DEVELOPING TOOLS TO SUPPORT OLDER ADULTS DURING CLIMATE-RELATED EMERGENCIES

by

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Author's Declaration

This thesis consists of material all of which I authored or co-authored: see Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

Gustavo Sigrist Betini was the sole author for Chapters 1 and 5, which were written under the supervision of Professor John P. Hirdes and were not written for publication. This thesis consists in part of three manuscripts written for publication.

The exceptions to sole authorship of material are as follows:

Chapter 2, 3, and 4: as the lead author, I conceived the study, conducted all analyses, interpreted the results and wrote the first draft of the manuscript under the supervision of Dr. John P. Hirdes. Dr. Chirstopher M. Perlman, Dr. Goerge Heckman, and Dr. Paul Hébert discussed the ideas and commented on subsequent drafts of the study.

Abstract

What makes a person more likely to experience adverse health outcomes caused by extreme weather events? Can we identify those individuals at high risk before an extreme event happens? Natural hazards can lead to death and physical injury, as well as non-specific psychological distress, post-traumatic stress disorder, depression, and anxiety. By now, we have a good understanding of the main outcomes and some group-level risk factors associated with these events, such as low socioeconomic status, certain health conditions, and older age. These risk-factors are often used to develop vulnerability indices that can identify people at risk of adverse outcomes during an extreme event. However, these indices can be highly inefficient because not all individuals within each group live with the same vulnerability. Thus, it is essential that we use real-time, clinical, and demographic information to identify individuals at risk before an extreme weather event happens instead of relying on general group membership. The goals of this thesis are a) to understand the risk and protective factors that place older adults at higher risk of adverse health outcomes caused by natural hazards, and b) to develop indices to identify those individuals at highest risk. To achieve these goals, the thesis uses clinical assessments and focuses on acute, short-term health complications often a result of heat-related events and wildfire smokes. The thesis is divided in 3 studies and all studies used data from the interRAI Home Care and interRAI Contact Assessment instruments, which are comprehensive assessments to evaluate the person's health needs and strengths.

Study 1 is an empirical investigation of the risk factors that place older adults at odds of living in homes with inadequate heating or cooling. The study uses longitudinal data and generalized estimating equations to explore risk factors such as demographic and social-economic characteristics as well as availability and quality of informal caregiver support for older adults with complex medical needs in Canada. These factors were used to identify geographic locations in Ontario with high percentages of home care clients living with inadequate heating or cooling at home. This is the first study that addresses the risks and protective factors associated with the thermal environment in home care clients, which is a population at high risk of adverse health outcomes during heat waves and cold spells.

Study 2 presents a new index to identify individuals that could be at risk of health complications during extreme weather events. The Brief Risk Index (BRI) was derived from data elements present in a screener that supports home care intake from community and hospital. It focuses on items indicating that individuals receiving home care services would have difficulty evacuating their homes during a time of crisis (e.g., cognitive impairment and difficulty performing activities of daily living). When compared with another tool that has been used in real-life situations, the BRI showed similar performance but with less items. This is the first index that targets the whole home care population in Canada, not only those receiving long-term services. Therefore, the BRI can be a game changing in emergency preparedness because of its efficiency and large target population.

Study 3 uses a similar approach as in Study 2 but focuses on home care clients at high risk of health complications caused by poor air quality. While the BRI is a more general tool, the

Cardiorespiratory Vulnerability index (CRV) contains 16 items from a standardized assessment for home care clients and includes clinical characteristics often associated with negative health outcomes caused by poor air quality, such respiratory and heart diseases. This is the first index related to risks associated with air quality available in vulnerable populations in Canada, and one of the few worldwide. The study makes an important contribution to public health because climate change is accelerating the conditions under which wildfires and their adverse effects on air quality are more likely to happen.

Identifying individuals at high risk before an extreme weather event happens is a pressing problem in our society. This is particularly important today because of our aging population combined with the increase of the frequency, duration, and severity of extreme weather events caused by climate change. This thesis advances our knowledge of the risk and protective factors associated with extreme weather events and provides ready-to-use predictive tools to identify individuals that are more likely to experience health complications. The indices developed here can also be used to identify regions (neighborhoods) with higher concentration of people at risk, meaning that long-term, climate adaptation programs can be applied not only for individuals but also for geographic regions. Thus, the results from the three studies in this thesis represent a unique perspective in how our public health system could prepare for climate change, avoid negative outcome to vulnerable populations and show new directions for research.

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Dedication

To Raquel.

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List of Abbreviations

AB	Alberta
ADL	Activities of daily living
CRV	Cardiorespiratory Vulnerability index
BRI	Brief Risk Index
BC	British Columbia
CHESS	Changes in Health, End Stage Disease and Signs and Symptoms
CI	Confidence interval
CPS	Cognitive Perform Scale
COPD	Chronic obstructive pulmonary disease
HR	Hazard ratio
IADL	Instrumental activities of daily living
interRAI HC	interRAI Home Care assessment
interRAI-CA	interRAI Contact Assessment
LHIN	Local health integration networks
NL	Newfoundland and Labrador
ON	Ontario
OR	Odds ratio
PM2.5	Particles with an aerodynamic diameter below 2.5 μm
PM10	Particles with an aerodynamic diameter below 10 μm

US	United States of America
VPR	Vulnerable Persons at Risk scale
WHO	World Health Organization
YT	Yukon Territory

Chapter 1

General Introduction

1.1 The relevance of extreme weather events to public health

According to the World Health Organization (WHO), climate change is the greatest health threat of the 21st century (World Health Organization, 2024). This statement is based on two facts. First, climate change has increased the frequency, severity, and duration of extreme weather events (IPCC, 2023). Second, these events can negatively affect human health (World Health Organization, 2024).

In the last 50 years, the number of natural hazards increased about five times worldwide (IEP, 2020; Keim, 2020; World Health Organization, 2024). In Canada, the number of days where the maximum temperature exceeded 30°C has increased three times, and the area burned by wildfires doubled from the 1970s to the 2000s (Berry & Schnitter, 2022; Jain et al., 2024). In addition, there has been an expansion of zoonotic diseases (e.g., Lyme disease) because of warmer conditions (Berry & Schnitter, 2022). Almost 50% of Canadians indicated that they had a personal experience with natural hazards in a survey conducted in 2014, and 75% of those indicated that the disaster was large enough to disrupt their regular daily routine (Ibrahim, 2016).

Because of these events, essential elements necessary for a good health are being threatened (e.g., safe shelter and clean air; World Health Organization, 2024). It is now estimated that climate change will cause approximately 250,000 additional deaths per year globally between 2030 and 2050, with costs around US$ 2-4 billion per year by 2030 (World Health Organization, 2024). Air pollution will cause 7 million deaths per year and between 2 to 3.5 billion people will reside in areas that are unlivable due to heat (Nikitin, 2021; World Health Organization, 2023a).

These estimates should not be surprising given the frequency of natural hazards and their adverse health effects. From 1969 to 2018, there were 22,173 disasters (including not only natural, but also man-made such as terrorism and technological disasters), an average of 443 disasters per year or 1.2 disasters per day. About 50% of these disasters were climate related and they were responsible for 95% of all people affected, causing over 2 million deaths and 4 million cases of diseases with over 7

billion people requiring immediate assistance (Keim, 2020). Natural hazards account for roughly 45% of all reported deaths and 74% of all reported economic losses from all types of disasters combined (IEP, 2020; WMO, 2021). Floods (47%) and tropical cyclones (30%) were the most common events. Tropical cyclones, droughts, and floods were responsible for the highest number of deaths (39%, 34% and 16%, respectively) and cold weather, floods, and tropical cyclones caused the highest morbidity (47%, 31%, and 18%, respectively; Keim, 2020). On average, all disasters combined killed 115 people and caused US$ 202 million in losses daily (IEP, 2020; WMO, 2021).

The adverse health effects of natural hazards and climate change led the WHO to recently declare the development of more climate-resilient health systems as their first major goal (World Health Organization, 2024). Moreover, adaptation and increased resilience to climate change are common targets in many of the UN Sustainable Development Goals, such as Goal 1 - End poverty in all its forms everywhere; Goal 2 - End hunger, achieve food security and improved nutrition and promote sustainable agriculture; Goal 11-Sustainable Cities and Communities; and Goal 13 - Climate Action (United Nations, 2023). Adaptation is particularly important when considering that some people are disproportionally affected by climate change, such as older adults, children, indigenous people (First Nations, Inuit, and Métis peoples in Canada), low income individuals, and people with chronic illnesses (Neria et al., 2008; Rhodes et al., 2010; Goldmann & Galea, 2014; North, 2017; Ursano et al., 2017; Berry & Schnitter, 2022). This means that without adaptation, these groups will be more affected than the general population. Thus, it is paramount that we develop a public health strategy to adapt our current public health system to this new scenario and promote resilience of those most affected (Noji, 2000; Watts et al., 2015). This thesis contributes to these goals by improving our understanding of the risk factors associated with adverse health outcomes caused by natural hazards in a population living with vulnerability and by developing empirically based indices that could be used to identify individuals at risk of adverse health outcomes.

1.2 The theoretical foundations

The theoretical investigations of the effects of natural hazards on human health started with a purely hazard-oriented approach, where the goal was to understand where events happened and who would be more sensitive to natural hazards (e.g., older adults and children; Schneiderbauer & Ehrlic, 2004). One example is the risk-hazard conceptual framework, which states that the impact of a natural hazard is a function of the exposure of broad classes of individuals (e.g., older adults) to a given hazard and their sensitivity (Ciurean et al., 2013; Turner et al., 2003). One criticism of this approach is that there are additional social, cultural, and political factors that could make an individual even more likely to experience adverse effects caused by hazards (i.e., some individuals are more vulnerable; Hilhorst & Bankoff, 2004; Birkmann, 2006; Hilhorst & Bankoff, 2022). As a response to this criticism, new theoretical frameworks emerged to explicitly introduced the idea of vulnerability. For example, the pressure-and-release model developed in the 1990s (Blaikie et al., 1994; Turner et al., 2003) equates risk with perturbation, added to the vulnerability of individuals, where vulnerability encompasses the social, political, and economic conditions that make exposure unsafe (Turner et al., 2003). The hazards-of-place model of vulnerability is another well-known example of the introduction of the idea of vulnerability in disaster research (Cutter, 1996; Cutter et al., 2003). The main goal of this model is to equate vulnerability to the social and demographic characteristics and risk perception of those at risk, in addition to the hazard exposure and sensitivity (Cutter, 1996; Cutter et al., 2003).

While social sciences perspective informed the development of theoretical approaches to disaster research in the 1980s and 1990s, ecological ideas (including human ecology) drove the next round of developments (Turner et al., 2003; Cutter et al., 2008). In the 2000s, the concept of vulnerability was expanded to include the different ways by which humans and their natural environment are tightly interconnected (this feedback loop between natural and humans is a main concept in human ecology; Hawley, 1986). This means that nature affects humans (natural hazards), but

humans can also affect nature (climate change), which can in turn further affect humans (increase in the frequency of natural hazards; Turner et al., 2003). Moreover, there was an increasing emphasis in ecological theories of resilience to promote adaptive capacity of individuals, populations, and communities (Cutter et al., 2008).

One example of this new theoretical development is the coupled human-environment system, where vulnerability is a function of the exposure, sensitivity and resilience of the individuals, populations, and communities affected (Turner et al., 2003). Although there are many ways by which these terms are defined, broadly speaking, sensitivity refers to proneness to hazards or the degree to which a system is modified or affected by perturbations. Adaptive capacity refers to adaptation/resilience, or the ability of a system to evolve to accommodate environmental hazards or policy change. Exposure refers to the idea that people are vulnerable to an adverse experience or event and is often defined as the nature and degree to which a system involves environmental stress (e.g., the magnitude, frequency, duration and areal extent of the hazard; Adger, 2006).

Today, most if not all conceptual frameworks in disaster research incorporate the idea of vulnerability and equates vulnerability to at least one of these three elements: exposure, sensitivity, and adaptive capacity (Turner et al., 2003; Adger, 2006; Cheng et al., 2021). This is also true in the application of the concept of vulnerability, i.e., the indices created to measure and identify the most vulnerable. For example, in a recent literature review, the most common theoretical framework used to develop heat-related vulnerability indices was the ‘population vulnerability to environmental hazards’ (30% of the articles), which states that vulnerability is a function of sensitivity, exposure, and adaptive capacity (Cheng et al., 2021).

Although there has been progress in the theory and application of the concept of vulnerability, there are also several criticisms around the use of these approaches. These include the lack of clear

definition, and the fact that indices created based on these models are too broad to identify those at risk (Birkmann, 2006; Ciurean et al., 2013; Wolf et al., 2013).

1.2.1 What is vulnerability and why it matters?

Vulnerability is a key concept in disaster research and health emergency that helps to identify those individuals, populations or communities who are most likely to experience adverse health outcomes during natural hazards. It also pertains to the need to adapt our public health system to the health effects of climate change (Birkmann, 2006; Wolf et al., 2013; Wisner, 2016). Identifying those who are in danger allows governments and public health agencies to take steps towards building a more resilient community.

Despite the relevance of the concept of vulnerability to disaster research, there is no shortage of criticism around the definition and use of vulnerability (Levine, 2004; Thywissen, 2006; Birkmann, 2006; Schroeder & Gefenas, 2009; Katz et al., 2020). These criticisms can be grouped into two different non-exclusive categories: a) problems with definition, and b) the vague nature of the group-membership approach when trying to identify individual living with vulnerability.

1.2.1.1 Vulnerability is not clearly defined

Maybe the most prominent issue with vulnerability is the lack of clear definition. For many, vulnerability cannot be defined (Hurst, 2008), or that attempts to define vulnerability created a "Babelonian confusion" (Thywissen, 2006) because of the lack of clarity in key terms. Moreover, the application of the vulnerability concept has been called a paradox because one cannot measure something that is not defined (Birkmann, 2006).

One of the main reasons for these criticisms is the fact that the term vulnerability has been used by different disciplines in different contexts (Cutter, 1996; Levine, 2004; Adger, 2006; Wolf et al., 2013). For example, vulnerability is common in biomedical research, where the main goal is to identify those who could be target for clinical trials (Schroeder & Gefenas, 2009) and in social sciences, where

the concern is with people who might not be in position to make informed decisions (Brown et al., 2017).

It is also the case that some fields have concepts that are very similar to the ones used in disaster research but with a different terminology. For instance, in gerontology, there has been much debate around the idea of frailty to identify older adults with reduced function that are more likely to experience adverse health outcomes (Clegg et al., 2013; Heckman et al., 2021). It is interesting that, as in the case of vulnerability, there are many discussions about the definition of frailty (Rockwood, 2005; Proietti & Cesari, 2020; Zhao et al., 2023) and how to measure it (Heckman et al., 2021; Zhao et al., 2023).

In disaster research, there have been attempts to solve the definition problem by looking at the common elements present in different definitions of vulnerability, such as sensitivity, adaptive capacity, and exposure (Adger, 2006; Schroeder & Gefenas, 2009; Hufschmidt, 2011; Wisner, 2016). Although this seems to be a promising approach, it only transfers the definition problem from vulnerability to its components. This is because defining exposure, sensitivity and adaptive capacity has also been difficult (Wolf, 2010; Wolf et al., 2013) and it is not uncommon that the same metric is used to measure more than one element of the concept of vulnerability.

1.2.1.2 Reliance on broad group membership to define vulnerability

Most tools available to identify vulnerable individuals and groups use a broad group membership strategy. These vulnerability measures are often based on broad social, economic, physical, and environment indicators (Centers for Disease Control and Prevention, 2015; Levine, 2004). For example, The Center for Disease Control and Prevention identify groups living with vulnerability based on 4 domains: socioeconomic status (e.g., below poverty line, no high school diploma, unemployed), household composition and disability (e.g., age, single-parent), minority status,

language, housing (e.g., mobile homes, crowding), and transportation (e.g., no vehicle; Centers for Disease Control and Prevention, 2015).

One potential problem with this approach is that during extreme-weather events, when public health agencies and governments need to deploy resources to support people, group membership can be very ineffective. Heterogeneity of individuals within each group is inevitable. For example, not all older adults or children are vulnerable to the consequences of heat waves (Foster, 1988; Forster et al., 2001; Levine, 2004; Kailes & Enders 2007). This means that vulnerability indices are often imprecise and can over-identify a larger number of individuals that rarely require assistance (Forster et al., 2001). This can make the application of interventions largely inefficient and sometimes logistically impossible (Forster et al., 2001; Levine, 2004; Kailes & Enders, 2007; Schroeder & Gefenas, 2009). In addition, while demographic reports on the populations at broad risk may be informative for general policy purposes, such reports cannot identify specific individuals who need help during a natural disaster.

1.2.2 One solution: the individual-empirical approach

One of the main reasons for the criticisms around the concept of vulnerability is that vulnerability is not a predetermined state, as assumed in most, if not all uses of the concept. Instead, vulnerability is context-dependent and dynamic (Vogel & O'Brien, 2004; Birkmann, 2006; Cutter et al., 2008). For example, individuals who are considered vulnerable might change in time and space and in relation to different threats. A child might be vulnerable to the effects of a heat wave today, but not in 2 or 3 years. A person might be vulnerable to a wildfire, but not to a flood or a heat wave (Cardona, 2013). Someone might be vulnerable because of a physical problem (e.g., coronary disease) but not vulnerable to mental health problems (e.g., no history of depression or post-traumatic stress disorder).

One way to minimize this problem is to identify the characteristics of individuals that place them at risk of adverse outcomes. This more analytical approach uses specific attributes of individuals to identify those who live with vulnerability (DeBruin, 2004). For example, functional needs,

communication impairments, medical needs, and cognitive factors such as dementia may affect the person's ability to respond to environmental hazards (Kailes & Enders, 2007).

This thesis uses this analytical approach as a basis for identifying those living with vulnerabilities that could place than in danger during an extreme weather event instead of relying on the historically broad conventions based on exposure, sensitivity, and adaptive capacity. One of the benefits of this individual-empirical framework is that, with enough data, one can calculate specific individual-level probabilities of risk. These probabilities are calculated at given point in time and space, and not in an absolute, fixed way. One example of this approach that has already being applied successfully is the Vulnerable Persons at Risk algorithm (van Solm et al., 2017).

1.2.2.1 The Vulnerable Persons at Risk algorithm

The Vulnerable Persons at Risk scale (VPR) was developed to identify home care clients that might be at high risk of an adverse health outcome caused by a natural hazard. The VPR is based on the interRAI Home Care assessment (interRAI HC; van Solm et al., 2017) and is a valid and reliable algorithm that uses real-time information and allows for a rapid identification of individuals living in the community. The VPR considers functional status, medical complexity, sensory-perceptual problems, cognition, social isolation, and dependence on medical technologies. The algorithm allows emergency responders to prioritize and allocate resources that can help those at risk during a natural hazard. A similar version of the VPR has already been successfully used in real life situation (earthquake in New Zealand in 2011; Health New Zealand, 2011) and the VPR has been shown to have a strong association with mortality, long-term care admission, and hospitalization in the context of an ice storm event in Toronto, Canada (van Solm et al., 2017).

Despite the potential for the use of the VPR in emergency preparedness, the VPR has a few limitations. First, the algorithm can only be applied for those assessed with the interRAI HC receiving supports for more than about 2 months (i.e., long-term home care clients). Despite the interRAI HC

being a broad, clinician-led assessment used in home care, many other vulnerable older adults living in the community are not assessed with the interRAI HC and could also be at risk. Second, the VPR was developed in the context of earthquakes and tested in relation to an ice storm. However, the algorithm has never been tested with other natural hazards like heat events and air quality problems related to forest fires, which may need different solutions. Thus, there is a need to develop new indices to prepare our public health system to deal with a broader range of extreme weather events.

1.3 Background: what are the adverse health outcomes caused by extreme weather events?

Natural hazards have been shown to have serious adverse consequences for physical and mental health. There is no shortage of recent examples that support this statement. The 2023 earthquake that affected Turkey and Syria resulted in more than 55,000 deaths, about four million people without homes, and 30 million people in need of immediate assistance (World Health Organization, 2023b; Mavrouli et al., 2023). In 1992, during a hurricane in Hawaii, there was an increase of almost 600% (1,353 people) in the number of people injured compared to the same period in the previous year (Hendrickson et al., 1997). The number of people with severe mental illness in New Orleans, USA doubled between 2003 and 2006 following the Hurricane Katrina (Kessler et al., 2006). In 2017, about 15% out of 1,510 study participants showed indications of major depression and anxiety disorders following devastating wildfires in Fort McMurray, Canada. These levels are about five times higher than the country average (Belleville et al., 2021). The prevalence of post-stress traumatic disorder was also about five times higher in Fukushima residents who experienced a severe tsunami compared to residents in two other cities in Japan that were not affected by the tsunami (Ben-Ezra et al., 2015).

1.3.1 The physical health burden of extreme weather events

Maybe the most severe health consequence of natural hazards are death and severe physical injury (e.g., brain damage and amputation). Some reports estimate that, in average, 40,000 to 50,000 people

die because of natural hazards every year (average for the last decades; Ritchie et al., 2022). However, these numbers can be misleading. As stated above, in 2023 a single event (the earthquake that affected Turkey and Syria), resulted in more than 55,000 deaths. In Canada, the decade average death associated with natural hazards in the 1990's was 13, jumping to170 in 2020 (a 1,239% increase), mainly caused by heat-related events (163 cases; Ritchie et al., 2022).

In addition to these most severe health outcomes, people who experience extreme weather events might develop other types of physical injuries. Pain, environmental exposures to chemical contaminants, and the spread of infections diseases are common in the time around a natural hazard (Beinin, 2012). The type of injury caused by extreme weather events varies greatly depending on the type of event. Earthquakes often cause limb, head, and torso injuries, while other types of natural hazards are linked to minor injuries, which can include cuts and lacerations (Ardagh et al., 2012; Bartholdson & von Schreeb, 2018). Flooding increases the risk of fecal-oral route transmitted diseases, which is not the case in earthquakes (except if there is infrastructure damage to sewer and water systems; Cook et al., 2008). It is also common that the risk of physical injuries persists during the clean-up phase after the earthquake has passed (Johnston et al., 2014).

Cardiovascular and respiratory diseases, hypertension, and diabetes are the most frequently reported long-term adverse health consequences of natural hazards (Cook et al., 2008; Beinin, 2012; Leppold et al., 2022). Wildfires are well-known for causing chronic respiratory conditions because of exposure to smokes and toxicant substances (Henderson et al., 2011; Brauer et al., 2012; Grant & Runkle, 2022). A study in 500 cities in the US from 2001 to 2005 found that extreme climate events were associated with poor self-rated physical health, high blood pressure, and asthma (Hahn et al., 2022).

