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INCLUSIVE RESILIENCE

A SOCIO-ECONOMIC VULNERABILITY INDEX TO MAP FLOOD RISKS FOR TARGETED COMMUNICATIONS AND DISASTER RISK REDUCTION

EXECUTIVE SUMMARY

Before, during, and after disasters, the Canadian Red Cross works with individuals and communities across Canada to strengthen their resilience. In 2019, Red Cross and Public Safety Canada started a four-year project, the ***Emergency Public Awareness Contribution Program***. This program develops and tests materials, methods, and tools to engage and empower communities in culturally relevant ways. It relies on continuous monitoring and evaluation to enhance emergency and disaster preparedness.

As part of this program, the Inclusive Resilience project aimed to promote inclusive approaches, tools, and actions that foster inclusive disaster risk reduction (DRR) and emergency preparedness across Canada. The Canadian Red Cross implemented the project in partnership with FireSmart Canada, Partners for Action (University of Waterloo), the BC Earthquake Alliance, the Native Women's Association of Canada, and community partners.

Partners for Action carried out two strands of research for the Inclusive Resilience project: one on public outreach and risk communications, and the other on how to understand where disproportionate socio-economic vulnerabilities exist to identify where to equitably and efficiently allocate resources for strengthening community resilience. This report presents findings from the latter.

A socio-economic vulnerability index (SoVI) is a decision-support tool that reveals the spatial distribution of disproportionate vulnerability based on a selection of variables. SoVI scores can be mapped through geographic information systems (GIS) applications, making it easy to visually identify areas of higher vulnerability relative to other areas within a community. Hazard exposure can also be mapped. Visualizing analyses of vulnerability and hazard exposure through GIS can guide emergency managers to focus efforts on areas where Canadians are at risk to different hazards. Once areas of disproportionate socio-economic vulnerability (referred to as social vulnerability) and/or risk to a specific hazard (such as floods) are identified, risk communications and strategies can be refined and delivered at the community-level more efficiently and effectively.

For more information about the research informing this report, visit the Inclusive Resilience research study website: uwaterloo.ca/inclusive-resilience/.

REPORT AT A GLANCE

Social vulnerability refers to the socio-economic conditions that lessen a population's ability to prepare for, cope with, and recover from a shock or hazard event. This renders them more susceptible to the negative consequences of a disaster than others within a community who are not subject to the same systemic or structural constraints. Disaster events, such as floods, landslides, and earthquakes, can both exacerbate existing inequalities and create new socio-economic vulnerabilities within a community. Once areas that experience disproportionate social vulnerabilities are identified, risk communications can be refined and delivered at the community-level with a greater understanding of where and how to prioritize efforts. Therefore, identifying the spatial variations in social vulnerability is critical for the efficient and effective distribution of awareness-building and preparedness strategies.

Constructing a social vulnerability index (SoVI) is one method of assessing social vulnerabilities. This decision support tool can narrow the spatial distribution of awareness and preparedness products to Canadians disproportionately affected by all hazards. By combining socio-economic variables from a dataset, such as a national census, a SoVI allows for comparisons to be made between communities or neighbourhoods using visual mapping representations expressed through GIS. However, assessing social vulnerabilities on its own is not enough to identify priority locations for designating risk communications and preparedness programs. Given the increased frequency and severity of natural hazard events due to climate change, it is crucial to combine social vulnerability analyses with hazard exposure data to identify where people that are most likely to experience risks are located, and who within those areas might be the most systemically disadvantaged, thus requiring additional support to prepare for, cope with, and recover from disasters.

Partners for Action combined a SoVI, constructed from publicly available census data, with a flood exposure analysis using JBA Risk Management data, licensed to the University of Waterloo, to identify areas within communities facing high levels of both social vulnerability and flood exposure.

This report begins by exploring the concept of social vulnerability and identifying the demographic groups most likely to be disproportionately impacted by flood events based on existing disaster risk reduction, emergency management, and climate change adaptation literatures within the North American context. The report continues with a discussion on how and for what purposes social vulnerability indices have been used to inform equity-informed decision-making. Methodologies are provided for how to construct a SoVI, carry out a flood exposure analysis, and overlay the two to visualize risk in web-based maps, with uses and limitations of each. Flood risk maps that overlay spatial analyses of flood exposure data and social vulnerability (via a SoVI) are provided for the following communities identified by Red Cross for this project:

(1) Richmond, British Columbia
(2) Thompson, Manitoba
(3) Ottawa- Renfrew, Ontario
(4) Ottawa-Gatineau, Ontario
(5) Moose Factory, Ontario and,
(6) Bay St. George, Newfoundland and Labrador

Finally, recommendations and areas of future research are provided for reproducing, validating, and advancing the SoVI and risk assessment methodologies outlined.

ABOUT PARTNERS FOR ACTION (P4A)

P4A is a research initiative of the University of Waterloo's Faculty of Environment, which seeks to empower Canadians to become flood resilient by promoting awareness and preparedness actions that are inclusive and evidence-based. Partnership is central to our approach; strategic collaborations allow us to focus on changing the flood response landscape at the ground level and with policy makers. As a thought leader and steward of Flood Smart Canada, P4A moves conversation and multi-level action forward by localizing community-engaged flood risk awareness and preparedness, partnering for adaptation, and developing flood resilience planning and foresight. These priorities will enable communities to access practical resources and innovative research, and to embrace inclusive resilience.

Learn more about us at: www.uwaterloo.ca/partners-for-action.

ABOUT THE CANADIAN RED CROSS

In Canada and overseas, the Red Cross stands ready to help people before, during, and after a disaster. As a member of the International Red Cross and Red Crescent Movement – which is made up of the International Federation of Red Cross and Red Crescent Societies, the International Committee of the Red Cross, and 192 national Red Cross and Red Crescent societies – the Canadian Red Cross is dedicated to helping people and communities in Canada and around the world in times of need and supporting them in strengthening their resilience.

ACKNOWLEDGEMENTS

Public Safety Canada has funded this project. The views expressed herein do not necessarily represent the views of Public Safety Canada.

Public Safety Canada   Sécurité publique Canada

The authors acknowledge the support of the Canadian Red Cross in providing input and support to define the research objectives and methodologies for this report. Red Cross also provided input on the design of data collection tools and guidance on inclusive approaches for the research. Together with Partners for Action, the Red Cross engaged in knowledge mobilization on research finds and supported the development of recommendations for the final report. The Canadian Red Cross, in partnership with Partners for Action, would also like to thank the following organizations who have supported this work: Public Safety Canada, BC Earthquake Alliance, FireSmart Canada, Native Women's Association of Canada, and community partners across Canada.

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Please reference as:

Partners for Action. (2023). *Inclusive resilience: A socio-economic vulnerability index (SoVI) to map flood risk for targeted communications and disaster risk reduction.* Waterloo, Ontario: University of Waterloo.

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LIST OF ABBREVIATIONS

2020 SoVI	The social vulnerability index developed by Chakraborty et al. (2020) based on 2016 Census data
2023 Canadian Red Cross SoVI	The social vulnerability index constructed for Canadian Red Cross using 2016 Census data
ATSDR	Agency for Toxic Substances and Disease Registry
CCA	Climate change adaptation
CDC	Centre for Disease Control
CHASS	Canadian Census Analyser
CSD	Census sub-division
CT	Census tract
DA	Dissemination area
DB	Dissemination block
DRR	Disaster risk reduction
EM	Emergency management
FRM	Flood risk management
GIS	Geographic information system
GWR	Geographically weighted regression
HTI	Integrated Hazard Threat Index
JBA	JBA Risk Management
NRCan	Natural Resources Canada
RDC	Research Data Centre
SES	Socio-economic status
SoVI	Social vulnerability index
P4A	Partners for Action
PCA	Principal Component Analysis
PSI	Physical Susceptibility Index

1 | INTRODUCTION, BACKGROUND, AND RATIONALE FOR THE STUDY

This work aims to inform a comprehensive risk assessment strategy for the Canadian Red Cross as part of their *Emergency Public Awareness Contribution Program* with Public Safety Canada. This program aims to facilitate the development and testing of materials, methods, and tools to better engage and empower communities, in culturally relevant ways, to enhance emergency and disaster preparedness. This approach relies on monitoring and evaluation to guide continuous improvements. As part of this program, Red Cross sought to better understand where disproportionate socio-economic vulnerability exists to help identify where to focus resources that strengthen community resilience.

Socio-economic vulnerability has been defined in several ways and is often referred to as social vulnerability. Within the environmental justice and disaster risk reduction (DRR) fields, the concept primarily refers to the socio-economic conditions that lessen a population's ability to prepare for, cope with, and recover from a shock or hazard event. It is based on the idea that certain demographic groups are more susceptible to the negative impacts of hazards. Disasters associated with natural hazards are worsening due to climate change, and can be considered "threat multipliers," creating new social vulnerabilities while exacerbating existing challenges (Hallegatte et al., 2016). Those with diminished socio-economic capacities often struggle to recover from severe shocks and disasters, which can lead to longer recovery timelines and reduced overall well-being, such as decreased mental health outcomes (Sherrieb et al., 2010).

For this research, **social vulnerability** is defined as the socio-economic and/or demographic characteristics that, generally speaking, increase an individual, group, or community's susceptibility to the negative impacts of natural hazards, making it challenging for them to prepare for, cope with, and recover from disasters (Cutter et al., 2003; Cutter, 1996; Wisner et al., 2004). **Identifying the spatial variation in social vulnerabilities is critical for the efficient and effective distribution of disaster risk reduction outreach, programming, and strategies**. Once the communities that experience disproportionate social vulnerability are identified, risk communications for awareness and preparedness can be refined and delivered at the community-level.

A **social vulnerability index (SoVI)** is one method of assessing social vulnerability. By combining socio-economic variables from a dataset (i.e., a national census), a SoVI enables the comparative analysis of vulnerabilities at a particular geographical scale (i.e., at the neighbourhood or community level). This analysis can be visually represented using geographic information system (GIS)-based mapping. As a decision support tool, a SoVI can be used by decision-makers and practitioners to target emergency awareness and preparedness programming, and disaster risk reduction interventions. In doing so, finite funding, resources, and capacity can be strategically allocated to strengthen disaster resilience where needed most within a community, prioritizing actions to support Canadians who are disproportionately vulnerable to hazards and their adverse impacts.

With the frequency and severity of natural hazard events increasing due to climate change, SoVI analyses can be combined with hazard exposure analyses to produce climate risk assessments, which can be used to identify target areas for disaster preparedness programming and risk communications.

Flooding is Canada's most widespread, frequent, and costly disaster (**Public Safety Canada, 2022**). Early settlements concentrated around Canada's abundant freshwater and coastal resources in flood-prone areas, resulting in land-use planning that overwhelmingly favours development in at-risk areas (**Rajabali & Agrawal, 2022**; **Wade, 2022**). Approximately 80% of Canadian cities are located on floodplains (**Chakraborty et al., 2021**), including many of the country's most populous and economically significant urban centres (**Public Safety Canada, 2023**).

Climate change is exacerbating flood risk in Canada through shifting streamflow, precipitation, and snowmelt patterns, sea level rise, permafrost, glacial melt, and intensified extreme weather events (**Bush & Lemmen, 2019**). Many Canadian communities have already begun to experience this new reality of flood risk under a rapidly shifting climate, as evidenced by recent disasters such as Hurricane Fiona (2022), the Manitoban and Northwestern Ontario floods (2022), British Columbia's atmospheric rivers (2021), and the Southern Alberta floods (2013). According to the Insurance Bureau of Canada (**2023**), "insured catastrophic losses now routinely exceed $2 billion annually," most of which result from flood-related events – a 338.6% increase in extreme weather-related losses compared to the 1998 – 2008 period. Annual flood damages alone total nearly $1.5 billion in both insured ($700 million) and uninsured ($800 million) losses (**Public Safety Canada, 2022**). Despite this, a national survey conducted by Partners for Action (P4A) found that 94% of Canadians remain unaware of their household's flood risk (**Ziolecki et al., 2020**).

Flood risk assessments and maps are critical in this context. Although flood exposure data are essential for identifying areas prone to flooding, it is necessary to combine these data with a social vulnerability analysis to determine flood risk, incorporating the locations of those who may be the most disadvantaged and susceptible to the negative impacts of flooding. To this end, a SoVI can be used in tandem with other decision-making tools to help identify and map **areas of risk**—areas where hazard exposure and social vulnerability converge.

For this research, P4A created a SoVI (referred to as the **2023 Canadian Red Cross SoVI**), and combined it with an analysis of flood exposure using JBA Risk Management data, licensed to the University of Waterloo, to produce flood risk maps that Red Cross can use to target emergency awareness and preparedness communications and programming, and to inform other disaster risk reduction strategies.

These flood risk maps can be used by decision-makers and practitioners to identify those who may require additional engagement, policy interventions, and supports to enhance their overall flood resilience, aligned with an inclusive resilience approach. An **inclusive resilience** approach ensures that all people can contribute meaningfully to and benefit from flood risk reduction decision-making, planning, and response efforts. Taking a holistic picture of risk that incorporates socio-economic and geographic dimensions is a step toward designing equitable and accessible flood risk reduction policies and programs that centre the needs of **disproportionately impacted people**.

* Please note that "social" and "socio-economic" are often used interchangeably when referring to this index type; however, social vulnerability indices are more commonly referred to within the disaster risk reduction and emergency management literature, and is the term used here.

Please see **Appendix A** for a complete glossary of the terms used in this report.

2 | WHO IS DISPROPORTIONATELY IMPACTED BY FLOODING?

Contextualizing social vulnerability

(1) Vulnerabilities and exposure to flooding events and other hazards are not distributed equally.

Systemic barriers and **structural disadvantages** prevent certain populations from accessing the necessary resources to prepare for, cope with, and recover from hazard events, putting them in harm's way. **Equity-deserving groups** and **marginalized populations** disproportionately experience climate change impacts (e.g., extreme weather) due to historical patterns of inequality, such as colonialism and discriminatory land use and infrastructure policies. Simply put, these populations are often excluded from the decision-making and planning processes that affect them, and/or face pre-existing barriers that are exacerbated during a disaster, thus reducing their overall resilience relative to others who do not experience the same constraints. This deepening of **vulnerability** may be happening deliberately because of **systemic racism** and **discrimination**, for instance, or inadvertently through initiatives with unintended consequences, creating a gap between well-meaning policies and the outcomes for at-risk populations.

While many terms can describe how various groups experience structural and systemic inequities due to social, cultural, and economic factors, we will refer to these populations as "**disproportionately impacted people.**"

(2) People are not inherently vulnerable in the face of adversity.

The power constructs and systems currently in place either privilege or marginalize certain populations, creating conditions that reduce a person's **resilience**—or their ability to cope with, adjust to, and recover from a natural hazard event. Resilience is essentially the opposite of vulnerability. The socio-ecological conditions that create or reduce resilience are unequally distributed throughout society and change over time (**Adger, 2006**). In other words, vulnerability is not a fixed, static state but dynamic and highly context-dependent. When assessing and responding to the needs of disproportionately impacted people, it is crucial to be mindful of this distinction and the nuances surrounding disaster resilience.

> "Social vulnerability, at its core, is determined by systems of power . . . People who face systemic oppression, exclusion, and marginalization receive labels of vulnerability based on demographic characteristics. Yet demographic characteristics are not an inherent vulnerability."
>
> Bouikidis & Tynan, 2022: pp. 5-6

(3) Research supports the idea that conditions of both vulnerability and resilience can co-exist. Reframing vulnerability to focus on those conditions is more reflective of reality, where societal systems and structures are designed for and by some—and not for and by others.

We advocate for reframing vulnerability to focus on systems and institutions that create disadvantage or harm rather than placing the onus on the individual (e.g., Haalboom & Natcher, 2012; Bankoff, 2001; Chmutina et al., 2023). Since not all populations have the same access to opportunities and resources, disaster risk reduction (DRR), emergency management (EM), and climate change adaptation (CCA) efforts must reduce systemic inequalities and strengthen the resilience capacities of disproportionately impacted people.

A SoVI is one way of assessing who may be disproportionally impacted by disasters and where they live, which can be used in risk reduction planning and programming to support equitable access to resources. It is based on socio-economic data determined to be either direct or proxy measures of what makes people susceptible to the negative impacts of a hazard event.

(4) A SoVI, as well as the demographic and economic data that it is derived from, should only be used as a starting point for understanding the multi-dimensional and intersectional ways that risk conditions are created.

While everyone will experience a disaster event differently based on their own lived experiences and individual circumstances, assessing risk at the population level reveals that some groups will experience multiple systemic challenges and/or compounding barriers that further exacerbate their social vulnerability. **Intersectional** analyses are thus helpful for unearthing these nuances. For example, disabled Canadians are twice as likely to experience abject poverty compared to non-disabled Canadians, with those heading up single-parent households (41%) or living alone (60%) being disproportionately at risk; however, irrespective of disability, 80% of lone parents are women (Morris et al., 2018). In Canada, people with disabilities aged 25 to 64 years old are more likely to be unemployed (41%) compared to working-age Canadians without disabilities (20%), often facing both social and economic marginalization (Morris et al., 2018). Additionally, older adults over the age of 65 are nearly twice as likely to have a disability than younger adults (Morris et al., 2018). These examples illustrate how multiple factors, such as disability, gender, age, and socio-economic status, can influence an individual's resilience or vulnerability to a natural hazard event.

'Unnatural' disasters as threat multipliers

The United Nations Office for Disaster Risk Reduction (UNDRR) recognizes that **there is no such thing as "natural disasters"** (McClean, 2021). The #NoNaturalDisasters campaign (NoNaturalDisasters, n.d.) explains why the term "natural disaster" is a misnomer in that the term can misdirect attention from the human actions and decisions that increase people's risk to the impacts of hazardous events. A natural hazard event only becomes a disaster when there are physical, financial, and social impacts on humans, resulting from planning and land-use decisions, a built environment not designed for particular natural hazards, and policy failures. One example is the decision to settle in floodplains or coastal areas, which increases the likelihood that residents of those areas will experience flooding.

Simply put, disasters do not start with the occurrence of a hazardous event but rather with the social, economic, and political conditions that create and exacerbate vulnerabilities, as well as the land-use planning decisions and regulatory structures that continue to place people, property, and infrastructure in harm's way. As such, UNDRR (2017) defines **flood risk** as a function of hazard occurrence, exposure, vulnerability, and coping capacity; here we focus on exposure and social vulnerability to identify areas of risk. **Exposure** refers to hazard proximity (e.g., floodplain development), while **vulnerability** can be characterized as either physical (i.e., underinvestment in aging infrastructure) or socio-economic (i.e., lower-income households possessing limited resources to cope with sudden shocks) susceptibility to adverse outcomes. Due to the latter, entrenched in historical and structural inequalities, adverse disaster outcomes continue to be unequally distributed throughout society (Fuentealba, 2021; Rivera, 2020). Efforts to reduce social vulnerabilities can serve as a tangible way to build individual and community coping capacity, ultimately strengthening overall resilience to climate- and disaster-related shocks.

Disproportionately impacted people

Several determinants of social vulnerability and associated disproportionate impacts have been identified within the existing DRR, EM, and CCA literatures in the North American context. These socio-economic factors point to those who may face more negative consequences than others during the response to and recovery from a hazardous event. This idea underlies the importance of a social vulnerability analysis as a crucial element of DRR and emergency planning. **Table 1**, based on a literature review, lists critical factors that influence who in Canada may be disproportionately impacted by the physical, emotional, social, cultural, economic, and health burdens associated with flood events.

