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Social vulnerability to floods: Review of case studies and implications for measurement

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ABSTRACT

A leading challenge in measuring social vulnerability to hazards is for output metrics to better reflect the context in which vulnerability occurs. Through a meta-analysis of 67 flood disaster case studies (1997–2013), this paper profiles the leading drivers of social vulnerability to floods. The results identify demographic characteristics, socioeconomic status, and health as the leading empirical drivers of social vulnerability to damaging flood events. However, risk perception and coping capacity also featured prominently in the case studies, yet these factors tend to be poorly reflected in many social vulnerability indicators. The influence of social vulnerability drivers varied considerably by disaster stage and national setting, highlighting the importance of context in understanding social vulnerability precursors, processes, and outcomes. To help tailor quantitative indicators of social vulnerability to flood contexts, the article concludes with recommendations concerning temporal context, measurability, and indicator interrelationships.

1. Introduction

Over the past decade, social vulnerability indices have emerged as a leading tool to quantify and map human dimensions of hazards vulnerability. From a set of seminal studies [27,31,33,37,104], social vulnerability modeling research has expanded to address questions of scale [15,44,86], temporal change [32], specific hazards [85,87,91,97], uncertainty [57,93], validation [21,42], and integration with physical vulnerability [18,23,51]. Despite these diverse developments, social vulnerability indices continue to exhibit a large degree of uniformity in index construction approaches. This homogeneity reflects growing methodological consensus among modelers, but also highlights limitations in the ability to translate social vulnerability processes into composite indicators. Such uniformity may result in misleading conclusions if dimensions of social vulnerability pertinent to specific hazards are excluded, or by contrast if weakly influential dimensions are overrepresented. Among the major challenges is to better incorporate the context in which social vulnerability occurs [25,28,56,61,62].

Context distinguishes generalized notions of social vulnerability, such as those often reflected in indicator studies, from its manifestations in specific disasters. Interacting contextual aspects explain, underlie, amplify, and attenuate the exposure, susceptibility, and coping capacity of vulnerable populations. Context is multifaceted and includes the geographic setting of the disaster, pre-existing social, economic and political conditions, hazard characteristics, degree of exposure, scales of impacts and responses, and disaster phase (e.g., before, during, after). Other important contexts may include cultural and institutional norms, societal networks, governance, and historical processes. These geographically and temporally varying characteristics are key for deconstructing vulnerability, because they describe the human and environmental precursors and interactions that make individual disasters unique. Social vulnerability theorists and case study researchers have long made this point [64,69], yet the vast majority of social vulnerability indices employ equal weighting and additive models based on the same leading indicators, regardless of context. There is a large gap between the contextual complexity revealed through qualitative studies and generalized, quantitative metrics produced by social vulnerability indices [70].

Despite design and contextual shortcomings, quantitative indicators offer many benefits for vulnerability reduction efforts. Quantifying social vulnerability can help identify which places are most vulnerable, and which dimensions of social vulnerability are the key drivers. The ability of well-designed indicators to simplify multidimensional complexity into aggregate measures makes them well suited for use in decision making, resource allocation,

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and project prioritization [13]. This policy relevance is increasingly transforming the development of indicators from academic exercises into political necessities [55]. Given the demand for quantitative metrics, one response to contextual critiques is to develop more contextually specific indicators.

This study focuses on the intersecting social vulnerability contexts of flood hazard, disaster phase, and national level of development. Relative to other natural hazards, floods are nearly ubiquitous in the environment, manifesting as large regional floods, local flash floods, coastal storm surge, and urban drainage overflow. Floods can occur as both frequent and rare events, as short and long duration, and produce adverse impacts across a range of magnitudes. Human processes such as urbanization and structural defenses (e.g., levees, dams, sea walls) have a large influence on the movement and severity of flooding, ameliorating impacts in some cases, but amplifying them in others. Ongoing changes in population, land use, and climate are widely believed to presage an intensification of flood disasters. The unique characteristics of floods and their wide array of manifestations suggest that social vulnerabilities to floods could be distinct from other hazards.

The aim of this paper is to identify and profile the leading drivers of social vulnerability to floods, with the underlying goal of strengthening the foundation for indicator development. To do so we conducted a meta-analysis of qualitative case studies of flood disasters. The remainder of the article is organized as follows. Section 2 details the methods used for the meta-analysis, while Section 3 describes the key drivers identified in the case studies. The discussion in Section 4 includes recommendations for how to improve quantitative indices of social vulnerability to floods, and conclusions are provided in Section 5.

2. Methods

We performed a literature review in November 2013, focused on empirical studies describing social vulnerability processes and outcomes in the context of severe flood events. Using the Web of Science, the following search terms were applied to identify peer-reviewed journal articles published between the years 2000 and 2013:

["flood" OR "flooding"]
AND
["social vulnerability" OR "vulnerability" OR "coping"]

The article selection process is illustrated on Fig. 1. We began by collecting the 125 articles (top arrows). After reading through the abstracts, we selected those with a specific focus on the social vulnerabilities of individuals and households (second level arrows). Hence, we excluded articles primarily focused on the physical aspects of flooding, built environment exposure, multi-hazard vulnerability, or climate change. Others were removed that centered on disaster management, quantitative indicators, or computer simulation. Some articles were later added in a snowball fashion based on citations in the papers reviewed. We then read the full papers, retaining those that investigated case studies through interviews, surveys, participant observation, focus groups, and literature review (third level arrow). At the conclusion of this process, what remained were sixty-seven empirical studies of social vulnerability to flood disasters. We coded them in a matrix for in-depth analysis.

The locations of the case studies are shown in Fig. 2. The article count is highest for the United States (dominated by investigations of Hurricane Katrina), Western Europe, and South Asia. Meanwhile, there were fewer studies situated in East Asia, Africa, and Central and South America, despite the occurrence of floods across these regions. Studies in the United States and England comprise approximately half of the total articles analyzed. The result of our English keyword selection is a bias favoring English-speaking settings. For countries such as Ghana, Nepal, the Philippines, South Africa, and Sri Lanka, there were one or two relevant peer-reviewed articles.

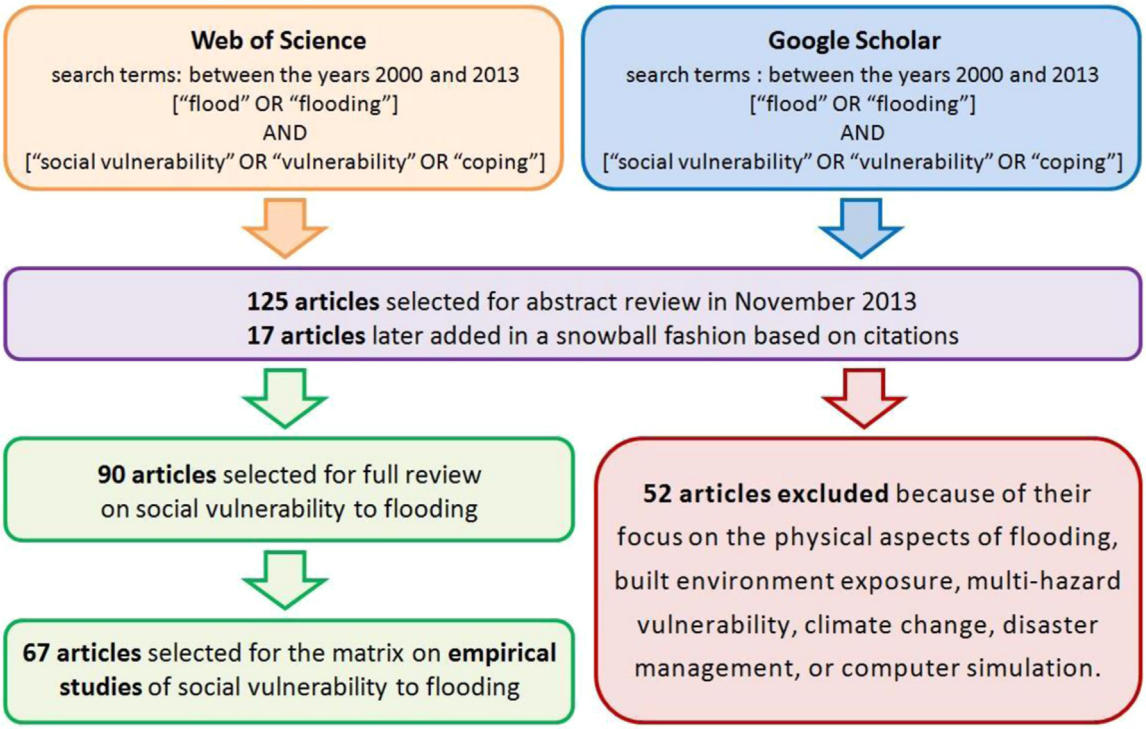

Fig. 1. Overview of the systematic literature review.

