics, almost all countries included in the EEA registered similar level of Human Development (2021). The human development index (HDI) is a summary measure that expresses a country's level of development, including its

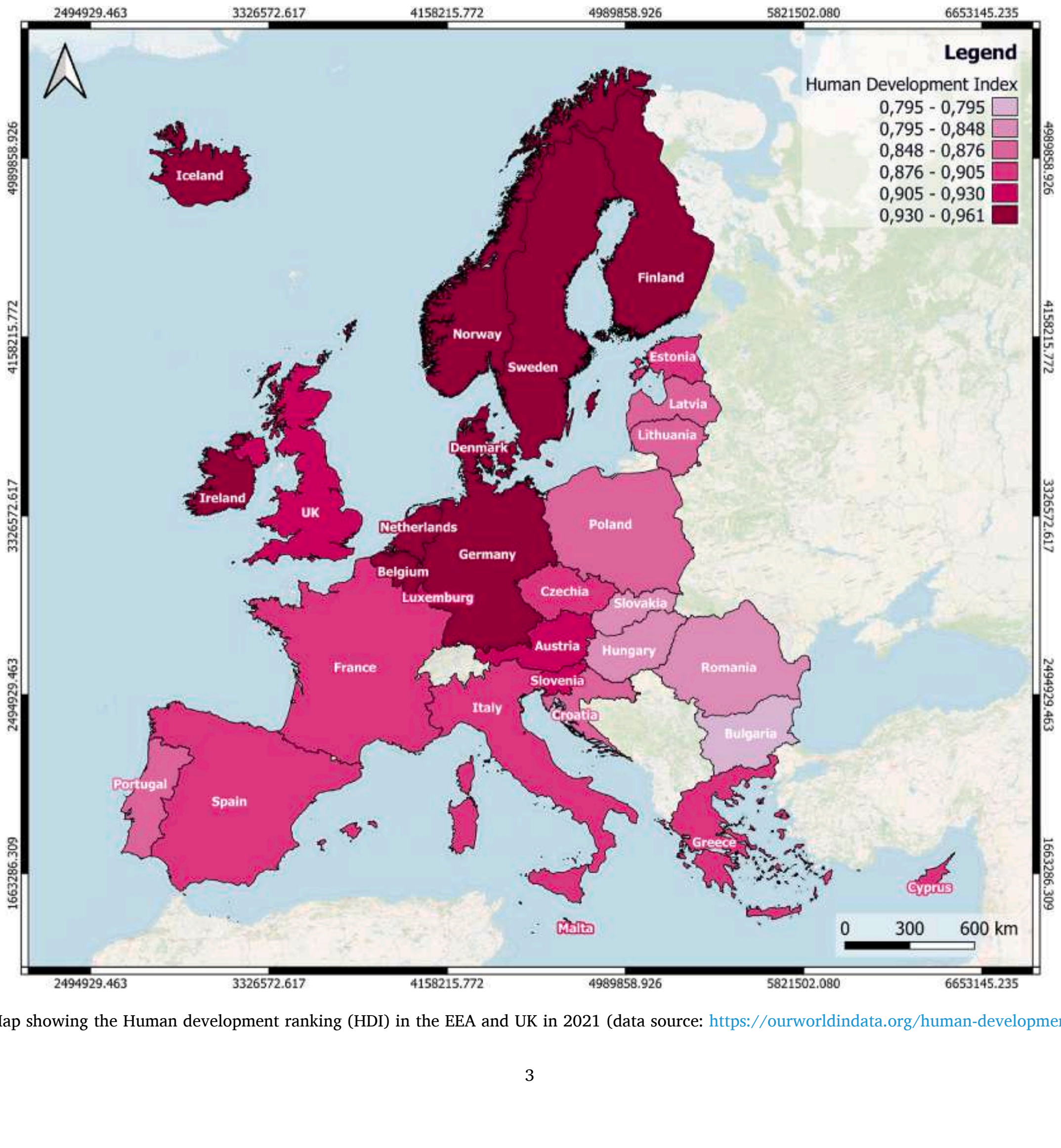

Fig. 1. Map showing the Human development ranking (HDI) in the EEA and UK in 2021 (data source: https://ourworldindata.org/human-development-index).

literacy rate, gross school enrollment rate, per capita income, and life expectancy in accordance with UNDP specifications (). A country's HDI is categorized as high (HHD: 0.8 or higher), medium (MHD: 0.5 to 0.79) or low (LHD: lower than 0.5) (). As shown in Fig. 1, all of the countries included in the EEA are characterized by HHD (HDI >0.790), however, slight differences can be observed. The highest values of HDI are located in North Europe (Iceland, Norway, Finland, Sweden, Ireland, Denmark, Netherlands, Belgium, Luxemburg and Germany), while most of the countries located towards the East Europe (Latvia, Lithuania, Poland, Slovakia, Hungary, Romania and Bulgaria) are characterized by lower values. Being the United Kingdom (UK) also categorized as high human developed country, the area was included within this systematic review.

Despite many human development goals – such as poverty reduction, quality education, affordable housing, social equity and equality, food security – reduce vulnerabilities of individuals, groups, and communities to disasters [40], there are still a number of deaths due to natural disasters in the area under review. As shown in Fig. 2, the most frequent natural events that occurred in the last twenty years were floods, followed by earthquakes, heatwaves, landslides, drought and volcanic activity. Some of these events are considered real "disasters" because of damages and deaths associated with them. In this respect, heat waves represent the deathliest disaster, followed by earthquakes, floods and landslides. An example is the heat wave occurred in 2003 in Europe [41] that caused the death of more than 71000 people and more than 11840000 US$ in damages (https://www.emdat.be/).

The maps in Fig. 3, based on data extracted from the Emergency Events Database (EM-DAT), spatially show the values for disaster-related deaths. As represented in Fig. 3 (panel a), Italy, Spain and France are the most risk countries in terms of the total number of deaths. Germany and Romania have the highest number due to flooding events (Fig. 3b), while Italy and Austria are the only countries that record deaths from landslides (Fig. 3c). With regard to earthquakes, Italy has the highest number (Fig. 3d), as well as for heat waves, together with Portugal, Spain, France, England, Northern Ireland, the Netherlands, Belgium and Germany (Fig. 3e).

2. Data and method

2.1. Data collection

To critically collect literature data about social vulnerability to natural hazards in the EEA and UK, we applied the PRISMA procedure [42] that consists of four different steps: 1) identification (searching and collecting data), 2) screening, 3) eligibility checking and 4) text inclusion (Fig. 4). The searching stage was conducted on the July 2, 2023 and we searched for articles published in English between January 2000 and June 2023 through 2 databases (SCOPUS and Web of Science). The choice to start our review from 2000 is linked to previous studies that already analyzed the international research progress on the topic of social vulnerability to natural hazards. The year 2000 corresponds to the starting point of the major research development period. Thanks to the recognition of intensified environmental changes, many research institutions put forward topics such as "vulnerability" and "adaptability" that led to a significant diversified and deepened research that was stabilized from 2012 on (Li & [43]). Before this period, only embryonic and theoretical studies were published, mostly outside Europe.

