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Natural Hazards and Social Vulnerability of Place: The Strength-Based Approach Applied to Wollongong, Australia

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ARTICLE

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Robert I. Ogie[1] · **Biswajeet Pradhan**[2,3]

Abstract Natural hazards pose significant threats to different communities and various places around the world. Failing to identify and support the most vulnerable communities is a recipe for disaster. Many studies have proposed social vulnerability indices for measuring both the sensitivity of a population to natural hazards and its ability to respond and recover from them. Existing techniques, however, have not accounted for the unique strengths that exist within different communities to help minimize disaster loss. This study proposes a more balanced approach referred to as the strength-based social vulnerability index (SSVI). The proposed SSVI technique, which is built on sound sociopsychological theories of how people act during disasters and emergencies, is applied to assess comparatively the social vulnerability of different suburbs in the Wollongong area of New South Wales, Australia. The results highlight suburbs that are highly vulnerable, and demonstrates the usefulness of the technique in improving understanding of hotspots where limited resources should be judiciously allocated to help communities improve preparedness, response, and recovery from natural hazards.

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Keywords Australia · Disaster vulnerability · Natural hazard · Placed-based model · Sense of community · Strength-based approach

1 Introduction

Natural hazards such as floods, bushfires, cyclones, hailstorms, earthquakes, and volcanic eruptions can pose disastrous threats to people and assets across the world (Ngo 2001; Pradhan et al. 2007). When natural hazards culminate in disastrous outcomes, the loss can be quite significant in terms of both fatalities and the financial costs to citizens and governments (Ogie, Shukla et al. 2017). Recent 5-year (2013–2017) data about disasters around the world indicate that on the average, frequently occurring hazards like floods, earthquakes, storms, and bushfires together accounted for 10,846 deaths, 49,303 injuries, and damage cost of USD148 billion every year (CRED 2018). This high level of loss calls for an improved response to the threats posed by natural hazards.

To improve response to natural hazard threats and to curtail associated losses, one must first understand the less obvious human connections between natural hazards and disastrous outcomes. According to Cannon (1994), natural hazards are often referred to as natural disasters, but the reality is that disasters are not natural; it is the actions, inactions, or activities of humans that potentiate the realization of disasters from natural hazards. How we exploit environmental resources for production and livelihood, where we live, how we build our homes, how we prepare for and act during natural hazards, who we are, the resources and opportunities we have, and how we communicate and respond to hazard warnings, all have ways of influencing the extent to which we are exposed to, and are

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impacted by, natural hazards (Pradhan 2010). Within society, there are inequalities in the level of access that people have to opportunities and in the extent to which they are exposed to natural hazard risks. This means that some people are more vulnerable than others and are more likely to suffer disastrous impacts from natural hazards (Chen et al. 2013). It is the vulnerable people and the vulnerable assets in society that often account for the high level of loss associated with disasters (Wisner et al. 2003). Vulnerable people are the main linkage between natural hazards and disastrous outcomes because "for a hazard to become a disaster it has to affect vulnerable people" Cannon (1994, p. 16). Hence, in the quest to curtail natural hazards losses, there has been growing interest worldwide to enhance the understanding of natural hazard vulnerability and to develop key metrics for assessing it (Yoon 2012; Ogie et al. 2016).

Several methodologies have been proposed for assessing vulnerability to natural hazards. Some of these methodologies are more useful for understanding the vulnerability of physical assets or lifeline infrastructure that are both critical for societal operation and for human survival. Examples of these techniques include topological/connectivity analysis of infrastructure networks based on graph theory (Holmgren 2006; Eusgeld et al. 2009; Buldyrev et al. 2010; Ogie, Dunn et al. 2017; Ogie et al. 2018), input–output models that can reveal cascading vulnerabilities across several sectors of the economy when one or more interdependent infrastructure network is impacted by natural hazards (Haimes et al. 2005; Setola et al. 2009), and agent-based models that help to simulate the impacts of natural hazards on people, assets, and the economy (Schoenwald et al. 2004; Ehlen and Scholand 2005). There are other methodologies that directly focus on people and help to reveal what is known as social vulnerability (Cutter and Finch 2008; de Loyola Hummell et al. 2016; Sun et al. 2017; Frigerio et al. 2018; Aksha et al. 2019).

Social vulnerability can be defined as those socioeconomic and demographic characteristics of a population that influence both the sensitivity of the population to natural hazards and its ability to prepare for, respond to, and recover from the impacts of hazards (Cutter and Finch 2008; Flanagan et al. 2011; Yoon 2012). Social vulnerability, often measured by a social vulnerability index (SVI), is an interesting way of comparatively assessing the vulnerability of different places. It deemphasises the physical aspects of vulnerabilities that are linked to interdependent networks of critical infrastructure; instead a SVI relies on socioeconomic and demographic characteristics of the population to highlight the spatial distribution of social inequalities and to identify the communities with the highest concentration of certain vulnerable groups who are more sensitive to the effects of natural hazards and are less able to adequately respond and recover (Cutter and Finch 2008). Hereafter, the term "community" will refer to a spatially defined social groupings of people living within the same neighborhood (Titz et al. 2018).

There are different methods that exist for specifically assessing social vulnerability. One such method is the "participatory rural appraisal" approach that is sometimes used by government, nongovernmental organizations (NGOs), and researchers to draw on the local knowledge and opinions of rural people in determining the origin of vulnerability (Chambers 1994; Thein et al. 2019). The participatory rural appraisal provides an avenue for the people to come together and analyze their own situation in order to develop a common perspective on the key vulnerability issues they face (Thein et al. 2019). It is similar to "participatory vulnerability analysis" in the sense that the communities themselves determine together what makes them vulnerable (Chiwaka and Yates 2010). When the place of interest is an indigenous community, Mercer et al. (2007) note that the participatory approach can only be effective for understanding vulnerability to environmental hazards, if it adequately combines Western science and indigenous knowledge in a culturally appropriate manner. The downside of participatory approaches is that they can be very expensive and challenging to administer when there are many small distinct communities in a large study area like an entire country or state (Chiwaka and Yates 2010; Rahman et al. 2018).

Another approach for assessing social vulnerability is the use of qualitative methods. Qualitative methods are often based on case studies that use data collected through interviews and/or focus group sessions (Rufat et al. 2015). Qualitative methods are advantageous for providing deeper insights into the context in which social vulnerability occurs. It is rare, however, to depend solely on qualitative data for social vulnerability assessment. Rather, some studies have adopted mixed methods research techniques that combine quantitative and qualitative analysis of data collected through structured surveys, interviews, and focused group discussions (Wilhelmi and Hayden 2010; Kuhlicke et al. 2011; Ajibade et al. 2013; Lin and Polsky 2016; Salami et al. 2017). Typically, findings from the interviews are used to determine key variables to include in the survey (Wilhelmi and Hayden 2010; Kuhlicke et al. 2011). Because data collection over an extensive study area (for example, a survey of an entire country) can be laborious and expensive, it is common to compute SVI based on quantitative analysis of existing census data collected at the household or individual level. In other words, quantitative methods are more feasible when the study area encompasses a large number of places. The drawback is that quantitative methods sometimes lack the rich context of social vulnerability obtainable through interviews and focus groups and there are also rare provisions to validate the findings. As noted in Schmidtlein et al. (2008), however, the majority of research on social vulnerability assessment is based on quantitative techniques that explore a rich set of sociodemographic census data to measure SVI.

A major limitation of the traditional approach to measuring SVI is that the emphasis is on weaknesses only (for example, old age, low-income, language barriers), with little or no attention paid to the strengths of communities, even as evident in their socioeconomic and demographic profiles. Under this regime, one is left with an unanswered question: are the conditions for determining vulnerable communities fair, knowing that different communities have unequal capabilities and resources to minimize disaster impact? It is, therefore, necessary to introduce a method of assessing social vulnerability that accounts for the innate strength embedded in communities. This issue accounts for the motivation of the present study and is quite crucial because the outcome of vulnerability measurement can potentially influence critical decisions about allocating limited resources to support communities in the mitigation, preparedness, response, and recovery phases of disaster management.

The present study contributes by proposing a strength-based approach for computing the social vulnerability of a community or place. The approach is based on a more balanced metric referred to as the strength-based social vulnerability index (SSVI). The technique considers several aspects of social vulnerability, including in relation to culturally and linguistically diverse (CALD) communities (a CALD-specific SSVI), low-income households (income-specific SSVI), highly dependent children aged 0–4 years (children-specific SSVI), people living with a disability or requiring assistance for daily activities (disability-specific SSVI), and the elderly population (elderly-specific SSVI). The study further contributes by demonstrating, through a case study in the greater Wollongong metropolitan area of Australia, how the proposed SSVI technique can be applied to comparatively assess the social vulnerability of different places or communities. Wollongong, Australia is selected for the case study because there are social inequalities that typify modern societies (Buchholz et al. 2008) and natural hazards do pose significant levels of risks to its increasingly multicultural population.

2 Method Development: Strength-Based Social Vulnerability Index

In this section, a strength-based social vulnerability index (SSVI) is developed. The strength-based approach of computing social vulnerability is a more balanced technique that aims to address a major limitation in the traditional method of calculating social vulnerability. Social vulnerability computations are based on social inequalities across different places or communities, but existing approaches tend to focus only on weaknesses, thereby undermining the resourcefulness of people within communities to self-organise and minimize their vulnerability to natural hazards (Cutter and Finch 2008; Zahran et al. 2008; Flanagan et al. 2011). The concept of strength-based social vulnerability is based on the notion that places or communities are not only defined by social inequalities, but also the marked difference in the unique communal strengths they bring to minimize the impacts of natural hazards.