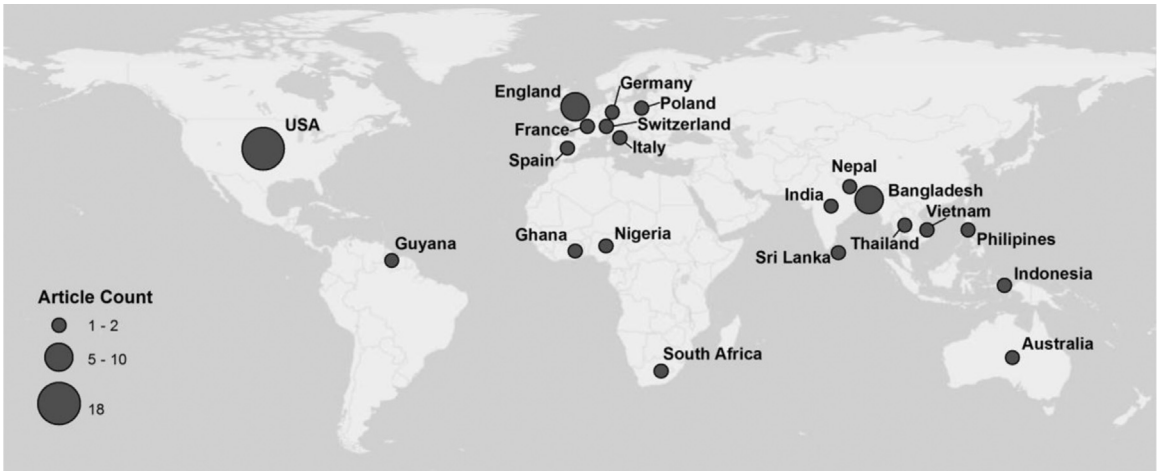

Fig. 2. Flood case study locations.

Table 1
Theoretical indicators of social vulnerability.

Thematic indicators	Specific indicators
Coping capacity	Individual capacity Household capacity Social capital
Demographic characteristics	Age Race and ethnicity Family structure Gender Functional needs Language proficiency
Health	Access Stress Disease Mortality Sanitation
Land tenure	Owners Renters Squatters
Neighborhood characteristics	Transportation Population density Housing Resource dependency
Risk perception	Awareness Prior experience Knowledge of flood protection measures Risk denial/acceptance Trust in officials
Socioeconomic status	Income Wealth Education Occupation

To analyze the articles we constructed a matrix, with theoretical indicators of social vulnerability in the rows and disaster contexts in the columns. The theoretical indicators (Table 1) were drawn from themes commonly found in the social vulnerability literature (e.g., Birkmann [14], Heinz Center [54], Phillips et al. [80]). To pinpoint characteristics that contribute to social vulnerability to floods, the thematic indicators were further subdivided into specific indicators. For example, income was included as a specific indicator of the thematic indicator of socioeconomic status. As the review progressed, additional specific indicators were added to the matrix as they were encountered. In particular, we focused on the flooding type, disaster phase, and national setting. Whenever a specific indicator was described in an article as influencing social vulnerability, the article was tallied in the matrix under the context(s) in which it occurred.

3. Results

A summary of the results is presented in Table 2. The thematic indicators are sorted by their frequency of appearance (highest to lowest) in the case studies, and characterized by their percentage of citations within a given disaster stage and development context. Because some articles may include findings spanning multiple disaster stages, or involve cases in multiple countries, the percentage sums may exceed one hundred for some indicators. Demographic characteristics were the most frequently appearing indicators of social vulnerability to floods, especially in the disaster response and recovery stages. Indicators of socioeconomic status had the second highest frequency of occurrence with the majority of instances involving the response phase. Linking demographic and socio-economic characteristics with social vulnerability to floods suggests that processes involving characteristics such as race, gender, age, and income are principal drivers of a population's ability to prepare for, respond to, and recover from damaging flood events. Other important drivers include health, coping capacity, risk perception, land tenure, neighborhood characteristics, and governance.

One way to interpret the frequency of vulnerability drivers and dimensions in Table 2 is as a measure of importance. However, frequency might also be dependent on research focus (i.e. the less frequent might attract fewer studies), previous routine in the field (i.e. path dependence, demographics were first linked to data availability and then became commonplace in vulnerability analysis) and theoretical frameworks (i.e. some dimensions are less easy to integrate or less often taken into account).

Visualizing the drivers through their interactions provides another perspective on indicator importance (Fig. 3). The seven

Table 2
Leading empirical indicators of social vulnerability to floods.

Driver	Overall frequency (%)	Flood type (%)				Disaster stage (%)			Development context (%)	
		River	Coastal	Urban	Regional	Mitigation	Response	Recovery	Less developed	More developed
Demographic characteristics	58	42	29	41	26	32	66	58	32	76
Socioeconomic status	55	44	39	53	26	17	53	42	39	61
Health	47	48	16	54	31	19	52	42	32	68
Coping capacity	39	58	23	53	24	16	48	48	54	46
Risk perception	36	62	33	48	20	46	54	21	33	67
Neighborhood quality of life	30	50	20	60	45	25	45	35	35	65
Land tenure	30	65	45	51	29	15	30	45	35	65

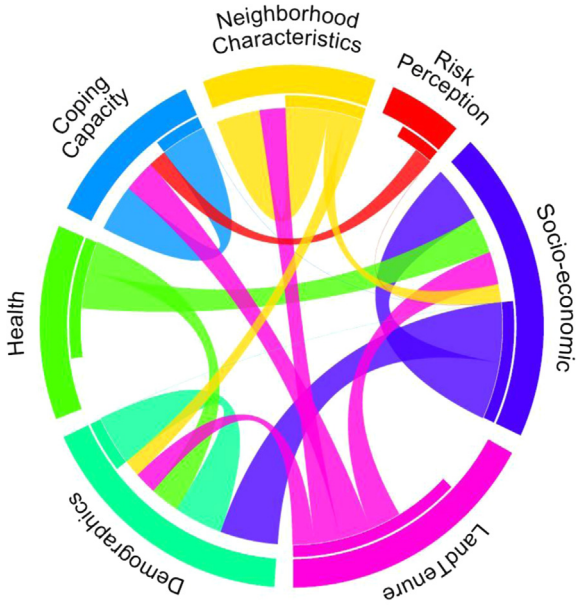

Fig. 3. Connectivity within and among social vulnerability drivers.

segments of the circle are associated with the leading dimensions of drivers of social vulnerability, while the width of the connections signifies their intensity. Only those drivers that co-occurred in more than five articles are depicted. The circular plot echoes the frequency statistics in Table 2, with indicators of socio-economic status and demographic characteristics occurring most often in interactions. By frequency alone, land tenure is the least influential of the social vulnerability drivers. However, it also has one of the most between-driver connections, indicating that land tenure processes operate as a highly interactive dimension. By contrast, social vulnerabilities associated with risk perception have fewer connections and can be interpreted to operate more independently. The findings for each of the leading drivers are discussed in the following sections.