A set of keywords was applied to identify empirical studies that measured and mapped social vulnerability to natural hazards within the EEA and UK. The keywords were: "social vulnerability" combined with "natural hazard" or "natural disasters", "climate change", "flood", "landslide", "volcano", "earthquake" or "seismic hazard", "heat wave", "drought", "tsunami", "multiple hazard" or "multi-hazard" or "multihazard". The search identified 4982 articles in total. After duplicate removal and abstract screening, 860

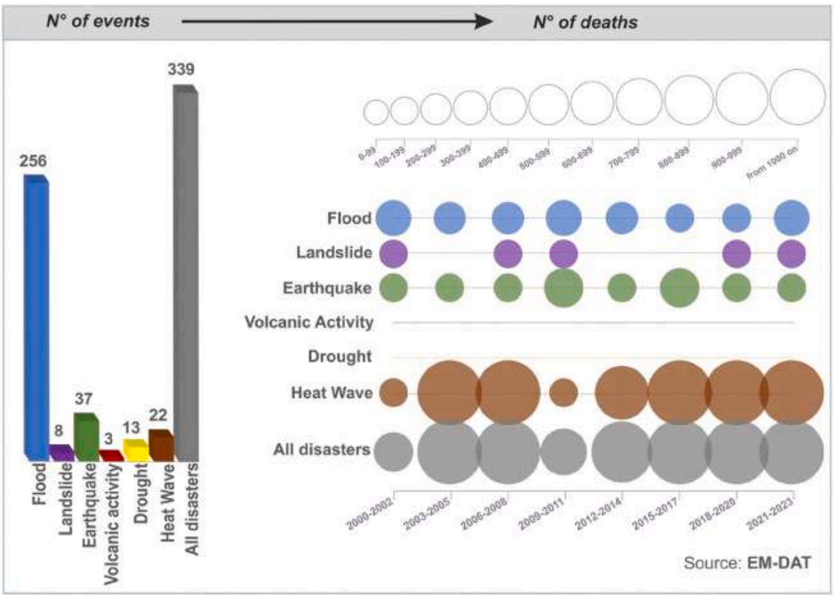

Fig. 2. On the left, the histogram showing the number of events occurred in the EEA between 2000 and 2023. On the right, the number of deaths associated with these events. The size of the circles is directly proportional, as shown in the top right-hand corner, to the number of deaths.

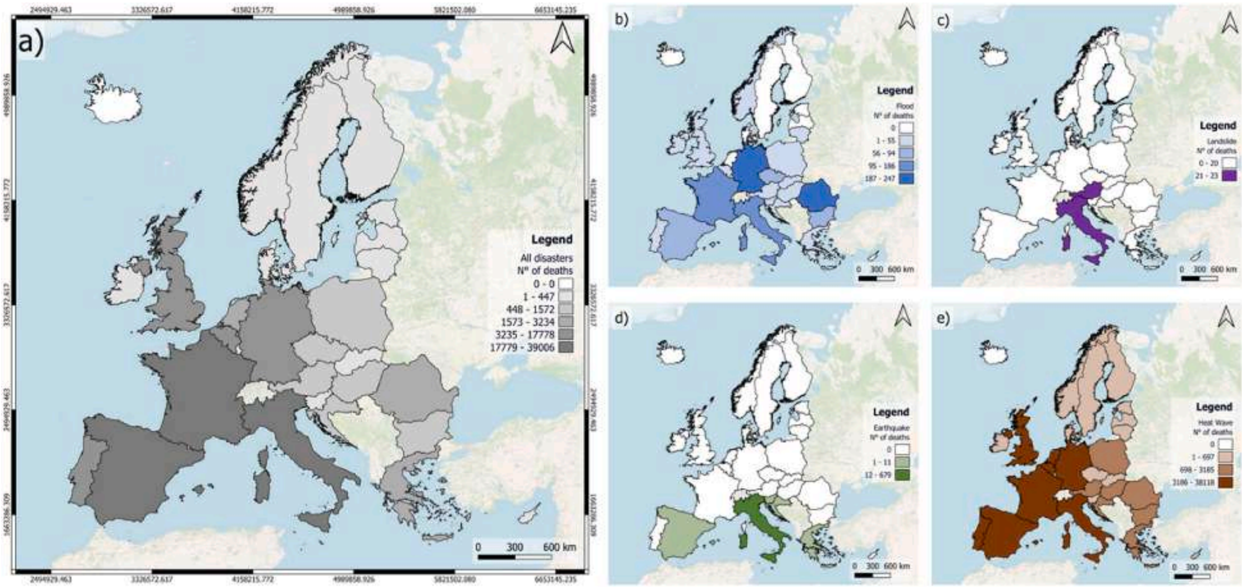

Fig. 3. Maps showing the spatial distribution of deaths in the EEA and UK between 2000 and 2023 for a) all disasters, b) floods, c) landslides, d) earthquakes and e) heat waves. The different color gradations indicate the class relative to the number of deaths.

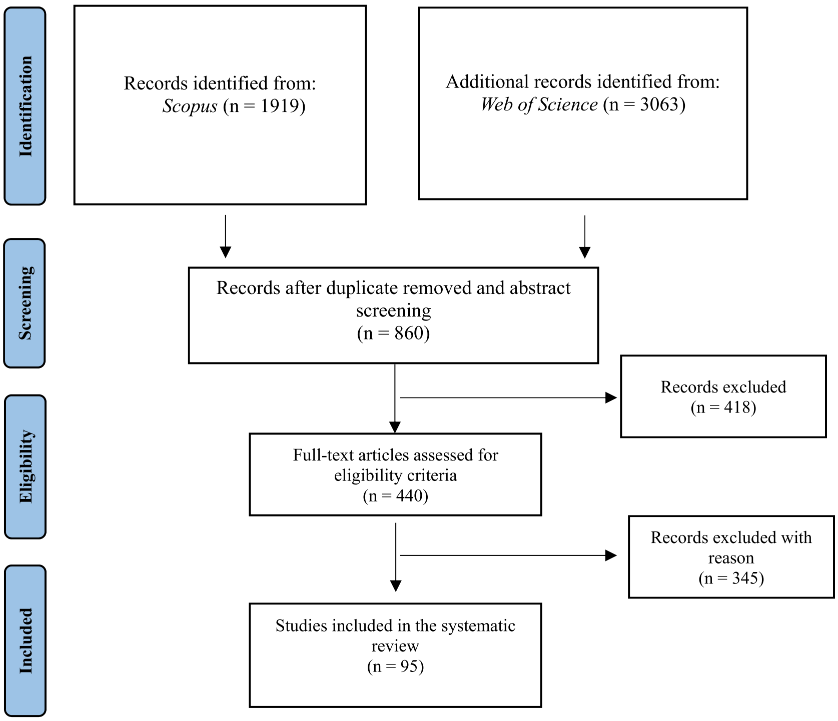

Fig. 4. Workflow scheme of PRISMA procedure.

articles remained for the next step. The screening was carried out manually by reading title and abstract and by excluding papers belonging to grey literature and not conducted within the EEA and UK. After full text reading, 440 studies were selected for eligibility criteria check. At this point, the following selection criteria were applied.

a) since integration operations necessarily require mapping, include only papers that present the social vulnerability outcomes using cartographic techniques;

b) Exclude papers that analyze only risk perception, resilience and exposure (unless they were considered as subcomponents of social vulnerability or integrated components);
c) Exclude papers that focused on risk assessment (unless social vulnerability were measured as subcomponents);
d) Exclude papers that focus on social behavior rather than vulnerability;
e) Exclude papers that measure social vulnerability of specific sub-groups of populations, e.g., farmers, elderly, children, etc.;
f) Exclude papers that investigates “adaptive capacity” but not cite “social vulnerability”.

The application of the eligibility criteria allowed us to include 95 studies in the systematic review.

2.2. Database construction and frequency analysis

The articles selected trough the PRISMA methodology were included in a pre-defined dataset form. This form was constructed with the aim to underline the general disaster context of each study case and to understand the various methodologies for social vulnerability investigation and its integration with hazard or other components. The database was developed by following the definition of risk provided in section 1, taking into account all the information provided for each component from each study case. According to the aim of the systematic review, the form was composed of 5 main sections: GENERAL, STUDY AREA, HAZARD, VULNERABILITY and INTEGRATION. The type of qualitative data extracted from the papers and the example of their description are shown in Table 1, whereas the entire database is depicted in Supplementary Material. The “GENERAL” section was created to provide information about general details of the paper (year or type of publication) and the research context of each study case. Looking at Table 1, the "Type of assessment” explains the analysis in which the investigation of social vulnerability was included. This aspect was necessary to understand the number of papers that try to overcome the boundaries of the vulnerability analysis by including its dimensions in broader investigation, such as the risk ones. Moreover, the “Conceptual framework” represents the base of any social vulnerability investigation as it provides the tools for constructing the most appropriate methods, while the study of social vulnerability analysis overtime (“Type of temporal analysis”) led to understand the different socio-economic features in the different phases of the disaster cycle.