2.1 Justification for the Strength-Based Approach to Social Vulnerability

In modern human societies, there is a "sense of community" that brings individuals together to help vulnerable community members and those in need to deal with or recover from the impacts of natural hazards (Ahmed 2011). Citing the Red River Valley Flood of 1997 as an example, Jencson (2001) described this observed community-mindedness as the "spontaneous sense of communitas" that arises in human societies during times of disaster. Clarke (2002) describes it as a sense of "we-ness" that emerges when people are together confronted with the same threat. Solnit (2009) described it as altruism that emerges in the crucible of great catastrophe. Bernardini and Hart (2011, p. 123) likened it to "social utopias that arise in communities in the aftermath of disaster." One can also add that this community-mindedness is a unifying quality that transcends egoistic tendencies and energizes the social human nature to become quickly immersed in the process of aiding one another (Kaniasty and Norris 1999). When this powerful force of humanity is at work, the calamity itself becomes the strength of the social bonds, bringing people together in a collective sense of determination to take the role of doers and not victims or bystanders (Kaniasty and Norris 1999; Clarke 2002). In essence, support for vulnerable community members can occur spontaneously in the wake of adversity, allowing individuals to temporarily put aside self-interest in pursuit of self-sacrificing noble acts of kindness (Oliver-Smith 2012).

Social support in disasters defies common beliefs about mass panic and chaotic disorganization wherein survivors are portrayed to perceive each other as obstacles to their own personal survival, so much so that uncontrolled competition ensues in the process of acquiring those rapidly diminishing resources or opportunities that are vital to reach safety (Kaniasty and Norris 1999; Drury et al. 2016). Without discounting the possibility of panic, looting, and other forms of social vice, disaster research from over 50 years has consistently shown that supportive behaviors far outweigh the occurrence of such negative actions and that panic is rare (Clarke and Chess 2008; Drury et al. 2016). The prevalence of such supportive behaviors can be better appreciated through the lens of the self-categorization theory, which suggests that people are more likely to emulate exemplary behaviors by others if a shared social identity exists (Turner and Reynolds 2011). When computing social vulnerability, there is, therefore, a strong case to consider the strengths that exist within different communities to help minimize the impact of natural hazards on people. "If people generally act well under the most trying of circumstances—precisely when it would be easiest to turn their backs on others—it gives us reason to look for the good and the sensible in them at other times as well" (Clarke 2002, p. 26). The following section presents the development of a more balanced approach for determining and comparing the social vulnerability of different places, taking into consideration the strength within communities.

2.2 Developing the Strength-Based Social Vulnerability Index

Everyone living in hazard-prone areas has vulnerabilities and has ways of dealing with those vulnerabilities and of helping others (Tapsell et al. 2010). However, the widespread social inequalities in societies requires that in recognizing everyone's needs, it is important to identify those with specific needs—who are least prepared for an emergency and who are likely to be disproportionately affected when exposed to natural hazards (Tapsell et al. 2010). Social vulnerability research has consistently identified that the social impacts of hazard exposure fall disproportionately on children (0–4 years), the elderly ($\geq$ 65 years), people living with a disability, low-income households, and people who are ethnic minorities or who are from culturally and linguistically diverse (CALD) backgrounds (Fernandez et al. 2002; Wisner et al. 2003; Phillips and Morrow 2007; Tapsell et al. 2010; Flanagan et al. 2011; Chen et al. 2013). Low-income individuals have less money to spend on preventative or mitigation measures, hence they are often unprepared (Flanagan et al. 2011). Priced out of the rental and housing market, they often end up in substandard houses built on areas of high disaster risks (Rygel et al. 2006). When disasters strike, the people on low income are also likely to have very limited access to lifelines such as communication and transportation options (Rygel et al. 2006). For example, low-income individuals without private vehicles may be trapped by natural hazards when public transportation or emergency mass transit cannot be provided (Flanagan et al. 2011). Once impacted by hazards, recovery can be slower for those on low income because of limited resources, lack of insurance, and the absence of decent savings to fall back on (Dwyer et al. 2004). Similarly, disasters have a disproportionate impact on highly dependent individuals and people from CALD backgrounds. People from CALD backgrounds are more likely to be impacted by natural hazards due to language and cultural barriers that affect access to emergency information and other resources available to support disaster-affected people (Dwyer et al. 2004; Tapsell et al. 2010). For example, language differences may cause people from CALD backgrounds to either delay response or completely ignore time-critical warnings/emergency messages that they do not understand, potentially resulting in catastrophic consequences (Tapsell et al. 2010).

Individuals with multilingual skills can potentially help to minimize the communication barrier by interpreting emergency warnings/messages for members of their neighborhoods who are from CALD (culturally and linguistically diverse) backgrounds. Places with high representations of high-net-worth individuals or people on high incomes are more likely to benefit from community-donated resources to restore infrastructure and services as compared to those with more people on low incomes. Similarly, natural hazards may occur in places with children, the elderly, and those living with disability, but the impact can be moderated if the affected communities also have high representations of "the rest of the population" (RoP), who can potentially contribute their time, efforts, and moral support to minimize loss and hasten recovery. The RoP, as introduced here, refers to the total population less the children, the elderly, and those living with disability. Nevertheless, social inequalities ensure that some communities or places are less fortunate than others in having high representations of the RoP, multilingual individuals, and high-income households who can provide support in times of need. In the strength-based approach proposed for computing social vulnerability, the RoP, multilingual representatives, and high-income individuals in any given community or place are considered as strengths to that community or place. Computationally, the RoP of a place can be determined using Eq. 1, where T_P is the total population, C_P is children population (0–4 years), D_P is the population of individuals living with a disability or needing assistance for daily living, E_P is the elderly population (age $\geq$ 65 years), CD_P is the children population (0–4 years) who are living with a disability, and ED_P is the elderly population (age $\geq$ 65 years) who are also living with a disability.

$$RoP = T_P - (C_P + D_P + E_P - CD_P - ED_P) \quad (1)$$

Considering that social vulnerability is a multidimensional construct (Yoon 2012), the proposed technique, strength-based social vulnerability index (SSVI) will consider various aspects as represented in Eq. 2 (CALD-specific SSVI), Eq. 3 (income-specific SSVI), Eq. 4 (children-specific SSVI), Eq. 5 (disability-specific SSVI), and Eq. 6 (elderly-specific SSVI). Each one of these metrics reveals a specific aspect of the strength-based social vulnerability of a place. For any given place:

$$\textit{CALD-specific SSVI} = (CALD_P/M_P) \times (CALD_P/CALD_{TP}) \qquad (2)$$

$$\textit{Income-specific SSVI} = (LI_P/HI_P) \times (LI_P/LI_{TP}) \times 1/P_S \qquad (3)$$

$$\textit{Children-specific SSVI} = (C_P/RoP) \times (C_P/C_{TP}) \times 1/P_C \qquad (4)$$

$$\textit{Disability-specific SSVI} = (D_P/RoP) \times (D_P/D_{TP}) \times 1/P_{DE} \qquad (5)$$

$$\textit{Elderly-specific SSVI} = (E_P/RoP) \times (E_P/E_{TP}) \times 1/P_{DE} \qquad (6)$$

$CALD_P$ is the CALD population in a given place who either cannot speak the dominant language (English for Australia) or does so with very little competence, $CALD_{TP}$ is the total CALD population in all the places under comparative assessment, who either cannot speak English or does so with very little competence, M_P is the multilingual population in the place who can speak English very well in addition to other languages. E_{TP} is the total elderly population in all the places under comparative assessment, C_{TP} is the total children population in all the places under comparative assessment, D_{TP} is the total population of individuals living with disability or needing assistance for daily living in all the places under comparative assessment. Pc is the propensity to provide unpaid care to another person's child. It is determined by calculating the proportion of people above the age of 15 years that provided unpaid care to another person's child. P_{DE} is the propensity to provide unpaid care to a person because of a disability, long-term illness, or problems related to old age. It is determined by calculating the proportion of people above the age of 15 years that provided unpaid care to a person because of a disability, long-term illness, or problems related to old age. All of the required data are available through the Australian census. HI_P is high-income population, LI_P is low-income population, and LI_{TP} is the total low-income population in all the places under comparative assessment. Ps is the propensity to give personal resources in support of community initiatives. The largest ever research on giving and volunteering in Australia has found that people who volunteer their intangible resources (time, knowledge, and skills) are also the ones that are most likely to give tangible resources (money) for the very same key reasons: altruism, personal satisfaction, family tradition, and connection to community (Giving Australia 2016). In the absence of comprehensive suburb-level data on giving, we use the data on volunteerism as a proxy to estimate the likelihood that individuals will donate personal resources in support of communities in crisis. Ps is therefore determined by computing the proportion of the high-income population that volunteered in the 12 months prior to the census night. In the Australian context, we define high income as yearly income > AU\$104,000 and low income as yearly income < AU\$33,799, including nil income and negative income. Nil income is when a person aged 15 years and over does not earn income while negative income includes business owners who report negative income due to losses incurred. These income thresholds are based on the data from the study area, that is, the 2016 Australia census data.

Several factors were considered in defining high income as yearly income > AU\$104,000 and low income as yearly income < AU\$33,799. First, we considered the minimum wage at the time of the 2016 census data, being the yearly income of AU\$34,975 at an hourly rate of AU\$17.70 or weekly income of AU\$673 (Fair Work Ombudsman 2016). We also considered that there is a constraint to work with the predefined income brackets used by the Australian Bureau of Statistics (ABS) for 2016 census data collection. All those with yearly income within or lower than the ABS AU\$26,000-AU\$33,799 income bracket (that is, equivalent to the minimum wage and below) were considered to be low-income earners. Furthermore, we take a clue from the methodology used by the Organization for Economic Cooperation and Development (OECD) in determining what constitute low income and high income in a population: income below 50% of the median income of the total population is considered to be in the low-income range while income above 150% of the median income is considered to be in the high-income range (OECD 2018). Based on the 2016 census data, the median weekly income for the study area—the Greater Wollongong metropolitan area in the Illawarra region of New South Wales, Australia—is AU\$1,352. With this value, we determine that the low-income threshold will be AU\$676 in weekly income or AU\$35,152 in yearly income. This again is consistent with the previous estimation using minimum wage. For the high income category, the threshold, using the OECD approach, is AU\$2,028 in weekly income or AU\$105,456 in yearly income. With this as a guide, we determine that all those with yearly income within or greater than the ABS AU\$104,000-AU\$155,999 income bracket will be considered to be high-income earners.