3.1. Demographic characteristics

Demographic characteristics are among the most commonly applied social vulnerability indicators, yet the literature often diverges in describing the contribution of certain demographic variables to socially vulnerable groups. For example, while some research argues that children are among the most vulnerable segment of the population, they can also serve as resilience drivers by bringing together community networks through their schooling [100], or by providing assistance to the household during recovery processes [61]. Similarly, women and the elderly are often considered among the most vulnerable, yet historical data on flood fatalities reveal that young [10,65] and middle aged men are also vulnerable due to risk-taking behavior [36], rescue activities, and temporary impairment due to alcohol or drugs [58]. These discrepancies require reexamination of the typical demographic drivers. Table 3 highlights some key case studies and findings regarding demographic characteristics.

Table A1 provides a detailed classification of the citation frequency for demographic drivers of social vulnerability to floods. The most frequently cited demographic characteristics are age (the elderly and the young), gender, race, recent migrants and single parent families. Age is the leading demographic driver of social vulnerability based on the number of citations within the literature. Extremes along the age spectrum affect mobility out of harm's way and increase the burden of care following a damaging event. This is partially the result of reductions in services that may make recovery especially difficult for age dependent populations [50,59,95]. The contribution of age to social vulnerability can be offset by previous disaster experience and anticipatory behavior during the mitigation phase; however, [77] and only a few linear relationships between age and vulnerability have emerged from

Table 3
Key case studies involving demographic characteristics.

Study	Flood event	Study design	Key findings
Jonkman et al. [59]	Hurricane Katrina, 2005	Dataset for 771 fatalities in the US state of Louisiana,	The majority of victims were elderly, unable/unwilling to evacuate, incapable of surviving the physical flood effect and/or suffered from deterioration of basic public health services inside and outside flooded areas.
Walker et al. [100]	UK severe flooding in June 2007	Mixed methods and workshop with 46 flood-affected children	Children are not only flood 'victims', but play a key role in recovery, bringing together community networks through schooling, leisure and friendship networks.
Zahran et al. [105]	Flood events in the U.S. (Texas), 1997–2001	Historical data on 112 flood casualties	Poor communities of color suffered disproportionately in human death and injury.

studies suggesting that only the 'very old' and the 'very young' tend to be more vulnerable because of their dependency status and physical conditions [61].

Among the most commonly cited drivers were special needs populations, which include institutionalized people, those with low capacity for self-care, long-term or chronically ill patients needing continued care, and nursing home residents. For example, studies show that evacuation and *in situ* sheltering were challenging for nursing home and hospital patients [59], and in extreme cases, family members might prevent those needing self-care from evacuating [99]. Limited mobility, dependence of care, and reliance on medication and other services are impediments to evacuation. Conversely, recovery processes are impeded when disruption of services makes caring for special needs populations difficult [50].

In addition to considering age dependent and institutionalized populations, flood vulnerability is linked to gender status where women disproportionately accept family care responsibilities [99]. Gendered vulnerability was apparent in both developed [90] and developing national settings [82] due to differential resource access, opportunities, power, rights, informal sector employment, and income. Women often work in low-wage informal sectors earning lower wages then men while suffering from a lack opportunity to diversify their economic activities [82].

The effect of gender on social vulnerability to floods is not straightforward, however. This is because women are also ascribed more coping-capacities, greater commitment to knowledge of risk, and social relations [90]. The case studies reveal that it is difficult to make generalizations about women's social vulnerability and that women's dependency and needs within the context of vulnerable populations might have been overemphasized. Even in developing countries with the most inequitable societies, gender alone is not predictive of social vulnerability because women's everyday living conditions vary across socio-economic status, household structures, and geographic locations [5]. Within this context, some studies found that gender had no impact on social vulnerability in the face of floods at all [61].

Race, class, ethnicity and immigration status are additional drivers of flood-related social vulnerability since these may impose cultural and language barriers that affect residential locations in high hazard areas, pre-disaster mitigation, and access to post-disaster resources for recovery [31]. As with gender, these drivers have spurred debate over ambiguities [28,39]. For Vietnamese migrants adversely affected by Hurricane Katrina, studies confirmed that the group's lack of acculturation and English proficiency were strong factors aggravating their social vulnerability [25]. However, the lack of acculturation was also associated with close social ties and shared resources that allowed them to recover quickly following the event with little outside assistance [98]. The case of the Vietnamese immigrants is one of the most clear-cut examples of the importance of context when identifying vulnerability drivers. Other studies considering demographic characteristics and flood damage impacts from Hurricane Katrina found that minority neighborhoods did not appear more vulnerable than non-minority neighborhoods in terms of damages sustained [29,59,60]. In addition, and although debatable, studies showed that it was not only race, but rather the combination of ethnic composition and lack mobility of the most affected neighborhoods that explained the disproportionate burden on African-American communities following Hurricane Katrina [29].

3.2. Socioeconomic status

Socioeconomic status drivers are among the most prominently measured characteristics in social vulnerability studies, and manifest in different ways across levels of geography. Common socioeconomic status indicators include measurements of household income, poverty, unemployment, educational status, wealth, inequality and home value. At the individual level, lack of resources, power relationships, poverty, and marginalization translate into social vulnerability through access to resources, coping behavior and stress [2]. At the community level, social vulnerability is determined by relative distribution of income, access to resources, and diversity of economic assets [45]. Table 4 highlights findings from key studies involving socioeconomic characteristics; detailed citation frequency data are provided in Table A2.

It is within this context that income and poverty are key drivers of social vulnerability. This is primarily because income is closely coupled with other forms of capital that may be used as proxy indicators for social vulnerability to floods. These indicators include educational access, wealth, and employment type, overcrowding in households, non-home or non-car ownership, and unemployment [91]. Education provides an example of the coupling of income with other forms of capital where higher levels of education may lead to better paying jobs and higher incomes [19]. This, in turn, may result in increased asset ownership where damage costs from flood events are higher for wealthier households in absolute costs, but flood damage costs represent a lower proportion of the total income and capital of wealthier households. As a result, the coping capacity of wealthier households remains greater than poorer households [20].

Conversely, lower education coincides with poverty, overcrowding, unemployment, income inequality, and marginalization. Even if the poor and marginalized face fewer economic damage costs, the relative impact of damaging flood events are generally greater for low- income groups. It may take years for those who cannot afford the costs of repair, reconstruction, or relocation to recover from even a moderately damaging event [67]. Not only do poorer and marginalized populations often live in highly exposed zones with less employment and housing opportunities, they are also less protected by formal institutions, such as those that

Table 4
Key case studies involving socioeconomic characteristics.

Study	Flood event	Study design	Key findings
Ajibade et al. [5]	Nigeria, 2011	Interviews ($n=36$), survey ($n=453$), focus groups ($n=6$)	Gendered vulnerability varied with income—no differences in wealthy and middle-income areas, great differences in poor areas. Gender alone is not predictive of social vulnerability, but it is when intersecting with income, occupation, and health care access.
Brouwer et al. [20]	Bangladesh, 2005	Survey ($n=672$) and semi-structured interviews ($n=45$)	Higher flood exposure was associated with the poor (in relative terms, not absolute), lack of land ownership, and income inequality. Income diversification was found to be an effective adaptation strategy.
Steinführer and Kuhlicke [90]	Germany, 2002	Survey ($n=404$) and interviews ($n=30$)	No single variable (e.g. age, income etc.) explained vulnerability of specific groups. No single social group (very poor, without social networks, etc.) proved to be vulnerable in all dimensions.

provide disaster mitigation and recovery assistance.