The “STUDY AREA” was added to highlight the geographic location of the case studies giving also information about specific environmental contexts. This choice was made to classify the different works considering their local setting that can be translated in different level of social vulnerability and that can be compared to each other’s. The “HAZARD” section was focused on the type of hazard related to social vulnerability. In this section, the physical components and the methods of data elaboration were included.

Table 1
Pre-defined dataset form. H = Hazard; V = Vulnerability; SV = Social vulnerability; I = Integration; AHP = Analytic Hierarchy Process.

	DATA	DESCRIPTION
GENERAL	Year	2000/2001
	Type of publication	Article/Book chapter
	Author	Author’s name
	Type of assessment	Vulnerability/Risk
	Conceptual framework	Theoretical background
	Temporal analysis	YES/NO
	Type of temporal analysis	Past/Future scenario
STUDY AREA	Geographic location	Name of the study area
	Environmental context	Flood plain/Urban
HAZARD	Type of hazard	Flood/Landslide
	H calculation	YES/NO
	H data	Susceptibility map/Hazard index
	H data description	Data details
	H method	Mapping/Modelling software
	Note	Name of data source and models
	Multi-hazard	YES/NO
	Multi-hazard analysis	Separate/merge
VULNERABILITY	Dimension	Social/Built
	Definition	Susceptibility/Adaptive capacity
	V_approach	Quantitative/Multicriteria
	SV analysis	PCA/Additive
	Weighting	YES/NO
	Weighting method	Statistical/Expert judjment
	Weight method description	Variance/AHP
	Data source	Census/Surveys
	Geographic unit	Municipality/District
	Other V component	Built/Physical
	Total V	Name of the overall index
	Total V calculation method	Additive/formula
INTEGRATION	Integration	YES/NO
	Other I component	Exposure/Evacuation plan
	Other I data	Land use/Population density
	I Method	Geographical/Formula
	I Description	Formula explanation/note

Multi-hazard information was also taken into account in order to provide methods in exploring people social vulnerability that face multi-hazard conditions. An extended part was dedicated to "VULNERABILITY", where definitions, dimensions and type of analyses of vulnerability were considered. Since the integration of social vulnerability was the main objectives of this systematic review, other vulnerability components were included in this section in order to select the methods to construct overall vulnerability indexes. Lastly, the "INTEGRATION" section, was included to underline the presence of other integration components, such as exposure, and to classify the method that combines vulnerability analysis with these components and hazard assessment.

As social vulnerability is treated differently based on the conceptual frameworks, integration method and type of assessment, the data entry into the pre-defined dataset form was conducted with respect to the choices made by the authors. For instance, study cases where different dimensions of vulnerability were treated together into a single analysis of social vulnerability, were included in the "SV analysis", whereas, those in which other dimensions were calculated separately from social vulnerability, were included in the column "Other V component". The same approach was taken into account for the exposure component. In some study cases, exposure was considered as dimension of social vulnerability, while in others it constituted a separate component which was integrated only in the risk analyses. In this second case, exposure was included in "Other I component" column. Same approach was used for all data included in the dataset.

After the database was completed, a frequency analysis was conducted for each data type also correlating multiple sections by the use of the SPSS statistical software.

3. Results

3.1. Overview of general results

The frequency analysis that was conducted on our dataset reveals an increasing trend of number of papers that focus on social vulnerability to natural hazard in the last twenty years. In particular, from 2009 to 2020 the publication of case studies in the EEA and UK developed significantly, ranging from 2 to 15 papers per year (Fig. 5c). Most of social vulnerability analyses are included in the context of vulnerability assessment (72,6 % of papers), whereas, 25.3 % of papers belong to risk assessment and 2.1 % considers social vulnerability in susceptibility analysis (Fig. 5b). As shown in Fig. 5a, Italy and Portugal represent the most investigated countries in

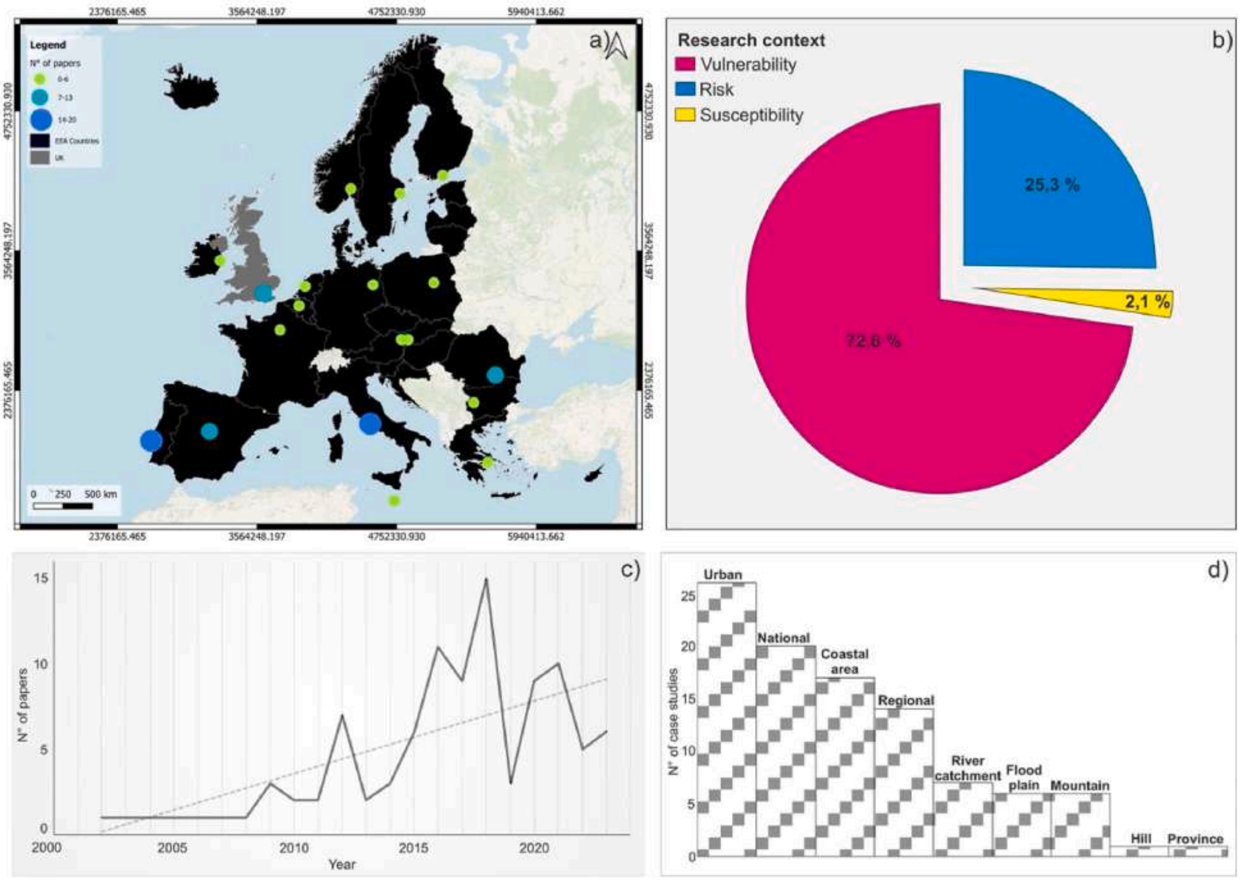

Fig. 5. General results of the frequency analysis. a) Spatial distribution of number of papers per country; b) percentage of papers in the different research context; c) research development over time between 2000 and 2023; d) histogram showing the study area context.

terms of case studies chosen by the authors (from 14 to 20 papers). Papers with case studies from UK and Romania ranges between 7 and 13, while the rest of countries are less taken into account (from 1 to 6 papers).

Considering the geographic scale and the environmental setting (Fig. 5d), more than 25 papers analyze social vulnerability in urban context, followed by coastal area, river catchment, flood plain, mountain and hilly landscapes. In terms of administrative boundaries, the national scale is represented by the highest number of studies (20), followed by regional (14 papers) and provincial level (1). Results of the frequency analysis of administrative boundary and environmental context are shown in Fig. 5d, regarding studies developed at national, regional and provincial context and including different environments (urban, coastal, etc.).