The different aspects of SSVI (Eqs. 2–6) can be computed for different places in order to understand how social vulnerability changes from one community to another. The concept and equations of SSVI are based on the belief that during a crisis people will provide support to their communities, for example, through volunteerism, giving, and the provision of unpaid care to support vulnerable individuals. This notion of SSVI thrives, particularly in areas where a strong sense of community exists and the people can feel some levels of social belonging to the place. For the purpose of comparison, computed values of SSVI should be standardized, say from 0 to 1 as demonstrated by Chakraborty et al. (2005) or through the use of the z-score approach as employed in Cutter and Finch (2008). In this study, we adopt the 0–1 standardized scores for social vulnerability using the minimum–maximum standardization method (Huang et al. 2011).

3 Case Study Application: Wollongong, Australia

The study area is the Greater Wollongong metropolitan area in the Illawarra region of New South Wales (NSW), on the southeast coast of Australia. The Wollongong metropolitan area (Fig. 1) is approximately 1296 km^2 in land size and has 108 suburbs spread across three different local government areas, namely Wollongong, Shellharbour, and Kiama. Figure 1 and all other maps in this study used the Geocentric Datum of Australia 1994 (GDA94) as the geographic coordinate system. For the purpose of GIS mapping, each suburb has been assigned a unique ID and a reference grid is used for indexing the location as shown in Fig. 1. Hereafter, reference to each suburb in the map will follow the format, name (ID, index location). An example is Port Kembla (39, J8). With a population of over 293,575 (49.2% male and 50.8% female), the greater Wollongong metropolitan area is the third largest city in NSW and the 10th in Australia. Wollongong City itself (57, J7) is approximately 70 km south of Sydney, nested in a narrow coastal plain with the Tasman Sea to the east and the Illawarra Escarpment to the west (Flentje and Chowdhury 2005). Historically, the economy of Wollongong and the surrounding region has thrived on coal mining, port activity, and heavy industry, but today its main employing industries are health care and social assistance, education, steel, and food service.

Every year, Wollongong experiences rainfall throughout the seasons, but in the warmer months, the rains are heavier with occasional hail and lightning associated with thunderstorms. Damaging winds of over 100 km/h are also common in the months of July and August, but storms and flash floods remain the biggest natural hazard threats in Wollongong. Wollongong is particularly prone to flash floods because of its steep terrain, flat coastal areas, and proximity of dwellings to several creeks and stormwater drains that sometimes get blocked by debris during rainfall. There have been several disastrous floods in the Wollongong region that have resulted in damage worth millions of dollars, including in 1984 and 1988. With prolonged heavy rainfall comes the risk of landslides (Flentje and Chowdhury 2005). The work done locally by Flentje and colleagues at the University of Wollongong suggests that there are over 569 landslide sites in Wollongong, with landslide damage costing the Illawara region a minimum of AU$4.8 million annually (Flentje and Chowdhury 2005; Palamakumbure et al. 2015).

As with most parts of Australia, Wollongong is among the world most culturally and linguistically diverse (CALD) communities. In the early 1960s, many migrants seeking job opportunities in the Port Kembla steelworks moved into the area and settled in neighborhoods around Port Kembla (39, J8), including suburbs such as Warrawong (93, J8), Cringila (38, I8), and Coniston (21, J7). These migrants were initially of British, Greek, Portuguese, Macedonian, German, Croatian, Bosnian, Chilean, Serbian, and Turkish backgrounds. However, decades later, the region became even more multicultural with additional migrants of Chinese, Filipino, and Indian backgrounds settling into the city. Today, the University of Wollongong attracts international students from various corners of the world, particularly from China and other countries in the Asian continent. Multiculturalism is not a problem, but emergency communication in a dominant language (English in Australia) can be problematic for soliciting a desired response from CALD communities, potentially leaving these communities less informed and prepared to act in emergencies. In Australia, migrants and natives alike are expected to thrive on the "fair go" principle that advocates for everyone to be treated fairly and have equal access to opportunities. Nevertheless, like any part of the world, Australian census data consistently reveal significant levels of social inequalities across different parts of the country. Average weekly income, for example, ranges from less than AU$149 to more than AU$3,000. The enormity of these social inequalities combined with the significant levels of natural hazard risks posed to a population that is increasingly multicultural provide a strong basis to assess social vulnerability within the Wollongong area.

In applying the proposed SSVI technique to compute social vulnerability in Wollongong, the recent 2016 census data set was utilized. The data for all variables in the analysis were retrieved from the Australian Bureau of Statistics 2016 census database (ABS 2018). The data contain the socioeconomic and demographic characteristics of the population. Based on the data, several aspects, including CALD-specific SSVI, income-specific SSVI, children-specific SSVI, disability-specific SSVI, and elderly-specific SSVI were computed.

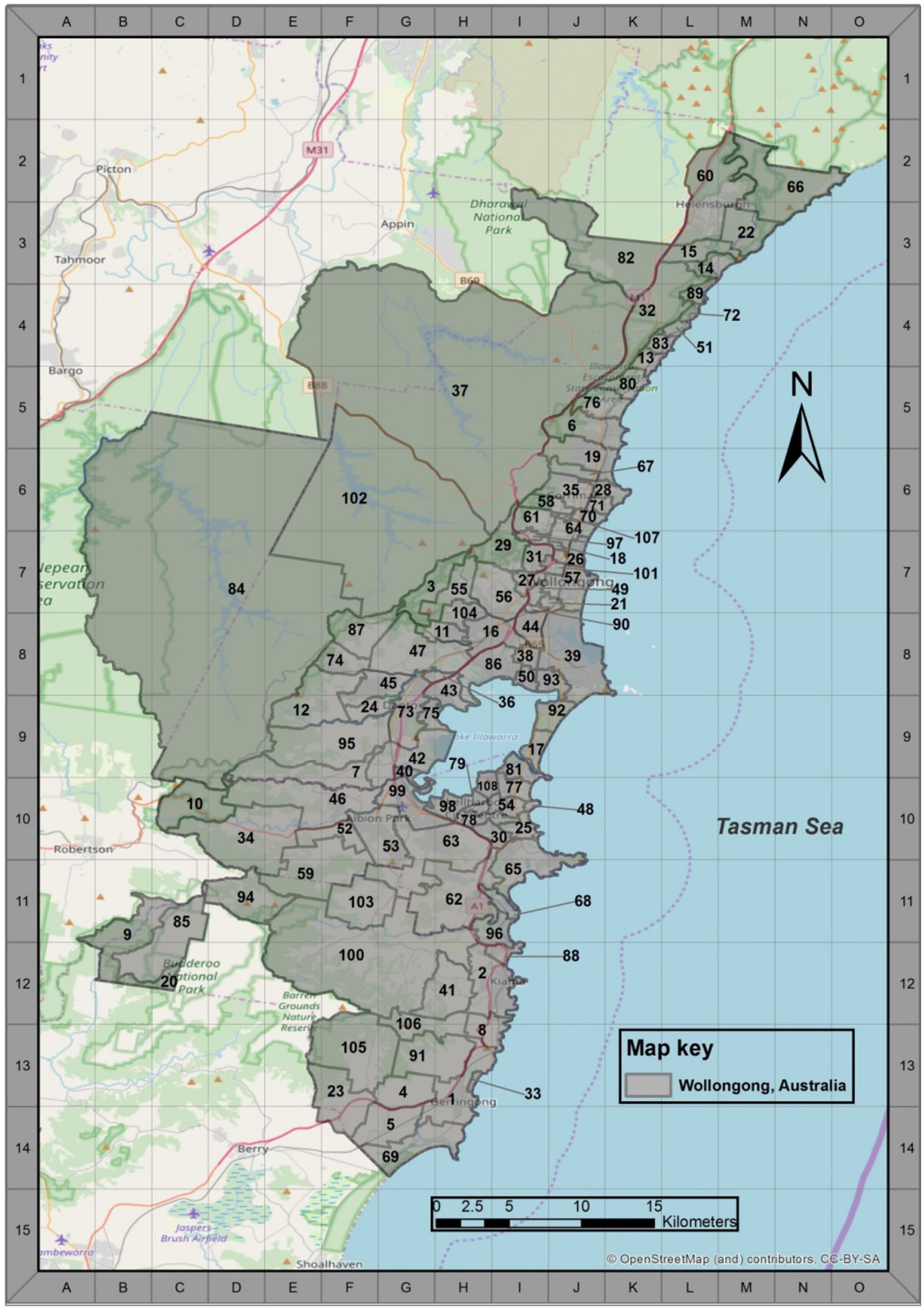

Fig. 1 Study Area: Wollongong, Illawarra region, New South Wales, Australia. *Source* Background layer is OpenStreetMap. https://www.openstreetmap.org/key

4 Results

This section presents the results of applying the SSVI technique to compute social vulnerability in different suburbs in the Wollongong area. For the purpose of presentation, each suburb is assigned a unique ID between 1 and 108. The bluish color indicates the lowest values of SSVI and the reddish color indicates the highest values of SSVI. The computed SSVI values have been standardized from 0–1, where 0 represents the smallest value in the dataset and 1 represents the highest value. The results are visualized using the open-source Quantum Geographical Information System (QGIS) platform,[1] with SSVI scores classified as follows using the equal interval classification algorithm (Erden and Karaman 2012): 0.00–0.20 = Very

[1] QGIS Development Team (2019). QGIS Geographic Information System. Open Source Geospatial Foundation Project. http://qgis.osgeo.org.