Long-lasting effects on people's physical health may also occur mainly via the development or aggravation of chronic physical illnesses because of the disruption of public services (Galea et al.,

2007; Cook et al., 2008; Rhodes et al., 2010; Grant & Runkle, 2022; Hahn et al., 2022). For example, after the Hurricane Iniki in Hawaii in 1992, there was an increase in the number of asthma cases reported in hospitals and emergency departments because the power outrage stopped many asthma patients from using their home nebulizers (Hendrickson et al., 1997; Cook et al., 2008). Another interesting long-term effect of extreme weather events is the increase in physician visits (Bell et al., 2018), even when no specific problems can be found with the patients (van den Berg et al., 2005; Galea, 2007). This last problem may be related to the mental health effects of natural disasters, which will be discussed next.

1.3.2 The mental health burden of extreme weather events

Most people who are affected by natural hazards will be able to resume their lives at a later stage depending on the severity of the disaster and its consequences (Morganstein & Ursano, 2020). However, some individuals will experience non-specific psychological distress, increased health risk behaviours, and they might even develop psychopathologies. In some cases, the psychological distress associated with an environmental hazard may be resolved within days or weeks. On the other hand, more severe psychological disorders might persist for weeks to months or even years with the need for specific mental health interventions, including pharmacological and non-pharmacological treatments. Many of these mental health issues can appear within the first hours or days after a disaster, but some may appear later with long-lasting effects.

Nonspecific psychological distress or distress reactions (e.g., sleep disturbance) usually happen within hours or days after a disaster and are the most common mental health issue caused by natural hazards (Fan et al., 2017; Morganstein & Ursano, 2020; Tang et al., 2018). A recent systematic review found that insomnia (63%-72.5%) and nightmares (33.3%-46.5%) were the most prevalent sleep disturbances after wildfires (Isaac et al. 2021). A less common distress response is somatization, but

many studies have shown an increase in “medically unexplained complaints” (North 2017) in the weeks after a natural hazard.

Sometimes people engage in behaviours that pose health risks. It is believed that these behaviours emerge as a way to cope with emotions during times of distress, but these behaviours sometimes have a negative effect on mental health (Morganstein & Ursano, 2020). This can create a feedback loop that can be difficult to break (i.e., people change their behaviour to cope with a negative emotion, but this new behaviour causes more negative emotions). Common health risk behaviours presented by individuals after an extreme weather event are the increase in tobacco and alcohol consumption and increase in the use of illicit drugs (Flory et al., 2009; Beaudoin, 2011; Fullerton et al., 2013). However, the incidence of initiation of substance use by new users is less common (North et al., 2011).

Several other adverse behaviours have been linked to natural hazards, such as individual conflict and violence, especially among family members, difficulties balancing life and work, and even suicidality (North, 2017; Ursano et al., 2017). For example, a systematic review indicated an increase in suicide attempts after the 2011 Tōhoku earthquake and tsunami in Fukushima (Terayama et al., 2021).

Persistent psychiatric disorders are the least frequent adverse mental health outcome associated with disasters and sometimes the ones that take the longest to appear. However, they can cause substantial increases in morbidity and mortality and may require intensive treatments (Morganstein & Ursano, 2020).

The most common psychiatric disorders linked to extreme weather events are post-traumatic stress disorder (more recently acute stress disorder), mood disorders (e.g., major depressive disorder) and generalized anxiety disorder (Norris et al., 2002; Goldmann & Galea, 2014; North, 2017; Ursano et al., 2017; Morganstein & Ursano, 2020; Novia et al., 2020, Saeed & Gargano, 2022). Post-traumatic

stress disorder is often triggered by a feeling of horror or intense fear by those who experience traumatic experiences in life, such as natural disasters (Van der Kolk, 2000). Levels of post-traumatic stress disorder among the general population vary between 5-10% (Goldstein et al., 2016) while levels among those exposed to natural hazards are around 30% (Norris et al., 2002, Ursano et al., 2017). After an earthquake in Mexico in 2017, the prevalence of post-traumatic stress disorder was 35% (Zuñiga et al., 2019). Post-traumatic stress disorder among survivors of the hurricane Katrina in US was about 45% two months after the hurricane, stayed stable around 30% from seven months to 5 years post-disaster (Galea et al., 2007) and dropped to 17% after 12 years (Galea et al., 2007; Paxson et al., 2012; Raker et al., 2019).

It is important to note that exposure to extreme weather events could also lead to positive mental health outcomes both at the individual and community levels. Community bonding might increase because of shared experiences and increase in resources available to the community (Morganstein & Ursano, 2020). At the individual level, reports of personal growth and personal rebuilding are common and even levels of suicidality that usually increase after a natural hazard, have been reported to be lower in the few months after a disaster (Kessler et al., 2006). In some cases, closer relationships may develop with loved ones and there may be confidence that disaster victims can rebuild their lives (Kessler et al., 2006). However, this “honeymoon phase”, both at the individual and community levels, seems to last no more than a few months (Zunin & Myers, 2000; Madianos & Evi 2010; Kõlves et al., 2013), coinciding with the end of additional help and resources to the community (Madianos & Evi, 2010).

1.3.3 Risk factors

Although risk factors associated with extreme weather events vary by the type of the negative health outcome, there has been some common risk factors reported in the literature, such as low socioeconomic status, proximity and severity of the disaster (e.g., personal injury, witnessing loss of

life, specially of family members, and loss of property) and previous mental health problems, particularly post-traumatic stress disorder (Fothergill & Peek, 2004; Goldmann & Galea, 2014; North, 2017; Ursano et al., 2017). Many studies showed that individuals living in poor areas or without a stable job before the Hurricane Katrina were the ones with the worst negative mental health outcomes (Kessler et al., 2006; Neria et al., 2008; Morris & Deterding, 2016; Nguyen et al., 2023). Similar patterns have been found in other places, such as the floods in 2010-2011 in Queensland, Australia (Clemens et al., 2013) and the 2006 Typhoon Xangsane in Vietnam (Brown et al., 2013).

Other risk factors related to natural hazards include minority ethnic status, female gender, lack of social network or poor relationships, being single and having children (Kosatsky, 2005; Goldmann & Galea, 2014; North, 2017; Ursano et al., 2017). For some older adults, lack of a primary caregiver and isolation (e.g., living alone) are important risk factors (van Solm et al., 2017). Advanced age has also been identified as an important risk factors, but the specific role of age is not clear (Morganstein & Ursano, 2020). For example, some argue that the health problems usually associated with age, such as cognitive, visual and hearing impairment and mobility issues are more important than age *per se* (Vandentorren, et al. 2006; Morganstein & Ursano, 2020).

For older adults, cognitive problems can be both a risk factor (Adelman & Legg, 2010, Ojo & Juba, 2024; Peterson et al., 2024) and an outcome of an extreme weather event (Thompson & Vasefi 2025). As a risk factor, dementia can impair the ability to interpret risks associated with natural hazards, follow directions without assistance, and manage stress that comes with potential relocation. In more advanced stages, individuals living with dementia might not even understand what actions they need to take to minimize the chances of harm (Adelman & Legg, 2010, Ojo & Juba, 2024; Peterson et al., 2024) or might not be able to rely on their physiological defense mechanisms. For example, older adults often experience lack of thirst and might be unaware that they are dehydrated and unable to express their discomfort (Conti et al, 2007). As an outcome, a recent literature review found evidence

that natural hazards increased the risks of cognitive decline in older adults by 25% (Thompson & Vasefi 2025). Hurricanes, earthquakes, tsunami, and heat waves were among the natural hazards with the greatest effects (Thompson & Vasefi 2025).

1.4 Study rationale

The goals of this thesis are to: a) understand the risk and protective factors associated adverse health outcomes caused by extreme weather events, and b) develop indices to identify individuals that could be at risk of adverse health outcomes because of these events. To achieve these goals, the thesis focuses on acute, short-term health complications often a result of heat-related events and wildfire smoke. The rationale for this approach is threefold. First, by using short-term effects to understand and identify those at risk before an event happens, long-term effects could also be minimized. Second, short-term effects happen at or around the time of the natural hazard, making it easier to investigate the causal relationship between them and health problems. Finally, in Canada, deaths and health complications caused by heat-related events and poor air quality related to wildfires have drastically increased (Berry & Schnitter, 2022; Balmes & Holm, 2023). In 2023, heatwaves were responsible for 99% of total deaths caused by extreme weather events in Canada. In Québec alone, direct health care costs of extreme high temperature will increase up to 5-fold from the historic 15 million dollars a year (Boudreault et al., 2025). More than 30,000 people were affected by wildfires in Canada (Ritchie et al., 2022). Between 2013 and 2018, up to 2,500 premature deaths could be attributable to short and long-term exposure to poor air quality from wildfire smoke, with health costs up to $1.8 billion per year (Matz et al., 2020). Although estimates for Canada are not available, in US the 2023 Canadian wildfire season resulted in an increase of 17% in emergency room visits because of asthma (McArdle, 2023). This estimate includes all geographic regions, but some regions observed increases up to 60% (Chen et al., 2023). Thus, our health system ought to deal with the health complications caused by these two natural hazards that are increasing in frequency, duration, and intensity because of climate change.

The main population of interest in the thesis is older adults (i.e., individuals 65 years and older). This choice was motivated by the fact that older adults are often the most affected demographic group during and after natural hazards (Ngo, 2001, Benevolenza & DeRigne, 2019; Ebi et. al, 2021; Durak, 2023; Kim et al., 2024). In the context of wildfire smoke and heat waves, older adults have complex medical needs, high incidence of chronic diseases, reduced social connections, and cognitive impairment that can reduce their ability to properly respond to these whether events. For example, older adults have reduced sweating capacity and reduced amount of water in their bodies, which compromised their ability to thermoregulate. Moreover, some medications (anticholinergic drugs and non-selective beta-blockers) can interfere with their ability to perceive temperature and thermoregulate properly (Hospers et al. 2024). They have higher rates of chronic diseases that are risk factors for both poor air quality and extreme temperature, such as cardiovascular and respiratory diseases (Henderson et al., 2011; De Vita et al., 2024). They have physical problems and small social network that might interfere with their ability to move to a safer place or ask and receive support (Bogdan et al., 2024). They have high levels of depression, which might interfere with their motivation to respond to a natural hazard but might also leave them isolated or less aware of the health problems caused by extreme weather (Karim et al, 2024). Finally, cognitive impairment and dementia can make it more difficult to understand risk and take actions to be safe (Adelman & Legg, 2010; Ojo & Juba, 2024; Peterson et al., 2024). Finally, emergency preparedness is low among older adults (Liao & Hu, 2025), including older adults in Canada (Bogdan et al., 2024). Therefore, older adults should be the focus of interventions that can minimize the adverse health outcomes caused by extreme weather event.

1.5 General approach

The general approach of this thesis was to use individual data about the strengths and needs of individuals, as well as social-demographic information to identify those who could be at high risk of adverse health outcomes cased by natural hazards. Data were obtained with clinical assessments

developed by the interRAI network, which is a not-for-profit, multinational network of over 100 researchers, clinicians, and policy experts from over 40 countries. The interRAI assessments are person-centred, completed during routine clinical practices and used in different Canadian health care sectors (Hirdes et al., 2008). For this dissertation, most data come from Ontario because it had the broadest and most established implementation of the two key interRAI systems used in this study.

There are two main sources of data, the interRAI Home Care (interRAI HC) and the interRAI Contact Assessment (interRAI-CA). The interRAI HC is a comprehensive assessment of a person's health, function, social support, diagnoses, service use, and health related quality of life (Hirdes et al., 1999; Morris et al., 2000; Poss et al., 2008). These assessments target individuals receiving long-term (> 2 months) home care services. Assessment information is obtained from diverse sources such as medical records, clinical observations and interviews with clients and collected by trained nurses or social workers. The interRAI-CA (only used in study 3) is a screener applied prior to the interRAI HC. It is completed either by phone or in-person for all individuals expected to be eligible for home care services. Although the interRAI-CA is a much shorter instrument, it covers a larger population compared to the interRAI HC, i.e., all potential home care clients and not only those already receiving home care services. It is estimated that around 25% of the individuals in Ontario assessed with the interRAI-CA also receive the interRAI HC assessment (Sinn et al., 2022).

A common approach was used to develop the two indices in this thesis, the Brief Risk Index and the Cardiorespiratory Vulnerability index: a) identifying items in the interRAI instruments that have been frequently associated with health complications caused by natural hazards; b) combining these items into an index and specifying cut-point values to indicate different levels of risk; c) validating the index against important health outcomes, such as hospitalizations, physician visits, and death; and d) applying the index in a real population of older adults living with vulnerability to understand the distribution of individuals at risk and their geographic locations. These indices were not, however,

validated against extreme weather events, which can be undertaken in future research. The main reason for this was the lack of interRAI data linked with hospital and physician data at the time this research was undertaken. Although this is a limitation, it is also the case that if individuals in the study population are more likely to experience adverse health outcomes during normal environmental conditions, then they would be at much higher risk during natural hazards. Moreover, linking environmental conditions with clinical, individual information has several methodological and ethical challenges that are beyond the focus of this thesis.

1.6 Study objectives

1.6.1 Summary of the studies

Study 1. Inadequate thermal environment at home of older adults with complex medical needs

Background: Extreme variation in temperature, either hot or cold, can trigger several health problems, including cardiovascular and respiratory diseases, mental health symptoms, and death. Older adults are at high risk not only because they often have high medical needs, but also because they tend to spend long hours indoors, where most health complications happen during extreme temperature events. Despite this, we have little information about the risk and protective factors associated with the quality of the thermal environment in this population.

Research question. This study investigates the association between thermal environment at home with demographic and socioeconomic characteristics as well as availability and quality of informal caregiver support. Moreover, study 1 also investigates if the rates of houses with poor thermal environment were different during the study period and across different geographic regions in Canada

Methods: This study used data from 388,429 unique older adults with complex medical needs in Canada who also received home care services. Because of the longitudinal nature of the data, statistical approaches were used to avoid unbiased estimates, such as generalized estimating equation models. To

our knowledge, this is the first investigation that quantified the risk factors linked to adverse health outcomes caused by poor thermal environment in older adults.

Study 2. A new index to identify individuals at risk of adverse health outcomes during extreme weather events

Identifying individuals at risk during extreme weather events is an essential step in adapting our health system to the increasing effects of climate change.

Research question: To address this issue, we developed the Brief Risk Index (BRI), an algorithm based on the interRAI-Contact Assessment, a screener used to support home care intake from community and hospital.

Methods: From this screener, we used 14 items related to impairment (e.g., activities of daily living), social isolation (e.g., living alone) and caregiver information (e.g., having an informal caregiver). For each individual, we identified whether the client had a problem in each item and then assigned a value of 1, or 0 if no problem was identified. To construct the index, we found cut-point values to construct a 4-point scale. We compared the performance of the BRI with an algorithm that had already been used to identify those at risk during an earthquake and then calculated the percentage of people in the interRAI Contact Assessment that could be at risk according to the BRI. This new index targets all individuals potentially eligible to receive home care services, which is a population with medical needs that could prevent them from properly respond to a natural hazard.

Study 3. Using interRAI assessments to identify older adults at risk during periods of poor air quality

Air pollution can negatively affect human health, especially older adults with multi-morbidity and geriatric syndromes, such as frailty and cognitive impairment. One important contributor of poor air

quality is wildfire smoke, which has increased in frequency, intensity, and duration because of climate change. Combined with an aging population, an increasing number of people could be at risk of health complications caused by wildfire smoke. Thus, it is important to equip our public health system and emergency preparedness agencies with ways to identify those individuals.

Research question: Study three aims to identify older adults living in the community that would be at higher risk of health complications during periods of poor air quality.

Methods: To address the research question, we developed the Cardiorespiratory Vulnerability index. The index used 16 items from the interRAI HC assessment. These items are clinical characteristics and health conditions that have been identified in the literature to be risk factors related to poor air quality. These items were dichotomized and, for each individual, added so that high scores indicated higher risk. Generalized estimating equations were used to understand the association of the CRV index with hospital admissions, emergency department, and physician visits, and poor self-rated health. Public health organizations could use this new index in the Spring to obtain an updated list of individuals that could be in trouble during forest fires and, therefore, improve their emergency preparedness.

Chapter 2

Study 1: Inadequate thermal environment at home of older adults with complex medical needs

This chapter was written for publication.

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Declarations

Ethics approval and consent to participate

Ethics clearance was obtained from the University of Waterloo Office of Research Ethics for secondary analyses of anonymized interRAI data obtained through a Data Sharing Agreement with the Canadian Institute for Health Information - ORE 30372.

Availability of data and materials

Data used for these analyses can be achieved through the Canadian Institute for Health Information. The authors do not have permission to transmit data to third parties.

Competing interests

We have no conflict of interest to declare.

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Author’s contribution

GSB and JPH conceived the study. GSB conducted the statistical analysis and wrote the first draft of the manuscript. All authors discussed the ideas and commented on subsequent drafts of the manuscript.

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2.1 Introduction

The home environment is an important determinant of health (Burdette et al., 2011; Howden-Chapman et al., 2011; 2017; Lee et al., 2020; Riva et al., 2022; Clair & Baker, 2022; Alidoust & Huang, 2023; Liu et al., 2024; McClatchey et al., 2025). Evidence suggests that substandard housing (houses with toxins, damp, mould, and overcrowding) is associated with the incidence of infection diseases, asthma, and other respiratory problems (Krieger & Higgins, 2002; Riva et al., 2022), as well as anxiety, depression (Krieger & Higgins, 2002; Suglia et al., 2011; Kim et al., 2021), and psychological distress (Hopton & Hunt, 1996). More recently, the home environment was found to be a determinant of mental health during the COVID-19 pandemic (Amerio et al., 2020) and poor housing was associated with increased incidence of COVID-19 cases and mortality (Ahmad et al., 2020).

An important aspect of the home environment is the thermal environment, which is determined by temperature and the conditions that influence heat transfer, such as relativity humidity, air velocity, and even human behaviour (e.g., clothing insulation and activity; Kim et al, 2018a; 2018b; Thomson et al., 2013; Wang et al., 2021; Liu et al., 2024). People living in poor thermal environment are more likely to be exposed to extreme temperatures, which have well-known adverse health consequences, such as cardiovascular and respiratory diseases, increase in symptoms of many mental health problems, and death (Kosatsky, 2005; Baccini et al., 2008; Gasparrini et al., 2015; Lima et al., 2020; Tham et al., 2020; Ebi et al., 2021; Henderson et al., 2022; Thompson et al., 2023). Thus, it is important to understand what are the factors that can increase the chances of having a poor thermal environment at home.

Extreme heat is considered one of the most hazardous natural disasters in many countries (Forzieri et al., 2017). Under extreme heat, the heart pumps more blood, which redistribute blood flow towards the skin (vasodilation) and improve heat transfer (Kenny et al., 2018). This process can be dangerous for people with heart-related diseases or if temperatures are too high for a prolonged period,

compromising our ability to thermoregulate. Cold weather can also be dangerous to our health and mortality attributable to low temperature is often higher than mortality attributable to high temperature (Collins, 1986; Gasparrini et al., 2015; Chen et al., 2016; Petkova et al., 2021; Masselot et al., 2023). Cold air can inflame the lungs and inhibit circulation, exacerbating the symptoms of respiratory and heart conditions (e.g., asthma, chronic obstructive pulmonary disease, ischaemic heart disease, stroke, and coronary heart disease; Janssen et al., 2023; Liu et al., 2024; Umishio et al., 2019). In addition, cold houses can also lead to mental health problems because of the stress associated with experiencing cold, feelings of lack of autonomy over the environment, and lack of sleep (Weilnhammer et al., 2021; Clair & Baker, 2022). Unfortunately, only 35% of the world population uses any kind of space-cooling/heating devices, and the use is highly concentrated among those high-income household in rich countries (Pavanello et al., 2021). Thus, the increase in the frequency, intensity, and duration of extreme temperatures caused by climate change combined with inadequate heating or cooling, will likely increase the adverse health outcomes caused by poor thermal environment at home (Fouillet et al., 2006; Egilson 2022).

The thermal environment is particularly important for people with complex medical needs because of their fragile health, physical inactivity, and a tendency to spend more time indoors (Thomson et al., 2013; Mulliner et al., 2020; E et al. 2024). Older adults have a diminished ability to thermoregulate (e.g., reduced sweating capacity and reduced amount of water in their bodies) and higher rates of chronic diseases (e.g., cardiovascular and respiratory diseases) that interfere with thermoregulation. For those older adults living in the community, the risks associated with poor thermal environment are even higher because they might not have the same type and quality of support compared to older adults living in care facilities (e.g., nursing homes). Given that interventions targeting energy efficiency in homes can improve overall health (Thomson et al., 2013; Ahrentzen et al., 2016), identifying older adults with complex medical needs living in the community with poor

thermal environment is essential to targeting assistance during periods of extreme temperature variation.

The primary objective of this study is to examine risk and protective factors associated with inadequate home thermal environment among older adults receiving home care services in Canada. We also investigated if the rates of houses with poor thermal environment were different during the study period and across different geographic regions in Canada.

2.2 Methods

2.2.1 Data

In Canada, provinces and territories offer community-based home care services to older adults and people of all ages with complex medical needs, persons with disabilities, and those requiring palliative care. Services available include personal care, home nursing, and limited rehabilitation. In Ontario, British Columbia, Alberta, Newfoundland and Labrador, and Yukon Territory, every client who receives home care service must be assessed with the RAI home care (RAI-HC) instrument (Hirdes et al., 2008). This is a comprehensive, person-centred, and internationally validated assessment with about 250 items designed to understand the needs, strengths, and preferences of each client (Hirdes et al., 2008). These assessments also collect demographic and socioeconomic information. Assessments are conducted by a trained person (usually a nurse or social worker) every 6-12 months or when there is a clinically important change in the client's health. The RAI-HC assessment also considers the home environment, including one item about the thermal environment ('inadequate heating/cooling' hereafter). Assessors can rely on their own observations (e.g., too hot in the summer or too cold in the winter) or use information given by the client and/or family members. Since 2018, Ontario has adopted the updated version of the RAI-HC (interRAI Home Care), and this transition is now underway in the rest of the country. Therefore, we examined only items present in both versions (RAI-HC and interRAI Home Care) or items with available crosswalks. We removed individuals younger than 65 years old because

they represent only about 12% of the total clients in the RAI-HC and interRAI Home Care (interRAI HC; as up to 2023). Because we want to understand the risk factors associated with poor thermal environment of older adults with complex medical needs living in the community, we excluded those clients who could receive care services beyond those offered by the home care program, such as clients living in care facilities or grouping living. Thus, we analyzed 531,880 assessments from 388,429 unique older adults who receive support at home because of their medical needs from 01-January-2019 to 31-December-2022.

