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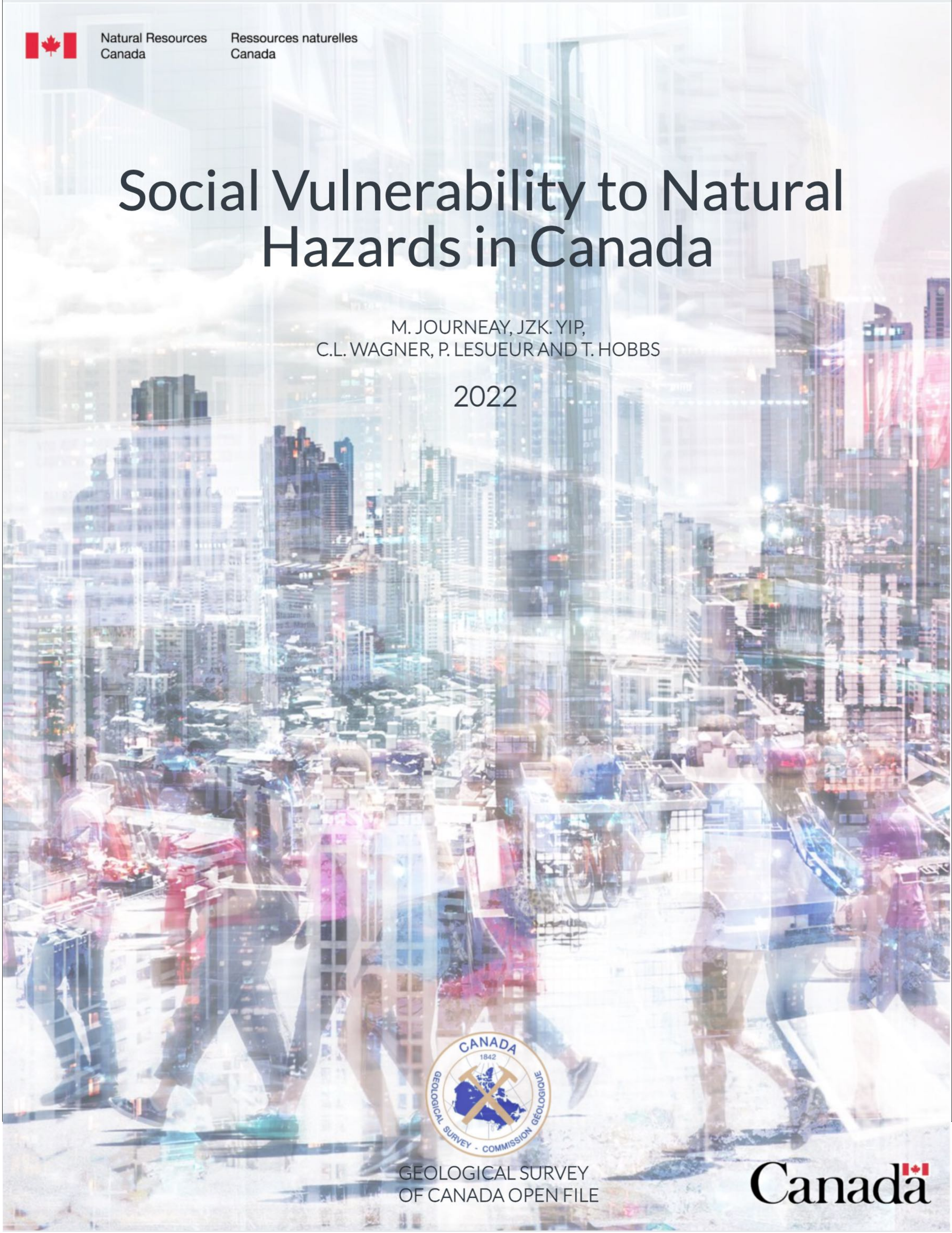

Social Vulnerability to Natural Hazards in Canada

M. JOURNEAY, JZK. YIP,
C.L. WAGNER, P. LESUEUR AND T. HOBBS

2022

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Author(s): M. Journeay, JZK. Yip, C.L. Wagner, P. LeSueur and T. Hobbs

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Social Vulnerability to Natural Hazards in Canada

Authors: M. Journeay[1], JZK. Yip[2], C.L. Wagner[1], P. LeSueur[1] and T. Hobbs[1]

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ABSTRACT

While we are exposed to the physical effects of natural hazard processes, certain groups within a community often bear a disproportionate share of the negative consequences when a disaster strikes. This study addresses questions of why some places and population groups in Canada are more vulnerable to natural hazard processes than others, who is most likely to bear the greatest burden of risk within a given community or region, and what are the underlying factors that disproportionally affect the capacities of individuals and groups to withstand, cope with, and recover from the impacts and downstream consequences of a disaster. Our assessment of social vulnerability is based on principles and analytic methods established as part of the Hazards of Place model (Hewitt et al., 1971; Cutter, 1996), and a corresponding framework of indicators derived from demographic information compiled as part of the 2016 national census. Social determinants of hazard threat are evaluated in the context of backbone patterns that are associated with different types of human settlement (i.e., metropolitan, rural, and remote), and more detailed patterns of land use that reflect physical characteristics of the built environment and related functions that support the day-to-day needs of residents and businesses at the community level. Underlying factors that contribute to regional patterns of social vulnerability are evaluated through the lens of family structure and level of community connectedness (social capital); the ability of individuals and groups to take actions on their own to manage the outcomes of unexpected hazard events (autonomy); shelter conditions that will influence the relative degree of household displacement and reliance on emergency services (housing); and the economic means to sustain the requirements of day-to-day living (e.g., shelter, food, water, basic services) during periods of disruption that can affect employment and other sources of income (financial agency). Results of this study build on and contribute to ongoing research and development efforts within Natural Resources Canada (NRCan) to better understand the social and physical determinants of natural hazard risk in support of emergency management and broader dimensions of disaster resilience planning that are undertaken at a community level. Analytic methods and results described in this study are made available as part of an Open Source platform and provide a base of evidence that will be relevant to emergency planners, local authorities and supporting organizations responsible for managing the immediate physical impacts of natural hazard events in Canada, and planners responsible for the integration of disaster resilience principles into the broader context of sustainable land use and community development at the municipal level.

Table of Contents

List of Figures

List of Tables

ACKNOWLEDGEMENTS

Social Vulnerability to Natural Hazards in Canada is the result of a five-year research and development effort by the Land and Minerals Sector of Natural Resources Canada (LMS/NRCan) to establish an integrated framework of methods, tools, and information to support the assessment of disaster risk at local and regional levels in Canada. Our study has benefited from the contributions of many individuals and organizations who have generously shared ideas and insights with our team over the years. From the beginning, this work has been made possible through organizational support provided by the Public Safety Geoscience Program and fellow colleagues including *Nicky Hastings, Malaika Ulmi, Julie Van de Valk, Joost van Ulden and Drew Rotheram*. *Vienna Watt* assisted our team in the delineation of developed areas boundaries in isolated rural and remote settings. Research colleagues at the UBC School of Architecture and Landscape Architecture (SALA; *Ron Kellett, Cynthia Girling, and Jon Salter*) generously shared ideas on modeling patterns of land use and associated archetypes of the built environment at local and regional scales, while colleagues at the UBC School of Community Planning (SCARP; *Stephanie Chang, Ryan Reynolds and Juri Kim*) shared valuable insights on modelling patterns of social vulnerability and community resilience at local and regional scales in Canada. *Christopher Burton* of the Global Earthquake Model Foundation (GEM) shared knowledge and expertise in developing national-level models of social vulnerability to support the requirements of natural hazard threat and integrated risk assessment. *Sahar Safaie* (Sage on Earth Consulting) provided guidance on the development and implementation of national assessment frameworks to promote a shared understanding of disaster risk in support of policy goals outlined in the UN Sendai Framework for Disaster Risk Reduction (SFDRR: 2015-2030). Testing and validation of model capacities to inform both emergency management and disaster resilience planning was made possible through collaborations with practitioners and private sector consultants working on behalf of municipal and provincial authorities in British Columbia. These include *Katia Tynan* and *Tamsin Mills* (City of Vancouver), *Fiona Dercole and John Chapman* (North Shore Emergency Management: NSEM), *Tamsin Lyle* (Ebbwater Consulting), *Sarah North* (Northwest Hydraulic Consultants Ltd.), *Kris Holm* (BGC Engineering Inc.), and provincial colleagues involved in regional emergency planning and policy development including *Katherine Forge and Robert White* (Emergency Management BC). We thank *Julie Van de Valk* for her insights and very constructive input as a technical reviewer of the final report. Finally, we are grateful to family and friends for their generous support and encouragement every step along the way.

1.0 INTRODUCTION

Disaster risk management is about setting priorities and negotiating trade-offs in a world of both limited resources and competing policy goals where the potential for negative consequences related to ongoing development in areas exposed to known natural hazards often exceed the limits of what society can handle. While we are exposed to the physical effects of natural hazard processes in a similar way, certain groups within a community often bear a disproportionate share of the negative impacts and related socioeconomic consequences when a disaster strikes. Lower-income households, recent immigrants, racially marginalized populations, and other groups whose rights and needs are not always fully considered in the context of community planning or disaster risk management are most often the ones who are encumbered with more limited access to support networks and the resources are needed to weather unexpected disaster events. (Blaikie et al., 1994; Comfort et al., 1999; Petterson, 1999; Godschalk, 2003; Andrews et al., 2016; Sarmiento et al., 2020). Understanding these disparities as the outcome of underlying social, economic, and political factors that have influenced patterns of development within a community or region is an important step in identifying and prioritizing actions that can be taken in advance to reduce intrinsic social vulnerabilities and to enhance the prospects of longer-term disaster resilience

This study describes both analytic methods and the resulting outputs of a national model developed to assess intrinsic social vulnerabilities to natural hazard threats at the community level in Canada. The model is designed to identify and evaluate characteristics of social vulnerability in the context of broad settlement types and associated patterns of land use that reflect both where people live and underlying socioeconomic factors that can differentially affect the capacities of communities to withstand and recover from a disaster event. Profiles of social vulnerability are assessed at the dissemination area level for all settled areas in Canada using a framework of indicators derived from demographic information compiled as part of the 2016 national census. Model results are incorporated into an integrated assessment of earthquake and tsunami hazards to evaluate the combined social and physical determinants of hazard threat and the implications for disaster risk management at the community level.

The national social vulnerability model (CanSVM) builds on and contributes to broader research and development efforts within Natural Resources Canada (NRCan) to establish a framework for integrated risk assessment at the community level. A framework with a capacity to analyze the potential impacts and related socioeconomic consequences of future disaster events and their implications for the most vulnerable members of society – and to assist local authorities in evaluating the efficacy of investing in risk reduction measures that increase capacities for functional recovery and the longer term prospects of sustainable development. The components of NRCan's framework for integrated risk assessment are summarized in Figure 1-1. Outputs of this work are useful in establishing a more holistic understanding of disaster risk that addresses both physical and social dimensions of vulnerability, and in building the analytic capacities needed to support implementation of policies developed as part of the Sendai Framework for Disaster Risk Reduction (SFDRR; United Nations Office for Disaster Reduction [UNDRR], 2015). The intended outcome of this work is to increase societal resilience through the development of a shared body of knowledge that informs emergency planning and sustainable development in accordance with established international guidelines (Safaie, 2017; Trogrlić et al., 2017; United Nations Office for Disaster Risk Reduction [UNDRR], 2017).

1.1. Context and Motivation

The demands of ongoing growth and development in areas exposed to known natural hazard threats are outpacing the capacities of many communities and organizations to manage corresponding levels of disaster risk in many parts of the world (UN International Strategy for Disaster Reduction [UNISDR], 2002; Pelling et al., 2004; Global Facility for Disaster Reduction and Recovery [GFDRR], 2016; Mcglade et al., 2019). In addition to the expansion and densification of metropolitan commmunities across Canada, the effects of a changing climate are increasing both the frequency and intensity of many hydrometeorological hazards. The Sendai Framework for Disaster Risk Reduction offers a foundation of policy goals and related target criteria that are intended to help guide the development of strategies to manage the effects of future damaging hazard events at a global scale (SFDRR 2015-2030: United Nations Office for Disaster Reduction [UNDRR], 2015). The SFDRR has been endorsed by the United Nations and participating member nations (including Canada). It is intended to be implemented in conjunction with International Sustainable Development Goals (SDG 2015-2030: United Nations General Assembly, 2015) to increase both overall disaster resilience and the prospects for longer-term sustainability at the community level. Priorities and core capabilities identified for successful implementation of SFDRR include:

- a shared understanding of disaster risk amongst key decision makers and their constituents — including both current conditions and the underlying social, economic, and political factors that are driving escalating levels of risk into the future, and
- a framework of indicators that improve the dissemination of disaster risk information, and that provide the necessary base of evidence to inform investments in mitigation and/or adaptation measures, and

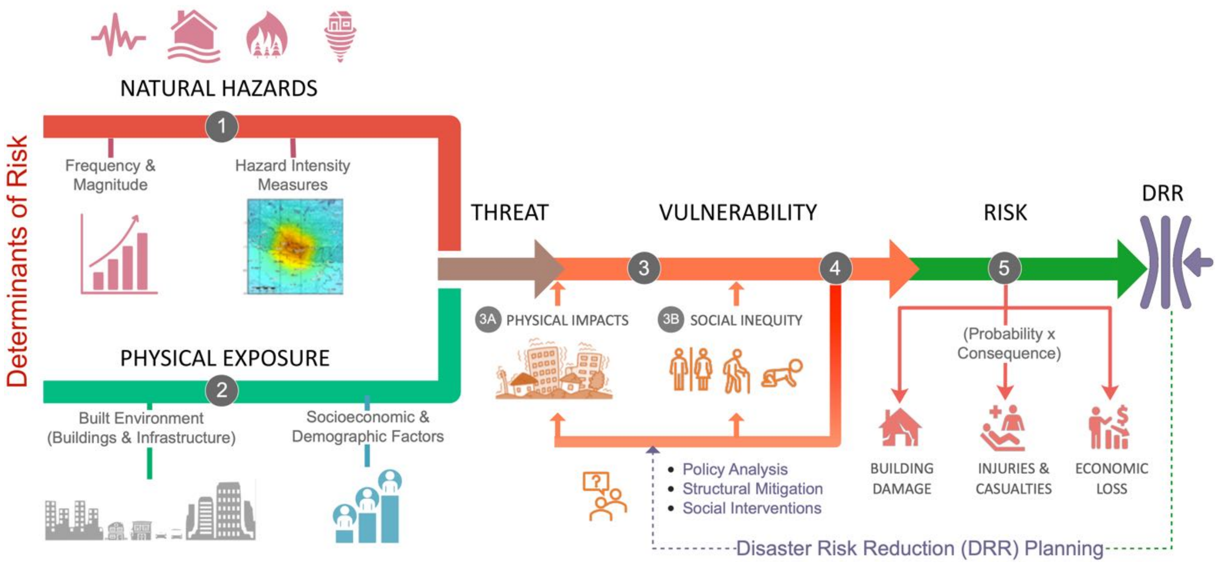


Figure 1-1: Analytic methods used in developing NRCan's national risk assessment framework to support disaster resilience planning at local and regional scales in Canada. Figure adapted from Freddi et al. (2021).

that promote the resilience of critical infrastructure systems.

The recent adoption of SFDRR principles in Canada has led to an increased understanding of the critical role that disaster risk information has in promoting community resilience and sustainable development strategies at all jurisdictional levels. Nonetheless, there remain significant challenges in establishing the evidence, incentives, and resources that are required to incorporate disaster risk information into the broader context of planning and policy development. To this end, Public Safety Canada and Defence Research and Development Canada have embarked on a multi-year project to establish a national profile of disaster risk with a goal of increasing our understanding of floods, wildfire, and earthquakes, and the capacities needed to transform this knowledge into actionable strategies for disaster risk reduction (Public Safety Canada, 2013, 2018).

While the need to incorporate an understanding of social fabric into mainstream emergency planning and disaster risk management is generally understood and acknowledged in SFDRR policy guidelines, the focus of these efforts remain on measuring the physical dimensions of risk and monitoring the effectiveness of actions taken to reduce the impacts of disasters on people and critical assets. Meanwhile, the mechanisms and capacities needed to address the underlying root causes of social vulnerability are situated in separate but complementary realms of spatial planning and policy development that support broader goals of sustainable development (SDG 2015-2030; UN General Assembly, 2015). The disconnect between realms of disaster risk managemenet and sustainable development is significant and often left to practitioners working at local levels of government to reconcile in the context of community planning and land use decision making. For many communities, the challenge is in sourcing the necessary information, knowledge, and insights needed to develop integrated disaster risk reduction strategies that are robust enough to meet the increasingly stringent requirements of sustainable community development where regulatory requirements for public safety and security of public assets must be balanced against competing demands for economic growth, social equity, and environmental integrity. For others, there are political challenges in considering investments in longer-term risk reduction measures that threaten to draw scarce resources away from what appear to be more immediate public policy concerns (Burby, 1998; Mileti, 1999; Mileti et al., 2005). In some cases, existing conditions of social vulnerability can be amplified through land use, mitigation and/or adaptation strategies that inadvertently undermine the capacities of community members to weather the impacts of unexpected disaster events.

1.2. THE SOCIAL DIMENSIONS OF VULNERABILITY

Social fabric describes the demographic characteristics of people living within a neighbourhood or region and their relative capacities to anticipate, withstand, and cope with the sudden shocks of hazard events that can disrupt the normal routines of day-to-day life. The threads of this complex and interwoven fabric of social interactions are often characterized through the lens of vulnerability and/or resilience. Vulnerability focuses on the underlying characteristics of social systems that exist prior to a disaster event that can predetermine where people live in a community and their exposure to known hazard threats, differential levels of access to resources and services that are needed to support the day-to-day activities of residents and businesses, and the degree to which members of a community may be negatively impacted (Cutter, 2001; Wisner, 2004; Birkmann, 2006). Resilience refers to the inherent capabilities of social systems to take actions in advance of or following a disaster event that increase levels of safety, security and the prospects of functional recovery for all members of a community or region (Folke et al., 2002; Adger et al., 2005; Walker et al., 2006).

Social vulnerability models are situated in the broader context of integrated assessment frameworks that seek to explain the complex set of interactions between human and natural systems. They vary considerably in terms of theoretical foundations used to explain the determinants of vulnerability, and the corresponding analytic methods used to measure the extent to which community members may be differentially affected in the event of a disaster (see reviews by: Brooks, 2003; Birkmann, 2006; Cardona et al., 2012; Burton et al., 2018). At one end of the spectrum are 'Hazard-Risk' models that define vulnerability as the capacity of people to withstand and recover from the physical impacts of natural hazard events and the potential to suffer harm as a result (see for example: Mileti, 1999; Alexander, 2005). Social vulnerability in this context is interpreted to be an outcome of natural hazard events in which human adjustment behaviours influence the extent to which certain populations are exposed and made susceptible to both the initial physical impacts and related downstream consequences of a disaster. From this perspective, behavioural adjustments are motivated by levels of risk perception and the extent to which actions are taken by individuals and groups to manage the physical impacts of natural hazard events through proactive investments in mitigation, adaptation, and/or emergency preparedness measures (e.g., land use zoning, building codes, emergency planning, insurance). Although reflecting underlying social and economic conditions that are particular to a given community, human adjustment behaviours are generally interpreted to be external factors that can either lessen or amplify the outcomes of a disaster event.

At the other end of the spectrum are conceptual models based on principles of political economy and/or human ecology that define vulnerability in terms of the intrinsic characteristics of different population groups (e.g., race, ethnicity, income, gender) and their relative degree of influence on decisions made within a broader societal context that can affect capacities to weather the impacts of a natural hazard event (e.g., Bohle et al., 1994;

Turner et al., 2003; Wisner, 2004; Adger, 2006). Vulnerability in this context is interpreted to be the outcome of deeply rooted inequities that differentially affect access to social, economic, and/or political entitlements, thereby predisposing certain populations within a community to bear a disproportionate burden of disaster risk. These systemic inequities are further amplified and made evident by the dynamic pressures of ongoing growth and development in areas subjected to persistent socioeconomic stress (e.g., unsafe housing conditions, resource allocation, marginalization), and/or the sudden physical impacts of a natural hazard event (Blaikie et al., 1994). By focusing on the underlying social determinants of vulnerability, these models seek to explain why people with similar levels of physical exposure and susceptibility to natural hazard threats may experience very different outcomes in terms of relative degrees of safety and socioeconomic security.

Situated between these two end-member views is the 'Hazards of Place' model, which considers both the underlying social determinants of vulnerability and corresponding physical characteristics of exposure and susceptibility to natural hazard threats that are specific to a particular geographic setting (Hewitt et al., 1971; Cutter, 1996). A distinguishing characteristic of this model is a focus on the spatial interactions between social, economic, and physical dimensions of vulnerability that vary over time and that are manifest in different ways at the scale of a given community or region. System interactions are evaluated using a blend of statistical analysis and geospatial modeling to assess how patterns of vulnerability vary from one place to another as a function of (i) social inequities that are intrinsic to a particular community or region; (ii) levels of physical exposure and susceptibility to natural hazards that are controlled by geographic setting; and (iii) human adjustment behaviors that have a potential to either amplify or lessen the outcomes of disaster events over time. The Hazards of Place model has been used to assess patterns of vulnerability at regional and national scales, and to situate vulnerability assessment into the broader context of disaster resilience, sustainability and climate change adaptation planning (e.g., Cutter et al., 2000; Chakraborty, 2001; Cutter, 2001; Chakraborty et al., 2005b; Collins, 2008; Birkmann et al., 2013; Koks et al., 2015). Assessments of social vulnerability that have been undertaken in a Canadian context include national surveys of inequity and marginalization that are rooted in principles of human ecology (Matheson et al., 2012; Statistics Canada, 2019), and regional studies that have implemented the Hazards of Place model to assess social vulnerability in the context of various natural hazard threats (Jones, 2003; Andrey et al., 2008; Fox, 2008; Chang et al., 2015; Journeay et al., 2015; Oulahen et al., 2015; Chang et al., 2018; Oulahen et al., 2018; Chakraborty et al., 2020; Chakraborty et al., 2021).

1.3. Study Scope and Objectives

This study documents a national implementation of the Hazards of Place model for assessing intrinsic social vulnerabilities to natural hazard threats at a community level in Canada. It specifically addresses questions of (i) *why* some places and population groups in Canada are more vulnerable to natural hazards than others; (ii) *who* is most likely to bear the greatest burden of risk within a given community or region; and (iii) *what* are the underlying factors that disproportionally affect the capacities of individuals and groups to withstand, cope with, and recover from the impacts and downstream consequences of a disaster. Conceptual framing of model components and their contribution to a broader assessment of integrated hazard threat are summarized in Figure 1-2.

Social dimensions of vulnerability are well documented in the literature (Morrow, 1999; Cutter et al., 2000; Cutter et al., 2003; Dwyer et al., 2004; Boruff et al., 2005; Mendes, 2009). They include a consideration of family structure and level of community connectedness that can affect levels of support in times of need (social capital); the ability of individuals and groups to take actions on their own that will affect the outcomes of a hazard event (autonomy); shelter conditions that will influence the relative degree of household displacement and reliance on emergency services (housing); and the economic means to sustain the requirements of day-to-day living (e.g., shelter, food, water, basic services) during periods of disruption that can affect employment and other sources of income (financial agency). Although land tenure and related governance structures are used to identify and measure disparities between those living on Indigenous lands and the general population, we do not specifically address underlying systemic issues of ethnic and racial marginalization or inequities related to community health and access to basic services. Also not included in the scope of this analysis are specific measures of community health such as medical conditions, coping skills, and local access to health services. While these factors are known to influence general capacities for both response and recovery, the supporting information needed to measure dimensions of community health at the neighbourhood scale is not yet available in a coherent and publicly accessible format for all regions in Canada.

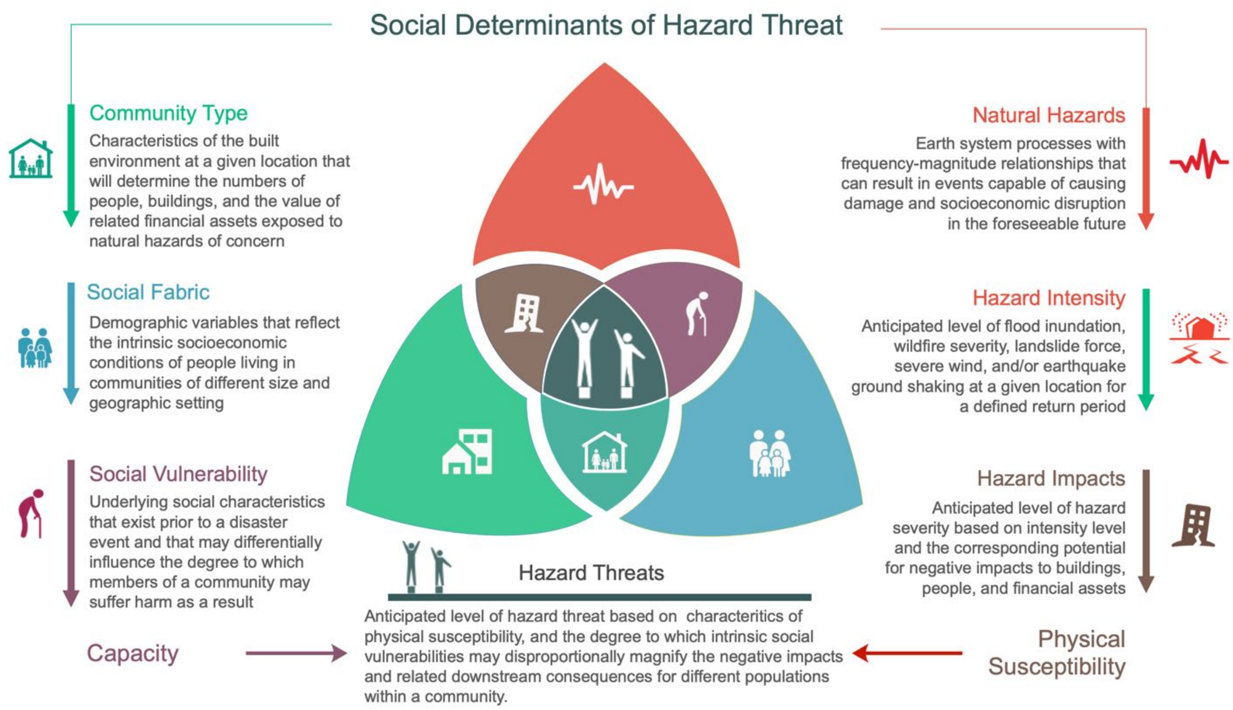


Figure 1-2: Theoretical framing and concepts used to characterize the social determinants of natural hazard threat.

Physical dimensions of vulnerability are based on a national exposure model documenting fundamental characteristics of the built environment and corresponding levels of susceptibility to natural hazard threats for settled areas in Canada (Journeay et al., work in progress, 2022). This includes the mapping of settled area boundaries, functional land use classes, and the corresponding portfolios of buildings, people, and financial assets that are susceptible to the physical impacts of known earthquake, tsunami, riverine flood, hurricane, wildfire, and landslide hazards in Canada. In addition to establishing the necessary context for understanding relationships between development and associated patterns of vulnerability, model outputs are used to pilot a methodology for assessing the combined physical and social determinants of hazard threat at the community level using available information on earthquake and tsunami hazard in Canada.

The primary goals and objectives of this report are to:

- Document the analytic methods used to develop the national social vulnerability model (CanSVM), including sources of information, overall design and structure of the assessment framework, and the specific steps involved in measuring underlying socioeconomic factors that influence profiles of vulnerability at a given location.
- Describe current patterns of social vulnerability in Canada through the lens of broad settlement types and regional land use profiles that reflect the influence of underlying social, economic, and political factors that can affect the capacities of community members to withstand, cope with, and recover from the negative consequences of a disaster event.

- Use detailed outputs of the social vulnerability model to carry out a preliminary assessment of who and what are situated in areas exposed to the physical impacts of earthquake and tsunami hazards, corresponding levels of integrated hazard threat, and the implications for disaster risk management in Canada.

1.4. Outputs and Intended Audience

Primary outputs of this study include a framework of indicators (maps and charts) that collectively measure the social and physical dimensions of natural hazard threat for all settled areas in Canada and an accompanying collection of geospatial datasets to support disaster resilience planning at local and regional scales. As illustrated in Figure 1-3, study outputs are framed around separate indices for social vulnerability and physical susceptibility to natural hazards. These indices are combined to generate an integrated hazard threat index that measures who and what are susceptible to the physical impacts of known natural hazards and underlying socioeconomic factors that may differentially affect the capacities of individuals and groups to bear the physical, social, and economic consequences associated with disaster events and the potential to suffer harm as a result.

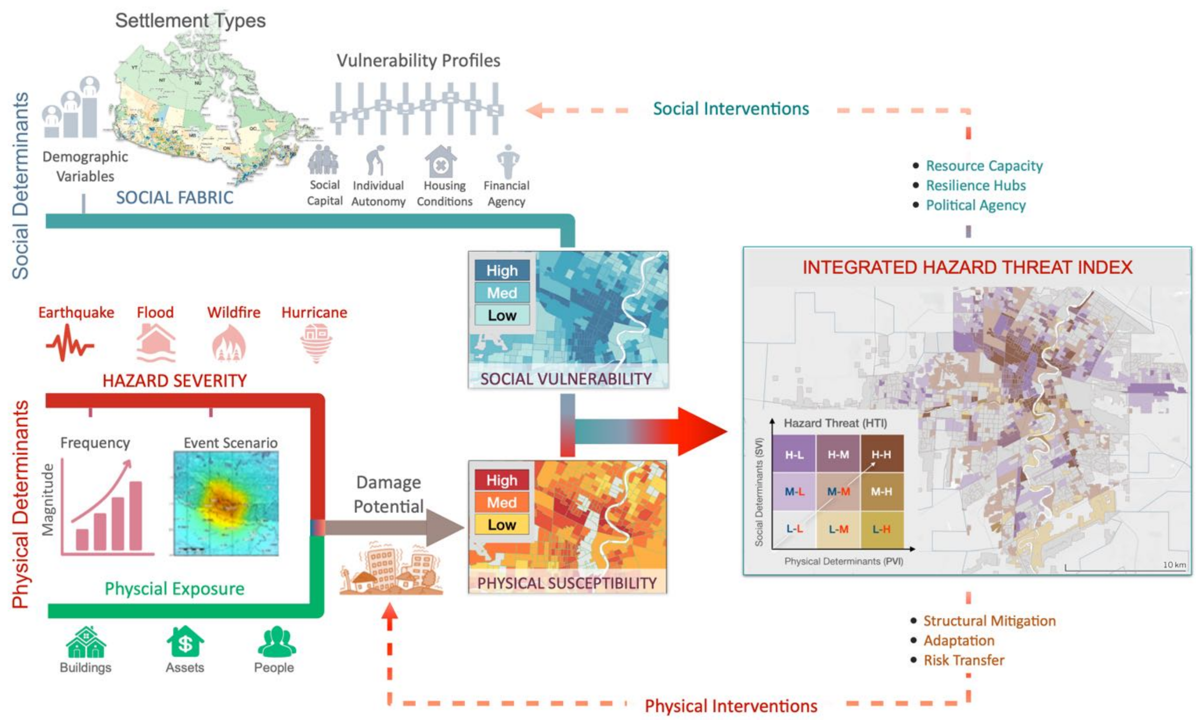


Figure 1-3: Components of a national model of social vulnerability to natural hazard threats in Canada.

Study results are published in accordance with the Government of Canada's Roadmap for Open Science and related policies that govern access to and the distribution of Open Data (Government of Canada, 2017, 2018, 2020). Model outputs are accessible through an open-data platform designed to support disaster resilience planning in Canada (Natural Resources Canada, 2021b). The overarching goal of this work is to raise awareness and understanding of the social determinants of risk and how this information can be used in practice to inform actionable disaster risk reduction strategies at local and regional scales in Canada. Primary end users are likely to include emergency management practitioners responsible for addressing the impacts of future hazard events during immediate and sustained response stages of disaster recovery, and community planners who may need additional information to undertake an integrated HVRA to inform policies that enhance both overall disaster resilience and the prospects for sustainable development.

2.0 METHODOLOGY

Our assessment of social vulnerability to natural hazards in Canada is based on theoretical principles established by the Hazards of Place model, and on methodological insights gained through previous implementations of the Social Vulnerability Index (SVI) in a North American context (Clark et al., 1998; Cutter et al., 2000; Cox et al., 2006; Cutter et al., 2008; Rufat, 2013; Oulahen et al., 2015; Horney et al., 2017; Chang et al., 2018; Chakraborty et al., 2020). Highlights of the model development process are summarized in Figure 2-1.

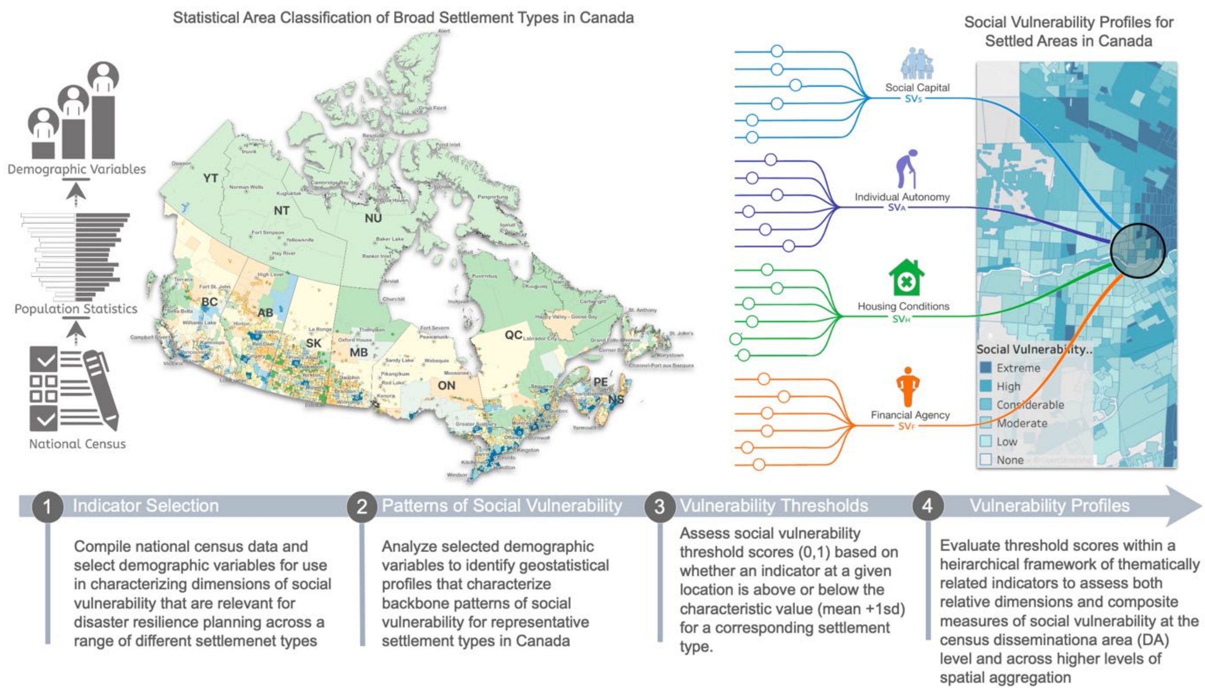


Figure 2-1: Summary of analytic workflow used to develop the national social vulnerability model for Canada.

Social dimensions of vulnerability are assessed in the context of broad settlement types that reflect both the history of development in different parts of Canada and underlying social, economic, and political systems that have influenced corresponding patterns of land use at the community level. Land use patterns include dense urban centres and surrounding suburban neighbourhoods that occur in larger metropolitan regions, rural hinterland communities of variable size and degree of metropolitan influence, and more remote settlements that are situated along isolated coastlines and/or within sparsely populated regions of Canada's far north. Relationships between these fundamental patterns of development and characteristics of social vulnerability are analyzed using demographic variables compiled at the dissemination area level as part of the national census. Principal Component Analysis (PCA) methods are used to select a subset of indicators that best describe relevant statistical trends at a national scale within a broader set of demographic variables. This smaller subset of indicators is then analyzed to identify how patterns of vulnerability are manifest in the context of different settlement types and corresponding patterns of land use.

Characteristics of social fabric are evaluated using a hierarchical framework of composite indices that measure both absolute levels of vulnerability at a given location, and the relative contributions of underlying socioeconomic factors that are known to influence the capacities of community members to withstand, cope with and recover from disaster events. These include characteristics of family structure, housing conditions, the capacity of individuals to make decisions that will affect their own well-being, and the financial resources needed to weather both the physical impacts and downstream economic consequences of a disaster event.

Fundamental patterns of social vulnerability are made evident by measuring the number of instances where indicators at a given location exceed values that are characteristics for a corresponding settlement type (mean + 1 standard deviation [sd]). Disparities in the level and distribution of social vulnerability are evaluated in the context of land governance and associated patterns of development to help shed light on potential inequities that may exist within a community or region.

Physical dimensions of vulnerability are based on a national exposure model documenting fundamental characteristics of the built environment and corresponding levels of susceptibility to natural hazard threats for all settled areas in Canada (Journeay et al., work in progress, 2022). Interactions between social and physical dimensions of vulnerability at a given location are examined using a combination of mathematical integration and thematic mapping techniques. Numerical integration is used to help identify and rank hotspot areas of concern where vulnerable populations are situated in areas exposed to significant levels of natural hazard threat. Bivariate mapping techniques are used to analyze spatial interactions and potential causal relationships between social and physical dimensions of vulnerability at the community level, and the implications for overall susceptibility to natural hazard threats.

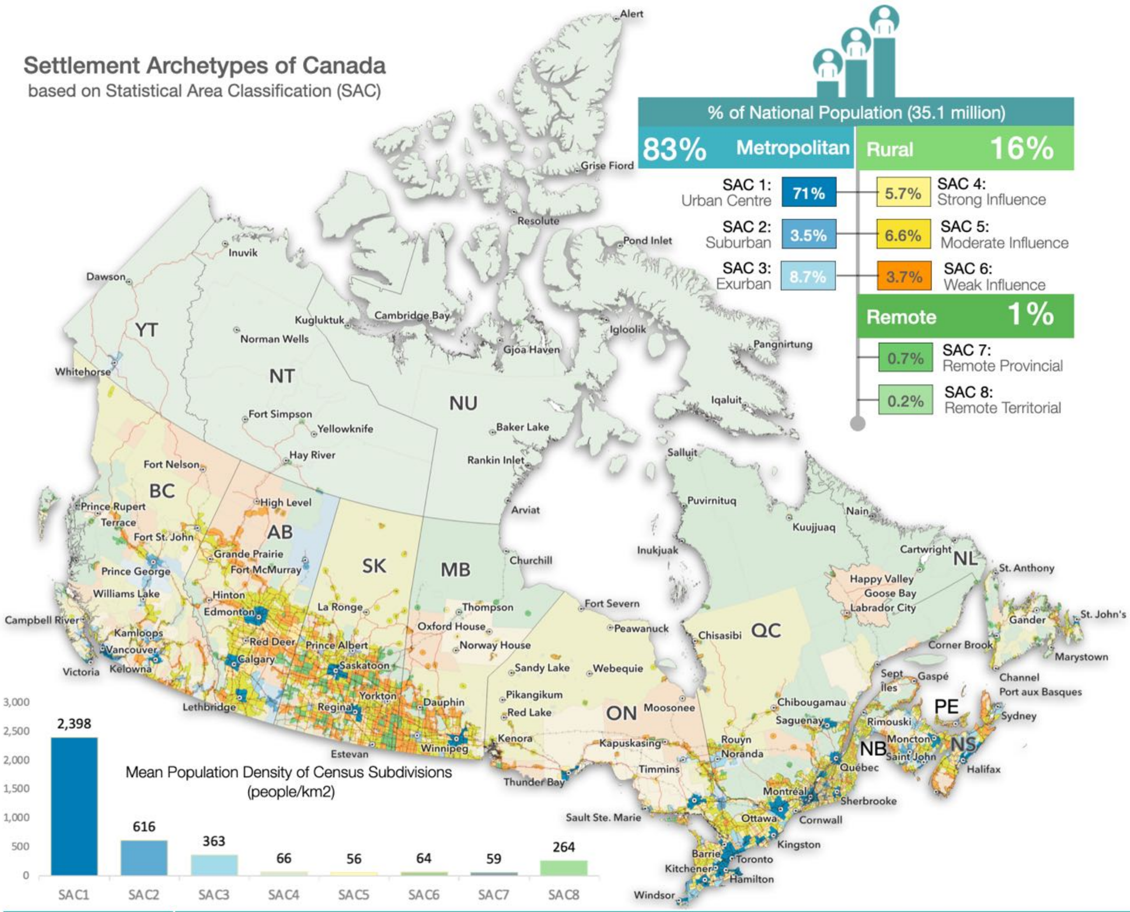
2.1. Model Design and Structure

The national CanSVM model is framed in the context of specific settlement types that reflect intrinsic characteristics of the built environment (e.g., density, land use, tenure, and governance), and the hierarchical arrangement of complex social, economic, and political systems that have shaped fundamental patterns of development over time. Acknowledging the relationships between broad patterns of land use and the corresponding socioeconomic characteristics of population groups that have evolved as part of the development process is an important first step in attempting to measure and evaluate underlying dimensions of social vulnerability (Blaikie et al., 1994; Burby, 1998; Mileti, 1999; Mileti et al., 2005). This is particularly important in large and sparsely populated countries like Canada where fundamental patterns of settlement can vary considerably from place to place as a function of geography, the dynamics of population growth, land management practices, and differential access to basic lifeline services. Each of these variables can influence the intrinsic capabilities of people to both withstand and recover from the impacts of a disaster event.