Low (VL) vulnerability, 0.21–0.40 = Low (L) vulnerability, 0.41–0.60 = Median (M) vulnerability, 0.61–0.80 = High (H) vulnerability, and 0.81–1.00 = Very High (VH) vulnerability. The results for the five different aspects of SSVI computed are shown in Figs. 2, 3, 4, 5, and 6.

5 Discussion

The discussion focuses on explaining the results of the analysis conducted, including information about vulnerability attribution where possible, and then provides a broader implication of the research for emergency and disaster management.

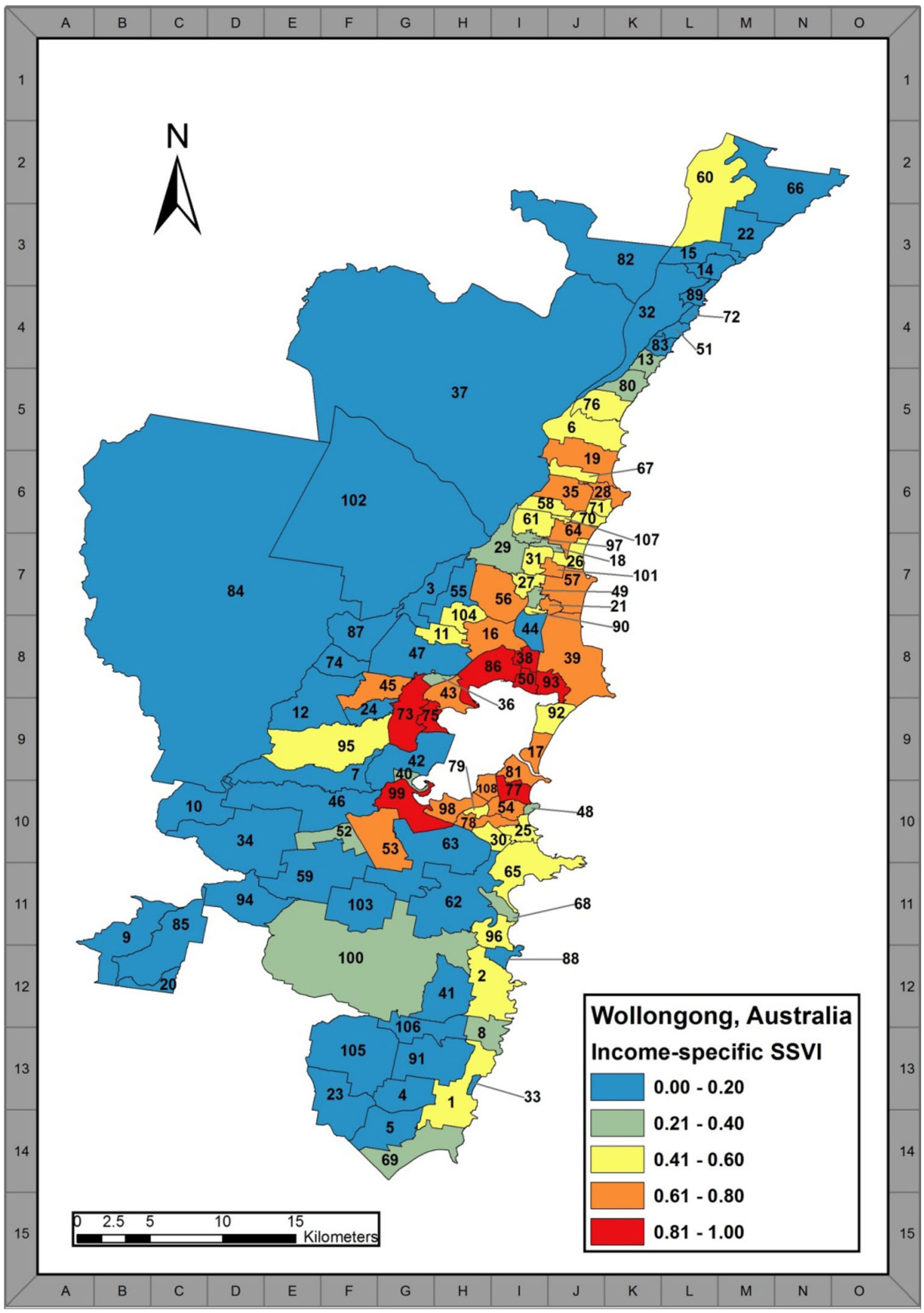

Fig. 2 Spatial distribution of income-specific strength-based social vulnerability index (SSVI) in the Wollongong area of New South Wales, Australia

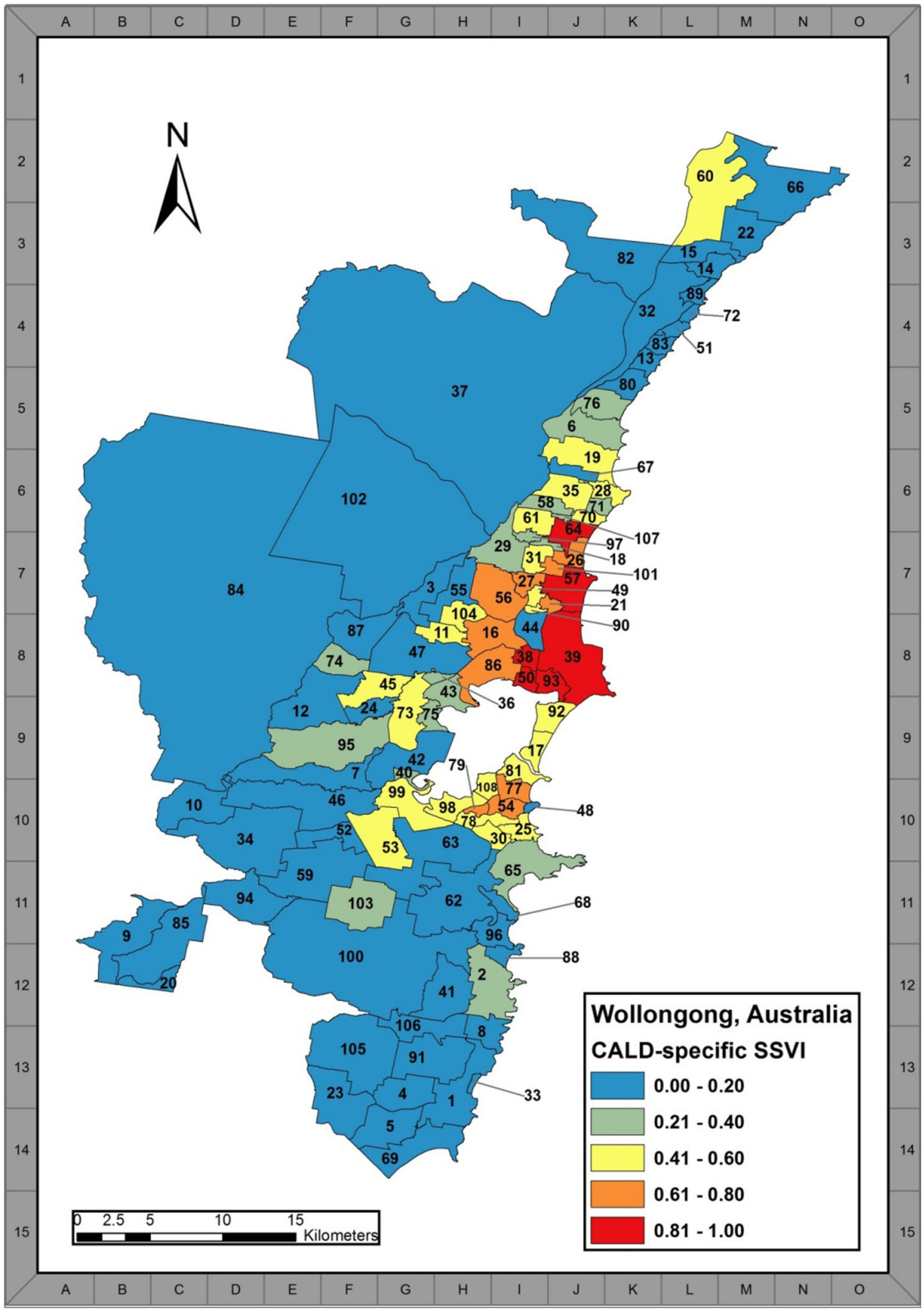

Fig. 3 Spatial distribution of culturally and linguistically diverse-specific strength-based social vulnerability index (SSVI) in the Wollongong area of New South Wales, Australia

5.1 Discussion of Strength-Based Social Vulnerability Index Results

Figure 2 shows the results of income-specific SSVI for the various suburbs in Wollongong. The most vulnerable suburbs in terms of financial capacity to cope with or recover from natural hazards are Warrawong (93, J8), Cringila (38, I8), Koonawarra (75, G9), Warilla (77, I10), Dapto (73, G9), Berkeley (86, H8), Lake Heights (50, I8), and Albion Park Rail (99, G10) in that order. These results mean that even with the few high-income community members and the propensity to donate resources taken into consideration, these eight suburbs rank as the most vulnerable, categorized into the VH class. Surrounding suburbs to these eights suburbs also recorded high vulnerability compared to other parts of the city, suggesting a concentration of vulnerability within several low-income neighborhoods that may not be as equally equipped financially to prepare for, withstand, or recover from the impacts of natural hazards. This finding is consistent with