We used demographic, socioeconomic, and lifestyle variables to investigate the risk and protective factors associated with inadequate heating/cooling (Table 2.1). We choose variables that were available in the assessments and have been shown to be associated with adverse health outcomes caused by poor thermal environment at home. Demographic variables were selected based on a literature review (Thomson et al., 2013) and included age, sex assigned at birth, primary language, province/territory, and geographic region (urban or rural). Economic situation (whether the client made trade-offs because of limited funding) was used as a socioeconomic variable because people with lower financial resources might not afford to keep an optimal thermal environment at home (Thomson et al., 2013). Lifestyle factors included living situation (living alone or with others), isolation (whether the client spent more than 2 hours alone at home), and whether the client (or family member) believed they would be better-off in another setting (e.g., long-term care). This last item is important because it could indicate that the thermal environment is inadequate. Because informal caregivers (friends or family members who provide unpaid care) have important roles in the lives of older adults with complex medical needs (Carretero et al., 2009), we also included the presence of an informal caregiver, whether there were signs of caregiver distress (e.g., caregiver is unable to continue with care or show signs of stress, anger, or depression), and signs of abuse of the client (e.g., fearful of family members, unexplained injuries, neglect, poor hygiene, and physically restrained; Table 2.1). Inflation and house

affordability became important economic issues in Canada since the COVID-19 pandemic, therefore, we also entered year as a covariate to investigate if there was an increase in houses with inadequate heating/cooling during the study period (2019-2022).

To better understand the overall health profile of our study population, we used the Armstrong Frailty Index, which is a cumulative deficit index calculated as the ratio of deficits or health problems to the total numbers of deficits considered (Armstrong et al., 2010). We also used the Cognitive Performance Scale (CPS), which is a validated scale to measure cognitive impairment with values ranging from 0 (no impairment) to 6 (severe) cognitive impairment (Morris et al., 2000).

2.2.2 Statistical analysis

To understand the association between inadequate heating/cooling in the house and our explanatory variables, we used a generalized estimating equation model. Inadequate heating/cooling was the response variable (yes or no) and age, sex assigned at birth, primary language, province/territory, economic situation, living situation, isolation, whether the client or family believed that the client would be better-off in another setting, presence of an informal caregiver, signs of caregiver distress, and indications of abuse (physical abuse, neglected, or mistreated) and year were used as explanatory variables. Client identification was entered as the grouping factor with an autoregressive correlation structure. Because inadequate heating or cooling could be observed more frequently during times when the outside temperature was too high (e.g., summer) or too low (e.g., winer), we also entered season as an explanatory variable. We tested the interactions between sex and living situation and sex and the presence of an informal caregiver because historically, women are more likely to live alone than men (Klinenberg, 2013; Stepler, 2016; Henning-Smith, 2016; Tang et al., 2019) and women are more likely to be an informal caregiver (Lee & Tang, 2015; Navaie-Waliser et al., 2002). We also tested for interactions between age and living situation and age and caregiver because age is frequently associated with the presence of a caregiver and living alone (Reher & Requena, 2018).

Finally, we tested for the interaction between sex and age because women tend to live longer than men (Zarulli et al., 2018). To investigate what levels were different from each other in all interactions, we used a post-hoc pairwise comparison with Tukey adjustment for multiple comparisons after obtaining the estimated marginal means (least-squares means) for each level. The interactions between sex and caregiver, age and living situation and sex and age were not statistically significant ($p>0.1$) and were removed from the final model. We also used a post-hoc pairwise comparison to understand rates of inadequate heating/cooling and home by province/territory. We used forward sortation area (FSA), which is a geographical unit based on the first three characters of the Canadian postal code, as the geographic unit to map the percentage of assessments with inadequate heating/cooling in each FSA.

Analyses were conducted in R v4.3.2 (R Core Team, 2024). We used the *geepack* package to perform the generalized estimating equation model (Højsgaard et al., 2006), the *pROC* package to obtain the area under the curve (Robin et al., 2011), and the *emmeans* package (Russell, 2018) to perform the post-hoc comparison among levels of all interactions.

2.3 Results

We found that 2,938 assessments (0.6% of the total sample) from 2,119 unique individuals (0.6%) had features of inadequate heating/cooling at home (Table 2.1; Figure 2.1). Summer was the season with the highest number of houses identified as having inadequate heating or cooling (Figure 2.1). The area under the curve was 0.8 for the full model. Having inadequate heating/cooling was positive associated with older adults who had to make economic trade-offs (OR = 5.28, 95% CI = 4.69-5.94), with those who had signs of abuse (OR = 3.35, 95% CI = 2.94-3.82), who lived in rural areas (OR = 2.22, 95% CI = 2.04-2.42), who answered that they would be better-off in another setting (OR = 2.06, 95% CI = 1.90-2.23), who spent long hours alone at home (OR = 1.54, 95% CI = 1.40-1.69), males (OR = 1.70, 95% CI = 1.31-1.52), and with those whose caregivers showed signs of distress (OR = 1.44, 95% CI = 1.32-1.57; Table 2.2, Figure 2.3). The odds of having inadequate heating/cooling at home was not

statistically different between 2019, 2020, and between 2019 and 2021 (Table 2.2, Figure 2.3), but in 2022 we found that the odds of having a house with inadequate heating/cooling was 17% higher than in 2019 (OR = 1.17, 95% CI = 1.07-1.29). Among the provinces and one territory investigated, living in Yukon Territory and Newfoundland and Labrador increased the odds of having inadequate heating/cooling compared to Ontario, British Columbia, and Alberta (Figure 2.3 and 2.4). There was no statistical difference in having a house with inadequate heating/cooling when comparing English speakers with those whose primary language was not English (Table 2.2, Figure 2.3).

We found significant interactions between sex at birth and living situation and between age and the presence of an informal caregiver (Table 2.2, Figure 2.5 and 2.6). For those living alone, the odds of having a house with inadequate heating/cooling were higher for males than for females. For those with informal caregiver, the odds of having inadequate heating/cooling at home decrease with age (Figure 2.6).

2.4 Discussion

The results of our analysis demonstrate that a combination of demographic and socioeconomic characteristics, as well as the presence of informal caregivers were associated with inadequate heating/cooling at home in older adults receiving health support at home. To our knowledge, this is the first study addressing the risks and protective factors associated with thermal environment in home care clients, which is a population at high risk of adverse health outcomes during heat waves and cold spells (Ebi et al., 2021; Arsad et al., 2022). Although any older adult could be living with vulnerabilities that place them at risk of the adverse effects of extreme temperature because of the high incidence of health problems and tendance to spend more time indoors, those receiving services at home might not have the financial means to buy, operate, and maintain heating and cooling systems. Moreover, home care clients might not have the cognitive capacity to understand the effects that an inadequate thermal environment might have on their health. Older adults living in care facilities, such as nursing homes,

can rely on healthcare works and other support workers to take care of their needs, making them potentially less vulnerable than those living in the community. Thus, older adults living in the community should be a priority group in initiatives to minimize the adverse health effects of extreme temperatures.

Older adults who had to make economic trade-offs were more than 5 times more likely to have inadequate heating or cooling at home. This is not surprising given that people experiencing economic problems are usually unable to buy and maintain heating and cooling systems and/or maintain proper house isolation. This result is concerning when considering that indoor temperature in houses without air conditioning can be higher than outdoor temperatures during heat waves (Lee & Lee, 2015; Nguyen et al., 2014; Henderson et al., 2022; Oetomo et al., 2022), placing older adults at high risk of health complications and death.

One way to solve this issue is to invest in housing upgrades. For example, small investments from Governments could have a positive impact on the thermal environment because improvements in energy efficiency can improve people's health, specially for those with inadequate heating or cooling at home and those with chronic respiratory disease (Thomson et al., 2013; Ahrentzen et al., 2016). These investments are small compared to the public costs of heat waves and cold spells. For example, in Ontario, a full subsidy program for all houses with inadequate heating/cooling in our population would cost around $12 million (809 clients; assuming the cost of an installed heat pump about $15,000 CAD). The cost of premature nursing home placements, where problems in the home environment are a driver, would be around $197 million (assuming a basic type of accommodation, for a low-income person at $66.95 per person, per day, for a period of 10 years, which is the average life expectancy of a heat pump; Ontario, 2024). Additional possible costs savings are related to acute hospitalizations from cardio-respiratory problems and dehydration.

Older adults with indications of abuse (physical abuse, neglected, and mistreated) were about three times more likely to have inadequate heating or cooling at home. Unpaid services that family members and friends provide to older adults are essential to the health of older adults, not only because it can keep them at home, but also because informal caregivers are an essential source of support (Gaugler et al., 2003). However, having an informal caregiver can result in negative outcomes, specially if the informal caregiver is under distress. Therefore, support for informal caregivers can also have positive effects on the thermal environment of home care clients and should be considered when thinking about climate change adaptation.

Our analysis indicated that having an informal caregiver was the most important protective factor, specially for those older than 75 years. For example, some older adults might not be able to maintain or operate heating/cooling systems or keep the house insulated with windows and doors at good working condition. An older adult who does not have a caregiver might not be able to perform regular maintenance and a caregiver that neglects the care recipient might place them at risk. It is not surprising that the importance of caregivers increases with age-related declines in cognition and function (Black & Rush, 2002; Mehta et al., 2002).

We found that living situation (living alone or with others) only increased the odds of having poor thermal environment if clients were male, but sex seemed unimportant for those clients living with others. These results suggest that females might be better able to maintain their house in working condition regardless of their living situation. This is supported by several facts. First, unmarried men or men living alone tend to have earlier onset of frailty than women (Kojima et al., 2020a; Trevisan et al., 2016). Second, women tend to improve both physical and mental health after their husbands die (Trevisan et al., 2016; Kojima et al., 2020a; 2020b) and life satisfaction increases for women after divorce (although this might be true only for women in low quality marriages; Bourassa et al., 2015). Finally, because women are more likely to live alone than men (Henning-Smith, 2016; Klinenberg,

2013; Stepler, 2016; Tang et al., 2019), they might be better able to maintain a house with a proper thermal environment.

Yukon and Newfoundland and Labrador had more assessments indicating poor thermal environment compared to the other provinces. Also, within each province and territory, the number of cases was not equally distributed. Instead, houses with inadequate heating or cooling were highly concentrated in some areas. Other studies also showed that there are geographical "hot spots" of adverse health outcomes associated with natural hazards. For example, 74% of deaths during the 2021 heat dome in British Columbia occurred in 2 out of 5 health authorities (Egilson, 2022). In British Columbia the effects of high temperature could be particularly important because it is estimated that only 33% of the houses have air conditioner (Government of Canada, 2023). Thus, our results provide essential information that can be used to public health agencies to concentrate efforts in "hot spots" areas before, during, and after periods of extreme temperature.

We found that 0.6% of houses of home care older adults in Canada were identified to have inadequate heating and cooling. To our knowledge, there is no estimate for this population available in Canada or elsewhere. Estimates for the general population can vary greatly depending on the metric, method used, and demographics. For example, energy poverty is often used to measure thermal environment, and it is defined as houses with inadequate levels of essential energy services that are needed to maintain a comfortable indoor environment (Riva et al., 2021). For Canada, estimates of energy poverty can vary between 6% and 19% depending on the metric, geographic region, age, and income (Riva et al, 2021; Das et al., 2022). Estimates for older adults are often higher compared to the general population (Tardy & Lee, 2019; Riva et al., 2021; Das et al., 2022), suggesting that we might have missed many houses with poor thermal environment. Conversely, in Canada, energy poverty is less than 1% in households with a yearly income higher than $75,000 CAD (Tardy & Lee, 2019). This suggests that our population might be in better financial situation than the average Canadian. Indeed,

only 2% of our sample indicated financial constrains resulting in economic trade-offs between food, shelter, clothing, and necessary medications or health care. Future studies should try to combine subjective measures of thermal environment, such as energy poverty and inadequate heating or cooling at home with other metrics such as indoor temperature and humidity. In addition, it would be helpful to determine whether inadequate heating or cooling in the home is associated with higher discharge rates from home care to hospital, long term care or death.

In addition to measurements at the population level, the evidence reported here could also be used as a basis for targeting individuals already identified as having inadequate home thermal environment. The interRAI assessments are comprehensive and provide reliable and high-quality data. Individual information is updated at least every 12 months, meaning that the risk factors are also updated as the person's needs change. Data are collected by health professionals and geocoded, which allows public health agencies to locate each individual client to plan pre-emptively. Finally, every home care client is assessed, providing full coverage for this population.

2.5 Limitations

The main limitation of our study is the fact that the question about inadequate heating or cooling at home was based on a snapshot of personal observations of the assessor. Although these assessors are trained to complete the instrument, the fact that they have only a snapshot in time could result in an underestimate of the true number of houses with thermal problems in our population. When assessments are conducted during periods of hot and cold weather (e.g., summer and winter), inadequate heating or cooling might be easy to detect because the house would feel too hot or cold to the assessor. However, during periods of mild temperature, the assessor might need to rely on the client's perception or information from family members and friends. Many older adults do not thermoregulate properly because of changes in their physiology (e.g., diminished sweating capacity or less fat below the skin) or because medications interfere with thermoregulation (e.g., diuretics). Thus,

information provided by clients might be insensitive to the dangers associated with extreme variation in indoor temperature. Another limitation is that indicators used here were not validated in terms of temperature-related health outcomes, even though they were selected based on literature. It would be important to use data from older adults who receive home care services and experienced adverse health outcomes because a heat- and cold-related events and investigate the frequency of these items in that population.

2.6 Conclusions

We found that having inadequate heating or cooling at home were associated with financial problems, informal caregiver (the presence of a caregiver, caregiver distress, and signs of abuse), isolation (living alone or spending long hours alone at home), sex, age, and geographic location (rural areas, Yukon, and Newfoundland). Considering the high risk of adverse health outcomes during extreme-weather events in this population, our results provide essential information to identify individuals at risk and develop interventions to minimize the negative effects of climate change. This is particularly important because a growing number of older adults will be at risk during periods of extreme temperature and wildfires in the next few years, given the aging population, the negative effects of climate change on health, and the fact that the odds of having a house with inadequate heating or cooling tended to increase during the study period (2019-2022).

Table 2-1 Characteristics of the study population. Data were collected from 01 January 2019 to 31 December 2022 (N = 388,429 unique individuals).

Item	Scores	Inadequate heating/cooling		Total
		No	Yes	
FRAILTY (ARMSTRONG SCALE)	0 = No frail	114,959 (99.4%)	678 (0.6%)	115,474 (29.7%)
	1 = Pre-frail	94,555 (99.4%)	566 (0.6%)	95,121 (24.5%)
	2 = Frail	179,959 (99.5%)	875 (0.5%)	177,834 (45.8%)
COGNITIVE PERFORMANCE SCALE	0 = Intact (0)	91,788 (99.5%)	488 (0.5%)	92,274 (23.8%)
	1-2 = Mild impairment (1-2)	232,909 (99.4%)	1,309 (0.6%)	234,218 (60.3%)
	3-6 = Moderate/severe impairment (3-6)	61,613 (99.5%)	322 (0.5%)	61,935 (16.0%)
DEMOGRAPHIC VARIABLES				
Age	65-74	74,566 (99.1%)	657 (0.9%)	75,223 (19.4%)
	75-84	141,281 (99.4%)	867 (0.6%)	142,148 (36.6%)
	85+	170,463 (99.6%)	595 (0.3%)	171,058 (44.0%)
Sex	Female	233,456 (99.5%)	1,088 (0.5%)	234,544 (60.4%)
	Male	152,854 (99.3%)	1,031 (0.7%)	153,885 (39.6%)
Language	English	317,262 (99.4%)	1,869 (0.6%)	319,131 (82.2%)
	Other language	69,048 (99.6%)	250 (0.4%)	69,298 (17.8%)
Province	Ontario	262,204 (99.5%)	1,326 (0.5%)	263,530 (67.8%
	British Columbia	77,655 (99.4%)	440 (0.6%)	78,095 (20.1%)
	Alberta	31,275 (99.4%)	182 (0.6%)	31,457 (8.1%)
	Newfoundland and Labrador	14,695 (99.0%)	148 (1.0%)	14,843 (3.8%)
	Yukon Territory	481 (95.4%)	23 (4.6%)	504 (0.13%)
Urban or rural location	Urban	322,507 (99.5%)	1,502 (0.5%)	324,009 (83.4%)
	Rural	63,803 (99.0%)	617 (0.9%)	64,420(16.6%)
SOCIOECONOMIC VARIABLES				
Economic trade-offs	No	378,858 (99.5%)	1,772 (0.5%)	380,630 (98.0%)
	Yes	7,452 (95.5%)	347 (4.4%)	7,799 (2.0%)
LIFESTYLE				
Living situation	Alone	145,108 (99.2%)	1,161 (0.8%)	146,269 (37.7%)
	Not alone	241,202 (99.6%)	958 (0.4%)	242,160 (62.3%)
Social isolation	Less than 1-2 hours a day	205,946 (99.6%)	747 (0.4%)	206,693 (53.2%)
	Long periods of time	180,364 (99.2%)	1,372 (0.7%)	181,736 (46.8%)
Better-off	No	303,19 (99.5%)	1,238 (0.4%)	304,428 (78.4%)
	Yes	83,12 (98.9%)	881 (1.0%)	84,001 (21.6%)
INFORMAL CAREGIVER				
Presence of caregiver	No	11,113 (98.0%)	227 (2.0%)	11,340 (2.9%)
	Yes	375,197 (99.5%)	1,892 (0.5%)	377,089 (98.1%)
Caregiver distress	No	225,68 (99.5%)	1,090 (0.5%)	226,770 (58.4%)
	Yes	160,63 (99.3%)	1,029 (0.6%)	161,659 (41.6%)
Abuse	No	379,254 (99.5%)	1,898 (0.5%)	381,152 (98.1%)
	Yes	7,056 (96.9%)	221 (3.0%)	7,277 (1.9%)
SEASONS	Spring	95,940 (99.5%)	480 (0.5%)	96,420 (24.8%)
	Summer	92,275 (99.3%)	667 (0.7%)	96,942 (23.9%)
	Fall	95,798 (99.5%)	479 (0.5%)	96,277 (24.8%)
	Winter	102,297 (99.5%)	493 (0.5%)	102,790 (24.5%)
YEAR				
2019		147,104 (99.5%)	749 (0.5%)	147,853 (38.1%)
2020		69,898 (99.5%)	356 (0.5%)	70,254 (18.1%)
2021		79878 (99.4%)	451 (0.6%)	80,329 (20.7%)
2022		89,43 (99.4%)	563 (0.6%)	89,993 (23.2%)

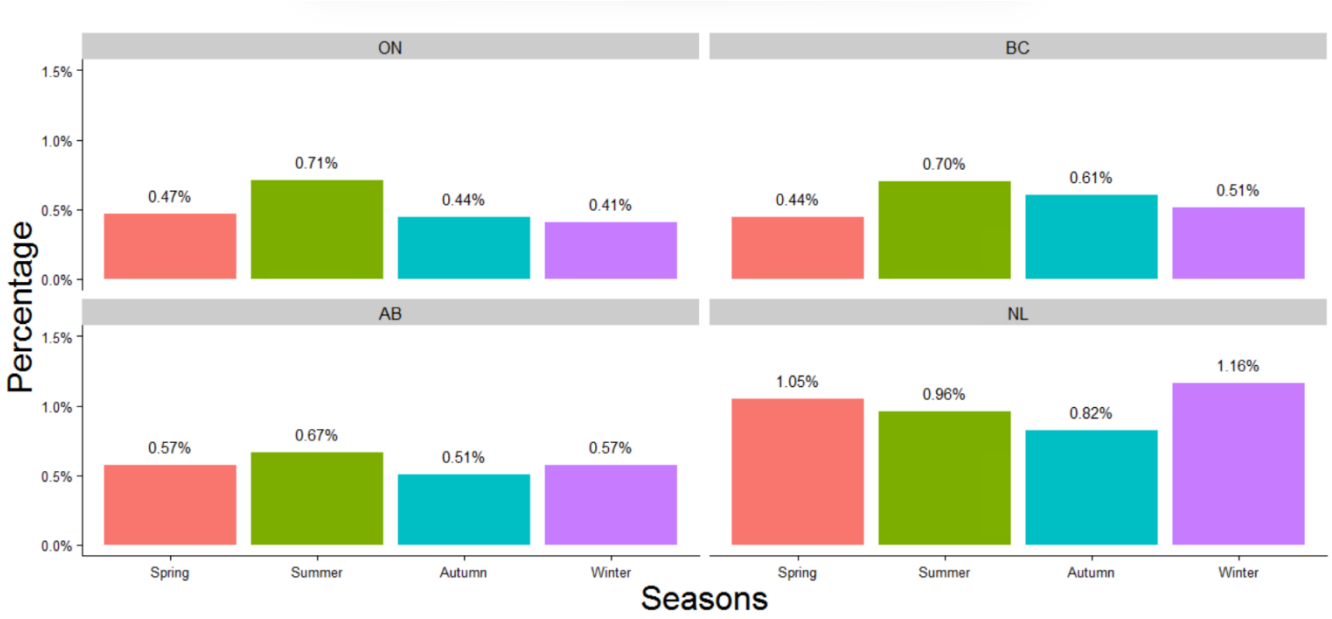
Note: Armstrong Frailty Scale grouping: 0: < 0.26 1: >= 0.26 < 0.36 2: >= 0.36.

Table 2-2 Adjusted odds ratio and 95% confidence interval (CI) for having a home with inadequate heating or cooling (yes or no). Values were obtained with a generalized estimating equation (area under the curve = 0.8). Values between parentheses are reference levels (N = 531,880 assessments).