For example, we know that people living in remote regions of Canada are generally more independent and resilient to change, but also more likely to experience poor health, unmet medical needs, and lower life expectancy as a result of limited access to lifeline services (Canadian Institute for Health Information (Cihi), 2012; Subedi et al., 2019). In contrast, metropolitan regions are characterized by dense urban neighbourhoods with mixed populations of different racial, cultural, and ethnic backgrounds who have more ready access to basic lifeline services, but who are more likely to experience deep-rooted patterns of social inequity, displacement, and exclusion from wealth-generating opportunities (Blaikie et al., 1994; Comfort et al., 1999; Cutter et al., 2003; Pelling, 2003; Wisner, 2003; Batty, 2013). Intrinsic patterns of social inequity in larger cities are amplified by development pressures associated with continued population growth and densification that can vary in both complexity and levels of intensity from one region to another. While there is diversity in the fundamental characteristics of social fabric across different types of communities, it is the mix of demographic variables, and their relative degree of influence, that ultimately shape patterns of vulnerability within any given community. Demographic variables such as age, family structure, and cultural identity that may limit the capacities of those living in high-density urban neighbourhoods to manage sudden disruptions caused by a hazard event are, in many cases, the same attributes that promote resilience and adaptability among those living in more rural and remote settings.

2.1.1. Characteristics of Settlement Type

With these considerations in mind, the assessment framework for evaluating conditions of social vulnerability in Canada is structured around a mosaic of eight fundamental settlement types that are distinguished based on characteristics of size, geographic setting, and level of hierarchy within broader socioeconomic systems that support the day-to-day functional requirements of homes and businesses at the community level. As illustrated in Figure 2-2 and described below in more detail, each settlement type is defined by Statistics Canada (2016a) based on a statistical area classification (SAC) that groups census subdivisions (CSD) according to population density and whether they are part of a broader census metropolitan area (CMA), a census agglomeration (CA), or distributed within less dense rural or remote settings with variable degrees of metropolitan influence (MIZ).



Geographic Context		Distribution of Census Subdivisions based on Statistical Area Classification (SAC)												
		Metropolitan				Rural				Remote				
Regions	Province/ Territory	SAC1: Urban Core	SAC2: Suburban	SAC3: Exurban	Sub Total	SAC4: High MIZ	SAC5: Moderate MIZ	SAC6: Weak MIZ	Sub Total	SAC7: Provincial	SAC8: Territorial	Sub Total	Totals
Cordillera	BC	74	45	99	218	40	105	81	226	293	—	293	737
Prairies	AB	51	15	17	83	53	104	72	229	113	—	113	425
	SK	43	—	27	70	88	244	168	500	380	—	380	950
	MB	12	—	11	23	19	56	70	145	61	—	61	229
Central	ON	99	19	38	156	109	120	70	299	120	—	120	575
	QC	164	16	58	238	327	425	112	864	183	—	183	1,285
Maritimes	NB	33	17	35	85	46	83	44	173	15	—	15	273
	PE	—	—	26	26	37	42	1	80	6	—	6	112
	NS	6	—	18	24	9	24	27	60	12	—	12	96
	NL	13	—	22	35	37	124	45	206	131	—	131	372
North	YT	—	—	7	7	—	—	—	—	—	29	29	36
	NT	—	—	1	1	—	—	—	—	—	40	40	41
	NU	—	—	—	—	—	—	—	—	—	31	31	31
CANADA		495	112	359	966	765	1,327	690	2,782	1,314	100	1,414	5,162

Figure 2-2: Characteristic settlement types based on a statistical area classification developed as part of the national census.

Relative degrees of remoteness and accessibility (RA Index) are measured based on travel distance along established transportation routes to the nearest population centre, and the availability of basic services that are needed to support both day-to-day activities and community well-being (Alasia et al., 2017). These include medical services, social assistance, financial/legal aid, and more general business functions that determine both baseline levels of community health, and the relative capacity of individuals and groups to withstand and recover from unexpected disaster events. Index values are rescaled to a range of 0 to 1 using MIN-MAX methods of transformation, where mean values are used to assess relative proximity to neighbouring population centres and increasing degrees of remoteness and/or limited access to essential services.

Larger municipalities occur within broad metropolitan regions characterized by a high degree of social and economic integration, and concentrated urban 'core zones' in which more than 50% of the population live in dense residential neighbourhoods and mixed-use business precincts. Suburban and exurban municipalities occur outside the urban centre and are distinguished based on population density and relative degree of integration with neighbouring socioeconomic centres. Smaller municipalities that are distributed in rural or remote settings are assigned to one of four categories according to the degree of influence from neighbouring metropolitan regions (strong, moderate, weak, or negligible). The degree of metropolitan influence is based on the percentage of residents employed in the regular labour force who commute to work in one or more urban core zones that serve as socioeconomic hubs for the broader region. Settlements that occur outside larger census agglomeration areas in the Yukon, Nunavut and Northwest Territories are assigned to a separate category. Distinguishing characteristics for each of the 8 broad settlement types shown in Figure 2-2 are summarized below:

Urban Centre (SAC-1): Census subdivisions situated within census metropolitan areas (CMA) with a minimum population of 100,000, of which 50,000 or more people live in a dense urban core zone with a minimum residential density of 400 people per square kilometre. Urban neighbourhoods situated outside established population centres have an average RA Index value of 0.17.

Suburban Neighbourhood (SAC-2): Census subdivisions situated within census agglomeration areas (CA) with a minimum population of 10,000 and residential density of 400 people per square kilometres in which at least 50% of the employed labour force commutes to and from adjacent urban core zones. Suburban neighbourhoods have an average RA Index value of 0.24.

Exurban Settlement (SAC-3): Census subdivisions situated within census agglomeration areas (CA) that lack concentrated population centres of 1,000 people or more (< 400 people/km^2) and in which at least 50% of the employed labour force commutes to and from adjacent urban core zones. Exurban fringe neighbourhoods have an average RA Index value of 0.32, reflecting more limited connectivity to major transportation routes and reduced access to goods and services that are more readily available in larger population centres.

Rural-Strong MIZ (SAC-4): Census subdivisions distributed across rural agricultural and/or wildland landscapes with an average population density of less than 100 people per square kilometre in which at least 30% of the resident labour force commutes into an adjacent metropolitan region (CMA or CA) for work on a regular basis. Settlements are situated adjacent to established transportation routes with an average RA Index value of 0.24.

Rural-Moderate MIZ (SAC-5): Census subdivisions distributed across rural agricultural and/or wildland landscapes with an average population density of less than 100 people per square kilometre in which at least 5% but no more than 30% of the resident labour force commutes into an adjacent metropolitan region (CMA or CA) for work on a regular basis. Travel distances to and from neighbouring population centres are more variable with an average RA Index value of 0.31.

Rural-Weak MIZ (SAC-6): Census subdivisions distributed across rural agricultural and/or wildland landscapes with an average population density of less than 100 people per square kilometre in which less than 5% of the resident labour force commutes into an adjacent metropolitan region (CMA or CA) for work on a regular basis. Most settlements have limited connectivity to major transportation routes and reduced access to essential services with an average RA Index value of 0.43.

Remote-Provincial (SAC-7): Census subdivisions situated in rural or remote areas under provincial jurisdiction with an average population density of less than 100 people per square kilometre in which none of the resident labour force commutes into an adjacent metropolitan region (CMA or CA) for work on a regular basis (Negligible MIZ). Most settlements have limited connectivity to major transportation routes and reduced access to essential services with an average RA Index value of 0.48.

Remote-Territorial (SAC-8): Census subdivisions situated in remote areas of the northern territories outside of established census agglomerations (CA) and with limited access to transportation infrastructure and essential services. As with their provincial counterparts, most settlements have limited connectivity to major transportation routes and reduced access to essential services with an average RA Index value of 0.71, the highest levels in Canada.

2.1.2. Land Use and Governance

Patterns of land use reflect the history of development within a community or region and are a manifestation of underlying social, economic and political factors that influence both where people live and corresponding levels of access to services and resources within the community or region. Functional characteristics of built-up areas are described using land use classes developed as part of a national physical exposure model for Canada (Journeay et al., work in progress, 2022). Each census dissemination area (DA) within a given settlement type is assigned to one of six land use classes based on measures of population density, the number and types of structures at a given location (e.g., construction type, height, floor area, site coverage), and the corresponding mix of building occupancies including single and multi-family residential, civic, commerical, and industrial (See Appendix A).

In order of increasing residential density and overall complexity development, broad classes of land use include:

Rural Lands: Low density settled areas with less than one person per hectare (PPH). Although consisting primarily of single-family residential homes, rural and remote settlements in agricultural and resource-based settings may also include non-residential buildings that provide a mix of commercial, industrial, and civic functions for the broader community.

Low-Density Urban Neighbourhoods: Residential areas with an average of 2-10 PPH that are situated within designated metropolitan regions of varying size and complexity. They are made up primarily of single-family residential homes but can contain smaller numbers of multi-family duplex and townhouse buildings, and a mix of non-residential buildings that provide commercial retail and professional services. Although concentrated primarily in suburban neighbourhoods along the periphery of major urban centres, low density areas can also occur along interstitial zones within higher density urban centres.

Commercial-Industrial Lands: Low density residential neighbourhoods with relatively high concentrations of buildings that are used primarily for commercial wholesale storage and distribution, mechanical services, light and heavy industrial factories, food, chemical and mineral resource processing plants, construction, and/or specialized technologies. Depending on location, these lands can include either interspersed clusters of residential buildings or diffuse zones of mixed-use buildings that transition into neighbouring areas.

Mixed Use Neighbourhoods: Moderate density residential neighbourhoods (10-35 PPH) with concentrations of non-residential buildings that support a diversity of civic, commercial retail, and/or professional service functions. Typically located in the downtown business districts of cities and towns, these lands are characterized by the massing of buildings in concentrated clusters or along major arterial corridors where overall site coverage generally exceeds 25%.

Medium-Density Urban Residential: Neighbourhoods with population densities of between 35 and 75 PPH, often characterized by concentrations of multi-family townhouse and mid-rise apartment buildings that occur within broader areas of single-family homes. They also contain higher concentrations of non-residential buildings that can include a wide mix of civic, commercial retail, and professional services. The massing of buildings within a given neighbourhood generally exceeds 20% of the built-up area.

High-Density Urban Residential: Neighbourhoods with population densities of greater than 75 people per hectare (7,500 people per km^2) with concentrations of medium- and high-rise residential apartment buildings that can be interspersed with low-rise townhouses and/or single-family homes. Larger apartment buildings can include mixed use businesses at street level and lower-level floors. Higher-density residential buildings are typically interspersed with concentrations of non-residential buildings clustered in dedicated business precincts or situated along major arterial corridors. Non-residential buildings and dedicated office towers can provide a wide diversity of functions including professional services, medical services, financial services, commercial retail, and/or entertainment. The massing of buildings within these neighbourhoods can exceed 75% of the total built-up area.

Establishing a correlation between land use and census-based measures of demographic variability provides a logical framework for describing the relationship between development history and characteristics of social fabric that are specific to a particular place. While the physical form and functional characteristics of individual land use classes are similar from one location to another, there can be significant variability in how these lands are managed and the resulting demographic profiles of population groups who end up living within a particular type of neighbourhood.

For example, there are fundamental differences in the level of service provided to disadvantaged and marginalized residents living in urban, rural, and remote communities (Collins, 2008; Matheson et al., 2012; Statistics Canada, 2019) and known disparities between lands administered by local authorities under provincial or territorial jurisdiction and those of equivalent type that are governed under various forms of Aboriginal land title (Fligg et al., 2020). These differences are a manifestation of underlying social, economic, and political factors that are specific to a particular community or region and may also reflect underlying conditions of inequity and/or marginalization that have evolved as part of the development process. Although demographic profile and mix of population groups may vary from place to place, those most affected by differential access to services and resources are often low-income households, recent immigrants, racially marginalized populations, and other groups whose rights and needs are not always fully considered in community planning or disaster risk management (Blaikie et al., 1994; Comfort et al., 1999; Godschalk, 2003; Andrews et al., 2016; Sarmiento et al., 2020).

2.2. ASSESSMENT FRAMEWORK

The following sections describe components of the analytic framework used to assess characteristics of social vulnerability as a function of settlement type and associated patterns of land use in Canada. This includes the selection and evaluation of indicators that are used to measure specific dimensions of social vulnerability at the census dissemination area level (DA), and the methods used to both evaluate and interpret resulting patterns of vulnerability within a community or region of interest.

2.2.1. Social Vulnerability Indicators

Indicators are quantitative variables used to measure the intrinsic characteristics of human and natural systems in the context of a specific place and time frame. They provide valuable insights on who might be disproportionately affected by hazard threats within a given community or region and are used to help inform planning and policy development in the broader realms of disaster risk reduction, climate change adaptation, and sustainable development. However, unlike indicators of physical system interactions that measure observed cause-effect relationships, indicators of social vulnerability are based on proxy variables that represent complex but intangible interactions that occur between social, economic, and political systems over time.

The challenges of compiling and integrating the volume and diversity of information that is needed to meaningfully represent patterns of social vulnerability is generally managed using either deductive or inductive modes of reasoning (Burton et al., 2018). Deductive methods of assessment start with a pre-conceived hypothesis or assertion about the underlying drivers of vulnerability for a particular place, then use a pre-selected set of indicators to measure the relative contributions of relevant causal factors such as age, gender, and income. They work well in situations where there is existing local knowledge and a clear understanding of underlying drivers of vulnerability. However, they can be misleading if applied across different physical, social, cultural, and/or economic settings where these relationships may no longer be valid. In contrast, inductive methods of assessment use geostatistical methods to identify trends and relational patterns in large multidimensional datasets that help explain observed behaviors or interactions in the context of a given place and/or socioeconomic setting. They generally start with a large set of fifty or more well-documented indicators, which are reduced to a smaller set of statistically significant factors that explain variability within the data using principal component and/or factor analysis. The resulting set of indicators are then assembled into a hierarchical structure (taxonomy) that reflects dimensions of vulnerability that are inferred to be relevant across a range of physical, social, cultural, and/or economic settings. The national CanSVM model builds on the strengths of these two different modes of reasoning. Deductive methods are used in identifying demographic variables that are known to influence patterns of vulnerability in a North American context while inductive methods of analysis are used in assessing which factors are most significant in explaining observed patterns that are specific to a given type of settlement.

Indicators used in the CanSVM model are derived from available population, demographic, and housing information compiled at the dissemination area level as part of the national census (Statistics Canada, 2016c). Our selection of vulnerability indicators is based on the results of comparable studies that have implemented the Hazards of Place model in a North American context. From an initial compilation and review of more than 67 demographic characteristics that have been shown to influence social vulnerability to natural hazards, we selected 49 candidate variables based on the geographic scale of reporting and the availability of information to evaluate indicators at the dissemination area level (DA) for all regions in Canada. Demographic variables with missing or supressed values due to low response rates and/or issues of confidentiality were either removed from the dataset or evaluated for those specific instances where interpolation could be justified based on the distribution of attribute values for neighbouring locations. Indicators with value characteristics not aligned with the concept of social vulnerability were adjusted with respect to cardinality so that high attribute values consistently reflect elevated levels of vulnerability. For example, income-related variables that reflect increased levels of financial capacity are inverted (multiplied by -1) to ensure internal coherence when comparing with other measures of reduced capacity. Attribute values are normalized into a common range of between 0 and 1 using a MIN-MAX transformation where a score of 0.0 indicates the lowest value of vulnerability and a score of 1.0 indicates the highest value (Burton et al., 2017).

Methods of Principal Component Analysis (PCA) are used to reduce the initial candidate list of 49 variables to a smaller and more coherent set of 31 indicators that collectively account for characteristic patterns of variability within the broader set of demographic variables at a national scale (see Table 2-1). A subsequent assessment of correlation levels for specific variables evaluated in the context of each major settlement type (i.e., factor loadings) was carried out to identify which of the 31 indicators best account for characteristic patterns of variability across different types of development. Parameters with eigenvalues of less than 1.0 that occur in the context of multiple settlement types were filtered out of the final selection, leaving a subset of 20 social vulnerability indicators that collectively explain more than ~80% of the statistical variability. Variations in the relative proportion of variance explained by each of the indicators are interpreted to reflect characteristics of social fabric that are distinct for each of the broad settlement types (see Appendix B1). While the selection of indicators used to measure social vulnerability as a function of settlement type is specific to this study, it is worth noting that many of the same parameters are identified in other complementary models that have been developed to assess characteristics of social marginalization at a national level in Canada (Matheson et al., 2012; Statistics Canada, 2019; Chakraborty et al., 2020). Indicators used in developing the social vulnerability index are summarized in Appendix B2.

Table 2-1: Description of candidate variables used in the national social vulnerability index (CanSVM; this study) and their overlap with equivalent national models developed as part of the Canadian Index for Multiple Deprivation (CIMD; Statistics Canada, 2019) and the Socioeconomic Status Index (SES; Chakraborty et. al., 2020.)

Demographic Variable	Description	Supporting Rationale	Influence	Can-SVM	CIMD	SES
AgeGT65	Proportion of population who are 65 years and older	Cutter et al. 2003; Burton 2015; Guillard-Gonçalves et al. 2015	(+)		✓	✓
AgeLT6	Proportion children under 6 years of age	Cutter et al., 2000; O'Brien and Mileti, 1992; Hewitt, 1997	(+)	✓		✓
AgeMedian	Median age of population	Cutter et al., 2000; Hewitt, 1997	(+)		✓	✓
FamGT5	Proportion households with 5 or more persons	Blaikie et al., 1994; Morrow, 1999; Cutter et al. 2003	(+)		✓	
Health	Proportion labour force (15yr+) employed in healthcare/social assistance fields	Hewitt,1997; Puente, 1999	(-)	✓	✓	✓
ImmLT5	Proportion of households who have immigrated in last 5 years	Adger 1998, Cutter et al. 2003, Guillard-Gonçalves et al. 2015	(+)	✓		✓
IncEmpl	Proportion of population who receive employment income	Matheson et al., 2012; Statistics Canada, 2019	(-)		✓	
IncHshld	Median household income value	Cutter et al. 2003; Cutter et al. 2008; Burton 2015	(-)		✓	✓
IncIndiv	Median individual income value	Cutter et al. 2003; Cutter et al. 2008; Burton 2015	(-)		✓	✓
Indigenous	Proportion of population that identifies as Aboriginal	Matheson et eal., 2012; Statistics Canada, 2019	(+)	✓	✓	✓
LivAlone	Proportion of persons living alone	Matheson et eal., 2012; Statistics Canada, 2019	(+)			✓
LonPar3Kids	Proportion of lone parent families with 3 or more children	Matheson et eal., 2012; Statistics Canada, 2019	(+)	✓	✓	✓
LowIncDecile	Proportion of family income in bottom half of decile distribution	Cutter et al. 2003; Morrow 1999; Burton and Silva 2015	(+)			✓
MntnAge	Proportion of households with primary maintainer either <25 years or > 65 years	Morrow, 1999; Hewitt, 1997	(+)	✓	✓	
MovedLT1	Proportion population that has moved within last year	Clark et al. 1998, Jones and Andry 2007, Fekete 2009	(+)	✓	✓	✓
NoEngFr	Proportion population with no working knowledge of English or French	Matheson et eal., 2012; Statistics Canada, 2019	(+)	✓	✓	
NonResHa	Number of non-residential buildings per hectare of settled area	Boruff and Cutter 2007; Birkmann 2007; Guillard-Goncalves et al 2014	(+)	✓	✓	
NoSecED	Proportion of population with no certificate, diploma, or degree	Cutter et al. 2003; Burton 2015	(+)	✓	✓	✓
NoWrkPlace	Proportion of population with no fixed workplace	Matheson et eal., 2012; Statistics Canada, 2019	(+)	✓	✓	
NSuitHouse	Proportion of households living in non-suitable conditions	Matheson et eal., 2012; Statistics Canada, 2019	(+)	✓	✓	
OneIncHshld	Proportion of households with only 1 maintainer income	Cutter et al., 2000; Blake et al., 1994; Hewitt, 1997	(+)	✓	✓	
PopHa	Number of permanent nighttime residents per hectare of settled area	Boruff and Cutter 2007; Birkmann 2007; Guillard-Goncalves et al 2014	(+)	✓	✓	
Pre1975	Proportion of building stock that predate modern seismic safety guidelines	Mendes 2009	(+)	✓	✓	✓
PubTrans	Proportion population who relies on public transit to commute to work.	Cutter et al. 2010; Burton 2015	(+)	✓		
Renter	Proportion of households that are tenants (or band housing)	Matheson et eal., 2012; Statistics Canada, 2019	(+)			✓
Retail	Proportion of population that rely on work in retail trade	Cutter et al. 2010	(+)	✓	✓	✓
ShltrGT30	Proportion of households that spend more than 30% of income on shelter costs	Matheson et al., 2012; Statistics Canada, 2019	(+)	✓		
Unemployed	Proportion of population (labour force) that is unemployed	Cardona 2005; Sherrieb et al 2010; Cutter et al. 2008	(+)	✓		
VisMinority	Proportion of population who self-identify as a visible minority	Matheson et eal., 2012; Statistics Canada, 2019	(+)		✓	
WorkNone	Proportion of population 15 and older that did not work in 2015	Matheson et.al., 2012; Statistics Canada, 2019	(+)		✓	
WorkPart	Proportion of population that worked part time or for only part of the year	Cutter et al., 2000; Blake et al., 1994; Hewitt, 1997	(+)	✓		

2.2.2. Evaluating the Dimensions of Vulnerability

A standard methodology for measuring absolute levels of vulnerability at a given geographic location is to aggregate relevant indicator values into a composite Social Vulnerability Index (SVI). This can be helpful in identifying hotspot areas of concern that may warrant further investigation at a local level, and in characterizing regional trends that may reflect underlying socioeconomic and/or political drivers of vulnerability. However, there are significant shortcomings in relying on a single composite measure to interpret patterns of vulnerability. The most obvious is that social vulnerability is, by definition, the outcome of complex interactions between human and natural systems that cannot be meaningfully reduced to an absolute value using statistical methods alone (Adger, 2006; Barnett, 2008; Tate, 2012; Rufat, 2013). A related issue is the challenge of clearly explaining the meaning and significance of an absolute social vulnerability index value in the context of planning and policy deliberations that require a defensible rationale for how best to invest scarce resources in capacity development measures that increase the prospects of disaster resilience.

An effective way to mitigate these limitations is to create a hierarchical arrangement of indicators (i.e., typology) that reflects knowledge about specific thematic dimensions of vulnerability (e.g., social, economic, physical) and how they are likely to influence capacities to withstand, cope with, and recover from the initial impacts and downstream consequences of natural hazard events (Rufat, 2013; Burton et al., 2018; Rufat et al., 2019). Indictors within the hierarchical model can be weighted based on input provided by domain experts who are familiar with the more specific vulnerability characteristics of population groups within a particular community and/or region (Oulahen et al., 2015). These additional measures increase both transparency and usability of the assessment framework by allowing the interrogation of individual indicator values within a particular dimension of vulnerability, and a comparison of performance measures across all thematic dimensions. More importantly, a focus on relative versus absolute measures is more likely to encourage an exploration of why some places and population groups are more vulnerable than others, as well as explore strategies that might be considered to inform disaster resilience planning at a community level. Thematic categories that are used to structure the national SVI assessment framework for Canada include social capital, individual autonomy, housing conditions and financial agency. Each thematic dimension of vulnerability is measured using a corresponding set of 5 indicators (See Figure 2-3). Although one of many possible configurations, the choice of these categories and the arrangement of corresponding indicators reflect general aspects of social vulnerability that are likely to be relevant at different stages of the disaster risk management cycle.

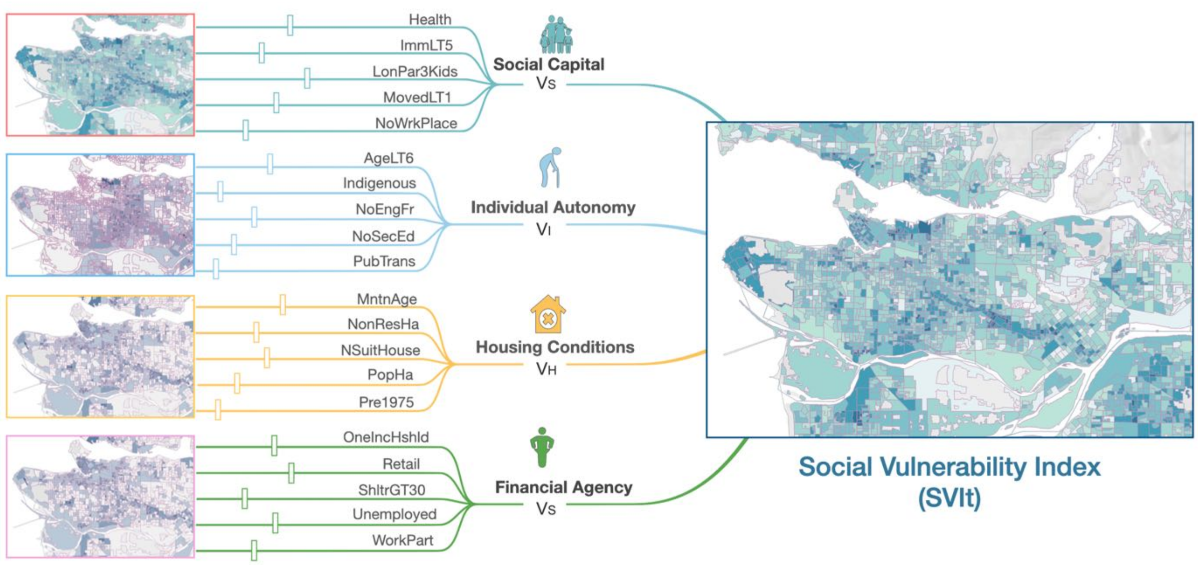


Figure 2-3: Social vulnerability indicators used to assess dimensions of social capital, individual autonomy, housing conditions and financial agency that will influence capacities to withstand and recover from disaster events. See Table 2-1 for a description of indicator variables.

Social Capital includes measures of family structure, migration, immigration, and regular workplace relationships that are relevant for assessing the degree of connectedness within a given community and the extent to which people can rely on one another in times of need. These variables are common to many social vulnerability assessment frameworks (Cutter et al., 2003; Cutter et al., 2008; Cutter et al., 2010; Oulahen et al., 2015; Cutter et al., 2016), and are often used to help assess the relative capacity of individuals and groups to both anticipate and withstand the immediate impacts of a hazard event.

Individual Autonomy includes measures of formal education level, caregiving responsibilities to young children, language barriers, Indigenous identity, and reliance on public transit that can influence the ability of individuals and groups to take actions on their own and/or to influence risk management decision made on their behalf to mitigate the effects of a disaster event (Chakraborty et al., 2005a; Cutter et al., 2010; Burton et al., 2015). Similar metrics are used to evaluate dimensions of marginalization and social disadvantage in the context of community-based social planning (Matheson et al., 2012; Statistics Canada, 2019). They are also effective in assessing the relative capacities of individuals and groups to both respond to the initial impacts of a hazard event and to take the necessary steps to reduce downstream negative consequences during both initial and prolonged phases of recovery.

Housing Conditions include measures of population density, suitability of accommodation, compliance with building safety guidelines, and relative capacities for maintenance and upkeep of physical assets. These facets are relevant in assessing whether people are more likely to shelter in place or seek assistance from emergency services. Capacity to make the necessary repairs caused by a hazard event is relevant in assessing how long it will take to restore baseline services. Housing stresses can also influence the relative degree of social disruption in the weeks and months following a disaster event and will influence overall capacities for functional recovery (Tierney, 2006; Cutter et al., 2010; Matheson et al., 2012; Tierney et al., 2012).

Financial Agency includes measures of income and employment security that reflect the capacities of individuals and groups to absorb the financial shock of a disaster event through proactive investments in mitigation and/or adaptation measures that are taken following a disaster event. These indicators are often used to assess dimensions of economic security and overall prospects of functional recovery. (Blaikie et al., 1994; Cutter et al., 2003; Rose, 2004; Cutter et al., 2008; Rose, 2016).

2.2.3. Threshold Scores – A Relative Measure of Vulnerability

Arranging indicators within a hierarchical model structure enables the aggregation of vulnerability metrics to identify hotspot areas of concern, while still preserving the ability to interrogate model results at a given location to determine which underlying factors may be affecting the disaster response capacities of different population groups in a community (see Figure 2-3). It also helps shift the focus of analysis away from an absolute measure of fragility or inequity to a more holistic evaluation of why some places and population groups are more likely to be affected by natural hazard threats than others and the implications for disaster management. For example, indicators of increased population density in urban neighbourhoods (‘*PopHa*’) that correlate with higher-than-average numbers of people living in unsuitable housing (‘*NSuitHouse*’) who are unable to communicate in either official language (‘*NoEngFr*’) provide the necessary context to identify specific actions that might be needed to address capacity deficits and are more useful than a single composite measure of overall social vulnerability for the same neighbourhood.

To facilitate the interpretation of model outputs, we transform indicator values from absolute MIN-MAX values (e.g., 0.342) to a relative vulnerability threshold score by comparing measured values at a given location against characteristic or average values for a given settlement type. A score of +1 is assigned when an indicator value exceeds a mean value plus one standard deviation, while those that fall below these threshold values are assigned a score of 0. Reference values used in assessing threshold scores for all 20 indicators within each of the 8 characteristic settlement types (e.g., urban, suburban, rural, remote) are summarized in Appendix B3. The assessment process begins with the aggregation of indicator values within each of the four corresponding thematic dimensions. This process results in four distinct measures of relative vulnerability that can then be aggregated into a composite social vulnerability index (SVI) using the following relationship:

$$SVI_t = (V_S + V_I + V_H + V_F) \quad [2.1]$$

Where:

V_S = **Social Capital** (component threshold score for all **SC** dimension indicators)
V_I = **Individual Autonomy** (component threshold score for all **IA** dimension indicators)
V_H = **Housing Conditions** (component threshold score for all **HC** dimension indicators)
V_F = **Financial Agency** (component threshold score for all **FA** dimension indicators)

As illustrated in Figure 2-4, positive SVI threshold scores at a given location record the number of instances where measures of vulnerability exceed reference threshold values (mean + 1sd) for all other locations that are part of the same settlement type. Relative degrees of vulnerability (low, moderate, considerable, high, and extreme) are evaluated by categorizing the distribution of threshold exceedance scores into statistically significant groupings using the Jenks classification – a data clustering method that optimizes the arrangement of values into pre-defined classes based on natural breaks. As there are five indicators within each of the four thematic dimensions, vulnerability threshold scores at any given location can range between a value of 0 and 5 for each of the model components with a maximum value of 20 for the composite index score.

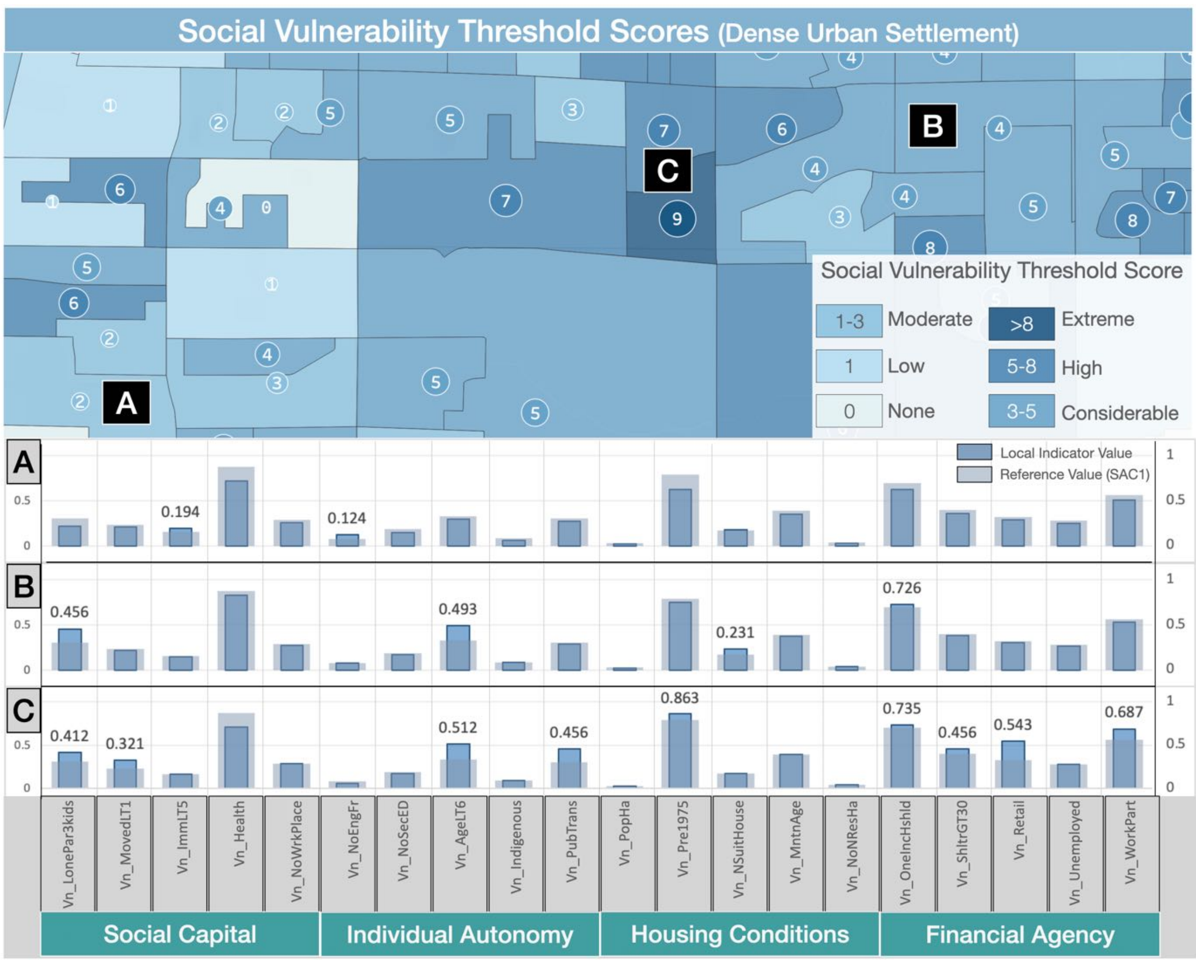


Figure 2-4: Sample profile of social vulnerability indicators for a given location and their degree variability compared with reference values (mean +1sd) for similar Urban Core settlement types in Canada (SAC-1).

In this example, indicator values at three separate locations show very different profiles of disparity when compared to reference threshold values for a densely populated urban neighbourhood (SAC1). Location “A” records a relatively low vulnerability threshold score of 2 but is characterized by a higher-than-expected number of people who have immigrated to Canada within the last five years (Vn_ImmLT5) and who do not have a proficiency in either English of French (Vn_NoEngFr). Location “C” is characterized by multiple indicators that exceed reference threshold values across all dimensions of vulnerability and is assigned a threshold score of 9. Underlying factors that may influence levels of social vulnerability at this location include a high-than-expected number of lone parent families with young children who are living on a single income and experiencing elevated levels of financial insecurity. Identifying recurring patterns of disparity within a community can assist local authorities in assessing the needs of specific population groups and additional resources and/or additional capacities that may be needed to increase levels resilience for specific population groups at the neighbourhood level.

Profiles of social vulnerability are evaluated at the census dissemination area level (DA) for all developed areas in Canada. The methodology allows for the assessment of social vulnerability at any geographic scale of interest by dividing the overall threshold score for a given level of aggregation and settlement type by the total number of unique locations (see Equation 2.2). In these cases, the relative degree of vulnerability across communities of the same settlement type would be evaluated by dividing the aggregate threshold score for a given community by the corresponding number of unique locations sampled. This preserves the overall scale range of the social vulnerability index (0 < **SVI** < 20) and facilitates the interpretation of regional patterns at variable scales of resolution.

$$SVI_{t_{Agg}} = \frac{\sum SVI_t}{\# DA} \qquad [2.2]$$

A consequence of our model design choice is that absolute measures of social vulnerability can only meaningfully be compared between developed areas that are part of the same broad settlement type. For example, areas with anomalously high vulnerability threshold scores that occur in dense urban neighbourhoods of a major city cannot be directly compared with equivalent levels of vulnerability that occur in neighbouring suburban neighbourhoods or surrounding rural hinterland communities. This is because the associated social vulnerability indicators are calibrated with respect to the distribution of values that are characteristic of a given settlement type, not a particular community or region. As a result, we recommend that model outputs be used to assess relative patterns rather that absolute measures of social vulnerability from one location or region to another.

2.3. Integrating the Social and Physical Dimensions of Hazard Threat

Integrated hazard threat is a general measure of who and what are susceptible to the expected physical impacts of future hazard events. It includes a consideration of both the physical dimensions of threat and the underlying socioeconomic factors within a community or region that may disproportionally limit the capacities of specific population groups to withstand, cope with, and recover from the negative downstream consequences associated with each stage of a disaster. The severity of hazard threat varies from place to place as a function of (i) geographic setting and exposure to different natural hazard processes; (ii) characteristics of the built environment such as density and patterns of land use that will determine levels of exposure and susceptibility to the expected physical impacts of a hazard event and; (iii) intrinsic characteristics of social vulnerability that have evolved as part of the development process.