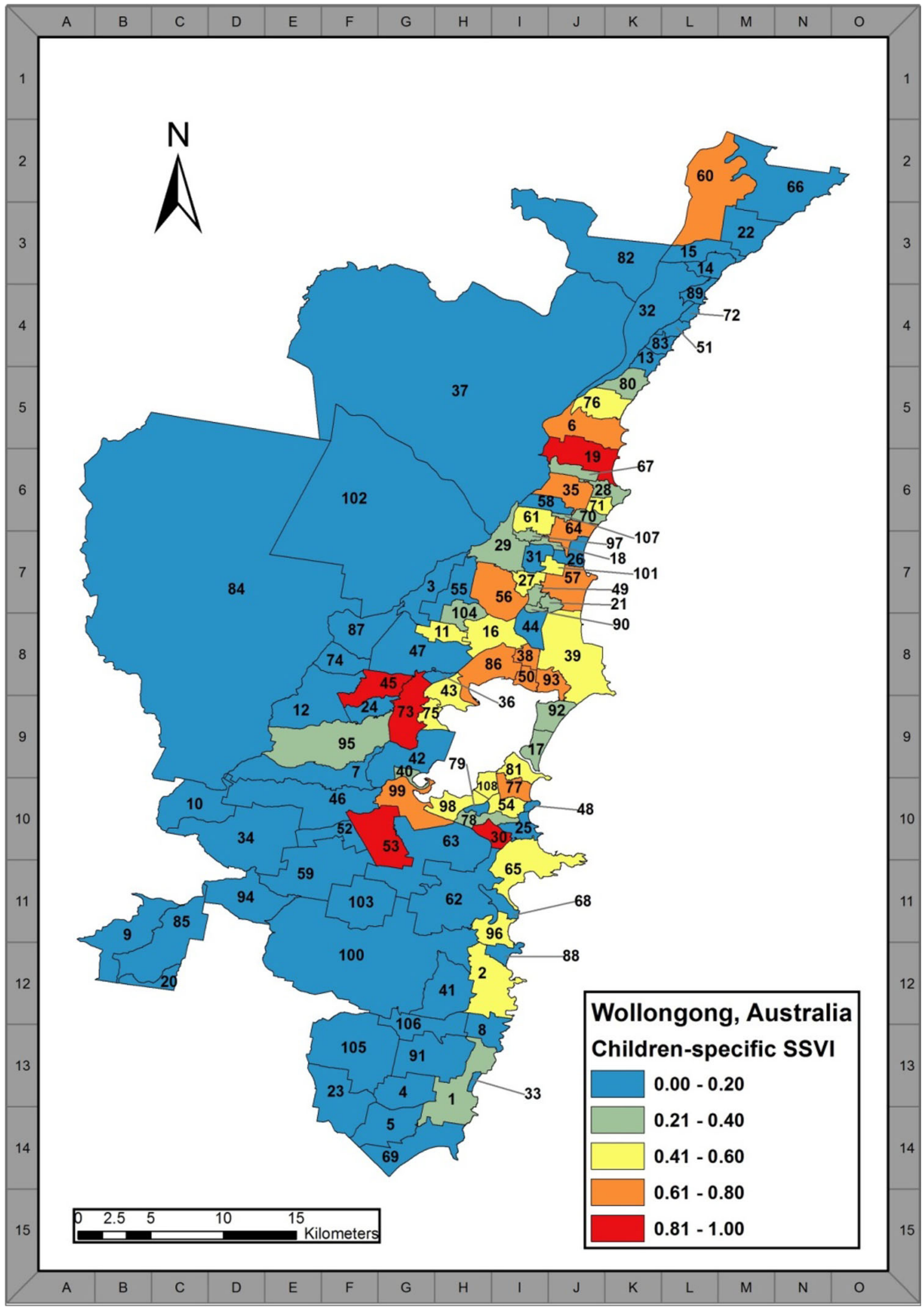

Fig. 4 Spatial distribution of children-specific strength-based social vulnerability index (SSVI) in the Wollongong area of New South Wales, Australia

results from previous studies, which indicate that social vulnerability can sometimes be concentrated in certain areas (McGuirk and O'Neill 2012; de Loyola Hummell et al. 2016). The concentration of social vulnerability can be explained by the large public housing settlements built by the government in Warrawong (93, J8), Berkeley (86, H8), and Koonawarra (75, G9) to cater to low-income households who cannot afford to live in other expensive suburbs. People with financial means tend to avoid these areas when making decisions about where to live. For this reason, accommodation is often relatively cheaper in and around suburbs with social housing, thereby attracting more low-income households to the areas. Note that Spring Hill (44, I8) is currently uninhabited according to the Australian 2016 census; hence it is ranked in the VL category even though it is situated near the neighborhoods with a high concentration of vulnerability.

Figure 3 shows the results of CALD-specific SSVI. In terms of vulnerability associated with language and cultural barriers, Wollongong (57, J7), Warrawong (93, J8),

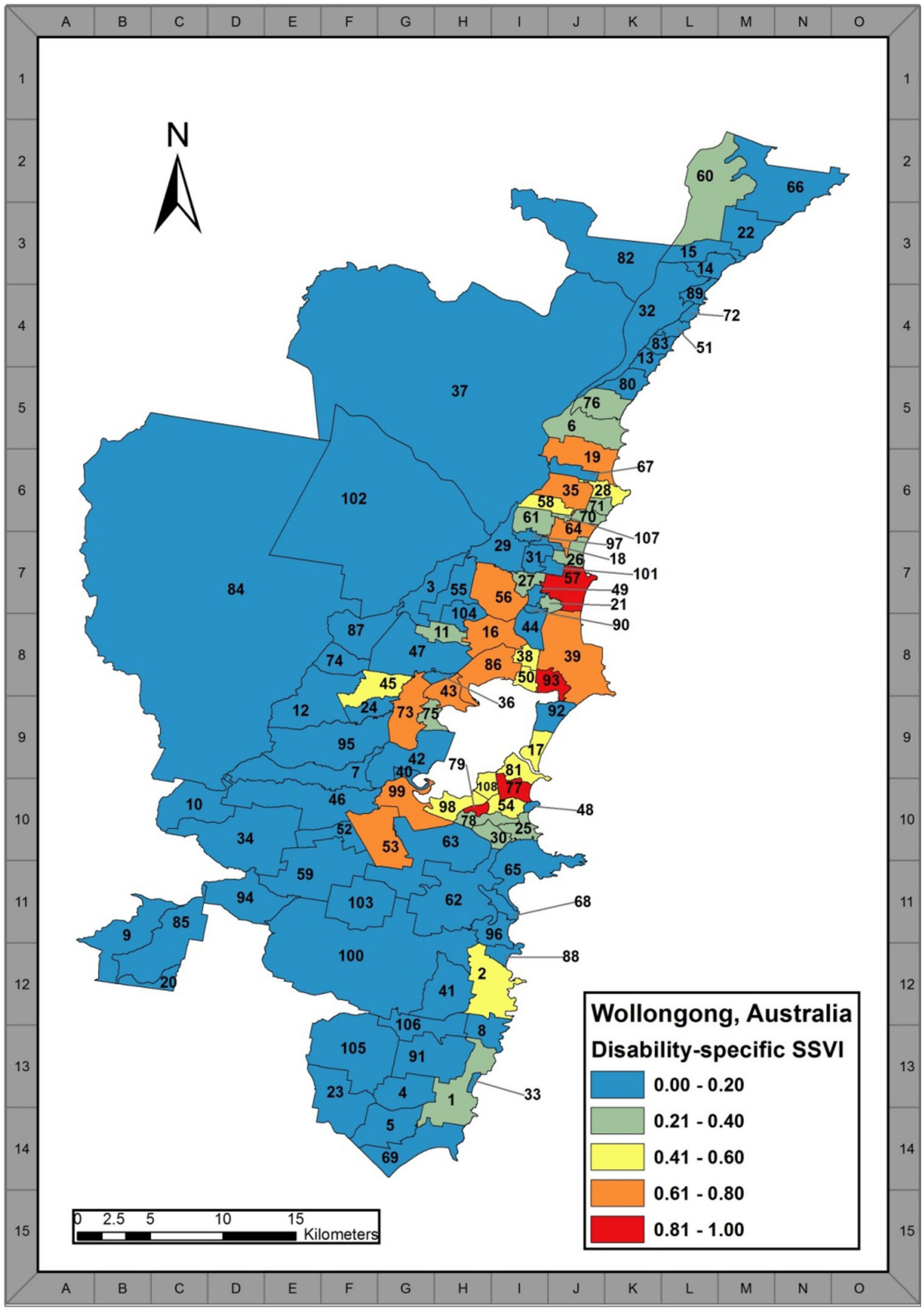

Fig. 5 Spatial distribution of disability-specific strength-based social vulnerability index (SSVI) in the Wollongong area of New South Wales, Australia

Port Kembla (39, J8), Cringila (38, I8), Fairy Meadow (64, J6), and Lake Heights (50, I8) ranked as the most vulnerable suburbs in that order. Again, these suburbs are all collocated within the same area, suggesting a concentration of vulnerability within several neighborhoods with a high representation of people who can hardly communicate in English. This can be explained by two underlying factors: (1) migrants may feel safer and more socially connected through living in close proximity to other like-minded individuals that share a similar culture, language, history, and challenges (Buffel 2017); (2) people who have migrated in their adulthood tend to maintain their mother tongue or first language as the preferred way to communicate at home, potentially limiting their ability to assimilate and learn to communicate in the predominant language of the new country (Soehl 2016). The high concentration of CALD communities in suburbs such as Port Kembla (39, J8), Warrawong (93, J8), Cringila (38, I8), and so on can be linked back to the early 1960s when many migrants seeking job opportunities in the Port Kembla