Categories	Variable	OR	2.5% CI	97.5% CI
DEMOGRAPHIC VARIABLES				
Age (ref=65-74)	75-85	1.17	0.90	1.52
	85+	0.84	0.59	1.20
Sex (ref=Female)	Male	1.70	1.53	1.88
Language (ref=English)	Other language	0.92	0.81	1.04
Province (ref=Ontario)	British Columbia	1.03	0.94	1.13
	Newfoundland	0.91	0.80	1.03
	Alberta	1.30	1.13	1.49
	Yukon	4.24	2.88	6.24
Urban or rural location (ref=Urban)	Rural	2.22	2.05	2.42
SOCIOECONOMIC VARIABLES				
Economic trade-offs (ref=No trade-off)	Trade-off	5.28	4.69	5.94
LIFESTYLE				
Living situation (ref=Not alone)	Alone	0.77	0.68	0.86
Social isolation (ref=No)	Yes	1.54	1.40	1.69
Better-off (ref=No)	Yes	2.06	1.90	2.23
INFORMAL CAREGIVER				
Presence of caregiver (ref=No)	Yes	0.58	0.47	0.71
Caregiver distress (ref=No)	Yes	1.44	1.32	1.57
Abuse (ref=No)	Yes	3.35	2.94	3.82
YEAR (ref=2019)	2020	0.94	0.84	1.05
	2021	1.10	0.99	1.21
	2022	1.16	1.05	1.28
SEASONS (ref=SPRING)	Summer	1.35	1.22	1.49
	Fall	1.01	0.91	1.13
	Winter	1.06	0.95	1.18
INTERACTIONS				
Sex:Living Situation (ref=Female:Alone)	Male:Not alone	0.70	0.60	0.81
Age:Caregiver (ref=65-74:Caregiver)	75-84: Caregiver	0.68	0.51	0.90
	85+: Caregiver	0.60	0.41	0.87

Note: Full comparison of interactions is available in Figures 2.3, 2.4, and 2.5.

A.



B.

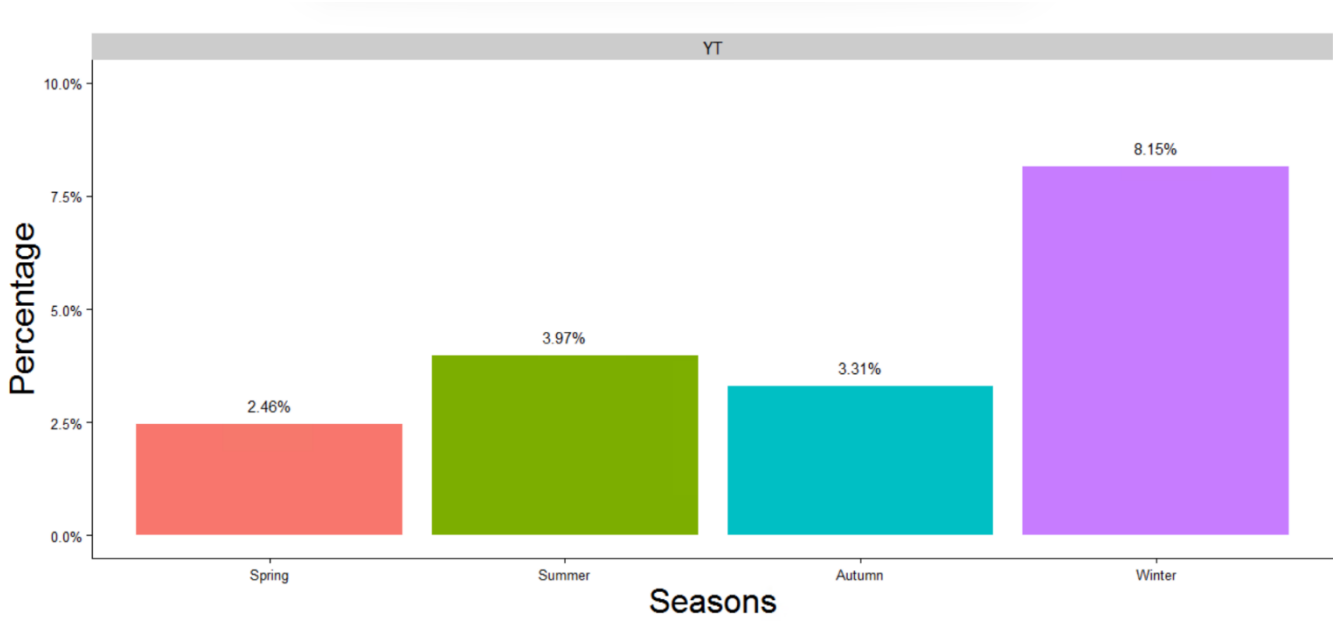


Figure 2-1 Percentage of home care clients with inadequate heating and cooling in each Province (A), and Yukon Territory (B) by season. Percents were calculated as the number houses with inadequate heating and cooling in each season, divided by the total number of houses assessed in that season.

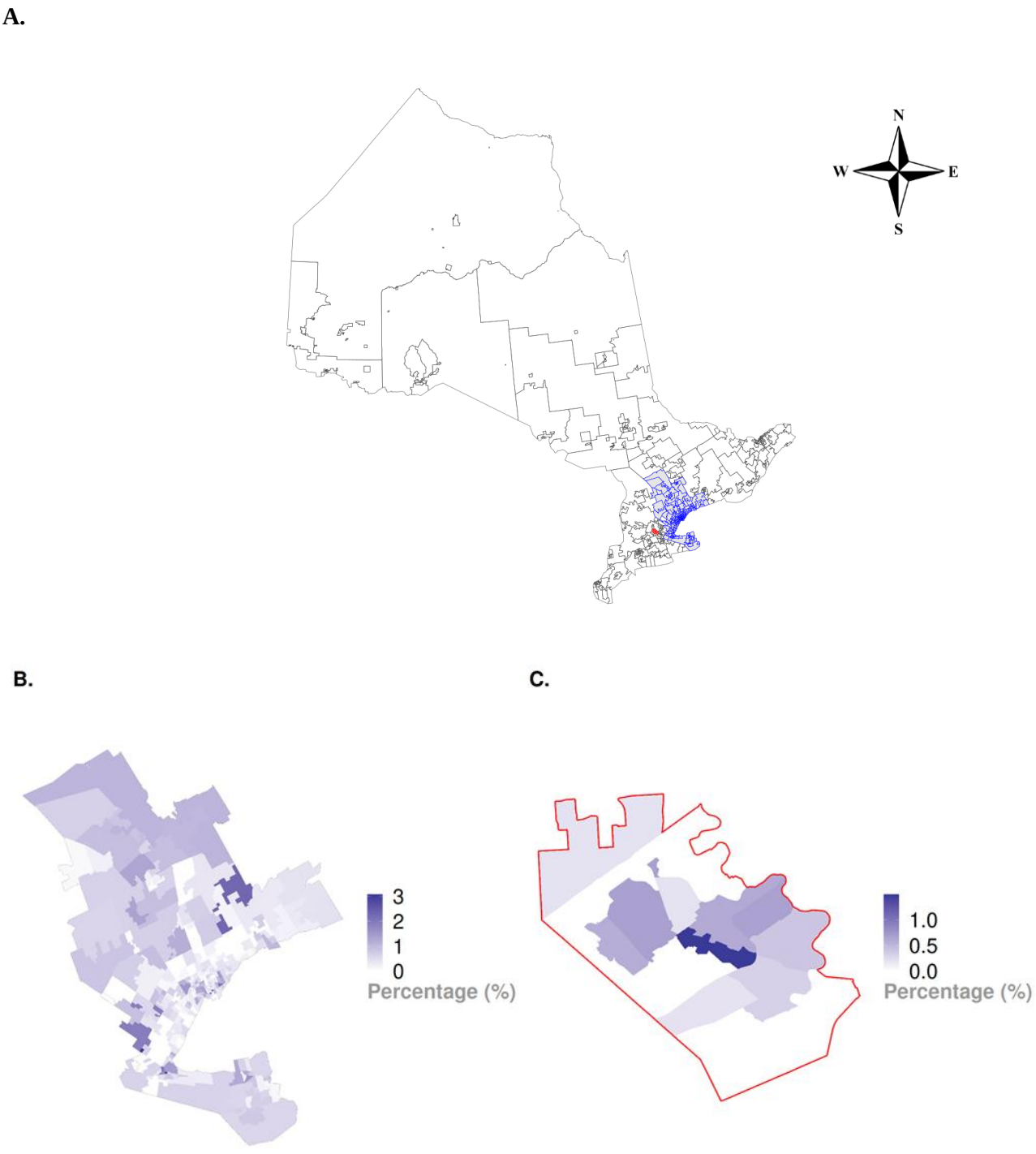


Figure 2-2 Map of Ontario with the percentage of people with inadequate heating or cooling at home in each forward sortation area (A). Blue lines represent the geographic location of houses with inadequate heating or cooling for Central Ontario (B), and the red lines represent this geographic location for Kitchener-Waterloo region (C).

Note: Forward sortation area is a geographical unit based on the first three characters of the Canadian postal code. Darker colours indicate a higher number of cases.

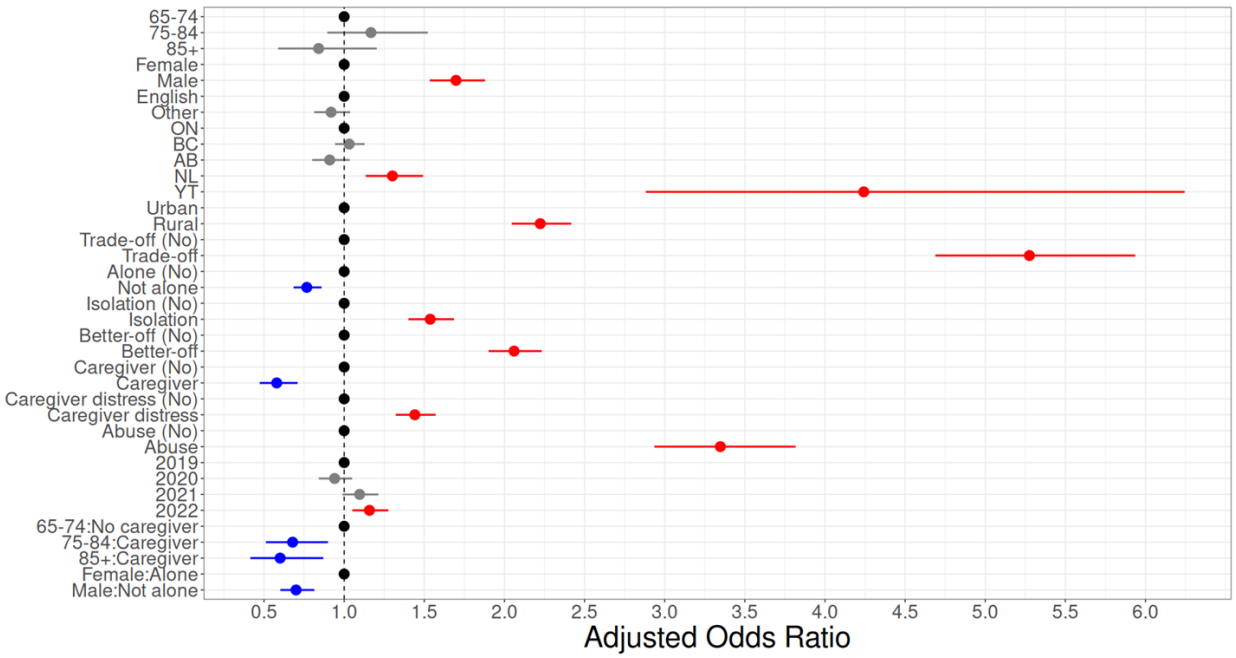


Figure 2-3 Adjusted odds ratios (dots) and 95% confidence interval (CI; bars) for having a home with inadequate heating or cooling (yes or no; N = 531,880 assessments). Values were obtained with a generalized estimating equation.

Note: Black points are reference values, red points represent a significant positive association between the variable and inadequate heating/cooling, blue points represent a negative association, and grey points represent no significant association. Odds-ratio values and 95% CI are available in Table 2.2.

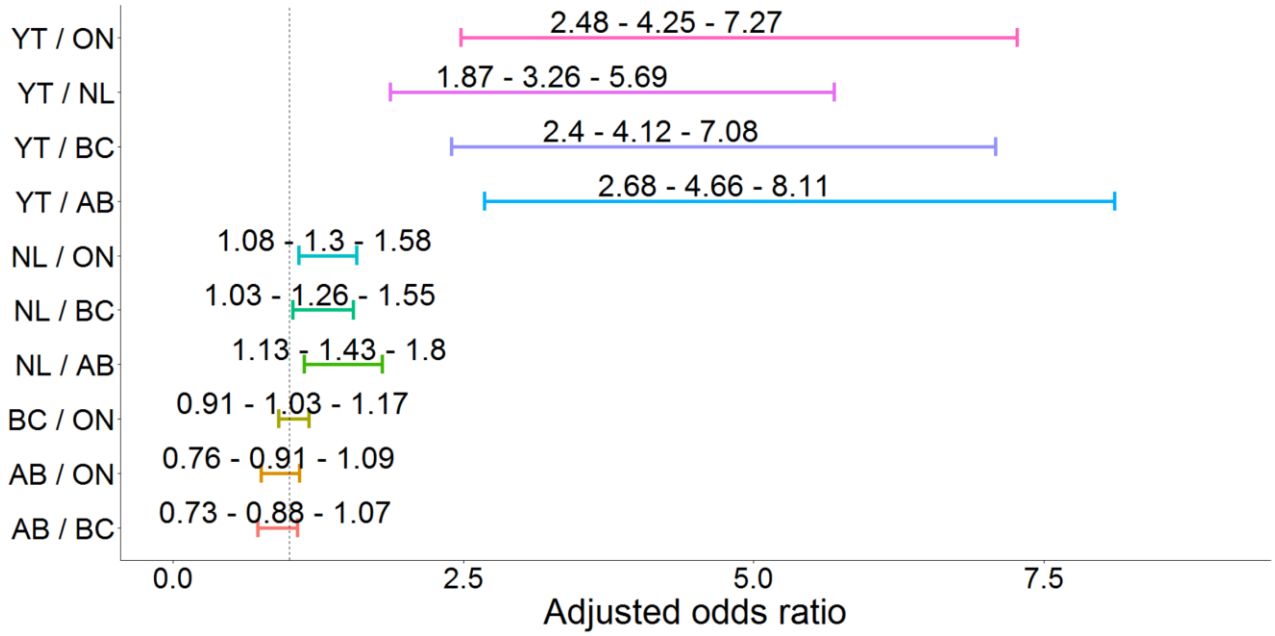


Figure 2-4 Adjusted odds ratio for having a home with inadequate heating or cooling from a post-hoc pairwise comparison and 95% confidence interval (bars) between the 4 Provinces and 1 Territory. Values were based on estimates from a generalized estimating equation.

Note: The first Province/Territory in the y-axis is the reference value, e.g., Yukon (YT) had a higher odds of having a house with inadequate heating or cooling than Ontario (ON). 'BC' refers to British Columbia and 'AB' refers to Alberta.

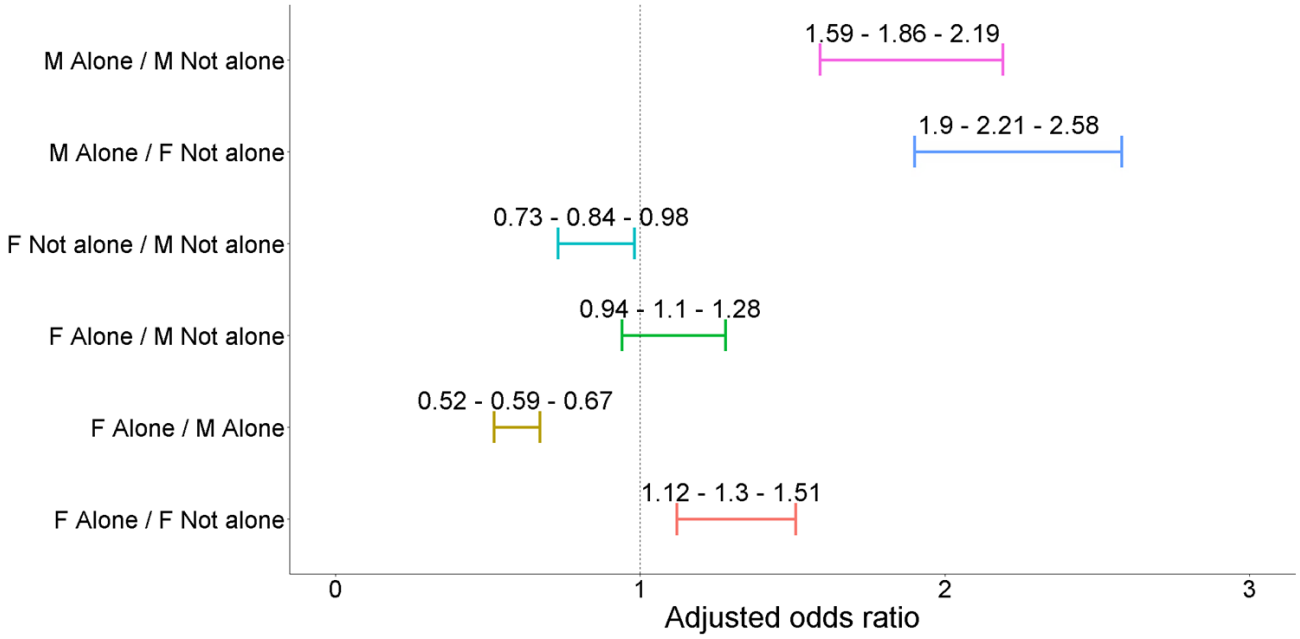


Figure 2-5 Adjusted odds ratios for having a home with inadequate heating or cooling from a post-hoc pairwise comparison based on the interaction between sex and living situation from a generalized estimating equation model (N = 532,021 assessments).

Note: The first sex-living situation combination in the y-axis is the reference value, e.g., 'M Alone' had a higher odds of having a house with inadequate heating or cooling than 'M Not alone'. 'F' refers to females, 'M' to males, 'Alone' to individuals who lived alone and 'Not alone' to individuals who did not live alone.

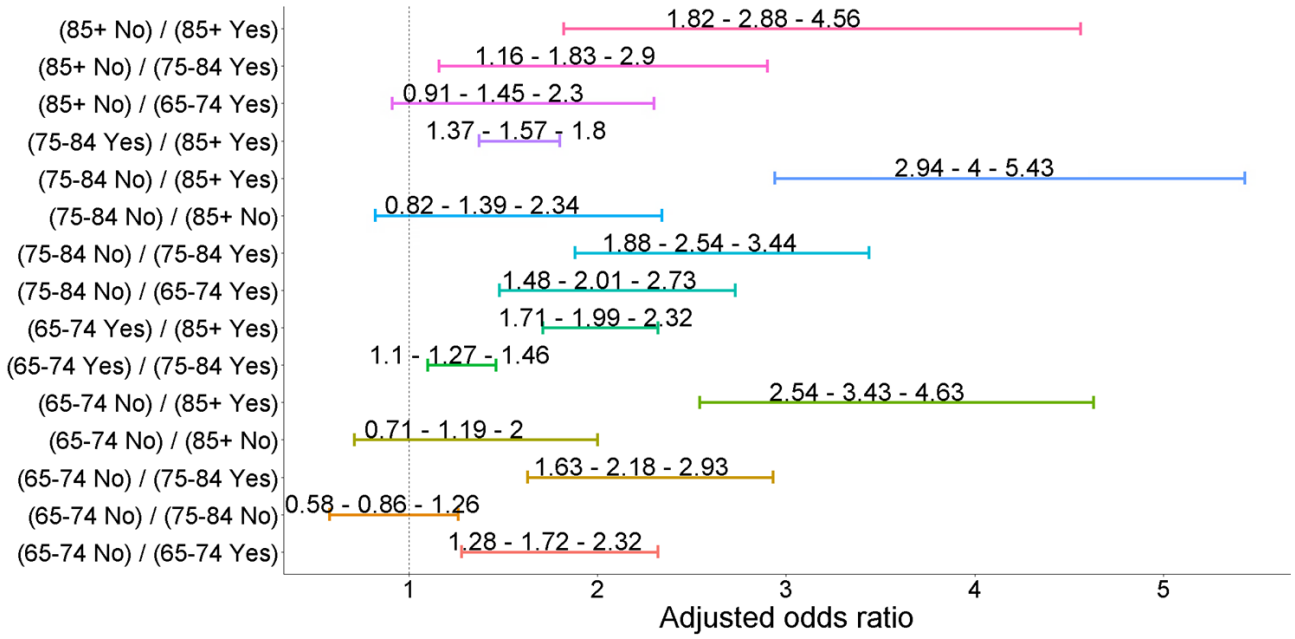


Figure 2-6 Adjusted odds ratio for having a home with inadequate heating or cooling from a post-hoc pairwise comparison based on the interaction between age and presence of informal caregiver from a generalized estimating equation model (N = 532,021 assessments).

Note: The first year-presence of informal caregiver combination in the y-axis is the reference value, e.g., '85+ No' had a higher odds of having a house with inadequate heating or cooling than '85+ Yes. 'No' refers to absence of informal caregiver and 'Yes' refers to the presence of informal caregiver.

Chapter 3

Study 2: A Brief Risk Index to identify individuals at risk of adverse health outcomes during extreme weather events and other disasters

This chapter was written for publication.

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Potential Journals
1. BMC Public Health
2. Canadian Journal of Public Health

Declarations

Ethics approval and consent to participate

Ethics clearance was obtained from the University of Waterloo Office of Research Ethics for secondary analyses of anonymized interRAI data obtained through a Data Sharing Agreement with the Canadian Institute for Health Information - ORE 30372.

Availability of data and materials

Data used for these analyses can be accessed through the Canadian Institute for Health Information. The authors do not have permission to transmit data to third parties.

Competing interests

We have no conflict of interest to declare.

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Author’s contribution

GSB and JPH conceived the study. GSB conducted the statistical analysis and wrote the first draft of the manuscript. All authors discussed the ideas and commented on subsequent drafts of the manuscript.

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3.1 Introduction

Extreme weather events can negatively affect human health. Death and physical injury are often the most immediate concerns; however, weather events can also lead to the spread of infections diseases, displacement, homelessness, economic struggles, and adverse mental health outcomes. For example, the earthquake that affected Turkey and Syria in 2023 resulted in more than 55,000 deaths, but about 4 million people lost their houses, and about 30 million needed assistance (World Health Organization, 2023b; Mavrouli et al., 2023). In addition to the physical harms, experiencing an extreme weather event can result in mental health problems, such as non-specific psychological distress (e.g., sleep disturbances), changes in health risk behaviours (e.g., increase in alcohol and recreational drugs consumption), and psychopathologies (e.g., post-traumatic stress disorder and mood disorders; Lawrance et al., 2022; Morganstein & Ursano, 2020; Saeed & Gargano, 2022; Thompson et al., 2023; Zunin & Myers, 2000). Climate change has increased the frequency, intensity, and duration of extreme weather events such that the World Health Organization (WHO) now considers climate change the greatest health threat of the 21st century (World Health Organization, 2024). Consequently, developing more climate-resilient health systems is the first major goal in the WHO's 2024 strategic plan (World Health Organization, 2024)

One way to minimize the impact of extreme weather events is to develop targeting mechanisms to identify individuals at increased risk when exposed to environmental challenges (Cheng et al., 2021; Polcari et al., 2022; Szagri et al., 2023). The great majority of available measures of this type are based on membership in general at-risk groups defined by social, economic, physical, and environment indicators. For example, older adults and children are often considered vulnerable (Benevolenza & DeRigne, 2019). However, these general high-risk groups are not homogeneous and relying simply on a group membership approach can result in many people being wrongly classified as at risk. For example, not all older adults would be at risk of health complications because of a heat wave. This

could create logistic problems when assisting those in need during a time of a crisis (Forster et al., 2001; Levine, 2004; Kailes & Enders, 2007; Schroeder & Gefenas, 2009).