A variety of analytic methods have been developed for assessing patterns of hazard threat to inform planning and policy development at regional and local scales. These include: the Americas Indexing Program for the Caribbean and South American countries (Cardona et al., 2005); the Integrated Risk Assessment of Multi-Hazards Framework for the European Union (Greiving, 2006; Greiving, 2007); the global Index for Risk Management (INFORM; De Groeve et al., 2015; Marin-Ferrer et al., 2017); the National Risk Index (NRI) for the United States (Federal Emergency Management Agency [FEMA], 2020); and the Social Vulnerability and

Resilience (SVR) component of the Global Earthquake Risk Model (Burton et al., 2015; Global Earthquake Model Foundation [Gem], 2020; Burton et al., 2022). Although distinct in terms of the selection and arrangement of indicators used to measure physical and social dimensions of vulnerability, most of these assessment methods are based on a conceptual framing of disaster risk that can be expressed mathematically using the following generalized expression:

$$Risk = [Consequence]_{\rho} \times [Social\ Vulnerability] \times \left(\frac{1}{[Resilience]}\right) \quad [2.3]$$

In this formulation, ***consequence*** is defined as the anticipated physical outcome of human exposure and susceptibility to natural hazard events of a given intensity and probability (*p*) of occurrence. In a quantitative risk assessment, outcomes are measured in terms of the expected level of structural damage to specific elements of the built environment (***physical vulnerability***) and/or related downstream consequences including injuries, socioeconomic disruption, and economic loss (***physical risk***). More general assessments of ***hazard threat*** measure outcomes based on the overall number of buildings, people, and asset values that are susceptible to varying levels of hazard intensity and related physical impact (***physical susceptibility***). An important distinction is that hazard threat models measure the severity of expected outcomes using normative impact scales that relate hazard intensity at a given location (e.g., ground shaking, flood inundation, wind speed) to general levels of damage and disruption based on observed impacts from historic disaster events. In contrast, ***physical risk*** models measure the severity of damage using engineering-based fragility and vulnerability functions that relate the capacity of specific building types to withstand the physical forces associated with hazard events of variable magnitude and frequency of occurrence, and the resulting downstream consequences (e.g., injuries, economic loss, downtime). In both cases, the physical consequences of a hazard event are multiplied by measures of ***social vulnerability*** to account for underlying conditions of disparity and/or inequity that may limit the capacity of some community members to weather the physical impacts of a hazard event, thereby amplifying the overall effects and disproportionally increasing the burden of risk for those least able to manage the downstream consequences. Whereas vulnerability focuses on the underlying characteristics of social systems that disproportionally amplify the degree to which community members experience the negative consequences of a disaster event, ***resilience*** represents the efficacy of collective actions that are taken either in advance of or following a disaster event to reduce risk and increase the prospects of functional recovery through proactive investments in mitigation and/or adaptation measures that target both physical and social vulnerabilities (United Nations Office for Disaster Risk Reduction [UNDRR], 2019).

2.3.1. Components of a National Hazard Threat Index

Our assessment of integrated hazard threat combines measures of social vulnerability (SVI) described above with outputs of a complementary physical exposure model developed by NRCan to measure the susceptibility of buildings, people, and financial assets to known natural hazard processes in Canada including earthquakes, tsunamis, riverine floods, hurricanes, wildfire, and landslides of various types (Journeay et al., work in progress, 2022). Model components and the general framework for integrating social and physical dimensions of hazard threat are summarized in Figure 2-5.

Physical dimensions of hazard threat are evaluated using published hazard models for Canada and disaster impact scales that relate measures of hazard intensity to expected levels of physical damage and socioeconomic disruption. Hazard intensities are derived from quantitative models that measure the likelihood of exceeding minimum thresholds of ground shaking, flood inundation, wildfire intensity, and/or hurricane winds at a given location over a specified future time horizon. These include national-level models developed by NRCan for earthquake and wildfire hazards, and open-source global models developed by various internaitonal organizations for earthquake-triggerd tsunami, riverine flood, and hurricane hazards (Alexander et al., 1996; Løvholt et al., 2015; Rudari et al., 2015; United Nations Global Risk Data Platform, 2015; Dottori et al., 2016; Adams et al., 2019; Kolaj et al., 2020b). We use hazard intensity levels corresponding to events that are likely

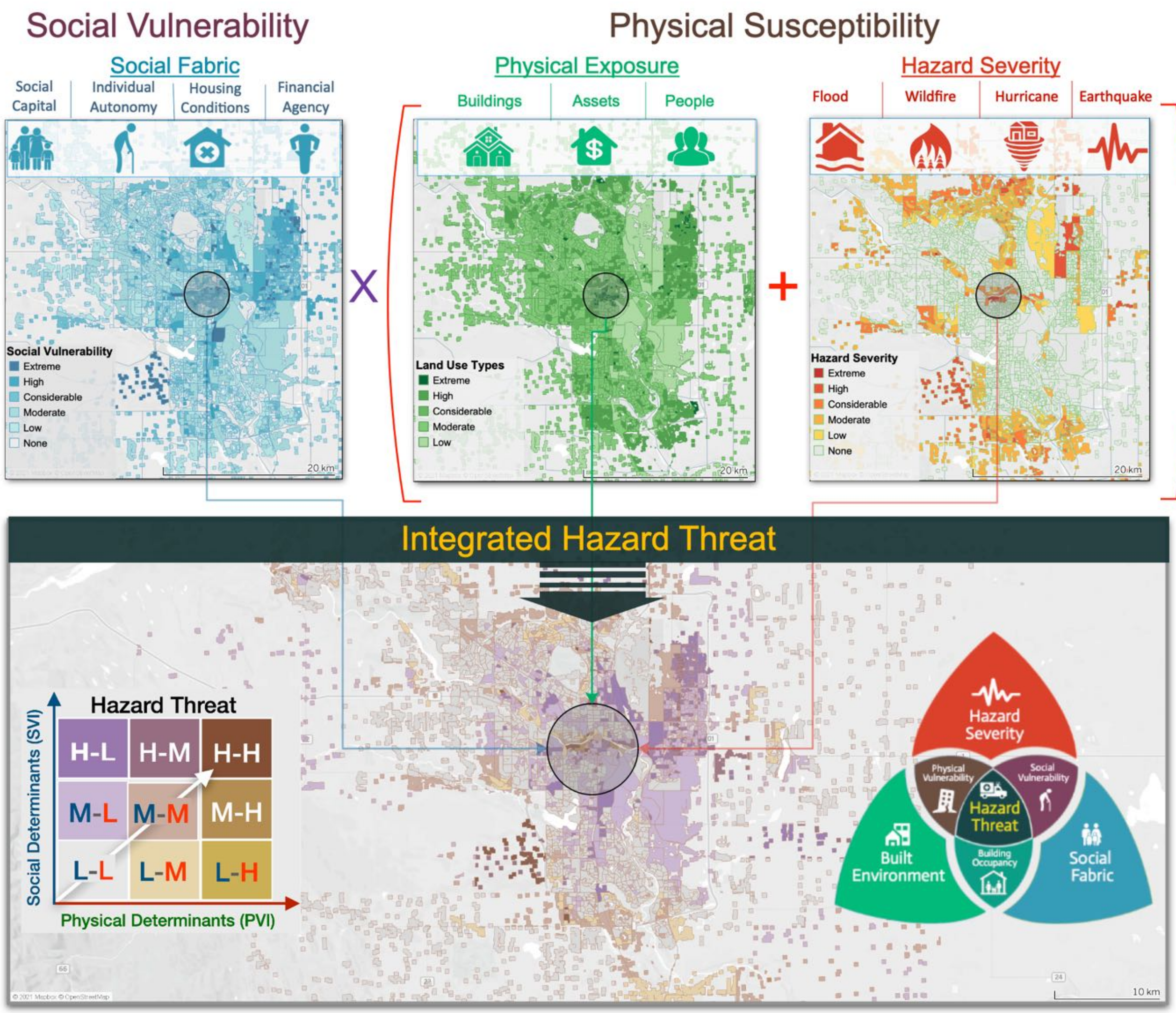


Figure 2-5: Model components and a summary of the analytic workflow used to assess integrated hazard threat in Canada.

to occur over a ~500-year time horizon to enable a uniform comparison across hazard processes that have different magnitude-frequency relationships. This corresponds with a 10% probability of occurrence over a 50-year time horizon or an annual exceedance probability (AEP) of 0.2%, which is aligned with hazard-based regulatory guidelines used in Canada to evaluate the capacity of financial institutions to withstand and recover from the sudden economic shocks of extreme disaster events (Office of the Superintendent of Financial Institutions (Osfi), 2013b, 2013a). Our assessment of damage potential is based on a compilation of disaster impact scales including the Modified Mercalli Index for earthquakes (Wood et al., 1931; Stover et al., 1993; Wald et al., 1999), generalized depth-damage functions for riverine floods (Margottini et al., 2008; Huizinga et al., 2017), the Wildland Urban Interface (WUI) fire hazard index (Maranghides et al., 2013), and the Saffir-Simpson cyclonic wind scale for severe storms and hurricanes (Taylor et al., 2010). Hazard footprints for each of these perils are intersected with areas of human settlement to assess mean hazard intensity, corresponding levels of expected damage (i.e. none, low, moderate, considerable, high, and extreme), and the numbers of people and buildings and the value of financial assets that are likely to be affected at a given location. The general structure of the composite physical susceptibility index is:

$$PSI_t = \mu(h_1 + h_2 + h_3 \ldots.) * (E_b, E_p) \quad [2.4]$$

Where:

$h_{1,2,3}$ = damage state index value for a corresponding hazard type at a given location

E_b = value of building assets exposed to hazard intensities capable of causing physical damage

E_p = number of people exposed to hazard intensities capable of causing physical damage

Susceptibility to financial loss (E_b) is evaluated by multiplying hazard-specific damage levels (h) by the combined replacement costs of exposed assets within a given settled area. The potential for human impact (E_p) is evaluated by multiplying hazard-specific damage levels (h) by the number of people who are likely to be affected in the same area over a 24-hour period. The Hazard Threat Index (HTI_t) is evaluated by multiplying physical susceptibility (***PSIt***) by composite social vulnerability threshold scores (***SVIt***) to account for disparities in the degree to which specific populations within a community are likely to experience the negative consequences of future disaster events and suffer harm as a result:

$$HTI_t = PSI_t * SVI_t \quad [2.5]$$

Where:

PSI_t = susceptibility to loss or socioeconomic disruption as a function of hazard intensity [2.4]

SVI_t = composite vulnerability threshold score $(SV_S + SV_A + SV_H + SV_F)$, [2.1]

The combined product of physical susceptibility and social vulnerability is a unit-less value representing the relative level of hazard threat at a given location. Values are calculated for each settled area in Canada at the census dissemination area (DA) level and can be aggregated up to census subdivision (CSD; city, town, village) census division (CD; county, region), and/or higher-level geometries to facilitate comparisons at a national scale. Composite index values at each level of aggregation are normalized by the number of settled areas, then clustered into statistically significant groupings (low, moderate, considerable, high, and extreme) to reflect spatial variations in the overall severity of hazard threat for a given region of interest.

This formulation of an integrated hazard threat index (HTI_t) is aligned with other frameworks developed to report on Sendai framework targets for disaster risk reduction at national sub-national scales (De Groeve et al., 2015; FEMA, 2020; Marin-Ferrer et al., 2017). However, the model described here does yet explicitly include a measure of resilience, which is intended to reflect a community's ability to recover from and adapt to the impacts and downstream consequences of a disaster event. Interventions that might be considered to reduce physical dimensions of vulnerability identified by the model include any combination of structural mitigation, relocation and/or re-purposing of structures that pose a specific threat to vulnerable populations, and the transfer of financial risk through proactive investments in property and casualty insurance. Social interventions that might be considered include (i) capacity development through a combination of emergency management and/or community development programs; (ii) the creation of neighbourhood-level resilience hubs that pre-position essential resources needed for individuals and groups to shelter in place until emergency services are available; and (iii) public advocacy for principles of disaster resilience to be incorporated into ongoing community planning and development proposals.

2.3.2. Identifying the Drivers of Hazard Threat

Spatial interactions between physical and social dimensions of hazard threat are evaluated using bivariate choropleth maps – a method that intentionally combines two separate variables on a single map layer using mathematically derived representation schemes in which color tone is used to reflect both sequential distributions and spatial relationships between variables for a given region of interest (Leonowicz, 2006). Map patterns that reflect the degree of overlap between variables can be used to infer cause-effect relationships within large heterogeneous datasets that would not otherwise be evident (Maceachren et al., 2001). The construction of bivariate maps involves a consideration of the processes that are likely to influence causal relationships between physical and social vulnerability, and statistical characteristics of the data used to represent these processes. Methods used in this study to develop bivariate hazard threat maps are summarized in Figure 2-6. First, value distributions for both physical and social measures of vulnerability are categorized into statistically significant groupings using the Jenks classification. Class selection is limited to intervals of low, medium, and high resulting in a 3x3 matrix of variable combinations that represent the range of interactions between physical hazard threat and social vulnerability. Once class boundaries have been defined, unique combinations between physical and social determinants of hazard threat are classified (e.g., low-low, medium-high) and mapped for each settled area.

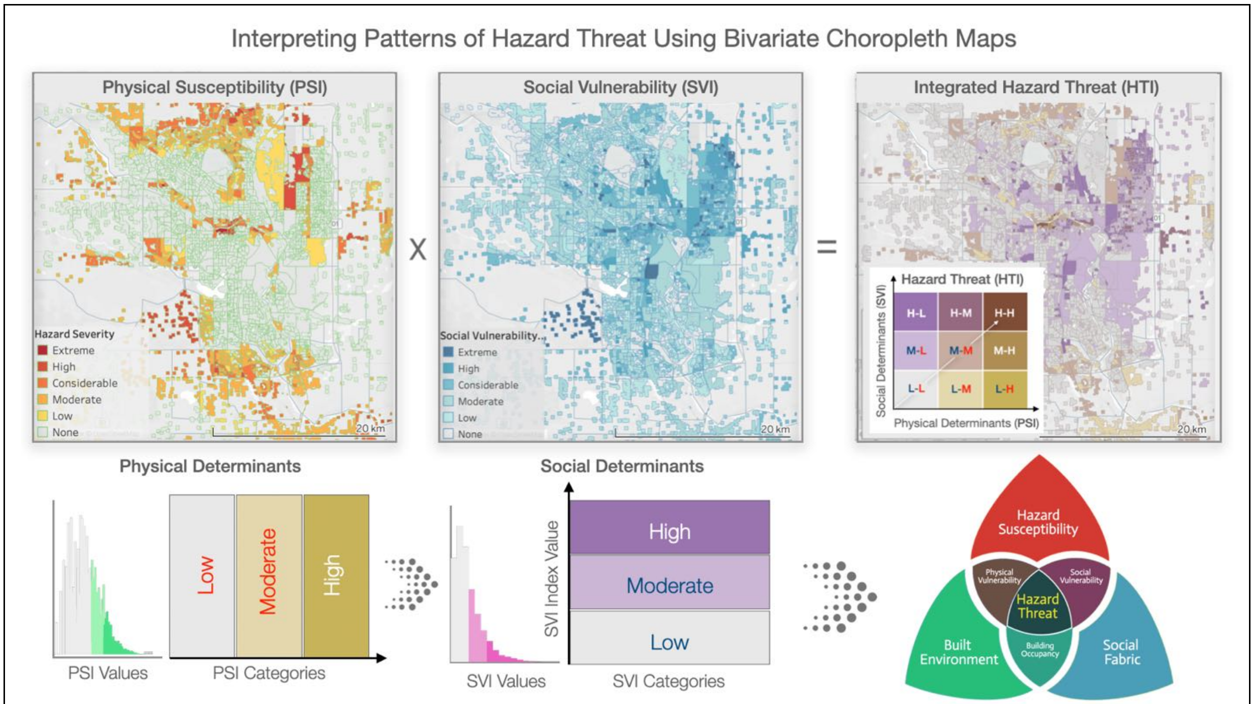


Figure 2-6: A summary of methods used in developing bivariate choropleth maps for visualizing spatial patterns of integrated hazard threat.

The resulting matrix of overlapping values are represented using a mix of two sequential color palettes that are combined mathematically to generate distinct variations in shade and tone that are suitable for people with color vision deficiencies (Brewer, 1994; Elmer, 2012; Stevens, 2015; Nowosad, 2020). In Figure 2-6, physical determinants of hazard threat are shown in shades of gold that increase in tone with the levels of susceptibility while social determinants are shown in shades of purple with intensities that increase based on threshold exceedance scores across all dimensions of social vulnerability. The goal is to enable users to read values for each of the variables independently while at the same time showing how interactions between these variables are distributed geographically (Leonowicz, 2006). For example, areas of overlap between moderate physical susceptibility and low social vulnerability have a very different meaning than areas where these patterns are reversed. Areas of overlap between high physical susceptibility and high social vulnerability provide important insights that can assist emergency managers and community planners in undertaking more detailed follow-up studies of specific neighbourhoods to determine what resources and/or services may be needed by different population groups to increase capacities to withstand and recover from future disaster events.

3.0 PATTERNS OF SOCIAL VULNERABILITY IN CANADA

There is an inherent organizational structure to human settlements that varies with geographic setting, population size, characteristics of the built environment, and corresponding levels of hierarchy within broader social, economic, and political systems that define a region or country (Alexander et al., 1977; Clifton et al., 2008; Marshall et al., 2009). We use these place-based organizational strucures and corresponding patterns of development as the context for assessing fundamental characteristics of social vulnerability that exist at the community level, and underlying factors that may differentially infuence the capacities of specific population groups to withstand, cope with, and recover from the impacts and consequences of future disaster events.

Social vulnerability profiles are evaluated in the context of broad settlement types at a national scale and in the context of major physiographic regions in Canada. Settlement types include urban, suburban, and exurban neighbourhoods that occur within densely populated metropolitan regions along the southern border of Canada, sparsely populated rural settlements that occur within broad agricultural and resource-based landscapes with variable degrees of metropolitan influence (i.e., strong, moderate, weak, and negligible), and more remote settlements that occur along isolated coastlines, interior boreal forests, and arctic regions of the north. Each of these broad settlement types are characterized by distinct patterns of land use and corresponding demographic profiles that reflect a complex set of historical interactions between underlying social, economic, and political systems. Regional profiles offer additional insights on how characteristics of social vulnerability are influenced by development patterns that are specific to each of the major physiographic regions in Canada. These include mountainous regions of the Cordillera in British Columbia, the Interior Prairie provinces of Alberta, Saskatchewan, and Manitoba, the central Canadian Shield and St. Lawrence Lowland regions of Ontario and Quebec, the eastern Maritime Provinces of New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador, and more remote regions of Nunavut, Yukon, and Northwest Territories in Northern Canada.

Based on methods described in Section 2, levels of social vulnerability within each of these settlement types are assessed using a common set of 20 indicators that measure dimensions of social capital, individual autonomy, housing conditions and financial agency for a given community or region. Threshold scores for more generalized levels of spatial aggregation are normalized by the number of corresponding site locations to preserve internal coherence of model results when comparing values from one region to another and/or when summarizing results to explore trends and potential causal relationships between observed patterns of land use and social vulnerability. Choropleth maps are used to assess spatial patterns of vulnerability from one region to another while a corresponding set of charts provide insights on statistical trends and potential underlying causal relationships. Collectively, this information provides a base of evidence for evaluating the social dimensions of natural hazard threat at a community level for all regions in Canada

3.1. SETTLEMENT TYPE PROFILES

The following sections describe general patterns of social vulnerability for each of the 8 broad settlement types in Canada. Characteristic profiles for each of these settlement types are summarized in Figure 3-1. Statistical profiles are used to evaluate relationships between physical characteristics of the built environment and socioeconomic factors that have evolved over time as part of the development process. Observed trends are consistent with the premise that underlying social, economic, and political factors that influence land management decisions about where people live also have a bearing on disparate patterns of social vulnerability that manifest at a local scale within urban and suburban neighbourhoods and communities situated in both rural hinterland and more remote settings.

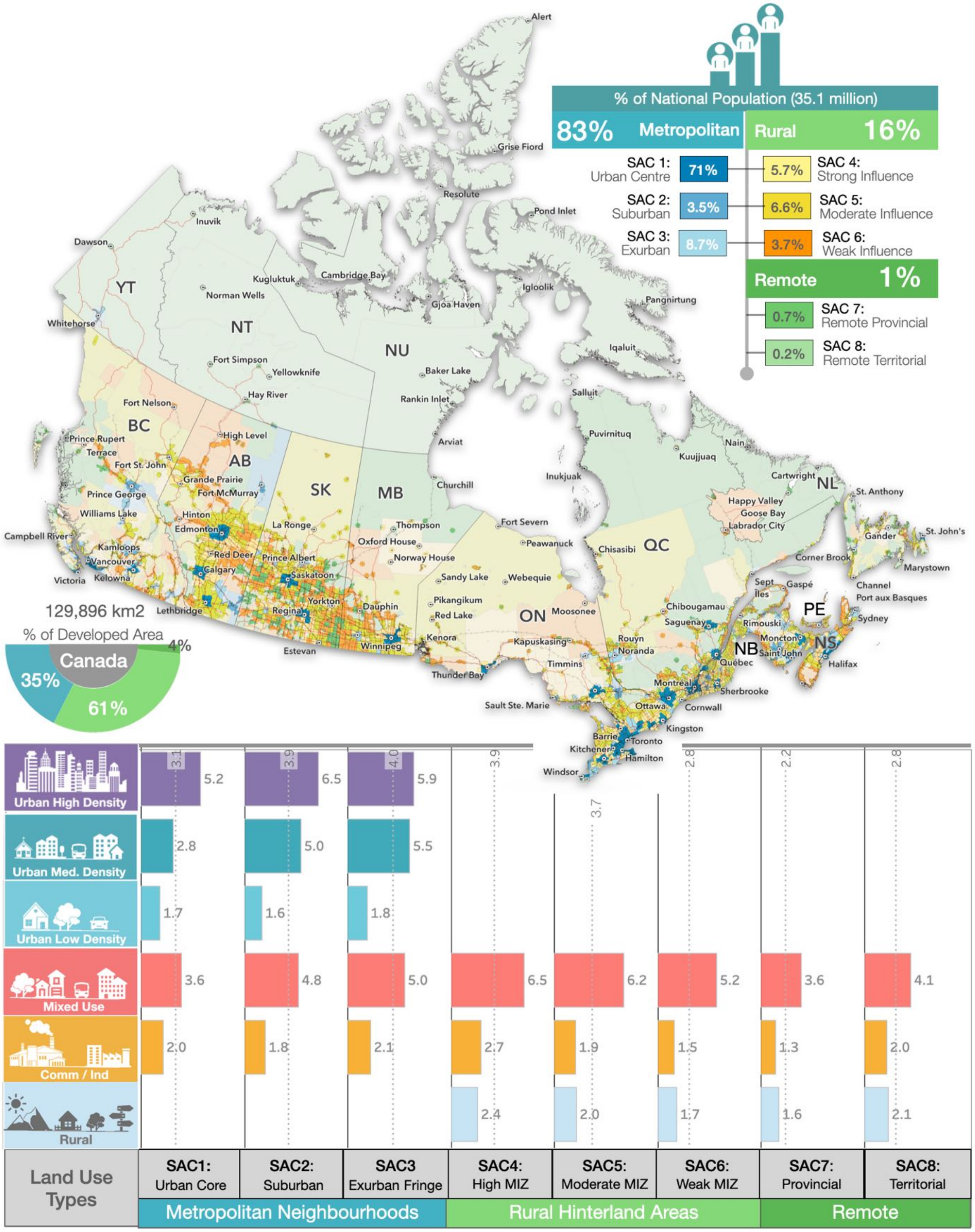


Figure 3-1: National distribution of settlement types and corresponding profiles of social vulnerability based on functional characteristics of land use.

3.1.1. Metropolitan Regions

Metropolitan regions are complex and interdependent social, economic and political systems which have evolved through the amalgamation of cities of varing size and complexity. They collectively encompass ~45,665 km^2 of developed lands in Canada (35% of total) and account for ~29 million people (~83% of the national population). They are characterized by densely populated urban cores surrounded by less dense suburban and exurban neighbourhoods with a high degree of socioeconomic integration. At least 50% of the employed labour force living in these broader metropolitan regions commute to one of the neighbouring urban centres for work on a regular basis and nearly all residents have ready access to health care and essential lifeline services.

Metropolitan regions function as hubs of commerce providing essential goods and services within a linear network of critical infrastructure systems (e.g., transportation, energy, water, communications) that connect areas of manufacturing, agriculture, and resource development across the country (Figure 3-2). They are engines of economic growth and development for the country and have experienced significant changes related to the re-distribution of people into urban areas, the densification of existing neighbourhoods, and the expansion of new development into neigbouring agricultural and wildland areas (Statistics Canada, 2015). The share of Canadians living in major metropolitan regions has nearly doubled over the last forty years while the relative proportion of people living in surrounding areas has steadily decreased over this same period (European Commission- Joint Research Centre, 2020).

Along with significant changes to the built environment, the history of urbanization in Canada has also led to more complex patterns of land use, a greater degree of racial and ethnic diveristy, and higher levels of disparity within underlying social and economic systems. Mean vulnerability threshold scores are relatively high for multi-family residential and mixed-use neighbourhoods in dense urban cores (SAC-1), and steadily increase in suburban (SAC-2) and exurban fringe areas (SAC-3) that are situated along the interface with less dense rural settlements (Figure 3-1). Corresponding profiles of social vulnerability are quite variable but are characterized by mean threshold scores that increase with density, complexity of land use, and distance away from the urban core (Figure 3-2). Detailed patterns of variability are described below for each of the major settlement types along with an assessment of underlying factors that contribute to observed trends.

Urban Settlements (SAC-1): occur in designated census metropolitan areas (CMA) having a minimum population of 100,000 with at least 50,000 people living in concentrated multi-family residential and mixed-use neighbourhoods adjacent to downtown commercial business centres. They encompass an area of 29,370 square kilometres in Canada (23% of total) and represent a total nighttime population of 25 million people (71% of total). Population centres vary in size from small (30,000 people) to medium (30,000-100,000 people) and large (>100,000 people). They are characterized by dense urban forms and complex patterns of land use that accommodate a wide range of multi-family residential, civic, commercial, and industrial functions. Population densities in these urban core zones average 850 people/km2 but range from a low of ~250 people/km^2 in neighbourhoods dominated by commercial and industrial land use to a high of 11,630 people/km^2 in dedicated urban high-density residential neighbourhoods. Higher levels of urban density are also characterized by a much greater diversity of building functions and a higher concentration of multi-family condominium and apartment buildings in medium- and high-density residential and mixed-use neighbourhoods.

As described above, measured levels of social vulnerability increase as a function of both residential density and the complexity of land use functions within a given neighbourhood. Average vulnerability threshold scores range from 3.9 to 5.8 for mixed-use and high density urban residential neighbourhoods and are above median levels for all land use classes in this settlement type (SVI_t = 3.4) while single-family residential neighbourhoods and lands dedicated to commercial and industrial uses record comparatively lower values of 1.7 and 2.0, respectively (see Figure 3-1). Corresponding patterns of social vulnerability are influenced primarily by reduced levels of social capital, individual autonomy, and increased housing stress in higher density residential and mixed-use neighbourhoods (Figure 3-2). Underlying factors that contribute to observed trends in these more densely populated areas include higher concentrations of people who have either recently moved or immigrated into

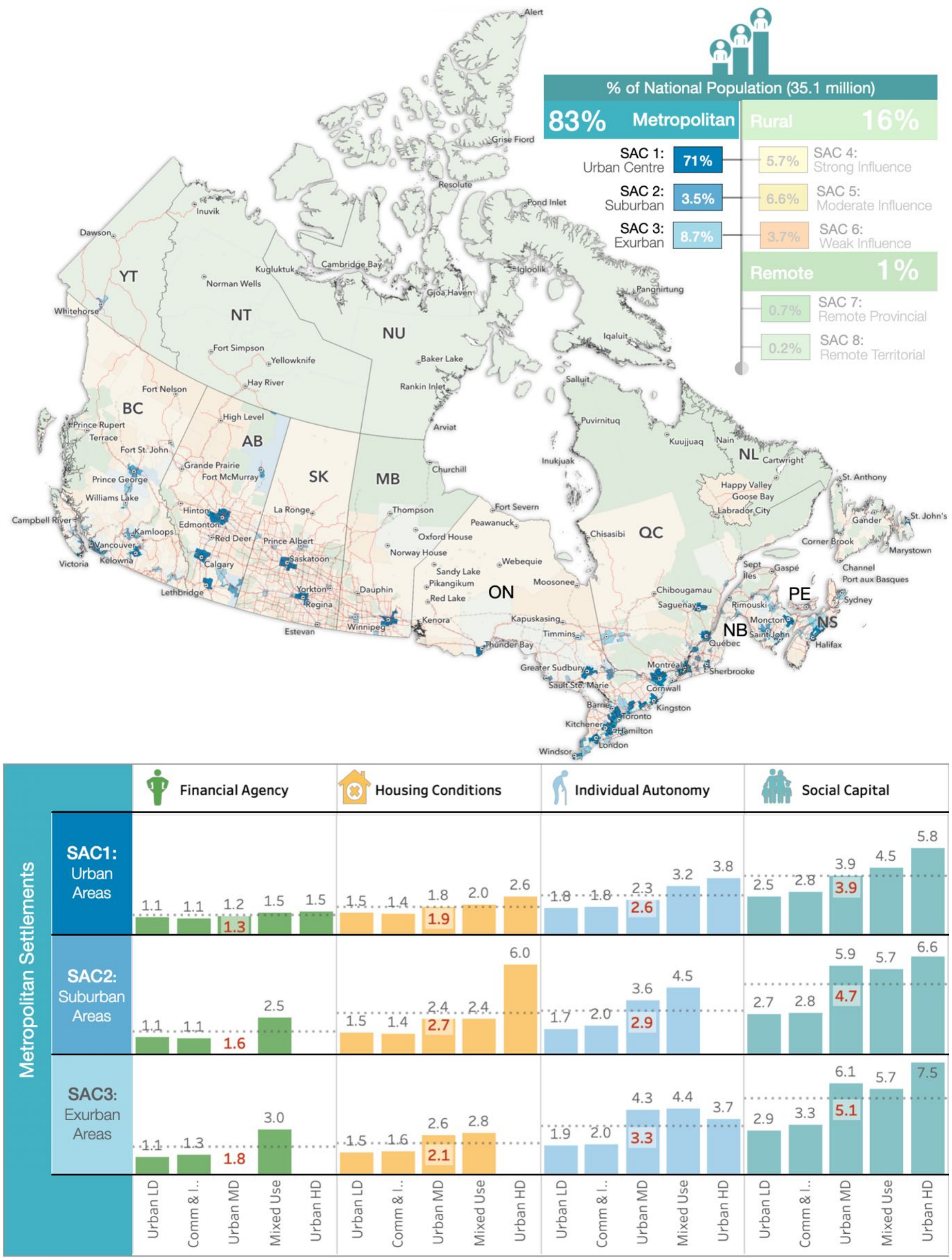


Figure 3-2: National distribution of metropolitan regions in Canada and corresponding statistical profiles summarizing relationships between land use and underlying dimensions of social vulnerability.

the region, higher concentrations of people living in unsuitable housing conditions and/or areas with higher levels of commercial activity, and increased economic stresses related to high shelter costs and unstable employment.

Suburban Settlements (SAC-2): along the margins of more densely settled urban centres and include census agglomeration areas (CA) with small- and medium-sized population centres (< 100,000 residents) in which at least 10,000 people live in higher density residential and mixed-use downtown business precincts. They encompass an area of ~4,000 square kilometres (3.1% of total) and are home to 1.24 million people (3.5% of total) with an average residential density of ~300 people/km^2. Although representing a relatively small share of the population, suburban settlements are characterized by high concentrations of single-family residential homes in all land use classes with proportions, ranging from 46% of the total building count in dedicated commercial/industrial lands to ~86% in low-density urban residential neighbourhoods. Multi-family townhouse, condominium, and apartment buildings are concentrated primarily in medium-density urban neighbourhoods with non-residential commercial buildings occurring both in dedicated downtown business districts and along arterial corridors that radiate out from downtown centres.

Patterns of social vulnerability at the community level are like those described above for more dense urban settlements, but with higher overall levels of disparity. Average threshold scores range between 5.0 and 6.5 for multi-family residential neighbourhoods and 4.8 for mixed-use commercial areas, well above the mean for this settlement type, while threshold scores for single-family residential and dedicated commercial/industrial land use classes are significantly lower (Figure 3-1). Reduced levels of social connectivity are evident across all land use classes while financial stress and reduced levels of individual autonomy occur primarily in mixed-use neighbourhoods (see Figure 3-2). Underlying factors that contribute to these observed trends include a greater proportion of residents who have either recently moved or immigrated into the region and for whom there may be language barriers, a greater reliance on public transit to support day-to-day activities, and a diversity of financial stresses for those households living on a fixed income and/or spending more than 30% on shelter costs.

Exurban Settlements (SAC-3): occur in the outer fringe areas of census agglomeration areas (CA) and are distinguished from other metropolitan regions by the absence of concentrated population centres with 1,000 or more people. They are also characterized by more diffuse patterns of development that encompass an area of 12,220 square kilometres (9.4% of total). Collectively, exurban areas account for ~3 million people (8.7% of total) with an average residential density of ~250 people/km^2. General patterns of land use are like those described for suburban settlements, but with more single-family homes and a greater diversity of non-residential buildings in all land use classes. Although present, medium- and high-density urban residential neighbourhoods represent a very small proportion of the overall developed area (~1%) and occur primarily in concentrated nodes at the intersection of major arterials. Overall, exurban areas are distinguished by lower levels of socioeconomic integration and connectivity to major transportation routes (RA Index value = 0.32) resulting in reduced accessibility to essential goods and services that are more readily available in larger population centres.

Exurban regions have the highest average threshold exceedance score of all settlement types in Canada (SVI_t = 4.0) with mixed-use and higher-density residential neighbourhoods recording anomalously high values ranging between SVI_t values of 5.0 and 5.9, respectively. Mean threshold scores in lower-density residential and dedicated commercial/industrial neighbourhoods (SVI_t = 1.8 and 2.1, respectively) are slightly higher than those observed in neighbouring suburban areas, but below the median for this settlement type. Underlying factors that contribute to these elevated levels of social vulnerability (Figure 3-2) include a higher overall proportion of the population with no fixed workplace, less stable employment, lower levels of secondary education and a higher concentration of lone parent families with young children. While the general characteristics of land use are like those in surrounding rural areas, financial stresses related to households reliant on a single income and/or who spend more than 30% of their income on shelter costs appear to be more pronounced in residential and mixed-used neighbourhoods.

3.1.2. Rural Hinterland

The rural hinterland encompasses a geographic area of ~79,800 square kilometres and represents ~61% of the total developed area in Canada. It includes rural communities of varying size that are situated within broad agricultural landscapes and/or wildland areas that support primary food production, resource development, and supply chain logistics that are required for the transport of goods into neighbouring commercial hubs. Although sparsely populated with an average density of less that 100 people/km^2, rural settlements collectively account for 5.6 million people or approximately ~16% of the total population in Canada.

Rural hinterland areas are generally characterized by reduced rates of growth and development caused by younger residents moving to other parts of the country in search of employment and economic security (Chagnon et al., 2019). They are distinguished primarily by distance away from major population centres and levels of metropolitan influence (i.e., strong, moderate, and weak). Although patterns of disparity are similar for most settlement types within the rural hinterland, overall levels of social vulnerability are lower in terms of average threshold exceedance scores and generally decrease with lower levels of metropolitan influence (see Figure 3-1). Average threshold exceedance scores range from a high of 3.9 in rural areas adjacent to major population centres to a low of 2.8 in more remote hinterland settings. As with less structured patterns of land use in neighbouring exurban settlements, threshold exceedance scores are highest in areas of mixed-use residential and commercial land use in which there is both higher density and greater diversity in the types of building functions at the neigbourhood level. National disparities as a function of land use and underlying dimensions of social vulnerability are shown in Figure 3-3.

Rural Settlements with Strong Metropolitan Influence (SAC-4): are situated outside metropolitan regions in the hinterland areas of all the larger provinces where at least 30% of the resident labour force commutes into an adjacent urban centre for work on a regular basis. There is a regular flow of goods and commercial services along major transportation routes and reliable access to health care and other essential needs. Collectively, these settlement types represent ~21% of the total settled area in Canada and 5.7% of the total population. Population densities range from 72 people/km^2 in more sparsely settled rural residential areas to 2,780 people/km^2 in more concentrated mixed-use areas that occur near the intersections of major transportation routes. While these areas of mixed use are relatively small in terms of overall developed area (~2% of total for SAC4), they are characterized by concentrations of non-residential buildings that are proportionally equivalent to those found in neighbouring areas of dedicated commercial/industrial land use (~25% of total for SAC4) and by a significantly higher share of multi-family townhouses and low-rise apartment buildings.

As shown in Figure 3-1, average threshold scores in lower-density rural residential areas (SVI_t = 2.4 are equivalent to those observed in the exurban fringe areas with increased levels of social vulnerability in commercial/industrial areas (SVI_t = 2.7) and in more densely settled mixed-use areas (SVI_t = 6.5). Underlying factors that contribute to elevated levels of social vulnerability (Figure 3-3) are also like those observed in exurban fringe areas including a higher overall proportion of the population with no fixed workplace, less stable employment, lower levels of secondary education and a higher concentration of lone parent families with young children. Additional factors that influence patterns of disparity in areas of mixed residential and commercial/industrial land use include housing stresses caused by higher concentrations of people living in older buildings that pre-date modern safety design guidelines and/or in accommodations considered unsuitable for the number of occupants; and financial stresses associated with households who rely on a single income or spend more than 30% on shelter costs.

Rural Settlements with Moderate Metropolitan Influence (SAC 5): are geographically more remote (RA Index = 0.31) and located in the hinterland of all larger provinces where at least 5% but no more than 30% of the resident employed labour force commutes into an adjacent metropolitan region for work on a regular basis. Although situated within a distributed network of infrastructure systems (transportation, water, and energy), the degree of remoteness translates into more limited connectivity and integration with neighbouring metropolitan regions

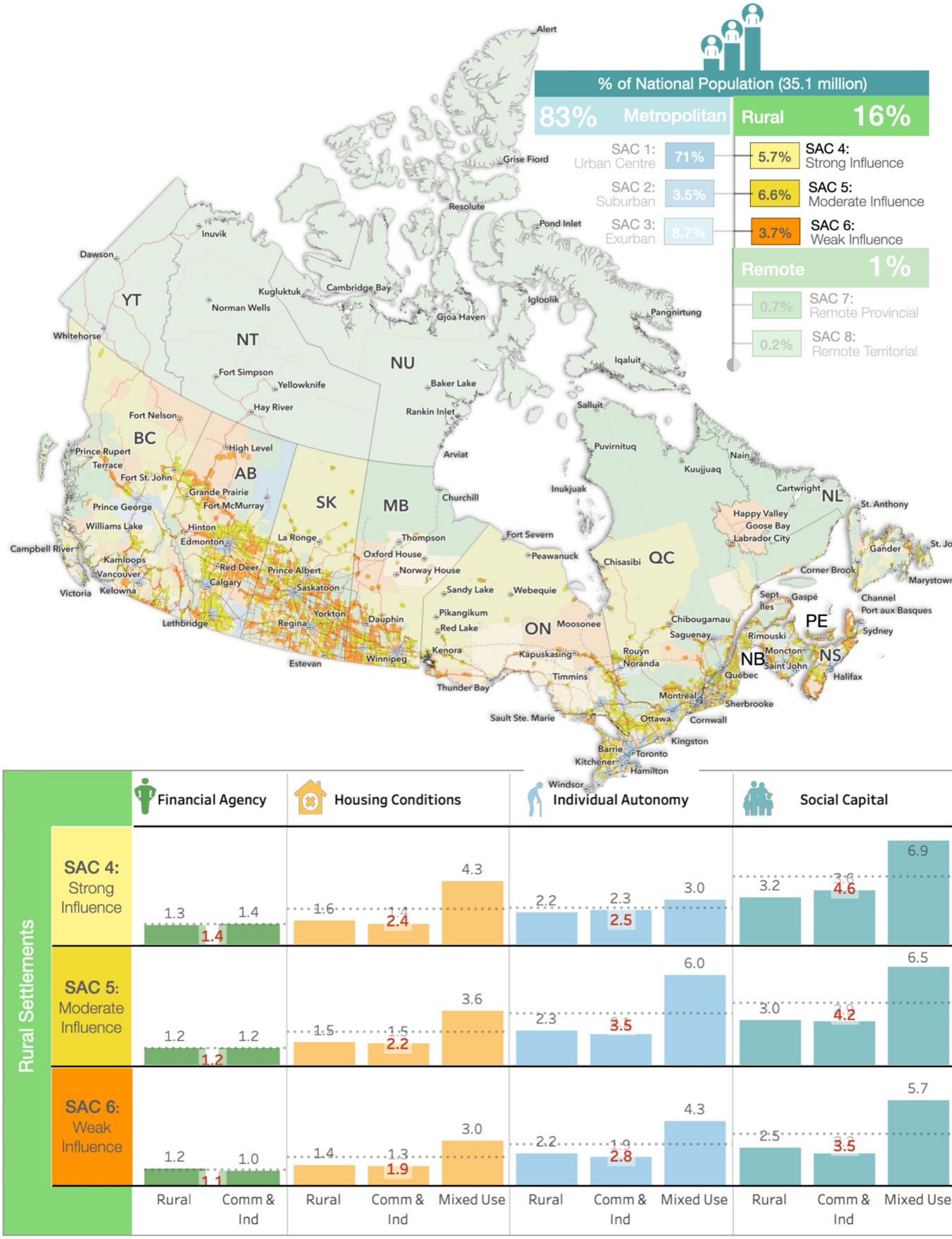


Figure 3-3: National distribution of rural settlements in Canada and corresponding statistical profiles summarizing relationships between land use and underlying dimensions of social vulnerability.

and reduced levels of access to both health care and other essential services. Collectively, these settlement types represent ~28% of the total settled area in Canada and 6.6% of the total population. They are characterized by higher proportions of non-residential buildings in all land use classes with mixed-use and commercial/industrial areas representing almost 14% of the total building stock for this settlement type.