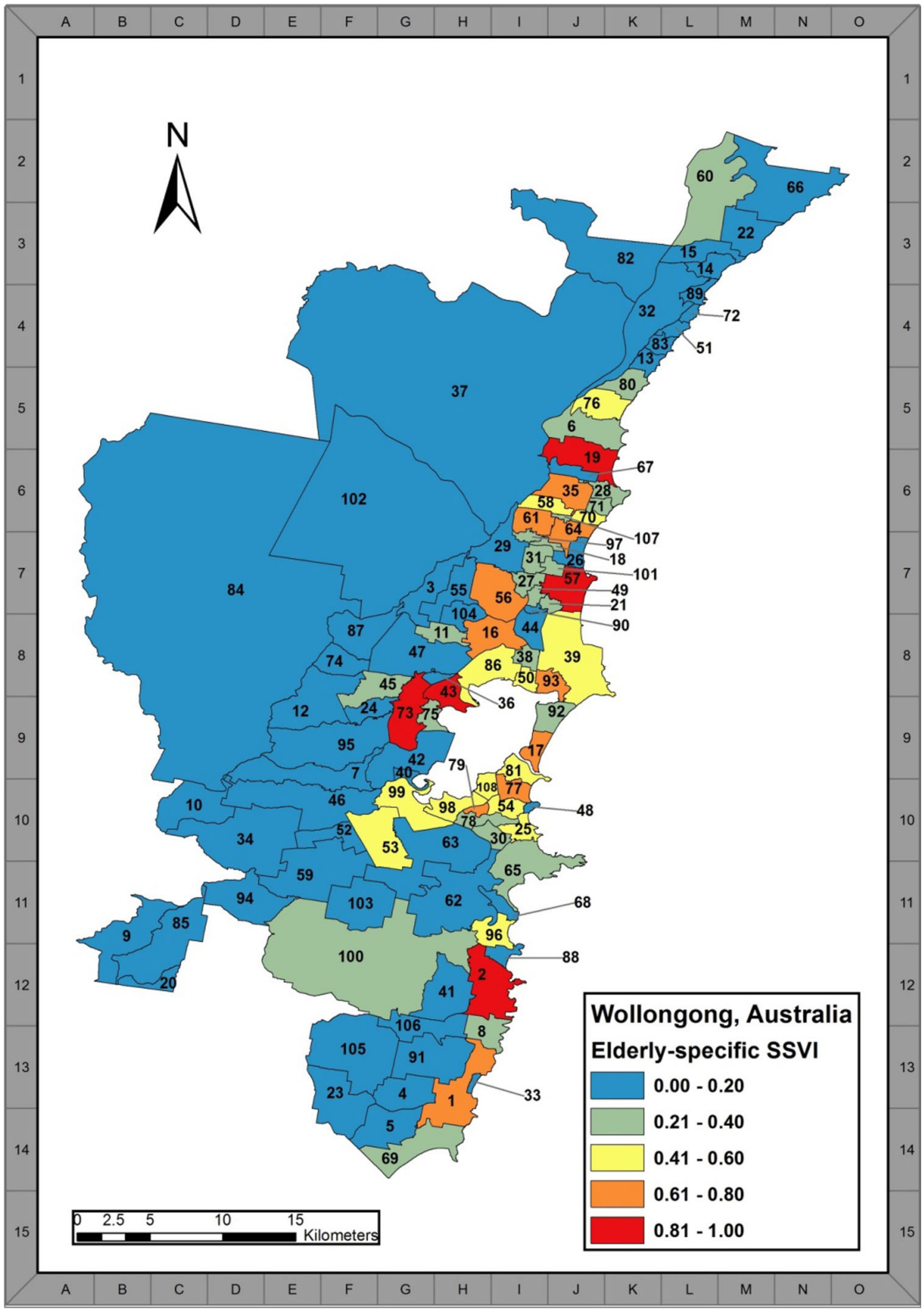

Fig. 6 Spatial distribution of elderly-specific strength-based social vulnerability index (SSVI) in the Wollongong area of New South Wales Australia

steelworks moved into the area and settled in these neighborhoods. Decades after, these CALD communities have stayed together, unified through language and culture, in the same neighborhoods where many of them have built their homes. Emergency communication in English only can be particularly challenging in such neighborhoods, characterized by high representations of non-English speakers and with relatively few multilingual representatives to help facilitate interpretation of time-critical warnings or messages about hazard risks. These results (Fig. 3) will help emergency services to gain spatial intelligence as required in allocating resources to priority locations where it is critical to improve emergency communication for CALD communities.

Regarding the children-specific SSVI (Fig. 4), five suburbs, namely Albion Park (53, G10), Woonona (19, J6), Dapto (73, G9), Horsley (45, G8), and Flinders (30, I10), ranked as the most vulnerable in that order. These five suburbs ranked in the VH category of vulnerability because they have the highest levels of children relative to the rest of the population (RoP) who can potentially provide support during disasters. These rankings have been reached after considering the propensity for a child to be freely cared for by another person who is not the parent or guardian. For disability-specific SSVI (Fig. 5), just four suburbs ranked in the highest (VH) category of vulnerability, namely Shellharbour City Centre (79, H10), Wollongong (57, J7), Warrawong (93, J8), and Warilla (77, I10) in that order. Shellharbour City Centre (79, H10) topped the list of suburbs in the VH category because it is a very small suburb and has a commercial centre comprising mainly shopping malls, an Aged Care facility, and Disability Homes, with little or no traditional residential dwellings for the rest of the population. Unsurprisingly, the four suburbs in the VH category have some of the highest numbers of disability care homes in the study area. Hence, the four suburbs have ranked very high in vulnerability even after considering other factors that may help to moderate vulnerability such as (1) others who can potentially provide support during disasters; and (2) the propensity for a person to provide unpaid care to support another individual living with a disability. Without society adjusting to their specific needs, people living with a disability are highly vulnerable to natural hazards and emergency planning often requires that places with high needs are determined in advance so that limited resources available for emergency support, for example, evacuation, can be judiciously allocated to minimize disastrous outcomes. These results will be useful to emergency planners when determining priority areas for disability-specific support in emergencies.

The results for the elderly-specific SSVI are shown in Fig. 6. The suburbs with the highest vulnerability are Wollongong (57, J7), Kiama (2, H12), Kanahooka (43, H8), Dapto (73, G9), and Woonona (19, J6) in that order. In reaching this finding, we considered both those who can potentially provide support during disasters and the propensity for a person to provide unpaid care to support an elderly person in need. This finding is vital to emergency services who must make adequate plans to properly support places with high representations of elderly people living in their personal homes or in residential aged care facilities. It was observed that Wollongong (57, J7) ranked in the VH category in four of the five aspects of SSVI investigated. This makes Wollongong (57, J7) a suburb of high priority when planning resource allocation for disaster preparedness, response (for example, evacuation priority), and recovery effort in different suburbs.

Overall, the SSVI maps (Figs. 2, 3, 4, 5, 6) presented provide a distinct understanding of how vulnerability is spatially distributed across the Wollongong region in relation to age, cultural and linguistic factors, income, and disability. In addition to emergency agencies and government authorities who require such information for emergency planning and allocation of limited resources, citizens and private donors of relief materials may also find such information useful for identifying highly vulnerable neighborhoods that may require specific supplies (for example, baby food, nappies, mobility aids, etc.) to support their recovery.

5.2 Implications for Emergency and Disaster Management

The proposed SSVI has implications for emergency and disaster management. The SSVI concept is underpinned by the fact that vulnerable people are likely to receive support from community members who have the capacity and willingness to do so and a balanced approach to vulnerability assessment needs to account for this strength within communities. When disasters strike, the real "first responders" at the scene to provide support are well-meaning community members, also called the zero-order responders (Briones et al. 2019). At such times, it is the efforts of the unstructured collectives that help to restore hope and control in disaster-stricken communities (Drury et al. 2016). This suggests the need for emergency planners and professional responders to acknowledge the role of community strength in moderating social vulnerability to disasters, including an appreciation of how such community capabilities change from one place to another. The SSVI approach can provide the required capability that enables emergency planners to make critical decisions about fair and judicious allocation of limited resources to meet the varying needs of different communities.

Emergency agencies need not only recognize community members as key partners in emergency response and recovery, but also do more in working harmoniously and in coordination with these communities. Emergency agencies should provide the enabling environment for community capabilities to be harnessed during disasters. In other words, in mass emergencies where emergency resources are overstretched, all members of the community should be sufficiently equipped and allowed to contribute meaningfully alongside emergency agencies who should ultimately facilitate and provide supervision for the process. This recommendation is consistent with the earlier study by Clarke (2002), which highlights the need for authorities to see community members as partners in recovery rather than as a "constituency" to be handled. Communities are resourceful and the people should never be preconceived as objects of panic who will foment problems in the emergency front: "operating on the assumption that people panic in disasters leads to a conclusion that disaster preparation means concentrating resources, keeping information close to the vest, and communicating with people in soothing ways, even if the truth is disquieting" (Clarke and Chess 2008, p. 994).

Past disasters have shown that the dysfunctional approach to emergency management, wherein the crowd is assumed to be a problem, is injurious to the community and creates an atmosphere of distrust, panic, excessive police militarization, and abuse of personal rights and freedoms of civilians, sometimes with tragic consequences (Solnit 2009). Solnit refers to this behavior from authorities as secondary disasters that are likely to occur when the fear of losing control causes those in power to take repressive actions against people they believe cannot be trusted to be in control. Avoiding future secondary disasters is crucial and requires tangible effort by disaster-specific agencies to partner with communities in emergency planning and response. This partnership should be based on trust, adequate information sharing, and genuine effort to recognize and empower the communities as the "fourth emergency service" (Drury et al. 2016, p. 220). Emergency drills should be inclusive of community members, with clear communication of roles, responsibilities, accountability, and expectations during actual emergencies. Importantly, emergency service workers and other formally enlisted volunteers should be trained on how to work alongside "spontaneous" or "informal" volunteers without having to see them as threats (Whittaker et al. 2015). Campaigns to reduce violence against emergency services personnel should be carried out as part of emergency preparation. Such programs should aim to strengthen the bonds between communities and emergency services, portraying uniformed emergency workers as well-meaning members of the community who are out to protect and not to violate the safety of communities.