Table 1: Canadian populations that are disproportionately impacted by flooding

Variable	Types of Impacts	An Example
Socio-economic status Low-income households, homelessness, education level, unemployment	▪ Access to resources/ economic insecurity ▪ Increased exposure/ susceptibility to flooding ▪ Mobility ▪ Housing quality	People with limited financial resources have fewer options for evacuation or relocation. Those who cannot afford alternative accommodations (e.g., hotel, short-term rental) or to repair damaged living spaces may face housing insecurity or homelessness due to the added financial strain (Burton et al., 2016; Walker et al., 2022).
Further Reading:	Bjarnadottir et al., 2011; Burton et al., 2016; Chakraborty et al., 2020; Collins et al., 2018; Fielding & Burningham, 2007; Hallegette et al., 2016; Hamideh et al., 2021; Gray-Scholz et al., 2019; McLeod & Kessler, 1990; Morris et al., 2018; Ramin & Svoboda, 2009; Rivera et al., 2021; Vickery, 2017; Walker et al., 2022	
Household composition and dynamics Lone-parent and single-person households, renters	▪ Housing quality ▪ Access to social supports ▪ Access to resources/ economic insecurity	Lone-parent and single-person households may have limited financial resources to cope with and recover from disasters due to one individual assuming the entire burden of household/ familial responsibilities (Oulahen et al., 2015a).
Further Reading:	ATSDR, 2022; Klinenberg, 2016; Oulahen et al., 2015a; Tobin-Gurley et al., 2010	
Age Infants, children, youth, older adults (aged 50+)	▪ Mobility ▪ Physical health and safety ▪ Mental health outcomes ▪ Access to resources/ economic insecurity ▪ Access to social supports	Older adults disproportionately experience adverse post-flood outcomes and often face additional barriers due to reduced mobility and existing medical conditions (Emrich et al., 2020). Further, older adults are more likely to experience social isolation, which reduces their access to non-financial coping mechanisms and social supports during a disaster (Oulahen et al., 2015a).
Further Reading:	Adams et al., 2020; Al-Baldawi et al., 2021; Aldrich & Benson, 2008; Arshad et al., 2020; Bjarnadottir et al., 2011; Burton et al., 2016; Burton & Cutter, 2008; Chakraborty et al., 2020; Cutter & Smith, 2009; Emrich et al., 2020; Fulton & Drolet, 2018; Gutman, 2007; Jensen, 2021; Lowe et al., 2013; Manuel et al., 2015; McDonald-Harker et al., 2021; Morris et al., 2018; Oulahen et al., 2015a; Scannell et al., 2017; Tapsell et al., 2010	

Variable	Types of Impacts	An Example
Gender Tied to economic factors, gender-based violence, societal gender norms, and risk factors such as pregnancy	▪ Physical health and safety ▪ Mental health outcomes ▪ Access to resources/ economic	Disasters are often linked to increases in gender-based violence due to factors such as exacerbated gender inequalities, increased community and familial stress, socio-economic instability, disruptions in essential social and healthcare services, and food insecurity (van Daelen et al., 2022; Ballard & Thompson, 2013).
Further Reading:	Ballard & Thompson, 2013; Bjarnadottir et al., 2011; Burton et al., 2016; Canadian Women's Foundation, 2022; Dancause et al., 2015; Enarson, 1999 a&b; Enarson & Scanlon, 1999; Haney & Gray-Scholz, 2019; Milnes & Haney, 2017; Vasseur et al., 2015; van Daelen et al., 2022; Walker et al., 2022	
Racial or ethnic background Indigenous Peoples, visible minorities (aka people of colour)	▪ Access to resources/ economic insecurity ▪ Increased exposure/ susceptibility to flooding ▪ Mobility ▪ Physical health and safety ▪ Mental health outcomes ▪ Housing quality	Indigenous people already experience health disparities compared to non-Indigenous people in Canada, particularly within northern communities, due to systemic issues of colonization. These disparities relate to limited access to healthcare services, inadequate housing infrastructure, and unsafe drinking water – all pre-existing social and health inequalities that are often exacerbated during a disaster (Furgal & Seguin, 2006).
Further Reading:	Ballard & Thompson, 2013; Bjarnadottir et al., 2011; Buckland & Rahman, 1999; Chakraborty et al., 2021; Collins et al., 2018; Furgal & Seguin, 2006; Kant et al., 2013; Martin et al., 2017; McKenzie et al., 2016; NCCPH et al, 2021; Reading & Wien, 2009; Statistics Canada, 2017a; Thompson et al., 2014; Walker et al., 2022; Waldram 1988; Wilson & MacDonald, 2010; Yumagulova, 2020	
Health and disability Presence of pre-existing mental and/or physical health conditions, chronic illnesses, disabilities	▪ Access to resources/ economic insecurity ▪ Mobility ▪ Physical health and safety ▪ Mental health outcomes	Pre-existing mental health conditions can limit an individual's ability to cope with a significant natural hazard event. The psycho-social stress experienced during and after a disaster can exacerbate pre-existing mental health conditions or create new ones linked to post-flood morbidities (Agyapong et al., 2022; Burton et al., 2016).
Further Reading:	Agyapong et al., 2022; Alderman et al., 2012; Burton et al., 2016; Caroll et al., 2009; Chakraborty et al., 2020; Goldmann & Galea, 2014; Hayes et al., 2020; Heagele & Pacquiao, 2019; Mao & Agyapong, 2021; McKeen & Slatnik, 2022; Mensah et al., 2005; Morris et al., 2018; NCCPH et al., 2021; Oulahen et al., 2015b; Owusu et al., 2022; Runkle et al., 2012; Sahni et al., 2016; Tapsell & Tunstall, 2008	

Variable	Types of Impacts	An Example
Immigration status Newcomers to Canada, recent immigrants	▪ Access to resources/ economic insecurity ▪ Communications barriers	Non-English speakers experience language barriers that make it difficult to access and understand emergency management communications (Oulahen et al., 2015a; Emrich et al., 2020).
Further Reading:	Chakraborty et al., 2020; Drolet et al., 2015; Emrich et al., 2020; Oulahen et al., 2015a	
Location Rural, remote, and northern communities, underserved neighbourhoods	▪ Access to resources/ economic insecurity ▪ Mobility ▪ Housing quality ▪ Infrastructure deficits ▪ Communications barriers ▪ Limited capacity/ services available	Rural and remote communities tend to experience significantly more challenges pertaining to emergency access routes, infrastructure deficits, and emergency services capacity compared to urban regions, leading to slower overall disaster response and recovery times (Houghton et al., 2017; RHIH, 2022).
Further Reading:	Cole & Murphy, 2014; Davis et al., 2010; Furgal & Seguin, 2006; Houghton et al., 2017; Myhre et al., 2017; RHIH, 2022; Russo et al., 2021; Wall & Marzall, 2007	
Housing type People living in older buildings or certain types of dwellings	▪ Housing quality ▪ Increased exposure/ susceptibility to flooding	The extent of flood damage to homes is influenced by building codes and standards, which have varied throughout time; thus, the period of construction and structural characteristics of a building can influence disaster outcomes (Hamideh et al., 2021).
Further Reading:	Chakraborty et al., 2020; Hamideh et al., 2021; Highfield et al., 2014; Oulahen et al., 2015a; Pal, 2002; Walker et al., 2022	

3 | AN INTRODUCTION TO SoVI RESEARCH AND APPLICATION

What is a social vulnerability index (SoVI)?

As mentioned earlier, social vulnerability can indicate a necessity for resources prior to, during, and in the aftermath of a shock, such as a public health crisis or a disaster from a natural hazard event (Wisner, 2004). An approach for assessing social vulnerability is to employ a SoVI—an empirical tool that combines variables to measure the relative susceptibility of a specific subset of the population within a defined geographical boundary. The variables can then be combined in a formula, mapped as a geospatial representation of relative vulnerability, to facilitate comparisons with other areas, such as between neighbourhoods, communities, provinces, or countries.

A SoVI combines the socio-economic variables that either directly or indirectly impact an individual's or household's vulnerability using proxy data. The analysis results in numerical scores, which are categorized into low, moderate, or high vulnerability levels. Constructing a SoVI using national census data supports decision-making at various levels, from the local (with scores of relative social vulnerability within a given community) to the national (differentiating among areas across a country).

Foundational SoVI research in the United States

The theoretical and methodological underpinnings of SoVIs took shape within the social sciences in the 1960s and 1970s when research on social variables and their application in social policy emerged (**Duncan, 1969** & **1984**; **Land, 1983**; **Land & Spilerman, 1975**; **Smith, 1973**; **Smith, 1981**—as cited in **Cutter et al., 2003**). Cutter re-envisioned the role of vulnerability within the field of DRR and environmental hazards as a dynamic function of time, place, and people, while Hewitt and Burton (**1971**) and Cutter (**1996**) developed a "*hazards of place model.*" This model illustrated the complex and interwoven connections among potential hazards, geographic context, biophysical vulnerability, and social vulnerability, all within the framework of place-based vulnerability, risk, and hazard mitigation. In doing so, Cutter (**1996**) advanced the idea that **risk is just as much a product of socio-economic and demographic factors as it is a result of hazard occurrence and geographical location**.

One of the foundational SoVIs is the index developed by Cutter et al. (**2003**) for the United States using county-level socio-economic data. Cutter et al.'s 2003 SoVI provided a methodological framework for calculating and mapping relative vulnerabilities (**Cutter & Finch, 2008**). Since this study, SoVIs have become more prevalent, with public agencies, academics, and research organizations using it to produce maps for targeted emergency preparedness, climate adaptation, risk mitigation, and the equitable allocation of public resources to promote disaster resilience worldwide. With Susan Cutter at the University of South Carolina, the

Hazards Vulnerability & Resilience Institute has led the work on SoVI data, methods, and applications. The institute provides training on a SoVI based on 29 socio-economic variables from the United States Census Bureau from 2010 to 2014, such as family structure, language barriers, vehicle availability, and medical disabilities (HVRI, n.d.)

SoVIs in the United States have been used at different scales as a decision-making tool to identify the spatial distribution of socio-economic conditions that affect all phases of the disaster cycle (i.e., mitigation, preparedness, recovery, and response). As an example of a local-level post-disaster application, Flanagan et al. (2011) developed a SoVI at the census tract level using 15 variables to explore the impact of Hurricane Katrina, providing insights into how a SoVI can be used within emergency management and flood risk management frameworks.

Another prominent SoVI framework being used in the United States was developed by the Centre for Disease Control (CDC). Its Agency for Toxic Substances and Disease Registry's (ATSDR) Geospatial Research, Analysis & Services Program developed a SoVI for Guam using 16 variables from the 2010 census data to identify areas in greater need of emergency support (e.g., shelters, aid) before, during, and after a hazardous event. The maps were designed to support aging, disabled, and non-native language-speaking populations in evacuation plans (Paulino et al., 2021). Other researchers and organizations have applied the CDC/ATSDR methodology to understand health risk behaviours and conditions, including teen pregnancy (Yee et al., 2019), chronic health conditions (Nguyen et al., 2019), physical inactivity (An & Xiang, 2015), obesity (Martins de Freitas & Moraes, 2016), and, more recently, coronavirus (Biggs et al., 2021).

In short, numerous SoVIs are being refined and used within the United States in the environmental hazard and DRR fields that stem from the work of Cutter et al. (2003) and colleagues, with more emerging as offshoots of the CDC/ATSDR's SoVI for DRR and health-related purposes.

Foundational SoVI research within the Canadian context

SoVIs generally do not measure vulnerabilities to a particular extreme natural hazard event, but instead indicate the spatial distribution of those who may be made vulnerable to a societal shock. Some SoVIs, however, have been developed specifically to understand hazard risk in connection to certain types of emergencies and health outcomes. For example, a SoVI developed by Environics (n.d.) was designed to identify Canadians facing challenges during and after a pandemic due to mental health issues and/or limited social networks. In this case, variables are specific to individuals' community involvement, self-esteem, and previously reported mental health conditions. This SoVI facilitated an analysis of the barriers faced by young or single urbanites, newcomers, and aging city dwellers (Andrew & Keefe, 2014), who may lack the community networks essential for supporting those with mental health conditions (Environics Analytics, n.d.).

Scholars and practionerers from both Canada and the United States have employed variables other than directly from nationally available datasets when constructing socio-economic indices. Chang et al. (2015) developed an index to compare community vulnerability profiles based on variables of both exposure (e.g., intensity of land development) and sensitivity (e.g., building characteristics, demographic variables), with a prototype demonstrating its use for coastal communities in British Columbia. This Hazard Vulnerability Similarity Index operates with several types of data: binary indicators, nominal or ordinal categorical variables (e.g., measured as high, medium, or low), and continuous variables (e.g., measured as a percentage of population) (Chang et al., 2015 & 2018).

Natural Resources Canada (NRCan) developed a SoVI (CanSVM) with census data as part of an Integrated Hazard Threat Index (HTI) for emergency management practitioners (see Journeay et al. 2022). While this model has been used to assess earthquake and tsunami threats nationally, it can be applied to other hazards and spatial scales. NRCan distinguishes between social and physical determinants of threat, where a SoVI and a Physical Susceptibility Index (PSI) are combined to produce an HTI. PSI is the interaction of a) physical exposure and b) hazard intensity and damage potential. Here, social vulnerability is determined by variables that comprise the community's "social fabric" to evaluate "the underlying factors that contribute to conditions of social vulnerability within a given neighbourhood" (Journeay et al. 2022, p. 5). There are five variables for each of the four vulnerability profiles (social capital, individual autonomy, housing conditions, and financial agency) that are reported in terms of land use and settlement type (metropolitan, rural, and remote; population density).

Finding SoVIs that map vulnerability to specific hazards is still uncommon. One way to develop SoVIs for specific hazards and circumstances is to take a stakeholder-engaged approach. This can entail seeking input from local practitioners who choose and assign weights to the variables used to construct a SoVI (Oulahen et al. 2015a). Chang et al. (2020) took another approach, comparing data on the existence and types of coastal flood risk tools that governments adopt, and on why they use them, against a hazard vulnerability assessment based on census data. Input by local experts enhances a SoVI's legitimacy by incorporating context-specific considerations, and can be combined with a process known as **ground-truthing** to improve the applicability of the analysis by validating results against local realities. While outside of this report's scope, developing and testing community engagement strategies for customizing SoVIs and flood risk maps using local and participatory data sources could be a next step of this research.

A national SoVI developed by Chakraborty et al. (2020)

Chakraborty et al. (2020) produced the first research and methodological framework for a national SoVI for Canada. Henceforth referred to as the **2020 SoVI**, it is the most comprehensive and nationally representative SoVI to date. Using 2016 census data, the 2020 SoVI incorporated 49 variables measuring social deprivation and economic instability conditions that contribute to vulnerability. The study compared social vulnerabilities across Canadian census tracts (CT) and discussed the practical applications of SoVI as a decision-support tool in nationwide flood risk assessments.

The 2020 SoVI does not have fundamental differences from the SoVIs mentioned earlier in terms of defining, analysing, and mapping vulnerability to natural hazards. The differences primarily lie in the number of variables chosen, the context-specific variables used, who decides on what variables are used and how, the computation methods, and the scale of analysis. Two distinctions of note:

(1) While national scale analyses have been conducted in the United States (e.g., Cutter et al., 2013; Tate et al., 2021), the development of SoVIs within Canada has, until recently with Chakraborty et al.'s (2020) and NRCan's work (Journeay et al. 2022), been primarily focused on municipal-scale analysis, such as at the metropolitan area (e.g., Oulahen, 2016; Chang et al., 2015).

(2) Chakraborty et al. (2020) included deprivation indices for neighbourhood instability and economic insecurity (e.g., combining variables such as household income and home value as a proxy of wealth). Using these sub-indices in a SoVI reinforces the idea that the higher the deprivation in a neighbourhood or community, the fewer social and financial resources are available for disaster preparedness and risk mitigation activities, which increases social vulnerability. These considerations enhance the reliability of the 2020 SoVI index scores.

How might a SoVI be useful for equity-informed decision-making?

Data that represents the social vulnerability of people to natural hazards can provide insights into **equity** considerations when planning risk mitigation strategies. Traditional risk assessments, which focus on economic damage and loss of life estimates, tend to neglect how the impacts of a hazard are unevenly distributed among groups of people (Koks et al., 2015). As such, flood risk management approaches have typically sought to find the most economically optimal path to reduce asset damage as much as financial constraints allow (Kind et al., 2020). However, people with fewer social and economic resources are constrained in their ability to effectively prepare for, respond to, and recover from disaster events (Wisner et al., 2004). For instance, lower-income households have fewer economic safeguards, which restricts their ability to make relocation or evacuation decisions and limits their capacity to invest in preparedness measures and costly post-disaster repairs (Walker et al., 2022). Therefore, although a lower-income household's total claim for damages may be less significant when compared to a home in an affluent neighbourhood, the household's overall recovery capacity is lower. Thus, people with fewer economic assets and lower social capital are disproportionately impacted by adverse disasters, such as coping with displacement or replacing damaged property.

Despite this disparity, asset ownership (e.g., property, finances) remains one of the primary considerations when developing traditional flood risk mitigation strategies, founded on the premise that the aim should be to reduce damage to and loss of economic assets. However, aside from asset ownership, various other socio-economic factors may influence an individual's vulnerability relative to others within the community when facing a hazard of the same intensity (Fielding & Burningham, 2005; Weichselgartner, 2001). Hence, a SoVI is helpful as one piece of evidence that enables the inclusion of more than purely economic asset-based data in decision-making, which is especially important when assigning finite financial resources (Tate et al., 2013).

In sum, a SoVI can be used as one tool for equity-informed decision-making within the fields of disaster mitigation, management, and recovery (Cutter et al., 2013; de Oliveira Mendes, 2009), having been developed for various hazards including floods (Chakraborty et al., 2021 & 2022), drought (Naumann et al., 2018), earthquakes (Siagian et al., 2014; Journeay et al., 2022), and heatwaves (Lehnert et al., 2020). SoVIs can help prioritize geographic areas with specific subpopulations that might benefit most from regulatory, educational, social, and/or financial supports to prepare for, cope with, and recover from hazard events. As such, as a decision-support tool, SoVIs promise to become more in demand as the frequency and severity of natural hazard events increase and as decision-makers look for easily interpretable methods of considering multiple factors, including equity, in policy and programming.

4 | AN OVERVIEW OF THE 2023 CANADIAN RED CROSS SoVI

Building on the work of Chakraborty et al. (2020, 2021, & 2022), P4A developed a new SoVI for the Canadian Red Cross that can be combined with hazard data for comprehensive risk assessments that take social, built, cultural, economic, and hazard-related factors into account. The SoVI index that P4A constructed for this project is methodologically similar to what Chakraborty et al. (2020) developed, but with fewer variables based on the accessibility of publicly available datasets. The 2023 Canadian Red Cross SoVI is methodologically sound and statistically robust; it involves verifying and testing assumptions of principal component analysis (PCA) *before* running the PCA in addition to post-validating the PCA-based results for enhanced accuracy. As these analyses are commonly missing in the literature, this report provides guidance on performing robustness tests.

P4A aimed to access the 49 variables identified in the 2020 SoVI at the dissemination area (DA) level; however, only 27 publicly available variables successfully passed testing for their inclusion in the SoVI. Even with the reduced number of variables, the 2023 Canadian Red Cross SoVI still incorporates variables consistent with the social vulnerability literature.

The 2023 Canadian Red Cross SoVI was calculated using a weighted combination of principal components. This data-driven method derives the statistical properties of sample data—with greater weight placed on variables that contribute more toward the total variance in the dataset. Allocating weights to variables based on their relative proportion is a statistically sound and empirically robust method, minimizing subjective bias in the index calculation process.

What follows is a description of this SoVI in terms of its variables and components, the rationale for selecting those variables, and the process for constructing the SoVI and mapping resultant scores. Figure 1 outlines the three main stages of creating the 2023 Canadian Red Cross SoVI: 1) data collection and preparation, 2) analysis and computation, and 3) geospatial dissemination. In the next section, a description of each stage is provided, while a step-by-step technical breakdown is outlined in Appendix B. Please refer to publications by Chakraborty et al. (2020, 2021, & 2022) in Appendix C for the detailed methodology for constructing a SoVI and applying a geospatial flood risk analysis.

STAGE 1
Data collection and preparation

Step 1.1
Determine the purpose of creating the index

Step 1.2
Select literature-consistent SoVI variables from national Census

Step 1.3
Choose a data source and download the data

Step 1.4
Transform input variables

Step 1.5
Verify for data accuracy

1/ **Replace** missing data with median values
2/ **Review** descriptive statistics
3/ **Verify** population count (min. and max.)

Step 1.6
Normalize all variables through normalization method (e.g., Z-score)

STAGE 2
Analysis and Computation

Step 2.1
Perform principal component analysis and index creation

Step 2.2
Reduce the dimensionality of the variables

Step 2.3
Obtain the components

Step 2.4
Weight and aggregate the components

STAGE 3
Geospatial distribution and dissemination

Step 3.1
Scale SoVI scores on a scale of 1 *(least vulnerable)* to 100 *(most vulnerable)*

Step 3.2
Classify final SoVI scores with standard deviation classification scheme for vulnerability mapping and geospatial representation

Step 3.3
Visualization and mapping of SoVI scores with graduated colour symbology using a geographical information system (GIS)-based software

Figure 1: Steps for constructing the 2023 Canadian Red Cross SoVI (adapted from Chakraborty et al., 2020)

5 | A GUIDE FOR HOW TO CONSTRUCT THE 2023 CANADIAN RED CROSS SoVI

Stage 1: Data collection and preparation

Publicly available data for 27 socio-economic variables were collected from the Statistics Canada 2016 Census database. This subset of variables, derived from Chakraborty et al. (2020)'s original 49 variables for the 2020 SoVI, was chosen due to the following reasons: a) all 49 variables were not publicly accessible; b) some errors were encountered while working with specific datasets (which could not be resolved because the sample information was not publicly available); and, c) some datasets were unavailable at the DA level, the spatial level of interest in this research.

The 2020 SoVI employed data from one of Statistics Canada's Research Data Centres (RDCs); however, most people are unable to access RDC data due to strict confidentiality and privacy measures that include a rigorous application process and security clearance. Further, RDC-based census microdata do not allow for vetted output at the DA level, which was used as a scale of analysis in this research for Canadian Red Cross.

Census data were instead obtained from the Canadian Census Analyser Data Centre (CHASS), a publicly available data source where DA-level data can be downloaded. These data met the analytical requirements at the DA level, and the variables selected represent socio-economic and demographic conditions of vulnerability (e.g., cultural, economic, and built environment characteristics) within DAs across Canada.

Appendix D provides a complete list of the chosen variables and rationales for their inclusion, while Table 2 compares three different approaches for constructing a SoVI based on data accessibility, variable selection criteria, and chosen scale of analysis.

After selecting and collecting the required socio-economic data, values of each variable were calculated by following a number of steps such as normalizing the data, verifying the reliability of the data, and removing the missing values and/or replacing them with the average values. Once those steps were completed and the pre-processed data were prepared, the variables' values were used in the calculation stage of SoVI construction.

2020 SoVI developed by Chakraborty et al.	2023 Canadian Red Cross SoVI developed by Partners for Action	An alternative option for future SoVI construction
Data were obtained through Statistics Canada's Research Data Centre (RDC), which includes data that is not publicly accessible and requires security clearance.	Data were obtained through the Canadian Census Analyser (CHASS) Data Centre, which is restricted to CHASS subscribers, such as the University of Waterloo.	Publicly accessible data can be obtained through Statistics Canada's Census Program Data Viewer. See instructions below.
The composite index includes 49 variables. All RDC variables are reported with a 100% estimated population from the census.	The composite index includes a final subset of 27 publicly available variables, as derived from the initial 49 variable set selected by Chakraborty et al. (2020).	Variable selection for a composite index depends on the project purpose, data accessibility, geographical scale, and the objective of the index.
The SoVI analysis was completed at the national scale, providing comparisons of the relative vulnerability scores across census tracts, census metropolitan areas, and provinces.	The SoVI analysis was completed at the dissemination area scale, providing the relative vulnerability of dissemination areas within a specified geographic region (e.g., within the City of Richmond).	The SoVI analysis can be completed for the desired geographic scale (e.g., municipal), given that the collected data is consistent with this scale.

Table 2: Alternative approaches for constructing a social vulnerability index (SoVI)

How to access the Canadian Program Data Viewer:

Step 1: Select "Census Year" (2016 or 2021)

Step 2: Select "Dissemination Area" under Other Geographic Level

Step 3: Select a topic
For example: Housing

Step 4: Select a variable
For example: Home ownership rate (%)

Step 5: Set the focus of the analysis
For example: Richmond, CY [CSD] (B.C.)

Step 6: Click on set as the focus of analysis.
In this case, a map would be generated for Richmond CSD with graduated colour schemes for the selected variable "Dissemination Area-Homeownership rate (%)"

Step 7: Under the Data Tables tab, click on the three dots adjacent to the Dissemination Area column and then export to CSV to download the relevant dataset.

Following the same procedure, all available census variables can be downloaded as a CSV file for the selected regions of interest.

Link to Census Program Data Viewer:
www12.statcan.gc.ca/census-recensement/2021/dp-pd/dv-vd/cpdv-vdpr/index-eng.cfm

Stage 2: Analysis and computation

Principal component analysis (PCA) is a prominent method for reducing the correlation of variables by forming components (or factors). Each component consists of multiple variables that demonstrate a similar statistical behavior based primarily on the inter-correlations among variables. Generally speaking, highly correlated variables will be in the same groups. For example, if the variables of "Income" and "Income after tax" are used as inputs, the two variables will become one component since PCA recognizes them as highly correlated (Schmidtlein et al., 2008). A high correlation between these two variables means that their amount varies similarly; in other words, geospatial units with high values of "Income" also have high values of the "Income after tax" variable.