Overall, rural settlements in hinterland areas with moderate levels of metropolitan influence have lower levels of socioeconomic disparity across all land use classes when compared with those situated in rural areas with higher levels of metropolitan influence. Average vulnerability exceedance threshold scores range from 1.9 in dedicated commercial/industrial land use classes to 2.0 in more sparsely populated rural residential areas, which make up more than 90% of the total building stock for this settlement type. As with other rural hinterland settlements, levels of disparity are highest in mixed land use classes (SVI_t = 6.2), which collectively represent less than 1.5% of the total building portfolio. Underlying factors that contribute to elevated levels of vulnerability (Figure 3-3) include reduced levels of social capital and individual autonomy related to the absence of a fixed workplace, unstable employment, higher concentrations of families with young children, fewer numbers of people with secondary education and more limited access to others with training, and/or expertise in the health sector.

Rural Settlements with Weak Metropolitan Influence (SAC 6): are represented by hinterland communities in all the larger provinces where less than 5% of the resident employed labour force commutes into a major population centre for work on a regular basis. They are characterized by sparsely distributed settlements in more remote locations (average RA Index value of 0.43) that have more limited access to health care and other essential services. Collectively, these more remote rural communities represent ~13% of the total developed land area and 3.7% of the total population in Canada. Rural residential areas are characterized by single family homes and related infrastructure that represent ~86% of the total building portfolio with higher concentrations of non-residential buildings in both mixed-use and dedicated commercial/industrial lands compared with other rural hinterland areas.

Patterns of socioeconomic disparity are like those described for rural hinterland areas with moderate levels of metropolitan influence, but with lower overall levels of social vulnerability. Average vulnerability exceedance threshold scores range from 1.5 in dedicated commercial/industrial land use classes to 1.7 in more sparsely populated rural residential areas. Levels of disparity are highest in mixed land use classes (SVI_t = 5.2), which collectively represent nearly 4% of the total building portfolio. Underlying factors that contribute to elevated levels of vulnerability in these more remote rural settlements are common across all land use classes and include higher proportions of lone-parent families and those caring for young children, unstable employment, and financial stresses related to the upkeep and care of households in which the primary maintainer is either younger than 25 years or older than 65 years of age (Figure 3-3).

3.1.3. Remote Settlements

Remote regions of Canada include sparse settlements along the coastline in western British Columbia and the eastern Maritime provinces, isolated regions in the Interior Prairies of Saskatchewan and Alberta, boreal forest regions of the Yukon and Northwest Territories, and arctic regions of Nunavut (Figure 3-4). Collectively, these communities represent ~3% of all settled areas in Canada and less than 1% of the total population. There is negligible socioeconomic influence from metropolitan regions and a greater focus on sustainable land use practices based on fishing, trapping, and subsistence hunting. People living in these areas may have limited or no direct connection with established critical infrastructure systems (transportation, water, and energy) and often must travel to neighbouring regions to access health care and other essential services.

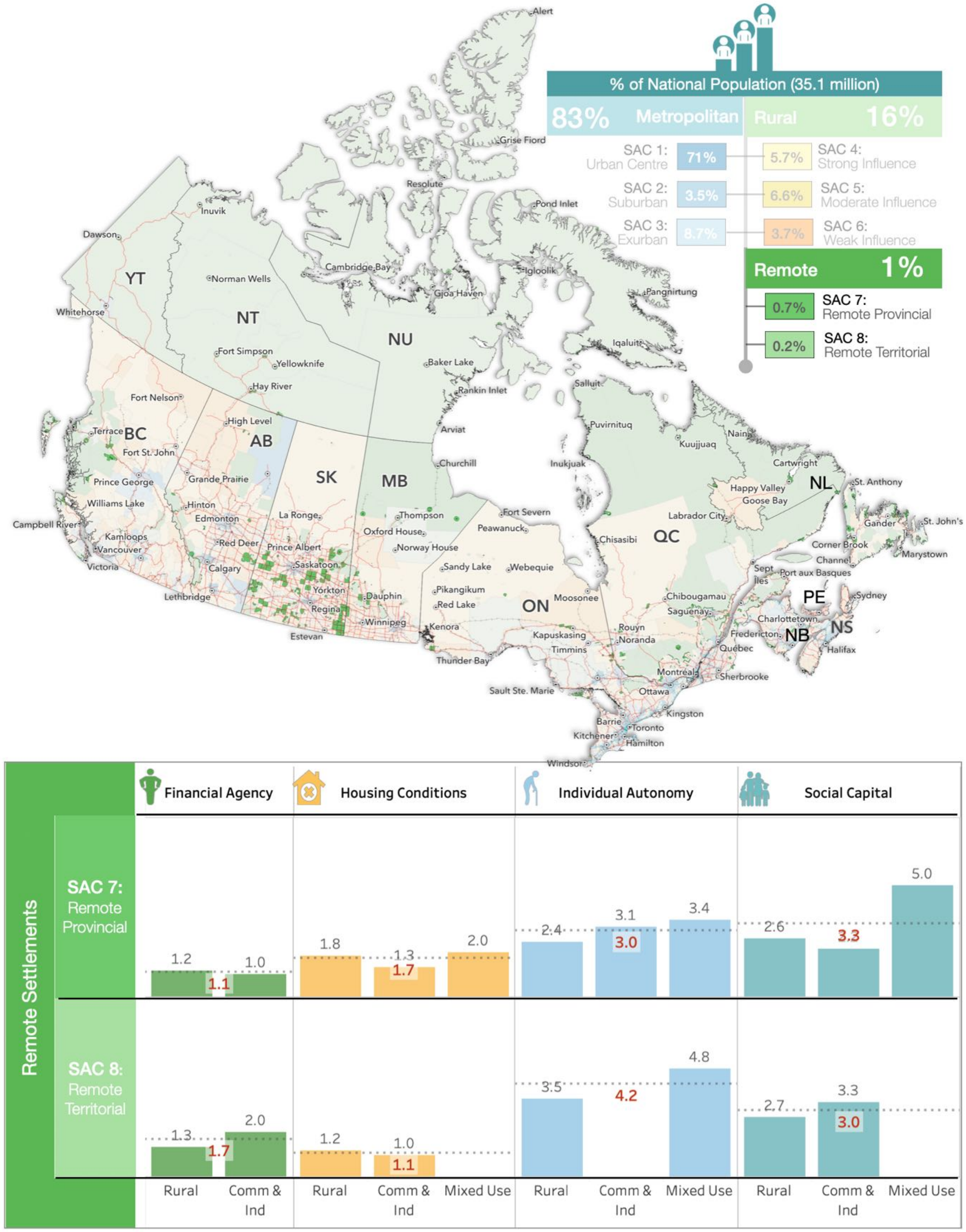


Figure 3-4: National distribution of remote settlements in Canada and corresponding statistical profiles summarizing relationships between land use and underlying dimensions of social vulnerability.

Remote Provincial Settlements (SAC Type-7) occur in geographically isolated areas characterized by sparsely distributed residential settlements and/or small clusters of buildings situated either along sections of coastline or deep within interior forested areas. Single-family residential homes represent nearly 90% of all buildings with smaller pockets of multi-family and non-residential structures making up the remaining 10% of the general building stock.

Collectively, remote provincial communities record the lowest overall level of socioeconomic disparity of all settlement types in Canada with an average threshold exceedance score of 2.2. Context-specific values range from a low of 1.3 to 1.6 in commercial/industrial and dispersed rural residential areas, respectively, to a high value of 3.6 in areas of mixed use residential and commercial activity. Underlying factors that contribute to elevated levels of vulnerability in these areas include reduced levels of individual autonomy related to concentrations of Indigenous people living in settlements with more limited connections to traditional territories, unreliable access to health care and essential services, unstable employment and related financial stresses, and higher concentrations of buildings constructed prior to the introduction of modern safety design guidelines (Figure 3-4).

Remote Territorial Communities (SAC-8) are similar in profile to their provincial counterparts but situated in the far north and arctic regions of Nunavut, the Yukon, and Northwest Territories. Patterns of land use are like those described above with single-family households and clusters of buildings distributed across vast landscapes with little or no direct connectivity to neighbouring population centres. However, small towns and villages are more common in these isolated settings with structured land use patterns characterized by low-density residential neighbourhoods interspersed with mixed residential and commercial/industrial areas containing roughly equal proportions of multi-family and non-residential buildings. Rural communities may have limited or no direct connection with established critical infrastructure systems (transportation, water, and energy) and residents often must travel long distances to access health care and other essential services.

Although representing a very small proportion of the overall Canadian population (~0.2%), these remote territorial settlements are characterized by higher overall levels of social vulnerability than their provincial counterparts (SVI_t = 2.8). Patterns of socioeconomic disparity are more like those observed in suburban metropolitan regions with threshold exceedance scores ranging from relatively low values of 2.0 and 2.1 in dedicated commercial/industrial and low-density single-family residential areas to considerably higher values of 4.8 in mixed use neighbourhoods. Underlying factors that contribute to observed patterns of vulnerability are like those described above for more remote rural hinterland communities. These include increased financial stresses related to unstable employment and higher concentrations of households in which the primary maintainer responsible for upkeep and improvements is either younger than 25 years or older than 65 years of age with lower levels of discretionary income. Other factors that contribute to elevated levels of vulnerability include higher concentrations of people with language barriers who may have more difficulty accessing health care and essential services, higher concentrations of people living in households considered unsuitable for the number of building occupants, and higher concentrations of buildings constructed prior to the introduction of modern safety design guidelines.

3.2. Regional Profiles

Having established backbone patterns and underlying factors that contribute to characteristics of social vulnerability for each of the eight broad settlement types, this section explores how these patterns vary from region to region across Canada (Figure 3-5). Regions are defined based on broad physiographic boundaries that reflect distinct characteristics of the landscape (e.g., geologic setting, topographic relief, land cover, continuous permafrost). They include mountain and coastal areas of the Cordillera region in British Columbia (BC); the Interior Prairies region of Alberta (AB), Saskatchewan (SK), and Manitoba (MB); the Canadian Shield and St. Lawrence Lowland regions of Ontario (ON) and Quebec (QC); the Maritime provinces of New Brunswick (NB), Prince Edward Island (PE), Nova Scotia (NS), and Newfoundland and Labrador (NL); and the Northern boreal forest and arctic regions of the Yukon (YT), Nunavut (NU), and Northwest Territories (NT).

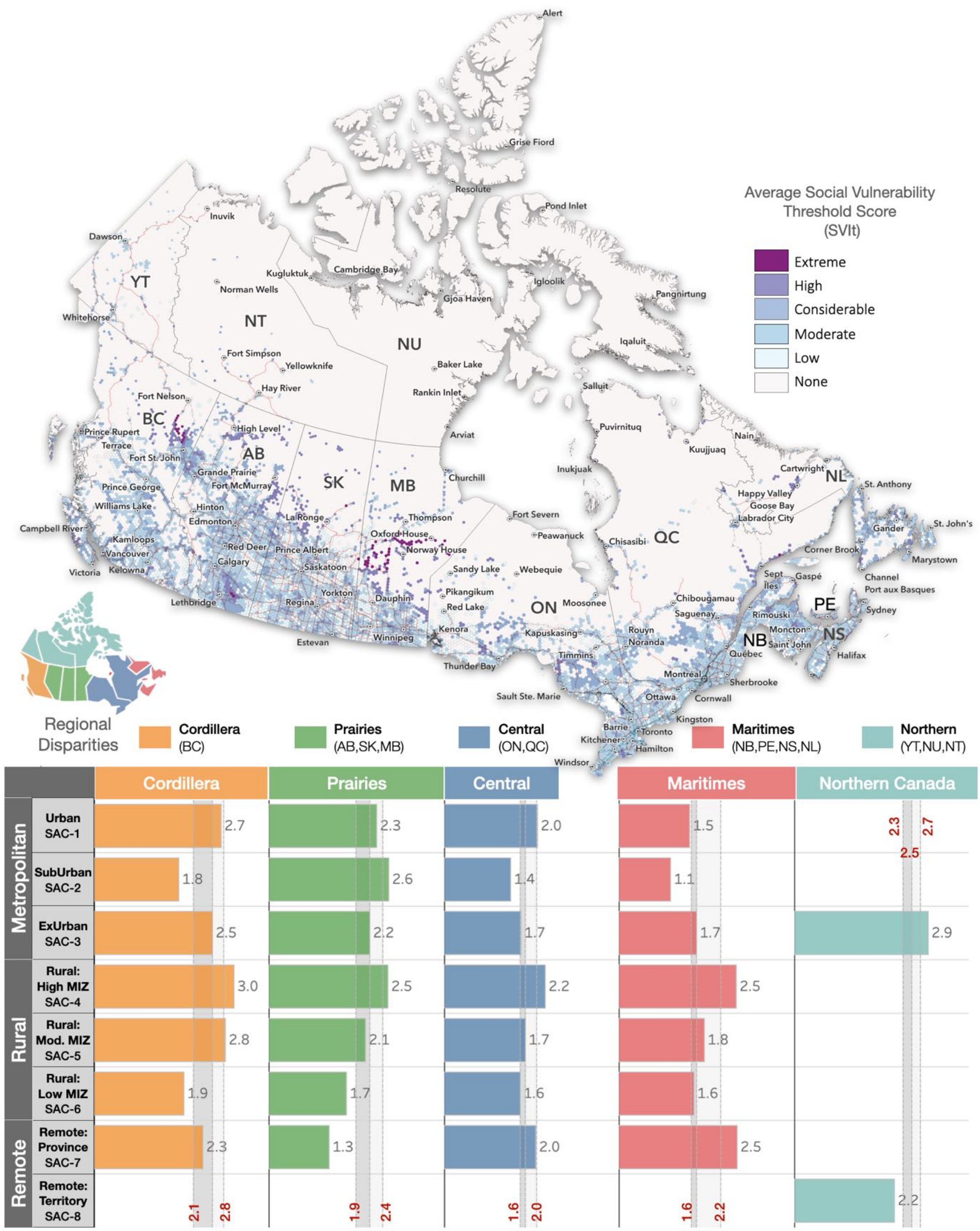


Figure 3-5: Spatial patterns of social vulnerability and corresponding profiles of mean threshold exceedance score for settlement types within each major physiographic region of Canada.

Place-based regional profiles are described using a combination of choropleth maps that show spatial variability in mean levels of social vulnerability from one location to another, and a corresponding set of statistical charts that summarize key trends in model results. Regional trends are interpreted based on established correlations between levels of social vulnerability and characteristics of functional land use for major settlement types (e.g., density and physical complexity of built environment), and on disparities in underlying patterns of vulnerability that exist between Indigenous communities and the rest of the population. Underlying socioeconomic factors are evaluated by comparing mean vulnerability threshold exceedance scores for each settlement type with corresponding median and quartile values for the full distribution of threshold values across all settlement types both within a given region and at a national level.

Results of our assessment (see Figure 3-5) show that regional profiles are distinct in terms of both overall levels of socioeconomic disparity, and the degree to which levels of social vulnerability for a given settlement type vary from one region of the country to another. Densely settled urban centres (SAC-1) with more complex patterns of land use are characterized by mean threshold exceedance scores that are consistently in the upper quartile range (upper 50% of distribution) for all regions of the county, except the Maritimes. In contrast, mean values for suburban settlements (SAC-2) are consistently in the lowermost quartile range, except for the Prairies, where values are in the uppermost 25% of the regional distribution. Mean threshold scores for lower density exurban settlements with less structured patterns of land use (SAC-3) are equivalent to median values for most regions of the country except for the far north, where values are in the uppermost 25% of the regional distribution.

Rural hinterland settlements with strong levels of metropolitan influence (SAC-4) are characterized by mean threshold exceedance scores that are consistently in the upper 25% of all regional distributions and that record some of highest levels of socioeconomic disparity in Canada. By comparison, mean levels of social vulnerability for rural hinterland settlements with moderate levels of metropolitan influence (SAC-5) are generally within the range of values between the first and third quartiles, while more distant settlements with weak levels of metropolitan influence (SAC-6) are characterized by vulnerability threshold scores that are in the lower quartile (lowest 25% of value distribution) for all settlement types within a given region.

3.2.1. Disparities Related to Land Governance

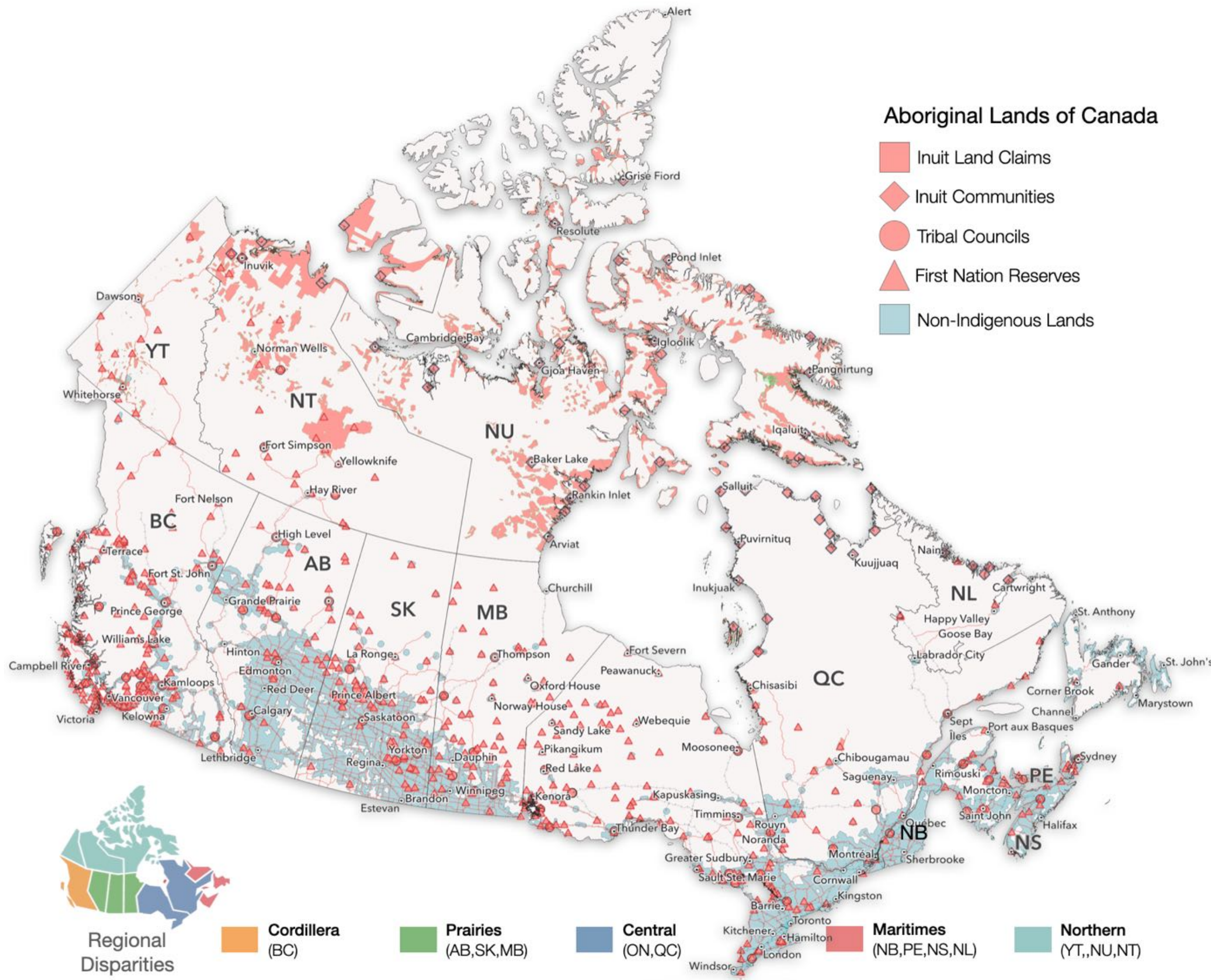
Place-based statistical profiles provide important insights on how patterns of social vulnerability vary for each settlement type as a function of physiographic setting and characteristics of the built environment (i.e., density and functional land use). However, they do not fully explain more localized patterns of socioeconomic disparity related to land title and associated land governance systems that exist between Indigenous communities and the general population. These disparities are well known and have been the focus of ongoing efforts to measure gaps in well-being and monitor the effectiveness of strategies that have been implemented to address underlying factors of inequity and marginalization that exist within many Indigenous communities across Canada (Matheson et al., 2012; O'sullivan, 2013; Auditor General of Canada, 2018; Indigenous Services Canada, 2019; Statistics Canada, 2019; Chakraborty et al., 2021). Results of our regional assessment provide an opportunity to evaluate these differences in more detail through the lens of broad settlement types and associated characteristics of land use that influence the ways in which patterns of social vulnerability are manifest at the community level.

The focus of our assessment is primarily on understanding relative patterns of disparity within a given region and identifying contributing factors that are relevant in the context of managing disaster risk rather than measuring absolute levels of social vulnerability or comparing index values between different communities. We acknowledge that metrics designed to measure levels of social vulnerability for Settler communities are based on North American cultural norms and may not be appropriate for assessing comparable levels of vulnerability for Indigenous communities; particularly those who have retained a strong connection to ancestral values, family structures, traditional forms of knowledge, and land-based sources of livelihood (Guthro, 2021). Nonetheless, census-based demographic variables are effective in providing a systematic description of social fabric for all regions in Canada and can be useful in identifying underlying factors that may differentially affect the capacity of community members to manage the impacts of a hazard event. These insights can help inform emergency planning and strategies that promote broader objectives of disaster resilience sustainable development at the community level.

The 2016 national census reports 1.67 million Indigenous Peoples in Canada, accounting for 4.9% of the total population (Statistics Canada, 2016c). This includes a First Nations population of 977,230 of whom nearly half live on reserve lands situated primarily in the southern provinces of Canada, the Yukon, and Northwest Territories; a Métis population of 587,545 people living mostly in metropolitan regions of Ontario and the western provinces of Canada; and an Inuit population of 65,025 of whom nearly three-quarters live in remote communities in the northernmost regions of Canada. Statistics Canada (2016d) estimates that 48% of people on First Nation reserves live in low-income situations compared with 31% for those living off reserve and 14% for the general population. The 2016 census also reports that nearly half (45%) of all First Nations people living on reserve lands occupy housing that is not suitable for the number of occupants and/or that needs major repairs (Statistics Canada, 2016b). This is over three times higher than for First Nations people living off reserve (14%) and more than seven times higher than for the general population (6%). While the national social vulnerability model accounts for the relative proportion of Indigenous peoples within a given dissemination area, it does not explicitly consider the effects of land management systems that can differentially affect the well-being of community members (Fligg et al., 2020). To better understand these differences, we have parsed model results based on whether a given census dissemination area is located on lands administered under provincial/territorial jurisdiction, or through governance systems associated with lands where the title has either been vested with specific Indigenous groups or set aside for their exclusive benefit. For purposes of clarity, we identify those living on designated Aboriginal Lands as primarily '**Indigenous Communities**' and those living on lands administered by provincial and territorial authorities as '**Settler Communities.**'

Administrative boundaries of Aboriginal Lands are based on parcel-level data maintained as part of the Canada Lands Survey Records (CLSR) by the Surveyor General Branch of Natural Resources Canada (NRCan 2010, 2021a). As defined, they include but are not limited to First Nation reserves; Cree-Naskapi Category and Kanesatake Mohawk Interim Lands of Quebec; First Nation Settlement Lands of the Yukon; the Tlicho, Inuvialuit, Gwich'in and Sahtu Lands of the Northwest Territories, and Inuit Owned Lands of the Nunangat region in Nunavut, the Northwest Territories, northern coastal areas of Quebec, and Newfoundland and Labrador. Statistical profiles based on physical characteristics of the built environment and socioeconomic indicators that are specific to jurisdictional boundaries are then used to assess how patterns of social vulnerability differ between Indigenous communities living on Aboriginal Lands and those of the broader Canadian population. Results of our analysis (see Figure 3-6) are generally consistent with broad measures of disparity that have been documented as part of the Community Well Being Index of Canada (Indigenous Services Canada, 2019). However, they provide additional insights on how specific dimensions of social vulnerability vary as a function of settlement type and related patterns of land use. Detailed patterns of disparity are summarized in Appendix C.

Differences in measured levels of social vulnerability between those living on Indigenous lands and those of the broader population (i.e., *Settler Communities*) are most pronounced in the Interior Prairie provinces of Alberta, Saskatchewan, and Manitoba. Relative degrees of variance in the southern part of the Prairies range between a factor of 1.5 and 2.4 for more densely settled metropolitan regions and increase to a factor of ~3.5 for more remote settlements that have little or no socioeconomic integration with neighboring population centres. Patterns of disparity are less extreme in Central and Maritime regions where relative degrees of variance range between 1.2 and 2.6 for more densely settled metropolitan regions, and from 1.1 to 1.5 in more remote settlements of northern Quebec and Labrador. Although still significant, patterns of disparity are more subdued in the Cordillera and Northern regions Differences in mean levels of vulnerability are negligible in the major urban centres of southwestern British Columbia but increase in more rural and remote settings where measures of vulnerability for Indigenous communities exceed those of the general population by a factor of between 1.3 and 1.9. These patterns are reversed in the North, where levels of disparity for Indigenous communities are negligible in remote settlements and lower than for those living under provincial jurisdiction in larger population centres. We explore these patterns more completely in the following series of regional profiles.



			Cordillera	Prairies	Central	Maritimes	Northern Canada
Metropolitan	Urban SAC-1	Prov/Terr Lands	2.7	2.3	2.0	1.5	
		Indigenous Lands	2.7	5.1	2.4	2.4	
	SubUrban SAC-2	Prov/Terr Lands	1.8	2.5	1.4	1.1	
		Indigenous Lands	2.8	6.1	3.3	2.9	
	ExUrban SAC-3	Prov/Terr Lands	2.5	2.2	1.7	1.6	3.1
		Indigenous Lands	3.3	3.4	3.7	3.5	2.6
Rural	High MIZ SAC-4	Prov/Terr Lands	3.0	2.5	2.2	2.5	
		Indigenous Lands	3.6	4.0	2.3	2.6	
	Mod. MIZ SAC-5	Prov/Terr Lands	2.8	2.0	1.7	1.8	
		Indigenous Lands	3.3	5.0	2.9	4.0	
	Low MIZ SAC-6	Prov/Terr Lands	1.9	1.6	1.6	1.6	
		Indigenous Lands	2.9	4.8	3.4	3.8	
Remote	Province SAC-7	Prov/Terr Lands	1.7	1.2	1.9	2.5	
		Indigenous Lands	3.3	4.2	2.9	2.7	
	Territory SAC-8	Prov/Terr Lands					2.2
		Indigenous Lands					2.1

Land Governance
Provincial/Territorial
Aboriginal Lands

Figure 3-6: Spatial distribution of Aboriginal Lands and corresponding measures of disparity within settlement types for major physiographic regions in Canada.

3.2.2. Cordillera (BC)

British Columbia encompasses ~8% of the total developed area of Canada (9,980 km^2) and is home to more than 4.6 million people, or approximately 13% of the national population. As in other regions of Canada, land governance in British Columbia is managed by local authorities (i.e., municipal, and regional district councils) who administer policies directing land use and future growth management in accordance with provincial legislation. Aboriginal Lands account for nearly 9% of the developed area in BC (~880 km^2) with an estimated Indigenous population of 270,585 people of whom ~64% are First Nations, 33% are Métis, and 0.6% are of Inuit origin. There are an estimated 230,790 people living on one of 201 First Nations reserves whose collective interests are represented by 21 tribal councils.

Regional patterns of development are controlled by the physical constraints of steep mountainous terrain and the limited availability of private lands for residential development (Figure 3-7). More than 3.9 million people (85% of BC population) live in metropolitan regions situated along low-lying coastal areas of the Georgia Basin (Metro Vancouver), southern Vancouver Island (Victoria), Fraser Valley (Langley-Abbotsford), and the Okanagan Lake region (Kelowna). Residential densities in these more densely populated urban centres are the third highest in Canada, with an average of ~2,500 people per square kilometre for Settler communities and ~685 people per square kilometre for Indigenous communities. A constellation of smaller towns and villages represented by suburban and exurban settlement patterns occur in rural hinterland areas along the coast and within interior regions of the Cordillera. These regional hubs are situated primarily along mountain valleys that serve as corridors for transportation and critical infrastructure systems serving both larger metropolitan regions in southwestern British Columbia and smaller rural and remote communities throughout the province. In contrast to metropolitan areas, average residential densities for Settler communities are significantly lower than their Indigenous counterparts in both rural and remote settings. Residential densities generally decrease with degree of remoteness from 90 to 55 people/km^2. However, these patterns are reversed for those living on Indigenous lands in equivalent settings where residential densities increase from ~160 to ~205 people/km^2 with distance away from major population centres.

Mean vulnerability threshold scores are relatively high overall (SVIt = 2.9) compared with other regions of the country with regional hotspot areas occurring primarily in i) densely populated metropolitan areas of the Georgia Basin in southwestern British Columbia including Vancouver, Victoria, Duncan, Nanaimo, Courtenay, and Campbell River; (ii) smaller towns and surrounding rural communities situated along the Fraser and North Thompson Rivers and in the Bulkley-Nechako, Dawson Creek, and Fort St. John areas; and (iii) remote coastal communities along western Vancouver Island and in the Prince Rupert areas. Underlying factors that contribute to these regional trends include reduced levels of housing security and individual autonomy for both Settler and Indigenous communities, and reduced levels of social capital for multi-family and mixed-use residential neighbourhoods in metropolitan centres and surrounding rural areas (see Figure 3-7).

Housing stresses are relatively high across most land use classes but most pronounced in medium-density urban residential neighbourhoods that occur in exurban regions of larger cities and towns (SAC-3), and in mixed-use and commercial/industrial areas that occur in rural and remote settlements with varying degrees of metropolitan influence (SAC-4, 5, 6, & 7). Threshold scores for mixed-use neighbourhoods in rural and remote settings exceed national averages for housing conditions by a factor of 1.5 to 2.5 while scores for equivalent Indigenous neighbourhoods exceed national averages for housing conditions on Aboriginal Lands by a factor of 1.4 to 4.0. Reduced levels of individual autonomy are most prevalent in less structured exurban settlements, and in commercial/industrial and neighbouring residential areas that occur in rural settlements with both strong and weak levels of metropolitan influence. Corresponding threshold scores exceed national averages by a factor of 1.3 to 1.4 in metropolitan and rural hinterland settings and are generally below national averages for those living on Indigenous lands across all settlement types. The exception is for multi-family neighbourhoods in metropolitan regions, where vulnerability scores exceed the national average by a factor of 1.2. Measures of financial agency are generally equivalent to or below national average values across all settlement types and land use categories.

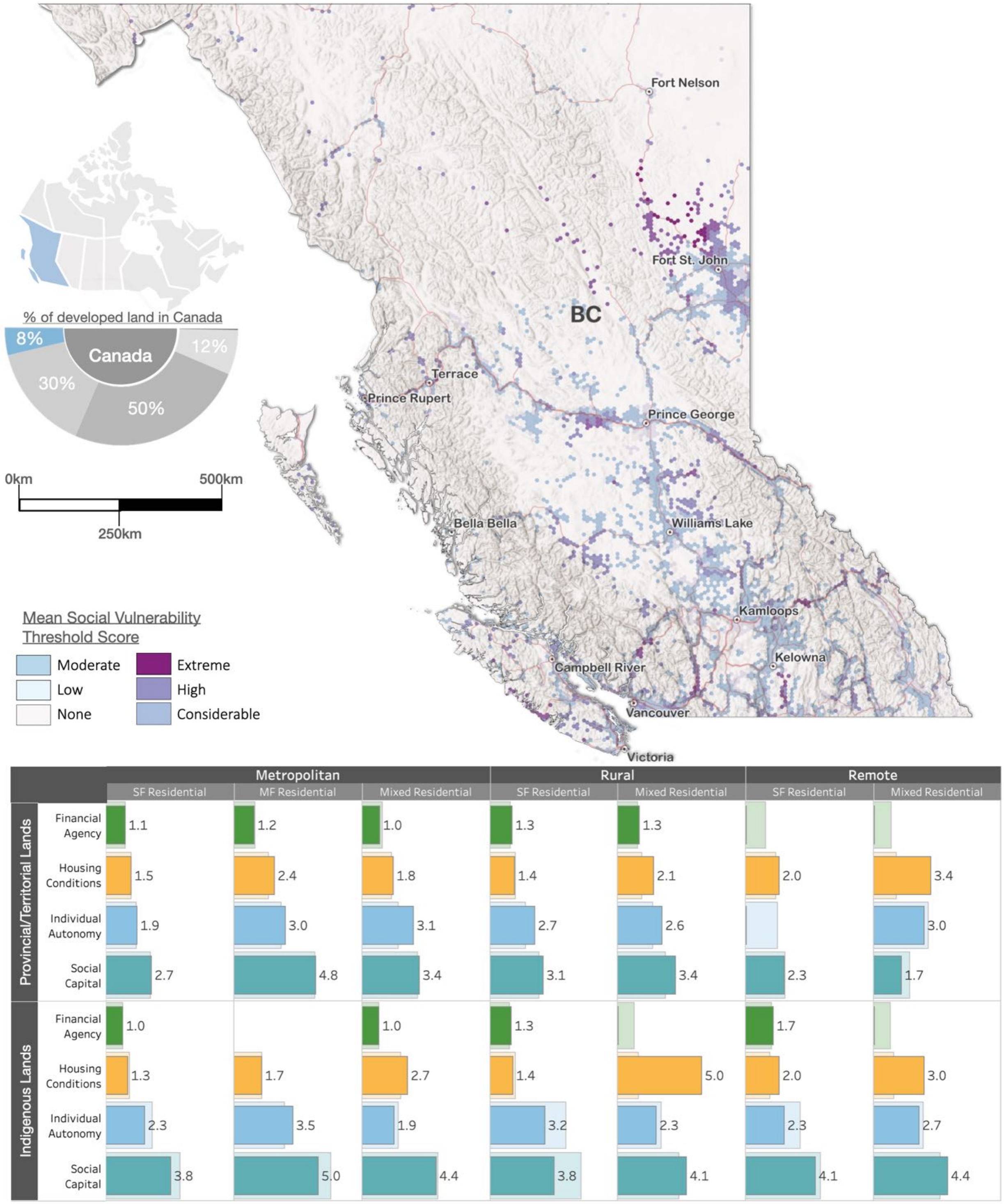


Figure 3-7: Regional patterns of social vulnerability and comparison of threshold levels for those living on lands administered under Provincial authority and those living on Indigenous lands in the Cordillera region of British Columbia (solid color) compared with national average (light color equivalent). Note that profiles of social vulnerability are referenced to a specific settlement type and should not be compared across settlement types.

Detailed choropleth maps of mean site-level threshold exceedance scores provide examples of how these regional profiles of social vulnerability are manifest on the ground for representative communities (Figure 3-8). High and extreme levels of social vulnerability in the larger urban centres of Greater Vancouver and the Victoria Capital Region are concentrated primarily in medium- and high-density urban residential neighbourhoods in downtown core areas of the larger municipalities and in mixed-use commercial and light industrial areas situated along major arterial corridors. As is characteristic for densely populated urban centres of this type across Canada, the primary determinants of vulnerability include higher shelter costs, concentrations of visible minorities and lower income families living in unsuitable housing, a reliance on public transit, and higher concentrations of recent immigrants with a limited capacity to communicate in either of the official languages. Levels of disparity between Indigenous communities and the rest of the population in urban centres are relatively low compared with other metropolitan regions in Canada with average threshold exceedance scores for designated First Nation reserve lands exceeding those in surrounding areas by a factor of 1.3 to 1.6.

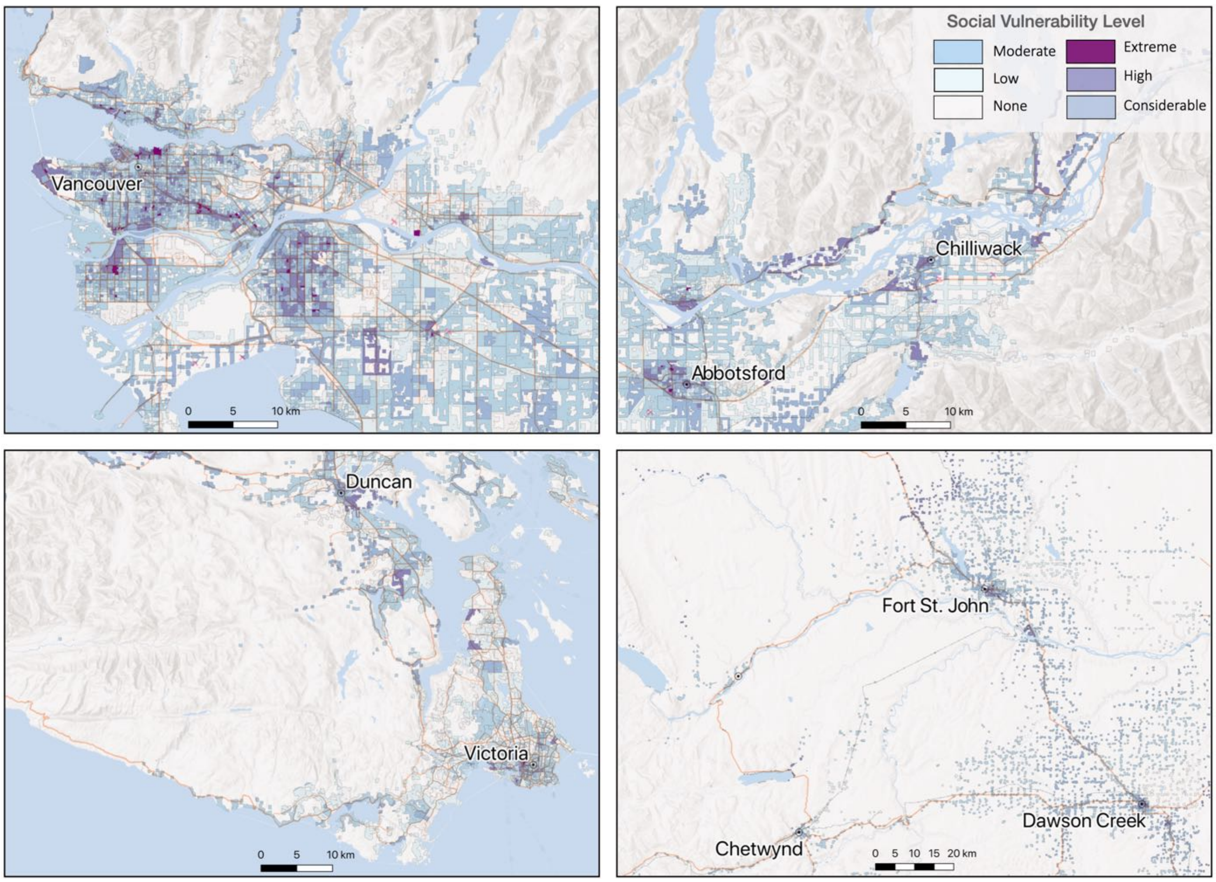


Figure 3-8: Detailed patterns of social vulnerability for representative communities in British Columbia

Areas of increased vulnerability in surrounding suburban and exurban areas of the Fraser Valley and southern Vancouver Island are concentrated primarily in multi-family residential, mixed-use, and commercial/industrial neighbourhoods surrounding downtown business districts, and low-density residential housing on designated First Nation reserve lands. Similar patterns are documented in rural hinterland areas of interior British Columbia where levels of social vulnerability increase toward higher density residential and mixed-use town centres and along major transportation routes. Disparities are most pronounced in rural areas with strong and moderate levels of metropolitan influence where average vulnerability threshold scores for Indigenous communities exceed those of the general population by a factor of 1.2 to 1.9. Contributing factors include overcrowded housing, higher than average levels of unstable employment, and additional financial stresses related to higher shelter costs and reduced capacities for household maintenance by homeowners who are either younger than 25 years or older than 65 years of age.