Concerning the theoretical frameworks of the reviewed literature, 32 different conceptual approaches have been applied to investigate social vulnerability in the context of natural hazards. When social vulnerability is included in more extended analysis, the theoretical basis concerns risk analysis. The majority of papers (27) utilized the "Vulnerability of places" proposed by Cutter et al., in 2003; 5 case studies are investigated through the "MOVE-Framework" provided by Birkmann, 2013 and 5 articles used the "Coastal risk assessment framework" by Ref. [44]. Other examples of theoretical procedures that are considered to a lesser extent are: the "Flood risk management strategy (Directive 2007/60/EC)", the "Fuzzy model" [45], the "Multicriteria approach", the "Risk perception and geographic location" ([46] and Cutter, 2000), the "Risk triangle [47,48]", the "BBC-Framework" [18], the "Coastal City Flood Vulnerability Index (CCFVI)" [49], the "Cost-benefit analysis", the "Coupled Human-Environment Model [50]", the "Potential Damage Index" (PDI) [51,52]; the "Disaster Risk Reduction (DRR)" approach, the "Environmental Assessment" [53,54], the "GIS-based multicriteria decision analysis approach" [55], the "Hazard-independent vulnerability approach", the "Holistic approach to disaster risk assessment and management" [56–63], the "Holistic approach" by Ref. [64], the "Impact chain method" [65], the "Integrated risk assessment in OpenQuake" (adapted from Ref. [66] and Cutter et al., 2000), the "IPCC framework" [67], the "KULTURisk (KR) approach" [68,69], the "Multi-Criteria Approach for risk management policies and decision-making" [18,70], the "Subdomains and indicator levels [71] and geon-concept [72]" approach, the "CRISSIS Program" approach, "The process model of vulnerability to flooding: threats, impacts and mediating influences" [73], "Uncertainty and sensitivity analysis" [74], "Vulnerability and resilience" [75], "Vulnerability assessment framework to heat-related phenomena" ([76–78]; Timmerman et al., 2016; [79–81]), "Vulnerability index approach" [82]. In 2 papers, the conceptual frameworks are constructed by the author, whereas the rest of articles (19) show a significant gap in the proper definition of the framework used. The list of conceptual frameworks with the author's details are shown in the main database (Supplementary Material).

In some papers (14 case studies), the investigation of social vulnerability focuses on temporal analysis that provide an outline of the changes in the social condition over the past years but also underline the development of future scenarios in the context of climate change. In particular, 6 papers analyze and map social vulnerability in the last 10- or 20-years using census data [39,83–86]. Future scenarios (especially developed for coastal environments) are proposed in 7 papers [87–93]. Only 1 paper consider both temporal directions [94].

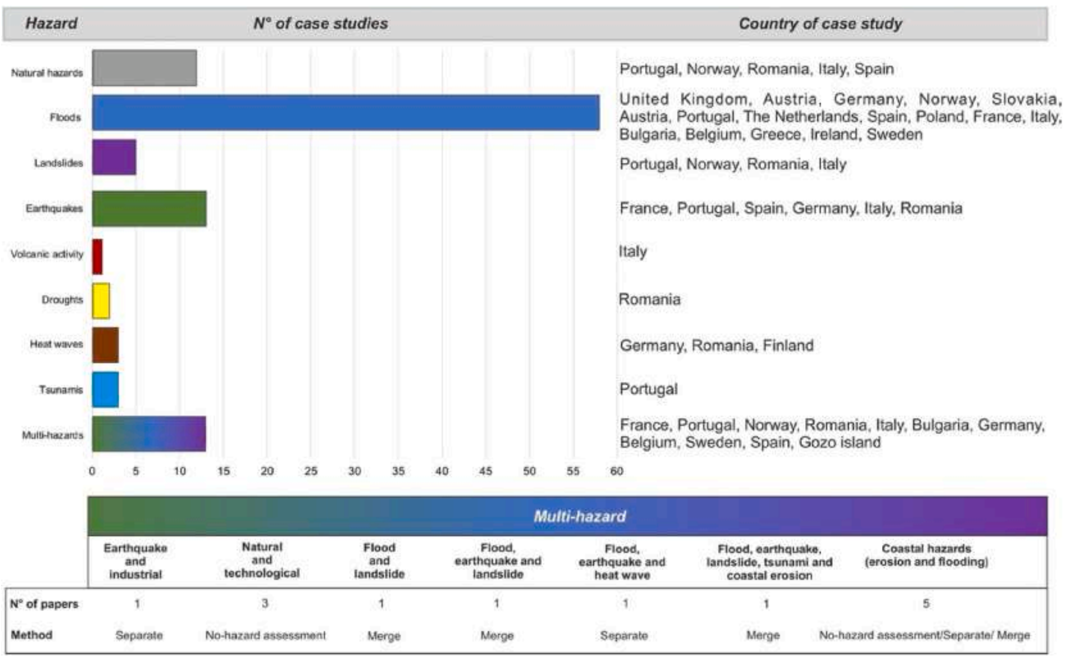

Fig. 6. On the top, the number of case studies of social vulnerability to different type of hazard with the indication of the country of the study area. On the bottom, the details about papers that investigate social vulnerability in a multi-hazard context.

3.2. Hazard assessment

Literature data about social vulnerability to natural hazards in the EEA and the UK reveal a significant interest of case studies (more than 55) developed within flood hazard settings (Fig. 6) in 17 different countries. It is followed by 13 cases analyzed in earthquake scenarios, 12 related to more general natural hazard context, 5 for landslides, 3 linked to heat wave condition, 2 for drought and tsunamis and only 1 focuses on volcanic activity in Italy. The list of hazards with author's details are shown in main database (Supplementary Material).

An eye of attention also concerns analyses that fall within the multi-hazard category consisting of 13 different case studies, in which hazards are treated in different way. In particular, 1 paper focuses on social vulnerability to earthquake and industrial hazard [95] and to flood, earthquake, and heat wave [96] without merging the results. 3 articles belong to natural and technological hazards ([97]; Mendes et al., 2010; [98]) lacking in hazard assessment, while 3 papers combine the results in case of flood and landslide [99], flood earthquake and landslide [100], earthquake, flood, landslide, tsunami and coastal erosion [101]. The last category of multi-hazard is composed of 5 papers that include social vulnerability in coastal hazard studies of which: 1 shows a gap in hazard assessment [102], 2 analyze coastal flooding and erosion separately [89,103], while 2 merge the results [91,104].

In terms of hazard assessment, our results show that more than half of the papers include hazard data, while 35 % investigate only social vulnerability (Fig. 7a). Considering the former, 29 different physical components are extracted (Fig. 7b) and processed with various approach (Fig. 7c). The physical components, in turn, are characterized or developed throughout physical parameters such as: return period, water depth, water velocity, rainfall, frequency, imperviousness, slope, hydrological soil group, density of sewer system, lithology, altimetry, curvature, river density and soil texture for flood; magnitude and peak ground acceleration for earthquake; time, topography, plume height, eruption mass, eruption magnitude, grain size and wind direction for specific volcano eruption scenarios.

Most of the papers (34 %) use hazard data/map directly available from district or governmental authority, governmental agency, national dataset or data already processed in the literature ([95,105,106]; Armaş & Gavriş, 2012 [101,107–109]; Armaş I et al., 2017 [94,110–115]; Chen et al., 2021; [116–119]).

24 % use modelling software such as the Tephra 2 software and transient 3D flow model (Willis et al., 2010) for volcanic activity and the GEM OpenQuake engine software for seismic hazard [120]. Other modelling software are used to estimate flood hazard. The Hydrologic Engineering Center - Hydraulic Modeling System (HEC-HMS), Iber 2D and the Hydrologic Engineering Center - River Analysis System (HEC-RAS) are applied in urban context ([121]; Romanescu et al., 2016), whereas the Seamless simulation of 3D baroclinic circulation across lake–river–estuary–shelf–ocean scales (SCHISM), the X-beach model, the 2D LISFLOOD inundation model, the Multivariate adaptive regression spline (MARS), the Simulating WAves Nearshore/till shore (SWAN/SWASH), the WAVEWATCH III and the Mike 21 software are used to investigate coastal areas [93,122–125].