Various statistical methods and criteria can be used to select the main components of the analysis. Two highly used methods are **1) the Kaiser criterion** (Kaiser, 1958) and **2) the percentage of variance explained**. Only components with eigenvalues higher than a value of 1.0 should be selected when using the former method. In the latter, a threshold of variation in the original dataset is chosen, equaling 80% in most cases. More information about these methods can be found in Bro & Smilde (2014), Ferré (1995), Kaiser (1958), Ringnér (2008), and Wold et al. (1987).

Once the components have been selected, different weighting and aggregation methods can be used to combine the components and produce the final SoVI scores. One approach is to add all selected components together, assuming that they have equal weights; however, a more reliable method is to assign weights to components based on the variance that they show and then aggregate those components (Chakraborty et al., 2022; Schmidtlein et al., 2008). The P4A team used the second approach to combine the components and estimate the SoVI index for the 2023 Canadian Red Cross SoVI.

Stage 3: Geospatial distribution and dissemination

After the SoVIs have been calculated for all geographical units, the next step is to assign these units to different classes of vulnerability—low, moderate/medium, or high—and represent these data on a map. Developing a classification scheme of SoVI scores is critical for the geospatial representation of vulnerability. There are several methodological approaches for classifying SoVI scores, including manual, equal interval, quantile, Jenks natural breaks, k-means cluster, and standard deviation. **Standard deviation classification** was used for this research, as this method aligns with existing literature and leverages the normal distribution of SoVI scores in the classification process. In this method, the algorithm clusters DAs based on the distance of each SoVI value from the mean value of SoVI among all DAs and the standard deviation of the entire country's SoVI database.

More information about standard deviation and other available data classification approaches can be found at: **pro.arcgis.com/en/pro-app/latest/help/mapping/layer-properties/data-classification-methods.htm**.

CONSTRUCTION OF THE 2023 CANADIAN RED CROSS SoVI

The P4A team calculated SoVI scores for six communities of interest to Canadian Red Cross for this research:

(1) Richmond, British Columbia
(2) Thompson, Manitoba
(3) Ottawa-Renfrew, Ontario
(4) Moose Factory, Ontario
(5) Ottawa-Gatineau, Ontario
(6) Bay St. George, Newfoundland and Labrador

P4A researchers accessed DA data from the CHASS hosted by the University of Toronto's Faculty of Arts and Sciences. Access to the CHASS census database servers is restricted to registered subscribers, including the University of Waterloo. Without this arrangement, data would have been limited to the census tract level. Instead, the analysis focused on DAs, a geographical scale commonly used by Statistics Canada to describe neighbourhood-level information. The final index was then categorized into three classifications of social vulnerability (low, moderate, and high) for the six communities of interest and analysed at the DA level. Static and dynamic (web-based, interactive) maps were then produced to visualize the SoVI scores for the communities of interest. **Figure 2** depicts visualizations of relative social vulnerability for the six study areas across Canada. Please refer to **Appendix E** for a technical guide on how the web-based maps were produced. **Appendix F** provides a visual representation of Statistics Canada's hierarchy of standard geographic areas for the 2016 census.

USES

- A SoVI can identify areas of relative social vulnerability to natural hazards and disasters within a geographic boundary (e.g., a community) based on census data that reflect socio-economic, demographic, cultural, and built environment characteristics (Chakraborty et al., 2021).
- When analysing and communicating results, it is essential to note that a SoVI is a relative measurement of social vulnerability, meaning that *results show low, moderate and high vulnerability in relation to other areas within a given geographical boundary.*
- A SoVI combined with a hazard analysis can facilitate equity-informed regional environmental risk assessment and planning (Chakraborty et al., 2020).
- As a disaster risk reduction support tool, a SoVI can enable decision-makers and planners to allocate resources and build capacity based on equity principles (Wood et al., 2021).

LIMITATIONS

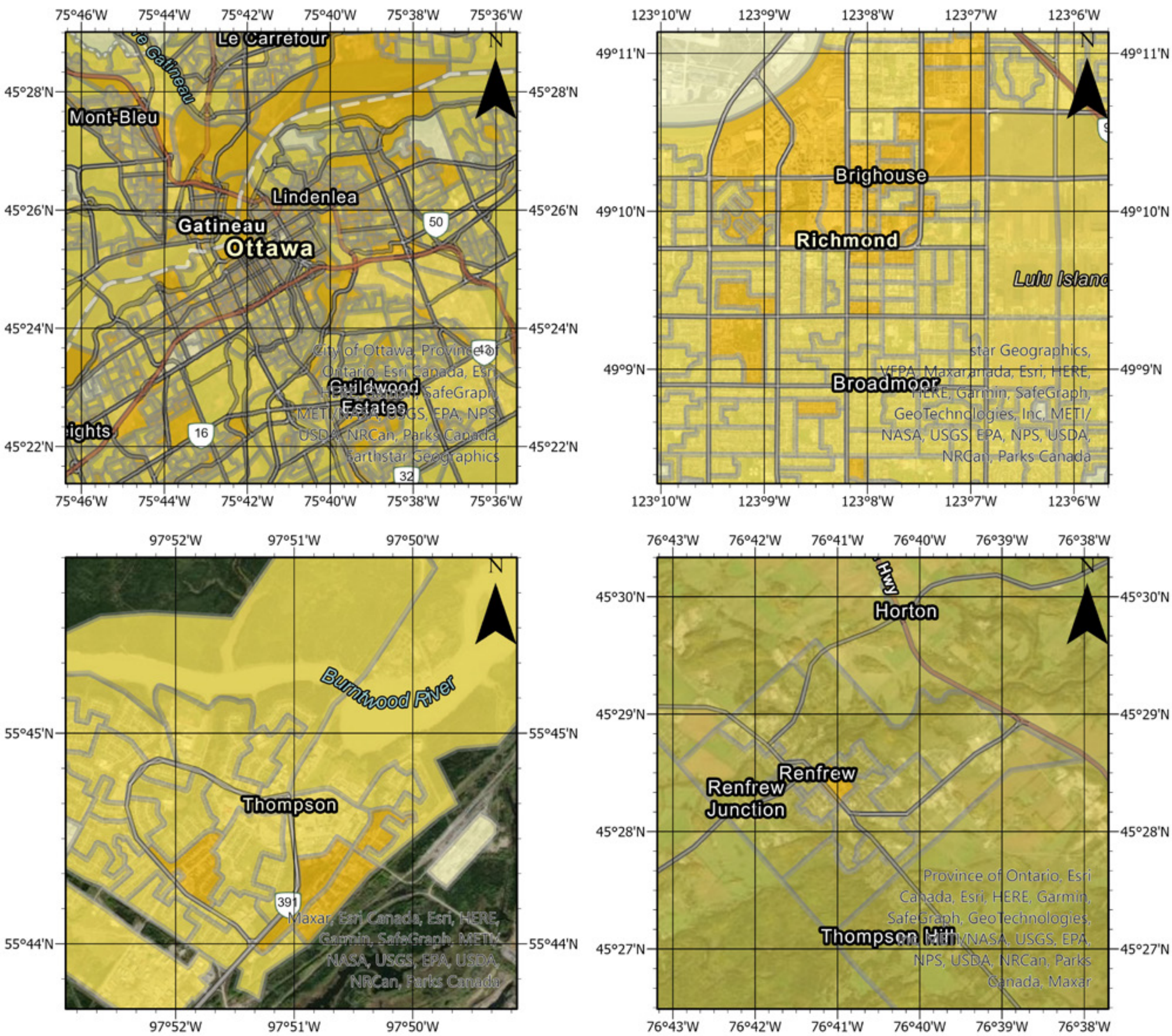
- It is important to note that when the geographic boundary of the SoVI analysis changes, so do the results, as SoVI scores indicate *relative* social vulnerability within a given boundary.
- Some national census data used in the 2020 SoVI were not publicly available for the communities of interest for this research at the DA level; instead, the 2023 Canadian Red Cross SoVI is based on 27 publicly- available variables that are methodologically sound and consistent with the literature (*see Section 5, Stage 1*).
- Not all aspects that contribute to social vulnerability are captured by a SoVI based on census data. Community-based and qualitative methods would provide nuanced and context-specific insights. For example, past experiences of hazard events and disasters affect people's ability to prepare for, cope with, and recover from a disaster, but these data are not captured in a SoVI. Other variables not generally included in SoVIs include the percentage of the population living with physical and mental disabilities, distance to medical services, rehabilitation centres per resident, number of exit routes per 1,000 inhabitants, risk perception, prior experience, knowledge of flood protection measures, risk denial/acceptance, and trust in officials (Fatemi et al., 2017).

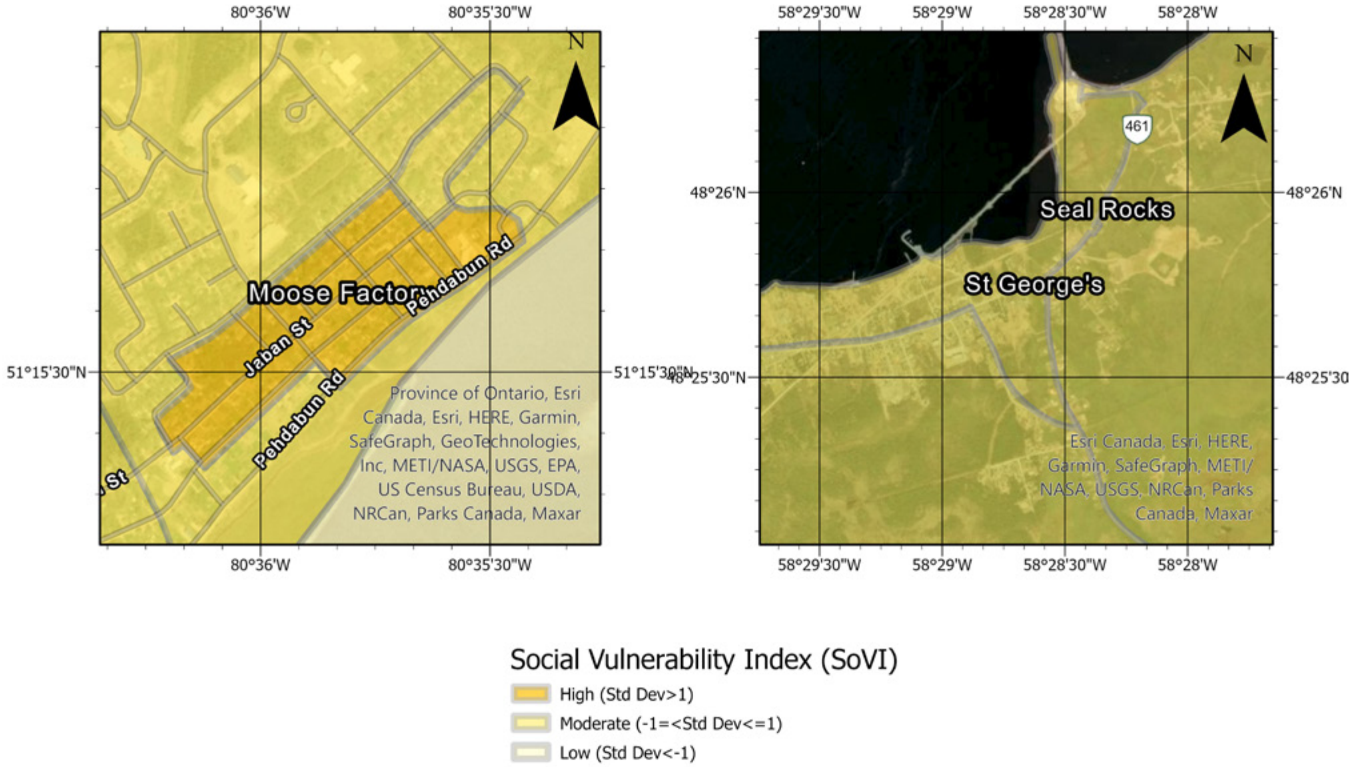
- Some variables are based on a 25% sample, because roughly 25% of Canadian households are chosen to participate in the long-form questionnaire survey, while the rest receive a short-form questionnaire. Given that some variables used in the SoVI are drawn from long-form questionnaire responses, there are uncertainties in scaling these data to the entire population of Canada. For more detailed information on Statistics Canada's data sources, methodology, and data accuracy, please refer to Statistics Canada (2020).
- The 2023 Canadian Red Cross SoVI was based on 2016 census data, which is the dataset available at the time the analysis was completed. An update of the analysis and maps using the 2021 census would be beneficial for decision-making, and an opportunity for a spatial-temporal analysis by comparing the 2016 and 2021 results. However, as of the writing of this report, some data are still not publicly available (e.g., what the 2016 Census termed, "Aboriginal population"[1] and what the 2021 Census refers to as "Indigenous population"), meaning that an analysis using 2021 data would be incomplete.
- Census data are gathered to reflect population statistics at a specific time. The five-year gap between census periods represents another source of uncertainty and limitation. Demographic characteristics have been evolving rapidly in recent years due to population movements associated with the Covid-19 pandemic, gentrification, and catastrophic hazard events. Therefore, it is important to assume that while SoVI scores given an indication of relative social vulnerability within an area, the results may not reflect the current reality. One way to address this limitation is to engage local experts and stakeholders in examining and providing feedback that can be incorporated into the maps (*see Section 3's mention of community-engaged approaches and ground truthing, and Recommendation 3*).

[1] *The terminology used by Statistics Canada was updated from 'Aboriginal population' to 'Indigenous population' for the 2021 Census. As this work used 2016 Census data, we reference the names of the variables used in that year's Census.*

Maps visualizing the 2023 Canadian Red Cross SoVI for six Canadian communities

Figure 2: Visualizations of relative social vulnerability using the 2023 Canadian Red Cross SoVI for six communities in Canada




80°36'W
80°35'30"W
Moose Factory
Jaban St
Pehdabun Rd
51°15'30"N
Province of Ontario, Esri Canada, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, US Census Bureau, USDA, NRCan, Parks Canada, Maxar
58°29'30"W
58°29'W
58°28'30"W
58°28'W
48°26'N
48°25'30"N
461
Seal Rocks
St George's
Esri Canada, Esri, HERE, Garmin, SafeGraph, METI/NASA, USGS, NRCan, Parks Canada, Maxar
Social Vulnerability Index (SoVI)
High (Std Dev>1)
Moderate (-1=<Std Dev<=1)
Low (Std Dev<-1)

6 | AREA-BASED FLOOD EXPOSURE ANALYSIS

Rationale and overview

Often, flood exposure and risk are used interchangeably, whereas a risk analysis combines hazard and vulnerability. Repeated hazard exposure can further exacerbate existing socio-economic vulnerabilities and create new vulnerabilities for affected residents. Therefore, combining these two spatial layers can aid decision-makers in identifying areas that need further recovery support and in determining how to equitably distribute funding and other resources.

In addition to developing a nationwide SoVI, Chakraborty et al. (2022) addressed the lack of a comprehensive flood risk assessment for Canada with a methodology that integrates SoVI and flood exposure data. They combined the nationwide SoVI with national flood data licensed from JBA Risk Management. This work has been foundational within the Canadian context in demonstrating the need to incorporate a social vulnerability analysis into hazard risk assessments rather than treating SoVI as an isolated decision-support tool.

For this research, three categories of flood-prone areas were analysed: fluvial, pluvial, and coastal flooding.

- Fluvial floods (riverine or river flooding) refer to conditions when a water body, such as a river, stream, or lake, overflows onto the adjacent lands (Sandink et al., 2016). Fluvial flooding happens primarily because of heavy rainfall, snowmelt, and ice-jamming.
- Pluvial floods occur when extreme rainfall exceeds the capacity of the urban drainage system, resulting in a surface water flood or flash flooding (Rözer et al., 2016).
- Coastal flooding refers to the inundation of land by seawater due to sea-level rise and storm surges, among other factors (Hinkel et al., 2014).

JBA Risk Management's Flood Dataset was obtained through a data sharing agreement with the University of Waterloo for floods with a yearly probability of occurrence of 0.01, commonly known as a 1-in-100-year flood event. This occurrence rate is an accepted regulatory standard for most of Canada as the minimum design flood event (NRCan & Public Safety Canada, 2019; Public Safety Canada, 2022). Flood exposure data were drawn from JBA's **Fluvial-Undefended** database, which assumes no flood defenses (e.g., berms, ditches, armouring). This is the typical approach the insurance industry uses when assessing flood risk, which is justified based on the assumption that catastrophic flooding will overwhelm existing defenses.

What follows is the methodology for producing a flood exposure analysis, followed by Section 7 that outlines how to combine it with a SoVI analysis to determine flood risk.

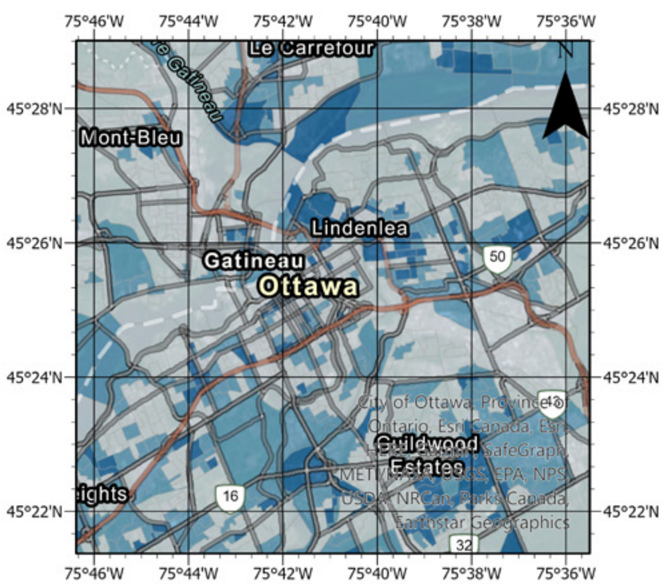
Geospatial analysis of flood exposure

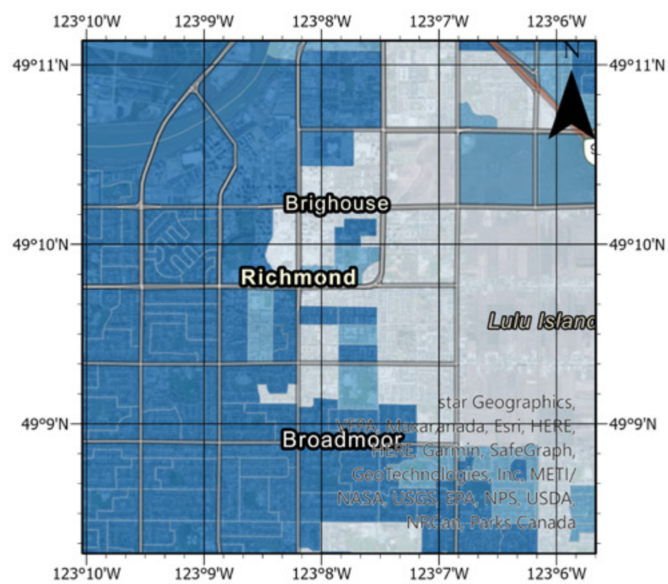
Once the flood-prone areas within the communities of interest were determined, an analysis of **physical exposure** was carried out. **Figure 3** presents visualizations of the flood exposure analysis for these six Canadian communities.

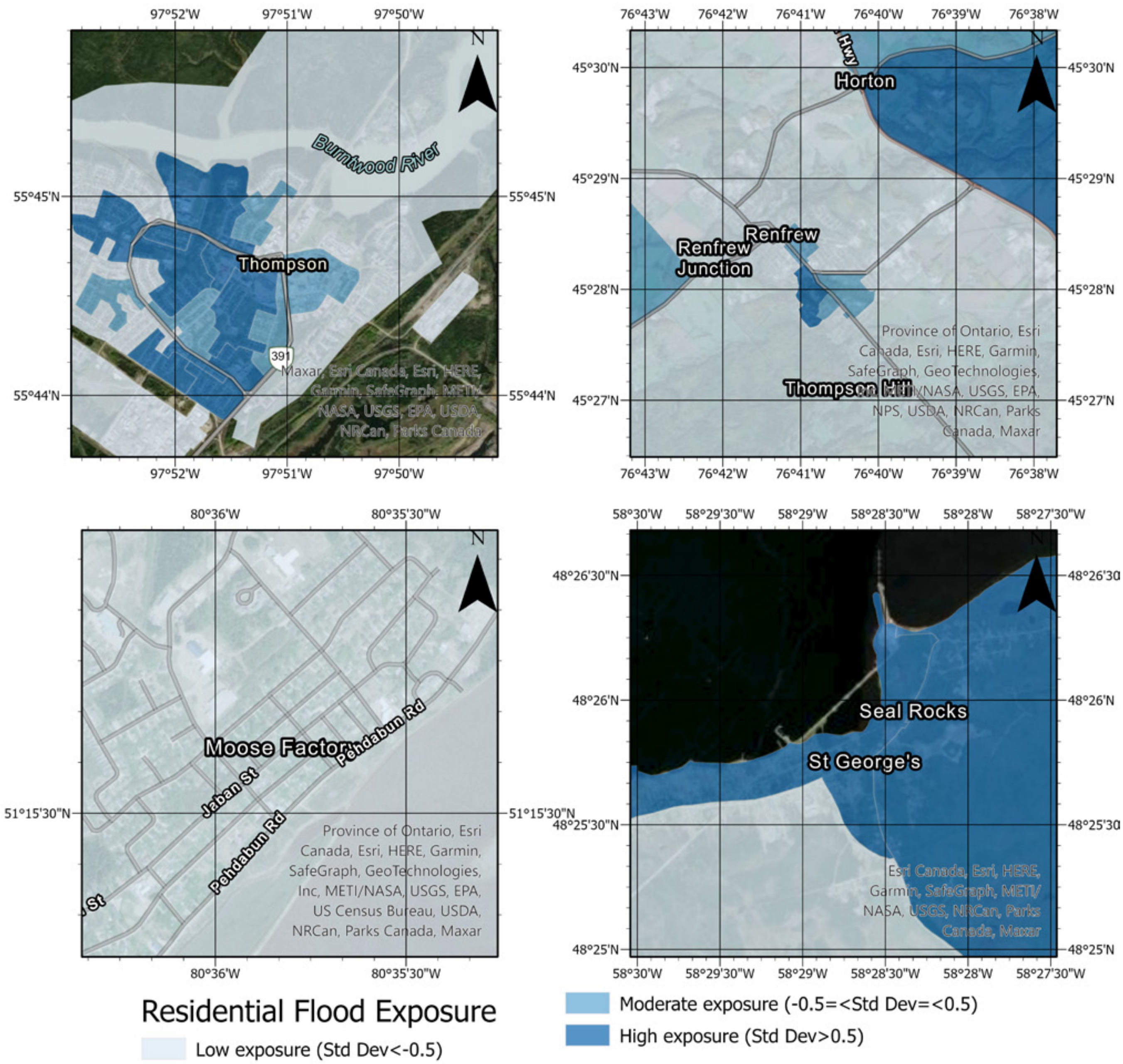
Physical exposure refers to the people and assets (e.g., private dwellings and critical infrastructure) affected by hazardous events (**UNDP, 2015**; **IPCC, 2022**). The predominant approach in the flood risk analysis literature regarding exposure was applied, where population and residential properties at risk of flooding are counted (**Chakraborty et al., 2021** & **2022**; **Qiang, 2019**). More detailed information about this approach is available in Chakraborty et al. (**2021** & **2022**).