6 Conclusion

Natural hazards threaten lives and property around the world, causing a disproportionate impact on communities because of social inequalities that account for the difference in people's sensitivity to natural hazards and their ability to respond and recover from the devastating impacts of such hazards. Social inequalities mean that some people are more vulnerable to natural hazards than others. Failing to identify the communities or places that are most vulnerable to natural hazards compromises judicious allocation of limited resources for mitigation and undermines the effectiveness of emergency planning, preparedness, response, and recovery efforts within communities, potentially resulting in disastrous outcomes.

The social vulnerability index is a metric that can be computed based on the socioeconomic and demographic characteristics of a population to determine the extent to which the population is both sensitive to natural hazards and able to respond and recover from them. However, existing techniques of computing social vulnerability indices have not accounted for the unique strengths that exist within different communities to help minimize disaster loss. To address this issue, this study has proposed the strength-based social vulnerability index (SSVI) as a more balanced approach for determining and comparing the social vulnerability of different places or communities. Several aspects of social vulnerability were covered, including in relation to culturally and linguistically diverse communities, low-income households, highly dependent children aged 0–4 years, people living with disability or requiring assistance for daily activities, and the elderly population. The proposed SSVI technique was applied to comparatively assess the social vulnerability of different suburbs in the greater Wollongong metropolitan area of New South Wales, Australia. The results highlight suburbs that are highly vulnerable, demonstrating the usefulness of the technique in improving understanding of hotspots where limited resources should be judiciously allocated to help communities improve preparedness, response, and recovery from natural hazards. The proposed method aims to maintain the discipline of accounting for the strength within different communities while estimating social vulnerability. Effort should, therefore, be made to maintain this approach even when using variables that may be specific to a particular study area.

Future work will focus on further establishing the relevance of the proposed SSVI technique through comparative analysis to assess how results from applying the SSVI technique performs when compared to the traditional approach of computing social vulnerability. The study will also be extended in the future to include an additive model for computing a summary score of SSVI for different places or communities. Few studies have reported the possibility that factors considered in computing vulnerability (for example, age, ethnicity, gender) may act to increase or decrease vulnerability, depending on their contingent interaction with hazard consequences (Saegert 1989; Miller et al. 1999; Paton and Johnston 2001). Hence, future studies will aim to further improve the accuracy of the proposed solution by integrating information from hazard analysis to help qualify or contextualized the interpretation of vulnerability results. Lastly, an indicator can be included in the future to account for variation in the degree of community-mindedness and social cohesion across places, subject to the availability of such data.

Data unavailability is often a major limitation in vulnerability research. Through interviews and focus group sessions with community stakeholders, however, the SSVI approach can be further improved by integrating other deeper factors such as institutional barriers and cultural taboos. There may be some case-specific factors that are relevant in one study area, but not the other. For example, factors such as widespread institutional corrupt practices, marginalization, community conflicts, and lack of social welfare may be more predominant in some locations than in others. This will suggest the need for future research to explore more flexible models that can be adapted to different study contexts, allowing the user to add or delete variables as the scenario demands. In this way, detailed sensitivity analysis can be performed to better understand various effects on vulnerability findings, including any observed limitations or advantages.

References

ABS (Australian Bureau of Statistics). 2018. Census. https://www.abs.gov.au/websitedbs/D3310114.nsf/home/census. Accessed 13 Mar 2019.

Ahmed, A. 2011. Use of social media in disaster management. In *Proceedings of the International Conference on Information Systems (ICIS)*, 4–7 December 2011, Shanghai, China.

Ajibade, I., G. McBean, and R. Bezner-Kerr. 2013. Urban flooding in Lagos, Nigeria: Patterns of vulnerability and resilience among women. *Global Environmental Change* 23(6): 1714–1725.

Aksha, S.K., L. Juran, L.M. Resler, and Y. Zhang. 2019. An analysis of social vulnerability to natural hazards in Nepal using a modified social vulnerability index. *International Journal of Disaster Risk Science* 10(1): 103–116.

Bernardini, S., and D. Hart. 2011. A paradise built in hell: The extraordinary communities that arise in disaster. *Journal of Moral Education* 40(1): 123–125.

Briones, F., R. Vachon, and M. Glantz. 2019. Local responses to disasters: Recent lessons from zero-order responders. *Disaster Prevention and Management: An International Journal* 28(1): 119–125.

Buchholz, S., D. Hofäcker, M. Mills, H.P. Blossfeld, K. Kurz, and H. Hofmeister. 2008. Life courses in the globalization process: The development of social inequalities in modern societies. *European Sociological Review* 25(1): 53–71.

Buffel, T. 2017. Ageing migrants and the creation of home: Mobility and the maintenance of transnational ties. *Population, Space and Place* 23(5): 1–13.

Buldyrev, S.V., R. Parshani, G. Paul, H.E. Stanley, and S. Havlin. 2010. Catastrophic cascade of failures in interdependent networks. *Nature* 464(7291): 1025–1028.

Cannon, T. 1994. Vulnerability analysis and the explanation of "natural" disasters. In *Disasters, development and environment*, ed. A. Varley, 3–30. Chichester, England; Brisbane, Australia: J. Wiley.

Chakraborty, J., G.A. Tobin, and B.E. Montz. 2005. Population evacuation: Assessing spatial variability in geophysical risk and social vulnerability to natural hazards. *Natural Hazards Review* 6(1): 23–33.

Chambers, R. 1994. The origins and practice of participatory rural appraisal. *World Development* 22(7): 953–969.

Chen, W., S.L. Cutter, C.T. Emrich, and P. Shi. 2013. Measuring social vulnerability to natural hazards in the Yangtze River Delta region, China. *International Journal of Disaster Risk Science* 4(4): 169–181.

Chiwaka, E., and R. Yates. 2010. Participatory vulnerability analysis, a step by step guide for field staff. Dorset: Action Aid International.

Clarke, L. 2002. Panic: Myth or reality? *Contexts* 1(3): 21–26.

Clarke, L., and C. Chess. 2008. Elites and panic: More to fear than fear itself. *Social Forces* 87(2): 993–1014.

CRED (Centre for Research on the Epidemiology of Disasters). 2018. The Emergency Events Database. Université catholique de Louvain (UCL), Brussels, Belgium. https://www.emdat.be. Accessed 29 Dec 2018.

Cutter, S.L., and C. Finch. 2008. Temporal and spatial changes in social vulnerability to natural hazards. *Proceedings of the National Academy of Sciences* 105(7): 2301–2306.

de Loyola Hummell, B.M., S.L. Cutter, and C.T. Emrich. 2016. Social vulnerability to natural hazards in Brazil. *International Journal of Disaster Risk Science* 7(2): 111–122.

Drury, J., R. Brown, R. González, and D. Miranda. 2016. Emergent social identity and observing social support predict social support provided by survivors in a disaster: Solidarity in the 2010 Chile earthquake. *European Journal of Social Psychology* 46(2): 209–223.

Dwyer, A., C. Zoppou, O. Nielsen, S. Day, and S. Roberts. 2004. *Quantifying social vulnerability: A methodology for identifying those at risk to natural hazards*. Geoscience Australia Record 2004/14. Canberra City: Commonwealth of Australia.

Ehlen, M.A., and A.J. Scholand. 2005. Modeling interdependencies between power and economic sectors using the N-ABLE agent based model. In *Proceedings of the IEEE Power Engineering Society General Meeting*, San Francisco, CA, June 12–16, 2005. Vol. 3: 2842–2846.

Erden, T., and H. Karaman. 2012. Analysis of earthquake parameters to generate hazard maps by integrating AHP and GIS for Küçükçekmece region. *Natural Hazards and Earth System Sciences* 12(2): 475–483.

Eusgeld, I., W. Kröger, G. Sansavini, M. Schläpfer, and E. Zio. 2009. The role of network theory and object-oriented modeling within a framework for the vulnerability analysis of critical infrastructures. *Reliability Engineering & System Safety* 94(5): 954–963.

Fair Work Ombudsman. 2016. Be prepared—Wage rate changes tomorrow. https://www.fairwork.gov.au/about-us/news-and-media-releases/archived-media-releases/2016-media-releases/june-2016/20160630-minimum-wage-increase-mr. Accessed 30 Mar 2019.

Fernandez, L.S., D. Byard, C.C. Lin, S. Benson, and J.A. Barbera. 2002. Frail elderly as disaster victims: Emergency management strategies. *Prehospital and Disaster Medicine* 17(2): 67–74.

Flanagan, B.E., E.W. Gregory, E.J. Hallisey, J.L. Heitgerd, and B. Lewis. 2011. A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management* 8(1): 1–22.

Flentje, P., and R.N. Chowdhury. 2005. Managing landslide hazards on the Illawarra escarpment. In *Proceedings of the GeoQuest Symposium on Planning for Natural Hazards—How can we mitigate the impacts?* 2–5 February 2005, Wollongong, Australia, eds. R.J. Morrison, S. Quinn, and E.A. Bryant, 65–78. Wollongong: GeoQuest Research Centre, University of Wollongong.

Frigerio, I., F. Carnelli, M. Cabinio, and M. De Amicis. 2018. Spatiotemporal pattern of social vulnerability in Italy. *International Journal of Disaster Risk Science* 9(2): 249–262.