Moreover, articles that apply a geographic approach (mapping) covers 18 % of methodologies [84,87,88,91,96,99,126–128], whereas 14 % of papers uses specific parameters to build indices through math formulas [89,100,104,129–132].

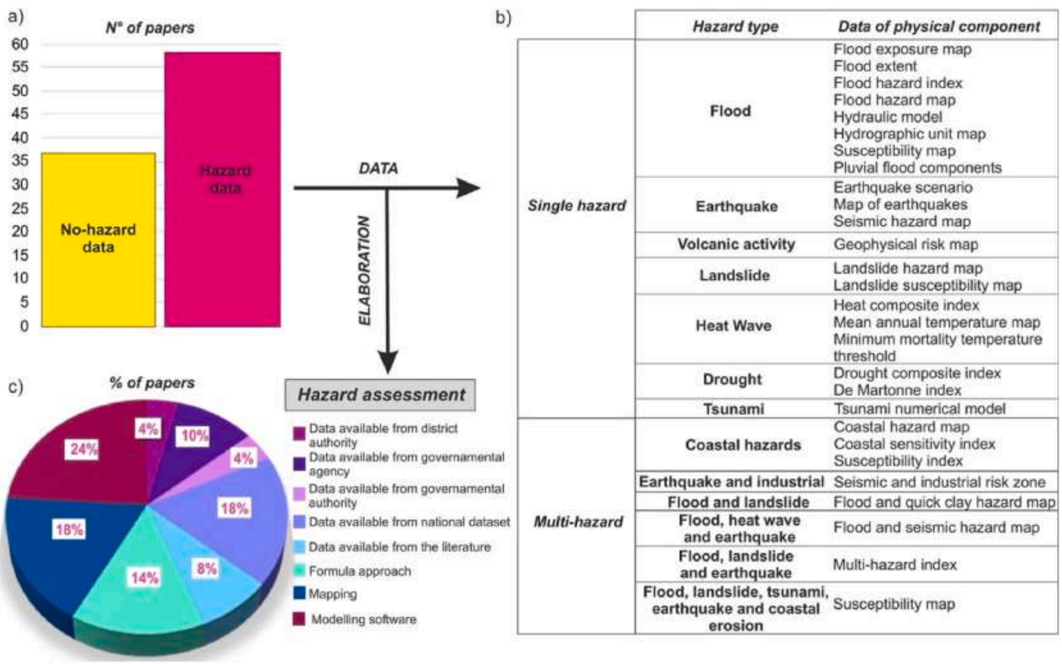

Fig. 7. Analysis framework for hazard assessment. a) Evaluation of papers that include hazard data; b) Descriptive list of physical components used for each hazard type; c) classification of elaboration methods.

3.3. Evaluation of social vulnerability

According to our criteria, 18 different terms are chosen by the authors of selected papers to describe "vulnerability". Fig. 8 shows the words that are frequently combined to build vulnerability definitions. The words that regularly occur, in order of frequency, are: "Susceptibility", "Exposure", "Sensitivity", "Intrinsic characteristic to cope", "Adaptive capacity", "Capacity to cope" with recurrences between 32 and 10. Other type of meanings are: "Lack of Resilience" (9 times), "Potential for loss" and "Ability to cope" (5 times), "Fragility" (3 times), "Impact" and "Resistance" (2 times), "Characteristic determined by social policy", "Consequence of a hazard", "Degree of loss", "Social response", "Inability to withstand" and "The propensity to be adversely affected" (1 time). 8 papers lack of a vulnerability definition.

Table 2 shows an overview of the different dimensions of vulnerability that are taken into account for each hazard type. As shown in the list, floods and earthquakes are the most explored in terms of vulnerability dimensions. In these study cases, authors include 9/8 dimensions of vulnerability. Built vulnerability is the second dimension extracted after the social one, particularly in the case of floods, earthquakes, landslide, heat waves, volcanic activity, tsunami and more in general natural hazards, followed by the environmental vulnerability linked to floods, earthquake, heat wave and multi-hazards. It is essential to specify that in Table 3 "built vulnerability" is related to the vulnerability of buildings, whereas the "physical vulnerability" concerns the geological vulnerability. This decision was made following the meaning proposed by the authors.

Concerning the methods of vulnerability evaluation, Fig. 9 depicts the classification of the various approach proposed in the selected literature (V approach), followed by the identification of the main techniques used for measuring social vulnerability (SV analysis) and the indicators/criteria weighted methods. It is necessary to specify that different social vulnerability analyses are also combined within the same approach.

The frequency analysis results in more than half of papers using a quantitative approach (58), followed by the multicriteria analysis (19 papers); 5 papers present a semi-quantitative approach, which is based on classes of vulnerabilities rather than on an overall index, while 5 use a geographical approach by means of the use of GIS (Geographic information system) tools; 5 papers take into account the collection of social vulnerability data already available from national datasets; 3 studies use qualitative approaches, 1 a fuzzy model and 1 focuses on a social vulnerability index validation. All of the approaches include statistical techniques that are specifically tailored to measure social vulnerability and that could be combined to calculate the overall vulnerability.

Another step of measuring social vulnerability, or more in general vulnerability, concerns the weighting approach. Since the literature generally lacks a common methodology for assigning weights [133], Fig. 9 underlines the weight approaches used in the selected literature. As shown in the pie chart, the majority of authors (31,6 %) prefer not to weight the results; 24,2 % follows the expert-judgment method (especially in Multicriteria Decision and Analytical Hierarchy elaborations); 21,1 % provides an equal weight procedure through expert judgment or statistical investigation; 17,9 % apply only statistical results (such as the variance extracted by the Principal Component investigation) and 4,3 % of papers choose different weight based on the combination of different techniques (geographical, statistical and expert judgment). Only in 1 case, the weighting method is unexplained.

The list of vulnerability approach and weighting methods with author's details are shown in main database (Supplementary Material).

The choice of data used in social vulnerability analysis depends on the type of conceptual framework proposed by the authors, and on data availability. With this respect, 85 authors collect census data, 6 authors work with surveys and 7 authors combine both of them. Other sources used to collect data about exposure or land use are orthophotos, remote sensing images and OpenStreetMap (OSM).

Lasly, since European countries do not have unified organization of the public administration that is coming out of historic development, cultural or social conditions [134] and have different administrative territorial divisions, Table 3 represents the collection of the different geographic boundaries used as spatial measure unit for vulnerability investigation.

Fig. 8. Word cloud of the definitions used by the authors to explain "vulnerability".

Table 2
List of vulnerability dimensions for each hazard type. In the papers, the dimensions are explicated thought indicators and criteria based on the type of vulnerability approach.

Hazard type	Vulnerability dimension
Flood	Socio-economic, demographic, health, built, environmental, accessibility, risk perception, transport network, land use, hydrogeological, institutional
Earthquake	Socio-economic, built, environmental, capacity, risk perception, systemic, accessibility, territorial, resilience
Landslide	Socio-economic and built
Heat wave	Socio-economic, demographic, built and environmental
Drought	Socio-economic, built, inhabited and geographical position
Volcanic activity	Social, built, evacuation, financial recovery, access to resources
Tsunami	Social, morphological, structural and property tax
Natural hazards	Social and built
Coastal hazards	Socio-economic, land use, transport network, environmental
Earthquake and industrial	Social
Natural and technological	Socio-economic, environmental and emergency
Flood and landslide	Social and physical
Heat waves, flood and earthquake	Social, environmental, institutional
Earthquake, flood and landslide	Social and material
Earthquake, flood, landslide, tsunami and coastal erosion	Socio-economic

3.4. Integration methods

This section considers the main methodologies that integrate social vulnerability in disaster studies, which is a major aim of the present review. 48 papers apply an integration approach (Fig. 10a). A few papers include some integration components (Fig. 10b) such as exposure (18), resilience (2) and physical risk (1 paper). Physical risk refers to property damage, life-line source damage, network damage [135]. The details of the data used for these components are explained in the main database (Supplementary Material).