Flood Exposure Maps for Six Canadian Communities

Figure 3: Visualizations of flood exposure using JBA data for six communities in Canada







USES

- Information about the exposure of specific elements (e.g., residential properties) to flood hazards is one part of a risk analysis to help plan and prioritize flood risk mitigation strategies.
- A flood exposure layer can provide insights for emergency management planning, which can include early flood warning systems and evacuation strategies.

- The flood data used in this analysis were sourced from JBA Risk Management, the only available flood layer at the national scale in Canada. In addition to this flood layer, it would be beneficial to incorporate regional high-resolution flood modelling (Chakraborty et al., 2021).
- This analysis was based on flood extent information from JBA. Flood intensity and depth data are also available; this information would be beneficial when analysing the likelihood of infrastructure and property damage due to flooding events (Chakraborty et al., 2021).
- JBA's data accounts for water levels in the larger gauged lakes, but not in some of the smaller ungauged water bodies. Collecting these data through community surveys would improve the analysis (Chakraborty et al., 2021).
- Based on historical data, the flood data do not account for real-time events or climate projections. Climate change alters hydrological patterns, bringing a level of uncertainty to flood projections. Several studies use downscaled (regional) climate models to investigate the effects of various climate change scenarios on flood frequency and intensity (Arnell & Lloyd-Hughes, 2014; Gaur et al., 2018; Reguero et al., 2015; Ukumo et al., 2022). In the past year, flood modelling companies like JBA have begun to produce and provide high-resolution climate change flood data at a national scale. This type of data is suitable for municipal decision-making and should be considered in ongoing studies. Without such data and models, one might apply precautionary principles and consider using more conservative historical flood data, such as data with a return period of 200 or 500 years, rather than 100 years.
- The data and analysis do not account for concurrent or compounded/interconnected hazards, or consider the impact of large-scale infrastructure projects. For example, flood exposure and propensity might change significantly after climate events like wildfires, landslides, and heat waves. Additionally, implementing grey or green infrastructure (e.g., berms, dikes) designed for flood mitigation should reduce flood exposure. One way to address these limitations is to apply an integrated multi-hazard risk assessment that considers the potential interactions of hazards of concern and their cascading effects. This involves assessing the likelihood and consequences of multiple hazards co-occurring or in close succession. Review the following resources to incorporate cascading hazards into a flood exposure analysis: Gill & Malamud, 2016; AghaKouchak et al. 2018 & 2020.

7 | FLOOD RISK MAPS: USING A SPATIAL OVERLAY METHOD

Web-based flood risk maps were created to visualize the spatial associations between SoVI scores and flood exposure in the communities of interest. The aim was to produce an intuitive and user-friendly tool for interpreting where and how flood exposure and social vulnerability intersect to indicate risk.

Figure 4 outlines the simple steps followed for the flood exposure analysis (Steps 1 and 2) and flood risk analysis (Step 3) to produce the web-based maps for this research (see Table 3 for the links).

Step 1:	Step 2:	Step 3:
Find the population and total residential properties in each dissemination block	Aggregate the counts from Step 1 into the dissemination area	Spatially combine the previous layer (social vulnerability) with the flood exposure

Figure 4: Simple steps for completing a geospatial analysis of flood exposure and flood risk

After carrying out the flood exposure analysis, flood exposure scores were classified into three groups (high, moderate, or low), just as SoVI scores were. Aggregation layers were then created, overlaying the SoVI and flood exposure layers to produce choropleth maps. Each aggregation layer includes a maximum of nine categories, derived from combining three SoVI classes (high, moderate, low) and three flood exposure classes (high, moderate, low). Each combined classification was then assigned a colour, with lighter colours representing lower risk and darker colours representing higher risk, shown in Figure 5. For example, if a DA is classified as having high SoVI and moderate flood exposure, the area would fall into the high SoVI-moderate flood exposure risk class.

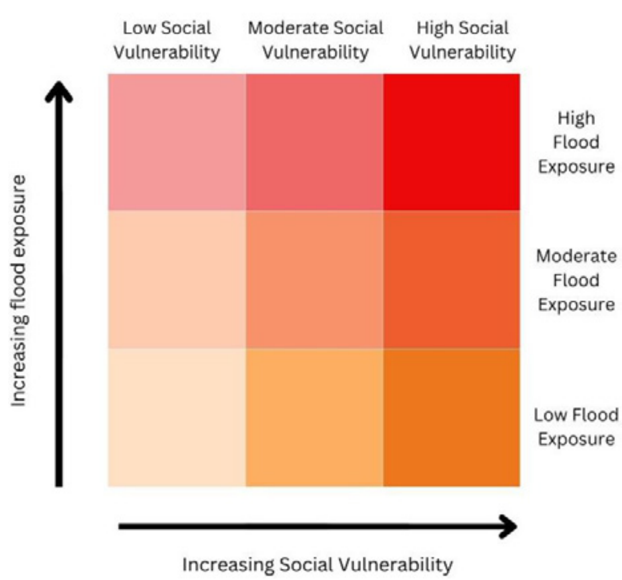


Figure 5: Legend of flood risk classifications

Table 3: Web-based maps of the 2023 Canadian Red Cross SoVI, flood exposure, and an overlay of the two to visualize flood risk

Location	URL Link
Richmond, BC	arcg.is/nz1Gy
Thompson, MB	arcg.is/1TqTzm0
Moose Factory, ON	arcg.is/0yy8Wi
Ottawa-Gatineau, ON	arcg.is/0DOnbH
Ottawa-Renfrew, ON	arcg.is/1DGHvD1
Bay St. George, Nfld and Labrador	arcg.is/0e1Cja0

The web-based maps in Table 3 allow users to view layers of analysis on the ESRI basemap of their choice. The maps were designed to be viewed by selecting the following layers individually:

- SoVI scores (relative social vulnerability)
- Flood exposure results
- Relative flood risk: an aggregated overlay layer of SoVI and flood exposure results

Selecting several layers to view does not provide useful information. When the SoVI and flood exposure layers overlap, the colours do not reflect relative risk, but are instead the result of colours on top of one another.

USES

- Areas of risk can be shown by overlaying the SoVI and hazard exposure layers.
- Bivariate choropleth maps allow people to explore the relationship between two variables in the same location (Meyer et al., 1975).
- The overlay maps facilitate identifying spatial patterns and differences within a region, especially when comparing the risk layer with the individual SoVI and flood exposure layers.
- This overlay method is useful for visualizing data that has been aggregated by administrative boundaries, such as dissemination areas.

- The colour palette matrix generated by the crossed variables can be difficult to interpret for some, especially those with different types of colour blindness, as it can be confusing for the map reader to distinguish the colours and their classification in the legend (Fienberg, 1979).
- There is no one standard colour palette that corresponds to the variables.
- Different colour palettes can skew a user's understanding of the variables and their relationships.

Guidance on reproducing social vulnerability and hazard assessments

To be able to reproduce the methods and maps outlined in this report, there are a few critical components and competencies that are needed.

(1) Purchase an ArcGIS license for the desired length of time that you want to be able to access the maps created.

(2) The technical team should have skills in data scraping, coding (R, Python), GIS, web-based GIS, data visualizations, and conducting statistical analyses.

(3) A workstation or a server with a minimum RAM of 64 GB is recommended to handle the substantial data processing tasks required (e.g., for flood exposure analysis).

(4) The following datasets form the foundation of any further assessment of socio-economic vulnerability. Hiring someone with expertise on statistics or econometrics should be sufficient for following the methodology.

   - **Flood hazard data** can be acquired through flood modelling companies, such as JBA Risk Management, KatRisk, or Aon Impact. These datasets are proprietary and can be purchased through a license. Additional hazard data is publicly available in some circumstances (e.g., Conservation Authorities, watershed agencies), but rarely at the national level. The exception is a recently released Flood Susceptibility Index produced by National Resources Canada.
   - **Exposure data** (i.e., building footprint) is publicly available through Microsoft Open Streets Data, and can also be acquired via licence through DMTI or Opta.
   - **Socio-economic data** was obtained through the Canadian Census Analyser Data Centre, which is restricted to CHASS subscribers (e.g., University of Waterloo); however, publicly accessible data can be obtained through Statistics Canada's Census Program Data Viewer. These data are used to populate a range of variables identified in existing literature as useful in illustrating socio-economic vulnerability.

8 | RECOMMENDATIONS FOR THE USE OF A SoVI

(1) **Risk visualizations should be validated through "ground-truthing" involving stakeholder engagement with local constituencies in high-risk areas.**

- The visualizations developed here need validation with local knowledge to address limitations involved in taking a top-down approach using national databases. For example, some communities are likely to be less vulnerable if they have already experienced a hazard and implemented preparedness programs, or if they have recently invested in defensive infrastructure (green and/or grey) that has reduced exposure.

(2) **Compare results using multiple data sources and methodological choices to improve the reliability of the SoVI.**

- Incorporating different methodological choices (e.g., different sets of variables, aggregation methods, and classification approaches) when constructing the SoVI and considering the measurement errors of the input variables (e.g., uncertainty associated with some of the Statistics Canada data) will improve the reliability of the index.
- Statistics Canada provides a comprehensive national dataset for assessing vulnerability, but there remains an opportunity to validate and compare findings with other datasets that have higher levels of local granularity. For instance, data on poverty rates are collected at the provincial level and available at the census metropolitan area scale; however, in a neighbourhood scale analysis, data at the granularity of the DA level would be required.
- Other variables can be included in a SoVI, such as data on prior experience with flooding, self-protective actions, trust in disaster forecasts, risk-taking behavior, social capital, and social networks. Understanding these aspects that influence vulnerability through bottom-up, community-based approaches (e.g., local surveys and community mapping exercises) and integrating them with top-down statistical analysis methods would increase the relevance and quality of a SoVI for decision-making.
- Social vulnerability is not static; it changes over time, and methods must reflect this. Although population characteristics and community capacities dynamically fluctuate over time, national census data are collected and released every five years, making it challenging to capture these nuances. As a result, some scholars are developing more predictive or probabilistic approaches that project how different pathways of social vulnerability might change over time.

(3) **Build relationships for Indigenous-led and/or co-designed assessments that use non-Census data sources and that adhere to OCAP principles.**

- Solely using census data to capture the characteristics of Indigenous Peoples is insufficient for conducting a social vulnerability analysis. Census tract data available at the DA level does not capture all Indigenous land reserves in Canada, so there is insufficient information to carry out an analysis of these populations' social vulnerability and flood risk.
- Overcoming these limitations takes long-term relationship and trust-building through in-depth community engagement. Through such engagement, alternate data sources and Indigenous methodologies for assessing social vulnerability can be identified, ensuring adherence to OCAP Principles (Ownership, Control, Access, and Possession, as per the First Nations Information Governance Data Centre).
- Engagement could include location-specific variable selection and weighting with Indigenous partners to construct a locally meaningful index (see the last paragraph in the 'Foundational SoVI research in the Canadian context' section).

(4) **Incorporate Indigenous perspectives of spatial boundaries.**

- The maps produced in this research are based on colonial, political boundaries that do not reflect the traditional territories of First Nations, which encompass broad ranges that often overlap with the territories of other nations.
- One source of territorial information is Native Land Digital (native-Land.ca), which, ideally should be cross-checked by First Nations, Métis and Inuit experts in the communities of interest before using.
- There are a total of 988 Indigenous Reserves based on the 2016 census subdivision (CSD) boundary file, with six types of CSD boundaries representing Indigenous Reserve communities. The following CSD types are based on the *legal definitions*[2] of communities affiliated with First Nations or Indian bands: Indian reserve (IRI), Indian settlement (S-É), Indian government district (IGD), Terres réservées aux Cris (TC), Terres réservées aux Naskapis (TK), and Nisga'a land (NL). Detailed information about on-reserve Indigenous populations and the data for SoVI and flood risk analysis across Indigenous communities can be found in Chakraborty et al. (2021).

(5) **Explore how SoVI can be used to assess risk in relation to other hazards**

- Other hazard data, including on earthquakes, extreme heat, and wildfires, can also be combined with SoVI with an aggregated layer for visualizing risk as was produced here. The caveat is that hazard exposure data must be available at the same geographical scale as the SoVI analysis.

[2] *The use of the word 'Indian' is outdated and is only used here to refer to legal definitions, which all stem from the colonial Indian Act. Some communities have changed their name from Indian band to First Nation, but some still carry the name.*

9 | AREAS OF FUTURE RESEARCH

(1) **Additional efforts are required to make the maps more user-friendly to improve user experience and facilitate interpretation.** Careful refinement of the map legend and explanations of elements would improve understanding, provide necessary disclaimers, and ensure visual clarity and functionality for diverse user groups (including those with various forms of colour-blindness) and for different use cases.

(2) **Further research is needed to determine how social vulnerability variables vary among hazard types.** The literature review for this research revealed that certain socio-economic characteristics, such as mobility and income, are consistent drivers of vulnerability to hazards beyond flooding. Since each hazard calls for specific preparedness, mitigation, response, or recovery measures based on their distinct nature and outcomes, further research is needed on how vulnerability differs by hazard and what variables reflect those differences.

(3) **Adding social vulnerability to risk analyses has significant policy implications that could be explored through further research.** Much of the existing research on risk that informs policy combines only hazard and exposure data, which misses the real impacts on people. Research can build on the work done here to explore how risk assessments and maps that incorporate social vulnerability can be used to shape policy and prioritize resources (e.g., recovery funding, disaster mitigation investments) with equity goals in mind, and how those policies relate to intended outcomes for disproportionately impacted people.

APPENDIX A: GLOSSARY OF TERMS

Areas of Risk:

Geographical areas where hazard exposure (e.g., flood) and social vulnerability converge. The methodology for flood risk used here focuses on exposure and social vulnerability to identify areas that might require further attention with respect to flood risk management and attention to socio-economic inequities.

Colonization:

Defined by the University of Waterloo* as "the action or process of settling among and establishing control over the Indigenous People of an area; the action of appropriating a place or domain for one's own use."

* For more definitions from the University of Waterloo President's Anti-Racism Task Force, please see **uwaterloo.ca/presidents-anti-racism-taskforce/part-report/glossary-terms**

Disaster:

Defined by Public Safety Canada (**2017**) as, "a social phenomenon that results when a hazard intersects with a vulnerable community in a way that exceeds or overwhelms the community's ability to cope and may cause serious harm to the safety, health, welfare, property, or environment of people."

It is not the environmental event itself that leads to a disaster, but the human actions and decisions that increase damage, loss, and suffering; therefore, the term 'natural disaster' is a misnomer (see **www.nonaturaldisasters.com**).

Discrimination:

Defined by the University of Waterloo as, "the unjust or prejudicial treatment of different categories of people, especially on the ground of race, ethnicity, age, sex, or disability."

Disproportionately impacted people:

Individuals or groups that are impacted more than others by hazards or shock events, such as a disaster. This disparity is often a result of structural disadvantages (e.g., discriminatory policies) and/or systemic barriers in a society. In the context of disaster risk reduction, this may include equity-deserving groups and other marginalized/vulnerable populations.

It is important to recognize that these populations are disproportionately impacted not because they are inherently vulnerable or lack resilience capabilities, but because of the systems and structures in place that prevent equitable access to risk preparedness, response, and recovery resources, or that lead to the exclusion of these populations from decision-making processes that affect them.

Equity:

Defined by the University of Waterloo as, "fairness and justice and is distinguished from equality, which means providing the same to all, whereas equity means recognizing that we do not all start from the same place and must acknowledge and adjust to imbalances. The process is ongoing, requiring us to identify and overcome intentional and unintentional barriers arising from bias or systemic structures."

Equitable Access:

Defined by the University of Waterloo as, "enabling all individuals to access services and resources by removing barriers and ensuring that the diverse backgrounds and identities that individuals hold are integrated in the development and implementation processes."

Equity-deserving groups:

Defined by the University of Waterloo as, "communities that identify barriers to equal access, opportunities, and resources due to disadvantage and discrimination, and actively seek social justice and reparation."

Ground-truthing:

Testing or verifying the assumptions with community members and practitioners. In the context of developing and using a SoVI, this community engagement process helps to ensure that the SoVI reflects the lived experiences and situated realities of the community (**Oulahen et al., 2015a**).

Hazard:

Defined by Public Safety Canada (**2017**) as "a potentially damaging physical event, phenomenon, or human activity that may cause the loss of life or injury, property damage, social and economic disruption, or environmental degradation."

Hazard Extent:

In risk assessments, this refers to where an environmental phenomenon, such as floods or wildfires, are likely to occur (i.e., where flood water flows, where the fire spreads).

Inclusive Resilience:

Resilience is the ability to prepare for and recover from disasters. To take an inclusive approach, we must recognize that different groups of people need different emergency response measures. Inclusive resilience ensures all people have an opportunity to make meaningful contributions to decision-making, planning, and response efforts.

Intersectionality:

Defined by the University of Waterloo as, "the interconnected nature of social categorizations such as race, class, and gender as they apply to a given individual or group, regarded as creating overlapping and interdependent systems of discrimination or disadvantage."

Marginalized/Vulnerable:

Defined by the University of Waterloo as "a person or group treated as insignificant or peripheral that may require greater care, support, or protection due to their unique circumstances."

Natural Hazards:

A natural hazard refers to severe and extreme weather and climate events (e.g., flood, earthquake, wildfire) that have the potential to negatively impact humans and populated areas. In other words, they are environmental events that people consider hazardous to safety, health, property, and livelihoods.

The occurrence of an environmental phenomenon, such as earthquakes, is not in itself considered a hazard; it is only when there is a threat to human interests that an event is considered a hazard. Taking it a step further, when a natural hazard occurs and has a significant negative impact on lives, property and livelihoods due to human actions and decisions, that event is considered a disaster.

See also: **hazard**, **disaster**.

Physical Exposure:

Defined by the UNDP (**2015**) as the "number of people located in areas where hazardous events occur combined with the frequency of hazard events."

Power Constructs:

Defined by the University of Waterloo as the "policies, practices, hierarchies, and ideologies that have institutional and systemic influence and may disproportionately impact members of certain groups (e.g., based on race or gender)."

Resilience (personal, community, social):

An individual's or group's ability to cope with, adjust to, and recover from shocks and stresses, such as a natural hazard event.

Social Vulnerability:

The US Federal Emergency Management Agency (FEMA) defines this as, "the susceptibility of social groups to the adverse impacts of natural hazards, including disproportionate death, injury, loss, or disruption of livelihood." Essentially, it refers to socio-economic, and/or demographic characteristics that are associated with an individual, group, or community's susceptibility to natural hazards, and that are thought to increase the challenges they face in coping with disasters (**Cutter et al., 2003**; **Cutter, 1996**; **Wisner et al., 2004**) in a particular time and place.

Social Vulnerability Index (SoVI):

A SoVI provides a quantitative, spatial analysis of variables of socio-economic vulnerability to produce a relative score (e.g., low, moderate and high) based on standard deviations within a given geographic boundary. In other words, a SoVI score indicates how socially vulnerable people in one area are relative to another, based on how much each variable (e.g., from the Census) differs from the average within that geographical boundary.

A SoVI can be combined with other spatial datasets, like hazard maps, to add socio-economic characteristics to resilience and risk assessments, which are usually limited to a hazard extent (e.g., where flood water is likely to flow, where wildfires are likely to occur) and exposure (e.g., interaction of people and property with a hazard like flood or wildfire).

This can provide a statistically robust foundation for prioritizing public investment in hazard management policies and decisions. It can be used to support Gender-based Analysis Plus (GBA+) and evidence-based equity considerations in emergency management and disaster risk reduction.

See also: **physical exposure**, **hazard extent**

Structural Disadvantage:

Defined by the University of Waterloo as "the unfavourable circumstance or condition experienced by individuals, groups or communities that results from the way in which society operates." [Examples: how resources are distributed, who holds power and in what spaces, and how institutions are organized.]

Systemic Barriers:

Defined by the University of Waterloo as "policies, practices, or procedures that result in some people receiving unequal access or being excluded."

Systemic Racism:

Defined by the University of Waterloo as "discrimination or unequal treatment on the basis of membership in a particular ethnic group (typically one that has been historically underrepresented), arising from systems, structures or expectations that have become established within society of an institution."

Visible Minorities:

Defined by Statistics Canada (**2017b**) and the Employment Equity Act as, "persons, other than Aboriginal *(sic)* peoples[3], who are non-Caucasian in race or non-white in colour. The visible minority population in Canada consists mainly of the following groups: Arab, Black, Chinese, Filipino, Japanese, Korean, Latin American, South Asian, Southeast Asian, and West Asian." (para. 1)

***Note:** This term is used interchangeably with "People of Colour," and there are calls to use the term "Global Majority" instead (see www.thestar.com/opinion/contributors/2021/02/09/we-are-not-visible-minorities- we-are-the-global-majority.html). All these terms are trying to get at—but are inadequate in describing— people who are equity-denied, underserved or marginalized based on skin colour and cultural background.*

[3] *Since this source was published, the term 'Aboriginal peoples' has been replaced by 'Indigenous peoples' to refer to First Nations, Métis and Inuit peoples, with the exception of Canada's 1982 Constitution Act and some Statistics Canada references where the term is still used.*

APPENDIX B: STEPS FOR CONSTRUCTING THE 2023 P4A SoVI FOR CANADIAN RED CROSS

STAGE 1 Data collection and preparation

Step 1.1

Determine the purpose of creating the index
(in this case, an index of social vulnerability)

Determine the following:

- What question(s) does your organization want to be able to answer?
- Who will use and view the results?

Why is this important?

- To get a clear understanding and definition of the phenomenon your organization is evaluating
- To be aligned on why you are creating an index and map
- To be clear on how you will use it – and for which audience(s)

Step 1.2

Select literature-consistent indicators

Determine the following:

- What variables are consistently supported in the literature as indicators of social vulnerability?
  - Assess the relationship of each variable to the index.
    Ask yourself: does this variable increase or decrease the index score?

Why is this important?

- The impacts of each selected variable on the index are based on the definition of the index and the phenomenon that it tries to represent — and how each variable is included (see Step 1.3).
  - For example, if the purpose of the index is to capture “resiliency,” then higher values of a variable might lead to higher resiliency. In contrast, if the purpose of the index is to capture “vulnerability,” then the higher the score of the variable, the less vulnerable the people are.