3.2.3. Interior Prairie Provinces (AB, SK, MB)

The Interior Prairie provinces of western Canada (Alberta, Saskatchewan, and Manitoba) encompass nearly 30% of the total developed area in Canada (38,600 km^2) and collectively account for 6.4 million people, representing 18% of the total national population. Formally recognized Aboriginal Lands account for nearly 3.7% of the developed area in the Prairies (~1,415 km^2) and there are 656,965 Indigenous people of whom ~58% are First Nations, ~40% are Métis, and 0.5% are of Inuit origin. It is estimated that ~196,900 people live on one of 181 First Nations reserves whose collective interests are represented by 25 tribal councils.

More than half of the total the population in the Prairies is concentrated in 6 urban centers that exceed a population of 100,000 people. In order of decreasing population size, these include the cities of Calgary, Edmonton, Winnipeg, Saskatoon, Regina, and Red Deer. Average residential densities in metropolitan regions range from ~430 people per square kilometre in Saskatchewan to nearly 1,000 per square kilometer in Alberta and Manitoba. The balance of Prairie residents live in small- and mid-sized rural towns that were initially settled along transportation lines established for the movement of agricultural produce from farms to city centres. (Mcgregor et al.; Vervoort, 2006). Average rural population densities for Settler communities on the prairies range between 25 people per square kilometer in Saskatchewan to 45 people per square kilometer in Alberta with settlement patterns characterized by small clusters of buildings dispersed over broad expanses of agricultural landscape. As in British Columbia, average residential densities on First Nations reserve lands in the rural hinterland are significantly higher, ranging between ~ 100 people per square kilometer in Saskatchewan and Alberta to more than 250 people per square kilometer in Manitoba.

Settlement patterns in the Prairies are structured along lines of latitude and longitude that reflect the arrangement of historical land subdivisions. The landscape is dominated by low topographic relief and large expanses of agricultural lands that transition northward into mixed grasslands and boreal forest. Overall levels of social vulnerability are equivalent to median national values in Alberta and Manitoba (SVI_t = 2.7 and 2.6, respectively), and in the lower quartile for most regions in Saskatchewan (SVI_t = 2.1). Average vulnerability threshold exceedance scores for metropolitan settlement types are lower than those described in western Canada with less overall variability from one type to another (see Figure 3-5). Rural hinterland areas of the Interior Prairie Provinces are characterized by moderate levels of social vulnerability compared with other parts of the country with average threshold exceedance scores that generally decrease with distance away from metropolitan hubs. Regional patterns of social vulnerability are influenced primarily by the distribution of larger population centres situated along major transportation corridors and disparities between Settler communities that are particularly evident in south-central Alberta and in regions of the northern plains and boreal forest extending from the Wood Buffalo area of northern Alberta to the Lake Winnipeg area of south-central Manitoba (Figure 3-9).

Population centres recording the greatest number of people exposed to elevated levels of social vulnerability include the cities of Calgary, Edmonton, Red Deer, Saskatoon, and Winnipeg. Areas of high and extreme vulnerability in Calgary are concentrated primarily in mixed-use, commercial/industrial, and lower density residential neighbourhoods situated along the Bow River and major transportation corridors; in medium- and low-density urban residential neighbourhoods surrounding the downtown core and on Indigenous reserve lands outside the city centre (see Figure 3-10). Similar patterns are observed in the urban core areas of Edmonton, Saskatoon, and Winnipeg, and in both suburban and exurban neighbourhoods surrounding many of the smaller cities in Alberta, Saskatchewan, and Manitoba.

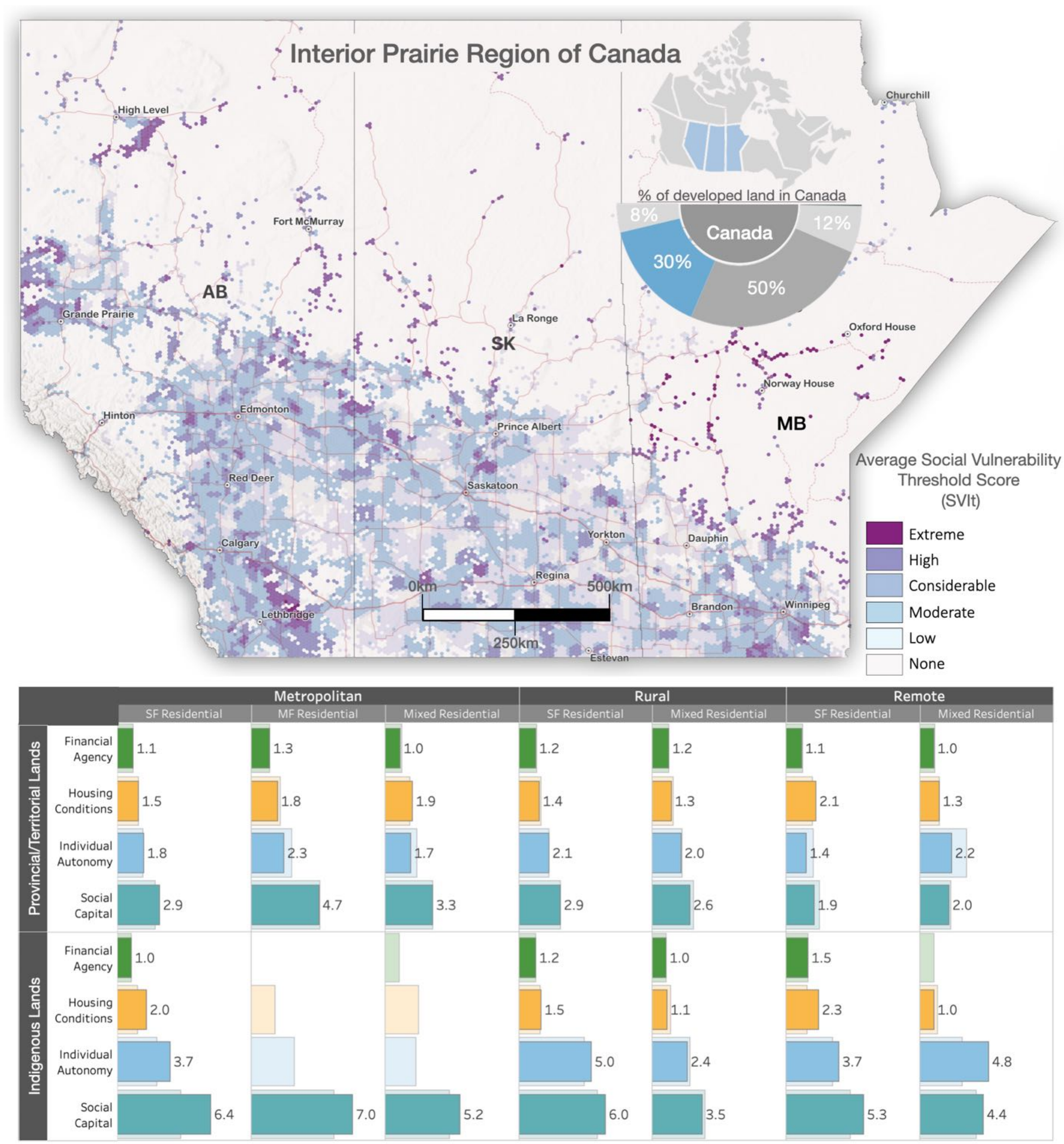


Figure 3-9: Regional patterns of social vulnerability and comparison of threshold levels for those living on lands administered under Provincial authority and those living on Indigenous lands in the Interior Prairie provinces of Alberta, Saskatchewan, and Manitoba (solid color) compared with national average (light color equivalent). Note that profiles of social vulnerability are referenced to a specific settlement type and should not be compared across different settlement types.

Rural hinterland areas of the Interior Prairie provinces are characterized by moderate levels of social vulnerability compared with other parts of the country with average threshold exceedance scores that generally decrease with distance away from metropolitan hubs. Underlying factors that contribute to regional trends include lower quality housing conditions, reduced levels of individual autonomy, and limited social capital with accompanying stresses that disproportionally affect Indigenous communities across most settlement types. Factors of particular concern include single-family residential housing on First Nation reserve lands in metropolitan settings to the south where average threshold exceedance scores exceed national averages by a factor of 1.3 to 1.5, and a mix of housing conditions and reduced autonomy in more remote settings where vulnerability scores exceed national averages by a factor of ~1.6. Specific factors that have the greatest influence on levels of vulnerability for those living on First Nation reserves include large families caring for young children under the age of 6 years, poor housing conditions related to both overcrowding and alignment with modern building safety standard, lower levels of secondary education, and higher than average levels of unemployment and a reliance on a single source of income.

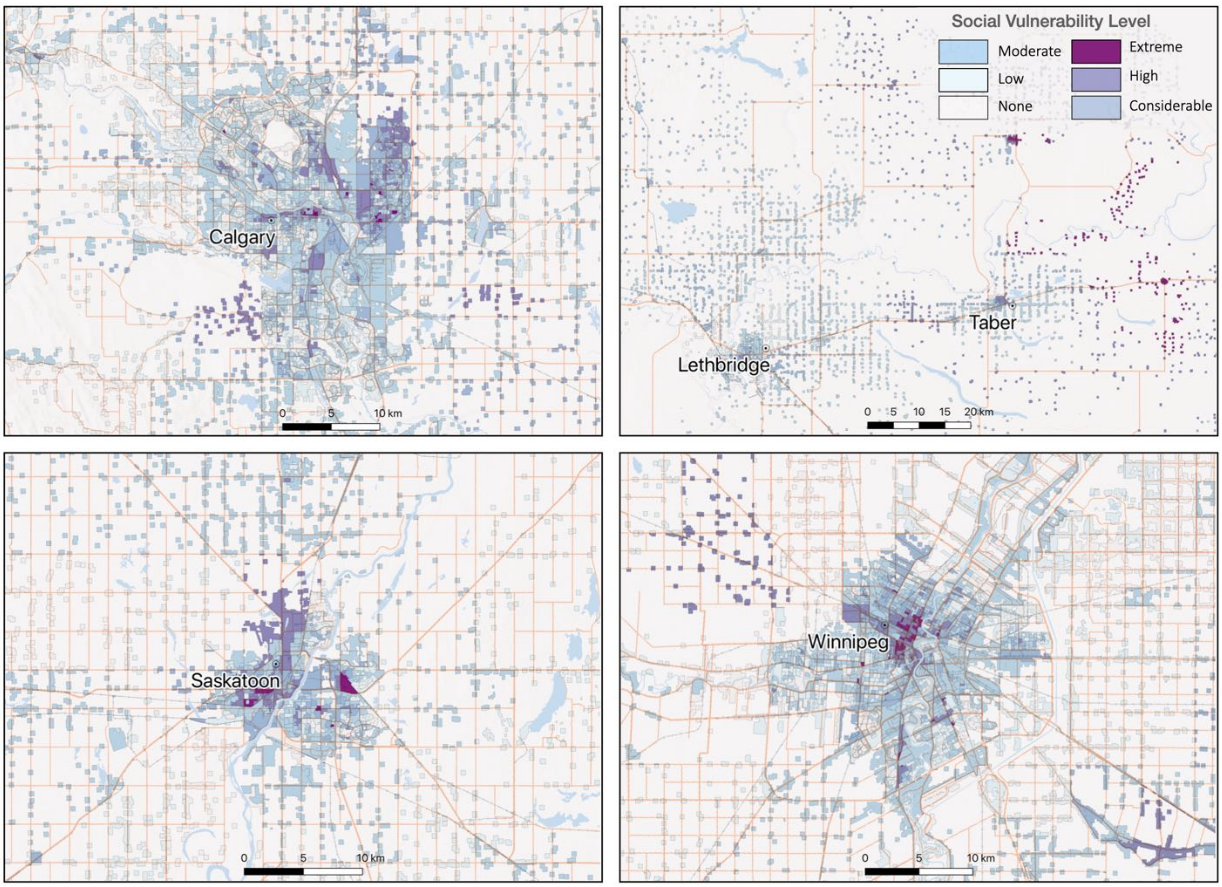


Figure 3-10: Detailed patterns of social vulnerability for representative communities in the Interior Prairie provinces.

3.2.4. Central Canada (ON, QC)

Built-up areas in Ontario and Quebec encompass more than 65,000 square kilometers or nearly half of all developed land in Canada (Figure 3-11). The region is home to 21.6 million people (~62% of total population) with most living in one of 36 major population centres of more than 100,000 people distributed along the southern margins of the Canadian Shield in the Great Lakes region of Ontario and the St. Lawrence Lowland region of Quebec. Average residential densities are ~1,800 to ~2,950 people/km^2 in the larger urban centres. However, there is broad diversity in urban form across the region with residential densities ranging from ~530 to ~1,000 people/km^2 in cities such as Ottawa, Kingston, Saguenay, and Sherbrooke that are spread out over a relatively large geographic area to as high as ~4,300 and ~4,860 people/km^2 for the major urban centres of Toronto and Montreal. Rural and remote settlements represent almost half of all developed lands in Ontario (~20,335 km^2; 52% of total), and ~69% of all developed lands in Quebec (~17,210 km^2). The rural hinterland

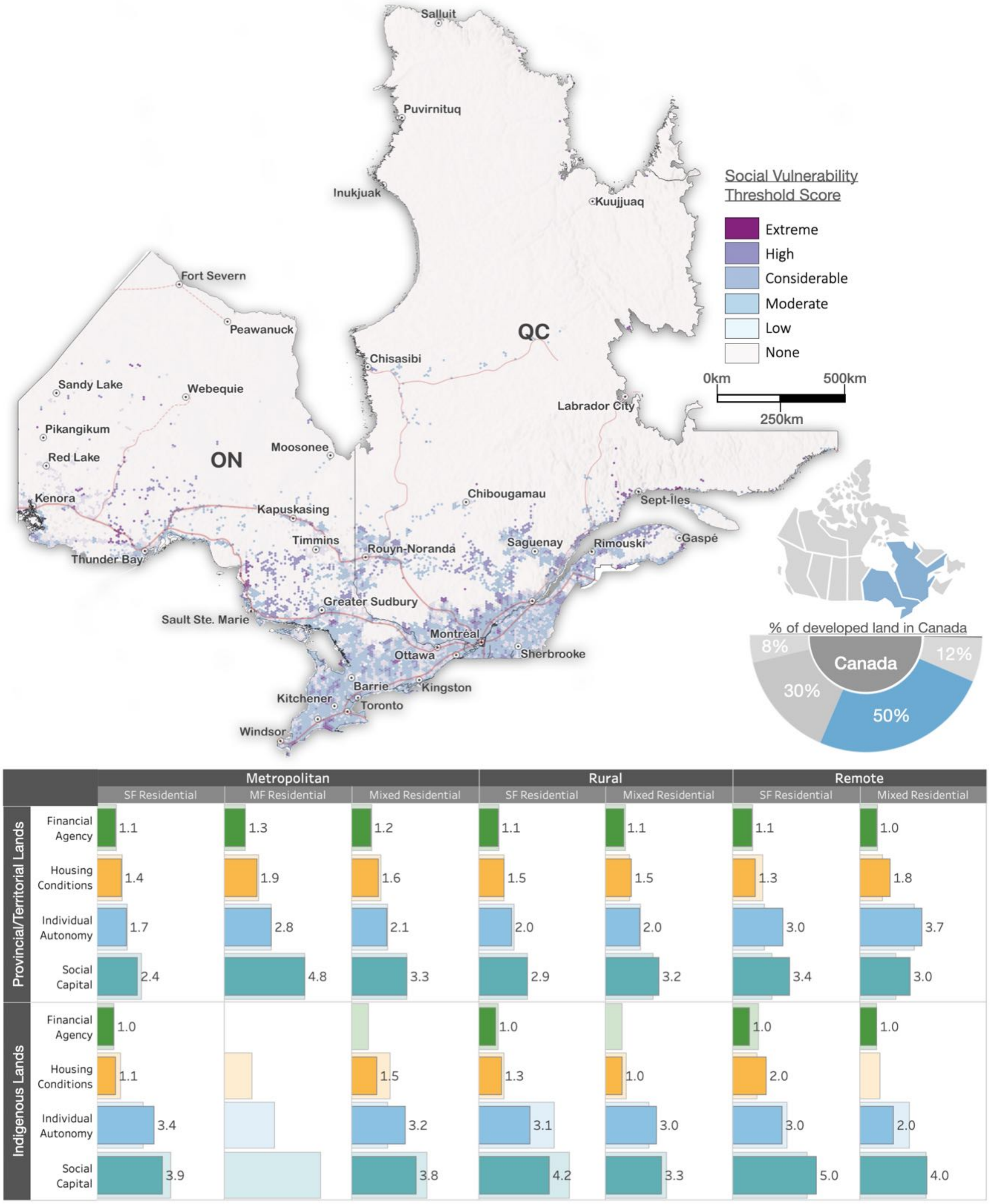


Figure 3-11: Regional patterns of social vulnerability and comparison of threshold levels for those living on lands administered under Provincial authority and those living on Indigenous lands in the Central Canadian Shield and St. Lawrence Lowland regions of Ontario and Quebec (solid color) compared with national average (light color equivalent). Note that profiles of social vulnerability are referenced to a specific settlement type and should not be compared across different settlement types.

includes a diverse mix of communities centred around agriculture, manufacturing, and recreational tourism with residential densities that range from ~70 people/km^2 in Ontario to ~100 people/km^2 in Quebec. Average residential densities in more remote communities range from ~30 people/km^2 in Ontario to ~75 people/km^2 in Quebec.

Designated Aboriginal Lands account for only 1% of all developed areas in the central Canadian Shield and St. Lawrence Lowlands region (~660 km^2) with a total Indigenous population of 557,285 of whom ~59% are First Nation, ~34% are Métis, and ~3.2% are of Inuit origin. There are an estimated 103,380 people living on one of 179 First Nation reserves in Ontario and southern Quebec whose collective interests are represented by 23 tribal councils and an additional ~17,800 people living in one of 14 remote communities on Inuit owned lands in the Nunavik region of northern Quebec. Residential densities on designated Indigenous lands are quite variable across the region but higher than those of the general population with values that range from ~130-415 people/km^2 in rural areas of southern Ontario and Quebec to well over ~640 people/km^2 in more remote settings.

Built-up areas throughout Central Canada are characterized by a patchwork of rectilinear development patterns that reflect the influences of land surveying practices and the subdivision of townships during early stages of colonial settlement. Rural settlements are situated primarily along major transportation corridors that cut across broad areas of the Canadian Shield. Remote settlements are situated primarily in boreal forests of northwestern Ontario, and along the shores of Hudson Bay in northern Ontario and Quebec. Compared with other parts of the country, mean vulnerability threshold scores are within ~10% of national average values for most settlement types (see Figure 3-5). Regional patterns of disparity are influenced primarily by densification and related patterns of social inequity established during periods of rapid growth and urban development, and by fluctuations in the vibrancy of mining, forestry, and manufacturing sectors in rural hinterland areas. Mean vulnerability threshold scores are in the upper quartile ($SVI_t >= 1.7$) for densely settled urban centres (SAC-1) in southern portions of Ontario and Quebec, surrounding rural hinterland areas that have relatively high levels of socioeconomic integration with neighbouring population centres (SAC-4), and more remote communities in northern regions of the Canadian Shield that have little or no metropolitan influence (SAC-7). Hotspot areas of concern in the major urban centres of the region include Montreal, Toronto, Windsor, Longueuil, Brampton, Markham, Oshawa, Gatineau, and Sherbrooke (Figure 3-11).

Spatial patterns of vulnerability in these dense urban centres are like those described in other parts of the country with concentrated areas of considerable, high, and extreme vulnerability interspersed with surrounding residential neighbourhoods of low and moderate vulnerability in suburban and exurban fringe areas (Figure 3-12). These patterns are particularly evident in the Greater Montreal region where hotpots of high and extreme vulnerability in the southwest, central, and northeast regions of the city are enveloped by areas of moderate and low vulnerability. Detailed profiles reveal a complex set of interactions between the various dimensions of social vulnerability with the primary drivers including lone parent families with three or more children, tenants living in rental housing, high concentrations of older buildings, and family incomes in the lower half of the decile distribution. The patterns of economic agency and housing conditions are like those documented in the Winnipeg area and are, again, consistent with findings of previous studies that focused more specifically on determinants of social inequity across Canada (Matheson et al., 2012; Statistics Canada, 2019).

Hotspot areas in the rural hinterland occur around the regional hubs of Thunder Bay, Sault Ste. Marie, Timmins, and Sudbury in Ontario, and in the Laurentian Highlands and St. Lawrence Seaway regions of Quebec. Underlying factors that influence regional patterns of social vulnerability include concentrations of high and extreme vulnerability for high-density residential and mixed-use neighbourhoods and a combination of poor housing conditions and reduced levels of individual autonomy and social capital for those living in rural and more remote settings. Mean vulnerability threshold scores for the general population exceed national average values by a factor of 1.4 to 1.6 while measures of vulnerability for Indigenous communities living on designated Aboriginal Lands exceed corresponding national averages by a factor of 1.4 to 1.5. Contributing factors for those living on both First Nation reserves and Inuit lands include higher than average levels of unemployment, reliance on a single source of income, lower levels of secondary education, large families caring for young children under the age of 6 years, and poor housing conditions related to both overcrowding and alignment with modern building safety standards. In addition, many of the more remote Indigenous communities are accessible only by air and have more limited access to health care and other essential services than their counterparts to the south.

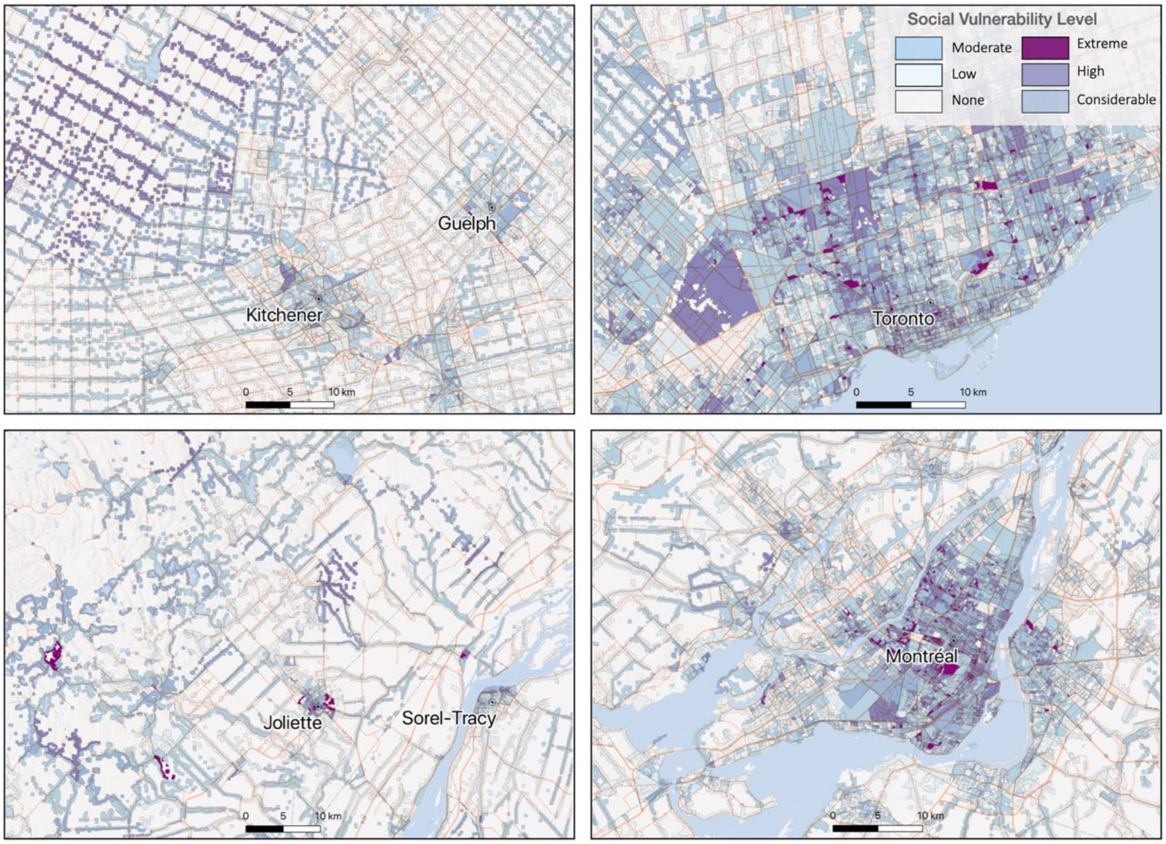


Figure 3-12: Detailed patterns of social vulnerability for representative communities in Ontario and Quebec.

3.2.5. Maritimes (NB, PE, NS, NL)

The Eastern Maritime provinces of New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador collectively encompass ~16,110 square kilometres of developed lands, representing ~12.4% of all built-up area in Canada (Figure 3-13). Most of these settled areas are under provincial jurisdiction with ~32% of the land base situated in metropolitan regions, ~66% in the rural hinterland, and 2.2% in more remote settings. Compared with other parts of rural Canada, there is a relatively higher proportion of unincorporated lands on which there is no formal local authority for land governance (Canadian Rural Revitalization Foundation, 2021). Approximately 220 km^2 of the developed land base (~1.3% of regional total) are distributed across 34 First Nation communities represented by 5 Tribal Councils, and 5 remote communities on Inuit owned lands in northern Labrador. The region accounts for 2.3 million people (~6.6% of the national population) with most living in a handful of larger population centres that are home to 1.43 million people representing ~62% of the regional total. The largest of these include the cities of Halifax (Nova Scotia), St. John's (Newfoundland and Labrador), Moncton, Saint John, and Fredericton (New Brunswick), and Charlottetown (Prince Edward Island). Approximately 868,000 people (37% of regional total) live in rural agricultural areas or in fishing villages along the coast with the remaining ~29,000 people (1.3% of regional total) living in more remote settings. The region has an Indigenous population of 129,340 people (2% of regional total) of whom ~57% are First Nations people, 33% are Métis, 6% are of Inuit origin and the remaining 4% are of mixed Indigenous origin.

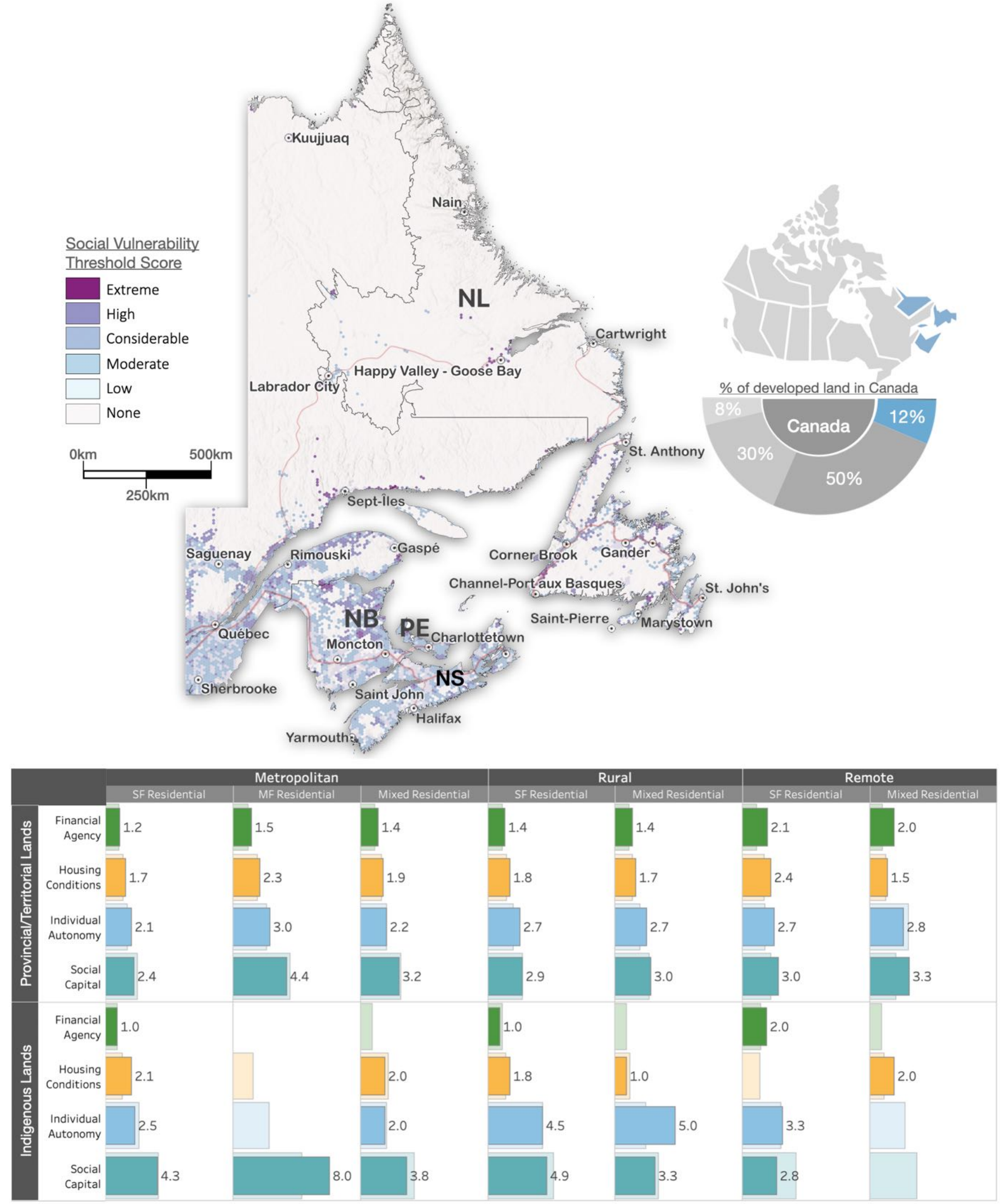


Figure 3-13: Regional patterns of social vulnerability and comparison of threshold levels for those living on lands administered under Provincial authority and those living on Indigenous lands in the Eastern Maritime provinces of New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland and Labrador (solid color) compared with national average (light color equivalent). Note that profiles of social vulnerability are referenced to a specific settlement type and should not be compared across different settlement types.

Settlement patterns in the region are characterized by linear tracts of land situated either parallel or perpendicular to inland waterways and major transportation routes, along sections of coastline and/or clustered around established port cities (Figure 3-13). Average residential densities in the larger population centres range from ~350 to 600 people/km^2 throughout most of the region with a high of ~1,250 people/km^2 in the St. John's area on the island of Newfoundland. Rural residential densities are like those described in Central Canada, ranging from a low of ~45 people/km^2 on Prince Edward Island to between ~65 and ~70 people/km^2 in Nova Scotia and New Brunswick with a high of ~190 people/km^2 in more concentrated settlements in Newfoundland and Labrador. Residential densities in more remote Settler communities are approximately half of their rural counterparts in New Brunswick and Newfoundland and Labrador, but nearly double that of rural counterparts in Nova Scotia and Prince Edward Island. As in other parts of the country, residential densities for those living on Indigenous lands are significantly higher than the general population ranging from a low of ~82-90 people/km^2 on Prince Edward Island to a high of ~580 people/km^2 in remote areas of Newfoundland and Labrador.

Regional patterns of social vulnerability in the Eastern Maritime region are like those described in Central Canada with median threshold exceedance scores of 1.7, a relatively narrow spread of lower quartile values, and a wider spread of values in the upper quartile of the regional distribution (see Figure 3-5). Mean vulnerability threshold scores are in the uppermost 25% of the distribution range for rural hinterland settlements with strong metropolitan influence (SAC-4) and remote settlements with little or no metropolitan influence (SAC-7). Unlike other parts of the country, mean vulnerability threshold scores for major urban centres are below median values. However, concentrated pockets of high and extreme vulnerability are consistently associated with higher density residential and mixed-use commercial neighbourhoods in both downtown urban centres and in smaller towns and villages that occur in fringing exurban and rural hinterland settings (Figure 3-14). The primary drivers of social vulnerability for Settler communities living in metropolitan and rural hinterland settings include increased financial stress and reduced levels of individual autonomy with mean threshold scores that exceed national average values by a factor of 1.1 to 1.3, respectively (see Figure 3-13). Housing conditions and reduced levels of social capital are the primary drivers of social vulnerability for Indigenous communities in metropolitan regions while reduced levels of individual autonomy are more prevalent in rural hinterland settings. Mean vulnerability threshold scores for these measures exceed national averages for those living on Indigenous Lands by a factor of 1.4 to 1.9. Overall, levels of vulnerability for Indigenous communities situated in rural hinterland settlements and in more densely populated metropolitan regions exceed those of the general population by a factor of 1.9 to 2.2, respectively.

It is estimated that ~97,200 people live on lands where the title has either been vested with recognized Aboriginal Groups or set aside for their exclusive benefit. Levels of disparity between Indigenous and Settler communities are less pronounced in more isolated remote settings with mean vulnerability threshold scores that vary by less than 10%. Hotspot areas for Settler communities are characterized by anomalously high values across all dimensions of social vulnerability with values that exceed national averages by a factor of between 1.3 and 2.0. Hotspot areas for Indigenous communities appear to be influenced primarily by poor housing conditions in remote settings where mean vulnerability threshold scores exceed the national average for Aboriginal Lands by a factor of 1.7. Factors that have the greatest overall influence include unstable employment, reduced levels of secondary education, reduced capacities for household maintenance due to age, and reliance on a single source of family income. Additional factors of concern for Indigenous communities living in remote settings include increased levels of mobility and a higher concentration of both large families caring for young children under the age of 6 years and lone parent families for three or more children. As in other parts of the country, those living in more isolated remote settings of the Maritimes have more limited access to health care and less reliable connectivity to critical infrastructure systems that provide essential services to other rural and metropolitan settlements in the region.

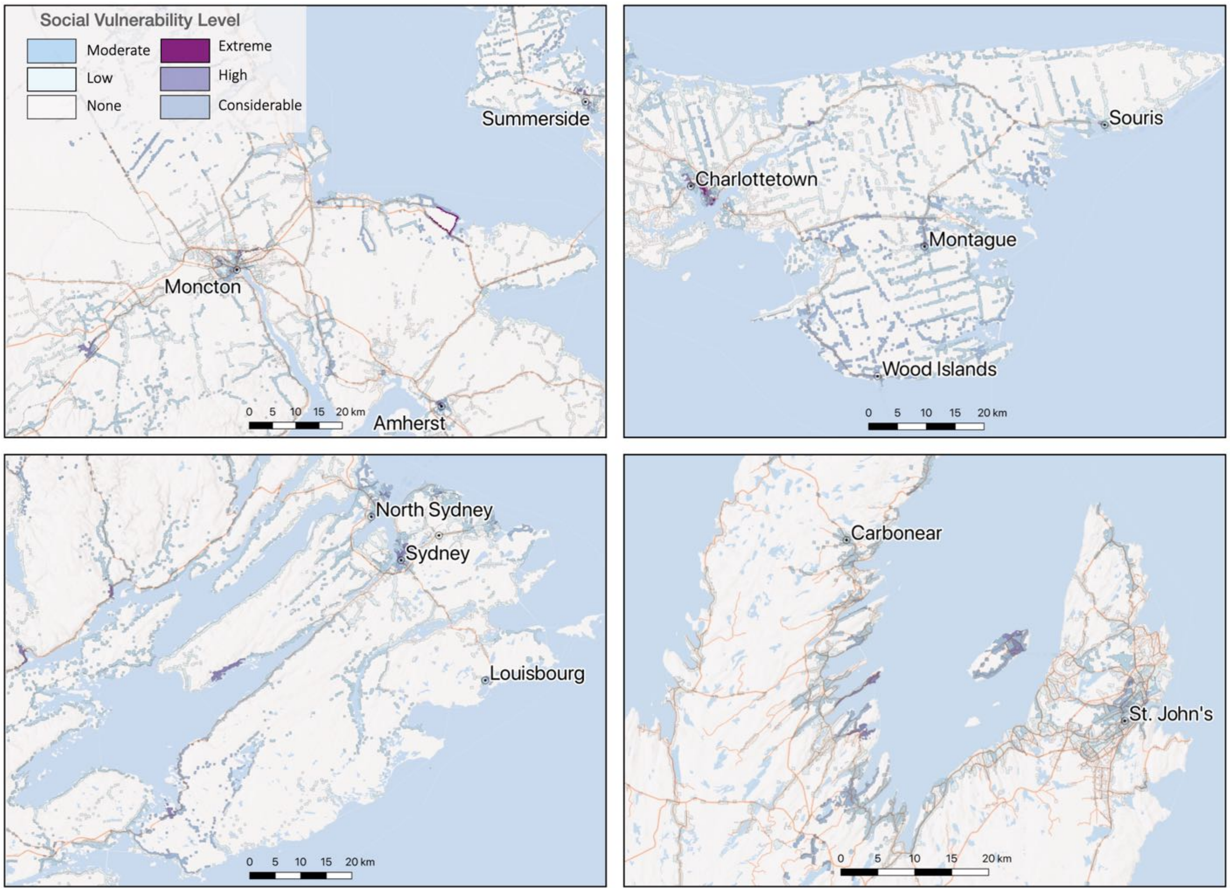


Figure 3-14: Detailed patterns of social vulnerability for representative communities in the eastern Maritimes.

3.2.6. The North (YT, NT, NU)

Northern regions of Canada, including the Yukon, Northwest Territories, and Nunavut encompass a vast and sparsely populated landscape that accounts for 76% of the total landmass in Canada (~7.5M km^2). However, built-up areas represent only 0.3% (~360 km^2) of all developed land in the country with approximately three-quarters of these lands situated in remote areas (Figure 3-15). The North is home to ~112,000 people (~0.3% of national total) with ~43% of the regional population living in a handful of population centres including the cities of Whitehorse (~25,000 people), Yellowknife (~19,600 people), Iqaluit (7,750 people), Hay River (~3,500 people), Inuvik (~3,250 people), and Rankin Inlet (~2,800 people). Most of the population (57%; ~64,200 people) live in more isolated remote communities of the North with limited or no connectivity to major critical infrastructure systems and related essential services. These settlements reflect a more intimate and direct connection to the land that is influenced by primary activities such as mining, animal husbandry, fishing, trapping, and subsistence hunting. The region has an Indigenous population of ~59,600 people (~53% of regional total) of whom ~33% are First Nations people, 8% are Métis, and 58% are of Inuit origin. It is estimated that ~38,840 people live either on one of 42 First Nation settlements of the Yukon and Northwest Territories or in one of 34 communities on Inuit owned lands of the Nunangat region that stretches across the Arctic from Inuvik in the west to Iqaluit in the east. Because settlements are concentrated in relatively small areas of development, residential densities are generally high in remote settings with values that range from ~450-530 people/km^2 in the Yukon to more than 1,000 people/km^2 in the Northwest Territories and Nunavut.