All integration methods include mapping procedures that mainly derived from a risk matrix. However, some slight differences can be noted in the choice of integration procedures. In particular, as shown in Figs. 10c and 5 main classes of integration techniques can be extracted from the dataset (Fig. 10c). 38 % of papers uses a geographical approach to combine hazard and vulnerability. The method consists of an overlay mapping of different informatic layers that produce an overall risk map ([95,105,111,121,126]; Romanescu et al., 2016; [104,109,113,116,119,124,132,136–138]). 6 % of papers apply statistical and geographical analysis (Willis et al., 2010 [100,106]; Chen et al., 2021). 2 % of papers conducts a fuzzy rules approach [45,135], whereas another 2 % carry out a multicriteria investigation [123]. Lastly, 52 % of papers uses 4 different type of integration formulas: group 1 integrates social vulnerability with other vulnerability components to construct an overall vulnerability index, group 2 combines social vulnerability with other vulnerability components and exposure data; group 3 merges social vulnerability or vulnerability with hazard or susceptibility; group 4 creates a risk index throughout the integration of vulnerability, hazard and exposure. A detailed explanation of the formula approach is provided in Table 4.

4. Discussion

4.1. The role of social vulnerability in the climate change perspective: the case of the developed countries of the Mediterranean area

While from the literature it emerges that generally more importance is given to the recurrency of hazardous events with respect to the number of deaths, this is not the case of Italy. The high number of social vulnerability studies in Italy (section 3.1) could be related to the great number of damages caused by natural disasters in that country. As shown in section 1.1, the country has been characterized by the highest number of deaths in the last twenty years, especially in case of earthquakes, landslides and heat waves. These events have caused destruction and casualties which, in turn, determined very high social and economic costs [27]. The correlation between number of deaths and number of studies on social vulnerabilities is strictly linked to the capacity of mitigating risk in its three components: hazard, exposure and vulnerability. Hazard can hardly be diminished (intrinsically depending on natural events), exposure depends on regulatory frameworks, urbanization plans and social choices are provided by institutional authorities. Consequently, disasters (including damage and deaths) could be significantly reduced by working on vulnerability of which the social component plays a major role.

Italy's natural exposure to different risks, caused by the highly active geodynamic and geomorphologic setting, has led the Italian population to naturally deal with frequent hazardous events. This has certainly increased the interest of the scientific community in studying the Italian populations and its vulnerability, particularly from 2010 on, when the first case study of Mt Vesuvius was published (Willis et al., 2010). Along with Italy, Portugal is also represented by a large number of papers and the country falls into the second place in the ranking of numbers of deaths due to disasters, particularly caused by heat waves (section 1.1).

Portugal is also vulnerable to extreme events associated to lack (droughts) or excess (floods) of rainfall, while they are expected to increase in Italy (https://climateknowledgeportal.worldbank.org). Both nations are located in the Mediterranean Region which is considered a hot spot of climate change that calls for attention on the environment, ecosystems and human communities [139] in terms of the evolution of the process at global scale. Climate change, desertification, and the hydrological cycle have contributed to environmental degradation in the Mediterranean region during the 20th century. In addition, human-induced demand factors (population growth, urbanization, agriculture/food demands) will increase pressure on this environment in the next years [140]. As shown in

Table 3
List of geographic units used for the social vulnerability analysis linked to the country of case study.

Country	Geographic unit
United Kingdom	District
	LSOA (Lower Layer Super Output Area)
	OAC (neighborhood)
Ireland	Small area (sub-municipality)
France	District
	Grid
	Building
	1 km sector
	Regional
	County
	Municipality
Portugal	Municipality
	Sub-municipality
	Neighborhood
	Parish
	Statistical block (sub-parish)
	1 km sector
	Block (sub-municipality)
	Sub-block (building)
Austria	Grid
Germany	County
	Sub-district
	1 km sector
Italy	Household
	Municipality
	1 km sector
	Census track (sub-municipality)
	Grid
Norway	Municipality
	Ward (sub-municipality)
Romania	Census track (sub-municipality)
	Village
	Building
	Neighborhood
	LAU (Local Administrative Level)
	Municipality
Spain	Municipality
	ZRP (Neighborhood small statistical zone)
	Sub-municipality
	1 km sector
	Urban area (quantile)
	District
Slovakia	Municipality
	Household
	Basic urban unit (sub-municipality)
Greece	Municipality
The Netherlands	Household
Poland	Household
	Census track (sub-municipality)
Gozo Island	Municipality
Belgium	1 km sector
	Province
	District
	Municipality
Bulgaria	1 km sector
	District
Sweden	1 km sector
	De-SO (sub-municipality)
Finland	Sub-municipality

section 3.2, the urgency of vulnerability studies in the Mediterranean zones, brought researcher to include social vulnerability in coastal hazards studies in order to consider the ability of population to face multi-hazards condition caused by coastal erosion and flooding [89,91,102–104]. Moreover, as also depicted in section 3.1, coastal area is the third environment investigated across the EEA and UK countries, preceded by national scale and urban system. Being the EEA and UK part of the most industrialized communities in the world, populated urban settings represent the main study area investigated in the last twenty years.

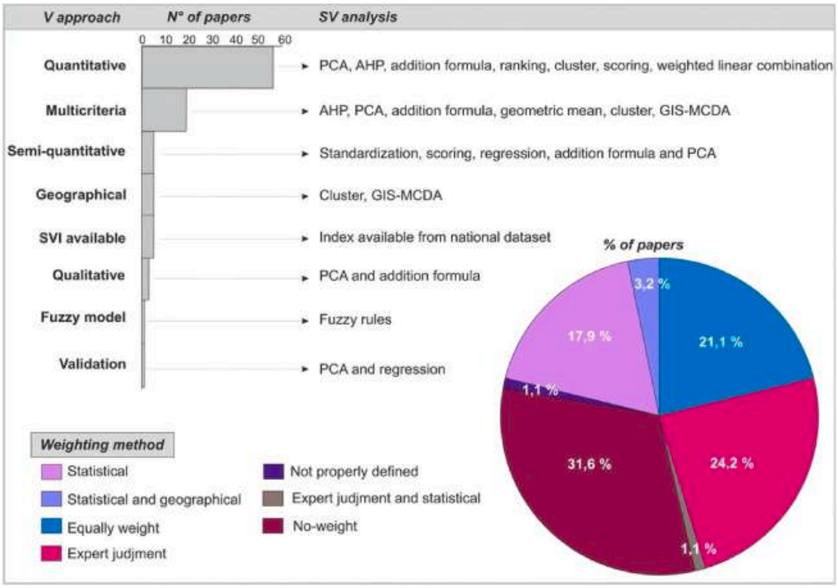

Fig. 9. Vulnerability assessment methods. On the top, the number of articles divided by the different vulnerability approaches. Each category, in turn, is characterized by a series of methodologies for investigating and calculating social vulnerability. On the bottom, the percentage of papers linked to the indicators/criteria weighing method. V = Vulnerability, SV = Social Vulnerability, SVI = Social Vulnerability Index, PCA = Principal Component Analysis, AHP = Analytical Hierarchy Process, GIS = Geographic Information System, MCDA = Multi-Criteria Decison Analysis.