Step 1.3

Determine how the indicators will be weighted

Determine the following:

- Are all variables equally important or is there a need to assign weights?
- What method will your organization use to weigh the variables?
  - P4A researchers used an objective weight determination method (standard deviation, principal component analysis (PCA)) to obtain variable weights through mathematical modeling.

Why is this important?

- The impacts of each selected variable on the index are based on the definition of the index and the phenomenon that it tries to represent — and how each variable is included (through weighting).
  - With PCA, variables that vary more from the mean will be weighted more. However, there are other methods you can use to determine how much influence each variable has on the final index score (e.g., a subjective method such as Pairwise Comparison Matrix (PCM)).

Step 1.4

Choose a data source and download the data

Determine the following:

- Assess what data are accessible for the variables chosen within the geographical region.
  - What geographical levels are the data available for?
  - Does your organization have access to the appropriate datasets to be able to include the variables of interest?

Why is this important?

- To ensure that all data are available at the same spatial resolution (e.g., census metropolitan area, census tract, or dissemination area)
- To ensure that variables are not being misrepresented due to missing data

Step 1.5

Transform the input variables

Determine the following:

- Does your organization need to transform the selected variables?
- If so, what transformation method(s) would work best for your organization?

Why is this important?

- Depending on the study and specific variable, one might decide to not transform the data and to use the absolute values instead, as some information might be lost in the transformation.

- ☐ For example, this could mean using the absolute population of older adults rather than the proportion of older adults to the total population.

  Note: P4A did transform the variables in constructing a SoVI for Canadian Red Cross (see below).

- ☐ It is important to be aware of the tradeoffs of the decision to use relative vs absolute values.

  For example, if you are using absolute values, the higher the number of elderly people in an area, the more that area may show up as socially vulnerable even if the percentage of elderly people relative to the total population is low.

- ☐ Depending on the research objective, using either absolute values or transformed data can be justified.

  A use case of using absolute values would be evacuation planning, when the number of people is important (Tate, 2013).

- If transforming the variables, there are two main options:

  (4) Population density: Dividing population-based and dwelling-based variables by the total population and the total number of dwellings.

  P4A researchers applied this first option since this approach aligns with the social vulnerability literature with respect to flood risk management.

  (5) Areal Density: The values of variables are divided by the total area. When this option is applied to a region's elderly population, the final variable is the "population of elderly per square kilometer (or other area units)" (Tate, 2013).

Step 1.6

Choose a data source and download the data

Sub-steps:

(1) Replace missing data

(2) Review descriptive statistics

(3) Verify population counts (minimum and maximum)

Determine the following:

- What are the spatial units for the variables that your organization is missing data for?
- Are there counterintuitive values for some of the variables?

Why is this important?

- Since the same SoVI methodology (with its characteristics, such as the number of variables) should be applied to all selected regions, it is essential to ensure that each spatial unit has values for all selected variables.
    - If a few variables are missing for a unit (negligible to the total number of variables), those empty cells can be replaced with the average of that variable among other units.
- Another essential task is to find the values of counterintuitive variables by looking at the data's descriptive statistics.
    - For example, if variables have been divided by the total population (in Step 1.4), there should be no values above 1. Having these logically infeasible values means there are errors within the data. This necessitates further investigation and reconsideration of selected variables, particularly if you find logically infeasible values for many spatial units.
- Other simple statistical checks should be performed on the maximum and minimum populations of spatial units.
    - For example, when using the dissemination areas (DA), the total population for each DA should fall within the range of 400 to 700 people, as defined by Statistics Canada.

Step 1.7
Normalize all variables

Why is this important?

- It is important to normalize all variables into a common dimensionless range to avoid the problems that might appear when deriving the factors for PCA.
- While there are numerous normalization methods, P4A researchers used the Z-score normalization method (subtract the mean, divide by standard deviation) because of its advantages in dealing with extreme values (**Tate, 2013**).

STAGE 2 Analysis and Computation

Principal Component Analysis (PCA) and Index Creation
Sub-steps:

(1) **Reduce** dimensionality of the variables

(2) **Weight** and aggregate the variables

Determine the following:

- Does your organization think that the selected variables are correlated?
    - For example, the variables 'median income' and 'percentage of people living under the poverty line' seem highly correlated.
- Which weighting approach to apply?

Why is this important?

- When multiple variables might be correlated, dimensionality reduction techniques can be useful in the following ways (Vyas & Kumaranayake, 2006):
    - Improve efficiency by reducing the number of variables or features needed to create an index. This can make the index easier to and interpret.
    - Reduce noise and redundancy in the data by identifying the most important variables or features that contribute to the index.
    - Improve generalization performance of the index by reducing the risk of overfitting. This can make the index more robust and reliable when applying it to new data.
- Among the methods available for reducing the dimensionality of the data, PCA has been widely used when working with many variables and combining them to build an index and was used by P4A.
    - Since there are nuances and methodological choices when using PCA, P4A recommends the resources provided below when considering this method.
- Factors determined by PCA (or another dimensionality reduction technique) as most important should be combined through weighting to produce a unique value to represent social vulnerability.
    - Weight-determining methods include equal, subjective (determined by experts), and objective or data-driven weighting.

ADDITIONAL RESOURCES:

Mazziotta, M., & Pareto, A. (2019). Use and misuse of PCA for measuring well-being. *Social Indicators Research 142* (2): 451– 476. doi.org/10.1007/s11205-018-1933-0

Tate, E. (2013). Uncertainty analysis for a social vulnerability index. *Annals of the Association of American Geographers 103 (3)*: 526–543. doi.org/10.1080/00045608.2012.700616

Reckien, D. (2018). What is in an index? Construction method, data metric, and weighting scheme determine the outcome of composite social vulnerability indices in New York City. *Regional Environmental Change 18* (5): 1439–1451. doi.org/10.1007/s10113-017-1273-7

Schmidtlein, M. C., Deutsch, R. C., Piegorsch, W. W., & Cutter, S. L. (2008). A sensitivity analysis of the social vulnerability index. *Risk Analysis 28* (4): 1099–1114. doi.org/10.1111/j.1539-6924.2008.01072.x

Vyas, S., & Kumaranayake, L. (2006). Constructing socio-economic status indices: How to use principal components analysis. *Health Policy and Planning 21* (6): 459–468. doi.org/10.1093/heapol/czl029

STAGE 3 Geospatial Distribution and Dissemination

Step 3.1

Scale SoVI scores on a scale of 1 (least vulnerable) **to 100** (most vulnerable)

Why is this important?

- Scale derived scores before mapping so that scores are relative to one another for comparison across adjacent geographic areas.
  - Note: After scaling, SoVI scores indicate relative vulnerability within a geographic boundary of analysis; this needs to be emphasized when communicating and basing decisions on results.
- P4A used the percentage min-max scaling method of scaling, where the largest value (highest derived SoVI = most vulnerable) is set as 100 and the smallest value (lowest derived SoVI = least vulnerable) is 0.

Step 3.2

Classify final SoVI scores with a standard deviation classification scheme for vulnerability mapping and geospatial representation

Why is this important?

- People need to be able to interpret the results. Dividing scores into ranges (classes) and assigning names to each range (e.g., high, moderate, and low) is one way to make meaning of the results (scores).
- There are different classification methods. The standard deviation method is commonly used, where classes are defined based on each score's distance to the mean.
  - A threshold of 1.0 was selected in P4A's research, where SoVI scores greater than 1.0 standard deviation from the mean were classified as "high," and scores less than 1.0 standard deviation from the mean were classified as "low." SoVI scores that were between 1.0 and -1.0 standard deviation were classified as "moderate."
- From Step 1 we know that SoVI scores after scaling are relative. Classifications are also relative designations, as the standard deviation and mean are calculated for SoVI scores within a specific geographic area (e.g., they are spatial statistics of a region of interest).
  - For example, a SoVI score for one location might be classified differently when considered against other locations within a neighbourhood versus a municipality.

Step 3.3

Visualize and map SoVI scores with a graduated colour symbology using a geographical information system (GIS)-based software

Determine the following:

- The choice of mapping method and/or style based on the user's preference and accessibility
  - P4A used the ArcGIS Webmap development tool with a University of Waterloo license.
  - There are free options, such as web map tools in Python or R, which do not require a license.
- The colours for each classification
  - ESRI has suggested colour ramps

Why is this important?

- To enable people to make sense of your results

APPENDIX C:
PUBLICATIONS BY CHAKRABORTY AND OTHERS

**Please refer to the following for a detailed breakdown of the methodologies and analyses used by Partners for Action to construct a social vulnerability index and identify hotspots of flood risk for Canadian Red Cross (2023).*

I. Chakraborty et al., 2020

Citation: Chakraborty, L., Rus, H., Henstra, D., Thistlethwaite, J., & Scott, D. (2020). A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice. *International Journal of Disaster Risk Reduction 43*: 101394.

Link to publication: doi.org/10.1016/j.ijdrr.2019.101394

Applicability:

- Offers a detailed explanation of how a multidimensional and composite socioeconomic status (SES) index can be constructed using census data, how to take that approach to measure social vulnerability, and the details of principal component analysis (PCA)-based index construction methods and results, including the following:
  - How to verify PCA assumptions (e.g., accuracy of the dataset; reliability, validity, and consistency in the dataset)
  - How to extract components using PCA
  - How to calculate a socioeconomic status (SES) index
  - How to perform a 'goodness-of-fit" evaluation during the PCA post-estimation phase
  - The use of Levene's Robust Test to assess the variances found within the SES index scores

II. Chakraborty et al., 2021a

Citation: Chakraborty, L., Thistlethwaite, J., Minano, A., Henstra, D., & Scott, D. (2021). Leveraging hazard, exposure, and social vulnerability data to assess flood risk to Indigenous communities in Canada. *International Journal of Disaster Risk Science 12*: 821–838.

Link to publication: doi.org/10.1007/s13753-021-00383-1

Applicability:

- Provides a detailed methodology on how to leverage data on social vulnerability, flood hazards, and residential flood exposure to comprehensively assess flood risk. The method outlines how to spatially overlay the social vulnerability index layer on top of the residential flood exposure layer.
- The paper compares flood risk between Indigenous and non-Indigenous communities in Canada by aggregating dissemination block (DB) level data to the census sub-division (CSD) level and then spatially combining this dataset with flood exposure data using a 100-year return period.
- Using a GIS-based bivariate choropleth mapping technique, the paper showed how to integrate two spatial layers to inform flood risk assessment.

III. Chakraborty, 2021

Citation: Chakraborty, L. (2021). *Social Equity Dimensions of Flood Risk Management in Canada*. Doctoral Thesis, Department of Geography and Environmental Management, University of Waterloo. UWSpace.

Link to publication: hdl.handle.net/10012/17156

Applicability:

- Provides an analysis of various spatial and non-spatial methodologies to evaluate flood-related inequalities.
- Provides a rationale for why geographically weighted regression (GWR) and GWLR approaches were chosen, rather than global regression methods, to assess the spatial heterogeneity of flood exposure.
- In the supplementary materials, a detailed methodology on how to conduct a GIS-based flood exposure analysis is provided, along with flood risk delineation maps.
- Provides an explanation of how the dependent and independent variables were chosen.
- Includes rationale for utilizing two neighbourhood deprivation indices (neighbourhood instability and neighbourhood economic insecurity) in the construction of the SoVI.
- Provides a detailed methodology for how to find bivariate correlations in the dataset, as well as how to test the results (e.g., spatial lag model, spatial error model, comparison of estimated regression models, Hosmer- Lemeshow Goodness-of-Fit test, Pearson chi-squared tests, AIC Goodness-of-Fit statistic for model comparison, testing for spatial-nonstationary).

IV. Chakraborty et al., 2021b

Citation: Chakraborty, L., Thistlethwaite, J., Henstra, D. (2021). *Flood vulnerability and climate change: Improving flood risk assessment by mapping socioeconomic vulnerability in a mid-sized Canadian city*. Canadian Climate Institute.

Link to publication: climatechoices.ca/publications/flood-vulnerability-and-climate-change

Applicability:

- A case study on flood risk assessment for Windsor CMA, focusing on urban flood risk that is a product of three interacting variables: the flood hazard, the exposure of people and assets, and the vulnerability of people and assets to flood impacts.
- It shows the ways to understand the validity of data on socioeconomic vulnerability for measuring flood risk.
- It helps generate knowledge about the spatial extent and geographic distribution of flood risk across a large urban centre and assess whether vulnerable communities are disproportionately exposed to flooding.
- The report considers policy recommendations to address urban flood risk in ways that particularly protect the most vulnerable.

V. Chakraborty et al., 2022a

Citation: Chakraborty, L., Thistlethwaite, J., Scott, D., Henstra, D., Minano, A., & Rus, H. (2022). *Assessing social vulnerability and identifying spatial hotspots of flood risk to inform socially just flood management policy.* Risk Analysis: 43 (5) 1-21.

Link to publication: doi.org/10.1111/risa.13978

Applicability:

- Provides rationale for how the original 49 variables from census were chosen and how the data was determined at the census tract (CT) level.
    - Includes a detailed explanation of how the flood hazard exposure analysis was conducted, including a) exposure analyses completed using both JBA Fluvial-Undefended and Fluvial-Defended databases, and b) how to conduct a spatial assessment of flood risk.
- Includes a detailed methodology of how to develop a flood risk assessment matrix, which demonstrates the spatial relationship between flood exposure and social vulnerability, incorporates BiLISA techniques to demonstrate flood risk spatial hotspots across Canada at the Census Tract level.

VI. Chakraborty et al., 2022b

Citation: Chakraborty, L., Rus, H., Henstra, D., Thistlethwaite, J., Minano, A., & Scott, D. (2022). *Exploring spatial heterogeneity and environmental injustices in exposure to flood hazards using geographically weighted regression*. Environmental Research 210: 112982.

Link to publication: doi.org/10.1016/j.envres.2022.112982

Applicability:

- Provides quantitative assessment of flood-related equity analysis.
- Rationalizes the use of a geographically weighted regression method to analyze flood-related equity and geospatially represent heterogeneity of populations occupying high risk areas.
- Compares various statistical methods, including spatial and non-spatial regression methods to analyze flood related environmental inequities.

APPENDIX D: SoVI INDICATORS & RATIONALE

Factor	Variable Code	Description (from Statistics Canada)	Census 2016 Variable Address	Rationale (Why this variable was chosen and how it affects vulnerability)	References
Social	ONEPERHH	One-person households (%)	Households by type / Total - Private households by household type - 100% data / Non-Census-family households / One-person households	Isolated individuals and/or persons that have full financial responsibility	Andrey & Jones, 2008; Oulahen et al., 2015
Social	NOLANG	Official language knowledge (People who know neither English nor French) %	Knowledge of official language - Both sexes / Total - Knowledge of official languages for the total population excluding institutional residents - 100% data; Both sexes / Neither English nor French	Limited ability to access information and resources without comfort in either official language	Hebb & Mortsch, 2007; Khan, 2012; Oulahen et al., 2015; Tate, 2012
Social	NODEGREE	Inhabitants with age 15 or older with no certificate/diploma/ degree (%)	Education - Total Sex / Total - Highest certificate, diploma or degree for the population aged 15 years and over in private households - 25% sample data / No certificate, diploma or degree	Affects socio-economic status and income	Andrey & Jones, 2008; Cutter et al., 2003; Holand et al., 2011; Lee, 2014; Oulahen et al., 2015; Schmidtlein et al., 2008; Wood et al., 2010b
Social	LONEPARENT	Lone-parent families (%)	Family characteristics / Total - Lone-parent census families in private households - 100% data	Can experience challenging childcare responsibilities and financial constraints	Andrey & Jones, 2008; Cutter et al., 2003; Khan, 2012; Oulahen et al., 2015

Infrastructure and built environment	CROWDHOME	Inhabitants who are not living in suitable accommodations according to the National Occupancy Standard (NOS) %	Housing - Total Sex / Total - Private households by housing suitability - 25% sample data / Not suitable	Buildings that need major repair or are substandard may be more more susceptible to flood damages	Jones & Andrey, 2007; Oulahen et al., 2015
Infrastructure and built environment	REPAIRHOME	Inhabitants living in private dwellings in need of major repair	Housing – Total Sex / Total – Occupied private dwellings by dwelling condition – 25% sample data / Major repairs needed		
Infrastructure and built environment	PUBTRANSIT	Inhabitants whose primary mode of transportation is public transit such as bus, subway, ferry	COL49 - Journey to Work - Total Sex / Total - Main mode of commuting for the employed labour force aged 15 years and over in private households with a usual place of work or no fixed workplace address - 25% sample data / Public transit	Limited transportation options (e.g., for evacuation)	Cutter et al., 2003; Hebb & Mortsch, 2007; Khan, 2012; Odeh, 2002; Oulahen et al., 2015
Infrastructure and built environment	MOVERS	People whose place of residence was in the same CSD but a different dwelling a year ago	Mobility - Total Sex / Total - Mobility status 1 year ago - 25% sample data / Movers	Potential for neighbourhood instability and potential constraints due to less established community networks	L. Chakraborty et al., 2020, 2021, 2022
Infrastructure and built environment	RENTER	The population of renters (%)	Housing - Total Sex / Total - Private households by tenure - 25% sample data / Renter	Lack of interest / incentive in investing in mitigation actions; limited financial resources; potential lack of adequate insurance	Andrey & Jones, 2008; Bjarnadottir et al., 2011; J. Chakraborty et al., 2005; L. Chakraborty et al., 2020; Collins et al., 2009; Cutter et al., 2003; Hebb & Mortsch, 2007; Khan, 2012; Odeh, 2002; Oulahen et al., 2015; Wood et al., 2010a, 2010b; Wu et al., 2002
Infrastructure and built environment	APT5STORY	Apartments in buildings with five or more storeys (%)	Dwelling characteristics / Total – Occupied private dwellings by structural type of dwelling – 100% data / Apartment in a building that has five or more storeys	Inhabitants can face evacuation challenges	Saatcioglu, 2013

Infrastructure and built environment	BUILT1960	Dwellings that had been built before 1960	Total Sex / Total - Occupied private dwellings by period of construction - 25% sample data / 1960 or before	Not constructed to current codes; higher possibility of damage due to age of materials	Fekete, 2009; Flanagan et al., 2011; Hebb & Mortsch, 2007; Holand et al., 2011; Holand & Lujala, 2013; Lee, 2014; Martins & Cabral, 2012; Oulahen et al., 2015
Economic	GOVTRANSFER	Recipient of government transfers	Income - Total Sex / Total - Income statistics in 2015 for the population aged 15 years and over in private households - 100% data / Number of government transfers recipients aged 15 years and over in private households	Indicates limited financial resources and marginalization; dependence on social safety net	Cutter et al., 2003; Jones & Andrey, 2007; Khan, 2012; Odeh, 2002
Economic	LOWINCOME	Annual family income less than $30,000 (after tax) %	Prevalence of low income based on the Low-income cut-offs, after tax (LICO-AT) (%)	Recovering from losses is harder	Andrey & Jones, 2008; J. Chakraborty et al., 2005; L. Chakraborty et al., 2020; Collins et al., 2009; Cutter et al., 2003; Greiving et al., 2006; Holand et al., 2011; Oulahen et al., 2015
Economic	LOWINCSENIOR	Annual family income less than $30,000 (after tax) for senior people (65 or above)	Prevalence of low income based on the Low-income cut-offs, after tax (LICO-AT) (%) / 65 years and over (%)	Seniors who possess a limited fixed income (e.g., savings, pension) have limited disposable income/ economic resources to invest in emergency preparedness or response measures	L. Chakraborty et al., 2020, 2021, 2022
Economic	SHELTCOSTR	Households with a shelter-cost-to-income ratio of over 30%	Housing - Total Sex / Total- Owner and tenant households with household total income greater than zero, in non-farm, non-reserve private dwellings by shelter-cost-to-income ratio - 25% sample data / Spending 30% or more of income on shelter costs	Households who spend a higher proportion of their income on shelter tend to have less disposable income/ economic resources to invest in emergency preparedness or response measures	L. Chakraborty et al., 2020, 2021, 2022

Economic	UNEMPRATE	Unemployed people with age 15 or above (%)	Labour - Total Sex / Total - Population aged 15 years and over by Labour force status - 25% sample data / In the labour force / Unemployed	Communities with higher unemployment rates have people with limited financial resources; may rely on government assistance programs / a social safety net	Andrey & Jones, 2008; Armaș & Gavriș, 2013; Bjarnadottir et al., 2011; Cutter et al., 2003, 2008; Flanagan et al., 2011; Holand et al., 2011; Khan, 2012; Lee, 2014; Lixin et al., 2014
Economic	MEDHHINC	Median total income of households in 2015 ($)	Income - Total Sex / Total - Income statistics in 2015 for private households by household size - 100% data / Median total income of households in 2015 ($)	Decreases the challenges of recovery from losses	Andrey & Jones, 2008; Collins et al., 2009; Cutter et al., 2003; Greiving et al., 2006; Oulahen et al., 2015
Economic	MEDHOMVAL	The median value of dwellings ($)	Housing - Total Sex / Total - Owner households in non-farm, non-reserve private dwellings - 25% sample data / Median value of dwellings ($)	A proxy of wealth that itself increases resiliency	Andrey & Jones, 2008; J. Chakraborty et al., 2005; Cutter et al., 2003; Flanagan et al., 2011; Tate, 2013; Wood et al., 2010a; Wu et al., 2002
Economic	NILF[4]	People (aged 15 or above) that are not in the labour force (%)	Labour - Total Sex / Total - Population aged 15 years and over by Labour force status - 25% sample data / Not in the labour force	Likely to experience more economic hardship with fewer financial resources for preparedness, coping and recovery	L. Chakraborty et al., 2020, 2021, 2022
Demographic	POPDENSITY	Population density	Population and dwelling counts / Population density per square kilometer	Might experience evacuation challenges	Cutter et al., 2003; Fekete, 2009; Holand et al., 2011; Holand & Lujala, 2013; Jones & Andrey, 2007; Khan, 2012; Martins & Cabral, 2012; Oulahen et al., 2015
Demographic	BELOW15	Inhabitants aged 0 to 15 (%)	Age & Sex - Both sexes / Total - Distribution (%) of the population by broad age groups - 100% data; Both sexes / 0 to 14 years; Both sexes	Dependent on caregivers during evacuation	Cutter et al., 2003; Hebb & Mortsch, 2007; Oulahen et al., 2015; Wu et al., 2002

[4] NILF Refers to persons who are neither employed nor unemployed. It includes students, homemakers, retired workers, seasonal workers in an 'off' season who were not looking for work, and persons who could not work because of a long-term illness or disability.