Most of the empirical studies highlight that floods disproportionately affect lower-socioeconomic status households. The impact of floods vary by social class not only during the pre-impact and response phases of a flood event, but also during recovery and rebuilding processes [49]. The quality and pace of recovery following an event, for instance, is influenced by access to timely and sufficient external assistance [60]. However, the ability to obtain assistance depends on power relations, social connections, and the social arrangement of flood relief [26] that are often beyond the reach of poor and marginalized populations. Likewise, preparedness and mitigation activities, and the ability to evacuate requires access to economic and social resources that are often lacking [49]. The poor are also more likely to be working in primary economic activities or doing domestic work that further hinders their ability to recover [17]. Flood disasters often reveal larger societal inequities, even if there remain some debates on the root causes of uneven post-disaster outcomes.

3.3. Health

Flooding adversely affects mortality, physical health, and mental health where the most substantial impact on health from floods is death by drowning. Approximately one-third of all deaths during flood events occur away from floodwaters, however, and are the result of dehydration, stroke, lack of medical supplies [59], and health issues that are often overlooked prior to flood events [4,6]. Flood deaths occurring in vehicles are primarily due to unnecessary and risky behavior that often result in drowning or accidents associated with alcohol or drug use [36]. Deaths that occur from flood-related illness are related to age, gender, disruption of medication, and public water consumption [19], whereas the effects of flooding on psychological symptoms appear to differ according to anxiety and stress, age, gender, previous health condition and recovery duration [89]. The psychological effects of floods are more acute after the flood, and they are long standing [66] particularly due to conflicts with insurance companies and homeowners, and disruptions of commercial, public, health and municipal services [22]. Health issues prove to be both drivers (i.e., chronic illness, etc.) and outcomes (plague, PTSD, food insecurity, etc.) of social vulnerability to floods. Table 5 highlights findings from key selected studies involving health characteristics, while detailed citation frequency results are provided in Table A3.

Although key drivers of health-related vulnerability to floods have been identified, studies are not convergent on the demographic and societal factors associated with health outcomes that are the product of flood events. Studies are also inconclusive on the role of flood context on health issues and mortality. Using flood mortality, injury, and illness as an example, the literature shows that factors related to health vary by timing rather then flood context. Here, adverse health effects are linked to phases that constitute:

- A *pre-flood phase* where the main issues are heart attacks while performing strenuous activity such as relocating furniture or sandbagging;
- A *during-flood phase* where adverse impacts are mainly attributed to drowning, vehicular accidents, flood-related injuries, and carbon monoxide poisoning. Other adverse effects include gastrointestinal illness, diarrhea, and psychological distress;
- A *post-flood recovery phase* where reductions in adverse health effects may result from displacement of flood-affected individuals (particularly those at increased risk of dying) to non-flooded areas, or increased support from care networks following a damaging event [65].

3.4. Coping capacity

Although social vulnerability analyses typically focus on the social characteristics that influence susceptibility to adverse impacts, social vulnerability is also a function of the capacity of people to cope with hazard impacts in the short term, and adapt in the longer term [16]. The case studies deconstruct coping capacity in terms of preventative/adaptive actions taken before the onset of the flood, but primarily as a set of reactive strategies adopted in the immediate aftermath [103]. For this paper, we define coping capacity as the aggregate of resources available to people to contest the negative effects of hazards, and the practices used to deploy them [11,12]. It includes both the capacities exerted by individuals and households, and those accessed through social networks. Coping strategies tend to be successful when they involve accessing or allocating resources to overcome immediate needs, without sacrificing long-term viability of assets and livelihoods, with the particular strategies adopted varying with social, physical, and geographic contexts [77]. Table 6 highlights some key case studies and findings regarding coping capacity, while detailed citation frequency data are provided in Table A4

Coping capacities often include preventative measures, and reliance on social networks. Preventative measures included storing food and medicine, saving money, organizing building materials, and purchasing insurance [11,38]. However, most actions taken before the flood tended to focus on structural mitigation of homes through the elevation of structures and contents. Common approaches found by Chatterjee [24] in India include raising foundations, construction of a second floor, and use of an elevated platform within the house to store valuables and protect household members. Studies in Guyana and Suriname found that residents raised the level of their yards, erected barriers near doors, and cleaned drainage channels as the primary preventative actions [63,79]. Although moderately effective in reducing damages, the use of preventative strategies is constrained by income and land tenure [20,63,78].

Table 5
Key case studies involving health characteristics.

Study	Flood event	Study design	Key findings
Alderman et al. [6]	Literature review	Analysis of papers (2004–2011) on the relationship between floods and health	Casualties in low-income countries, dominated by ethnic minorities who are poor, live on floodplains and in unstable dwellings, females, the very young, and the elderly. In medium to high-income countries, the elderly, males, and poor communities of color experience more flood-related health casualties.
Lowe et al. [65]	Literature review	Literature review of 38 studies of floods in the OECD	Target populations differ for morbidity and mortality effects, and differ pre-, during, and post-flood time periods.
Mason et al. [66]	UK 2007 flooding	Cross-sectional survey (n=444) 6 months following the flood	Females, children, people in poor health and evacuees had higher mean scores on PTSD, anxiety and depression after the flood.

Table 6
Key case studies involving coping capacity.

Study	Flood event	Study design	Key findings
Chatterjee [24]	India, 2005	Household surveys ($n=50$) in two urban slum settlements	Mitigation at city and household levels was not protective; assistance for long-term recovery and adaptation occurred mostly at local scales via bonding social capital.
Paul and Routray [77]	Bangladesh, 2007	Household survey ($n=331$) and secondary data collection in 3 coastal and inland villages	Adoption of coping strategies can substantially reduce flood vulnerability, but their effectiveness varies temporally, spatially, and across socio-demographic settings.
Steinführer and Kuhlicke [90]	Germany, 2002	Survey ($n=404$) and 30 interviews in 5 villages heavily affected by river floods	Major differences in the importance of social capital across demographic characteristics and disaster phases.

Individuals can boost coping capacity by using social networks to connect to the emotional, social, and economic resources of others. Such social capital is a function of social norms, mutual trust, and social networks [3,71], and is often described as sets of bonding, bridging, and linking ties. Bonding ties link people that occupy similar socio-demographic levels and are geographically proximal, such as families, neighbors, close friends, and work colleagues. These horizontal networks tend to be the strongest, most common, and most durable of network ties. Manifestations of bonding ties included remittances and sharing of seeds among farmers [9], and small loans to flood-affected families for temporary needs such as food, clothing, and medicine [20]. Bonding ties also increase knowledge capacities, in particular strengthening memory of past disasters and exchange of information about future risks in Poland [38], and in Ghana influencing out migration by providing information about economic opportunities elsewhere [9]. The effectiveness of bonding ties varies with other social vulnerability drivers. In Hurricane Katrina, bonding capital was particularly useful for low-income affected residents [53]. Meanwhile, Chen et al. [25] found that strong bonding ties were associated with improved physical and mental health outcomes in the Vietnamese community.

Despite the benefits of social capital, it has its limits in reducing social vulnerability. In a study of flooding in Germany, Steinführer and Kuhlicke [90] found formal networks to be more important than informal networks for pre-event information gathering. Social capital also cannot be assumed to always operate as a positive force: bonding ties in Hurricane Katrina were the most important factor influencing evacuation behavior [1], but also led some people not to evacuate who possessed the resources and ability to do so [53]. In both India and the United States, strong social capital widened divisions between dominant and marginalized groups [7], with disparities expanding over the course of the disaster [40].

3.5. Risk perception

The analysis for risk perception focused assessing the state of knowledge of the influence of perception on vulnerability-reducing behavior. Across the case studies, risk perception was most frequently identified as a social vulnerability driver during the mitigation and response phases of flood disasters, and in more developed national settings (Table 2). Flood awareness and prior experience were the primary perceptual aspects explored in the articles, and to a lesser extent, trust, estimation of flood risk, and demographic characteristics. But in general, the findings regarding perception and vulnerability were often contradictory. Table 7 highlights some key case studies and findings regarding risk perception; detailed citation frequency is in Table A5.