Alternatively, it is also possible to develop indices using personal clinical and demographic information to calculate the individual risk of experiencing adverse health outcome during a natural hazard. One of the few examples of this approach is the Vulnerable Persons at Risk algorithm (VPR), a valid and reliable instrument that uses real-time information for a rapid identification of individuals that could be at risk (van Solm et al., 2017). The risk calculated by the VPR relies on information associated with health outcomes (e.g., health instability, cognitive impairment), social isolation (e.g., living alone and limited access to informal caregivers), and dependence on medical technologies (e.g., oxygen therapy). This information is collected with the interRAI Home Care assessment (interRAI HC; Hirdes et al., 2008; van Solm et al., 2017). However, one major limitation of the VPR is the narrow coverage of the target population, i.e., individuals receiving long-term home care services. Because many other vulnerable older adults living in the community might also be at risk, it is important to develop measures that could cover a wider population.

To address this issue, we created the Brief Risk Index (BRI). The BRI contains 14 items from the interRAI Contact Assessment (interRAI-CA), 6 of which are items similar to the ones present in the VPR. The interRAI-CA is used in the community and hospitals, including emergency rooms, to support home care intake, i.e., individuals transitioning between different levels of care. It is more broadly applied to all home care clients, including short-stay cases and it could be applied as a screening tool in other contexts. We chose to use the VPR as a point of reference for the BRI because a similar version has already been successfully used in real life situation (earthquake in New Zealand in 2011), and the VPR has a strong association with mortality, long-term care admission, and hospitalization in the context of an ice storm event in Toronto, Canada (van Solm et al., 2017). In addition, the population and items covered in the two assessments (interRAI-CA and interRAI HC) overlaps because the

interRAI-CA is used to inform the decision of who requires the full interRAI HC in-person assessment. Hence, the interRAI-CA provides a rapid basis for early identification of risk levels that can be verified with more comprehensive evaluation later.

3.2 Methods

3.2.1 Data

We first developed and tested the performance of the BRI compared to the VPR using data collected with the interRAI HC assessment to ensure that the two measures would be congruent with each other. The interRAI HC evaluates the strengths, preferences and needs of long-stay (usually > 60 days) home care clients (Carpenter & Hirdes, 2013; Gray et al., 2009; Morris et al., 2013). The instrument is used in most provinces and territories in Canada. Eligibility is mostly based on needs (individuals with complex medical needs such as chronic conditions, disabilities, and in palliative care). A trained health professional, usually a nurse, conducts the interRAI HC assessment every 6-12 months or when there is an important change in the client's health. We constrained our analysis to Ontario, Canada because both the interRAI HC and interRAI-CA are mandated in Ontario, meaning that we have a full coverage of this population. We used data from 2018 or later because Ontario adopted a newer version of the interRAI HC at that time. Finally, we removed individuals younger than 18 years because there were only 135 observations in this group. Our dataset contained 1,253,349 observations from 514,745 unique individuals assessed from 01 January 2018 to 31 March 2023.

We tested the performance of the BRI with the interRAI-CA using data collected from Ontario. The interRAI-CA is a screener used prior to the interRAI HC to inform decisions related to home care intake and service initiation at the start of an episode of care. It is completed either by phone or in-person for all individuals expected to be eligible for home care services, including short-stay clients (usually less than 60 days). The interRAI-CA is a much shorter instrument (about 50 items compared to about 250 items in the interRAI HC). It covers a population of almost 1 million people in Ontario.

Around 25% of the individuals in Ontario assessed with the interRAI-CA also receive the interRAI HC assessment (Sinn et al., 2022). This dataset contained 1,134,593 observations from 750,755 unique individuals assessed from 01 January 2018 to 31 March 2023, about 70% more individuals than those assessed with the interRAI HC.

3.2.2 Development of the BRI

To develop the BRI, we first found common items between the interRAI HC and interRAI-CA that were used to develop the VPR (Table 3.1). If an item in the VPR was not present in the interRAI-CA, we looked for similar items that could be used as an alternative. Of the 21 items in the VPR, 6 of them were similar between the VPR and BRI, 8 were replaced with a similar item, and 8 were not included in the BRI because there was no comparable measure in the interRAI-CA (Table 3.1). For example, the Cognitive Performance Scale (CPS) measures cognitive impairment and is part of the VPR, but it is not fully present in the interRAI-CA. However, the items “Cognitive skills for decision making”, and “Ability to understand others” are in the interRAI-CA (one of the items is part of the Cognitive Performance Scale) and, therefore, were used as replacements. The Changes in Health, End-stage disease, and Symptoms and Signs (CHESS) scale measures frailty and health instability, and it is a good predictor or mortality (Hirdes et al., 2014). We used the CHESS to test the BRI against the VPR but then replaced the CHESS with the CHESS-CA to use the BRI with the interRAI-CA (the CHESS-CA is a similar scale developed for the interRAI-CA; Sinn et al., 2020).

3.2.3 Statistical analysis

We first investigated the association between each item used to create the BRI and the question “Client or primary caregiver feels that client would be better off in another living environment.”, which was one of the indicators used to develop the VPR. The rationale for using this question was that, if the environment was considered inadequate under normal circumstances, it would be a problem during a natural hazard (van Solm et al., 2017). We then investigated the association between the BRI and the

VPR with a generalized estimating equation where the VPR was entered as response variable and the BRI as an explanatory variable. The VPR is a 3-point scale (low risk, mild risk and high risk). For simplicity, we dichotomized the VPR in our analysis (0 if the individual was classified as low risk and 1 if classified as medium or high risk). Client identification was used as the grouping factor with an auto-regressive correlation structure. We obtained cut-point values for the BRI based on hospital admissions and the VPR using two methods: the Youden index and the maximum product of sensitivity and specificity method (Hassanzad & Hajian-Tilaki, 2024). The Youden index is defined as $J_{max} = max_t$ [sensitivity (t) + specificity (t) – 1], where *t* denotes the classification threshold that maximizes *J* (Ruopp et al. 2008). The maximum product of sensitivity and specificity is defined as $Prod_{max} = max_t$ (sensitivity(t)) * (specificity(t)), where *t* denotes the threshold that maximizes *Prod*. Our goal was to create a 4-level scale to understand the distribution of risks within our study population. Therefore, we also calculated cut-point values for those who scored above and below the first cut-point obtained with the whole population.

To understand the association between the BRI and potential adverse health outcomes, we used a generalized estimating equation with hospital admissions as response variable and the BRI as explanatory variable. Hospital admissions were coded as 0 if the client had no admissions in the last 90 days or 1 if they had 1 or more visits in the same period. Client identification was used as the grouping factor with an auto-regressive correlation structure. We also used a cox-regression model to investigate the 1-year survival probability of those classified as at risk (low, mild, medium, and high risk) according to the BRI.

All statistical models had age, sex assigned at birth, and geographic region (Local Health Integration Networks - LHINs) as co-variates. Analyses were conducted in R v4.3.2 (R Core Team, 2024). Generalized estimating equations were conducted with the *geepack* package (Højsgaard et al., 2006), the cox-regression survival analysis was conducted with the *survival* package (Therneau, 2023),

and the Youden index was calculated with the *cutpointr* package (Thiele & Hirschfeld, 2021). We used the *tidyverse* package (Wickham et al., 2019) for data filtering and cleaning. Figures were made with the *tidyverse* and the *survminer* package (Kassambara, 2021).

3.3 Results

About a third of the population assessed with the interRAI HC were 85 years and older (Table 3.2), and between 20%-30% had problems with frailty and health instability (measured with the CHESS scale) and problems with activities of daily living (ADL) and instrumental activities of daily living (IADL; 44% indicated problems with meal preparation; Table 3.2). Only 4% of individuals did not have an informal caregiver, and among those, 38% had caregivers with signs of distress (Table 3.2).

For the interRAI-CA, the percentage of people 85 years and older were lower (24%) than the interRAI HC population (37%). Rates of individuals indicating problems with ADL and IADL, mood, and problems with cognition were overall higher in the interRAI-CA (Table 3.2). Although a similar percentage of individuals indicated that they had an informal caregiver in both instruments, rates of caregiver distress were lower in the interRAI-CA (Table 3.2).

Of the 14 items used to develop the BRI, 13 had a positive association with the question of whether the client would be better off in another environment (Table 3.3). Having an informal caregiver decreased by 8% the chances of indicating that the client would be better off in another setting (OR = 0.91, 95% CI = 0.91-0.92; Table 3.3). The strongest associations were found with the two items related to informal caregiver distress. Individuals who had caregivers with signs of distress were 3 times more likely to answer that they would be better off in another setting (OR = 2.92, 95% CI = 2.89-2.95 and OR = 2.85, 95% CI = 2.82-2.89 for caregiver who is unable to continue and show signs of stress, respectively; Table 3.3). For each point increase in the BRI, there was a 32% increase in the odds of answering that the client would be better off in another setting (OR = 1.32, 95% CI = 1.32-1.33).

We found a strong positive association between the VPR and our newly developed BRI (OR = 3.92, 95% CI = 3.90-3.95; Table 3.4). For each unit increase in the BRI score, the chances of being classified as at risk by the VPR were almost 4 times higher than not being classified as at risk. We also found a positive association between hospitalization and greater BRI scores, meaning that for each point increment in the BRI, the chances of being hospitalized increased by 17% (OR = 1.14, 95% CI = 1.14-1.14; Table 3.4).

The average cut-point was 4.25 for those classified as at risk. Among those with scores 4 or lower, the average cut-point was 2.75 and 6.5 for those with scores 4 or higher. These cut-points were used to created four ranges in the BRI (Table 3.5), indicating low risk (score = 0), mild risk (score between 1 and 3), moderate risk (score between 4 and 6) and high risk (score of 7 or higher). About 43% of unique individuals in the interRAI HC population were classified as at risk according to the VPR, while 51% were classified as at some level of risk according to the BRI (Table 3.5). The 1-year survival probability was higher for all three BRI ranges compared to those classified at low risk (Table 3.4 and Figure 3.1). Individuals at high risk were 67% more likely to die than those classified at now risk (HR = 1.67, 95% CI = 1.61-1.72; Table 3.6 and Figure 3.1).

The distribution of individuals assessed with the interRAI-CA who were classified as at risk according to the BRI was similar to the distribution obtained with the interRAI HC population (30.6%, 45.6%, and 13.2%, for low, medium, and high risk, respectively; Table 3.4). These values were influenced by the geographic region (i.e., health region or LIHN; Table 3.7). The Waterloo Wellington region had the highest percentage of individuals classified at high risk (23.4%) while the North West region had only 625 individuals (3.3%) classified at high risk (Table 3.6).

3.4 Discussion

We developed a new index to identify people at risk of adverse health outcomes caused by extreme weather events. The BRI uses real time, updated information about the clinical condition, functional

abilities, preferences, and needs of individuals transitioning between different levels of care. All the items used to develop the BRI were associated with the question of whether the client would be better-off in another setting, suggesting that the items in the BRI indicated potential health risks if individuals stayed in their homes during a natural hazard. The BRI also performed similarly to the VPR, a reliable and valid instrument based on an index that has already been used in real-life situation (van Solm et al., 2017). Finally, individuals classified as at risk with the BRI are at higher odds of being hospitalized and have a higher chance of dying within a 1-year period. Taken together, these results suggest that the BRI is likely to correctly identify those in need of support before, during, and after a natural hazard.

Although the BRI performed similarly compared to the VPR, the BRI has the advantage of being a simpler instrument and it targets a larger population. The BRI uses less items than the VPR with similar performance, permitting the index to be used with less complex assessments, such as the interRAI-CA. The interRAI-CA population in our sample (individuals assessed in Ontario from 2018-2023) is about 70% larger than the population in the interRAI HC and has the potential to increase if more organizations adopted the instrument. On the other hand, the interRAI HC is mandated in most provinces and territories and focus on the narrower long-stay home care population. Therefore, the interRAI-CA and the BRI have the potential to increase capacity for disaster preparedness by reaching larger populations at earlier stages using less complex assessment protocols than the interRAI HC.

Our results might suggest that the BRI can replace the VPR in the interRAI CA. However, the BRI is not a replacement for the VPR in the interRAI-HC. This is because the interRAI HC is a more precise and comprehensive system to support care planning and service delivery based on direct, in-person assessment by regulated health professionals. Using the BRI at the beginning of an episode of care and then the VPR with those who transitioned to long-stay home care services have two clear advantages. First, it allows public health organizations to target a larger population. Second, it allows the use of more precise information to identify risks from those with higher complex medical needs.

This stepped approach to screening and assessment is a cost-effective solution to identifying populations at risk due to natural hazards because individuals can receive interventions at different 'steps' according to their needs (amount and type of treatment; Richards et al, 2012). Thus, the adoption of standardized clinical assessments, such as the interRAI-CA, is key in preparing our health system to the impact of natural hazards on people's health (Ebi et al., 2021b; Patel et al., 2022).

In addition to identify individuals, the BRI could be used in urban planning by identifying geographic areas that need more investments on climate change adaptation. There has been increasing evidence that physical and social environment of neighbourhoods are associated with health status and behaviours (Mouratidis, 2021). Studies have found links between neighbourhood and mental health outcomes, disease prevalence, overall mortality, as well as diet and physical activity (Yen et al., 2009). Our results indicated that the percentage of those classified at risk was highly influenced by the geographic location. Therefore, using the BRI, provinces and cities could identified areas with high percentage of individuals at risk and provide cost-effect actions to minimize the risk of health complications caused by natural hazards. This is important because the costs to adapt to climate change are much lower than the costs associated with the negative effects of climate change (Ahmed, 2014).

3.5 Strengths and limitations

Our results suggest that the BRI has the potential to correctly identify individuals at risk of adverse health outcomes during extreme weather events in a large population living with vulnerabilities. However, we validated the BRI based on adverse health outcomes (e.g., hospitalization and death) that were not associated with extreme weather events. We adopted this approach because if an individual is in trouble during normal environmental conditions, they would be at even higher risk during a natural hazard. Nevertheless, it would be important to validate the BRI against different health outcomes observed during and after a natural hazard to understand if the BRI performs better in some kinds of weather events.

Another limitation of the BRI is the number of items in the interRAI-CA. The interRAI HC has about 250 items that collect detailed information about the individuals' preferences, needs, and their clinical condition. On the other hand, the interRAI-CA has less than 50 items used to determine their level of care and, therefore, whether the person will need to be assessed with the interRAI HC. The interRAI HC is done in-person by health professionals, so it may also be a more precise measure of the person's needs. Therefore, the BRI could be less efficient, potentially identifying too many false positives, i.e., people wrongly classified as at risk. Although a more sensitive index is not necessarily a disadvantage when trying to provide support to people during a natural hazard, more work should be done to improve the BRI, specially with tests in real-life situations.

Finally, all items in the BRI have the same weight, i.e., each one contribute to one point in the scale. However, it is possible that some items might be more important than others when classifying individuals at risk. For example, for older adults, cognitive decline and dementia might be more important than ADL and IADL. This is because individuals with cognitive impairment could be in good physical condition, but unable to understand the threats of natural hazards or identify actions to minimize health complications (Adelman & Legg, 2010; Ojo & Juba, 2024; Peterson et al., 2024). Physical problems might also unable a person to properly react to a threat, but if they have their cognition intact, they can plan ahead and take precautions to be ready when the threat happens. The BRI includes two items on cognition, but further developments of the index should consider if they need to receive more weight when the BRI is applied to real populations.

3.6 Conclusion

The BRI is a simple algorithm with a strong association with the VPR and was a good predictor of hospitalizations and death. Because of the larger target population assessed with the interRAI-CA and the use of real-time information, the BRI is likely to correctly identify those at high risk of experiencing adverse health outcomes during natural hazards. The BRI can be used as an early warning

system for those who will receive home care services and, therefore, better prepare them to deal with extreme weather events. Moreover, public health organizations can apply the BRI to support urban planning and identify geographic regions based on percentage of people at risk and deploy programs towards climate change adaptation. Thus, this new index can add to the tools available to public heath organizations to adapt our health system to the consequences of climate change.

Table 3-1 Crosswalk between interRAI Home Care and interRAI-Contact Assessment instruments. In the 'Mapping' column, 'SI' indicates items that were similar or the same between the two instruments, 'RE' indicates a replacement item, and 'NA' indicates that no item in the interRAI-CA could be used to replace the item present in the interRAI HC.

Home Care		**Contact Assessment**		**Mapping**
Name and Description	Code	**Name and Description**	**Code v9.2**	
Impaired Capacity				
Cognitive Performance Scale (CPS)	CPS=2+	Cognitive skills for decision making Ability to understand others	C1=3+ D2=3+	RE
Frailty/health instability (CHESS)	CHESS=3+	CHESS-CA	CHESS_ca=3+	RE
Vision impairment	D1=3+	NA	NA	NA
Impairment in activities of daily living (ADL)				
ADL Self Performance		ADL Self Performance		
- Transfer	G2g=3+	- Bath transfer	C2a=1	RE
- Locomotion in home	G2f=3+	- Locomotion	C2d=1	SI
- Toilet use	G2h=3+	- Hygiene	C2b=1	RE
IADL Difficulty		IADL Capacity		
- Medication management	G1db=6	- Manage medications	D4c=1	SI
- Meal preparation	G1ab=6	- Meal preparation	D4a=1	SI
Social Isolation				
Who lived with at referral	A14a=1	Expected residential status during service provision	B3=1	RE
Isolation	F3a=3	NA	NA	NA
Has primary helper	P1b1=8	Informal helper	D19aA=9	SI
Shows withdrawal from activities	E1i=3	Self-reported mood	D3=1	RE
Has reduced social interaction	E1j=3	NA	NA	NA
Caregiver Support				
A caregiver is unable to continue caring activities	P2a=1	Family or friends overwhelmed	D20b=1	RE
Primary caregiver is not satisfied with support received from family and friends*	P2c			NA
Any signs of caregiver distress	P2b=1	Helper: Feelings of Distress, Anger or Depression	D20a=1	SI
Client openly expresses conflict with family/friends	F1d=1	NA	NA	NA
Primary mode of locomotion indoors	G3a	NA	NA	NA
Oxygen	N2e=2+	Oxygen	D15c=2,3	SI
Dialysis	N2b=2+	NA	NA	NA
Wheelchair	H4b	NA	NA	NA

* This item has been removed from the new version of the interRAI Home Care assessment and from recent implementations of the Vulnerable Persons at Risk.

Table 3-2 Characteristics of the population assessed with the interRAI Home Care and interRAI-Contact Assessment instruments. Data from 01 January 2018 to 31 March 2023.

Variable	Level	Home Care	Contact Assessment
Age (years)	<65	75,089 (14.6%)	190,214 (25.3%)
	65-74	88,554 (17.2%)	166,325 (22.2%)
	75-84	162,544 (31.6%)	214,461 (28.6%)
	85	188,558 (36.6%)	179,755 (23.9%)
Sex	Female	306,210 (59.5%)	331,800 (44.2%)
	Male	208,535 (40.5%)	418,955 (55.8%)
Cognitive impairment	No	420,412 (81.7%)	570,433 (76.0%)
	Yes	94,333 (18.3%)	180,322 (24.0%)
Frailty/health instability	No	368,332 (71.6%)	542,015 (72.2%)
	Yes	146,413 (28.4%)	208,740 (27.8%)
Living alone	No	337,849 (65.6%)	486,469 (64.8%)
	Yes	176,896 (34.4%)	264,286 (35.2%)
ADL Self performance			
Transfer (on/off toilet or bath)	No	395,883 (76.9%)	342,926 (45.7%)
	Yes	118,862 (23.1%)	407,829 (54.3%)
Locomotion (inside home)	No	405,117 (78.7%)	532,859 (71.0%)
	Yes	109,628 (21.3%)	217,896 (29.0%)
Toilet use / hygiene	No	373,776 (72.6%)	571,608 (76.1%)
	Yes	140,969 (27.4%)	179,147 (23.9%)
IADL Difficulty			
Managing medication	No	395,535 (76.8%)	486,469 (64.8%)
	Yes	119,210 (23.2%)	264,286 (35.2%)
Meal preparation	No	290,752 (56.5%)	241,676 (32.2%)
	Yes	223,993 (43.5%)	509,079 (67.8%)
Presence of caregiver	Yes	491,573 (95.5%)	713,196 (95.0%)
	No	231,72 (4.5%)	37,559 (5.0%)
Caregiver distress	No	320,850 (62.3%)	539,976 (71.9%)
	Yes	193,895 (37.7%)	210,779 (28.1%)
Mood disturbance	No	467,530 (90.8%)	646,936 (86.2%)
	Yes	47,215 (9.2%)	103,819 (13.8%)
Oxygen therapy	No	491,836 (95.5%)	710,903 (94.7%)
	Yes	22,909 (4.5%)	398,52 (5.3%)
Total		514,745 (100%)	750,755 (100%)

Note: For ADL and IADL, ‘No’ indicates no difficulty performing the tasks. For ADL self-performance, the interRAI Home Care asks about transfer on and off toilet and toilet use the interRAI-CA asks about transfer in and off bath and overall hygiene.

Table 3-3 Unadjusted odds ratios and 95% confidence interval for individuals being rated as better-off in another environment. Values were obtained with generalized estimating equations (N = 1,134,593 assessments).

Variable		OR	2.5% - 97.5% CI
Cognitive skills for decision making (RE)	D2 = 3,4	1.79	1.70 - 1.80
Ability to understand others (RE)	C1 = 3,4,5	1.80	1.79 - 1.81
CHESS (SI)	CHESS >= 3	1.32	1.31 - 1.32
ADL transfer (RE)	G2g >= 3	1.26	1.25 - 1.26
ADL locomotion (SI)	G2f >= 3	1.23	1.23 - 1.24
ADL toilet use (SI)	G2h >= 3	1.30	1.29 - 1.30
IADL meal preparation (SI)	G1ab = 6	1.32	1.32 - 1.33
IADL manage medication (SI)	G1db = 6	1.35	1.34 - 1.35
Living Situation (RE)	A14a = 1	1.09	1.08 - 1.09
Mood (RE)	E1i = 3	1.17	1.16 - 1.18
Informal caregiver (SI)	P1b1 = 8	0.91	0.91 - 0.92
A caregiver is unable to continue caring activities (RE)	P2a = 1	2.92	2.89 - 2.95
Any signs of caregiver distress (SI)	P2b = 1	2.85	2.82 - 2.89
Oxygen (SI)	N2e >= 1	1.08	1.07 - 1.08

Note: Values between parentheses: ‘SI’ indicates items that were similar or the same between the two instruments, ‘RE’ indicates a replacement item, and ‘NA’ indicates that no item in the interRAI Contact Assessment could be used to replace the item present in the interRAI Home Care.