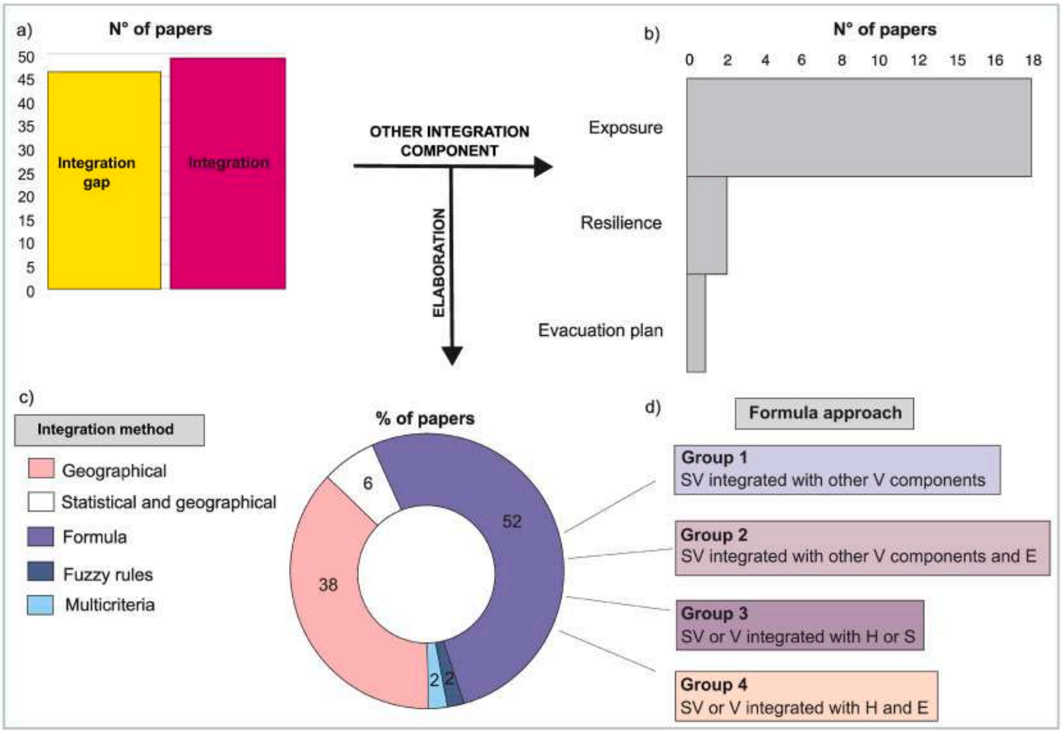

Fig. 10. Interpolation of different techniques that integrate social vulnerability in disaster studies. a) Histogram of number of papers that apply an integration approach; b) frequency of other integration component included in the analysis; c) classification of integration method; c) result clustering of formula approach. SV = Social vulnerability; V = Vulnerability; H = Hazard; E = Exposure; S = Susceptibility.

Table 4
Explanation of groups deriving from integration formula approach.

Group	Formula	Description	Hazard	Author
1	**CVI = Mv + Bv + Sv + TPv**	Composite vulnerability index = morphological vulnerability + built vulnerability + social vulnerability + Taxable property vulnerability	Tsunami	Tavares et al., 2017
	TCCFVI= CCFVI (Hydr+Socio+Inst)/3	Total Coastal City Flood Vulnerability = (Hydrogeological coastal flood vulnerability index + Social coastal flood vulnerability index + Institutional coastal flood vulnerability index)/3	Flood	Giannakidou et al., 2019
	HVI = (EVI + SEVI)/2	Heat related vulnerability = environmental vulnerability + socio-economic vulnerability/2	Heat wave	Grigorescu et al., 2021
2	**IntVI = w1*EI + w2*SoVI**	Integrated vulnerability index = (Weight of the exposure index * Exposure Index) + (Weight of the social vulnerability index * Social vulnerability index)	Flood	Lujala et al., 2014
	V = E*(S + LoR)/2	Vulnerability = Exposure * (Susceptibility + Lack of resilience)/2	Multi-hazard	Welle et al., 2014
	IntVI = w1*EI + w2*SeVI + w3*BEVI	Integrated vulnerability index = (Weight of the exposure index* Exposure Index) + (Weight of the social vulnerability index*Social vulnerability index) + (weight of built vulnerability index*built vulnerability index)	Flood	Rød et al., 2015
3	**R = SV * S**	Risk = Social vulnerability * Susceptibility	Multi-hazard	Guillard-Gonçalves et al., 2015
	R = V * H	Risk = Vulnerability * Hazard	Flood, earthquake, landslide	Freire et al., 2016; Frigerio et al., 2016; Roder et al., 2017; Leis & Kienberger, 2020; Ivanov et al., 2022; Lapietra et al., 2023; Vojtek, 2023
	E = (SV + RI) * H	Exposure to seismic risk = (Social vulnerability + Resilience) * Seismic hazard	Earthquake	Azzimonti et al., 2020
	RT= RF * (1+F)	Total earthquake risk index = Physical risk index (average annual loss) * (1 + social fragility (social vulnerability)).	Earthquake	Burton & Silva, 2016
	R = V + H	Risk = Hazard + Vulnerability	Flood	Ferreira et al., 2018
	CI = (CESI * CFSI)/2	Coastal index = (Coastal Exposure Index * Coastal suceptibility index)/2	Multi-hazard	Aucelli et al., 2018
	R = E * H	Coastal risk = Coastal Exposure * Coastal Hazard	Multi-hazard	Di Paola et al., 2021
	PFI = w1*IMP - w2*S + w3*HSG - w4*DSS + w5*SV	Pluvial flood index = weight of IMP*Imperviousness - Weight of S*Slope + Weight of HSG* Hydrologic Soil Group - weight of DSS*Density of Sewer System + weight of SVI * Social Vulnerabilty Index	Flood	Pacetti et al., 2022
4	**R = H * E * V**	Risk = Hazard * Exposure * Vulnerability	Flood, landslide, heat wave, multi-hazard	Koks et al., 2015; Ferreira et al., 2018; Guillard-Gonçalves & Zezere, 2018; Ferri et al., 2020; Santos et al., 2020; Landreau et al., 2021; Paranunzio et al., 2022

4.2. Hazard and vulnerability issues: recommendation for future studies

In countries subject to multiple risks, a multidisciplinary approach is needed to develop integrated methodologies for the analysis of social vulnerability. Considering the type of hazards and the methods of estimation (section 3.1), only few papers analyzed in more details heat waves, volcanoes and landslide hazards that covers areas of very different extensions in Europe and UK. This outcome could be interpreted as a minor perception of the scientific community in exploring social vulnerability, especially for heat waves which represent major disasters in the EEA and UK (section 1.1). On the contrary, the absence of deaths during volcanic eruptions in the last twenty years (section 1.1) underlines a significant gap in social vulnerability studies. In this context, since the relevant presence of numerous active volcanoes in the Mediterranean region [141] and knowing that eruptions give warning signals before they occur, providing a range of time to evacuate the area, studies on social vulnerability could be a significant development tool in this type of emergency planning. Another aspect regards the lack of studies focused on social vulnerability to meteorological hazards such as cyclones, extra-tropical cyclones, tornados which often occurred in Europe. Examples of such events were the tropical cyclones occurred in Portugal in 2018 that caused a total damage of 134611 $ and 88 people affected or the tornado occurred at Hautmont city (Nord distric, Nord-Pas-de-Calais province) in France in 2008 characterized by 2100 people affected and 108742 $ of damage.

A brief consideration is also need in terms of data elaboration. As shown in section 3.2, most of papers collect hazard maps provided by governmental or district authority. Although this is sufficient for study cases at national or regional level, works at local scale require high spatial and/or temporal resolution model for hazard calculation and therefore emergency planning. Indeed, local features (rapid variations in topography, land use and infrastructure) may not be adequately captured by coarse-resolution maps and models (as those often provided by governmental and district authority), leading to inaccurate hazard predictions. In emergency planning, accuracy is essential for the effective response strategies, and relying on large-scale maps and models can lead to insufficient preparedness and resource allocation. Therefore, for robust hazard assessment and emergency planning at the local scale, it is essential to use constantly updated and higher resolution maps and models that better capture the complexities of the specific environment and community characteristics. In addition, risks are strictly linked to the concept of uncertainty [142] that need be taken into account in hazard assessment. Turning uncertainty into scientific data could be a fundamental step towards true scientific knowledge of natural and social phenomena and the ability to prevent.