Demographic	SENIOR	Inhabitants aged 65 or older (%)	Total - Distribution (%) of the population by broad age groups - 100% data; Both sexes / 65 years and over; Both sexes	Mobility challenges due to health conditions; lower fixed incomes	Andrey & Jones, 2008; Bjarnadottir et al., 2011; Collins et al., 2009; Cutter et al., 2003; Greiving et al., 2006; Hebb & Mortsch, 2007; Khan, 2012; Tate, 2013
Demographic	FEFAMLE	Female population (%)	Total - Age groups and average age of the population - 100% data; Females	Women receive lower wages (on average); can have significant caregiving responsibilities	Bjarnadottir et al., 2011; Collins et al., 2009; Cutter et al., 2003, 2008; Greiving et al., 2006; Khan, 2012; Lee, 2014; Tate, 2013; Wood et al., 2010b; Wu et al., 2002)
Cultural	RECENTIMMIGNT	People who recently immigrated (%)	Total - Immigrant status and period of immigration for the population in private households - 25% sample data / Immigrants / 2011 to 2016	Limited opportunities to get financial support after a disaster; can lack the privilege of well-paid jobs	Andrey & Jones, 2008; Oulahen et al., 2015
Cultural	FIRSTGEN	Inhabitants with First-Generation status (%)	Generation Status/ First-Generation	Can be associated with differences in socio-economic status, limited available financial resources, cultural and communication barriers, and preferred information sources not widely used. These factors can make preparedness, coping and recovery more challenging	L. Chakraborty et al., 2020, 2022; Cutter et al., 2003, 2008; Emrich & Cutter, 2011; Holand & Lujala, 2013; Schmidtlein et al., 2008)
Cultural	VISMIN	Inhabitants, other than Indigenous peoples, who are non-Caucasian in race or non-white in colour	Indigenous Peoples and Visible Minorities - Total Sex / Total - Visible minority for the population in private households - 25% sample data / Total visible minority population / Visible minority		See above
Cultural	INDIGENOUS[5]	Indigenous Peoples[6] (%)	Indigenous Peoples and Visible Minorities - Total Sex / Total - Indigenous identity for the population in private households - 25% sample data / Indigenous identity		See above

[5] The updated term 'Indigenous' is used here because one can choose any word to use as a code, as long as it reflects what the variable refers to.

[6] The term 'Aboriginal Peoples' is an outdated term that was used in Statistics Canada's 2016 Census, which this work was based on. In 2021, this Census variable was renamed from 'Aboriginal Peoples' to 'Indigenous Peoples' to "reflect a change in terminology in the Census of Population. The term 'Indigenous' replaced 'Aboriginal' when referring to the collective term for people who identify as First Nations, Métis or Inuit. Its usage aligns with the Government of Canada and is coherent with standard terminology used in the United Nations Declaration on the Rights of Indigenous Peoples Act" (Statistics Canada, 2024). As such, updated terminology is used in this text, rather than the original terminology.

References

Andrey, J., & Jones, B. (2008). The dynamic nature of social disadvantage: Implications for hazard exposure and vulnerability in Greater Vancouver. *The Canadian Geographer / Le Géographe Canadien*, *52*(2), 146–168. **doi.org/10.1111/j.1541-0064.2008.00206.x**

Armaș, I., & Gavriș, A. (2013). Social vulnerability assessment using spatial multi-criteria analysis (SEVI model) and the Social Vulnerability Index (SoVI model) – a case study for Bucharest, Romania. *Natural Hazards and Earth System Sciences*, *13*(6), 1481–1499. **doi.org/10.5194/nhess-13-1481-2013**

Bjarnadottir, S., Li, Y., & Stewart, M. G. (2011). Social vulnerability index for coastal communities at risk to hurricane hazard and a changing climate. *Natural Hazards*, *59*(2), 1055–1075. **doi.org/10.1007/s11069-011-9817-5**

Chakraborty, J., Tobin, G. A., & Montz, B. E. (2005). Population evacuation: Assessing spatial variability in geophysical risk and social vulnerability to natural hazards. *Natural Hazards Review*, *6*(1), 23–33. **doi.org/10.1061/(ASCE)1527-6988(2005)6:1(23)**

Chakraborty, L., Rus, H., Henstra, D., Thistlethwaite, J., Minano, A., & Scott, D. (2022). Exploring spatial heterogeneity and environmental injustices in exposure to flood hazards using geographically weighted regression. *Environmental Research*, *210*, 112982. **doi.org/10.1016/j.envres.2022.112982**

Chakraborty, L., Rus, H., Henstra, D., Thistlethwaite, J., & Scott, D. (2020). A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice. *International Journal of Disaster Risk Reduction*, *43*, 101394. **doi.org/10.1016/j.ijdrr.2019.101394**

Chakraborty, L., Thistlethwaite, J., Minano, A., Henstra, D., & Scott, D. (2021). Leveraging Hazard, Exposure, and Social Vulnerability Data to Assess Flood Risk to Indigenous Communities in Canada. *International Journal of Disaster Risk Science*, *12*(6), 821–838. **doi.org/10.1007/s13753-021-00383-1**

Collins, T. W., Grineski, S. E., & Aguilar, M. de L. R. (2009). Vulnerability to environmental hazards in the Ciudad Juárez (Mexico)–El Paso (USA) metropolis: A model for spatial risk assessment in transnational context. *Applied Geography*, *29*(3), 448–461. **doi.org/10.1016/j.apgeog.2008.10.005**

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. *Global Environmental Change*, *18*(4), 598–606. **doi.org/10.1016/j.gloenvcha.2008.07.013**

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

Emrich, C. T., & Cutter, S. L. (2011). Social Vulnerability to Climate-Sensitive Hazards in the Southern United States. *Weather, Climate, and Society*, *3*(3), 193–208. **doi.org/10.1175/2011WCAS1092.1**

Fekete, A. (2009). Validation of a social vulnerability index in context to river-floods in Germany. *Natural Hazards and Earth System Sciences*, *9*(2), 393–403. doi.org/10.5194/nhess-9-393-2009

Flanagan, B. E., Gregory, E. W., Hallisey, E. J., Heitgerd, J. L., & Lewis, B. (2011). A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management*, *8*(1). doi.org/10.2202/1547-7355.1792

Greiving, S., Fleischhauer, M., & Lückenkötter, J. (2006). A methodology for an integrated risk assessment of spatially relevant hazards. *Journal of Environmental Planning and Management*, *49*(1), 1–19. doi.org/10.1080/09640560500372800

Hebb, A., & Mortsch, L. (2007). Floods: Mapping vulnerability in the Upper Thames watershed under a changing climate. *Project Report XI, University of Waterloo*, 1–53. www.eng.uwo.ca/research/iclr/fids/publications/cfcas-climate/reports/vulnerability_mapping_report.pdf

Holand, I. S., & Lujala, P. (2013). Replicating and Adapting an Index of Social Vulnerability to a New Context: A Comparison Study for Norway. *The Professional Geographer*, *65*(2), 312–328. doi.org/10.1080/00330124.2012.681509

Holand, I. S., Lujala, P., & Rød, J. K. (2011). Social vulnerability assessment for Norway: A quantitative approach. *Norsk Geografisk Tidsskrift - Norwegian Journal of Geography*, *65*(1), 1–17. doi.org/10.1080/00291951.2010.550167

Jones, B., & Andrey, J. (2007). Vulnerability index construction: Methodological choices and their influence on identifying vulnerable neighbourhoods. *International Journal of Emergency Management*, *4*(2), 269. doi.org/10.1504/IJEM.2007.013994

Khan, S. (2012). Vulnerability assessments and their planning implications: A case study of the Hutt Valley, New Zealand. *Natural Hazards*, *64*(2), 1587–1607. doi.org/10.1007/s11069-012-0327-x

Lee, Y.-J. (2014). Social vulnerability indicators as a sustainable planning tool. *Environmental Impact Assessment Review*, *44*, 31–42. doi.org/10.1016/j.eiar.2013.08.002

Lixin, Y., Xi, Z., Lingling, G., & Dong, Z. (2014). Analysis of social vulnerability to hazards in China. *Environmental Earth Sciences*, *71*(7), 3109–3117. doi.org/10.1007/s12665-013-2689-0

Martins, V. N., & Cabral, P. (2012). Social vulnerability assessment to seismic risk using multicriteria analysis: The case study of Vila Franca do Campo (São Miguel Island, Azores, Portugal). *Natural Hazards*, *62*(2), 385–404. doi.org/10.1007/s11069-012-0084-x

Odeh, D. J. (2002). Natural hazards vulnerability assessment for statewide mitigation planning in Rhode Island. *Natural Hazards Review*, *3*(4), 177–187. doi.org/10.1061/(ASCE)1527-6988(2002)3:4(177)

Oulahen, G., Mortsch, L., Tang, K., & Harford, D. (2015). Unequal Vulnerability to Flood Hazards: “Ground Truthing” a Social Vulnerability Index of Five Municipalities in Metro Vancouver, Canada. *Annals of the Association of American Geographers*, *105*(3), 473–495. doi.org/10.1080/00045608.2015.1012634

Saatcioglu, M. (2013). High-Rise Buildings in Natural Disaster. In P. T. Bobrowsky (Ed.), *Encyclopedia of Natural Hazards* (pp. 451–452). Springer Netherlands. doi.org/10.1007/978-1-4020-4399-4_168

Schmidtlein, M. C., Deutsch, R. C., Piegorsch, W. W., & Cutter, S. L. (2008). A Sensitivity Analysis of the Social Vulnerability Index. *Risk Analysis*, *28*(4), 1099–1114. doi.org/10.1111/j.1539-6924.2008.01072.x

Statistics Canada. (2024, March 20). *Indigenous Peoples [webpage]*. www12.statcan.gc.ca/census-recensement/2021/rt-td/indigenous-autochtones-eng.cfm

Tate, E. (2012). Social vulnerability indices: A comparative assessment using uncertainty and sensitivity analysis. *Natural Hazards*, *63*(2), 325–347. doi.org/10.1007/s11069-012-0152-2

Tate, E. (2013). Uncertainty Analysis for a Social Vulnerability Index. *Annals of the Association of American Geographers*, *103*(3), 526–543. doi.org/10.1080/00045608.2012.700616

Wood, N. J., Burton, C. G., & Cutter, S. L. (2010a). Community variations in social vulnerability to Cascadia-related tsunamis in the US Pacific Northwest. *Natural Hazards*, *52*(2), 369–389. doi.org/10.1007/s11069-009-9376-1

Wood, N. J., Burton, C. G., & Cutter, S. L. (2010b). Community variations in social vulnerability to Cascadia-related tsunamis in the U.S. Pacific Northwest. *Natural Hazards*, *52*(2), 369–389. doi.org/10.1007/s11069-009-9376-1

Wu, S.-Y., Yarnal, B., & Fisher, A. (2002). Vulnerability of coastal communities to sea-level rise: A case study of Cape May County, New Jersey, USA. *Climate Research*, *22*(3), 255–270. doi.org/10.3354/cr022255

APPENDIX E: HOW TO CREATE WEB-BASED MAPS OF SoVI WITH ARCGIS

What follows is the methodology used for creating the web-based maps of a Social Vulnerability Index (SoVI) and its components (e.g., economic insecurity and neighborhood instability) for Partner's for Action's project for the Canadian Red Cross Service on *Inclusive Resilience: A Social Vulnerability Index (SoVI) to Assess and Map Flood Risk for Targeted Communications,* completed in 2023.

Details on the derivation of this SoVI can be found in Chakraborty et al. (2022, 2020) and are beyond the scope of this document. In other words, **before following the steps below to create a map, you must derive the index values and produce the associated polygon(s).**

1. Define the classes of SoVI (using a standard deviation method)

For defining the clusters, the following steps are taken:

- The mean of the index values (χ_i) is calculated (μ)
- The standard deviation (std. dev) of the index values is calculated (σ)
- All the index values are z-normalized (Z_i; zero mean, std. dev.=1) through:
  - ☐ $Z_i = \frac{\chi_i - \mu}{\sigma}$ where Z_i is the normalized value of the index
- Based on Z_i value, Z_i is classified into three groups:
  - ☐ If $Z_i < 0$: Low (Class -1)
  - ☐ If $0 \leq Z_i < 1$: Moderate (Class 0)
  - ☐ If $Z_i \geq 0$: High (Class 1)
  - ☐ In the case of a missing value (restriction in data access), a distinguishable class is assigned to the class (e.g., -5)
  - ☐ Save the values in a CSV file

This method is referred to as the std. dev method; ArcGIS has the capability of classifying this way. However, if classification is done manually, the classes could be directly added to the shapefile's attribute table.

2. Add the classes to the original shapefiles

- Open ArcGIS pro (or ArcGIS desktop)
- Using the **insert tab**, create a new map
- Using the **map tab**, add the SoVI layer (**add data**) and the saved CSV file
- **Right-click** on the SoVI layer and select **Join and Relates**, **Add Join**
- Join based on FID (FID column should be available in the CSV file)
- Export the new shapefile
- Zip all the files associated with the exported shapefile *(not only the shapefile!)*

3. Create the web-based map application

Part 1: Creating the online map

Before the web map app is created, the online map (webmap) should be designed.

- Sign into ArcGIS online account (www.arcgis.com/index.html)
- Go to the **Content tab**
- Click **New Item**, and upload the zipped file
- Go to the **Map tab**
- **Add** the uploaded layer

The environment is like the ArcGIS desktop.

- **Select the class column** (the column you added to the attribute table, the classifications) as the variable of interest and rename the classes' label based on the designed thresholds and class values (e.g., low, moderate, high).
- Play with visibility, transparency, and other **appearance settings.**
- **Select your basemap.** The basemap controls the projection of the map, so basemaps should be aligned with other layers.
- When finished, click **save.**

Part 2: Webapp Builder

- Once again, go to **Content Tab**
- Click **Create App**, select **Webapp Builder**
- On the popped-up page, give the project name, and fill in the description section (highly recommended)
- Select the **Theme** which best suits your application

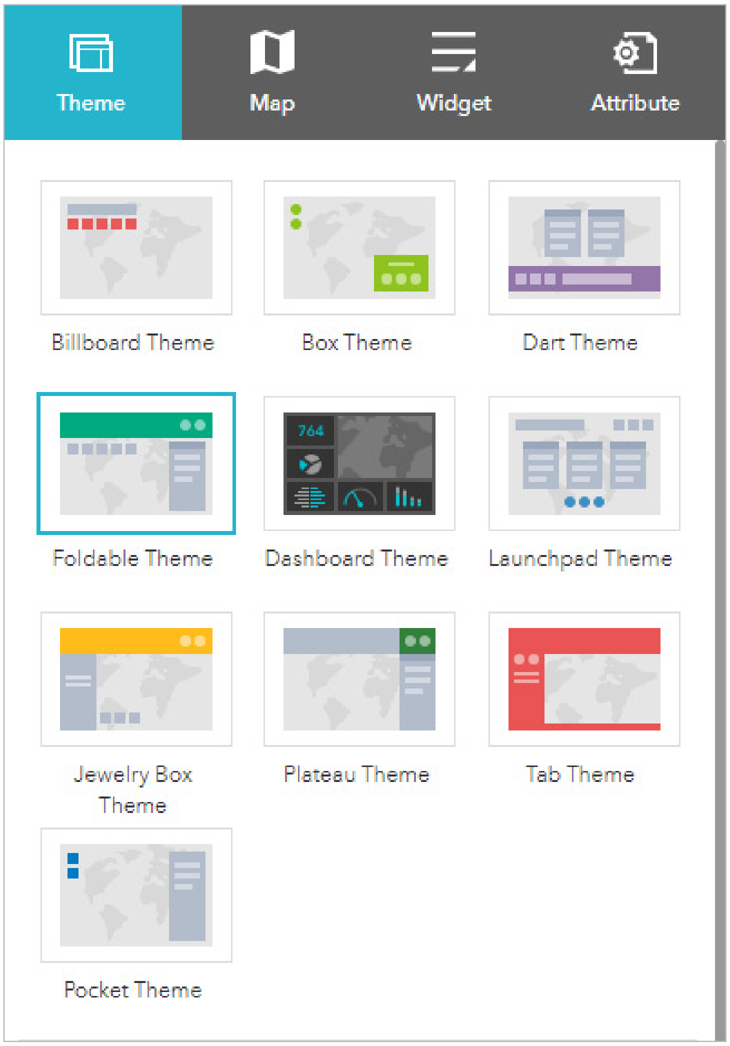


Fig 1: The available themes. Themes control the general appearance of the application

- In the **Map** tab, select the map of interest (the map developed in the previous steps)

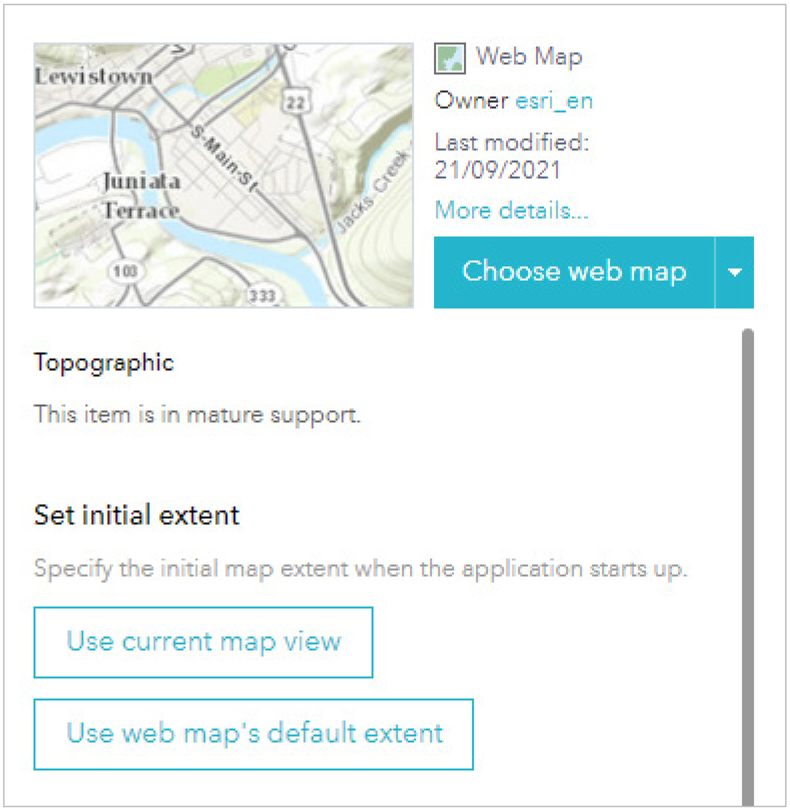


Fig 2: Select the web map

- Customize the widgets through the **Widget** tab. There are various options. The widget position and layout are controlled by the theme (**Theme** tab) selected for the web app.
- Modify the title, icon, and description of the map using the **Attribute** tab

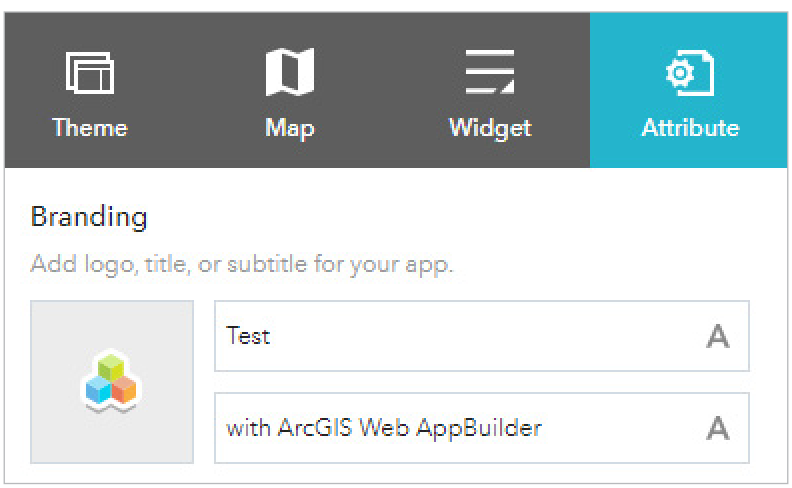


Fig 3: The attribute tab

Final comment: There are multiple options and details that are not covered in this document. The best way to explore the capabilities of the Webapp Builder is to test it.

4. References

Chakraborty, L., Rus, H., Henstra, D., Thistlethwaite, J. and Scott, D., (2020). A place-based socioeconomic status index: Measuring social vulnerability to flood hazards in the context of environmental justice. *International Journal of Disaster Risk Reduction*, 43: 101394. **doi.org/10.1016/j.ijdrr.2019.101394**

Chakraborty, L., Thistlethwaite, J., Scott, D., Henstra, D., Minano, A., & Rus, H. (2022). Assessing social vulnerability and identifying spatial hotspots of flood risk to inform socially just flood management policy. *Risk Analysis 43*(5): 1058-1078. **doi.org/10.1111/risa.13978**.