Table 3-4 Distribution of individuals classified at low and risk according to the Vulnerable Person Algorithm (VPR), and at low, mild, moderate, and high risk according to the Brief Risk Index (BRI). Distributions include both the interRAI Home Care and interRAI Contact Assessment instruments.

Item	Level	Value
Home Care		
VPR	Low risk (0)	293,511 (57.0%)
	Risk (1,2)	221,234 (43.0%)
BRI	Low risk (0)	58,630 (11.4%)
	Mild risk (1-3)	197,590 (38.4%)
	Moderate risk (4-6)	188,519 (36.6%)
	High risk (7+)	70,006 (13.6%)
Total		514,745 (100%)
Contact Assessment		
BRI	Low risk (0)	79,519 (10.6%)
	Mild risk (1-3)	229,709 (30.6%)
	Moderate risk (4-6)	342,163 (45.6%)
	High risk (7+)	99,365 (13.2%)
Total		750,755 (100%)

Note: Values between parentheses in the ‘Level’ column represent the grouping level of the VPR or BRI used to classified individuals at risk.

Table 3-5 Adjusted odds ratio and 95% confidence interval (CI) from two different generalized estimating equations for three outcomes of interest: triggering Vulnerable Persons at Risk algorithm (VPR; model 1), and hospitalizations (model 2). The area under the curve was 0.95 and 0.60 for Model 1 and Model 2, respectively). In models 1 and 2, the non-grouped Brief Risk Index (BRI; ranging from 0-13) was used as an explanatory variable (N = 1,134,593 assessments).

Variable	OR	2.5% CI	97.5% CI
Model 1: VPR			
Intercept	0.07	0.06	0.07
BRI	3.92	3.90	3.95
Age (years)	1.00	1.00	1.00
Sex (Reference = Female)	1.17	1.15	1.19
Model 2: Hospitalizations			
Intercept	0.52	0.50	0.54
BRI	1.14	1.14	1.14
Age	0.99	0.99	0.99
Sex (Reference = Female)	1.02	1.00	1.03

Note: Adjusted odds ratios comparing each health regions (reference = Erie St Clair):

Model 1 VPR: Varied from 0.43 (95% CI = 0.41-0.46) to 1.09 (95% CI = 1.04-1.04)

Model 2 Hospitalizations: Varied from 0.86 (95% CI = 0.84-0.88) to 1.22 (95% CI = 1.18-1.26)

Table 3-6 Hazard ratio and 95% confidence interval (CI) from a cox-regression model with individuals classified as at low, mild, moderate and high risk according to the BRI (N = 1,134,593 assessments).

Variable	OR	95% CI
Survival (Reference = Low risk)		
BRI – mild risk	1.10	1.06 - 1.13
BRI – moderate risk	1.26	1.23 - 1.30
BRI – high risk	1.67	1.61 - 1.72
Age (years)	0.99	0.99 - 0.99
Sex (Reference = Female)	1.02	1.00 - 1.03

Note: Adjusted odds ratio comparing each health regions (reference = Erie St Clair) varied from 0.85 (95% CI = 0.81-0.89) to 1.06 (95% CI = 1.02-1.11).

Table 3-7 The number and percentage of people in each health region in Ontario (local health integration networks; LIHN) classified as at risk based on the 4-point Brief Risk Index (BRI).

LIHN	Low risk	Mild risk	Moderate Risk	High risk	Total
Central	6,350 (8.7%)	15,449 (21.1%)	35,056 (47.9%)	16,265 (22.2%)	73,120 (9.7%)
Central East	9,677 (10.2%)	24,439 (25.9%)	48,344 (51.2%)	11,969 (12.7%)	94,429 (12.6%)
Central West	3,516 (9.4%)	9,614 (25.6%)	18,688 (49.8%)	5,734 (15.3%)	37,552 (5.0%)
Champlain	6,962 (9.2%)	22,830 (30.3%)	33,881 (45.0%)	11,608 (15.4%)	75,281 (10.0%)
Erie St Clair	3,240 (7.8%)	13,016 (31.4%)	20,261 (48.9%)	4,958 (12.0%)	41,475 (5.5%)
Hamilton Norfolk	7,915 (9.5%)	25,792 (31.0%)	36,918 (44.3%)	12,644 (15.2%)	83,269 (11.1%)
Mississauga Halton	5,696 (9.6%)	20,149 (33.9%)	26,747 (45.0%)	6,881 (11.6%)	59,473 (7.9%)
North East	6,840 (14.2%)	18,734 (38.9%)	19,216 (39.9%)	3,428 (7.1%)	48,218 (6.4%)
Simcoe Muskoka	2,577 (9.8%)	6,038 (23.0%)	12,187 (46.5%)	5,396 (20.6%)	26,198 (3.5%)
North West	4,036 (21.6%)	8,341 (44.6%)	5,697 (30.5%)	625 (3.3%)	18,699 (2.5%)
South West	7,249 (15.0%)	26,321 (54.4%)	11,653 (24.1%)	3,143 (6.5%)	48,366 (6.4%)
South East	7,694 (15.0%)	27,087 (52.7%)	12,794 (24.9%)	3,847 (7.5%)	51,422 (6.8%)
Toronto Central	7,345 (9.4%)	24,471 (31.2%)	37,177 (47.4%)	9,380 (12.0%)	78,373 (10.4%)
Waterloo Wellington	422 (2.8%)	2,167 (14.6%)	8,804 (59.2%)	3,487 (23.4%)	14,880 (2.0%)
Total	79,519 (10.6%)	229,709 (30.6%)	342,162 (45.6%)	99,365 (13.2%)	750,755

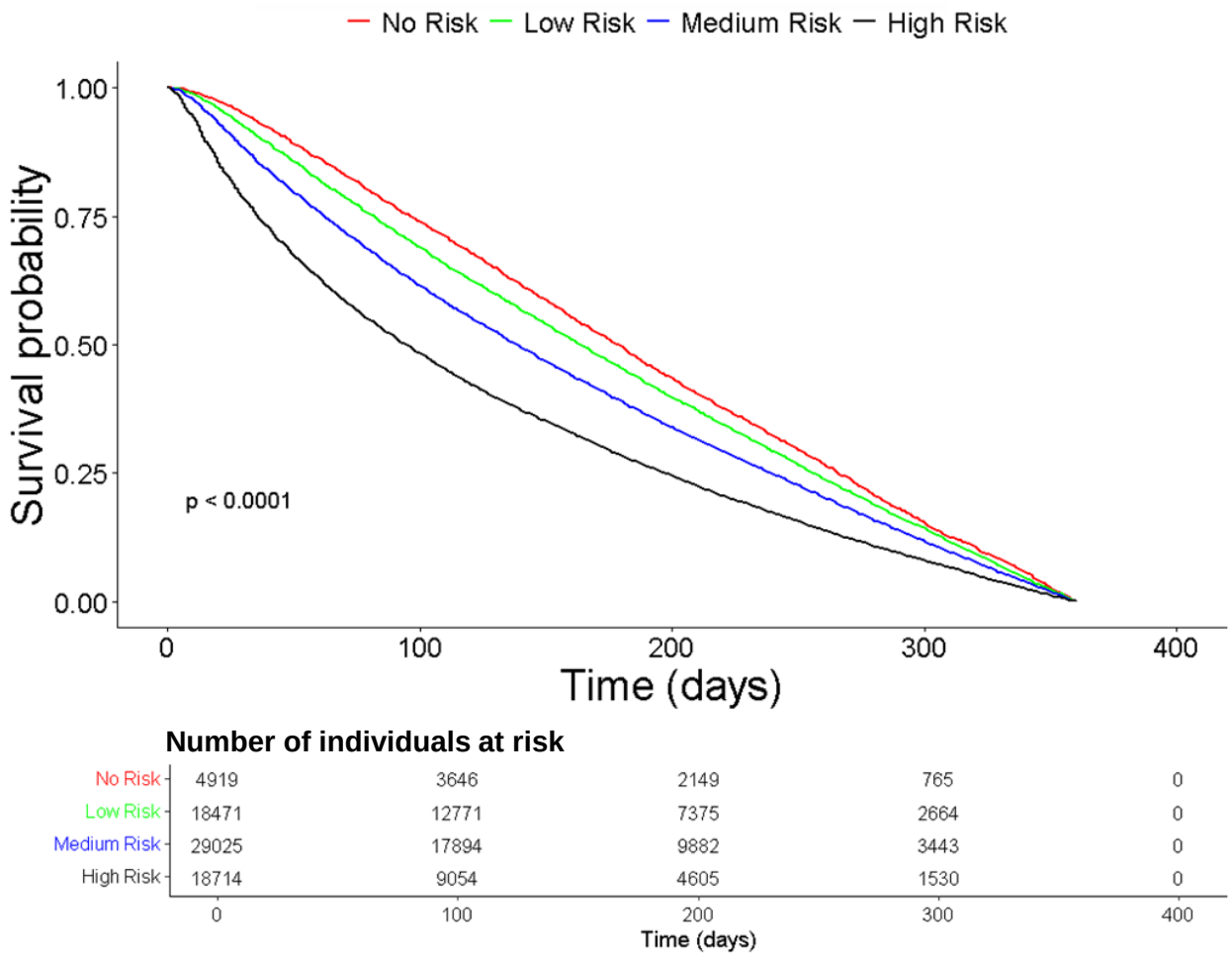


Figure 3-1 Survival curves for the 1-year survival analysis with the comparison between those classified at low risk, mild, moderate, and high risk with the Brief Risk Index (BRI; N = 750,755 unique individuals).

Note: The table below the curves shows the number of individuals classified in each category of the BRI for 0, 100, 200, 300, and 400 days according to the 1-year survival analysis.

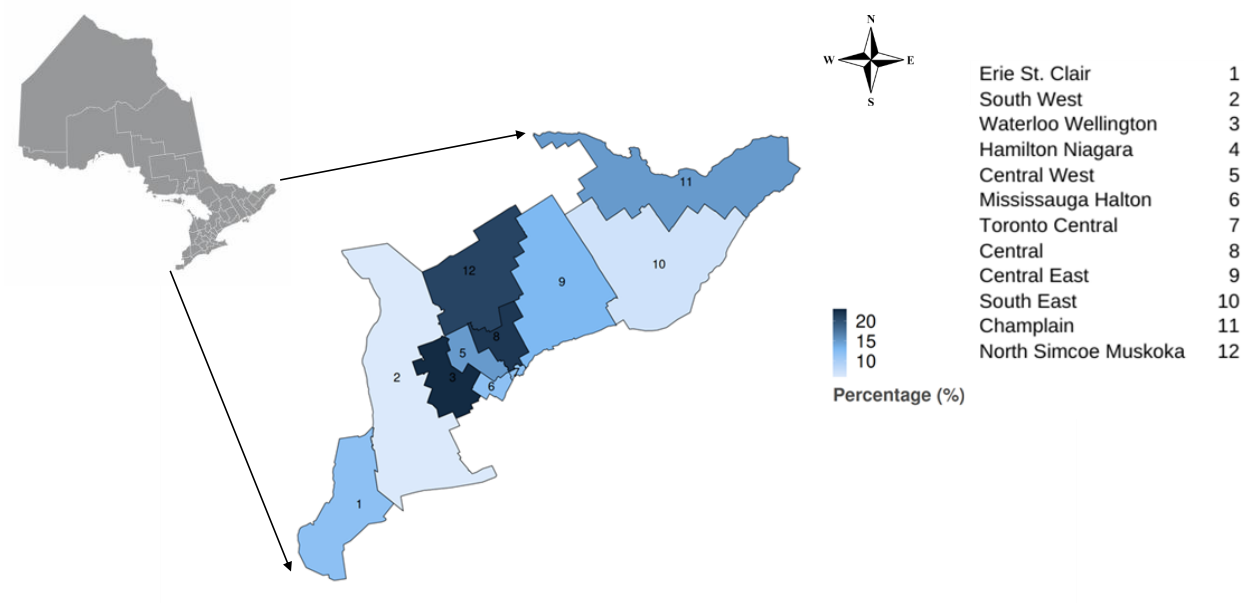


Figure 3-2 Map of the percentage of clients who were identified as at high risk of adverse health outcomes based on the Brief Risk Index (BRI) in each of the 12 health regions (i.e., local health integration networks, LHIN) in southern Ontario.

Note: Darker shade of blue indicates a higher percentage of individuals at risk of adverse health outcomes within each local health integration network (LHIN).

Chapter 4

Study 3: Using interRAI assessments to identify older adults at risk during periods of poor air quality

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Declarations

Ethics approval and consent to participate

Ethics clearance was obtained from the University of Waterloo Office of Research Ethics for secondary analyses of anonymized interRAI data obtained through a Data Sharing Agreement with the Canadian Institute for Health Information - ORE 30372.

Availability of data and materials

Data used for these analyses can be accessed through the Canadian Institute for Health Information. The authors do not have permission to transmit data to third parties.

Competing interests

We have no conflict of interest to declare.

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Author’s contribution

GSB and JPH conceived the study. GSB conducted the statistical analysis and wrote the first draft of the manuscript. All authors discussed the ideas and commented on subsequent drafts of the manuscript.

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4.1 Introduction

Air pollution is a major risk factor for adverse health outcomes, including death (Brauer et al., 2012, Landrigan et al., 2018; Sun & Zhu, 2019; Dominski et al., 2021; Balmes et al., 2025; Bolan et al., 2025). The World Health Organization (WHO) have estimated that 9 million people die every year because of air pollution (World Health Organization, 2023a). This represents 16% of all deaths worldwide, making it the second highest risk factor for noncommunicable diseases (Landrigan et al., 2018; World Health Organization, 2023a). This is not surprising considering that in 2019, most of the world's population lived in areas where air quality was below the WHO guidelines (World Health Organization, 2021). Also, acute and long-term exposure to polluted air is associated with several adverse health outcomes, especially cardio-respiratory problems like stroke or chronic obstructive pulmonary disease (Dominski et al., 2021; Kampa & Castanas, 2008; Sun & Zhu, 2019; World Health Organization, 2021; World Health Organization, 2023a).

Although there are many types of pollutants in the air, such ambient carbon monoxide, ozone, and nitric oxide, particles with an aerodynamic diameter below 2.5 μm (PM2.5) and 10 μm (PM10) are the leading causes of adverse health outcomes related to air pollution (Henderson et al., 2011; Johnston et al. 2012; Landrigan et al., 2018; Sanyal et al., 2018; Cong Liu et al., 2019; Dominski et al., 2021; Balmes et al., 2025; Bolan et al., 2025). The Global Burden of Disease study estimates that 4.2 million people died every year because of air pollution caused by particulate matter, compared to 0.3 million deaths caused by ambient ozone (GBD 2015 Risk Factors Collaborators, 2016; Landrigan et al., 2018). These particulate matters are formed via fuel combustion, (e.g., motor vehicles and industrial

facilities) or agricultural burning, and forest fires. Although the release of PM2.5 and PM10 has been steadily decreasing in many parts of the world (e.g., Europe and North America) some studies suggest that wildfire smoke might become the dominant source of PM2.5 and PM10 during the fire season (Ford et al., 2018; Chen et al., 2021; Burke et al., 2023; Cunningham et al., 2024) and might cause a reverse in the historical decline observed in the last decades. This has important public health consequences because wildfires are expected to increase because of climate change, which will likely increase the levels of PM2.5 and PM10 in the air in the next few decades. Moreover, we might observe a higher frequency of acute episodes of poor air quality that are often deadly for people with certain health conditions.

Older adults are at high risk of health complications during poor air quality because heart and respiratory problems become common with age (Akgün et al., 2012; van Riet et al., 2016). Half of deaths cased by air pollution are from cardiovascular diseases, and around half of these deaths occur among people over the age of 65 years (Chang et al. 2022). Even low to moderate levels of outdoor air pollution can result in adverse health outcomes in older adults (Curtis et al., 2006; Melton et al., 2023). For example, hospitalizations for chronic obstructive pulmonary disease in elderly was positively associated with low levels of PM2.5 in Vancouver, Canada (Chen et al., 2004), and short-term exposures to PM2.5 below the national standards was associated with increased risk of mortality in older adults in the USA (Di et al., 2017). Climate change promotes the conditions under which fire might happen, such as dryer years and longer fire season (Jones et al., 2020; Pausas & Keeley, 2021; Burke et al., 2023, Cunningham et al., 2024). Hence, identifying older adults at risk of health

complications during acute episodes of poor air quality is an essential step in adapting our health system to the negative effects of climate change.

Here we used clinical assessments of older adults with complex medical needs living in the community to develop a cardiorespiratory vulnerability index able to identify individuals who are more likely to experience health complications during periods of poor air quality. This population is likely the most at risk not only because of their clinical needs, but also because they live in the community and might not have the support needed during times of crisis, such as older adults living in nursing homes. To understand whether our index was a good predictor of health problems in our population, we investigated the association between the index and four health outcomes. We then calculated how many individuals in Ontario would be classified at risk during the summer of 2023, the worst wildfire season registered in Canada.

4.2 Methods

4.2.1 Data

In Ontario, any person with complex medical needs (e.g., chronic conditions, disabilities, and those in palliative care) is eligible to receive publicly funded health services including community-based home care. Since 2002, interRAI assessments have been used to evaluate the strengths, preferences and needs of all long-stay home care clients (Gray et al., 2009; Carpenter & Hirdes, 2013; Morris et al., 2013). Assessments are conducted by a trained health professional (e.g., nurse, social worker) every 6-12 months or when there is an important change in the client's health. For this analysis, we considered only older adults (65

years or older) because they are often the most vulnerable individuals among the home care clients and represent 85% (489,582 individuals) of our sample. Our dataset contained 942,439 observations from 416,008 unique individuals collected from May 2018 to December 2023. In 2023 alone, there were 157,573 observations from 56,835 unique individuals. We constrained our analyses to 2018 or later because Ontario adopted a newer version of the interRAI Home Care (interRAI HC) assessment at that time. The interRAI HC provides additional items on health vulnerabilities and many items include a more granular response set than older instruments.

To develop the Cardiorespiratory Vulnerability index (CRV), we used all items (16) in the interRAI HC assessment that have been directly associated with poor health outcomes during poor air quality (Table 4.1). Recent reviews of the effects of air pollution on health have identified respiratory (e.g., chronic obstructive pulmonary disease and pneumonia) and cardiovascular diseases (e.g., ischemic heart disease and ischemic stroke) as the most studied outcomes (Sun & Zhu 2019, Dominski et al., 2021). Those 16 items (Table 4.1) were the ones available in the interRAI HC that could indicate a diagnosis of respiratory (e.g. pneumonia) and/or cardiovascular disease (e.g., chronic obstructive pulmonary disease; COPD). We also used items related to health conditions often associated with these diseases, such as chest pain or flare-up of a chronic condition (e.g., a sudden period of shortness of breath in someone with a history of asthma), and identified individuals who had trouble clearing airway secretions, and those who smoke cigarettes daily. In addition, we included four treatments and procedures (oxygen therapy, suctioning, tracheostomy care, and

ventilator or respirator) that could be related to respiratory and/or cardiovascular problems (Table 4.1). We combined all four treatments and procedures and the aspiration item into one variable called ‘respiratory problems’ if the client had at least 1 of the 4 treatments presented or ordered in the last three days or the presence of aspiration in the last three days. Aspiration refers to the inhalation of food or fluid into the lungs. All variables were coded as present or absent (Table 4.1). We then used these 12 items and, for each individual sum them up to create a scale from 0 to 12, where 0 indicated absence of problems and 12 indicated that the individual had problems in all items.

4.2.2 Statistical analysis

We used the Pearson correlation coefficient to calculate the correlation among each of the 12 items described above as well as their correlation with the overall CRV. To understand the association between the CRV and potential adverse health outcomes, we used generalized estimating equation models with four health outcomes as response variables: hospital admissions, emergency department and physician visits, and self-rated health. Client identification was entered as the grouping factor with an auto-regressive correlation structure. Hospital admissions and emergency department were coded as 0 if the client had no visits/admissions in the last 90 days (from the day of the assessment) or 1 if they had 1 or more visits in the same period. Self-rated health was coded as 0 if the client rated their health as excellent, good, or fair, and 1 if they rated as poor. Physician visit was coded as 0 if they had 1 or less visits in the last 90 days or 1 if they had 2 or more visits in the same period. We coded physician visits differently from hospital admissions and emergency department visits

because most individuals in our sample had at least one visit in the last 90 days (476,778 observations or about 50% of the total) while 0 hospital admissions (839,261 or 89%) and 0 emergency department visits (659,707 or 77%%) were more frequent in the dataset.

To investigate how many clients could be at risk in Ontario, we first obtained cut-point values for the Cardiorespiratory Vulnerability index using the Youden index, defined as $J_{max} = max_t$ [sensitivity (t) + specificity (t) – 1], where *t* denotes the classification threshold that maximizes *J* (Ruopp et al., 2008). We averaged the cut-points based on the Youden index for all outcomes to obtain a single cut-point for the Cardiorespiratory Vulnerability index. We then used this value to calculate the number and percentage of older adults classified as at risk during the summer of 2023 in each health region in Ontario (i.e., local health integration networks; LHIN).

All analysis were conducted in R v4.3.2 (R Core Team, 2024). Generalized estimating equations were conducted with the *geepack* package (Højsgaard et al., 2006), correlations were calculated with the *corrplot* package (Wei et al., 2013), and the Youden index was calculated with the *cutpointr* package (Thiele & Hirschfeld, 2021). We used the *tidyverse* package (Wickham et al., 2019) for data filtering and cleaning, and figures. Maps were made with the *sf* package (Pebesma, 2018).

4.3 Results

From the 416,008 unique individuals in this study, 41% were 85 years and older, 41% were married, 44% were widowed and 86% lived in urban areas (Table 4.1). The lowest percentage of issues were observed among items related to treatments and procedures (e.g.,

oxygen therapy and ventilation) while the highest percentages were related to respiratory problems and flare-up (Table 4.1).