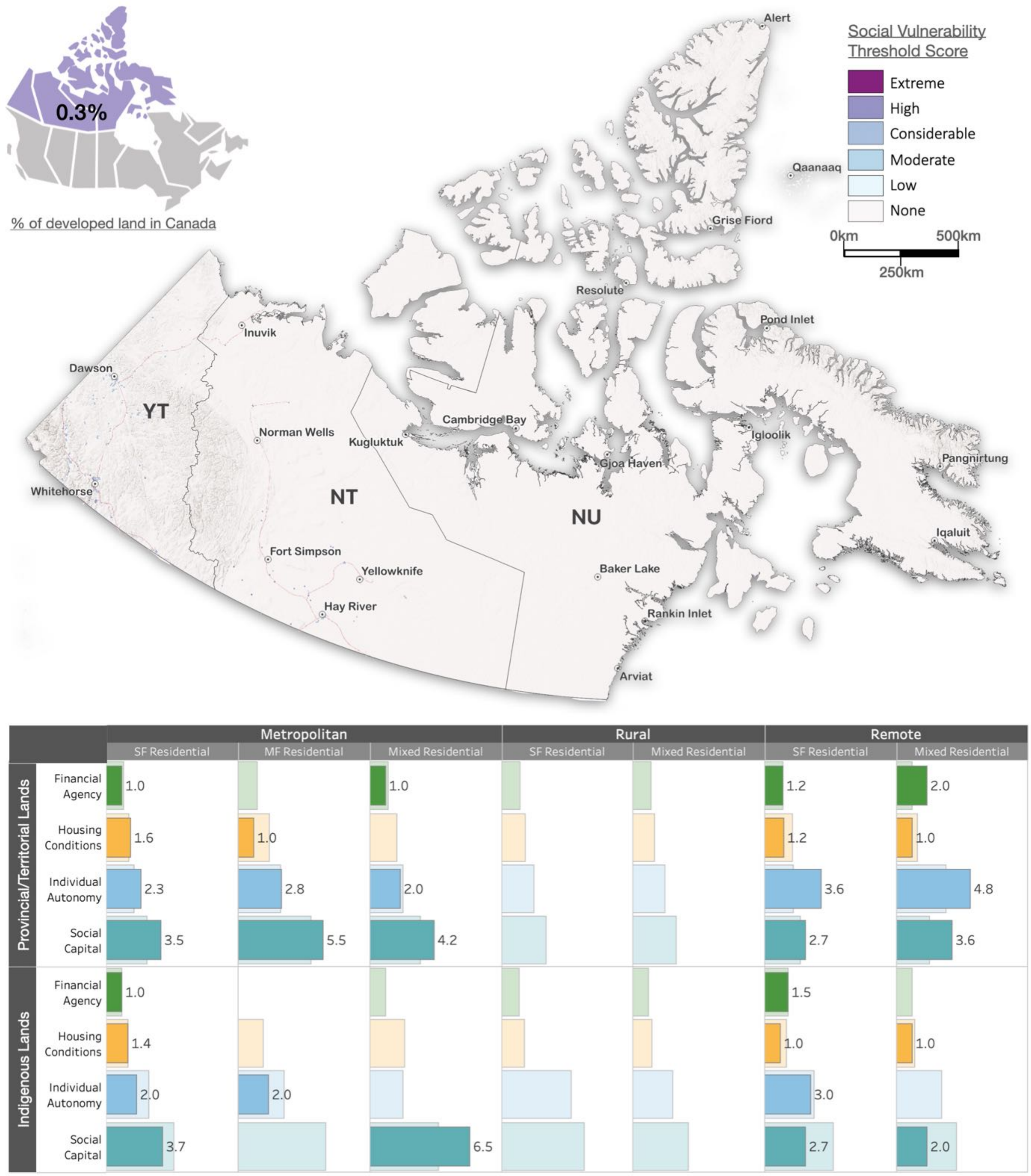


Figure 3-15: Regional patterns of social vulnerability and comparison of threshold levels for those living on lands administered under Provincial authority and those living on Indigenous lands in the Yukon, Nunavut, and Northwest Territories of the far North (solid color) compared with national average (light color equivalent). Note that profiles of social vulnerability are referenced to a specific settlement type and should not be compared across different settlement types.

As shown in Figure 3-15, regional patterns of social vulnerability are quite variable in the North with mean threshold exceedance scores that are in the uppermost 25% of all values for more densely settled exurban settlements containing major population centres (SAC-3), and in the lowermost 25% of all values for isolated remote communities with little or no socioeconomic integration with other regions of the North (SAC-8). Unlike all other parts of the country, patterns of disparity are reversed with mean vulnerability threshold scores for those living on Indigenous lands in exurban settings lower than those in equivalent Settler communities by a factor of 0.8. As in the Maritimes, levels of disparity between Indigenous and Settler communities are less pronounced in more isolated remote settings with mean vulnerability threshold scores that vary by less than 5%. Reduced levels of individual autonomy and social capital are the primary factors influencing patterns of social vulnerability in Settler communities of the North with increased levels of financial stress for those living in more remote settings (see Figure 3-15). Mean vulnerability threshold scores exceed national average values by a factor of ~1.3 in exurban settlements, and by a factor of between 1.5 to 2.0 in more isolated remote communities. Mean levels of social vulnerability are generally below national averages for those living on Indigenous lands, except for mixed-use residential neighbourhoods in more populated exurban settings where vulnerability threshold scores exceed reference values by more than 40% (Figure 3-16).

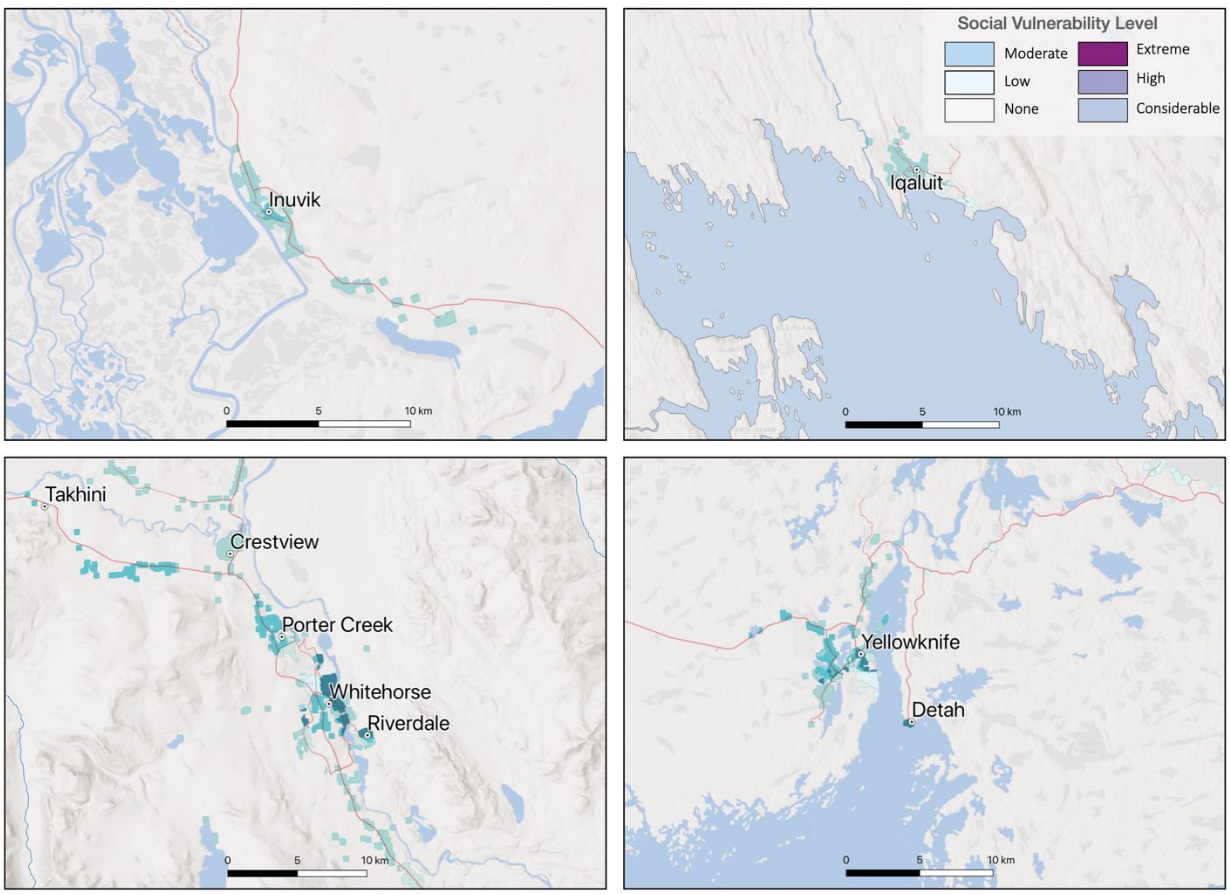


Figure 3-16: Patterns of social vulnerability for selected population centres and more remote settlements of the North.

4.0 IMPLICATIONS FOR DISASTER RISK MANAGEMENT

A primary motivation for developing the national social vulnerability model and assessing how associated patterns of disparity are manifest across different settlement types has been to establish a detailed base of evidence to inform sustainable development strategies that will minimize the negative effects that natural hazard events can have on the most vulnerable members of a community. To this end, we have piloted a methodology for integrating the social and physical dimensions of vulnerability to better understand who is most likely to bear a disproportionate burden of risk for known hazards of concern in Canada and how these patterns of vulnerability are influenced by fundamental characteristics of the built environment. The methodology builds on outputs of this study and a national physical exposure model developed by NRCan to assess the overall susceptibility of communities to natural hazard threats in Canada (Journeay et al., work in progress, 2022). It uses available public domain information to establish a shared understanding of:

- Natural hazard processes and the corresponding magnitude-frequency relationships that will determine who and what are in harm's way at a given location,
- Detailed patterns of land use for different types of settlement and the corresponding mix of buildings and related critical infrastructure assets that are likely to be found at a given location including overall density, types of construction, and related services that are provided to support the day-to-day activities of residents and businesses,
- The capacity of buildings and critical infrastructure systems to resist the physical forces associated with natural hazard processes (e.g., ground shaking, flood inundation, severe wind) based on calibrated damage impact scales and/or on more detailed engineering-based models of physical vulnerability, and
- Underlying socioeconomic factors that influence where different groups of people live within a given community or region and their capacity to weather both the physical impacts and downstream consequences of a future disaster event based on characteristics of social capital, individual autonomy, housing conditions, and financial agency.

We have tested and validated preliminary outputs of a national model developed at the census dissemination area level (DA) to assess integrated hazard threats associated with earthquakes, tsunami, riverine floods, wildland interface fire, hurricanes, and landslides for all regions in Canada. Results of this initial assessment have been used to identify hotspot areas of concern, to evaluate the overall usability of model outputs in support of emergency management and land use planning, and to direct future research and development activities in partnership with other organizations who share a responsibility for disaster resilience planning at the community level in Canada. While a description of preliminary model outputs for multiple natural hazard perils is beyond the scope of this report, the following sections provide an example of how available information on the physical threats associated with earthquake and tsunami hazards in Canada can be integrated with insights on social vulnerability to better understand causal relationships and to help identify actions that can be taken in advance to increase disaster resilience at the community level.

4.1. EARTHQUAKE HAZARD THREAT IN CANADA – A CASE STUDY

Canada is exposed to rare but potentially catastrophic earthquake events that have the potential for significant damage, loss of life, and socioeconomic disruptions. Although less frequent than floods, wildfire, and other hazards of concern, a single earthquake event has the potential for human and economic losses that exceed the combined effects of all disaster events experienced in Canada over the past 200 years. We know from historical accounts that significant earthquake events of magnitude M5.0 or greater have occurred in Canada since the mid-1600s (Cassidy et al., 2010; Lamontagne et al., 2018). Oral history of Indigenous Peoples extend the observed record of catastrophic earthquakes and related tsunami events back to ~4,500 year BP (Finkbeiner, 2015). As illustrated in Figure 4-1, areas of significant earthquake hazards occur mainly in (i) tectonically active zones along the western North American plate boundary and offshore regions of the Pacific plate; (ii) in distributed zones of crustal deformation throughout the Cordilleran regions of British Columbia, the Yukon, and Northwest Territories; (iii) across the Arctic margin region of northern Canada; and (iv) along reactivated zones of crustal weakness in the St. Lawrence Lowlands of Quebec and eastern Ontario, the northern Appalachian regions of New Brunswick, and offshore Atlantic regions of Canada.

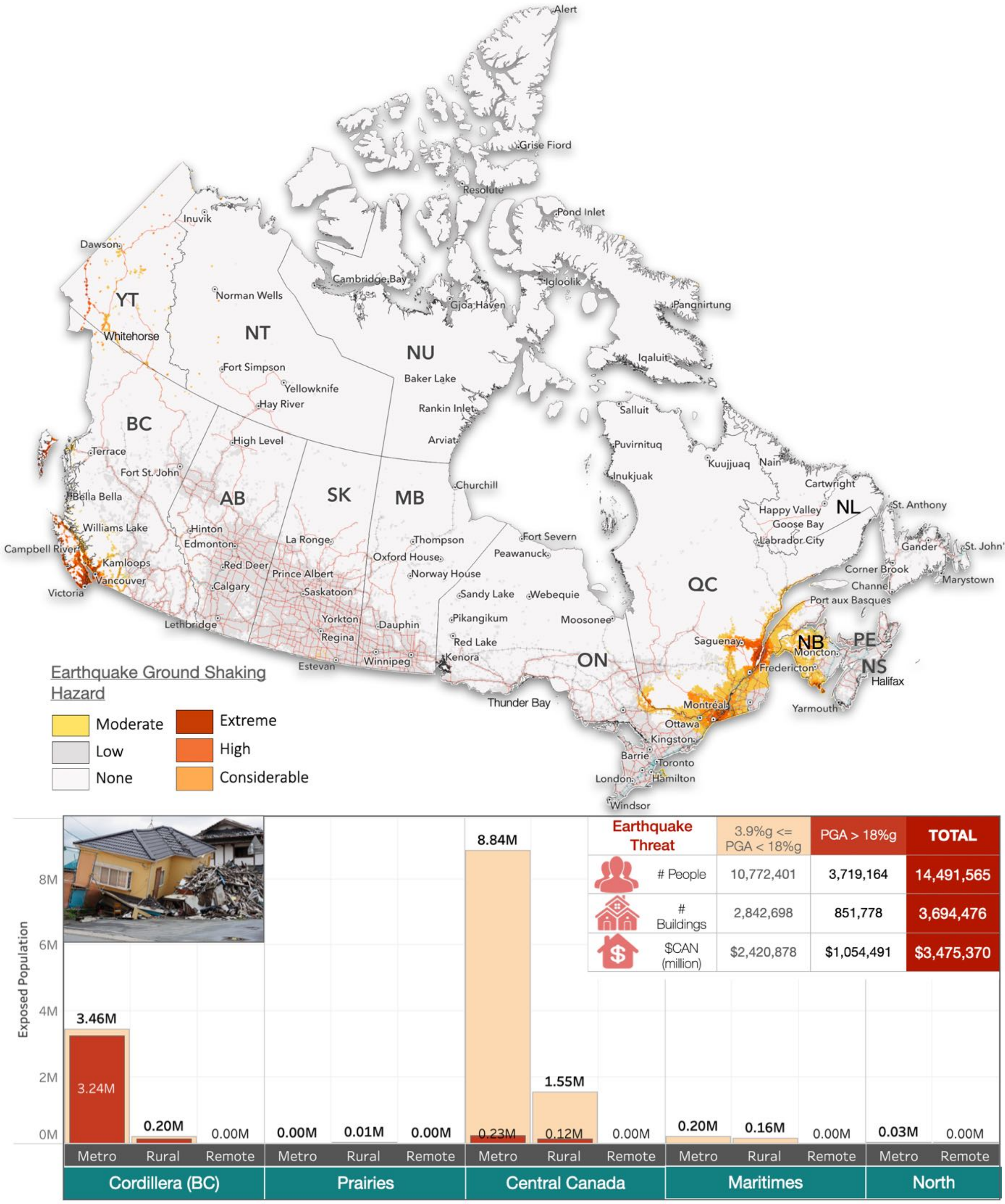
4.1.1. Hazard Assessment Information

Earthquake-related hazards considered in this study are limited to the effects of ground shaking, the compounding influences of local site amplification in low-lying areas of less dense sedimentary rock and soils, and the effects of tsunamis triggered by large subduction zone earthquakes. Not included are the secondary effects of permanent ground deformation (liquefaction, landslides, surface fault rupture) and fire following the initial earthquake event. The intensity of ground shaking at any given location reflects the contribution from all earthquake ruptures that are likely to occur within the surrounding region over a specified future time horizon. Ground motion intensities used in this study are based on a fully probabilistic seismic hazard model that is updated on a regular basis to inform seismic safety guidelines in the National Building Code of Canada (Adams et al., 2015; Allen et al., 2015; Adams et al., 2019; Kolaj et al., 2020a). Ground shaking intensities at a grid spacing of ~10 kilometres are interpolated for the locations of all settled areas in Canada using site amplification factors that account for corresponding variations in geologic setting. We use the average value of Peak Ground Acceleration (PGA) for a given settled area polygon to assess relative levels of ground shaking intensity that are expected from one location to another. PGA values corresponding with earthquake events that are likely to occur with an Annual Exceedance Probability (AEP) of 0.2% (Return Period [RP] = ~500 years) are used to ensure comparability with other hazard threats of concern such as major floods and hurricanes that have caused significant levles damage and disruption over the last 200 years. It is worth noting that hazard intensities associated with less frequent but more severe earthquake events (AEP=0.04%; RP=~25000 years) are used to inform safety design guidelines in the National Building Code of Canada.

Coastal land areas susceptible to earthquake-driven tsunami inundation are based on a global scale probabilistic model developed in support of the 2015 Global Assessment Report (Løvholt et al., 2015). The tsunami model estimates maximum wave heights and corresponding coastal inundation areas for earthquake-triggered events (> M7.8) based on a global catalogue of earthquake source zones that have a potential to rupture the sea floor with an AEP of 0.2% (RP = ~500 years). Tsunami wave heights are modeled at a spatial resolution of ~2km for all coastal regions and intersected with global tomographic data to provide a first-order approximation of inland areas that are likely to be inundated. The geographic extent of tsunami inundation is reported at a spatial resolution of ~500 metres. The relative severity of tsunami hazard is estimated based on the average land surface area that is likely to be affected within a given settled area.

4.1.2. Physical Susceptibility

Our assessment of overall earthquake hazard threat in Canada makes use of the Modified Mercali Index to estimate the number of buildings, people and related financial assets that are susceptible to increasing levels of earthquake damage at a given location based on measures of mean ground shaking intensity with an annual exceedance probability (AEP) of 0.2% (Return Period [RP] = ~500 years). The Modified Mercalli Index (MMI) is a graduated damage scale that describes the general effects of an earthquake in terms of what people have felt or are likely to experience on the ground and the expected levels of damage to buildings and other engeineered structures. Each level of the MMI scale is correlated with ground shaking intensity values using empirical relationships developed as part of the US Geological Survey (USGS)ShakeMap project (Wald et al., 2006; Worden et al., 2012).



Earthquake Threat	3.9%g <= PGA < 18%g	PGA > 18%g	TOTAL
# People	10,772,401	3,719,164	14,491,565
# Buildings	2,842,698	851,778	3,694,476
$CAN (million)	$2,420,878	$1,054,491	$3,475,370

Figure 4-1: Regional distribution of earthquake ground shaking hazards (AEP = 0.2%: RP ≅ 1/500 years) and related patterns of physical susceptibility in Canada.

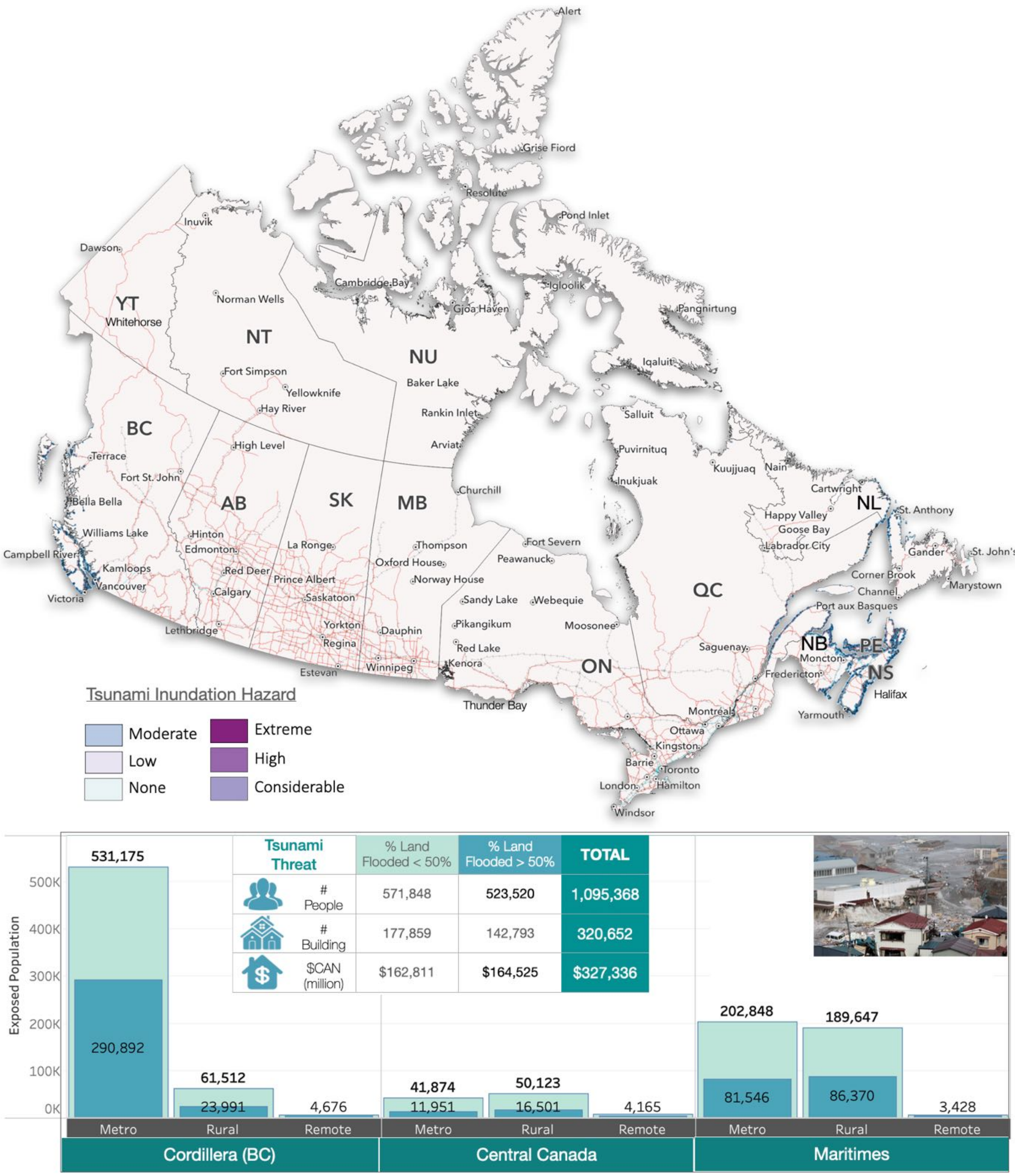


Figure 4-2: Regional distribution of earthquake-triggered tsunami inundation hazards (AEP = 0.2%: RP □ 1/500 years) and related patterns of physical susceptibility in Canada.

Settled areas exposed to intensity measures corresponding to MMI levels I to IV where there is little or no potential for structural damage occur throughout much of the Interior Prairies, northern portions of the Candian Shield in Ontario and Quebec, the East Coast regions of Newfoundland and Labrador, and inland portions of the Northern Arctic. MMI intensity values of V to VII (3.9%g ≤ PGA < 18%g) occur in the Appalachian reigon of New Brunswick, throughout much of the St. Lawrence Lowland regions of Quebec and Ontario, along the Rocky

Mountain Foothils of western Alberta, and both inland and coastal regions of the Cordillera in Brisitsh Columbia and the Yukon (Figure 4-1). Results of our assessment indicate that nearly 30% of the total population and building assets of Canada are exposed to moderate and very strong levels of ground-shaking in these regions with corresponding low to moderate levels of expected damage for well-designed buildings and the potential for considerable damage to older structures that predate modern safety design guidelines. This represents a population of 10.8 million people and more than 2.84 million buildings worth an estimated CAN$2.4 trillion. The majority of people and assets exposed to these levels of earthquake damage (~80%; 8.6M people) are situated in more densely settled metropolitan regions of the St. Lawrence Lowlands in southern Quebec and Ontario with ~13% (1.4M people) in surrounding rural hinterland areas and the remaining ~7% distributed across a mix of settlement types in New Brunswick, western Alberta, and British Columbia.

Settled areas exposed to MMI values of VII to IX (PGA ≥ 18%g) occur in concentrated zones along the St. Lawrence Lowland in Quebec and Ontario (i.e. Charlevoix, Saguenay, Montreal, Monteregie, and Ottawa), coastal regions of British Columbia (Vancouver, Victoria, Vancouver Island, and Haida Gwaii), and portions of the Yukon. These areas reflect proximity to more severe earthquake rupture events with corresponding levels of ground motion that are sufficient to cause extensive or complete damage to older buildings, and collapse of brittle masonry and concrete structures that are not designed to withstand the physical forces associated with severe and violent shaking. These more severe levels of earthquake hazard threat affect a smaller proportion of the overall population (10.6%; 3.72M people) and a corresponding stock of 850,000 buildings worth an estimated CAN$1.05 trillion. Nearly all of those exposed to these higher levels of hazard threat (87.2%; 3.1M people) live in densely settled metropolitan neighbourhoods of southwestern British Columbia with and additional~100,000 people (3.3%) living in surrounding regions of the Fraser Valley, Vancovuer Island and Haida Gwaii (see Figure 4-1). The remaining ~10 of those susceptible to at least considerable levrls of earthquake damage live in either the metropolitan regions of Montreal, Monteregie, and Ottawa, or in rural settlemenets in the Charlevoix, Saguenay, and Kamouraska region of the St. Lawrence Seaway.

Physical threats associated with severe earthquake ground shaking are compounded in areas exposed to coastal flood inundation caused by secondary tsunami hazards. For the purposes of this study, we assume that all buildings located in settled areas with at least 25% of the land surface area exposed to tsunami flood inundation will sustain some level of structural damage with the potential for loss of life in low-lying coastal areas where evacuation options are limited. Based on this minimum threshold, it is estimated that nearly 1.1 million people and 320,650 buildings worth CAN$327.3 billion are susceptible to the physical impacts of earthquake-triggered tsunamis. More than half of these assets are situated in areas where tsunami inundation is likely to exceed 50% of the exposed area (Figure 4-2). Although concentrated primarily in coastal regions of British Columbia that are exposed to major subduction zone earthquakes along the Pacific Plate margin (~55% of total), some coastal areas of the Maritime provinces (36% of total) and Quebec (~9% of total) are also exposed to the impacts of major crustal earthquakes that occur along the Atlantic continental shelf margin.

4.1.3. Integrated Hazard Threat

While it is important to measure the potential physical impacts of natural hazards and how they vary from one location to another, it is equally important from the perspective of sustainable land use planning to understand who is in harm's way, cultural perceptions of risk and potential issues of social inequity that may be associated with the spatial distribution of hazard threats within a given community or region. The integration of social and physical dimensions of hazard threat provides important insights on who is likely to bear the greatest burden of risk following a disaster event, underlying causal factors that systematically disadvantage the most vulnerable in our communities, and strategic opportunities for increasing capacities for functional recovery at the neighbourhood level.

As described in Section 2.3 the assessment of integrated hazard threat Index values (*HTI*) at a given location involves combining measures of physical susceptibility (PSI_t) with mean social vulnerability threshold scores (SVI_t) to determine the extent to which physical impacts and downstream consequences of a hazard event may be amplified for disadvantaged groups within a community. The goal is to identify areas of overlap between neighbourhoods that are more susceptible to physical damage and socioeconomic disruption caused by earthquake ground shaking and/or tsunami inundation, and neighbourhoods with the least capacity to absorb and/or adapt to these impacts should a significant hazard event occur at some point in the foreseeable future. Relative degrees of integrated hazard threat are expressed mathematically as the product of mean physical susceptibility and social vulnerability index scores for a given location (see Section 2-3). The methodology allows for the mapping of integrated hazard threat across different scales of spatial aggregation to identify hotspot areas of concern and the filtering of model outputs based on characteristics of physical and/or social vulnerability within a given community or region. Bivariate choropleth maps provide additional insights on the spatial interactions between physical and social determinants of hazard threat and can assist local authorities in evaluating potential causal relationships and strategies that may be effective in reducing hazard threat at the community level.

The following sections provide a summary of results for an integrated threat assessment of settled areas that are susceptible to significant earthquake and tsunami hazards in Canada. Choropleth maps of mean hazard threat scores are used to identify hotspot areas of concern while statistical profiles provide insights on regional trends for those areas most susceptible to the impacts of future disaster events. Although hazard threats are analyzed and reported at the census dissemination area level, statistical summaries discussed below are aggregated at the level of census divisions to facilitate a description of key model outputs. Census divisions are administrative boundaries that are geographically equivalent in size to regional districts or counties and are commonly used for reporting statistical trends at a national scale. Regional hotspots are identified based on mean hazard threat scores, which measure *relative* levels of susceptibility for settled areas within a given census division, and *absolute* measures of the total number of people who are likely to be affected within each region. To facilitate a discussion of national trends, model outputs have been filtered to highlight settled areas with elevated social vulnerability that are situated in regions where the effects of severe earthquake ground shaking and/or tsunami inundation have the potential for at least considerable levels of damage and associated socioeconomic disruption.

Based on preliminary model outputs, we estimate that nearly one in six Canadians (~5.8 million people; 16.5% of total) live in areas of the country where community members are least able to withstand and cope with the negative impacts of future earthquake and/or tsunami disasters (Figure 4-3). More than half of all those most affected (56%) are situated in more densely settled areas of the St. Lawrence Lowland in southern Quebec and eastern Ontario with 41% of the population concentrated in areas of higher overall threat along the west coast of British Columbia. The New Brunswick region of the Maritimes contributes another ~3% to the overall national profile of hazard threat while more remote settlements in the Yukon, Northwest Territories, and Nunavut represent ~0.2% of the total. Disparities in the relative level of hazard threat are variable from place to place and reflect the combined influences of local geological conditions that result in the amplification of ground shaking intensities, variations in topographic relief that affect tsunami wave heights and the severity of inundation in communities situated along isolated coastlines, and anomalous levels of social vulnerability related to the history of development and related patterns of land use. Detailed profiles of hazard threat are described below for the Cordillera region and the North, and in affected regions of both Central Canada and the Maritimes.

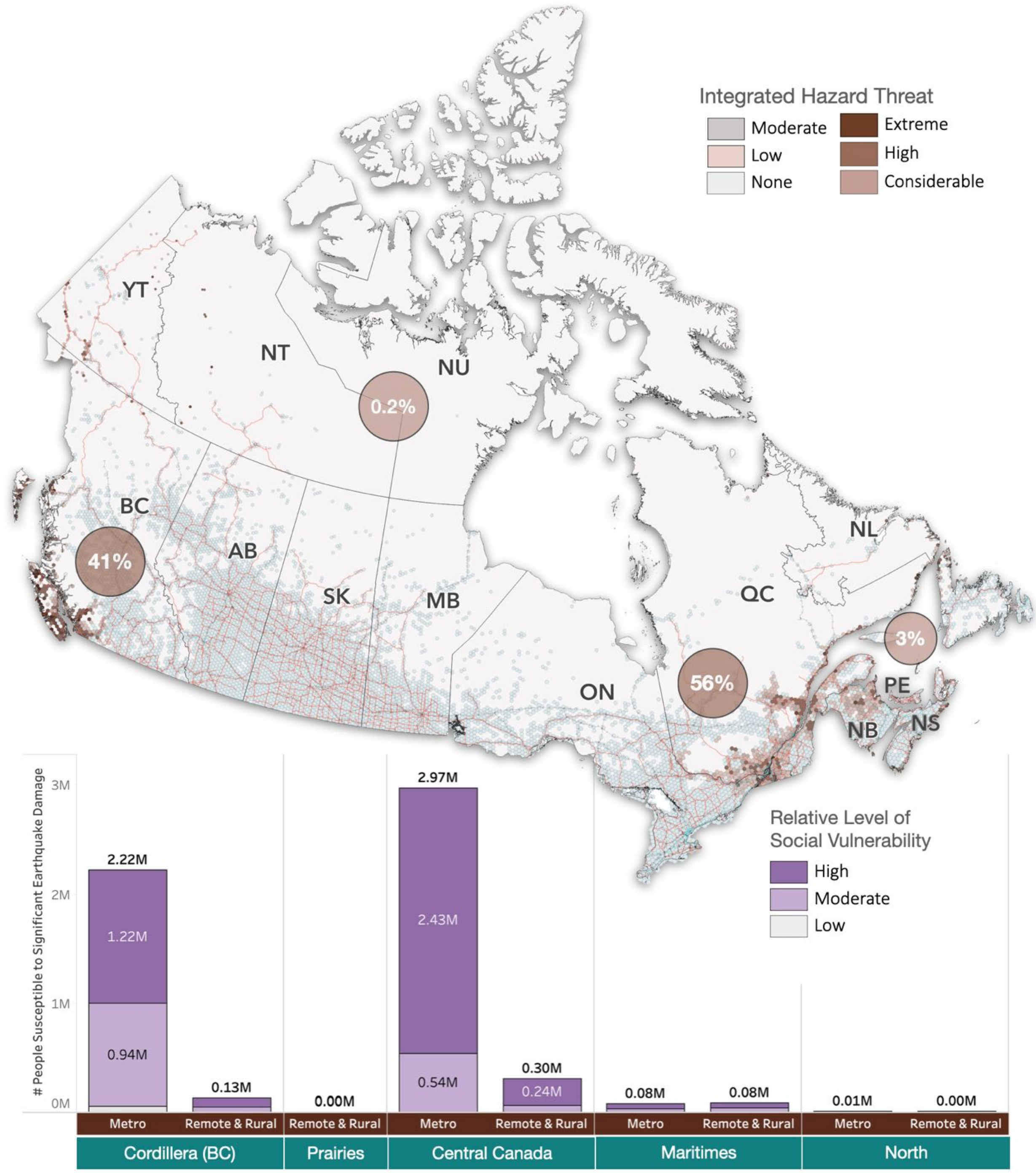


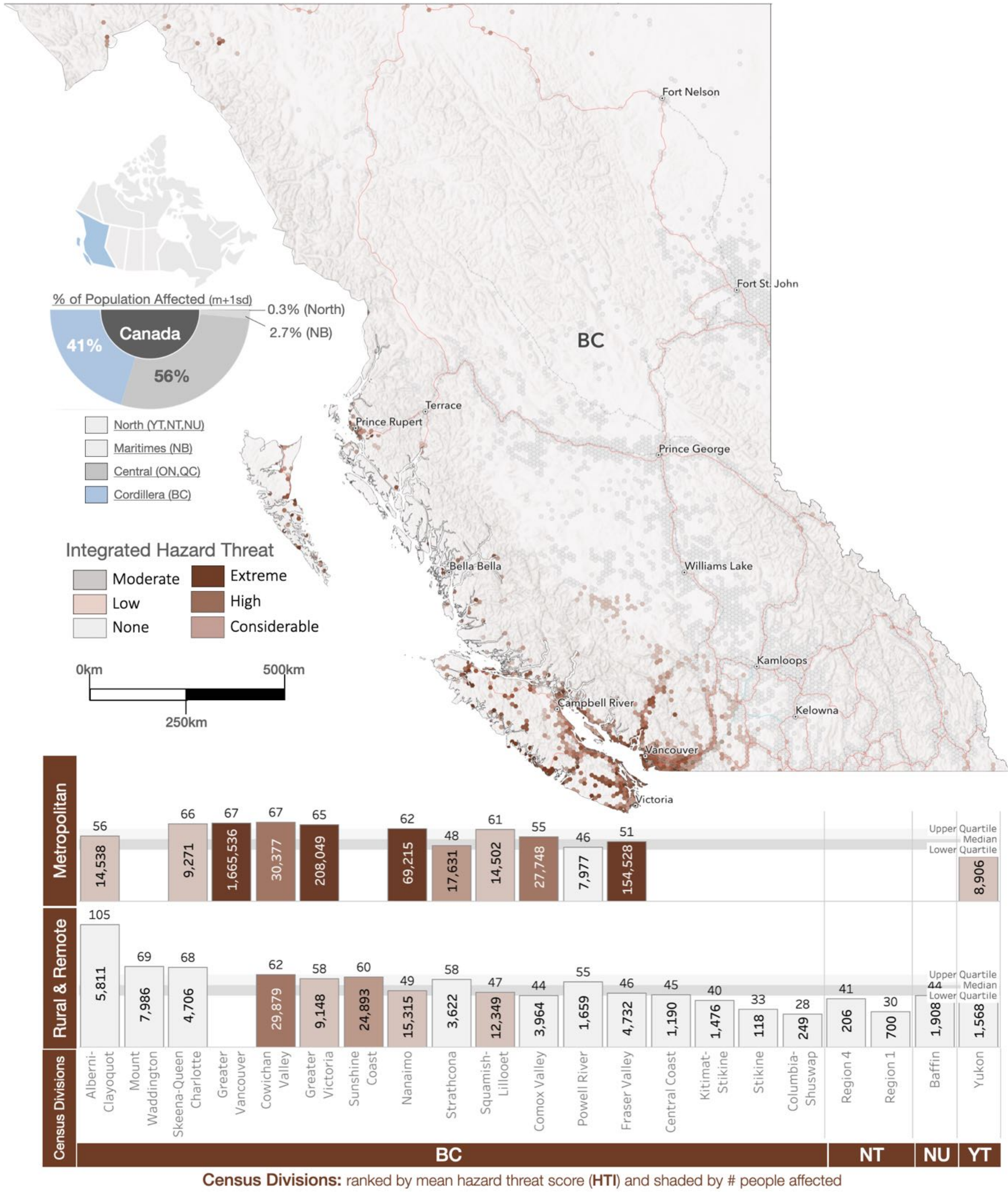
Figure 4-3: Share of national population affected by significant earthquake and tsunami hazard threats in Canada. Charts summarize exposure by relative level of social vulnerability.

Western and Northern Canada. Areas of high integrated hazard threat in Western Canada and the North occur in more densely settled metropolitan regions along the active Cascadia subduction zone in southwest British Columbia; in rural/remote settlements of Haida Gwaii and central coast regions of British Columbia that are situated along the Queen Charlotte Fault; and in more remote settlements of the Yukon, Northwest Territories, and Nunavut that are exposed to a variety of seismic hazards (see Figure 4-4). Increased levels of hazard threat affect more than 2.3 million people across a range of settlement types in British Columbia and ~13,280 people in more remote settings of the Yukon, Northwest Territories, and Nunavut. This represents half of the total provincial population in British Columbia, 12% of the combined population for all settled areas of the North, and ~41% of all those affected by similar levels of hazard threat at a national level across Canada. Of those people most affected by higher levels of hazard threat, it is estimated that nearly 98,000 live on Indigenous lands throughout the region. This represents 1.7% of all those affected in the country overall and more than 15% of the total Indigenous population in Canada. Differences in the level of hazard threat between Indigenous and Settler communities reflect regional patterns of social vulnerability with mean threat scores for those living on designated Aboriginal Lands exceeding average regional values by ~12%. Although fewer people are affected overall, mean levels of hazard threat are higher than in other parts of the country with values in the upper half of the regional distribution for many areas of southwestern British Columbia and the North.

Census divisions with rural and remote communities that exceed median regional values of integrated hazard threat include coastal areas of Alberni-Clayoquot, Powell River, and Mount Waddington on Vancouver Island, the Skeena Queen Charlotte region of Haida Gwaii, and the Greater Victoria, Cowichan Valley, and Sunshine Coast regions situated along the margins of the Georgia Basin in southwestern British Columbia (Figure 4-4). Anomalously high levels of hazard threat in these communities affect a total of 87,700 people, representing nearly 70% of all those impacted by similar levels of threat in rural and remote settings of British Columbia and the North. Metropolitan regions that record the highest levels of integrated hazard threat include larger urban centres and surrounding suburban neighbourhoods in the Greater Vancouver, Greater Victoria, Cowichan Valley, Nanaimo, and Squamish-Lillooet regions of southwestern British Columbia, and areas surrounding Prince Rupert in the Skeena-Queen Charlotte region along the central coast of British Columbia (Figure 4-4). Anomalously high levels of hazard threat in the Greater Vancouver region affect ~1.7 million people, representing 74% of all those impacted by similar levels of threat in metropolitan regions of British Columbia and the North.