APPENDIX F: HIERARCHY OF STANDARD GEOGRAPHIC AREAS FOR DISSEMINATION, 2016 CENSUS

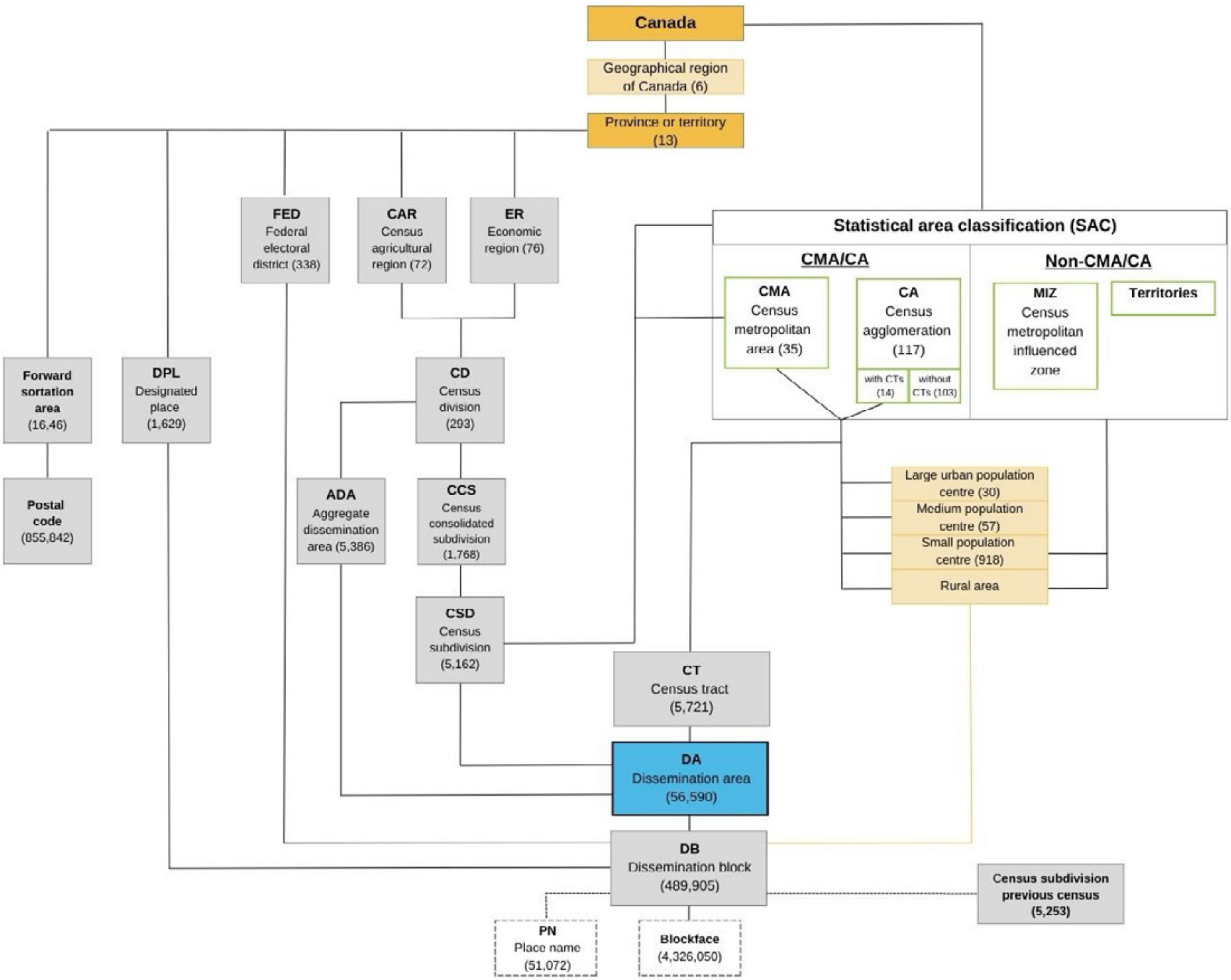


Figure adapted from Statistics Canada, 2017b

REFERENCES

Adams, R., Evans, C., & Peek, L. (2020). Mortality from forces of nature among older adults by race/ethnicity and gender. *Journal of Applied Gerontology 40 (11)*: 1517-1526. **doi.org/10.1177/0733464820954676**

Adger, W. (2006). Vulnerability. *Global Environnemental Change 16 (3)*: 268-281. **doi.org/10.1016/j.gloenvcha.2006.02.006**

Agency for Toxic Substances and Disease Registry (ATSDR). (2022, October) *CDC/ATSDR SVI Fact Sheet*. Retrieved December 2022 from **www.atsdr.cdc.gov/placeandhealth/svi/fact_sheet/fact_sheet.html**

AghaKouchak, A., Huning, L.S., Chiang, F., Sadegh, M., Vahedifard, F., Mazdiyasni, O., & Mallakpour, I. (2018). How do natural disasters cascade to cause disasters? *Nature 561*: 458-460. **doi.org/10.1038/d41586-018-06783-6**

AghaKouchak, A., Chiang, F., Huning, L.S., Love, C.A., Mallakpour, I., Mazdiyasni, O., Moftakhari, H., Papalexiou, S.M., Ragno, E., & Sadegh, M. (2020). Climate extremes and compound hazards in a warming world. *Annual Review of Earth and Planetary Sciences 48*: 519-548. **doi.org/10.1146/annurev-earth-071719-055228**

Agyapong, B., Shalaby, R., Eboreime, E., Obuobi-Donkor, G., Owusu, E., Adu, M., Mao, W., Olywasina, F., & Agyapong, V. (2022). Cumulative trauma from multiple natural disasters increases mental health burden on residents of Fort McMurray. *European Journal of Psychotraumatology 13 (1)*: 1-15. **doi.org/10.1080/20008198.2022.2059999**

Al-Baldawi, Z., Pickering, C., Champagne-Poirier, O., & O'Sullivan, T. (2021). Framing of youth as a high-risk population in Canadian disaster news media. *International Journal of Disaster Risk Reduction 58*: 1-9. **doi.org/10.1016/j.ijdrr.2021.102174**

Alderman, K., Turner, L. R., & Tong, S. (2012). Floods and human health: A systematic review. *Environmental International 47:* 37-47. **doi.org/10.1016/j.envint.2012.06.003**

Aldrich, N., & Benson, W. (2008). Disaster preparedness and the chronic disease needs of vulnerable older adults. *Preventing Chronic Disease 5 (1)*. Retrieved from **www.ncbi.nlm.nih.gov/pmc/articles/PMC2248769/**

Anderson, C., Hagenlocher, M., Renaud, F., Sebesvari, Z., Cutter, S., & Emrich, C. (2019). Comparing index-based vulnerability assessments in the Mississippi Delta: Implications of contrasting theories, indicators, and aggregation methodologies. *International Journal of Disaster Risk Reduction 39*: 101128. **doi.org/10.1016/j.ijdrr.2019.101128**

Andrew, M., & Keefe, J. (2014). Social vulnerability from a social ecology perspective: a cohort study of older adults from the National Population Health Survey of Canada. *Biomedical Centre Geriatrics 14 (90)*: 1-14. doi.org/10.1186/1471-2318-14-90

Anselin, L. (1995). Local Indicators of Spatial Association—LISA. *Geographical Analysis, 27*: 93-115. doi.org/10.1111/j.1538-4632.1995.tb00338.x

Anselin, L., Syabri, I. & Kho, Y. (2009). GeoDa: an introduction to spatial data analysis. In *Handbook of applied spatial analysis: Software tools, methods and applications* (pp. 73-89). Berlin, Heidelberg: Springer Berlin Heidelberg. doi.org/10.1007/978-3-642-03647-7_5

An, R. & Xiang, X. (2015). Social vulnerability and leisure-time physical inactivity among U.S. adults. *American Journal of Health Behavior 39 (6)*: 751-760. doi.org/10.5993/AJHB.39.6.2

Arnell, N. W., & Lloyd-Hughes, B. (2014). The global-scale impacts of climate change on water resources and flooding under new climate and socio-economic scenarios. *Climatic Change 122(1);* 127–140. doi.org/10.1007/s10584-013-0948-4

Arshad, M., Mughal, M., Giallo, R., & Kingston, D. (2020). Predictors of child resilience in a community-based cohort facing flood as natural disaster. *BioMed Central Psychiatry 20*: 543. doi.org/10.1186/s12888-020-02944-y

Ballard, M., & Thompson, S. (2013). Flooding hope and livelihoods: Lake St. Martin First Nation. *Canadian Journal of Non-profit and Social Economy Research 4* (1): 43-65. doi.org/10.22230/cjnser.2013v4n1a129

Bankoff, G. (2001). Rendering the world unsafe: 'Vulnerability' as Western discourse. *Disasters 25* (1): 19-35. doi.org/10.1111/1467-7717.00159

Biggs, E., Maloney, P., Rung, A., Peters, E., & Robinson, W. (2021). The relationship between social vulnerability and COVID- 19 incidence among Louisiana census tracts. *Frontiers in Public Health 8*: 1-7. doi.org/10.3389/fpubh.2020.617976

Bjarnadottir, S., Li, Y. & Stewart, M. (2011). Social vulnerability index for coastal communities at risk to hurricane hazard and a changing climate. *Natural Hazards 59*: 1055–1075. doi.org/10.1007/s11069-011-9817-5

Bro, R., & Smilde, A. (2014). Principal component analysis. *Analytical Methods, 6*(9), 2812–2831. doi.org/10.1039/C3AY41907J

Bouikidis, A., & Tynan, K. (2022). Social infrastructure and community resilience. In S. Safaie, S. Johnstone, & N. Hastings (Eds.), *Resilience pathways report: Co-creating new knowledge for understanding risk and resilience in British Columbia*. Geological Survey of Canada, Open File 8910. doi.org/10.4095/330521

Buckland, J., & Rahman, M. (1999). Community-based disaster management during the 1997 Red River Flood in Canada. *Disasters 23* (2): 174–191. doi.org/10.1111/1467-7717.00112

Burton, C., & Cutter, S. (2008). Levee failures and social vulnerability in the Sacramento- San Joaquin Delta area, California. *Natural Hazards Review 9* (3): 1-14. doi.org/10.1061/(ASCE)1527-6988(2008)9:3(136)

Burton, H., Rabito, F., Danielson, L., & Takaro, T. (2016) Health effects of flooding in Canada: A 2015 review and description of gaps in research. *Canadian Water Resources Journal 41* (1-2): 238-249. doi.org/10.1080/07011784.2015.1128854

Bush, E., & Lemmen, D.S. (2019). *Canada's changing climate report*. Government of Canada: Ottawa, ON. Retrieved from changingclimate.ca/CCCR2019/

Canadian Women's Foundation. (2022, May). *Insights from the Gender Justice Labs on Emergency Preparedness*. Retrieved from canadianwomen.org/wp-content/uploads/2022/06/Gender-Justice-Labs-Final-Report-EN.pdf

Carroll, B., Morbey, H., Balogh, R., & Araoz, G. (2009). Flooded homes, broken bonds, the meaning of home, psychological processes and their impact on psychological health in a disaster. *Health & Place 15* (2): 540-547. doi.org/10.1016/j.healthplace.2008.08.009

Chakraborty, L., Rus, H., Henstra, D., Thistlethwaite, J., & Scott, D. (2020). A place-based socio-economic status index: Measuring social vulnerability to flood hazards in the context of environmental justice. *International Journal of Disaster Risk Reduction 43*: 101394. doi.org/10.1016/j.ijdrr.2019.101394

Chakraborty, L. (2021). *Social Equity Dimensions of Flood Risk Management in Canada*. Doctoral Thesis, Department of Geography and Environmental Management, University of Waterloo. UWSpace. hdl.handle.net/10012/17156

Chakraborty, L., Thistlethwaite, J., Minano, A., Henstra, D., & Scott, D. (2021). Leveraging hazard, exposure, and social vulnerability data to assess flood risk to Indigenous communities in Canada. *International Journal of Disaster Risk Science 12*: 821–838. doi.org/10.1007/s13753-021-00383-1

Chakraborty, L., Thistlethwaite, J., Scott, D., Henstra, D., Minano, A., & Rus, H. (2022). Assessing social vulnerability and identifying spatial hotspots of flood risk to inform socially just flood management policy. *Risk Analysis*: *43* (5): 1-21. doi.org/10.1111/risa.13978

Chang, S., Yip, J., van Zijll de Jong, S., Chaster, R., & Lowcock, A. (2015). Using vulnerability indicators to develop resilience networks: a similarity approach. *Natural Hazards 78*: 1827–1841. doi.org/10.1007/s11069-015-1803-x

Chang, S., Yip, J., Conger, T., Oulahen, G., & Marteleira, M. (2018). Community vulnerability to coastal hazards: Developing a typology for disaster risk reduction. *Applied Geography 91*: 81-88. **doi.org/10.1016/j.apgeog.2017.12.017**

Chang, S., Yip, J. Conger, T., Oulahen, G., Gray, E., & Marteleira, M. (2020). Explaining communities' adaptation strategies for coastal flood risk: Vulnerability and institutional factors. *Journal of Flood Risk Management 13* (4): e12646. **doi.org/10.1111/jfr3.12646**

Chmutina, K., von Meding, J., Williams, D., Vickery, J., & Purdum, C. (2023). From pity to fear: Security as a mechanism for (re)production of vulnerability. *Disasters 47* (3): 546-562. **doi.org/10.1111/disa.12568**

Cole, J., & Murphy, B. (2014). Rural hazard risk communication and public education: Strategic and tactical best practices. *International Journal of Disaster Risk Reduction 10:* 292–304. **doi.org/10.1016/j.ijdrr.2014.10.001**

Collins, T., Grineski, S., & Chakraborty, J. (2018). Environmental injustice and flood risk: A conceptual model and case comparison of metropolitan Miami and Houston, USA. *Regional Environmental Change 18*: 311-323. **doi.org/10.1007/s10113-017-1121-9**

Cutter, S. (1996). Vulnerability to environmental hazards. *Progress in Human Geography 20*: 52-539. **doi.org/10.1177/030913259602000407**

Cutter, S., Boruff, B., Shirley, W. (2003). Social vulnerability to environmental hazards. *Social Science Quarterly 84* (2): 242-261. **doi.org/10.1111/1540-6237.8402002**

Cutter, S., Emrich, C., Morath, D., & Dunning, C. (2013). Integrating social vulnerability into federal flood risk management planning. *Journal of Flood Risk Management 6* (4): 332–344. **doi.org/10.1111/jfr3.12018**

Cutter, S., & Finch, C. (2008). Temporal and spatial changes in social vulnerability to natural hazards. *Proceedings of the National Academy of Sciences 105* (7): 2301–2306. **doi.org/10.1073/pnas.0710375105**

Cutter, S., & Smith, M. (2009). Fleeing from the hurricane's wrath: Evacuation and the two Americas. *Environment: Science and Policy for Sustainable Development 51* (2): 26-36. **www.tandfonline.com/action/showCitFormats?doi=10.3200/ENVT.51.2.26-36**

Dancause, K., Laplante, D., Hart, K., O'Hara, M., Elgbeili, G., Brunet, A., King, S. (2015). Prenatal stress due to a natural disaster predicts adiposity in childhood: The Iowa flood study. *Journal of Obesity*: 570541. **doi.org/10.1155/2015/570541**

Davis, J., Wilson, S., Brock-Martin, A., Glover, S., & Svendsen, E. (2010). The impact of disasters on populations with health and health care disparities. *Disaster Medicine and Public Health Preparedness 4* (1): 30-38. doi.org/10.1017%2Fs1935789300002391

de Oliveira Mendes, J. (2009). Social vulnerability indexes as planning tools: Beyond the preparedness paradigm. *Journal of Risk Research 12* (1): 43–58. doi.org/10.1080/13669870802447962

Drolet, J., McDonald-Harker, C., Lalani, N., & Tran, J. (2020). Impacts of the 2013 flood on immigrant children, youth, and families in Alberta Canada. *International Journal of Social Work 2* (2): doi.org/10.5296/ijsw.v7i1.16872

Duncan, O. (1969). *Towards Social Reporting: New Steps*. New York: Russell Sage Foundation.

Duncan, O. (1984). *Notes on Social Measurement, Historical and Critical*. Beverly Hills, California; Russell Sage Foundation.

Emrich, C., Tate, E., Larson, S., & Zhou, Y. (2020). Measuring social equity in flood recovery funding. *Environmental Hazards 19* (3): 228-250. doi.org/10.1080/17477891.2019.1675578

Enarson, E. (1999a). Violence against women in disasters: A study of domestic violence programs in the United States and Canada. *Violence Against Women 5* (7): 742-768. doi.org/10.1177/10778019922181464

Enarson, E. (1999b). Women and housing issues in two U.S. flood: Hurricane Andrew and the Red River Valley Flood. *International Journal of Mass Emergencies and Disasters 17* (1): 39-63. doi.org/10.1177/028072709901700103

Enarson, E., & Scanlon, J. (1999). Gender patterns in flood evacuation: A case study in Canada's Red River Valley. *Applied Behavioural Science Review 7* (2): 103-124. doi.org/10.1016/S1068-8595(00)80013-6

Environics Analytics. (N.d.). *Social Vulnerability Index*. Retrieved December 2022 from environicsanalytics.com/en-ca/data/health-databases/social-vulnerability-index

Environics Analytics. (2020, May). *The many faces of vulnerability in the time of COVID-19* [Study]. Retrieved December 2022 from environicsanalytics.com/en-ca/resources/blogs/ea-blog/2020/05/08/the-many-faces-of-vulnerability-in-the-time-of-covid-19-study

Fatemi, F., Ardalan, A., Aguirre, B., Mansouri, N., & Mohammadfam, I. (2017). Social vulnerability indicators in disasters: Findings from a systemic review. *International Journal of Disaster Risk Reduction 22*: 219-227. doi.org/10.1016/j.ijdrr.2016.09.006

Ferré, L. (1995). Selection of components in principal component analysis: A comparison of methods. *Computational Statistics & Data Analysis 19* (6): 669–682. doi.org/10.1016/0167-9473(94)00020-J

Fielding, J., & Burningham, K. (2005). Environmental inequality and flood hazard. *International Journal of Justice and Sustainability 10* (4): 379–395. doi.org/10.1080/13549830500160875

Fienberg, S.E. (1979). Graphical methods in statistics. *The American Statistician 33* (4): 165-178. doi.org/10.2307/2683729

Flanagan, B., Gregory, E., Hallisey, E., Heitgerd, J., & Lewis, B. (2011). A social vulnerability index for disaster management. *Journal of Homeland Security and Emergency Management 8* (1): Article 3. doi/10.2202/1547-7355.1792/html

Fuentealba, R. (2021). Divergent disaster events? The politics of post-disaster memory on the urban margin. *International Journal of Disaster Risk Reduction 62*: 1-11. doi.org/10.1016/j.ijdrr.2021.102389

Fulton, A., & Drolet, J. (2018). Responding to disaster-related loss and grief: Recovering from the 2013 flood in Southern Alberta, Canada. *Journal of Loss and Trauma 23* (2): 140-158. doi.org/10.1080/15325024.2018.1423873

Furgal, C., & Seguin, J. (2006). Climate change, health, and vulnerability in Canadian northern Aboriginal communities. *Environmental Health Perspectives 114* (12): 1964-1970. doi.org/10.1289/ehp.8433

Goldmann, E., & Galea, S. (2014). Mental health consequences of disasters. *Annual Review of Public Health 35*: 169-183. doi.org/10.1146/annurev-publhealth-032013-182435

Government of Alberta. (2023, March 22). 2021 *Census of Canada: Indigenous People*. Retrieved from open.alberta.ca/dataset/487a7294-06ac-481e-80b7-5566692a6b11/resource/257af6d4-902c-4761-8fee-3971a4480678/download/tbf-2021-census-of-canada-indigenous-people.pdf

Gray-Scholz, D., Haney, T., & MacQuarrie, P. (2019). Out of sight, out of mind? Geographic and social predictors of flood risk awareness. *Risk Analysis 39* (11): 2543-2558. doi.org/10.1111/risa.13357

Gaur, A., Gaur, A., & Simonovic, S. P. (2018). Future Changes in Flood Hazards across Canada under a Changing Climate. *Water 10* (10): 1441. doi.org/10.3390/w10101441

Gill, J.C., & Malamud, B.D. (2016). Hazard interactions and interaction networks (cascades) within multi-hazard methodologies. *Earth System Dynamics 7* (3): 659-679. doi.org/10.5194/esd-7-659-2016

Gutman, G. (2007). *Seniors and disasters: A synthesis of four Canadian case studies*. Retrieved from ccsmh.ca/wp-content/uploads/2016/03/Seniors-and-Disasters-Synthesis-of-Four-Case-Studies.pdf

Haalboom, B., & Natcher, D. (2012). The power and peril of "vulnerability:" Lending a cautious eye to community labels in climate change research. *Arctic 65* (3): 319-327. www.jstor.org/stable/41758938

Hallegatte, S., Bangalore, M., Bonzanigo, L., Fay, M., Kane, T., Narloch, U., Rozenberg, J., Treguer, D., & Vogt-Schilb, A. (2016). *Shock waves: Managing the impacts of climate change on poverty*. Washington, DC: World Bank. doi.org/10.1596/978-1-4648-0673-5

Hamideh, S., Peacock, W., & Van Zandt, S. (2021). Housing type matters for pace of recovery: Evidence from Hurricane Ike. *International Journal of Disaster Risk Reduction 57*: 1-12. doi.org/10.1016/j.ijdrr.2021.102149

Haney, T., & Gray-Scholz, D. (2019). Flooding and the 'new normal': What is the role of gender in experiences of post-disaster ontological security? *Disasters 44* (2): 262-284. doi.org/10.1111/disa.12372

Hayes, K., Poland, B., Cole, D., & Agic, B. (2020). Psychosocial adaptation to climate change in High River, Alberta: implications for policy and practice. *Canadian Journal of Public Health 111* (6): 880-889. doi.org/10.17269/s41997-020-00380-9

Hazard and Vulnerability Research Institute (HVRI). (N.d.). SoVI® Social Vulnerability Index for the United States — 2010–14. *University of South Carolina*. Retrieved January 2023 from sc.edu/study/colleges_schools/artsandsciences/centers_and_institutes/hvri/data_and_resources/sovi/index.php

Heagele, T., & Pacquiao, D. (2019). Disaster vulnerability of elderly and medically frail populations. *Health Emergency and Disaster Nursing 6*: 50-61. doi.org/10.24298/hedn.2016-0009

Hewitt, K., & Burton, I. (1971). *The hazardousness of a place: A regional ecology of damaging events*. University of Toronto, Department of Geography. Toronto: University of Toronto Press.

Highfield, W., Peacock, W., & Van Zandt, S. (2014). Mitigation planning: Why hazard exposure, structural vulnerability, and social vulnerability matter. *Journal of Planning Education and Research 34* (3): 287-300. dx.doi.org/10.1177/0739456X14531828

Hinkel, J., Lincke, D., Vafeidis, A., Perrette, M., Nicholls, R., Tol, R. Marzeion, B., Fettweis, X., Ionescu, C., & Levermann, A. (2014). Coastal flood damage and adaptation costs under 21st century sea-level rise. *Proceedings of the National Academy of Sciences 111* (9): 3292–3297. doi.org/10.1073/pnas.1222469111

Houghton, A., Austin, J., Beerman, A., & Horton, C. (2017). An approach to developing local climate change environmental public health indicators in a rural district. *Journal of Environmental and Public Health*: 3407325. doi.org/10.1155/2017/3407325

Insurance Bureau of Canada. (2023, January 18). *Severe weather in 2022 caused $3.1 billion in insured damage—making it the 3rd worst year for insured damage in Canadian history*. Retrieved from www.ibc.ca/news- insights/news/severe-weather-in-2022-caused-3-1-billion-in-insured-damage-making-it-the-3rd-worst-year-for- insured-damage-in-canadian-history

Intergovernmental Panel on Climate Change (IPCC). (2022). *Climate Change 2022: Impacts, Adaptation, and Vulnerability*. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press: Cambridge, UK and New York, NY, USA. DOI:10.1017/9781009325844. Retrieved from www.ipcc.ch/report/ar6/wg2/

Jensen, D. (2021). Multi-dimensional disaster response for older adults. *Humboldt Journal of Social Relations 43*: 10-18. www.jstor.org/stable/48638656

Journeay, M., Yip, J.Z.K., Wagner, C.L., LeSueur, P., & Hobbs, T. (2022). Social vulnerability to natural hazards in Canada: an overview of methods and findings. *Geological Survey of Canada,* Open File 8902. doi.org/10.4095/330295

Kaiser, H. (1958). The varimax criterion for analytic rotation in factor-analysis. *Psychometrika 23* (3): 187–200. doi.org/10.1007/BF02289233

Kant, S., Vertinsky, I., Zheng, B., & Smith, P. (2013). Social, cultural, and land use determinants of the health and well-being of Aboriginal peoples in Canada: A path analysis. *Journal of Public Health Policy 34*: 462-472. doi.org/10.1057/jphp.2013.27

Kind, J., Botzen, W. & Aerts, J. (2020). Social vulnerability in cost-benefit analysis for flood risk management. *Environment and Development Economics 25* (2): 115–134. doi.org/10.1017/S1355770X19000275

Klinenberg, E. (2016). Social isolation, loneliness, and living alone: Identifying the risks for public health. *American Journal of Public Health 106* (5): 786-787. doi.org/10.2105%2FAJPH.2016.303166

Koks, E.E., Jongman, B., Husby, T.G., & Botzen, W.J.W. (2015). Combining hazard, exposure and social vulnerability to provide lessons for flood risk management. *Environmental Science and Policy 47*: 42-52. doi.org/10.1016/j.envsci.2014.10.013

Land, K. (1983). Social indicators. *Annual Review of Sociology 9*: 1-26. doi.org/10.1146/annurev.so.09.080183.000245

Land, K. & Spilerman, S. (1975). *Social Indicator Models*. New York: Russell Sage Foundation.