As regards vulnerability, one of the main issues of constructing the social vulnerability index concerns the choice of indicators. The majority of authors of the EEA and UK select the variables following the indicator list provided by previous studies developed in other socio-economic context such as the United States, where the first social vulnerability index was created [9]. This indication could be definitely used for some "standard" indicators such as age, gender, employment, income, education and presence of foreign people, but a detail study of the socio-economic context needs to be implemented by other specific local indicators (access to resources, insurance, type of local business or daily mobility). In this respect, as shown in section 3.3, some authors that include social vulnerability in their analysis collect values of social vulnerability indices directly from national statistics dataset providing specific territorial vulnerability indices at municipality level [89,91,100,103,116]. Also, detailed territorial data could provide information about historical, naturalistic and heritage sites that represent the cultural base of the European context and need special consideration in risk analysis.

In addition, temporal analyses of social vulnerability are needed in pre- and post-disaster phases for preparedness and recovery actions. However, census data publication timing is generally scheduled every 10 years lacking in annual information. Therefore, understanding social vulnerability as dynamic process in disaster studies is still challenging [39,83–86,94].

Researches that investigate social or community vulnerability to natural hazards need to underline the environmental context or the different environments limited by the same administrative boundaries, especially when the work is carried on at national or regional scale. The characteristics of population such as type of work, income, presence of infrastructure or access to resources is largely influenced by the socio-economic context they live in, which in turn gains the resources from the environment. Particularly, urban centers have had to adapt to environmental conditions and available resources. Therefore, multidisciplinary competences that also integrate environmental studies are highly recommended as to develop vulnerability analyses to natural hazards as land use is eroding the natural buffers that protect communities from hazards and these same changes often erode people's capacity to recover from disaster [143]. The strict connection between the unsustainability of the urban structure and the frequency with which natural disasters occur is principally due to the consequences generated by the consumption of natural soil and is confirmed by the economic, social and environmental damages recorded in recent years [144].

Lastly, land use and management plans are strictly related to institutional vulnerability. According to Paul [145], institutional vulnerability does not refer to the vulnerability of the institutions but to their role in causing societies to become more vulnerable to natural hazards. Therefore, institutional vulnerability could be considered as a weakness of the institutional framework in risk governance [146]. Although these components are strictly linked to social vulnerability in developed countries, our systematic review highlights 10 papers that include the environmental dimension in vulnerability analysis (Armaș, 2012; [98,104,113,117,125,147–150]) and only 2 case studies include institutional vulnerability [96,151].

4.3. Proposal of a multidisciplinary scheme for risk analysis

With the aim of helping to introduce standard methodologies in areas subject to different natural disasters, a scheme is here proposed for a multidisciplinary approach in risk analysis.

Table 5 shows this scheme. It represents a potential database that could be used to conduct multidisciplinary approaches in risk analysis for case studies in the EEA and UK. The database takes into account the three main components of the risk definition provided in section 1 (HAZARD, EXPOSURE and VULNERABILITY) proposing a set of data collection extracted from the works investigated in this systematic review coupled with global literature data. In this context, the HAZARD component gathers all types of data, maps and

Table 5
Multidisciplinary approach for risk analysis in the EEA and UK.

HAZARD		
	Category	Data
Single hazard	Flood	Flood exposure map Flood extent Flood hazard index Flood hazard map Hydraulic model Hydrographic unit map Susceptibility map Pluvial flood components
	Earthquake	Earthquake scenario Map of earthquakes Seismic hazard map
	Volcanic activity	Geophysical risk map
	Landslide	Landslide hazard map Landslide susceptibility map
	Heat waves	Heat composite index Mean annual temperature map Minimum mortality temperature threshold
	Drought	Composite drought index De Martonne index
	Tsunami	Tsunami numerical model
Multi-hazard	Coastal hazard (erosion and flooding)	Coastal hazard map Coastal sensitivity index Susceptibility index for each hazard type
	Earthquake and industrial	Seismic and industrial risk zone
	Flood and landslide	Flood and quick clay hazard map
	Heat waves, flood and earthquake	Seismic and flood hazard map
	Earthquake, flood and landslide	Multihazard index
	Earthquake, flood, landslide, tsunami and coastal erosion	Susceptibility map

EXPOSURE
Data
Land use
Population density
Density of buildings (household stay and grocery stores)
Density of infrastractures (transport network, hospitals and medical centers, schools, institutional and enforsment centers)
Density of natural and heritage sites

VULNERABILITY	
Category	Data
Social	Age Income Employment Education level Disability
Built	Construction age Construction material Maintanance
Economic	Productvity sector Food production Income dependency from private sector
Environmental	Flora characteristics Fauna characteristics Environmental quality Land cover
Institutional	Socio-cultural pillar Socio-political pillar legislative and regulatory pillar fiscal-economic pillar

models categorized by the different hazards treated by authors. These data represent the final results deriving from the various elaborations explained in section 3.2 which are strictly connected with the hazard category. At the same time, the EXPOSURE and VULNERABILITY components collect the types of data used in the different study cases and in the global literature for all hazard categories. In particular, the EXPOSURE component takes into account the number or density of the elements exposed (e.g. population/buildings/infrastructure/natural and heritage sites density) coupled with the land use which represents one of the most used data by authors for exposure identification [152,153]. According to Ref. [10], the VULNERABILITY component is divided into 5 categories which include data for the analysis of the social, physical, economic, environmental and institutional dimensions of vulnerability.

Clearly, the data collected in Table 5 can be used separately for the analysis of each component with respect to the author investigation that can be focused only on hazard assessment or overall vulnerability. However, in disaster studies, the approach shows that it is essential to analyze the socio-economic components of communities affected by natural hazards as it is equally significant to investigate the probability of these events. It is well known that only multidisciplinary methodologies provide information about the real interaction between physical components and society and could be used for emergency planning and risk reduction strategies [154–156]. Although this consideration seems obvious, there is still a lot of work to unify the definitions and methods related to the concept of risk and disaster. This issue is caused by the different schools of thought provided by the various disciplinary sectors. Looking at Table 5 and it is clear that all scientific, economic, social and legal subjects deal with one or more elements proposed in the table requiring an openness to the role of multidisciplinary in the field of disasters.

5. Conclusion

The present research aimed to synthesize the various approaches proposed in the literature for the analysis of social vulnerability through the integration of this component with other elements pertinent to risk analysis such as hazard, other vulnerability dimensions and exposure.

In this context, we conducted a systematic review of case studies that measure and map social vulnerability to natural hazards in the EEA and UK. Being our research systematic, some limitations need to be underline. Firstly, the investigation is based on specific criteria (section 2.1) that are strongly influenced by the research aims. In our case, only 95 papers satisfied our eligibility criteria and were extracted from two data sources thought the PRISMA procedure. Secondly, systematic review considers specific time period that can exclude any new research during the investigation period that can provide new insight for the topic under review. For this reason, any update of this research is recommended in order to give more perspective to risk analysis and the inclusion of social vulnerability as a risk component.

Our review represents a methodological manual for all those who works on data integration in risk analysis or emergency planning. The main results reveal a more pronounced perception of the scientific community to recurrent events (floods) rather than number of death (heat waves). The gap of studies that analyze social vulnerability to volcanic eruption is a relevant example as only 3 significant volcanic activities and 0 deaths were registered in the last twenty years. Moreover, this study underlines the high need of multidisciplinary approach (Earth, Social, Economic, Engineering Sciences) in the context of disaster management and risk reduction strategies. Given the above findings, the review provides a broader look at future research developments in the field of climate change and emergency planning pointing out the need to improve integration methods and the development of territorial socio-economic indicators. With this aim a scheme is finally proposed for a standard multidisciplinary approach in risk analysis, which is useful for the investigation of different types of natural disasters.

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CRediT authorship contribution statement

Isabella Lapietra: Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Rosa Colacicco:** Writing – original draft, Software, Investigation, Data curation. **Domenico Capolongo:** Writing – review & editing, Supervision. **Marco La Salandra:** Software, Data curation. **Anna Rinaldi:** Writing – review & editing, Investigation. **Pierfrancesco Dellino:** Writing – review & editing, Supervision, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data are shared in Supplementary Material (SM file)

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijdrr.2024.104507.

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