Flood awareness and knowledge often served as the focus of investigation, predicated on the notion that awareness is a necessary precursor to preparedness [45]. Feelings of fear, uncertainty, and worry were found to be important intermediary between awareness and protective action [102,88]. Indeed, several studies reported an association between low flood awareness and limited adoption of flood protection and preparedness measures [17,22]. Such measures generally include elevating homes, purchasing flood insurance, stockpiling supplies, moving building contents to higher floors, and evacuation. The provision of official flood information by governments can increase awareness, but it is insufficient by itself to result in reduced social vulnerability.

Prior experience with flooding [45,52,88], longer duration of residence [102,17,61], and shorter length of time since the previous flood event [22,38] were associated with greater awareness, understanding, and personal action. However, greater experience also led to people to underestimate risks associated with large flood events, particularly if previous flooding was less severe [26,38,61,81]. In particular, automobile drivers who lacked experience with flash floods, took longer routes, and lived in urban areas, were more likely to underestimate risk [84].

Some of the strongest associations between perception and vulnerability-reducing behavior were associated with social networks. Networks were widely found to be key information sources for warnings and evacuation, and more important than communication from mass media and official sources [1,52]. Housing tenure was associated with strong links between risk perception and behavior [102,90]. However, other population characteristics such as socioeconomic status, age, and gender had inconsistent relationships with the perception of risk [45,52].

Table 7
Key case studies involving risk perception.

Study	Flood event	Study design	Key findings
Carroll et al. [22]	England, 2005	Focus groups and interviews ($n=46$)	Low flood awareness and expectation of flooding led homeowners to eschew installing flood defenses.
De Marchi and Scolobig [34]	Italy, 2000 and 2002	Interviews ($n=400$)	Strong structural and institutional flood defenses associated with reduced flood awareness and self-protective behavior.
Siegrist and Gutscher [88]	Switzerland, 2005	Surveys ($n=200$)	Negative emotions from previous flood experience are an important motivating factor for implementation of mitigation measures.

Table 8
Key case studies involving neighborhood characteristics.

Study	Flood event	Study design	Key findings
Chomsri and Sherer [26]	2011 Mega Flood in Thailand	Narrative interviews, participant observation (n=10), focus group	People in slums and in the rural areas felt inferior, and criticized the information presented.
Elliott et al. [39]	Hurricane Katrina	Survey 6 months after Hurricane Katrina (n=418)	Lack of adequate transportation explains the failure of evacuation plans: immobility is a key factor in decisions to stay or for challenges returning home.
Whittle et al. [101]	June 2007 flood in the UK	Interviews (n=18), 18-month diaries (n=44), stakeholder participation	Paradoxically, the efficiency of insurers and builders may explain evacuation behavior and length to recover. Insurance tends to monopolize all available rental accommodation after the flood, the resulting lack of affordable housing available for rent hinders reconstruction in the moderate income neighborhoods.

3.6. Neighborhood quality of life drivers

Scale emerged as an important social vulnerability factor with several quality of life drivers operating at the neighborhood level during all disaster stages. The most common neighborhood or quality of life drivers found within the literature are linked to the prevalence of transportation access, illegal and/or uncontrolled urbanization, housing quality, schools, and neighborhood intersectionality. Transportation dependence is the foremost-cited driver affecting quality of life at the neighborhood level. Hurricane Katrina demonstrated how a lack transportation access inhibits large-scale mobility and increases social vulnerability [29]. Here, it is not strictly an issue of individual car ownership [91] that affects social vulnerability. Rather, unequal access to transportation alternatives [40] and collective dependence on public transportation [101] explained the failure of evacuation plans since immobility is a key factor guiding decisions to stay prior to an event, or to return home following an event [41]. Table 8 highlights some key case studies and findings regarding neighborhood characteristics, with detailed citation results included in Table A6.

A neighborhood's population density, urbanicity, and legitimacy of settlements also impact social vulnerability to floods. Some authors question the historic bias towards positioning and permitting lower income housing in floodplain areas [99], and it may be impossible for populations occupying lower income housing in floodplain areas to return following a damaging flood event. This is partially because affordable housing that is often rented can undergo serious inflation as rents are being paid by insurance companies, allowing rental prices to skyrocket overnight [101]. Informal or uncontrolled neighborhoods and illegal settlements generate mental suffering, especially in flood prone areas, with populations having a general feeling of being neglected [26]. In these neighborhoods, residents were also faced with poor drainage and infrastructure [92], as well as exclusion from participatory processes and political leverage, leaving them unable to access mechanisms to reduce their social vulnerability [79]. Population and built environment density are key drivers of social vulnerability that often correspond with lower income settlements. They may introduce evacuation difficulties prior to an event [43], increase the risk of disease transmission during and after a flood event, and hamper post-event relief and recovery processes [35].

Other drivers of flood-related social vulnerability include population growth and urban sprawl, the number of schools per resident, and neighborhood intersectionality considering race, gender, and class. Especially in the developing burgeoning metropolises, rapid urbanization and population growth are associated with the unregulated sprawl, often with informal settlements and weak infrastructural and economic bases [81]. In the developing world, the number of schools per resident has been used as a proxy for educational background, access to damage compensation, and satisfaction with damage regulation [43].

Neighborhood intersectionality is a concept constructed to foster recognition that perceived group membership can make people socially vulnerable to various natural hazards. Intersectionality, particularly between race, gender, and class, means that no single dimensions can be reduced to the other when seeking to understand the wide array of populations' abilities to prepare for, respond, and recover from floods [41]. The latter suggests that the neighborhood's context has to be grasped as a whole to assess social vulnerability.

3.7. Land tenure

Property ownership can strongly influence the level of control a resident has over the adoption of protective measures and access to post-disaster assistance, leading to differences in flood susceptibility among owners, renters, squatters, and the homeless. Compared to property owners, renters were associated with higher inundation levels [20], more adverse health impacts [101,95], lower economic loss [1], and higher rates of displacement and job loss [41]. Although such disproportionate impacts are often associated with the lower social status of renters, the causal relationship between tenure and social vulnerability is culturally fluid [90]. For example, in Germany, renters were well represented among the middle class [61], while in Bangladesh, landlords were found to be major contributors to post-flood

Table 9
Key case studies involving land tenure.

Study	Flood event	Study design	Key findings
Land tenure			
Kamel [60]	Hurricane Katrina, 2005	Analysis of two government disaster assistance programs	Post-disaster housing and individual assistance programs favored property owners over renters.
Steinführer and Kuhlicke [90]	Germany, 2002	Survey (n=404) and 30 interviews in 5 villages	Local attachment, use of precautionary measures, and structural mitigation were higher among homeowners than renters.
Whittle et al. [101]	England, 2007	Diaries, interviews, group discussions (n=44)	Post-disaster housing shortages and rent inflation led to adverse health, financial and family life impacts

building repairs and social support [11,19]. Table 9 highlights some key case studies and findings regarding neighborhood characteristics, detailed citation results are in Table A7.

The social vulnerabilities among land tenure classes also varied by disaster stage, meaning that a member of particular tenure class may be vulnerable in one disaster phase, but not another [61]. In advance of flooding, homeowners have shown a greater awareness of flood risks [61], deeper understanding of warnings [77], taken more immediate action to reduce damage [76], and were less likely to seek emergency shelter [42]. However, the relationship between tenure and flood insurance is not clear-cut. For instance, homeowners had higher rates of insurance purchases in England [95], while Steinführer and Kuhlicke [90] concluded that insurance adoption rates were instead tied to age and income. Flood insurance was a mitigative factor primarily in studies in more developed nations.

In the aftermath of flooding, renters had lower rates of return than homeowners [39]. This reflects a combination of greater attachment to place among homeowners [41,90], higher prices and availability constraints for rental properties [101], and greater control by homeowners over the pace and quality of repairs [101,39,95]. In response to flooding, property owners were also more likely to make structural improvements to reduce future flood losses [78,90]. Disparities in access to post-disaster resources in the United States were related to the design of government programs for disaster assistance, which privilege homeowners [60]. Renters experienced more health effects and stress than owners at the time of the flood, and remained dependent on owners during the recovering/rebuilding process [95].