The correlations among the 12 items used to develop the Cardiorespiratory Vulnerability index were between 0.03 (smoke and congestive heart failure) and 0.29 (dyspnea and pulmonary disease; Figure 4.1). The correlations between the Cardiorespiratory Vulnerability index and the 12 items ranged between 0.21 for pneumonia and smoke and 0.59 for fatigue (see Figure 4.1). All correlations were significant (p-value<0.05).

All four health outcomes were positively associated with the Cardiorespiratory Vulnerability index (Figure 4.2). Each single point increment in the Cardiorespiratory Vulnerability index increased the odds of a client being admitted to a hospital in the 90 days before the assessment by at least 25% (OR = 1.26, 95% CI = 1.25-1.26; Table 4.2), by 12% the odds of visiting a physician (OR = 1.12, 95% CI = 1.12-1.13; Table 4.2), by 16% the odds of going to the emergency room (OR = 1.16, 95% CI = 1.16-1.17; Table 4.2), and by 37% the odds of rating their health as poor (OR = 1.37, 95% CI = 1.36-1.38; Table 4.2).

The best cut-points based on the Youden index were 3 for all 4 health outcomes investigated. About 36% (19,547) of unique individuals in 2023 were classified as at increased risk (Table 4.3; Figure 4.3). The number of clients at risk in each health region (LHIN) varied between 292 (33.4% of the total clients in the North West health region) and 3,644 (44.3%, Hamilton Niagara; Table 4.3; Figure 4.3).

4.4 Discussion

We used clinical information of older adults with complex medical needs living in the community to construct a 12-item risk index. This new index, the CRV, was associated with major adverse outcomes, such as hospitalizations and self-rated health. When applied to the home care population, the CRV identified 20,000 residents who were at much higher risk of being hospitalized during or after a major poor air quality event. This represented approximately 35% of individuals who required home care services in 2023 in Ontario. Thus, our results suggest that the CRV could correctly identify those at risk and would allow for targeted programs and services prior to and during acute deterioration of air quality. Moreover, because the interRAI HC assessment is already mandated in Ontario, using this tool would improve the ability of health care organizations to prepare for wildfires without needing additional assessment resources.

The ability to identify individuals at risk during periods of crisis can give public health agencies time to prepare and prioritize the use of resources. Our CRV could be important in early spring to obtain a list of clients potentially in danger during the wildfire seasons (usually between May through September in Canada). Preventive interventions could be applied early and targeted to minimize the adverse health outcomes in this population. For example, the information provided by the CRV could be shared with primary care providers and other community providers to monitor clients and prepare for early intervention during periods of poor air quality.

In addition to the use at the individual level, the CRV could also inform broader, population-level actions. We identified geographic regions, measured by health regions, with higher proportion of older adults at risk in Ontario. With postal code, it would be also possible to identify neighbourhoods with high frequency of individuals at risk. These geographic "hot-spots" should be the focus of community emergency preparedness initiatives related to the health risks associated with wildfire smokes.

We believe that the use of routine clinical information is a promising way to identify individuals living with vulnerabilities during wildfire season and other natural hazards (van Solm et al., 2017). First, detailed clinical information from each home care client is already available to public health agencies in many Provinces in Canada, as well as other countries. This means that there is no need to create additional resources, such as local registries of people with disabilities and chronic health issues (Fox et al., 2007). More recently, there has been attempts to use social media and text analysis to identify those at risk in areas affected by natural hazards (Ragini et al., 2018; Khatoon et al., 2022). The problem with this approach is that although social media use has been increasing among older adults, is still much less common compared to the younger population (Cotten et al., 2022), i.e. many older adults at risk would not be identified. Moreover, this approach could only be used during the time of the disaster, not in preparation of the disaster, such as our index. Second, because the interRAI assessments collect detailed and updated clinical information, our index has a greater chance of correctly identifying those individuals at risk, compared to other methods that might not be so complete nor are regularly updated. Finally, given the use of interRAI

systems internationally (Vesentini et al., 2011, Carpenter & Hirdes, 2013; Schluter et al., 2016) this solution could be employed in other countries using these assessments.

The CRV identified around 20,000 people at risk only among home care clients in Ontario, in 2023. This number will likely be much higher in the next couple of decades because of the concurrent trends in population aging and climate change that increases the risk of wildfire (Jones et al., 2020). The area burned by wildfires double in Canada from the 1970s to the 2000s (Berry & Schnitter, 2022; Jain et al., 2024). From 2001 to 2021, the number of people 85 years and older doubled and it is expected to triple by 2046 (Hallman, 2022). Thus, it is essential that we develop approaches to protect older adults who might be living with vulnerabilities to the negative effects of wildfire smoke.

4.5 Limitations

One of the limitations of our study is that only home care clients can be identified by our index. There might be older adults living in the community who do not receive publicly funded community services who are equally vulnerable to the adverse effects of air pollution. Older adults with complex medical needs might also live in care facilities (e.g., nursing homes, hospitals), which are not covered by our data. Thus, it would be important to extend the use of Cardiorespiratory Vulnerability index to other settings, especially those places where individuals are assessed with similar interRAI instruments (e.g., nursing homes). Another limitation of our study is the lack of data to evaluate its performance directly in the context of changes in air quality. Once the 2023 interRAI HC data are linked to hospitalization and emergency department databases, it will become possible to conduct a

direct evaluation. For example, it will be possible to compare individuals who were identified as at risk by our index with adults who were admitted to hospitals or went to emergency departments because of health complications caused by poor air quality. The challenge with such analysis is that many older adults live alone and might not seek help during periods of crisis, which would underestimate the real number of those at risk.

4.6 Conclusions

Our results indicate that the CRV can correctly identify individuals at risk of adverse health outcomes during periods of wildfire smoke and could also use to identify geographic locations with higher frequency of those at risk. The correct identification of individuals living with vulnerability in the community who might also be at high risk of health complications because of natural hazards is an essential step to adapt our health system to the adverse effects of climate change on our physical and mental health. Climate change is increasing the frequency, intensity, and duration of some natural phenomena that can negatively impact our health, such as heat waves and floods (Romanello et al., 2023). Particularly important for air quality is the increase in the conditions under which wildfires might happen, such as hot and dry years (Jones et al., 2020). It is expected that acute periods of poor air quality might become routine under this scenario, which will certainly affect the health of older adults with complex medical needs. The CRV developed here represents an important tool to support public health organizations in the adaptation of our public health system to this new scenario.

Table 4-1 List of the 16 items used to develop the Cardiorespiratory Vulnerability index (CRV) based on interRAI Home Care assessment and their prevalence among the studied population (N = 416,008 unique individuals).

Item	Code	N
Age	65-74	90,397 (21.7%)
	75-84	153,274 (36.8%)
	85+	172,337 (41.4%)
Marital Status	Married	169,484 (40.7%)
	Not married	64,077 (15.4%)
	Widowed	182,447 (43.9%)
Rural/Urban	Rural	58,444 (14%)
	Urban	357,564 (86.0%)
Disease diagnosis		
COPD	0 = absent; 1 = diagnosis	58,569 (14.1%)
Coronary Heart Disease	0 = absent; 1 = diagnosis	127,232 (30.6%)
Congestive Heart Failure	0 = absent; 1 = diagnosis	55,810 (13.4%)
Pneumonia	0 = absent; 1 = diagnosis	11,320 (2.7%)
Diabetes	0 = absent; 1 = diagnosis	121,194 (29.1%)
Health conditions		
Chest Pain	0 = absent; 1 = present (exhibited or not) in the last 3 days	29,983 (7.2%)
Difficulty Clearing Airway Secretions	0 = absent; 1 = present (exhibited or not) in the last 3 days	26,095 (6.3%)
Dyspnea	0 = absent; 1 = present at rest, in day-to-day and moderate activities	85,463 (20.5%)
Fatigue	0 = absent or minimal; 1 = moderate or severe	167,679 (40.3%)
Flare-up	0 = absent; 1 = present	137,823 (33.1%)
Smoke	0 = absent; 1 = smokes tobacco daily	27,608 (6.6%)
Aspiration	0 = absent; 1 = present (exhibited or not) in the last 3 days	5,682 (1.4%)
Treatments and procedures		
Oxygen therapy	0 = absent; 1 = ordered or occurred in the last 3 days	18,841 (4.5%)
Suctioning	0 = absent; 1 = ordered or occurred in the last 3 days	1,124 (0.3%)
Tracheostomy care	0 = absent; 1 = ordered or occurred in the last 3 days	933 (0.2%)
Ventilator or respirator	0 = absent; 1 = ordered or occurred in the last 3 days	1,429 (0.3%)

Note: 'COPD' refers to chronic obstructive pulmonary disease, 'Flare up' refers to sudden worsening of a chronic condition, 'Smoke' refers to individuals who smoke cigarettes daily, and 'Aspiration' refers to the inhalation of food or fluid into the lungs.

Table 4-2 Unadjusted odds ratios and 95% confidence interval (CI) for individuals being admitted to a hospital (model 1), visiting a physician (model 2), going to the emergency room (model 3), and rating their health as poor (model 4; N = 942,439 assessments). Values were obtained with 4 different generalized estimating equations, one for each model. The area under the curve was 0.59, 0.57, 0.61, and 0.65 for models 1, 2, 3, and 4, respectively.

Variable	OR	95% CI
Model 1: Hospitalization		
Intercept	0.28	0.27 – 0.28
Cardiorespiratory Vulnerability index	1.26	1.25 – 1.26
Model 2: Physician Visits		
Intercept	1.97	1.95 – 1.98
Cardiorespiratory Vulnerability index	1.12	1.12 – 1.13
Model 3: Emergency room		
Intercept	0.22	0.22 – 0.22
Cardiorespiratory Vulnerability index	1.16	1.16 – 1.17
Model 4: Self-rate health		
Intercept	0.08	0.08 – 0.08
Cardiorespiratory Vulnerability index	1.37	1.36 – 1.38

Table 4-3 The number (and percentage) of people in each health region in Ontario (local health integration networks; LIHN) in 2023 classified as at risk of health complications based on a score of 3 or more on the Cardiorespiratory Vulnerability index (CRV).

	Cardiorespiratory Vulnerability index		
Health Region	<3	>=3	Total
Central	4,415 (70.1%)	1,883 (29.9%)	6,298 (11.1%)
Central East	5,128 (66.4%)	2,594 (33.6%)	7,722 (13.6%)
Central West	1,691 (62.1%)	1,032 (37.9%)	2,723 (4.8%)
Champlain	3,116 (64.8%)	1,695 (35.2%)	4,811 (8.5%)
Erie St. Clair	1,978 (63.4%)	1,142 (36.6%)	3,120 (5.5%)
Hamilton Niagara	4,583 (55.7%)	3,644 (44.3%)	8,227 (14.5%)
Mississauga Halton	2,553 (73.7%)	913 (26.3%)	3,466 (6.1%)
North East	1,593 (60.7%)	1,032 (39.3%)	2,625 (4.6%)
North Simcoe Muskoka	1,154 (57.3%)	859 (42.7%)	2,013 (3.5%)
North West	582 (66.6%)	292 (33.4%)	874 (1.5%)
South East	1,382 (57.7%)	1,015 (42.3%)	2,397 (4.2%)
South West	4,230 (70.5%)	1,774 (29.5%)	6,004 (10.6%)
Toronto Central	2,367 (75.7%)	759 (24.3%)	3,126 (5.5%)
Waterloo Wellington	2,516 (73.4%)	913 (26.6%)	3,429 (6.0%)
Total	37,288 (65.6%)	19,547 (34.4%)	56,835

Note: The cut-point value of 3 or more items was calculated using the Youden index. The map with each health region and percentages is shown in Figure 4.3.

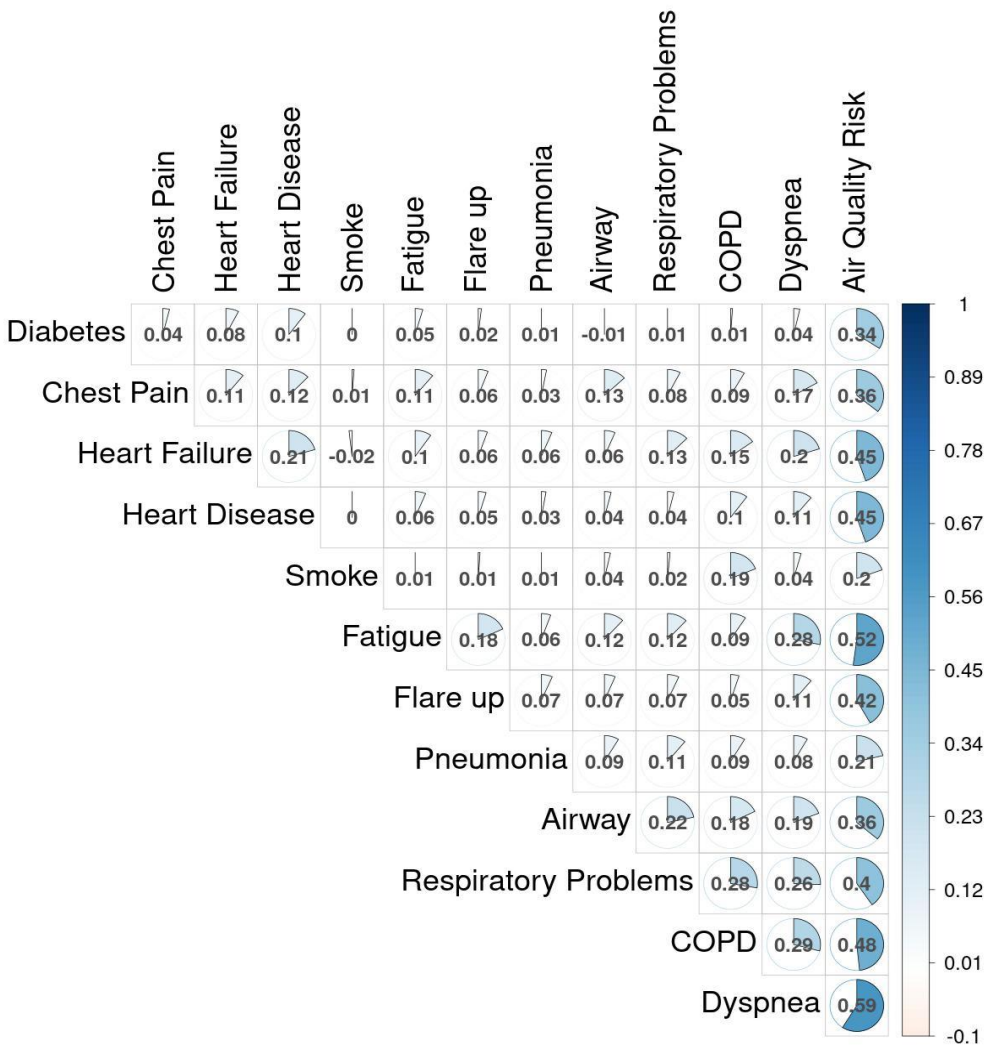


Figure 4-1 Correlation matrix with all 12 items used to develop the Cardiorespiratory Vulnerability index (N = 942,439 assessments).

Note: Numbers inside the rectangles are Pearson correlation coefficients. Darker shades of blue indicate greater correlation coefficient. 'Heart failure' refers to congestive heart failure, heart disease' refers to coronary heart disease, 'COPD' refers to chronic obstructive

pulmonary disease, ‘Airway’ refers to difficulty clearing airway secretions, ‘Flare up’ refers to a sudden worsening of a chronic condition, and ‘Smoke’ refers to individuals who smoke cigarettes daily.

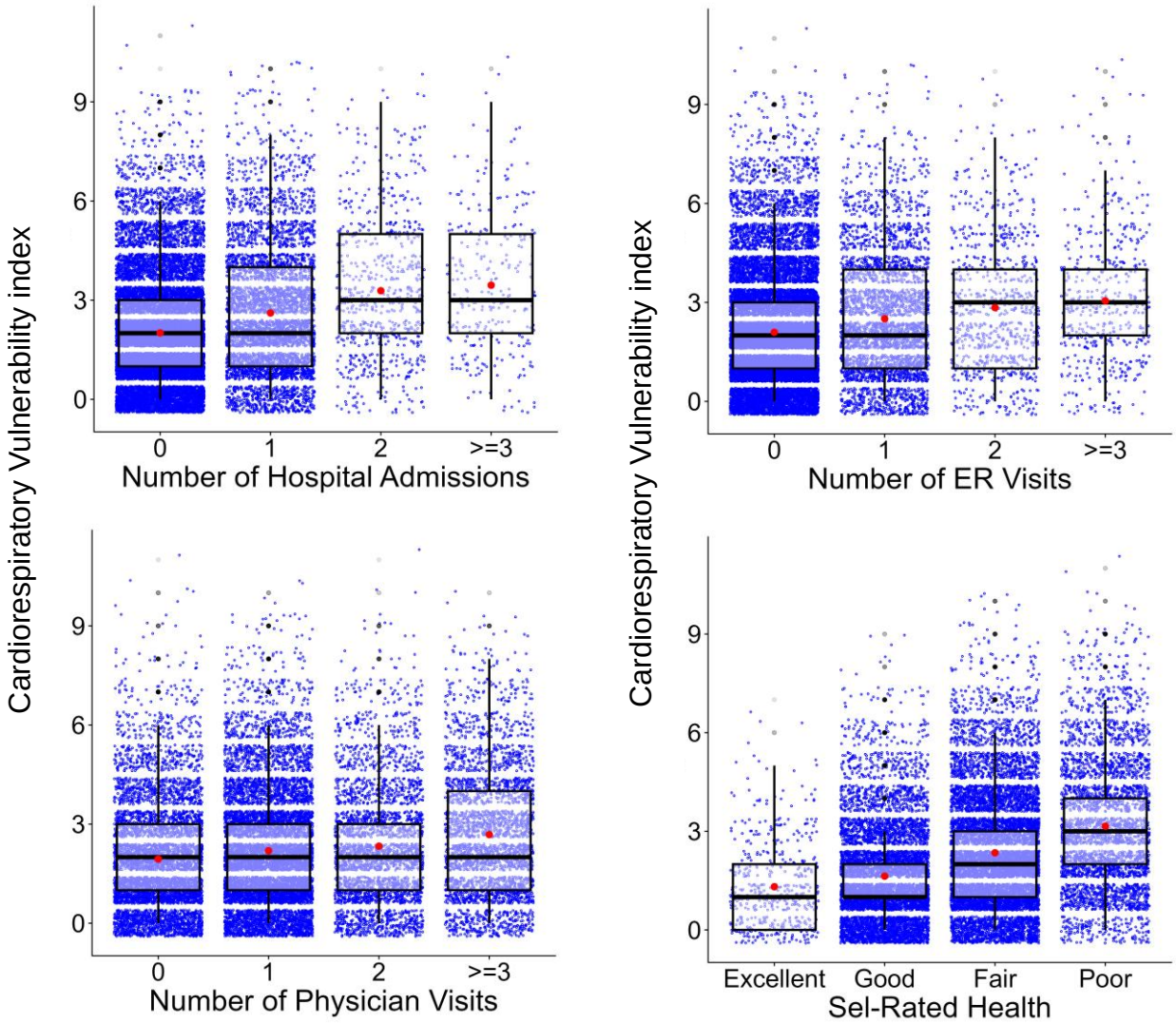


Figure 4-2 Association between the Cardiorespiratory Vulnerability index and four health outcomes investigated in this study.

Note: Figures were created with a random selection of 20,000 observations for better visualization. 'ER' means emergency room. Blue points indicate observations and red points indicate mean. The horizontal line within each box represents the median value, the edges are

25th and 75th percentiles, the whiskers extend to the most extreme data points, and black points on top of the whiskers are potential outliers.

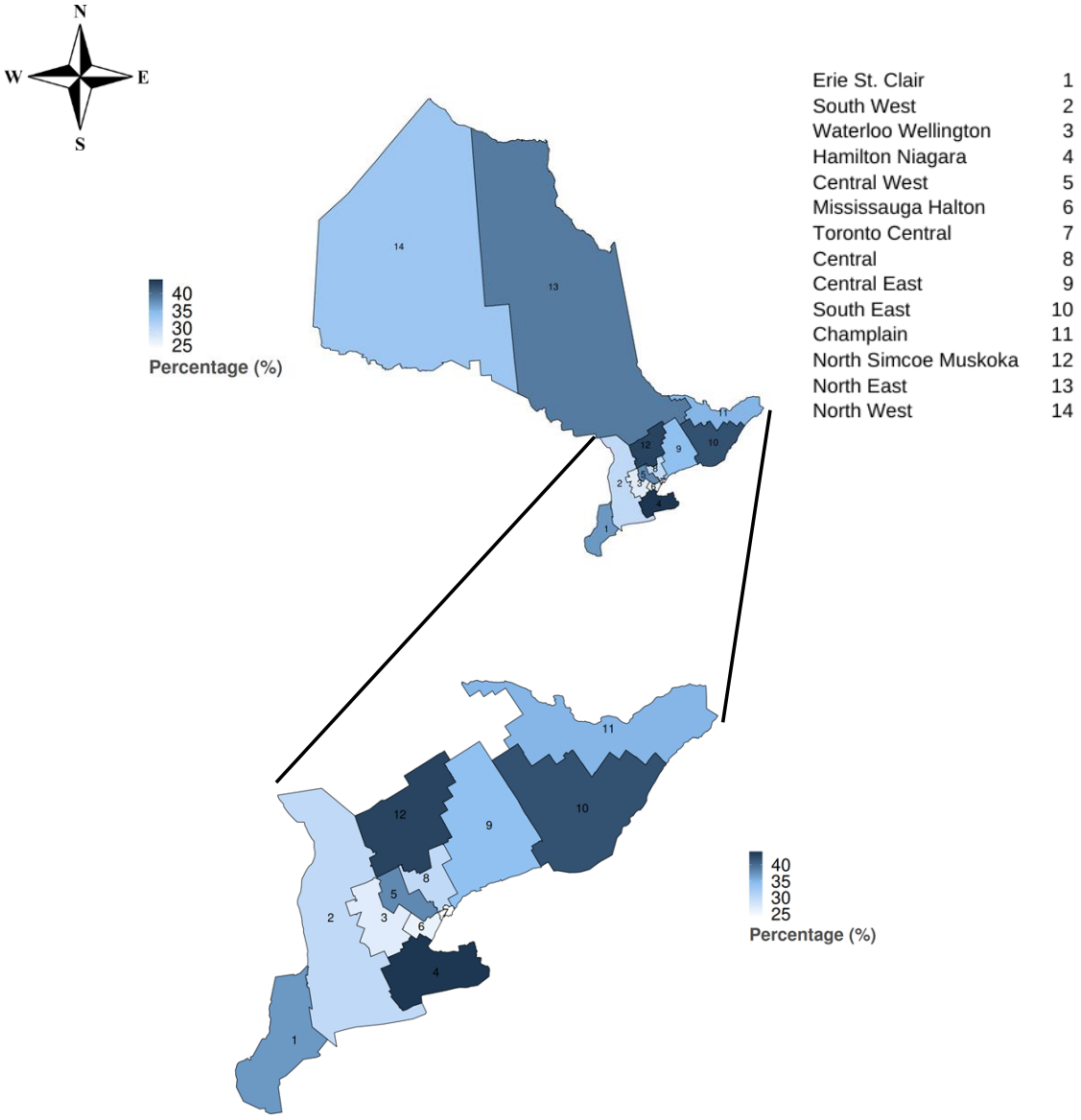


Figure 4-3 Map with the percentage of clients who were identified as at risk based on the Cardiorespiratory Vulnerability index (CRV) in all 14 health regions (i.e., local health integration networks; LHIN) in Ontario in 2023.