Giving Australia. 2016. Individuals: Volunteering overview. https://www.communitybusinesspartnership.gov.au/wp-content/uploads/2017/04/giving_australia_2016_fact_sheet_-_individual_volunteering_accessible.pdf. Accessed 10 Apr 2019.

Haimes, Y.Y., B.M. Horowitz, J.H. Lambert, J.R. Santos, C. Lian, and K.G. Crowther. 2005. Inoperability input-output model for interdependent infrastructure sectors. I: Theory and methodology. *Journal of Infrastructure Systems* 11(2): 67–79.

Holmgren, Å.J. 2006. Using graph models to analyze the vulnerability of electric power networks. *Risk Analysis* 26(4): 955–969.

Huang, J., Y. Liu, and L. Ma. 2011. Assessment of regional vulnerability to natural hazards in China using a DEA model. *International Journal of Disaster Risk Science* 2(2): 41–48.

Jencson, L. 2001. Disastrous rites: Liminality and communitas in a flood crisis. *Anthropology and Humanism* 26(1): 46–58.

Kaniasty, K., and F. Norris. 1999. The experience of disaster: Individuals and communities sharing trauma. In *Response to disaster: Psychosocial, community, and ecological approaches*, ed. R. Gist, and B. Lubin, 25–61. Philadelphia, PA: Brunner/Mazel.

Kuhlicke, C., A. Scolobig, S. Tapsell, A. Steinführer, and B. De Marchi. 2011. Contextualizing social vulnerability: Findings from case studies across Europe. *Natural Hazards* 58(2): 789–810

Lin, K.H.E., and C. Polsky. 2016. Indexing livelihood vulnerability to the effects of typhoons in indigenous communities in Taiwan. *The Geographical Journal* 182(2): 135–152.

McGuirk, P., and P. O'Neill. 2012. Critical geographies with the state: The problem of social vulnerability and the politics of engaged research. *Antipode* 44(4): 1374–1394.

Mercer, J., D. Dominey-Howes, I. Kelman, and K. Lloyd. 2007. The potential for combining indigenous and western knowledge in reducing vulnerability to environmental hazards in small island developing states. *Environmental Hazards* 7(4): 245–256.

Miller, M., D. Paton, and D. Johnston. 1999. Community vulnerability to volcanic hazard consequences. *Disaster Prevention and Management* 8(4): 255–260.

Ngo, E.B. 2001. When disasters and age collide: Reviewing vulnerability of the elderly. *Natural Hazards Review* 2(2): 80–89.

OECD (Organization for Economic Cooperation and Development). 2018. Compare your income—Methodology and conceptual issues. https://www.oecd.org/statistics/Compare-your-income-methodology.pdf. Accessed 15 Mar 2019.

Ogie, R.I., S. Dunn, T. Holderness, and E. Turpin. 2017. Assessing the vulnerability of pumping stations to trash blockage in coastal mega-cities of developing nations. *Sustainable Cities and Society* 28: 53–66.

Ogie, R.I., T. Holderness, S. Dunn, and E. Turpin. 2016. Vulnerability analysis of hydrological infrastructure to flooding in coastal cities—A graph theory approach. In *Transforming the Future of Infrastructure through Smarter Information: Proceedings of the International Conference on Smart Infrastructure and Construction (ICSIC)*, 27–29 June 2016, Cambridge, UK, eds. R.J. Mair, K. Soga, Y. Jin, A. Parlikad, J.M. Schooling, 633–644. London: ICE Publishing.

Ogie, R.I., T. Holderness, S. Dunn, and E. Turpin. 2018. Assessing the vulnerability of hydrological infrastructure to flood damage in coastal cities of developing nations. *Computers, Environment and Urban Systems* 68: 97–109.

Ogie, R.I., N. Shukla, F. Sedlar, and T. Holderness. 2017. Optimal placement of water-level sensors to facilitate data-driven management of hydrological infrastructure assets in coastal mega-cities of developing nations. *Sustainable Cities and Society* 35: 385–395.

Oliver-Smith, A. 2012. The brotherhood of pain: Theoretical and applied perspectives on post-disaster solidarity. In *The angry earth: Disaster in anthropological perspective*, ed. A. Oliver-Smith, and S.M. Hoffman, 170–186. New York: Routledge.

Paton, D., and D. Johnston. 2001. Disasters and communities: Vulnerability, resilience and preparedness. *Disaster Prevention and Management* 10(4): 270–277.

Palamakumbure, D., D. Stirling, P. Flentje, and R. Chowdhury. 2015. ArcGIS V. 10 landslide susceptibility data mining add-in tool integrating data mining and GIS techniques to model landslide susceptibility. *Engineering Geology for Society and Territory*. IAEG (International Association for Engineering Geology and the Environment) XII Congress, 15–19 September, 2014, Turin, Italy. Vol. 2: Landslide Processes, eds. G. Lollino, D. Giordan, G.B. Crosta, J. Corominas, and R. Azzam, 1191–1194. Cham, Switzerland: Springer.

Phillips, B.D., and B.H. Morrow. 2007. Social science research needs: Focus on vulnerable populations, forecasting, and warnings. *Natural Hazards Review* 8(3): 61–68.

Pradhan, B. 2010. Flood susceptible mapping and risk area delineation using logistic regression, GIS and remote sensing. *Journal of Spatial Hydrology* 9(2): 1–18.

Pradhan, B., M.D.H.B. Suliman, and M.A.B. Awang. 2007. Forest fire susceptibility and risk mapping using remote sensing and geographical information systems (GIS). *Disaster Prevention and Management: An International Journal* 16(3): 344–352.

Rahman, M.M., U. Barua, F. Khatun, I. Islam, and R. Rafiq. 2018. Participatory Vulnerability Reduction (PVR): An urban community-based approach for earthquake management. *Natural Hazards* 93(3): 1479–1505.

Rufat, S., E. Tate, C.G. Burton, and A.S. Maroof. 2015. Social vulnerability to floods: Review of case studies and implications for measurement. *International Journal of Disaster Risk Reduction* 14(Part 4): 470–486.

Rygel, L., D. O'sullivan, and B. Yarnal. 2006. A method for constructing a social vulnerability index: An application to hurricane storm surges in a developed country. *Mitigation and Adaptation Strategies for Global Change* 11(3): 741–764.

Saegert, S. 1989. Unlikely leaders, extreme circumstances: Older black women building community households. *American Journal of Community Psychology* 17(3): 295–316.

Salami, R.O., J.K. von Meding, and H. Giggins. 2017. Urban settlements' vulnerability to flood risks in African cities: A conceptual framework. *Jàmbá: Journal of Disaster Risk Studies* 9(1): 1–9.

Schoenwald, D.A., D.C. Barton, and M.A. Ehlen. 2004. An agent-based simulation laboratory for economics and infrastructure interdependency. In *Proceedings of the 2004 American Control Conference*, June 30-July 2, 2004, Boston, Massachusetts. Vol. 2: 1295–1300. Evanston, IL: American Automatic Control Council; Piscataway, NJ: IEEE, 2004

Setola, R., S. De Porcellinis, and M. Sforna. 2009. Critical infrastructure dependency assessment using the input–output inoperability model. *International Journal of Critical Infrastructure Protection* 2(4): 170–178.

Schmidtlein, M.C., R.C. Deutsch, W.W. Piegorsch, and S.L. Cutter. 2008. A sensitivity analysis of the social vulnerability index. *Risk Analysis: An International Journal* 28(4): 1099–1114.

Soehl, T. 2016. But do they speak it? The intergenerational transmission of home-country language in migrant families in France. *Journal of Ethnic and Migration Studies* 42(9): 1513–1535.

Solnit, R. 2009. *A paradise built in hell: The extraordinary communities that arise in disaster*. New York: Viking Adult.

Sun, Y., P.H. Chau, M. Wong, and J. Woo. 2017. Place-and age-responsive disaster risk reduction for Hong Kong: Collaborative place audit and social vulnerability index for elders. *International Journal of Disaster Risk Science* 8(2): 121–133.

Tapsell, S., S. McCarthy, H. Faulkner, and M. Alexander. 2010. Social vulnerability to natural hazards, CapHaz-Net WP4 Report. London: Flood Hazard Research Centre (FHRC).

Thein, A.K., R. Gregory, M. Akester, F. Poulain, and R. Langeard. 2019. Participatory rural appraisal: Vulnerability study of Ayeyarwady delta fishing communities in Myanmar and social protection opportunities. FAO Fisheries and Aquaculture Circular No. 1177. Rome: FAO.

Titz, A., T. Cannon, and F. Krüger. 2018. Uncovering 'community': Challenging an elusive concept in development and disaster related work. *Societies* 8(3): 1–28.

Turner, J.C., and K.J. Reynolds. 2011. Self-categorization theory. In *Handbook of theories in social psychology,* ed. P.A.M. Van Lange, A.W. Kruglanski, and E.T. Higgins, 399–417. London: SAGE.

Whittaker, J., B. McLennan, and J. Handmer. 2015. A review of informal volunteerism in emergencies and disasters: Definition, opportunities and challenges. *International Journal of Disaster Risk Reduction* 13: 358–368.

Wilhelmi, O.V., and M.H. Hayden. 2010. Connecting people and place: A new framework for reducing urban vulnerability to extreme heat. *Environmental Research Letters* 5(1): Article 014021.

Wisner, B., P. Blaikie, T. Cannon, and I. Davis. 2003. *At risk: Natural hazards, people's vulnerability and disasters*, 2nd edn. London: Routledge.

Yoon, D.K. 2012. Assessment of social vulnerability to natural disasters: A comparative study. *Natural Hazards* 63(2): 823–843.

Zahran, S., S.D. Brody, W.G. Peacock, A. Vedlitz, and H. Grover. 2008. Social vulnerability and the natural and built environment: A model of flood casualties in Texas. *Disasters* 32(4): 537–560.