4. Discussion

Academic research on social vulnerability to hazards is largely bifurcated. In one group are post-disaster case studies that collect empirical data to provide rich, detailed, place-specific, and hazard-specific understandings of vulnerability processes, interactions, and outcomes. However, using the findings from a few individual case studies to make broad generalizations may yield unreliable conclusions [48]. In a second group are geospatial modeling studies, which tend to focus on the construction, mapping, and analysis of quantitative indicators. The metrics are used to rank and compare the social vulnerability of different places, yet the studies often lack context and rarely attempt to validate findings.

For social vulnerability to floods, a few studies have integrated case study and indicator development approaches [42,46,74,91]. But overall, connections between case study knowledge and choices made in the modeling process are largely tenuous. Typically, the rationale for decisions regarding variable selection, analysis scale, weighting, and aggregation is either unstated or justified based on simplicity or choices made in previous studies. In many cases, no justification is provided at all. Better integration of context can improve the ability of social vulnerability indices to represent observed conditions. The results of this study highlight several gaps in knowledge regarding the construction of social vulnerability indicators. Among the leading research needs for social vulnerability indicators are accounting for temporal context, improving the measurability of influential drivers, and understanding interactions between indicators.

4.1. Temporal context

A leading conclusion of the meta-analysis is that social vulnerability drivers can vary considerably with the stage of disaster. This reinforces the understanding of social vulnerability as a dynamic situation of which people can move in and out [79,99]. The importance of temporal characteristics was succinctly captured by ([61], p. 803)

> "*The same group may be vulnerable in certain event phases and not vulnerable in others. This means that the same indicator may have explanatory power in more than one phase of the event but with opposite meanings in terms of social vulnerability.*"

Table 10
Phase-oriented approach to indicator selection.

Potential indicators	Pre-flood/ mitigation	During flood/ response	Post flood/ recovery
Children	±	+	−
Young adults	+	+	−
Elderly	−	+	+
.....			

Findings from the review of demographic and health-related studies are particularly instructive. Children and non-whites appeared to be the more vulnerable before the flood due to lack of awareness and preparedness [39,66]. During the flood, men and middle-age populations were more vulnerable due to risk-taking behavior [58] and involvement in rescue and emergency operations [101]; as well as children and the elderly due to their difficulty to swim and reach shelter or safety [10]. After the flood, women, single-parent families, and the elderly were found to be more vulnerable due to resource availability and difficulties coping with disruptions to long-term care and services [50].

Incorporating the phase of the flood disaster is a key to improving the contextual validity of social vulnerability indicators and maps. To account for temporal context, one approach is to differentiate indicator development according to preparedness, response and recovery phases of a flood disaster. Borrowing from Steinführer and Kuhlicke [90], Table 10 provides a demonstration of this approach, with particular indicators evaluated based on their directional effect on vulnerability (e.g., + increases, − decreases) for each disaster phase.

Such a phase-oriented approach could inform variable selection (e.g., what are the key vulnerability drivers for flood recovery?), weighting (what is the relative importance of indicators for flood preparedness?), and aggregation (what is the individual and combined effect of individual indicators of flood response?). It could also make social vulnerability analysis more salient for emergency managers, whose responsibilities are likely to be organized around the emergency management cycle. Currently, the most common internal structure for social vulnerability modeling and mapping is the thematic organization of indicators into sub-indices [47,70] or statistical factors [31,42,83] derived from themes such as those shown in Table 1. Based on the findings of this research, an alternative thematic structure based on disaster phase should also be considered.

4.2. Measurability

Although indicators are increasingly recognized as useful tools for policy formulation and public communication, they are subject to measurability limitations [14]. The use of social vulnerability indicators may mislead decision-making if practical considerations of cost, data availability, and measurability are prioritized over validity: does the indicator faithfully represent vulnerability processes? As one article put it, "*understanding vulnerability and flood recovery is not as straightforward as mapping socio-economic characteristics* ([101], p. 17)."

Improving measurability is particularly important for social

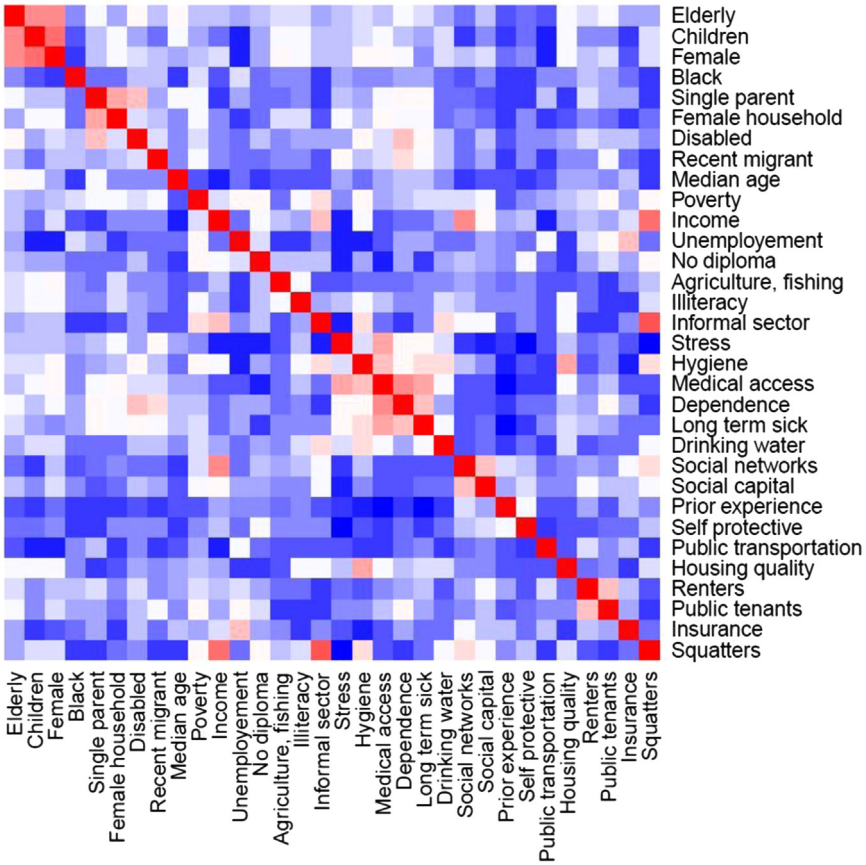

Fig. 4. Heatmap of social vulnerability drivers (mentioned in more than 5 papers).

capital, risk perception, and psychosocial dimensions of health, which stymie standardized measurement because they are often situationally dependent and may require quantification at scales (e.g., individual, network) different from other indicators. Indicators for these aspects typically cannot be computed from publicly available databases (e.g., national censuses) and require the use of qualitative methods, targeted surveys, and participatory approaches. To address this caveat, scorecards have become a popular survey mechanism, especially for researchers interested in understanding urban resilience (see [94], [75], [96]). Research is needed, however, to better integrate the findings of studies employing such methods. In particular, the potential of participatory approaches to generate salient quantitative data is still underestimated [68].

Measurability is also constrained by limited understanding of underlying social vulnerability processes. For example, being a child [100,61], an elder [77,95], a woman [36,90] and a member of a minority [28,98] were protective factors in some studies. Ambiguity and nuance in the effect on social vulnerability were particularly pronounced for risk perception. Fielding [45] found scale effects to risk perception, with variation between, but not within neighborhoods, regardless of socioeconomic status and flood risk. Although structural flood protection and institutional management can reduce flood exposure, higher levels of trust in these elements may lead to erosion of awareness and self-protective skills [34,61]. The belief that flood protection is an institutional as opposed to a private responsibility was associated with reduced individual agency [76,90]. Collectively, many results regarding risk perception are too contradictory to make generalizations for indicator selection in the flood context. The development and testing of new geospatial indicators of social capital is also key research need [8], and should be augmented by continued search for suitable existing proxy measures.