Lowe, D., Ebi, K., & Forsberg, B. (2013). Factors increasing vulnerability to health effects before, during, and after floods. *International Journal of Environmental Research and Public Health 10* (12): 7015-7067. doi.org/10.3390/ijerph10127015

Lee, S.I. (2001). Developing a bivariate spatial association measure: an integration of Pearson's r and Moran's I. *Journal of Geographical Systems 3*: 369-385. doi.org/10.1007/s101090100064

Lehnert, E. A., Wilt, G., Flanagan, B., & Hallisey, E. (2020). Spatial exploration of the CDC's Social Vulnerability Index and heat-related health outcomes in Georgia. *International Journal of Disaster Risk Reduction, 46*, 101517. doi.org/10.1016/j.ijdrr.2020.101517

Manuel, P., Rapaport, E., Keefe, J., & Krawchenko, T. (2015). Coastal climate change and aging communities in Atlantic Canada: A methodological overview of community asset and social vulnerability mapping. *Canadian Geographies 59* (4): 433-446. doi.org/10.1111/cag.12203

Mao, W., & Agyapong, V. (2021). The role of social determinants in mental health and resilience after disasters: Implications for public health policy and practice. *Frontiers in Public Health 9*: 658528. doi.org/10.3389/fpubh.2021.658528

Martin, D., Thompson, S., Ballard, M., & Linton, J. (2017). Two-eyed seeing in research and its absence in policy: Little Saskatchewan First Nations Elders' experiences of the 2011 flood and forced displacement. *International Indigenous Policy Journal 8* (4): 1-25. ir.lib.uwo.ca/iipj/vol8/iss4/6

Martins de Freitas I. & Moraes S. (2016). Social vulnerability effect over obesity anthropometric indexes: results from population-based epidemiological study. *Revista Brasileira De Epidemiologia 19*(2): 433-450. doi.org/10.1590/1980-5497201600020018

Mavhura, E., Manyena, B., & Collins, A. (2017). An approach for measuring social vulnerability in context: The case of flood hazards in Muzarabani district, Zimbabwe. *Geoforum 86*: 103–117. doi.org/10.1016/j.geoforum.2017.09.008

McClean, D. (2021, March 17). Sendai Framework 6th Anniversary: Time to recognize there is no such thing as a natural disaster—we're doing it ourselves. *United Nations Office for Disaster Risk Reduction*. Retrieved from www.undrr.org/news/sendai-framework-6th-anniversary-time-recognize-there-no-such-thing-natural-disaster-were

McDonald-Harker, C., Drolet, J., & Sehgal, A. (2021). A strength-based approach to exploring factors that contribute to resilience among children and youth impacted by disaster. *The British Journal of Social Work 51* (5): 1897-1916. **doi.org/10.1093/bjsw/bcab109**

McKenzie, H., Varcoe, C., Browne, A., & Day, L. (2016). Disrupting the continuities among residential schools, the Sixties Scoop, and child welfare: An analysis of colonial and neo-colonial discourses. *The International Indigenous Policy Journal 7* (2): 1-24. **ir.lib.uwo.ca/iipj/vol7/iss2/4/**

McKeen, K., & Slatnik, M. (2022). The impacts of flooding on health. *BC Medical Journal 64* (10): 434. Retrieved from **bcmj.org/cohp/impacts-flooding-health**

McLeod, J., & Kessler, R. (1990). Socio-economic status differences in vulnerability to undesirable life events. *Journal of Health and Social Behaviour 31* (2): 162-172. **doi.org/10.2307/2137170**

Mensah, G., Mokdad, A., Posner, S., Reed, E., Simoes, E., Engelgau, M. (2005, November). When chronic conditions become acute: Prevention and control of chronic diseases and adverse health outcomes during natural disasters. *Preventing Chronic Disease 2*: 1-4. Retrieved from **www.ncbi.nlm.nih.gov/pmc/articles/PMC1459465/**

Meyer, M.A., Broome, F.R., & Schweitzer, R.H. (1975). Color statistical mapping in the U.S. Bureau of the Census. *American Cartographer 2* (2): 100-117. **doi.org/10.1559/152304075784313250**

Milnes, T., & Haney, T. (2017). “There’s always winners and losers:” Traditional masculinity, resource dependency, and post- disaster environmental complacency. *Environmental Sociology 3* (3): 260-273. **doi.org/10.1080/23251042.2017.1295837**

Morris, S., Fawcett, G., Brisebois, L., & Hughes, J. (2018, November 28). *Canadian Survey on Disability Reports: A demographic, employment, and income profile of Canadians with disabilities aged 15 years and over, 2017*. Retrieved from **www150.statcan.gc.ca/n1/pub/89-654-x/89-654-x2018002-eng.htm**

Myhre, D., Bajaj, S., Fehr, L., Kapusta, M., Woodley, K., & Nagji, A. (2017). Precepting at the time of a disaster. *The Clinical Teacher 14* (2): 104-107. **doi.org/10.1111/tct.12523**

Nguyen T.N., Ngangue P., Bouhali T., Ryan B.L., Stewart M., & Fortin M. (2019). Social vulnerability in patients with multimorbidity: a cross-sectional analysis. *International Journal of Environmental Research and Public Health 16* (7): 1244. **doi.org/10.3390/ijerph16071244**

National Collaborating Centres for Public Health, Yumagulova, L., Yellow Old Woman-Munro, D., & Dicken, E. (2021). *From the floodwaters: Siksika Nation and the Bow River Flood—Insights for a public health response to long-term evacuation (Case study #2)*. National Collaborating Centres for Public Health (NCCPH). Retrieved from **nccph.s3.amazonaws.com/uploads/2022/06/v2-Case-Study2-Long-term-Evacuation-Recovery-Series-2021.pdf**

Natural Resources Canada & Public Safety Canada. (2019). *Federal geomatics guidelines for flood mapping*. Natural Resources Canada, General Information Product 114e. **doi.org/10.4095/299810**

Naumann, G., Carrão, H., & Barbosa, P. (2018). Indicators of social vulnerability to drought. *In Drought* (pp. 111–125). John Wiley & Sons, Ltd. **doi.org/10.1002/9781119017073.ch6**

No Natural Disasters campaign. (N.d.). *There is no such thing as a 'natural' disaster*. Retrieved from **www.nonaturaldisasters.com/**

Oulahen, G., Mortsch, L., Tang, K., & Harford, D. (2015a). Unequal vulnerability to flood hazards: "Ground truthing" a social vulnerability index of five municipalities in Metro Vancouver, Canada. *Annals of the Association of American Geographers 105* (3): 473-495. **doi.org/10.1080/00045608.2015.1012634**

Oulahen, G., Shrubsole, D., & McBean, G. (2015b). Determinants of residential vulnerability to flood hazards in Metro Vancouver, Canada. *Natural Hazards 78*: 939-956. **doi.org/10.1007/s11069-015-1751-5**

Oulahen, G. (2016). The production of unequal vulnerability to hazards: a conceptual framework for hazards research in Canada's cities. *Canadian Geographer 60*: 82-90. **doi.org/10.1111/cag.12232**

Owusu, E., Shalaby, R., Eboreime, E., Nkire, N., Lawal, M., Agyapong, B., Pazderka, H., Obuobi-Donkor, G., Adu, M., Mao, W., Oluwasina, F., & Agyapong, V. (2022). Prevalence and determinants of generalized anxiety disorder symptoms in residents of Fort McMurray 12 months following the 2020 flooding. *Frontiers in Psychiatry 13*: 1-10. **doi.org/10.3389/fpsyt.2022.844907**

Pal, K. (2002). Assessing community vulnerability to flood hazard in Southern Ontario. Canadian *Water Resources Journal 27* (2): 155-173. **doi.org/10.4296/cwrj2702155**

Paulino, Y., Badowski, G., Chennaux, J., Guerrero, M., Cruz, C., King, R., & Panapasa, S. (2021). Calculating the social vulnerability index for Guam. *Natural Hazards Center Public Health Grant Report Series, 12*. Boulder, CO: Natural Hazards Center, University of Colorado Boulder. Retrieved from **hazards.colorado.edu/public-health-disaster-research/calculating-the-social-vulnerability-index-for-guam**

Pelling, M., Maskrey, A., Ruiz, P., Hall, P., Peduzzi, P., Dao, H., Mouton, F., Herold, C., Kluser, S., Harris, M., & Green, P. (2004). Reducing disaster risk: A challenge for development. *United Nations Development Programme, Bureau for Crisis Prevention and Recovery*. Retrieved from www.preventionweb.net/files/1096_rdrenglish.pdf

Public Safety Canada. (2017). *Building resiliency together: an emergency management framework for Canada*. Retrieved from www.publicsafety.gc.ca/cnt/rsrcs/pblctns/2017-mrgnc-mngmnt-frmwrk/2017-mrgnc-mngmnt-frmwrk-en.pdf

Public Safety Canada. (2022, August). *Adapting to rising flood risk: An analysis of insurance solutions for Canada*. A report by Canada's Task Force on Insurance and Relocation. Retrieved from www.publicsafety.gc.ca/cnt/rsrcs/pblctns/dptng-rsng-fld-rsk-2022/dptng-rsng-fld-rsk-2022-en.pdf

Public Safety Canada. (2023, May 11). *Backgrounder: Floods*. Retrieved from www.publicsafety.gc.ca/cnt/mrgnc- mngmnt/ntnl-rsk-prfl/bckgrndr-flds-en.aspx

Qiang, Y. (2019). Flood exposure of critical infrastructures in the United States. *International Journal of Disaster Risk Reduction 39*: 101240. doi.org/10.1016/j.ijdrr.2019.101240

Rajabali, R., & Agrawal, N. (2022). Taming the flow, then and now: A Canadian case of floodplain management. *Frontiers in Water 4*: 931214. doi.org/10.3389/frwa.2022.931214.

Ramin, B., & Svoboda, T. (2009). Health of the homeless and climate change. *Journal of Urban Health 86* (4): 654-664. doi.org/10.1007%2Fs11524-009-9354-7

Reading, C., & Wien, F. (2009). *Health inequalities and social determinants of Aboriginal People's health*. National Collaborating Centre for Aboriginal Health. Retrieved from www.ccnsa-nccah.ca/docs/determinants/RPT- HealthInequalities-Reading-Wien-EN.pdf

Reguero, B., Losada, I., Díaz-Simal, P., Méndez, F., & Beck, M. (2015). Effects of climate change on exposure to coastal flooding in Latin America and the Caribbean. *PLOS ONE 10* (7): e0133409. doi.org/10.1371/journal.pone.0133409

Ringnér, M. (2008). What is principal component analysis? *Nature Biotechnology 26* (3): 303-304. doi.org/10.1038/nbt0308-303

Rivera, D. (2020). Disaster colonialism: A commentary on disasters beyond singular events to structural violence. *International Journal of Urban and Regional Research 46* (1): 126-135. doi.org/10.1111/1468-2427.12950

Rivera, D., Jenkins, B., & Randolph, R. (2021). Procedural vulnerability and its effects on post-disaster recovery in low-income communities. *Journal of the American Planning Association 88* (2): 220-231. doi.org/10.1080/01944363.2021.1929417

Rözer, V., Müller, M., Bubeck, P., Kienzler, S., Thieken, A., Pech, I., Schröter, K., Buchholz, O., & Kreibich, H. (2016). Coping with pluvial floods by private households. *Water 8* (7): 1-24. doi.org/10.3390/w8070304

Runkle, J., Brock-Martin, A., Karmaus, W., & Svendsen, E. (2012). Secondary surge capacity: A framework for understanding long-term access to primary care for medically vulnerability populations in disaster recovery. *American Journal of Public Health 102* (12): 24-32. doi.org/10.2105%2FAJPH.2012.301027

Rural Health Information Hub (RHIH). (2022). *Rural Emergency Preparedness and Response*. Retrieved November 2022 from www.ruralhealthinfo.org/topics/emergency-preparedness-and-response

Russo, Hissa, K., Murphy, B., & Gunson, B. (2021). Photovoice, emergency management and climate change: a comparative case-study approach. *Qualitative Research: QR 21 (4)*: 568–585. doi.org/10.1177/1468794120934398

Sandink, D., Kovacs, P., Oulahen, G., & Shrubsole, D. (2016). Public relief and insurance for residential flood losses in Canada: Current status and commentary. *Canadian Water Resources Journal, 41* (1–2): 220–237. doi.org/10.1080/07011784.2015.1040458

Sahni, V., Scott, A., Beliveau, M., Varughese, M., Dover, D., Talbot, J. (2016). Public health surveillance response following the southern Alberta floods, 2013. *Canadian Journal of Public Health 107* (2): 142-148. doi.org/10.17269/cjph.107.5188

Scannell, L., Cox, R., & Fletcher, S. (2017). Place-based loss and resilience among disaster-affected youths. *Journal of Community Psychology 45* (7): 859-876. doi.org/10.1002/jcop.21897

Scherrieb, K., Norris, F., & Galea, S. (2010). Measuring capacities for community resilience. *Social Indicators Research 99*: 227-247. doi.org/10.1007/s11205-010-9576-9

Schmidtlein, M., Deutsch, R., Piegorsch, W., & Cutter, S. (2008). A sensitivity analysis of the social vulnerability index. *Risk Analysis 28(4)*: 1099–1114. doi.org/10.1111/j.1539-6924.2008.01072.x

Siagian, T., Purhadi, P., Suhartono, S., & Ritonga, H. (2014). Social vulnerability to natural hazards in Indonesia: Driving factors and policy implications. *Natural Hazards 70 (2)*: 1603–1617. doi.org/10.1007/s11069-013-0888-3

Smith, D. (1973). *Geography of Social Well Being*. New York: McGraw Hill.

Smith, T. (1981). Social indicators: A review essay. *Journal of Social History 14*: 739-747. doi.org/10.1353/jsh/14.4.739

Statistics Canada. (2017a, October 25). *Census in brief: The housing conditions of Aboriginal people in Canada*. Retrieved from www12.statcan.gc.ca/census-recensement/2016/as-sa/98-200-x/2016021/98-200-x2016021-eng.cfm

Statistics Canada. (2017b, November 29). *Dictionary, Census of Population, 2016.* Retrieved from www12.statcan.gc.ca/census-recensement/2016/ref/dict/index-eng.cfm

Statistics Canada. (2020). *Census of Population*. Retrieved from www23.statcan.gc.ca/imdb/p2SV.pl?Function=getSurvey&SDDS=3901#a3

Tapsell, S., & Tunstall, S. (2008). "I wish I'd never heard of Banbury:" The relationship between "place" and the health impacts from flooding. *Health & Place 14* (2): 133-154. doi.org/10.1016/j.healthplace.2007.05.006

Tapsell, S., McCarthy, S., Faulkner, H., & Alexander, M. (2010). Social vulnerability to natural hazards. *CapHaz-Net WP4 Report, Flood Hazard Research Centre—Middlesex University, London*. Retrieved from giam.zrc-sazu.si/sites/default/files/caphaz-net_wp4_social-vulnerability2.pdf

Tate, E. (2013). Uncertainty analysis for a social vulnerability index. *Annals of the Association of American Geographers 103* (3): 526–543. doi.org/10.1080/00045608.2012.700616

Tate, E., Rahman, M., Emrich, C., & Sampson, C. (2021). Flood exposure and social vulnerability in the United States. *Natural Hazards, 106* (1): 435–457. doi.org/10.1007/s11069-020-04470-2

Thompson, S., Ballard, M., & Martin, D. (2014). Lake St. Martin First Nation community members' experiences of induced displacement: 'We're like refugees.' *Refuge: Canada's Journal on Refugees 29* (2): 75-86. doi.org/10.25071/1920-7336.38168

Tobin-Gurley, J., Peek, L., & Loomis, J. (2010). Displaced single mothers in the aftermath of Hurricane Katrina: Resource needs and resource acquisition. *International Journal of Mass Emergencies and Disasters 28 (2)*: 170-206. doi.org/10.1177/028072701002800202

Ukumo, T., Abebe, A., Lohani, T., & Edamo, M. (2022). Flood hazard mapping and analysis under climate change using hydro-dynamic model and RCPs emission scenario in Woybo River catchment of Ethiopia. *World Journal of Engineering* (ahead-of-print). **doi.org/10.1108/WJE-07-2021-0410**

United Nations Development Program (UNDP). (2015). *Reducing disaster risk: A challenge for development—Global report*. Retrieved from **www.undp.org/sites/g/files/zskgke326/files/publications/Reducing%20Disaster%20risk%20a%20Challenge%20for%20development.pdf**

United Nations Office for Disaster Risk Reduction (UNDRR). (2017). Words into action guidelines: National disaster risk assessment. *Hazard specific risk assessment: Flood hazard and risk assessment.* Retrieved from **www.preventionweb.net/files/52828_04floodhazardandriskassessment.pdf?_gl=1*109oj5z*_ga*MTQ0Mj kwMDAyNC4xNjgzMDQ5MTY3*_ga_D8G5WXP6YM*MTY5MTg2NDYwNy44LjAuMTY5MTg2NDYxNi4wLjAuMA**

University of Waterloo. (N.d.). *President's Anti-Racism Taskforce, Glossary of Terms*. Retrieved from **uwaterloo.ca/presidents-anti-racism-taskforce/part-report/glossary-terms**

van Daalen, K., Savic Kallesoe, S., Davey, F., Dada, S., Jung, L., Singh, L., Issa, R., Emilian, C., Kuhn, I., Keygnaert, I., & Nilsson, M. (2022). Extreme events and gender-based violence: A mixed methods systematic review. *Lancet Planetary Health 6* (6): e504-523. **doi.org/10.1016/S2542-5196(22)00088-2**

Vasseur, L., Thornbush, M., & Plante, S. (2015). Gender-based experiences and perceptions after the 2010 winter storms in Atlantic Canada. *International Journal of Environmental Research and Public Health 12(10)*: 12518–12529. **doi.org/10.3390/ijerph121012518**

Vermont Department of Health. (N.d.). *Social Vulnerability Index: A User's Guide*. Retrieved from **ahs-vt.maps.arcgis.com/apps/MapSeries/index.html?appid=9478be15d6d4410f8eef8d420711310b**

Vickery, J. (2017). Using an intersectional approach to advance understanding of homeless persons' vulnerability to disaster. *Environmental Sociology 4 (1)*: 136-147. **doi.org/10.1080/23251042.2017.1408549**

Vyas, S., & Kumaranayake, L. (2006). Constructing socio-economic status indices: how to use principal components analysis. *Health Policy Plan 21 (6)*: 459-468. **doi.org/10.1093/heapol/czl029**

Wade, T. (2022, August). Overview of Canadian communities exposed to sea level rise. *National Collaborating Centre for Environmental Health*. Retrieved from **ncceh.ca/resources/evidence-reviews/overview-canadian-communities-exposed-sea-level-rise**

Waldram, J. (1988). *As long as the rivers run*. Winnipeg: University of Manitoba Press.

Walker, H., Reid, M., & Fletcher, A. (2022). Applying intersectionality to climate hazards: a theoretically informed study of wildfire in northern Saskatchewan. *Climate Policy 21 (2)*: 171-185. doi.org/10.1080/14693062.2020.1824892

Wall, E., & Marzall, K. (2007). Adaptive capacity for climate change in Canadian rural communities. *International Journal of Justice and Sustainability 11 (4)*: 373-397. doi.org/10.1080/13549830600785506

Weichselgartner, J. (2001). Disaster mitigation: The concept of vulnerability revisited. *Disaster Prevention and Management: An International Journal 10 (2)*: 85–95. doi.org/10.1108/09653560110388609

Wilson, D., & Macdonald, D. (2010, April). The income gap between Aboriginal peoples and the rest of Canada. *Canadian Centre for Policy Alternatives*. Retrieved from policyalternatives.ca/sites/default/files/uploads/publications/reports/docs/Aboriginal%20Income%20Gap.pdf

Wisner, B., Blaike, P., Cannon, T., & Davis, I. (2004). *At Risk: Natural Hazards, People's Vulnerability, and Disasters* (second ed.). London: Routledge. doi.org/10.4324/9780203974575

Wold, S., Esbensen, K., & Geladi, P. (1987). Principal component analysis. *Chemometrics and Intelligent Laboratory Systems 2 (1)*: 37–52. doi.org/10.1016/0169-7439(87)80084-9

Wood, E., Sanders, M., & Frazier, T. (2021). The practical use of social vulnerability indicators in disaster management. *International Journal of Disaster Risk Reduction 63*: 102464. doi.org/10.1016/j.ijdrr.2021.102464

Yee C., Cunnigham S., & Ickovics, J. (2019) Application of the social vulnerability index for identifying teen pregnancy intervention need in the United States. *Maternal Child Health Journal 23 (11)*: 1516-1524. doi.org/10.1007/s10995-019-02792-7

Yumagulova, L. (2020). Disrupting the riskscapes of inequities: a case study of planning for resilience in Canada's Metro Vancouver region. *Cambridge Journal of Regions, Economy, and Society 31 (2)*: 293-318. doi.org/10.1093/cjres/rsaa029

Ziolecki, A., Thistlethwaite, J., Henstra, D., & Scott, D. (2020, September). *Canadian Voices on Flood Risk 2020: Findings from a national survey about how we should manage an increasingly costly and common peril.* Waterloo, Ontario: Partners for Action, University of Waterloo. Retrieved from uwaterloo.ca/partners-for-action/sites/default/files/uploads/files/finalreport_nationalsurvey_sept20.pdf

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