Bivariate choropleth maps are used to help interpret how detailed patterns of social vulnerability and physical susceptibility interact to generate conditions of hazard threat within a given community (Figure 4-5). The bivariate mapping scheme is a 3 x 3 matrix that represents the integration of two sequential colour pallets. Physical determinants of hazard threat are shown in shades of gold that increase in tone as a function of the relative number of people at a given location that are susceptible to the combined effects of earthquake ground shaking, localized site amplification, and tsunami inundation along exposed sections of coastline. Social determinants of threat are shown in shades of purple with darker tones reflecting increased levels of social vulnerability that occur primarily in higher density multi-family and mixed-use neighbourhoods in which there are higher concentrations of people with reduced capacities to withstand the negative impacts and consequences of a disaster event. Darker colors in the bivariate mapping scheme represent areas of increased hazard threat in the community where are there are moderate to high levels of both physical susceptibility and social vulnerability.

Areas of increased hazard threat in the Greater Vancouver region occur primarily in mixed-use residential and commercial neighbourhoods that occur in the downtown urban core and waterfront areas of North Vancouver and the City of Vancouver, along major arterial corridors leading to New Westminster and Richmond, and in the urban centres of Surrey and Abbotsford. Areas of increased hazard threat on Vancouver Island occur in higher density multi-family residential and commercial neighbourhoods of the Victoria Capital and Nanaimo regions, and in complex patterns of low density residential and mixed-use commercial/industrial development that occur in surrounding rural hinterland and more remote settings. These include areas of mixed-use development in the Cowichan Valley on southern Vancouver Island, the Comox Valley region of central Vancouver Island, and outer coastal communities of the Alberni-Clayoquot region, many of which are situated on Indigenous lands.



Census Division	Metropolitan HTI	Metropolitan # affected	Rural & Remote HTI	Rural & Remote # affected
Alberni-Clayoquot	56	14,538	105	5,811
Mount Waddington			69	7,986
Skeena-Queen Charlotte	66	9,271	68	4,706
Greater Vancouver	67	1,665,536		
Cowichan Valley	67	30,377	62	29,879
Greater Victoria	65	208,049	58	9,148
Sunshine Coast			60	24,893
Nanaimo	62	69,215	49	15,315
Strathcona	48	17,631	58	3,622
Squamish-Lillooet	61	14,502	47	12,349
Comox Valley	55	27,748	44	3,964
Powell River	46	7,977	55	1,659
Fraser Valley	51	154,528	46	4,732
Central Coast			45	1,190
Kitimat-Stikine			40	1,476
Stikine			33	118
Columbia-Shuswap			28	249
Region 4			41	206
Region 1			30	700
Baffin			44	1,908
Yukon		8,906		1,568

Figure 4-4: Regional distribution of integrated hazard threat related to intrinsic patterns of social vulnerability and physical susceptibilities to the combined effects of earthquake ground-shaking and tsunami inundation in western Canada.

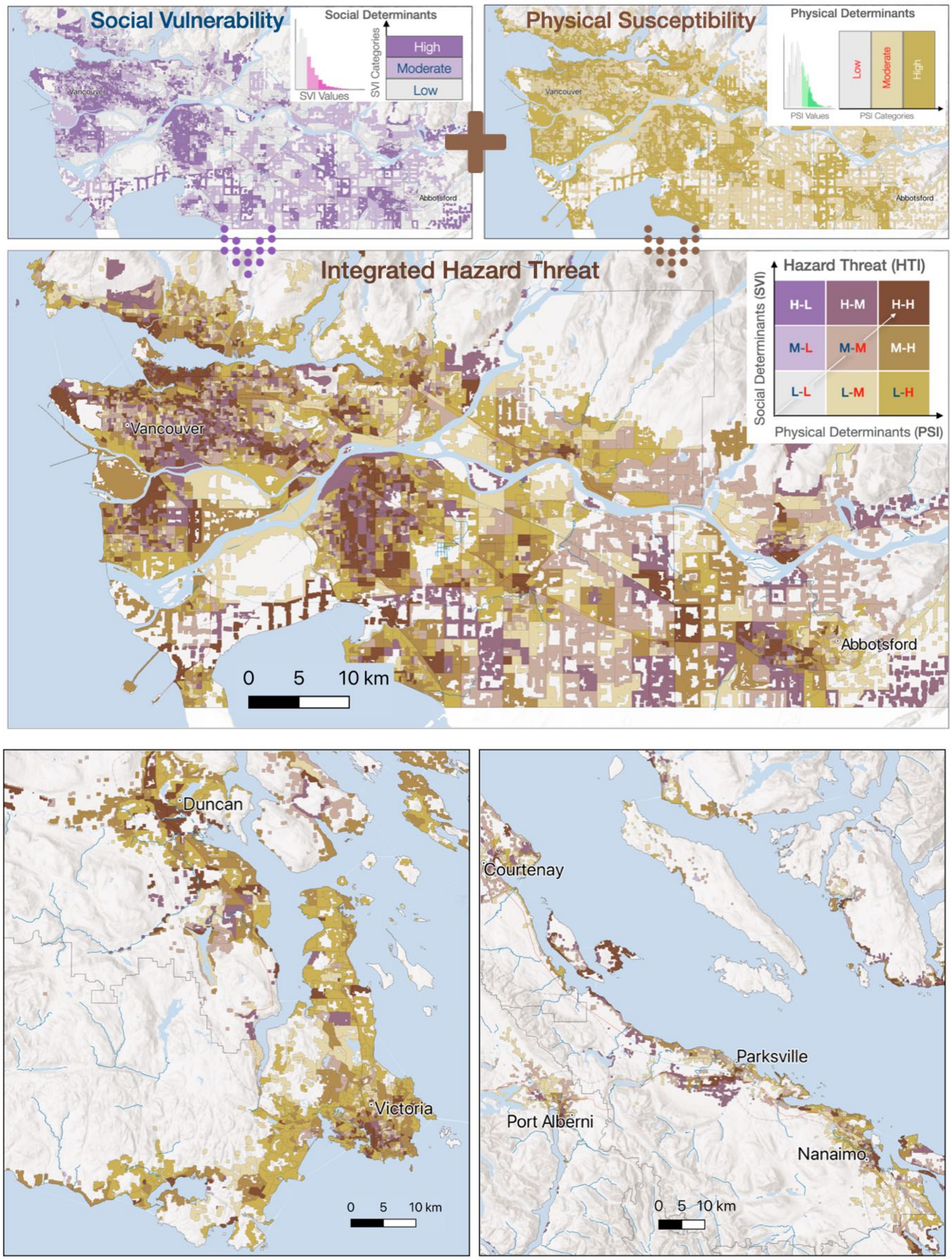


Figure 4-5: Bivariate choropleth maps showing detailed patterns of integrated hazard for representative communities in southwest British Columbia.

Central Canada and the Maritimes. Levels of integrated hazard threat in Central Canada and the Maritimes are ~18% lower than in western Canada but affect 3.2 million people in the region overall. This represents ~15% of the regional population and ~56% of all those situated in areas that are susceptible to more severe earthquake and/or tsunami hazards in Canada. The majority of those affected (~90%; 2.9 million people) live in more densely settled metropolitan regions along the St. Lawrence Lowland with the balance situated in the neighbouring Laurentian Highland and Appalachian Upland regions of the rural hinterland in Eastern Quebec and New Brunswick (see Figure 4.6). Although representing less than 1% of all those affected, people living on designated Aboriginal lands in the Central Canada and Maritimes are susceptible to levels of mean hazard threat that are ~45% higher than those living on lands governed under provincial legislation.

Census divisions with rural and remote settlements that record mean hazard threat values equal to or above median values for the region overall include lower density residential and mixed-use neighbourhoods of Beauharnois-Salaberry near the confluence of the St. Lawrence and Ottawa Rivers, and more remote settlements further east along the St. Lawrence River including Charlevoix, Charlevoix-Est, Kamouraska, Les Basques, Rivière-du-Loop, and La-Haute-Côte-Nord (Figure 4-6). Metropolitan regions that record the highest levels of integrated hazard threat in the region include densely populated neighbourhoods of Montréal, Laval, Longueuil, Ottawa-Gatineau, Quebec City, Pierre-De Saurel and Les Maskoutains along the St. Lawrence River. Other hotspot areas include the Lac Saint-Jean/Saguenay area, and smaller cities, towns, and surrounding rural areas of the Joliette, St Jérôme, and Saint Sauveur region of the Laurentian Highlands, and more remote coastal communities of the Maritimes that are exposed to tsunami inundation hazards related to major crustal earthquakes that occur along the continental shelf margin of the Atlantic Ocean.

Areas of anomalously high hazard threat are concentrated primarily in multi-family and mixed-use residential/commercial neighbourhoods that occur in downtown core areas of the major urban centres, and in lower density but complex areas of mixed residential, commercial, and industrial land use that occur in rural and more remote settings (see Figure 4-7). Bivariate choropleth maps reveal that detailed patterns of hazard threat in the Greater Montréal, Quebec City, and Ottawa-Gatineau regions are controlled primarily by variations in social vulnerability that affect large numbers of people in areas that are also susceptible to considerable earthquake ground shaking hazards. In addition to underlying patterns of social vulnerability related to historic patterns of development, the region is also characterized by a high proportion of older concrete and unreinforced masonry buildings that pre-date seismic safety design guidelines that were introduced into the National Building Code in the mid-1970s.

Although expected ground shaking intensities for earthquake events with a ~1/500-year return period are generally lower here than for equivalent settled areas in southwestern British Columbia, the concentration of people with higher intrinsic levels of social vulnerability in multi-family residential and mixed-use neighbourhoods that are also susceptible to significant levels of physical damage creates a major concern for communities throughout the St. Lawrence Lowland region of southern Quebec and neighbouring parts of Ontario and New Brunswick. While many would feel the negative impacts and related downstream consequences of a major earthquake event, it is the most vulnerable members of communities throughout the region who will disproportionally bear the greatest burden of risk.

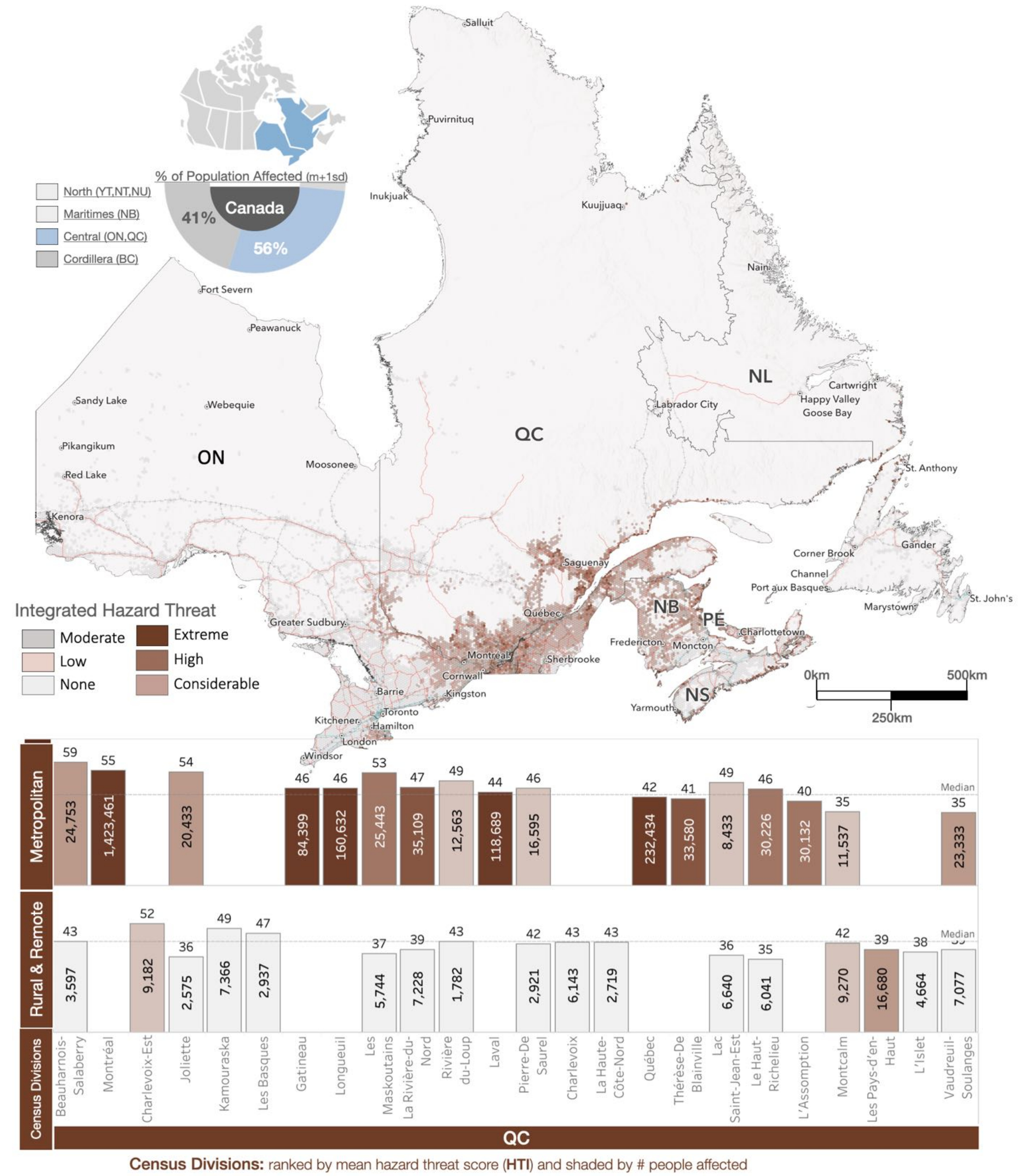


Figure 4-6: Regional distribution of integrated hazard threat related to intrinsic patterns of social vulnerability and physical susceptibilities to the combined effects of earthquake ground-shaking and tsunami inundation in eastern Canada.

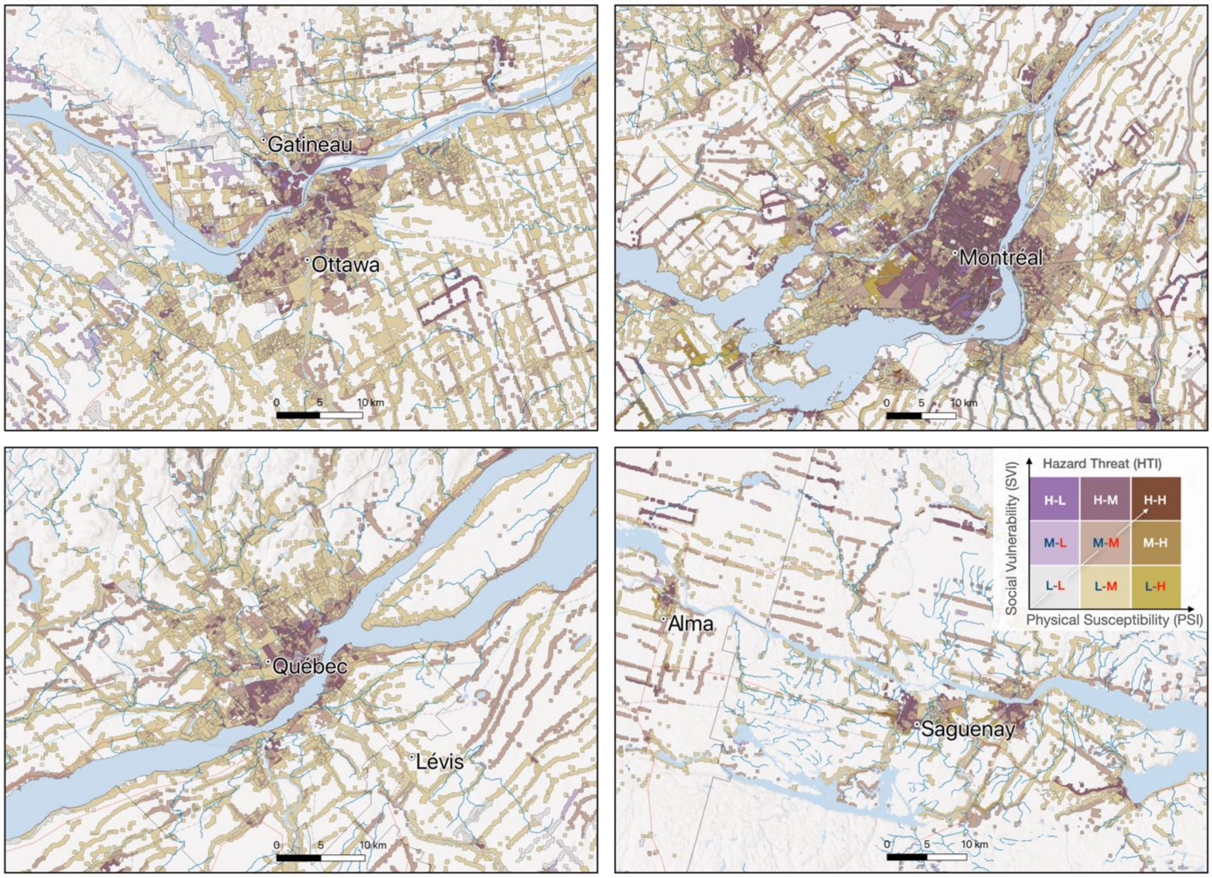


Figure 4-7: Bivariate choropleth maps showing detailed patterns of integrated hazard for representative communities in the St. Lawrence Lowland region of southern Quebec and Ontario.

5.0 SUMMARY AND DISCUSSION

A primary goal of this study is to establish a detailed base of evidence to inform sustainable development strategies that will minimize the negative effects that natural hazard events can have on the most vulnerable members of a community. To this end, we have endeavored to establish methods and results that can be effectively used in practice to measure intrinsic social vulnerabilities and their relationship to local patterns of development, and to evaluate the relative contribution of underlying factors that may differentially affect the capacities of individuals and groups to bear the physical, social, and economic consequences associated with disaster events and the potential to suffer harm as a result.

This study builds on and contributes to broader research and development efforts within NRCan to establish a platform for integrated risk assessment to assist local authorities in evaluating the efficacy of investing in risk reduction measures that increase capacities for functional recovery and the longer term prospects for disaster resilience and sustainable development at a community level. It also complements other similar assessments of social vulnerability that have been undertaken at a national level to evaluate systemic issues of inequity and marginalization from the perspective of human ecology and environmental justice (Matheson et al., 2012; O'sullivan, 2013; Auditor General of Canada, 2018; Chang et al., 2018; Indigenous Services Canada, 2019; Statistics Canada, 2019; Chakraborty et al., 2021). Innovations that are specific to this study and that contribute to a more holistic understanding of social vulnerability and its relationship to disaster resilience in Canada include:

- Assessing the dimensions of social vulnerability in the context of specific patterns of development. This includes backbone patterns that are associated with different types of human settlement (i.e., metropolitan, rural, and remote), and more detailed patterns of land use that reflect physical characteristics of the built environment and related functions that support the day-to-day needs of residents and businesses at the community level. The correlation of social fabric with specific characteristics of land use provides insights on underlying social, economic, and political factors that have governed patterns of development over time and that may not otherwise be evident when evaluating the determinants of vulnerability for a particular place.
- Assessing patterns of disparity based on thematically relevant pillars of social vulnerability (i.e., social capital, individual autonomy, housing conditions and financial agency) and measuring relative levels of vulnerability based on context-specific thresholds of exceedance. Comparing measures of social vulnerability at a given location with baseline values (mean + 1sd) that are characteristic of a particular settlement type (e.g., urban, rural, remote) provides a rational basis for interpreting disparities and underlying causal factors that are specific to a given type of neighbourhood. These additional measures increase both transparency and usability of model results by allowing practitioners to interrogate patterns of disparity within a community and to identify underlying socioeconomic factors that may be contributing to increased levels of social vulnerability. Arranging indicators within a hierarchical model structure enables the aggregation of vulnerability metrics to identify potential hotspot areas of concern while also helping shift the focus of analysis away from an absolute measure of fragility or inequity to a more holistic evaluation of (i) why some places and population groups are more likely to be affected by natural hazard threats than others and (ii) the implications of these patterns for disaster risk management.
- Assessing the influence of land title and associated frameworks of land governance. Land tenure can differentially affect levels of access to resources and essential services that are needed to support day-to-day activities and has been shown to increase disaster vulnerabilities and limit capacities to achieve sustainable development at the community level (UN General Assembly, 2015; Andrews et al., 2016; Sarmiento et al., 2020; Chmutina et al., 2021). To better understand these influences, we have parsed model results based on whether a given census dissemination area is located on lands administered by local authorities under provincial/territorial jurisdiction, or through governance systems associated with

lands where the title has either been vested with specific Indigenous groups or set aside for their exclusive benefit. Statistical profiles based on physical characteristics of the built environment and socioeconomic indicators that are specific to these jurisdictional boundaries are then used to assess how patterns of social vulnerability differ between Indigenous people living on designated Aboriginal Lands and those living in areas where land governance and access to essential services is administered by local authorities under provincial or territorial jurisdiction.

- Integrating social and physical dimensions of vulnerability to better understand overall susceptibilities to known natural hazard threats in Canada. Our analysis of integrated hazard threat combines measures of social vulnerability (SVI) with outputs of a complementary physical exposure model developed by NRCan to measure the susceptibility of buildings, people, and financial assets to known natural hazard processes in Canada including earthquakes, tsunamis, riverine floods, hurricanes, wildfire, and landslides of various types (Journeay et al., work in progress, 2022). In addition to establishing the necessary context for understanding relationships between development and associated patterns of vulnerability, model outputs are used to pilot a methodology for assessing the combined physical and social determinants of hazard threat at the community level using available information on natural hazard threats in Canada.

5.1. KEY FINDINGS AND INSIGHTS

Outputs of the CanSVM model indicate that patterns of disparity are influenced by where people live in a community or region (i.e., settlement type and characteristics of land use), and by deeply rooted social, economic, and political factors that can disproportionally affect access to resources and services needed to support day-to-day activities, and the capacities of individuals and groups to weather the impacts of a disaster event. Levels of disparity can vary significantly from place to place within a community or region as a function of geographic setting, land tenure, development history, overall density of the built environment, the diversity and complexity of land use functions at a given location (e.g., residential, commercial, civic, industrial), and physical susceptibilities to natural hazard processes.

5.1.1. Place Matters

Broad patterns of social vulnerability are influenced by geographic setting and the type of settlement in which people live. Although levels of disparity are highly variable from place to place, results of our assessment show that people living in dense urban centres are more likely to experience underlying socioeconomic conditions that can increase disaster vulnerabilities compared with those living in remote rural communities governed under provincial jurisdiction. As illustrated in Figure 3-1 mean vulnerability threshold scores are highest in suburban and exurban neighbourhoods that occur within major population centres and in immediately adjacent agricultural, manufacturing, and resource-based communities of the rural hinterland.

Underlying factors that contribute to observed trends in more densely populated areas include higher concentrations of people who have either recently moved or immigrated into the region, higher concentrations of people living in unsuitable housing conditions and/or areas with higher levels of commercial activity, and increased economic stresses related to high shelter costs and unstable employment. Factors that contribute to elevated levels of vulnerability in more remote rural and settings include reduced levels of social capital and financial agency related to higher proportions of lone-parent families and those caring for young children, unstable employment, overcrowded housing conditions, and financial stresses related to the upkeep and care of households in which the primary maintainer is either younger than 25 years or older than 65 years of age. Although intrinsic characteristics of social vulnerability are different between settlement types, it is the number of intersecting factors at a given location that appear to have the greatest overall effect on observed patterns of disparity.

When compared with cohorts in rural and remote counterparts, those living in dense urban centres and transitional neighbourhoods in metropolitan and rural hinterland settings experience more variability in how underlying socioeconomic factors manifest at a given location, and a higher likelihood of experiencing multiple conditions that exceed mean values for a particular settlement type. Higher-density residential and mixed-use neighbourhoods also bring together a much broader mix of residents with diverse racial, ethnic, and socioeconomic backgrounds, whereas more dispersed rural and remote settlements tend to show less variability and a lower likelihood of experiencing multiple conditions of disparity at a given location. The higher concentration of neighbourhoods in which there are multiple underlying conditions of vulnerability may help explain the differences between settlement types that are observed at a national level.

5.1.2. Know Your Neighbourhood

While geographic setting and type of settlement provide the overarching context for evaluating broad national trends in social vulnerability, results of our study show that physical characteristics of the built environment and local patterns of functional land use have a much more profound effect on both patterns of disparity and associated levels of vulnerability within a community or region. We find that mean vulnerability threshold scores increase significantly as a function of residential density and complexity of land use activities at a given location and are anomalously high when compared to mean values for all other land use classes of a given settlement type. In metropolitan regions, vulnerability threshold scores are significantly above mean values for higher density residential and mixed-use neighbourhoods of a given settlement type sand consistently below mean values for low-density residential neighbourhoods that are interspersed with lands designated for more general commercial and/or industrial use. Similar trends are observed in rural and remote settings where higher density mixed-use residential and commercial/industrial lands record vulnerability threshold scores that are significantly above mean values and lower density rural residential lands are consistently below the mean.

In the core of many metropolitan regions, we find that threshold scores for multi-family residential neighbourhoods in dense urban and suburban settlements are ~68% above mean overall values and generally decrease in surrounding exurban settlements that occur in transitional settings along the interface with more rural landscapes. These trends are reversed for medium-density residential and mixed-use neighbourhoods where average vulnerability threshold scores increase with distance away from the urban core. Vulnerability threshold scores for multi-family residential neighbourhoods range from 28-38% above the mean in suburban and exurban settings to nearly 10% below the mean in the urban core. Trends for mixed-use neighbourhoods are similar but record lower variability with average vulnerability threshold scores that range from 23-25% above the mean in suburban and exurban settings to 16% above the mean in the urban core. In rural hinterland settings, comparable vulnerability threshold scores for areas of mixed residential and commercial/industrial land use increase with distance away from neighbouring population centres, ranging from ~67% above mean values in agricultural, manufacturing, and resource-based communities that are adjacent to metropolitan regions to more than 85% above mean values in more remote rural communities with little or no metropolitan influence. As with larger metropolitan regions, mean vulnerability threshold scores for lower density commercial/industrial lands and single-family rural residential areas are more variable but consistently 25-45% lower than overall mean values for a given settlement type.

5.1.3. Mind the Gaps

Place-based statistical profiles provide important insights on how patterns of social vulnerability vary as a function of physiographic setting and characteristics of the built environment (i.e., density and functional land use). However, they do not fully explain more localized patterns of socioeconomic disparity related to land title and associated land governance systems that exist between Indigenous and Settler communities across Canada. These disparities are well known and have been the focus of ongoing efforts to measure gaps in well-being and monitor the effectiveness of strategies that have been implemented to address underlying factors of inequity and marginalization that exist within many Indigenous communities across Canada (Matheson et al., 2012;

O'sullivan, 2013; Auditor General of Canada, 2018; Indigenous Services Canada, 2019; Statistics Canada, 2019; Chakraborty et al., 2021).

Results of our analysis are generally consistent with broad measures of disparity that have been documented as part of the Community Well Being Index of Canada (Indigenous Services Canada, 2019). However, they provide additional insights on how specific dimensions of social vulnerability vary as a function of settlement type and related patterns of land use. We find that differences in measured levels of social vulnerability between Indigenous peoples living on designated Aboriginal Lands and those of the broader population are most pronounced in the Interior Prairie provinces of Alberta, Saskatchewan, and Manitoba. For example, Indigenous communities in the southern Prairies record mean vulnerability threshold scores that exceed those of the general population by a factor that ranges between 1.5 and 2.4 for more densely settled metropolitan regions. These gaps widen in more remote settlements, where vulnerability threshold scores can vary to as much as ~3.5. Patterns of disparity are less extreme in central Canada and the Eastern Maritime provinces where relative degrees of variance range between 1.2 and 2.6 for more densely settled metropolitan regions, and from 1.1 to 1.5 in more remote settlements of northern Quebec and Labrador. Although still significant, patterns of disparity are more subdued in the western Canada and in northern regions of the Yukon, Northwest Territories, and Nunavut. Differences in mean levels of vulnerability are negligible in the major urban centres of southwestern British Columbia but increase in more rural and remote settings where measures of vulnerability for Indigenous communities exceed those the general population by a factor of between 1.3 and 1.9.

5.1.4. Disasters by Design

Disasters are the predictable outcome of ongoing growth and development in areas where both physical systems of the built environment, and the complex network of interconnected social, economic, and political systems that define the essential fabric of cities, towns, and rural communities are periodically overwhelmed by the forces associated with natural hazard events (Burby, 1998; Kunreuther et al., 1998; Mileti, 1999; Cutter, 2001; Tierney et al., 2001). If so, why is it that the most vulnerable members of society continue to be situated in areas that are both more susceptible to the physical impacts of future disaster events and disproportionally affected by land governance decisions that limit their capacity to weather the downstream socioeconomic consequences? May and Deyle (1998) suggest the answer to this thorny question may lie at the intersection of conflicted public policy agendas where common good goals of public safety, economic security, social equity, and environmental justice are systematically overshadowed by the more immediate concerns of promoting growth and maximizing the shorter-term economic benefits of developing privately owned lands at the community level.

Although not surprising, the results of our assessment of earthquake-related hazard threats in Canada are consistent with other studies that document higher intrinsic levels of social vulnerability in areas that are more highly susceptible to the both the immediate physical impacts and negative downstream consequences of future disaster events (e.g., Cutter et al., 2003; Burby, 2006; Burton et al., 2018; Global Earthquake Model Foundation [Gem], 2020). Disparities in the relative level of physical susceptibility to seismic hazards vary from place to place as a function of local geological conditions that result in the amplification of ground shaking intensities, variations in topographic relief that affect tsunami wave heights and the severity of inundation in communities situated along isolated coastlines, and anomalous levels of social vulnerability related to the history of development and related patterns of land use. However, the cumulative effects of land use decisions that determine where people live in each community or region appear to have the most significant influence on observed patterns of natural hazard threat.

As it turns out, centres of commerce established early in the history of colonial settlement which have since become the hubs of major urban growth and development are situated in active tectonic regions that are susceptible to some of the most severe earthquake and tsunami hazards in Canada. Areas of greatest concern include high-density urban centres with concentrated patterns of mixed residential and commercial land use in which intrinsic levels of social vulnerability are ~68% above mean values for surrounding regions; and rural/remote communities exposed to the combined effects of earthquake ground shaking and tsunami inundation where less structured frameworks of land management result in higher levels of intrinsic social vulnerability. Based on preliminary model outputs, we estimate that nearly one in six Canadians (~5.8 million people; 16.5% of total) live in areas of the country where community members are least able to withstand and cope with the negative impacts of future earthquake and/or tsunami disasters (see Figure 7).

More than half of all those affected by earthquake-related hazards capable of causing significant structural damage (56%) are situated in more densely settled areas of the St. Lawrence Lowland in southern Quebec and eastern Ontario with an additional 41% of the population concentrated in areas of higher overall threat along the west coast of British Columbia. The New Brunswick region of the Eastern Maritimes contributes another ~3% to the overall national profile of hazard threat while more remote settlements in the Yukon, Northwest Territories, and Nunavut represent ~0.2% of the total. In Western Canada and the North, we find that mean hazard threat scores for those living on Indigenous lands exceed average values for the rest of the population by ~12%. Although fewer people are affected overall, mean levels of hazard threat are higher than in other parts of the country with values in the upper half of the regional distribution for many areas of southwestern British Columbia, the Yukon, Nunavut, and Northwest Territories.

While there is an obvious need to measure the potential physical impacts of natural hazards and how they vary from one location to another, it is equally important to understand who is in harm's way, cultural perceptions of risk, and potential issues of social inequity that may be associated with the spatial distribution of hazard threats within a given community or region. The integration of social and physical dimensions of hazard threat provides important insights on who is likely to bear the greatest burden of risk following a disaster event, the underlying causal factors that systematically disadvantage the most vulnerable in our communities, and strategic opportunities for increasing capacities for functional recovery at the neighbourhood level.

5.2. Limitations and Recommended Use of Model Outputs

By design, we have constructed the national model to assess patterns of social vulnerability in the context of eight broad settlement types that reflect unique characteristics of geography, development history, and associated patterns of land use. A consequence of this design choice is that absolute measures of social vulnerability can only meaningfully be compared between developed areas that are part of the same broad settlement type. For example, areas with anomalously high vulnerability threshold scores that occur in dense urban neighbourhoods of a major city cannot be directly compared with equivalent levels of vulnerability that occur in neighbouring suburban neighbourhoods or surrounding rural hinterland communities. This is because the associated social vulnerability indicators are calibrated with respect to the distribution of values that are characteristic of a given settlement type, not a particular community or region. As a result, we recommend that model outputs be used to assess relative patterns rather that absolute measures of social vulnerability from one location or region to another.

The strength of this approach is that it highlights characteristics of social vulnerability that are specific to a particular type of neighbourhood and allows a comparison of neighbourhood types from one region to another at a national scale. The alternative is to reference indicator values with respect to mean values for all neighbourhood types within a given region. This approach is useful when comparing absolute measures of vulnerability from one place to another but can obscure intrinsic patterns of disparity and underlying factors that are specific to a given neighbourhood type.

Indicators of social vulnerability used in this study were selected primarily based on proxy variables that reflect underlying conditions known to disproportionally affect the capacity of community members to withstand, cope with, and recover from the physical impacts of natural hazard events. While every effort has been made to develop models that reflect the best available information about the physical and social characteristics of communities and their susceptibility to known natural hazards across Canada, there remain significant limitations in our ability to measure intrinsic patterns of hazard threat and explain underlying causal factors that will affect disaster vulnerabilities at a scale that is relevant to local planners and policy analysts. Not included in the scope of our analysis are specific measures of community health such as medical conditions, coping skills, and local access to health services. While these factors are known to influence general capacities for both response and recovery, the supporting information needed to measure dimensions of community health at the neighbourhood scale is not yet available in a coherent and publicly accessible format for all regions in Canada. Initial attempts at downscaling available national community health datasets were not successful in replicating patterns detected with more granular datasets used in an initial pilot study for the province of British Columbia. In some cases, the inclusion of more generalized measures of health and wellbeing overshadowed other significant measures of vulnerability considered relevant in the broader context of emergency management and disaster risk reduction planning.

Aleatory uncertainties include well-known issues of under-reporting by socially marginalized groups in urban settings, and the exclusion of many Indigenous communities and smaller settlements from dissemination area level reporting in situations where the global response rate is less than 50% or where data have been suppressed for reasons of confidentiality (Statistics Canada, 2016c). These additional factors combined with a more rigorous assessment of social inequities related to systemic marginalization of racial and ethnic groups are expected to significantly amplify patterns of vulnerability and levels of disparity identified in this study, particularly in areas of rapid urbanization where the pressures of development often outpace competing efforts to ensure social equity. Addressing these gaps will require broader collaboration with those working in the social sciences and more focused investigations to fully assess the social determinants of risk across all settlement types in Canada.

The physical exposure model used in this study to identify fundamental characteristics of the built environment and levels of susceptibility to known hazard threats in Canada is limited by existing conditions of development. While this information provides a foundation for addressing questions of who and what are in harm's way to support the operational requirements of emergency management, it is of more limited value in the context of longer-term strategic community planning and sustainable development that are focused on forward-looking solutions for how best to manage the pressures of ongoing growth and development. To address these needs, it will be important to extend existing models to measure anticipated future growth and associated patterns of development – and to couple these models with quantitative risk assessment frameworks that integrate both physical and social dimensions of vulnerability.

Except for earthquake risk in Canada, we note that there are outstanding gaps in our understanding of systemic risk and a limited capacity to anticipate the likely outcomes of complex disaster events with the necessary degree of certainty that will justify the allocation of scarce public funds toward risk reduction measures— even though these measures are known to increase both levels of disaster resilience and the longer-term prospects of sustainable development. For these reasons, we consider outputs of the hazard threat assessment presented in this report to be an initial step toward developing a more robust multi-hazard risk assessment framework for Canada.

Achieving this goal will require ongoing research, development and broader collaboration with academics and federal agencies who are collectively responsible for disaster risk reduction planning in Canada, and input from a much broader coalition of practitioners working across the boundaries of emergency management and community planning. Rather than relying on existing models as predictive tools to answer specific questions, the emphasis at this stage of development should be on using the available hazard threat assessment information as a screening tool to assist in exploring underlying social and physical vulnerabilities that may exist within a given community or region, and to work toward a shared understanding of risk that will support ongoing planning and policy development. Although model outputs are reported at the census dissemination area level, they are not intended for use in evaluating site level hazard threats that are required for operational planning (e.g., land use bylaws, building permits) or land use decisions that involve the allocation of public funds for disaster risk reduction measures. Nonetheless, they do provide a useful framework for bottom-up assessments that make use of local knowledge and community input to identify more detailed patterns of vulnerability that are specific to individuals and groups at the local neighbourhood level.

5.3. From Vulnerability to Resilience

Resilience refers to the inherent capabilities of people and social systems to take actions in advance of or following a disaster event that increase levels of safety, economic security, and the prospects of functional recovery for all members of a community or region (Folke et al., 2002; Adger et al., 2005; Walker et al., 2006). Community resilience planning is focused primarily on the post-disaster recovery process and is a relatively new field of active research and practice. It includes the identification of pre-event mitigation and adaptation measures aimed at minimizing the numbers of people who are likely to be directly affected; and post-event interventions that increase the capacities of more vulnerable populations to weather the impacts and consequences on their own, thereby reducing the degree of social disruption and the time required to restore functional levels of operation for homes and businesses. For the initial stages of recovery planning, there is a need to identify key gaps that may exist between shelter and essential service requirements of different neighbourhood groups, and levels of functionality for critical lifeline services that are likely to be impacted in the days and weeks following a disaster event. For later stages of sustained recovery and re-building, there is a need to ensure that those who are likely to bear the greatest burden of risk are both represented and engaged in the decision-making process.

While the theoretical principles and methods used to assess community resilience are robust, successful implementation of these frameworks is largely dependent on knowledge that is held by local authorities, social planners, and/or organizations who are more intimately familiar with the social fabric of a given community or region. To address these challenges, we have initiated research and development activities aimed at identifying characteristic profiles of community members who are most susceptible to the potential impacts and socioeconomic consequences of disaster events in the context of a given neighbourhood. Machine learning and related pattern recognition techniques are used to identify neighbourhood-level vulnerability archetypes that make evident the critical relationships between affected population groups and corresponding patterns of social vulnerability (Yip et al., 2020). The methodology is similar in principle to hierarchical clustering techniques used to establish regional profiles of social vulnerability and community resilience (Rufat, 2013; Tuccillo et al., 2016; Burton et al., 2018; Chang et al., 2018).

By identifying who is most likely to be impacted within a given neighbourhood, it is then possible to assess what specific resources might be needed by any one group to increase their capacity to both withstand and recover from future disaster events and the impacts of climate change. Re-framing the context of analysis in this way has the potential to bridge top-down quantitative methods of assessing levels of social vulnerability with bottom-up approaches that reflect local knowledge and understanding of the many ways in which a particular community can be vulnerable to natural hazards and the underlying causal factors. This is particularly relevant for prioritizing planning and policy development efforts around those neighbourhood archetypes that are likely to bear the greatest burden of risk, and the specific capacities and/or additional services they may need to enhance disaster resilience and related prospects of functional recovery. Outputs of initial case studies demonstrate the potential for and usefulness of extending the assessment of neighbourhood-level vulnerability archetypes to other regions in Canada. The success of these efforts will depend very much on the engagement of social planners and organizations who have a first-hand understanding of who is most vulnerable within a given community or region and the specific resources and capacities these groups may need to increase their resilience to future disaster events. When coupled with methods of integrated risk assessment, these efforts have the potential to help mainstream the implementation of Sendai Framework policy goals for disaster risk reduction (SFDRR 2015-2030) into the broader context of urban planning and sustainable development at a community level in Canada.