Overall, measurability challenges are important to consider when interpreting the rankings and spatial distributions of output indicators. In contexts where social vulnerability drivers that are difficult to measure are particularly important, what is the meaning of the index when they are not included? To what extent are assertions valid that the resultant indicators measure social vulnerability? An important step in social vulnerability indicator development is to consider the meaning of gaps in the input information.

4.3. Indicator interrelationships

> "*Some of these categories intersect in complex ways* (*for instance disabled people are disproportionately likely to be poor, as are members of minority ethnic groups, women and older people*); *not all within them are equally vulnerable and vulnerability is a dynamic rather than a static quality* (*people can move in and out of vulnerability*)" ([99], p.223).

More research is needed to further explore how social vulnerability drivers interact, particularly across geographic and temporal scales. Examples from the case studies include examination of connections between demographic characteristics, wealth, land tenure, and social capital [90], race and class [41], and age, income, and social isolation [61,81]. The issue of flood insurance highlights the interrelationships of social vulnerability drivers and effects. At an individual level, the purchasing of an insurance policy is strongly correlated with income, home ownership, and mitigation

behavior [38]. Lack of insurance magnified flood impacts [65] and slowed house rehabilitation due to delays in public or federal payments [50]. Meanwhile, being uninsured or having problems with insurers were among the leading precursors to psychological impacts, inducing stress or PTSD [95].

A finer understanding of the relationships between social vulnerability drivers could benefit the weighting and aggregation stages of composite indicator development. The weighting of indicators should ideally reflect their relative importance in affecting social vulnerability. In practice, however, equal weighting has become the norm for modelers, with typical justification similar to the following:

> "… *each factor was viewed as having an equal contribution to the county's overall vulnerability. In the absence of a defensible method for assigning weights, we felt this was the best option.* ([30], p. 254)."

However, it is more likely than not, that individual indicators differ in their degree of influence on social vulnerability. Previous research has demonstrated that hierarchical and inductive indices of social vulnerability are highly sensitive to the weighting approach employed [93]. The development and testing of additional defensible methodologies for indicator weighting represents a key research need. For indicators applied to resource allocation and planning processes, the use of context-specific weights developed using participatory and survey methods [74] is one path toward better weighting schemes. However, for applications focused on first-pass identification of vulnerable populations, comparing places, and advocacy, the time and resource investment required for such an approach might be too high.

Perhaps it is possible to generate weighting schemes applicable to broad categories of flood contexts, for instance, leading to one set of weights for mitigation of coastal flooding in Bangladesh, and another for recovery from river flooding in England. If shown to be moderately valid, such an approach could represent a reasonable intermediary between the default assumption of equal weights and methods involving primary data collection and analysis. Using participatory methods that incorporate the opinion of experts within the respective regions could foster such actions while assuring local context and insight is considered. This local contextualization can be fulfilled using web-surveys or workshops in which community leaders, local governments, and other relevant stakeholders work together to guide the indicator weighting process. For an in-depth discussion on participatory methods see [72] and [73].

Regarding indicator aggregation, additive methods are still applied by a large proportion of social vulnerability indicators. While such an approach has the advantage of simplicity, it is based on the mathematical assumption that each vulnerability driver operates independently and that a deficit in one dimension of social vulnerability can be offset (or compensated) by a surplus in another. However, the numerous indicator interactions profiled in the meta-analysis (Figs. 3 and 4) make clear that such an assumption is untenable in the context of social vulnerability to floods, strengthening the argument in favor of social vulnerability modeling and mapping approaches that focus on interactions between drivers [83]. Fig. 3, for instance, illustrates the interactions between social vulnerability drivers emerging from the qualitative studies: when a paper mentions a demographic driver (e.g. age) it is far more likely to be subsequently associated with socioeconomic driving factors (e.g. income) rather than factors such as risk perception. Conversely, case studies focused on risk perception are more likely to associate coping capacity with social vulnerability rather than any other underlying cause. The heatmap in Fig. 4 is based on a Pearson linear correlation of drivers' cited in each of our respective studies. The latter takes the interaction between drivers one step further by revealing precisely which drivers are positively (red) or negatively (dark blue) correlated. This does not necessarily mean that there is some causal relation between the drivers, they just tend to emerge together from the empirical fieldwork, and in most cases the empirical studies discuss the more prominent interactions.

5. Conclusions

This paper has profiled the leading drivers of social vulnerability to floods, with the underlying goal of shedding light on the development of social vulnerability indicators. In our view, the field of social vulnerability measurement has entered somewhat of a transitional period. Debates regarding definitions of social vulnerability have been largely settled, and the need for reliable metrics is well established. However, the results of this meta-analysis demonstrate that much more work needs to be done to reflect the contextual characteristics of social vulnerability processes in measurement and mapping. The findings highlight the situational variability of social vulnerability drivers. Not all drivers have a consistent influence on social vulnerability, even for the most widely agreed upon characteristics such as age and class. Some factors contribute to vulnerability in one context, yet detract from it in another. And there can be considerable variation in the identity and effect of vulnerability drivers throughout the temporal progression of a flood disaster.

Improved incorporation of context will help produce indicators that not only reflect vulnerability as a state, but also as a situation. Empirical case studies are a rich source of situational understanding of the root causes of social vulnerability, their relative importance, interactions between drivers, and scales (geographic, administrative, and temporal) of operation. This understanding can be of great value for decisions during quantitative indicator construction, involving variable selection, scale of analysis, internal structure, weighting, and aggregation. Moreover, greater consideration of context, measurability, and interaction between drivers can help highlight not only what *is* reflected in resultant vulnerability indices, but also what is absent.

The measurability and simplicity features of indicators mean that they will never be able to fully represent the complexity of vulnerability processes. However, strengthening linkages between empirical studies and quantitative/geospatial modeling has the potential to result in more valid metrics that are suitable for decision-making. The state of knowledge and research needs profiled in this review represent one step in that direction.

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Appendix A

See Tables A1–A7

Table A1
Frequency of demographic vulnerability drivers.

Driver	Article count	Impact on vulnerability		Main disaster stage			Flood type					Development context	
		Increasing (%)	Decreasing (%)	Mitigation (%)	Response (%)	Recovery (%)	River (%)	Coastal (%)	Flash flood (%)	Urban flood (%)	Regional (%)	Developed (%)	Developing (%)
Elderly	**27**	81	15	30	48	37	48	41	19	48	30	70	41
Children	**21**	81	10	14	52	33	33	43	19	33	24	52	57
Female	**15**	70	15	15	55	25	55	50	20	45	15	50	55
Black	**9**	56	0	33	56	78	22	0	0	11	56	100	0
Single parent families	**8**	100	0	25	38	50	38	38	13	38	0	88	13
Female headed households with children	**7**	86	0	29	43	71	29	57	14	29	0	71	43
Recent immigrants	**7**	57	43	29	43	71	57	14	14	57	14	100	14
Handicapped/disabled	**7**	100	0	29	57	43	29	29	0	43	14	71	29
Dependency	**6**	100	0	0	17	33	17	17	0	33	33	67	33
Low capacity for self-care	**6**	100	0	17	83	50	50	33	0	50	33	67	33
Non white	**6**	67	17	33	83	67	33	17	0	33	17	100	0
Middle age	**6**	67	17	33	50	33	50	17	17	17	17	100	0
Male	**5**	100	0	20	100	20	60	40	40	20	40	100	0
Twenties	**4**	100	0	0	50	50	50	50	50	50	50	100	0
Institutionalized	**4**	100	0	25	25	25	25	25	0	50	25	100	25
Non-native speakers/language barriers	**4**	75	0	0	0	75	50	50	25	75	25	100	0
Hispanic	**4**	50	50	0	25	100	0	0	0	50	50	100	0
Acculturation	**3**	67	33	0	33	67	33	33	0	100	67	100	0
Nursing home residents	**2**	100	0	50	50	50	50	50	0	0	0	100	50
People per housing unit	**2**	100	0	50	50	0	100	50	50	100	50	100	0
Social security beneficiaries	**2**	100	0	50	100	100	0	0%	0	50	50	100	0
Households with small children	**1**	100	0	100	100	0	100	0	0	0	0	100	0
Living space per person	**1**	0	100	100	0	0	100	100	0	100	0	100	0
Rooms per housing unit	**1**	0	100	100	0	0	100	0	0	0	100	100	0
Total	**38**	**79**	**12**	**20**	**41**	**35**	**42**	**30**	**14**	**41**	**26**	**53**	**29**

Table A2
Frequency of socioeconomic vulnerability drivers.