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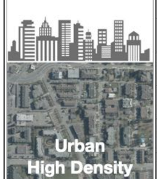
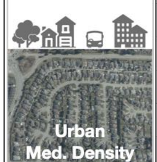
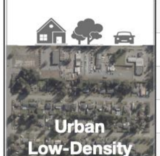
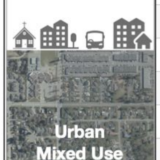
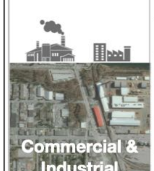
Appendices

APPENDIX A: LAND USE CHARACTERISTICS FOR MAJOR SETTLEMENT TYPES

Land Use	Physical Characteristics	Land Use Characteristics for Major Settlement Types in Canada											
		Metropolitan				Rural				Remote			CANADA
		SAC1: Urban Core	SAC2: Suburban	SAC3: Exurban	Sub Totals	SAC4: High MIZ	SAC5: Moderate MIZ	SAC6: Weak MIZ	Sub Totals	SAC7: Provincial	SAC8: Territorial	Sub Totals	National Profile
 CANADA	Settled Area(km2)	29,369	4,073	12,223	45,665	26,851	36,212	16,727	79,790	4,229	213	4,442	129,896
	Nighttime Population	24,948,619	1,238,531	3,050,850	29,238,001	1,986,849	2,319,900	1,310,860	5,617,609	230,994	64,206	295,200	35,150,810
	Density (# People/km2)	850	304	250	468	74	64	78	72	55	302	178	239
	Non-Residential Bldgs	478,814	32,646	92,293	603,753	51,960	76,359	52,169	180,488	7,325	1,883	9,208	793,449
	Multi-Family Bldgs	876,766	39,621	93,614	1,010,001	27,756	40,044	23,092	90,892	2,287	2,013	4,300	1,105,193
	Single-Family Bldgs	4,526,194	322,137	862,354	5,710,685	706,351	819,176	440,427	1,965,954	77,322	12,795	90,117	7,766,756
 Urban High Density	Settled Area(km2)	341	1.0	0.4	342	–	–	–	–	–	–	–	342
	Nighttime Population	3,964,954	10,380	4,406	3,979,740	–	–	–	–	–	–	–	3,979,740
	Density (# People/km2)	11,628	10,673	11,645	11,315	–	–	–	–	–	–	–	11,315
	Non-Residential Bldgs	52,025	52	99	52,176	–	–	–	–	–	–	–	52,176
	Multi-Family Bldgs	166,957	359	161	167,477	–	–	–	–	–	–	–	167,477
	Single-Family Bldgs	105,866	110	198	106,174	–	–	–	–	–	–	–	106,174
 Urban Med. Density	Settled Area(km2)	1,586	37	49	1,672	–	–	–	–	–	–	–	1,672
	Nighttime Population	7,536,451	160,201	220,536	7,917,189	–	–	–	–	–	–	–	7,917,189
	Density (# People/km2)	4,752	4,318	4,510	4,527	–	–	–	–	–	–	–	4,527
	Non-Residential Bldgs	96,020	1,829	3,922	101,771	–	–	–	–	–	–	–	101,771
	Multi-Family Bldgs	322,725	7,581	11,368	341,674	–	–	–	–	–	–	–	341,674
	Single-Family Bldgs	1,157,154	24,602	31,095	1,212,851	–	–	–	–	–	–	–	1,212,851
 Urban Low-Density	Settled Area(km2)	25,292	3,812	11,688	40,792	–	–	–	–	–	–	–	40,792
	Nighttime Population	12,311,514	944,120	2,512,429	15,768,063	–	–	–	–	–	–	–	15,768,063
	Density (# People/km2)	487	248	215	316	–	–	–	–	–	–	–	316
	Non-Residential Bldgs	214,956	19,692	58,558	293,206	–	–	–	–	–	–	–	293,206
	Multi-Family Bldgs	345,046	27,428	71,915	444,389	–	–	–	–	–	–	–	444,389
	Single-Family Bldgs	3,145,468	281,710	782,382	4,209,560	–	–	–	–	–	–	–	4,209,560
 Urban Mixed Use	Settled Area(km2)	303	28	74	406	10	18	24	52	0.4	1	1	459
	Nighttime Population	678,362	71,873	182,492	932,727	27,932	44,334	65,581	137,847	2,249	4,257	6,506	1,077,080
	Density (# People/km2)	2,236	2,554	2,464	2,418	2,779	2,527	2,726	2,677	5,518	4,107	4,812	9,907
	Non-Residential Bldgs	42,217	4,159	16,401	62,777	1,932	4,872	6,153	12,957	18	768	786	76,520
	Multi-Family Bldgs	25,922	2,650	6,413	34,985	975	1,672	1,732	4,379	15	109	124	39,488
	Single-Family Bldgs	57,007	8,353	24,401	89,761	4,697	6,228	11,366	22,291	574	481	1,055	113,107
 Commercial & Industrial	Settled Area(km2)	1,846	195	412	2,453	774	2,387	1,940	5,102	903	10	913	8,467
	Nighttime Population	4,567,339	51,956	130,988	4,750,283	71,088	150,934	122,706	344,728	29,689	785	30,474	5,125,486
	Density (# People/km2)	248	266	318	277	92	63	63	73	33	78	55	405
	Non-Residential Bldgs	73,596	6,914	13,313	93,823	6,623	18,062	16,081	40,766	4,597	115	4,712	139,301
	Multi-Family Bldgs	16,116	1,603	3,757	21,476	1,195	2,753	2,207	6,155	250	33	283	27,914
	Single-Family Bldgs	60,699	7,362	24,278	92,339	18,928	42,449	32,646	94,023	12,050	252	12,302	198,664
 Rural	Settled Area(km2)	–	–	–	–	26,067	33,807	14,763	74,636	3,326	202	3,527	78,164
	Nighttime Population	–	–	–	–	1,887,829	2,124,632	1,122,573	5,135,034	199,056	59,164	258,219	5,393,253
	Density (# People/km2)	–	–	–	–	72	63	76	70	60	293	177	247
	Non-Residential Bldgs	–	–	–	–	43,405	53,425	29,935	126,765	2,710	1,000	3,710	130,475
	Multi-Family Bldgs	–	–	–	–	25,586	35,619	19,153	80,358	2,022	1,871	3,893	84,251
	Single-Family Bldgs	–	–	–	–	682,726	770,499	396,415	1,849,640	64,698	12,062	76,760	1,926,400

APPENDIX B: SOCIAL VULNERABILITY METRICS

B1: Principal Component Analysis (PCA) for Major Settlement Types

Note: See Table 2-1 for a description of census variables used in the national assessment of social vulnerability.

Urban Centres (SAC1): 36,068 records

	SAC1	Eigenvalue	Variability (%)	Cumulative %
1	No Eng Fr	1.42025	5.681	5.681
2	Age GT65/Mntn_age	1.671	6.684	12.365
4	One Inc Hshld	0.9695	3.878	16.243
5	No Sec School	1.03225	4.129	20.372
6	OnePar3kids	1.06875	4.275	24.646
7	Retail Job	1.017	4.068	28.715
8	Health Job	1.011	4.044	32.758
9	No Job Loc	1.02025	4.081	36.840
10	Business Dens	1.031	4.124	40.963
11	PreCode	1.06025	4.241	45.204
12	Unemployed	1.039	4.156	49.361
13	Fam GT5	1.062	4.248	53.608
14	Pop Dens	1.06175	4.247	57.856
15	Aborig	1.030	4.120	61.975
16	Work Parttime	1.02325	4.093	66.068
17	Moved	1.0765	4.306	70.374
18	Nsuit House	0.97875	3.915	74.289
19	AgeLT6	1.01025	4.041	78.329
20	Immigrant	1.05775	4.231	82.561
21	Pub Transit	1.021	4.084	86.644
22	ShltrGT30	0.886	3.544	90.189
23	Inc_Med_Hshld	0.7945	3.178	93.366
24	Live_Alone	0.944	3.776	97.143
25	Vis Min	0.33025	1.321	98.464
			1.536	100.000

Factor loadings after reduction, after rotation

Suburban Neighbourhoods (SAC2): 2,092 records

	SAC2	Eigenvalue	Variability (%)	Cumulative %
1	Age GT65/Mntn_age	1.99675	7.987	7.987
3	Immigrant	1.5265	6.106	14.093
4	Aborig	1.01475	4.059	18.152
5	One_Par_3kids	1.065	4.260	22.412
6	Work_Parttime	1.01875	4.075	26.487
7	PreCode_percent	1.0995	4.398	30.884
8	Health_Job	1.02075	4.083	34.967
9	Bus_Dens_Settled	1.063	4.250	39.217
10	Retail_Job	1.03675	4.147	43.364
11	No_Eng_Fr	1.035	4.140	47.505
12	No_Job_Loc	1.01925	4.077	51.582
13	NSuit_House	1.02425	4.097	55.679
14	One_Inc_Hshld	1.01975	4.079	59.758
15	Pop_Dens_Settled	1.04125	4.165	63.923
16	Fam_GT5	1.023	4.090	68.013
17	Moved_Recent	0.99225	3.969	71.982
18	Pub_Trans	1.18925	4.757	76.739
19	Unemployed	1.024	4.096	80.835
20	No_Sec_School	1.053	4.212	85.047
21	Age_LT6	0.9235	3.694	88.741
22	Shltr_FT30	0.973	3.890	92.631
23	Live_Alone	0.86975	3.479	96.110
24	Vis_Min	0.37175	1.487	97.597
25	Inc_Med_Hshld	0.42125	1.685	99.282
			0.718	100.000

Factor loadings after reduction, after rotation

Exurban Fringe (SAC3): 5,399 records

	SAC3	Eigenvalue	Variability (%)	Cumulative %
1	One_Inc_Hshld	1.052	4.208	4.208
2	Age GT65/Mntn_age	1.66525	6.661	10.869
4	One_Par_3kids	1.05875	4.235	15.104
5	Aborig	1.01325	4.053	19.157
6	No_Eng_Fr	1.027	4.108	23.265
7	Health_Job	1.01175	4.047	27.313
8	PreCode_percent	1.07225	4.289	31.602
9	Retail_Job	1.0205	4.082	35.683
10	Unemployed	1.01975	4.079	39.762
11	Pub_Trans	1.019	4.076	43.838
12	Bus_Dens_Settled	1.0315	4.126	47.964
13	No_Job_Loc	1.00875	4.035	51.999
14	NSuit_House	1.01225	4.049	56.048
15	Pop_Dens_Settled	1.024	4.096	60.144
16	Immigrant	1.123	4.490	64.634
17	Fam_GT5	1.02775	4.111	68.745
18	Work_Parttime	1.02625	4.105	72.850
19	Moved_Recent	1.026	4.104	76.953
20	No_Sec_School	1.06525	4.261	81.215
21	AgeLT6	1.02275	4.091	85.306
22	Shltr_GT30	0.96525	3.861	89.167
23	Vis_Min	0.83775	3.351	92.518
24	Live_Alone	0.943	3.770	96.288
25	Inc_Med_Hshld	0.61475	2.459	98.747
			1.253	100.000

Factor loadings after reduction, after rotation

Rural-Strong MI (SAC4): 3,484 records

SAC4	Eigenvalue	Variability (%)	Cumulative %
Age GT65/Mntn_age	1.57625	6.305	6.305
No_Sec_School	1.02075	4.083	10.388
Vis_Min	1.00675	4.027	14.415
Unemployed	1.0105	4.042	18.457
No_Eng_Fr	1.02675	4.107	22.564
Aborig	1.00575	4.023	26.587
PreCode_percent	1.0365	4.146	30.734
Retail_Job	1.01025	4.041	34.775
Pub_Trans	1.00175	4.007	38.782
No_Job_Loc	1.0045	4.018	42.800
Bus_Dens_Settled	1.00625	4.025	46.825
Health_Job	1.01075	4.043	50.868
NSuit_House	1.013	4.052	54.919
Immigrant	1.0045	4.018	58.937
Moved_Recent	1.005	4.020	62.958
Pop_Dens_Settled	1.001	4.004	66.961
Shltr_GT30	1.00975	4.039	71.000
Work_Parttime	1.01275	4.051	75.051
Live_Alone	0.99325	3.973	79.024
One_Par_3kids	1.01975	4.079	83.103
Fam_GT5	0.977	3.908	87.011
One_Inc_Hshld	1.03025	4.121	91.132
Age LT6	1.0735	4.294	95.426
Inc_Med_Hshld	0.82625	3.305	98.731
		1.269	100.000

Factor loadings after reduction, after rotation

Rural - Moderate MI (SAC5): 4,612 records

SAC5	Eigenvalue	Variability (%)	Cumulative %
Age GT65	0.57025	2.281	2.281
One_Inc_Hshld	1.02875	4.115	6.396
Immigrant	1.03575	4.143	10.539
Unemployed	1.02075	4.083	14.623
No_Eng_Fr	1.03075	4.123	18.746
Work_Parttime	1.01875	4.075	22.821
Moved_Recent	1.00775	4.031	26.851
PreCode_percent	1.028	4.110	30.962
Pub_Trans	1.0035	4.014	34.976
Retail_Job	1.02025	4.081	39.058
Health_Job	1.01375	4.055	43.113
Bus_Dens_Settled	1.01125	4.045	47.157
No_Job_Loc	1.00775	4.031	51.188
Pop_Dens_Settled	1.000	4.000	55.188
Shltr_GT30	1.01325	4.053	59.241
No_Sec_School	1.01575	4.063	63.304
NSuit_House	1.025	4.100	67.404
Mntn_Age	1.31325	5.253	72.657
One_Par_3kids	1.01625	4.065	76.722
Live_Alone	0.993	3.970	80.692
Inc_Med_Hshld	0.91225	3.649	84.342
Aborig	0.953	3.812	88.154
Vis_Min	0.9485	3.794	91.948
Fam_GT5	0.9985	3.994	95.942
Age LT6	1.0145	4.058	100.000

Factor loadings after reduction, after rotation

Rural - Weak MI (SAC6): 2,588 records

SAC3	Eigenvalue	Variability (%)	Cumulative %
One_Inc_Hshld	1.052	4.208	4.208
Age GT65/Mntn_age	1.66525	6.661	10.869
One_Par_3kids	1.05875	4.235	15.104
Aborig	1.01325	4.053	19.157
No_Eng_Fr	1.027	4.108	23.265
Health_Job	1.01175	4.047	27.313
PreCode_percent	1.07225	4.289	31.602
Retail_Job	1.0205	4.082	35.683
Unemployed	1.01975	4.079	39.762
Pub_Trans	1.019	4.076	43.838
Bus_Dens_Settled	1.0315	4.126	47.964
No_Job_Loc	1.00875	4.035	51.999
NSuit_House	1.01225	4.049	56.048
Pop_Dens_Settled	1.024	4.096	60.144
Immigrant	1.123	4.490	64.634
Fam_GT5	1.02775	4.111	68.745
Work_Parttime	1.02625	4.105	72.850
Moved_Recent	1.026	4.104	76.953
No_Sec_School	1.06525	4.261	81.215
AgeLT6	1.02275	4.091	85.306
Shltr_GT30	0.96525	3.861	89.167
Vis_Min	0.83775	3.351	92.518
Live_Alone	0.943	3.770	96.288
Inc_Med_Hshld	0.61475	2.459	98.747
		1.253	100.000

Factor loadings after reduction, after rotation

Remote Settlement-Provincial (SAC7): 1,176 records

SAC7	Eigenvalue	Variability (%)	Cumulative %
Age_LT6	1.024	4.096	4.096
Vis_Min	0.98875	3.955	8.051
Inc_Med_Hshld	1.0585	4.234	12.285
Unemployed	1.0285	4.114	16.400
No_Eng_Fr	1.03575	4.143	20.542
No_Job_Loc	1.00725	4.029	24.571
One_Par_3kids	1.03325	4.133	28.704
Pop_Dens_Settled	1.0035	4.014	32.718
Retail_Job	1.01025	4.041	36.759
PreCode_percent	1.24025	4.961	41.720
Pub_Trans	1.003	4.010	45.730
Moved_Recent	1.0095	4.038	49.768
Health_Job	1.01425	4.057	53.825
Bus_Dens_Settled	1.033	4.132	57.958
Shltr_GT30	1.0165	4.066	62.024
One_Inc_Hshld	1.015	4.060	66.083
Live_Alone	1.0155	4.062	70.146
Mntn_Age	1.14075	4.563	74.709
Work_Parttime	1.04025	4.161	78.869
Immigrant	1.0115	4.046	82.915
Fam_GT5	1.086	4.344	87.259
No_Sec_School	0.99325	3.973	91.233
NSuit_House	0.878	3.512	94.744
Age_GT65	0.8035	3.214	97.958
Aborig	0.5105	2.042	100.000

Factor loadings after reduction, after rotation

Remote Settlement-Territorial (SAC8): 129 records

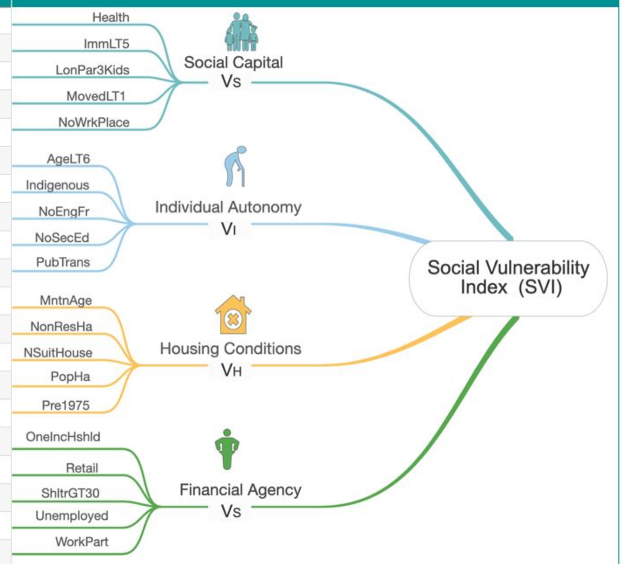
SAC8	Eigenvalue	Variability (%)	Cumulative %
Age_LT6	0.6935	2.774	2.774
Inc_Med_Hshld	1.0395	4.158	6.932
One_Inc_Hshld	1.12725	4.509	11.441
Pub_Trans	1.027	4.108	15.549
Bus_Dens_Settled	1.04075	4.163	19.712
Work_Parttime	1.06375	4.255	23.967
Mntn_Age	1.22825	4.913	28.880
No_Job_Loc	1.0715	4.286	33.166
Immigrant	1.1435	4.574	37.740
Retail_Job	1.12825	4.513	42.253
Pop_Dens_Settled	1.365	5.460	47.713
Shltr_GT30	1.099	4.396	52.108
No_Eng_Fr	1.20475	4.819	56.928
PreCode_percent	1.07775	4.311	61.239
Health_Job	1.08525	4.341	65.579
Vis_Min	0.92675	3.707	69.287
One_Par_3kids	1.3465	5.386	74.672
Moved_Recent	1.098	4.392	79.064
Aborig/No_Sec_School	1.86825	7.473	86.537
Unemployed	0.91525	3.661	90.199
FAM_GT5	0.69925	2.797	92.996
NSuit_House	0.40175	1.607	94.603
Age_GT65	0.6635	2.654	97.257
Live_Alone	0.593	2.372	99.629
		0.371	100.000

Factor loadings after reduction, after rotation

B2: Social Vulnerability Indicators & Assessment Framework

Dimension	Social Vulnerability Indicators	Description
Social Capital (VS)	Health	Proportion labour force (15yr+) employed in healthcare/social assistance fields
	ImmLT5	Proportion of households who have immigrated in last 5 years
	LonPar3Kids	Proportion of lone parent families with 3 or more children
	MovedLT1	Proportion population that has moved within last year
	NoWrkPlace	Proportion of population with no fixed workplace
Individual Autonomy (VI)	AgeLT6	Proportion children under 6 years of age
	Indigenous	Proportion of population that identifies as Aboriginal
	NoEngFr	Proportion population with no working knowledge of English or French
	NoSecED	Proportion of population with no certificate, diploma, or degree
	PubTrans	Proportion population who relies on public transit to commute to work.
Housing Conditions (VH)	MntnAge	Proportion of households with primary maintainer either <25 years or > 65 years
	NonResHa	Number of non-residential buildings per hectare of settled area
	NSuitHouse	Proportion of households living in non-suitable conditions
	PopHa	Number of permanent nighttime residents per hectare of settled area
	Pre1975	Proportion of building stock that predate modern seismic safety guidelines
Financial Agency (VE)	OneIncHshld	Proportion of households with only 1 maintainer income
	Retail	Proportion of population that rely on work in retail trade
	ShltrGT30	Proportion of households that spend more than 30% of income on shelter costs
	Unemployed	Proportion of population (labour force) that is unemployed
	WorkPart	Proportion of population that worked part time or for only part of the year

SVI Assessment Framework



B3: Statistical Profile of Indicators by Settlement Type

Dimension	Social Vulnerability Indicators	Metropolitan						Rural Hinterland						Remote			
		SAC1-Urban		SAC2-Suburban		SAC3: Exurban		SAC4: Strong		SAC5: Moderate		SAC6-Weak		SAC7-Provincial		SAC8: Territorial	
		mean	m+1sd	mean	m+1sd	mean	m+1sd	mean	m+1sd	mean	m+1sd	mean	m+1sd	mean	m+1sd	mean	m+1sd
Social Capital (VS)	Health	0.7736	0.8747	0.7547	0.8613	0.7939	0.8869	0.7034	0.8408	0.8233	0.9177	0.7586	0.8915	0.8865	0.9904	0.5733	0.8247
	ImmLT5	0.0674	0.1571	0.0399	0.1205	0.0311	0.1013	0.0260	0.0966	0.0187	0.0755	0.0534	0.1691	0.0285	0.1088	0.0770	0.2390
	LonPar3Kids	0.1466	0.3047	0.1290	0.2784	0.1519	0.3157	0.1503	0.3071	0.1651	0.3384	0.1449	0.3052	0.1626	0.3724	0.2802	0.4965
	MovedLT1	0.1400	0.2299	0.2471	0.3899	0.1295	0.2051	0.1908	0.3024	0.2260	0.3652	0.2364	0.3831	0.1896	0.3520	0.4202	0.6243
	NoWrkPlace	0.1865	0.2852	0.2298	0.3569	0.1152	0.1826	0.1379	0.2051	0.1345	0.2116	0.2169	0.3414	0.1671	0.3192	0.2813	0.5066
Individual Autonomy (VI)	AgeLT6	0.2410	0.3303	0.3541	0.4816	0.3049	0.4211	0.3641	0.5000	0.2944	0.4192	0.3075	0.4395	0.1634	0.2702	0.5035	0.6963
	Indigenous	0.0299	0.0845	0.0875	0.2162	0.0792	0.2154	0.0436	0.1188	0.0891	0.2751	0.1811	0.4510	0.4668	0.9065	0.7350	0.9910
	NoEngFr	0.0296	0.0766	0.0485	0.1408	0.0167	0.0654	0.0125	0.0566	0.0171	0.0768	0.0162	0.0799	0.0207	0.1106	0.1237	0.3575
	NoSecED	0.1015	0.1817	0.1254	0.2131	0.1995	0.3241	0.1665	0.2657	0.1898	0.2989	0.1973	0.3273	0.2869	0.4839	0.5116	0.7725
	PubTrans	0.1613	0.3018	0.0746	0.2079	0.0575	0.1659	0.0461	0.1518	0.0114	0.0436	0.0212	0.0842	0.0191	0.0959	0.0469	0.1998
Housing Conditions (VH)	MntnAge	0.2683	0.3927	0.3142	0.4599	0.3217	0.4439	0.3629	0.4871	0.3396	0.4502	0.4032	0.5524	0.2959	0.4720	0.3280	0.5061
	NonResHa	0.0083	0.0345	0.0224	0.0689	0.0177	0.0624	0.0049	0.0277	0.0146	0.0538	0.0203	0.0752	0.0392	0.1518	0.0874	0.2659
	NSuitHouse	0.0764	0.1694	0.0568	0.1352	0.0683	0.1599	0.0561	0.1333	0.0623	0.1732	0.0604	0.1767	0.1366	0.3475	0.2989	0.5695
	PopHa	0.0102	0.0254	0.1553	0.2799	0.1085	0.2106	0.0463	0.1302	0.0346	0.0927	0.0285	0.0727	0.0022	0.0317	0.1379	0.3024
	Pre1975	0.4865	0.7904	0.4506	0.7242	0.5233	0.7650	0.4950	0.6733	0.5234	0.7151	0.5083	0.7204	0.3034	0.6077	0.2928	0.5121
Financial Agency (VE)	OneIncHshld	0.5663	0.6973	0.4868	0.6413	0.6131	0.7320	0.6402	0.7513	0.6347	0.7384	0.6450	0.7517	0.6769	0.8307	0.4413	0.6089
	Retail	0.2256	0.3232	0.1268	0.1851	0.1330	0.1936	0.2663	0.3929	0.2140	0.3337	0.1133	0.1787	0.1278	0.2751	0.3249	0.5192
	ShltrGT30	0.2640	0.3995	0.2936	0.4610	0.2627	0.4059	0.2824	0.4133	0.2666	0.4013	0.2825	0.4341	0.3310	0.4808	0.4308	0.6832
	Unemployed	0.1757	0.2783	0.2228	0.3576	0.1776	0.2932	0.1661	0.2835	0.1489	0.2612	0.2007	0.3425	0.1909	0.3545	0.3752	0.5508
	WorkPart	0.4667	0.5616	0.5731	0.7010	0.5276	0.6434	0.4574	0.5828	0.4211	0.5211	0.5370	0.6662	0.4208	0.5648	0.5251	0.6916

APPENDIX C: REGIONAL DISPARITIES BY LAND TENURE

SVItn_CordilleraStats

		Metropolitan									Rural						Remote					
		SF Residential			MF Residential			Mixed Residential			SF Residential			Mixed Residential			SF Residential			Mixed Residential		
		CAD	CORD	VAR	CAD	CORD	VAR	CAD	CORD	VAR	CAD	CORD	VAR	CAD	CORD	VAR	CAD	CORD	VAR	CAD	CORD	VAR
Non-Indigenous	Financial Agency	1.1	1.1	1.0	1.3	1.2	1.0	1.2	1.0	0.9	1.2	1.3	1.1	1.2	1.3	1.1	1.2		0.0	1.0		0.0
	Housing Conditions	1.5	1.5	1.0	2.0	2.4	1.2	1.7	1.8	1.1	1.5	1.4	1.0	1.4	2.1	1.5	1.8	2.0	1.1	1.3	3.4	2.5
	Individual Autonomy	1.8	1.9	1.0	2.8	3.0	1.1	2.2	3.1	1.4	2.1	2.7	1.3	2.1	2.6	1.3	1.9		0.0	3.2	3.0	0.9
	Social Capital	2.6	2.7	1.0	4.8	4.8	1.0	3.3	3.4	1.0	2.9	3.1	1.1	2.8	3.4	1.2	2.3	2.3	1.0	2.2	1.7	0.8
Indigenous	Financial Agency	1.0	1.0	1.0				1.0	1.0	1.0	1.2	1.3	1.1	1.0		0.0	1.5	1.7	1.1	1.0		0.0
	Housing Conditions	1.4	1.3	0.9	1.7	1.7	1.0	2.3	2.7	1.2	1.5	1.4	0.9	1.3	5.0	4.0	1.4	2.0	1.4	1.2	3.0	2.5
	Individual Autonomy	2.8	2.3	0.8	3.0	3.5	1.2	2.1	1.9	0.9	4.5	3.2	0.7	2.6	2.3	0.9	3.2	2.3	0.7	3.0	2.7	0.9
	Social Capital	4.4	3.8	0.9	5.7	5.0	0.9	4.5	4.4	1.0	5.4	3.8	0.7	3.6	4.1	1.1	4.5	4.1	0.9	3.9	4.4	1.1

SVItn_PrairiesStats

		Metropolitan									Rural						Remote					
		SF Residential			MF Residential			Mixed Residential			SF Residential			Mixed Residential			SF Residential			Mixed Residential		
		CAD	PRA	VAR	CAD	PRA	VAR	CAD	PRA	VAR	CAD	PRA	VAR	CAD	PRA	VAR	CAD	PRA	VAR	CAD	PRA	VAR
Non-Indigenous	Financial Agency	1.1	1.1	1.0	1.3	1.3	1.0	1.2	1.0	0.8	1.2	1.2	1.0	1.2	1.2	1.0	1.2	1.1	0.9	1.0	1.0	1.0
	Housing Conditions	1.5	1.5	1.0	2.0	1.8	0.9	1.7	1.9	1.1	1.5	1.4	0.9	1.4	1.3	0.9	1.8	2.1	1.2	1.3	1.3	1.0
	Individual Autonomy	1.8	1.8	1.0	2.8	2.3	0.8	2.2	1.7	0.8	2.1	2.1	1.0	2.1	2.0	1.0	1.9	1.4	0.7	3.2	2.2	0.7
	Social Capital	2.6	2.9	1.1	4.8	4.7	1.0	3.3	3.3	1.0	2.9	2.9	1.0	2.8	2.6	0.9	2.3	1.9	0.8	2.2	2.0	0.9
Indigenous	Financial Agency	1.0	1.0	1.0				1.0		0.0	1.2	1.2	1.0	1.0	1.0	1.0	1.5	1.5	1.0	1.0		0.0
	Housing Conditions	1.4	2.0	1.4	1.7		0.0	2.3		0.0	1.5	1.5	1.0	1.3	1.1	0.8	1.4	2.3	1.6	1.2	1.0	0.8
	Individual Autonomy	2.8	3.7	1.3	3.0		0.0	2.1		0.0	4.5	5.0	1.1	2.6	2.4	0.9	3.2	3.7	1.2	3.0	4.8	1.6
	Social Capital	4.4	6.4	1.5	5.7	7.0	1.2	4.5	5.2	1.2	5.4	6.0	1.1	3.6	3.5	1.0	4.5	5.3	1.2	3.9	4.4	1.1

SVItn_Central

		Metropolitan									Rural						Remote					
		SF Residential			MF Residential			Mixed Residential			SF Residential			Mixed Residential			SF Residential			Mixed Residential		
		CAD	CENT	VAR	CAD	CENT	VAR	CAD	CENT	VAR	CAD	CENT	VAR	CAD	CENT	VAR	CAD	CENT	VAR	CAD	CENT	VAR
Non-Indigenous	Financial Agency	1.1	1.1	1.0	1.3	1.3	1.0	1.2	1.2	1.0	1.2	1.1	0.9	1.2	1.1	0.9	1.2	1.1	0.9	1.0	1.0	1.0
	Housing Conditions	1.5	1.4	0.9	2.0	1.9	1.0	1.7	1.6	0.9	1.5	1.5	1.0	1.4	1.5	1.1	1.8	1.3	0.7	1.3	1.8	1.4
	Individual Autonomy	1.8	1.7	0.9	2.8	2.8	1.0	2.2	2.1	1.0	2.1	2.0	1.0	2.1	2.0	1.0	1.9	3.0	1.6	3.2	3.7	1.2
	Social Capital	2.6	2.4	0.9	4.8	4.8	1.0	3.3	3.3	1.0	2.9	2.9	1.0	2.8	3.2	1.1	2.3	3.4	1.5	2.2	3.0	1.4
Indigenous	Financial Agency	1.0	1.0	1.0				1.0		0.0	1.2	1.0	0.8	1.0		0.0	1.5	1.0	0.7	1.0	1.0	1.0
	Housing Conditions	1.4	1.1	0.8	1.7		0.0	2.3	1.5	0.7	1.5	1.3	0.9	1.3	1.0	0.8	1.4	2.0	1.4	1.2		0.0
	Individual Autonomy	2.8	3.4	1.2	3.0		0.0	2.1	3.2	1.5	4.5	3.1	0.7	2.6	3.0	1.2	3.2	3.0	0.9	3.0	2.0	0.7
	Social Capital	4.4	3.9	0.9	5.7		0.0	4.5	3.8	0.8	5.4	4.2	0.8	3.6	3.3	0.9	4.5	5.0	1.1	3.9	4.0	1.0

SVItn_Maritimes

		Metropolitan									Rural						Remote					
		SF Residential			MF Residential			Mixed Residential			SF Residential			Mixed Residential			SF Residential			Mixed Residential		
		CAD	MARIT	VAR	CAD	MARIT	VAR	CAD	MARIT	VAR	CAD	MARIT	VAR	CAD	MARIT	VAR	CAD	MARIT	VAR	CAD	MARIT	VAR
Non-Indigenous	Financial Agency	1.1	1.2	1.1	1.3	1.5	1.2	1.2	1.4	1.2	1.2	1.4	1.2	1.2	1.4	1.2	1.2	2.1	1.8	1.0	2.0	2.0
	Housing Conditions	1.5	1.7	1.1	2.0	2.3	1.2	1.7	1.9	1.1	1.5	1.8	1.2	1.4	1.7	1.2	1.8	2.4	1.3	1.3	1.5	1.2
	Individual Autonomy	1.8	2.1	1.2	2.8	3.0	1.1	2.2	2.2	1.0	2.1	2.7	1.3	2.1	2.7	1.3	1.9	2.7	1.4	3.2	2.8	0.9
	Social Capital	2.6	2.4	0.9	4.8	4.4	0.9	3.3	3.2	1.0	2.9	2.9	1.0	2.8	3.0	1.1	2.3	3.0	1.3	2.2	3.3	1.5
Indigenous	Financial Agency	1.0	1.0	1.0				1.0		0.0	1.2	1.0	0.8	1.0		0.0	1.5	2.0	1.3	1.0		0.0
	Housing Conditions	1.4	2.1	1.5	1.7		0.0	2.3	2.0	0.9	1.5	1.8	1.2	1.3	1.0	0.8	1.4		0.0	1.2	2.0	1.7
	Individual Autonomy	2.8	2.5	0.9	3.0		0.0	2.1	2.0	1.0	4.5	4.5	1.0	2.6	5.0	1.9	3.2	3.3	1.0	3.0		0.0
	Social Capital	4.4	4.3	1.0	5.7	8.0	1.4	4.5	3.8	0.8	5.4	4.9	0.9	3.6	3.3	0.9	4.5	2.8	0.6	3.9		0.0

SVItn_North

		Metropolitan									Rural						Remote					
		SF Residential			MF Residential			Mixed Residential			SF Residential			Mixed Residential			SF Residential			Mixed Residential		
		CAD	NORTH	VAR	CAD	NORTH	VAR	CAD	NORTH	VAR	CAD	NORTH	VAR	CAD	NORTH	VAR	CAD	NORTH	VAR	CAD	NORTH	VAR
Non-Indigenous	Financial Agency	1.1	1.0	0.9	1.3		0.0	1.2	1.0	0.8	1.2		0.0	1.2		0.0	1.2	1.2	1.0	1.0	2.0	2.0
	Housing Conditions	1.5	1.6	1.1	2.0	1.0	0.5	1.7		0.0	1.5		0.0	1.4		0.0	1.8	1.2	0.7	1.3	1.0	0.8
	Individual Autonomy	1.8	2.3	1.3	2.8	2.8	1.0	2.2	2.0	0.9	2.1		0.0	2.1		0.0	1.9	3.6	1.9	3.2	4.8	1.5
	Social Capital	2.6	3.5	1.3	4.8	5.5	1.1	3.3	4.2	1.3	2.9		0.0	2.8		0.0	2.3	2.7	1.2	2.2	3.6	1.6
Indigenous	Financial Agency	1.0	1.0	1.0				1.0		0.0	1.2		0.0	1.0		0.0	1.5	1.5	1.0	1.0		0.0
	Housing Conditions	1.4	1.4	1.0	1.7		0.0	2.3		0.0	1.5		0.0	1.3		0.0	1.4	1.0	0.7	1.2	1.0	0.8
	Individual Autonomy	2.8	2.0	0.7	3.0	2.0	0.7	2.1		0.0	4.5		0.0	2.6		0.0	3.2	3.0	0.9	3.0		0.0
	Social Capital	4.4	3.7	0.8	5.7		0.0	4.5	6.5	1.4	5.4		0.0	3.6		0.0	4.5	2.7	0.6	3.9	2.0	0.5

APPENDIX D: OPEN-SOURCE DATA

APPENDIX D-1: DATA REPOSITORIES ON THE OPENDRR PLATFORM

The national physical exposure model for all settled areas in Canada is made available as an open-source geospatial dataset in accordance with the Government of Canada's Roadmap for Open Science and related policies that govern access to and the distribution of Open Data (Government of Canada 2018, 2017; Office of the Chief Science Advisor of Canada 2020). The purpose is to support those tasked with natural hazard risk reduction activities and policy development in Canada, and support collaboration with public, private, and academic sector organizations who may share an interest in co-developing future iterations of the model. Primary end users are expected to include:

- Emergency planners working at local and regional scales who need to know the numbers of people, buildings, and critical assets likely to be impacted by future disaster events for the purpose of establishing operational capacities needed to manage both immediate response and post-disaster recovery efforts.
- Land use planners who may need additional information about representative building archetypes to support natural hazard risk assessments and the development of actionable mitigation/adaptation strategies that enhance disaster resilience and the prospects for sustainable development at the community level.
- Private sector engineering and planning consultants who undertake risk assessments and/or disaster risk reduction planning activities on behalf of local authorities and who may not have the mandate or resources needed to independently develop detailed physical exposure models.
- Researchers involved in modeling other aspects of the built environment such as greenhouse gas emissions, energy use, and other dimensions of land cover change that might benefit from a national level assessment of land use and associated building archetypes developed as part of this study.

The physical exposure model, as well as accompanying metadata, is shared through OpenDRR and the Federal Geospatial Platform (FGP). OpenDRR (https://github.com/OpenDRR/national-human-settlement) is a publicly available repository of datasets and software developed by Natural Resources Canada (Journeay et al., in prep) that facilitate a national assessment of earthquake risks. Information included within this repository includes the software that has been developed to carry out the assessment, input datasets to support the assessment such as the national physical exposure model, and outputs datasets such as a repository of earthquake scenarios. The repository is hosted on GitHub (i.e., a provider of internet hosting for software development and version control) and provides a means for open data access, collaboration, and transparency. The FGP (https://open.canada.ca/en/open-maps) is a collaborative online environment hosted by the Government of Canada, which consists of authoritative geospatial data, services, and applications built on a shared infrastructure that will enable the government's most relevant information to be managed spatially, analyzed, and displayed in a visual context to enhance decision-making support of government priorities.

On both platforms, the current version of the physical exposure model is provided in two formats:

- According to settled areas (i.e., polygons), which are areas that approximately delineate clusters of buildings across Canada and associated land-use patterns. In cities, settled area boundaries generally correspond with census dissemination areas (Statistics Canada, 2016), but in rural areas where census dissemination areas can span more than thousands of square kilometers, these boundaries approximately correspond to areas where buildings are situated. Summary statistics about buildings and populations within each settled area boundary are provided to support with understanding the general patterns of physical exposure across Canada at the neighborhood scale.

- According to building archetypes (i.e., points) within settled areas. These groups are represented as point locations at the centroid of the corresponding settled area, and each settled area can have multiple groups of buildings corresponding to different building archetypes present within that area.

The data is provided in digital as geopackages (.gkpg), which are geospatial files that can be opened with most geographic information systems (GIS). Each dataset has an accompanying data dictionary that provides a detailed summary of attributes.

The physical exposure model is designed to be a living database that establishes a baseline for describing physical characteristics of the built environment at the community level for all regions in Canada. It will likely be updated on a regular basis with future releases of national census data and will be refined with more detailed site-level building inventories as they become available for use in the public domain.

We note that the current version of the model is subject to limitations and there are some uncertainties at very local scales (e.g., at the scale of individual settled areas). We encourage end users to provide our team with feedback about model use, the accuracy of information at detailed scales, as well as any site-specific adjustments that are proposed. Any site-level information obtained from the community of end users can help our team better calibrate future iterations of the model and reduce uncertainties for communities across Canada. If you wish to provide feedback, please contact the authors of this report.