Driver	Frequency	Impact on vulnerability		Main disaster stage			Flood type					Development context	
		Increasing (%)	Decreasing (%)	Mitigation (%)	Response (%)	Recovery (%)	River (%)	Coastal (%)	Flash flood (%)	Urban flood (%)	Regional (%)	Developed (%)	Developing (%)
Poverty and deprivation	**20**	90	0	20	50	40	40	35	15	65	30	55	45
Household or per capita income	**15**	80	0	0	40	27	47	20	0	33	20	40	60
Unemployed	**11**	82	0	18	18	36	27	18	9	45	27	82	18
Poverty rate	**10**	80	0	20	40	30	40	10	0	70	20	40	60
Adults with no high school diploma	**10**	60	0	20	60	40	50	30	0	50	20	40	60
Fishing, agriculture, forestry	**8**	25	0	13	50	38	25	38	0	25	13	25	75
Literacy rate	**6**	67	0	50	33	50	17	17	0	33	33	17	83
Informal sector/day laborer	**5**	100	0	20	40	40	40	20	0	40	20	0	100
Income inequality	**4**	100	0	50	75	50	25	0	0	50	50	25	75
Wealth/savings	**4**	100	0	25	50	25	50	25	0	50	25	25	75
No secondary degree education	**4**	100	0	25	0	75	50	50	25	25	25	75	25
Managerial sector	**3**	33	67	33	33	67	0	33	0	67	33	67	33
House value	**2**	100	0	50	0	50	50	50	0	50	50	100	0
Service sector	**2**	50	50	0	0	100	0	50	0	50	50	100	0
Households with no telephone	**1**	100	0	0	0	100	100	0	0	0	0	100	0
Total	**36**	**77**	**3**	**20**	**40**	**41**	**44**	**39**	**5**	**52**	**26**	**47**	**53**

Table A3
Frequency of health vulnerability drivers.

Driver	Frequency	Impact on vulnerability		Main disaster stage			Flood type					Development context	
		Increasing (%)	Decreasing (%)	Mitigation (%)	Response (%)	Recovery (%)	River (%)	Coastal (%)	Flash flood (%)	Urban flood (%)	Regional (%)	Developed (%)	Developing (%)
Stress and mental health	20	95	0	20	40	55	45	25	20	50	40	80	30
Hygiene and sanitation	12	92	0	17	42	8	42	25	17	67	25	42	58
Hospital/clinic availability and access	11	100	0	27	45	36	45	36	27	45	27	64	36
Medically dependent	9	100	0	22	56	56	44	22	11	44	33	78	22
Chronically ill and long-term sick	8	100	0	38	25	50	38	38	25	50	25	63	38
Access to clean drinking water	8	100	0	38	75	38	63	38	0	63	38	50	63
Skin disease	5	100	0	20	100	40	80	40	20	40	20	20	80
Vector borne disease	4	100	0	25	75	50	50	50	25	50	25	25	75
Food insecurity	4	100	0	25	75	25	50	0	0	50	25	25	75
Pregnant women	3	100	0	67	100	67	67	33	33	33	33	67	67
Health insurance	2	100	0	0	50	100	50	50	50	50	50	100	0
Total	**31**	**98**	**0**	**26**	**54**	**42**	**48**	**16**	**19**	**54**	**31**	**58**	**46**

Table A4
Frequency of coping capacity vulnerability drivers.

Driver	Frequency	Main disaster stage			Flood type					Development context	
		Mitigation (%)	Response (%)	Recovery (%)	River (%)	Coastal (%)	Flash flood (%)	Urban flood (%)	Regional (%)	Developed (%)	Developing (%)
Social Networks	21	14	33	33	24	5	5	52	24	38	62
Social Capital	18	11	22	22	22	0	0	44	28	67	33
Individual/ household action	3	100	0	0	0	0	0	100	0	0	100
Reliance on emotional support	3	33	100	67	0	0	0	67	33	100	0
Total	**26**	**20**	**31**	**29**	**58**	**2**	**2**	**53**	**24**	**51**	**49**

Table A5
Frequency of risk perception vulnerability drivers.

Driver	Frequency	Main disaster stage			Flood type					Development context	
		Mitigation (%)	Response (%)	Recovery (%)	River (%)	Coastal (%)	Flash flood (%)	Urban flood (%)	Regional (%)	Developed (%)	Developing (%)
Prior experience with floods	19	42	42	21	63	32	21	47	16	63	42
Self protective actions	7	29	43	29	71	43	29	29	14	43	57
Quality/trust in disaster forecast	4	50	75	50	50	50	0	50	25	50	50
Knowledge about flood protection measures	3	67	67	33	67	67	33	67	0	67	67
Flood warnings	2	50	50	50	50	50	50	100	50	50	50
Length of time since last flood event	2	0	0	0	50	50	0	0	50	50	0
Overconfidence/ risk-taking behavior	2	0	100	0	50	0	50	0	50	100	0
Flood event characteristics	2	0	50	50	0	0	50	50	0	50	50
Risk denial	2	50	50	0	50	0	50	50	0	50	50
Others	3	33	33	33	33	0	0	33	33	67	33
Total	**24**	**37**	**48**	**26**	**62**	**33**	**24**	**48**	**20**	**59**	**43**

Table A6
Frequency of neighborhood quality of life vulnerability drivers.

Driver	Frequency	Main disaster stage			Flood type					Development context	
		Mitigation (%)	Response (%)	Recovery (%)	River (%)	Coastal (%)	Flash flood (%)	Urban flood (%)	Regional (%)	Developed (%)	Developing (%)
Public transportation (dependence)	6	50	67	33	50	17	17	67	50	100	0
Housing quality	5	20	60	20	20	40	20	80	60	40	60
Illegal or uncontrolled urbanization	4	75	25	0	25	25	25	50	25	50	50
Rented accommodations	4	20	40	60	40	40	20	60	40	80	20
Mobile or modular homes	3	33	33	33	100	100	67	100	33	67	33
Density	3	67	33	0	33	0	0	33	67	33	67
Rural/urban	3	33	67	33	67	0	0	33	67	33	33
Crime rates	2	0	50	50	0	0	0	50	50	50	50
Others	5	33	33	33	33	33	33	33	33	67	33
Total	**20**	**38**	**47**	**29**	**41**	**29**	**21**	**59**	**47**	**85**	**35**

Table A7
Frequency of land tenure vulnerability drivers.

Driver	Frequency	Main disaster stage			Flood type					Development context	
		Mitigation (%)	Response (%)	Recovery (%)	River (%)	Coastal (%)	Flash flood (%)	Urban flood (%)	Regional (%)	Developed (%)	Developing (%)
Renters	14	14	21	64	50	43	21	43	36	93	7
insurance	8	13	0	88	25	13	25	63	38	100	0
Public Tenants	8	0	38	63	63	50	38	63	38	100	0
Squatters/ slum dwellers	8	13	25	25	38	38	0	75	13	0	100
Homeowners	5	40	40	20	60	20	0	20	20	60	40
Total	**20**	**14**	**23**	**56**	**47**	**35**	**19**	**53**	**30**	**74**	**26**

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