Note: Darker shade of blue indicates a higher percentage of individuals at risk within each LHIN.

Chapter 5

General discussion and conclusions

5.1 Introduction

In 2023, the United Nations' Intergovernmental Panel on Climate Change published a report indicating that global warming will reach 1.5°C above pre-industrial levels in the next decades (IPCC, 2023). At 1.5°C, extreme weather events are expected to drastically increase in frequency, duration, and intensity (IPCC, 2023; in 2024, the global average temperature was 1.6°C; Goessling et al., 2025). As discussed in this thesis, these events often result in large human suffering and financial costs to our public health system (Leppold et al. 2022). Older adults are among those who are most affected (Bell et al., 2020; Durak, 2023) because of the high incidence of multi-morbidity and geriatric syndromes among those 65 years and older (Durak, 2023). Moreover, older adults with multi-morbidity use health care more frequently than other age groups, and natural disasters can lead to interruptions in health care and prevent access to infrastructure (Bell et al., 2020; Durak, 2023). Unfortunately, this scenario will only become more aggravated as the proportion of older adults increases in the next decades (UN DESA, 2023).

In Canada, the situation is not different. People experience several adverse health complications associated with extreme high temperatures and wildfires (Berry & Schnitter, 2022; Lulham et al., 2023; Jain et al., 2024). Every year, the health costs of these extreme events in the billions of dollars (Matz et al., 2020, Boudreault et al., 2025). We have now around 7 million Canadians aged 65 and older, a 20% increase since 2011. By 2046, we might reach 3 million Canadians 85 years and older. At the same period, the growth rate among the youngest (below 15 years) was 6 times slower (Statistic Canada, 2022). Thus, around the world and in Canada, climate change and an aging population are creating the

conditions under which an increasing number of people will be at risk of adverse health outcomes. This thesis aimed to provide solutions to promote the adaptation of our public health system to this new scenario.

5.2 Summary of findings

The three studies in the thesis used clinical, demographic, and social-economic data collected at the individual level to: a) understand what places older adults at higher odds of living in houses with inadequate heating or cooling, and b) develop indices to identify individuals at high risk of health complications caused by extreme weather events.

Study 1 investigated, for the first time, the risk and protective factors associated with inadequate thermal environment in a population of home care clients in Canada. Using data from older adults who receive support at home because of their medical needs, the findings from this study indicate that older adults with financial problems, lack of informal caregiver or caregiver experiencing abuse or distress, and those living in rural areas and Yukon were more likely to live in houses with inadequate heating or cooling. Age was a protective factor, but only for older individuals within our population (75+). Not living alone was also a protective factor for males, but not for females. These results are concerning because poor thermal environment has been associated with both adverse physical and mental health outcomes, such as incidence of infection diseases, asthma, anxiety, depression, and psychological distress. Investments to provide proper heating or cooling to this population are a fraction of the current public costs of heat waves and cold spells, such as acute admission to care facilities (e.g., long-term care) and hospitalizations from cardio-respiratory

problems and dehydration. Thus, the results in study 1 can inform climate adaptation strategies, such as cost-effective investments to improve the thermal environment of those at risk.

Study 2 presented a new index to identify those at high risk of adverse health complications during extreme weather events. The goal of the index was to identify individuals that would be in trouble if they had to evacuate their houses during a natural hazard. Analysis showed that all the items and the new scale were associated with clients indicating that they would be better off in another environment. The rational for using this question is that if clients believe that they should not be in their current home under normal circumstances, their situation could be much worse during a natural hazard. The new index, the BRI, was associated with hospitalizations and death regardless of the environmental conditions, suggesting that individuals identified by the BRI could be in real trouble during a crisis. The main advantage of the new index is that it contains less items than a similar tool, the VPR, an algorithm that has been successfully used in the context of an earthquake. Despite having less items, the BRI showed similar performance compared to the VPR. The BRI could be used with assessments that cover a larger population, such as the interRAI-CA, which includes potential long-stay home care clients. Therefore, the BRI is also ideal to guide conversations with potential home care clients about how they could better prepare to minimize health risks during natural hazards.

Study 3 also developed a new index, but a more specific one to be applied during periods of poor air quality, which are becoming more frequently because of wildfire smoke. The 12-point scale includes items that are well-known risk factors associated with poor air

quality, such as respiratory and heart diseases. For this study, data came from home care clients living in Ontario. The results indicate that the index might perform well in a time of crises given that it was positively associated with hospital admissions, emergency department and physician visits, and poor self-rated health. When applied the study population actively reviving services in 2023 (the year of the worse wildfire season registered in Canadian history), the index indicated that 35% of the clients could be at risk of health complications. This is essential information for public health. For example, home care providers could adopt actions to better prepared those at risk, such as conversations about what to do during periods of poor air quality. In addition, the index could identify geographic locations (e.g., neighbours) with high incidence of individuals at risk, and support the development of public health initiatives to increase emergency preparedness about poor air quality in these areas.

Together, the three studies in this thesis represent a unique perspective about how our public health system could prepare for climate change and show new directions for research. Up to now, most studies aiming to understand the health consequences of natural hazards have used health data combined with environmental data (Leppold et al., 2022; Grant & Runkle, 2022) to find associations between health outcomes (e.g., hospital admissions for asthma) and environmental events (e.g., wildfire smoke). Study 1 in this thesis presents a different perspective because it shows how detailed information about the individual and their environment can shed new light into the reasons people might experience adverse health outcomes during a natural hazard. The novelty of study 1 relies on the combined use of clinical, demographic, environmental, and social-economic data to understand the conditions under which people are more likely to live in houses with poor thermal environment. Thus,

study 1 provides information about actions that could be taken before an event happen instead of investigating what happened with people after the event already occurred. For emergency preparedness, knowing the consequences of natural hazards and how to prevent human suffering are both essential information. While we have good studies on the health outcomes of heat-related events, study 1 is one of the few that use clinical and environmental data to provide information about the risk factors associated with poor home thermal environment in older adults with complex medical needs.

The approach taken in study 1 is aligned with more recent studies on the health consequences of climate change. For example, some researchers are placing thermometers inside of people's house (or using available online data) to understand the temperature variation that people could be exposed at home during hot days (Henderson et al., 2022). Thus, study 1 moves into the same direction of the newest studies in the field, where the goal is to have a more refined understanding of the causes that place people at risk.

Studies 2 and 3 present two new "vulnerability" indices. Considering the high number of indices available, it is fair to ask what are the contribution of study 1 and 2 to the field of disaster research and emergency preparedness. First, the CRV and the BRI do not rely on ill-defined notions of vulnerability, which has been a main criticism of the use of these indices. Second, the CRV and the BRI do not use group-level risk factors, which can be very imprecise when trying to support people in need during the time of a disaster. Instead, the indices were developed using the same high quality, individual and clinical level data used in study 1.

5.2.1 The use of clinical dimensions

The use of different clinical dimensions, instead of vague categories (e.g., older adults) has the advantage of being more precise and allow individuals to be located before, during and after a natural hazard. For instance, the items used in the three studies in this thesis are often associated with adverse health outcomes caused by extreme weather events. Individuals with cognitive impairment and dementia have difficulty interpreting risks, taking actions to protect themselves, and managing stress during relocation. Study 2 and 3 have three different items that measure cognitive impairment. Problems with ADL and IADL, such as difficult managing medication, preparing meals, and moving around the house can create physical challenges and reduce the ability to move and leave the house or navigating through evacuation processes. The BRI has items on both ADL and IADL. Many older adults have high medical needs that make them more sensitive to perturbations like extreme temperature change, and loss of water supply. This means that older adults rely more heavily on health services that might be unavailable during a natural hazard. All studies in this thesis included several items related to medical complexity, such as coronary heart disease, congestive heart failure, and pneumonia. Frail individuals have lower capacity to maintain homeostasis in the context of stressors, including heat waves and cold spells. The BRI includes an item related to frailty (CHESS-CA). Individuals living with vulnerability often rely on support of others, such as informal caregivers. If the support is not available during a natural hazard, or if somebody lives alone and are incapacitated, they may not get the assistance they need to deal with the environmental and logistical challenges posed by a natural hazard. All three studies have living arrangements (living alone) in their analyses. Finally, depression can be

associated with fatigue, loss of motivation, and lack of social engagement. This may lead to lack of awareness of risk events, reduced motivation to respond, lack of energy when they need it to get out of harms way. The BRI has a mood disorder item that captures symptoms of depression.

Considering all the advantages of using clinical data, it is surprisingly that they have been largely underutilized in emergency preparedness. This is paradoxical given the abundance of individual data in our society today and the calls for a more unified health system. Indeed, there has been much discussion about interoperability in healthcare, where data can be shared across providers, researchers, patients, and public health organizations regardless of their geographic location (Gordon & Catalini, 2018). The studies in this thesis used assessments compatible across different levels of care, aligned with the calls for interoperability.

5.3 Implications for policy

In Canada, we have a real opportunity to change emergency preparedness and create more effective ways to provide support for people in need during time of crisis. The studies presented in this thesis contribute to this change in 2 main different ways. First, the BRI and the CRV could be applied to identify people in need with no additional costs beyond those already incurred to complete interRAI assessment systems. interRAI assessments and the VPR are already available in many provinces and public health organizations in Canada and countries around the world. Where interRAI HC and interRAI-CA are already adopted, it would be possible to add the BRI and the CRV as additional tools. This means that these

organizations would have at least 3 different tools to address different types of extreme weather events.

Second, the indices presented here can indicate geographic regions and specific individual homes eligible to receive support for climate adaptation. One example already discussed in this thesis is the use of financial incentives to improve the indoor thermal environment for older adults. This approach has been shown to be a cost-effective solution to minimize the adverse health effects of extreme temperature variation. In addition, these same geographic regions and homes could be the target of specific policies addressing people's awareness about what to do in the case of an extreme weather event. Because costs related to adaptation are much smaller than climate change costs, the use of indices such as the BRI and the CRV could contribute to a more cost-effective public health system. Thus, the studies in this thesis are aligned with the first major goal of WHO, which is to develop more climate-resilient health systems.

Policy makers should expand the use of standardized instruments, such as the ones interRAI developed, and, consequently, the use of the indices presented here. This policy change would result in more people being assessed and potentially being able to receive support during a time of crisis. As more data become available, the existent indices could be improved, and new ones develop (please see item 5.5. Implications for research and future directions). Moreover, the BRI and the CRV can also be used for planning. Climate-change adaptation policies could be first applied in areas where the BRI and the CRV identified as having a higher concentration of people at risk.

5.4 Implications for practice

The indices develop here have an advantage in terms of application compared to the demographic reports on the populations at broad risk such as older adults and children. Although these reports can be useful for general policy purposes, they cannot identify specific individuals who need to be supported during a disaster. Another advantage of the BRI and CRV that include clinical information collected by standardize assessments is to find people at risk before, during, and after an extreme weather events.

Maybe the best way of explaining how this thesis can inform important changes in practices is to describe a real application of the VPR and some of the motivations to develop the BRI. One of the organizations in British Columbia (BC-Island Health) uses the VPR to identify people that could be at risk because of heat-related events (E. Heffel, personal communication, January 27th, 2025). The main motivation for using the VPR was the heat dome that killed more than 600 people in 2021 in British Columbia. To avoid the adverse heath effects of another heat dome, people at BC-Island Health uses the VPR to first identify only those at very high risk (VPR = 2). Then case managers review each case and identify a subset of individuals that they believe are in real trouble. Finally, people at BC-Island Health call each of these individuals to create another subset that would need immediate help (e.g., re-location). The organization took this approach in the spring of 2024. Out of 934 active home care clients assessed with the interRAI HC, 245 clients were identified as at risk by the VPR. Case managers further identified 18 highly critical cases, who where all contacted by phone. Four clients were classified at extremely risk in the case of a heat wave (E. Heffel, personal communication, January 27th, 2025).

BC-Island Health also identified some limitations of the VPR, such as smaller target population. The need to address a larger population was one of the reasons behind the development of the BRI. The organization already committed to include the BRI as soon as the scale is available and is interested in learning more about the CRV to include in their emergency preparedness toolkit (E. Heffel, personal communication, January 27th, 2025). Therefore, using the BRI and the CRV just before natural disasters are more likely to happen (e.g., spring for heat waves) could become routine practice in the organizations that already adopted the interRAI-HC and the interRAI-CA. For example, the Canadian Institute for Health Information and other health organizations should recommend that vendors build the CRV and the BRI into their specifications. As these indices become part of the system, reporting the results of CRV and BRI should also become part of CIHI common practice.

5.5 Limitations

Maybe the most important limitation of this thesis is the fact that validation of the indices created was not done against a population that experienced adverse health outcomes caused by natural hazards. In addition, the studies here did not investigate specific outcomes that are related to natural hazards. Instead, study 2 and 3 used general health outcomes, such as survival, hospital admissions, and physicians' visits. For example, we did not look at hospital admissions because of asthma during the wildfire smoke of 2023. Although the outcomes used in study 2 and 3 are likely to be relevant for many different types of natural hazards, an important next step is to validate the BRI and the CRV against specific health outcomes (e.g., asthma for the CRV). Moreover, the BRI should be validated against different

types of natural events (e.g., heat waves, wildfires, snowstorms, and floods). This could inform whether a general tool such as the BRI is precise regardless of the type of hazard, or if there is a need to develop specific tools to address each type of extreme weather event, such as the CRV for wildfires.

Individuals might not be at risk if they do not live in areas affected by natural hazards. For example, a frail older adult might be identified as at risk during a wildfire according to the CRV, but they might not live in an area that is being affected by the event. This means that trying to provide support for people who do not live in risk areas is not cost-effective. One solution to mitigate this limitation is to obtain maps of environmental risk areas and overlap these maps with individual postal code of those classified as at risk. Although this could be done by public health organizations, it would be more challenging for researchers given that postal code is often not available in health data in Canada due to privacy concerns.

The studies in this thesis cover a population of almost 1.5 million individuals living with some kind of vulnerability; however, they still represent a small portion of our population (i.e., home care clients or those being considered to receive this service). There could be more individuals at risk living in the community that might not be in our sample, such as older adults receiving private care and many older adults with less physical and mental health challenges. Although these populations should also be included in future investigations, it is also the case that older adults who are not receiving home care services might have other supports, such as good social network and good family connections. Thus, despite this limitation, the thesis addressed the needs of older adults who are most likely to be at risk of health complications because of extreme weather events.

In addition to older adults, many other populations could be at risk in the case of a natural hazard. For example, this thesis did not include children and those with low social-economic status. In Canada, First Nations, Inuit, and Métis peoples are at very high risk of health complications, both physical and mental, because of climate change (Ford, 2012). Future studies should aim to broader the scope of the investigations presented in this thesis. One potential area of future research is to use the interRAI instrument for child and youth (Stewart et al., 2022) to investigate climate change effects on this population and created tools like the ones presented here.

Finally, this thesis addresses only short-term effects of extreme weather events. The rationale for this is that by addressing short-term effects, long-term effects will likely to be minimized. However, a new line of investigation is required to properly understand the links between extreme events and poor health outcomes that might occur months or even years after the event happened. This is because items included in indices such as the BRI and the CRV might be very different when investigating long-term effects. For example, the distance from the event or witnessing somebody suffering during an event might be more important for long-term effects than for short-term effects. This would be particularly important for mental health given that many studies have shown the long-lasting effects of natural hazards on people's mental health.

5.6 Implications for research and future directions

In addition to new areas of research indicated in the previous section, the results of the three studies presented in this thesis indicate areas of future research that are ready or nearly ready to happen.

5.6.1 A suite of risk indices based on interRAI assessments

Study 2 and 3 successfully demonstrated how clinical, demographic, environmental, and social-economic data about individuals can be used to calculate risks of adverse health outcomes associated with natural hazards. This area of research has been highly underutilized given the wealth of interRAI assessments.

Over the past 30 years, interRAI has developed several instruments, including comprehensive and short assessments, screeners, and indicators covering both research and applied areas. These instruments were created to serve different populations, from older adults with complex medical needs to child and youth and people experiencing mental health problems. The application of these instruments also covers several settings, from hospitals and long-term care facilities to people's home. There are hundreds of items available and more recent versions of these instruments contain many common elements, promoting continuity of care and interoperability. Only in Canada, interRAI has over 20 million assessments completed. The use of these instruments to develop new indices could represent a game-changing in disaster research and emergency preparedness given the wide coverage of these assessments in relation to populations, geographic locations, and settings.

One example already mentioned is the youth and child assessment (Stewart et al. 2022). As in the case of older adults, children are often considered a population at risk during

natural hazards. The BRI and CRV could be adapted to the child and youth instrument in a similar approach that the BRI was adapted from the VPR in study 2. In addition, studies have indicated that young adults are experiencing high levels of anxiety, depression and overall distress with climate-related problems (Clayton, 2020). Items related to mental health in the child and youth instrument could be linked to environmental data to measure the mental health effect of extreme weather events in this population.

In addition to the adoption of the indices discussed in this thesis (VPR, BRI, and CRV), new indices could be created. There is an urgency to understand and identify people that could be in trouble because of heat-related and wildfire events in Canada. Because extreme temperature can aggravate the conditions of those with heart and respiratory problems, priority should be given to instruments targeting populations more likely to have these health issues, such as those serviced by the interRAI HC and interRAI-CA, but also by the interRAI-Long Term Care Facility, used in nursing homes.

The mental health suit of assessment could also be considered to investigate the short and long-term health effects of climate change. For example, the interRAI Mental Health assessment for in-patient psychiatry is used in all admissions to psychiatry beds in Ontario. Because this assessment contains detailed information about the physical and mental status of individuals, it is a great tool to be linked with environmental data. This could shed new lights into how and why there has been a clear association between extreme weather events and increase in hospital admissions for mental health issues (Lawrance et al., 2022).

5.6.2 Extreme weather events and climate change related items in current interRAI instruments

Although there are several types of interRAI instruments, there are three barriers when using them in the context of disaster research. First, there is no interRAI instrument specific to understand the physical and mental problems that usually happen because of natural hazards. For example, young adults are among those who are suffering the most with climate change and although there are assessments available to measure the effects of climate change in this population, interRAI has not developed its own version.

The second problem of using interRAI instruments for disaster research is that there are very few items in the current assessments that evaluate the environment, or needs, strengths, and preferences of individuals related to extreme weather events. Post-traumatic-stress disorder is one of the most common psychiatry disorder associated with extreme weather events, but only the newest version of the interRAI HC and interRAI-LTCF (version 10) include post-traumatic-stress disorder diagnosis. Moreover, the few items present in the assessments need improvements. The only item that evaluates the house environment in the interRAI assessments (the item that was used in this thesis), has no more than 5 questions and the answers are dichotomized (yes or no). The consequence is that only extreme cases are identified (e.g., houses extremely dirty or invested by rats and insects), leading to a very low frequency of responses indicating any problem, often less than 5%. Instead, the item could include a scale to measure the home environment, which would provide a better distribution of poor home environment within the target population. There should also be items measuring important aspects that link health and home environment, such as number of

people per square footage, presence of mould, quality of indoor air (e.g., second-hand smoke, strong smells).

The third problem is related to how the interRAI assessments measure thermal home environment. Here I used a subjective metric based on the assessor observation, i.e., inadequate heating or cooling at home. However, I also showed that this metric was influenced by seasons, i.e., assessments conducted in the summer where more likely to identify that the house had inadequate heating or cooling. This means that I might have underestimated the real number of home care clients that live in houses with poor thermal environment. Although the use of precise tools, such as thermometers, could potentially solve this problem, the thermal environment is not only influenced by temperature, but also by people's behaviour and even by their physiology. For example, many older adults do not thermoregulate properly and perceive temperature differently than the rest of the population. They might also have cognitive impairment that stop them from taking actions that would cool their bodies, such as using air conditioners, wear llightweight fabrics, and avoid going outside during a heat wave. interRAI assessors can obtain subjective information via their own observation and talking to the client and family members, which would not be possible with the use of a thermometer. Nevertheless, it would be important to combine the interRAI assessor's judgment with more precise metrics to better understand the thermal environment of older adults.

5.6.3 Linking interRAI based indices with broader scope data

An important area of future investigations is to expand the approach used in this thesis beyond interRAI instruments. This is important because, as discussed here, not only the populations represented in the interRAI instruments are experiencing health complications because of extreme weather events. Moreover, people might experience all kinds of limitations during and after a natural hazard, such as loss of propriety, being forced to evacuate and permanently move, and overall economic burden, which interRAI does not assess. Thus, important future research would be to understand how broader data, collected with the general population, could be included in the developments of the indices, such as the BRI and the CRV.

One important source of data is Statistics Canada. The datasets maintained by Statistical Canada could complement the detailed health information in the interRAI assessments. For example, with Statistics Canada data, indices could include a more detailed description of the social and economic conditions of those identified as at risk, adding to these indices not only the health burden, but also potential financial costs associated with natural hazards. This approach could facilitate the linkage of health data present in the interRAI assessments with risk environmental areas to address a limitation already discussed here (i.e., this thesis did not identify geographic hot-spot areas related to different types of natural hazards).

5.6.4 Improvements of current indices via application

The use of indices such as the VPR in Vancouver (and likely the BRI and the CRV in 2026) are essential to the improvement of current indices. The case of the application of the

VPR by BC-Island Health represents a unique opportunity. It would be important to investigate what criteria case managers are using to select a subset of clients from the group identified by the VPR in 2024 and 2025, and the BRI in 2026. This information could then help to improve the VPR and the BRI by either removing or adding items according to the case managers criteria. It could also be the case that some items should be given more weight. For example, one information that has been used by case managers to subset the clients identified by the VPR is whether the client live alone or not (E. Heffel, personal communication, January 27th, 2025). Therefore, this item (living arrangements) could be more important to determined individual's risk.

Finally, the recent increase in heatwaves and wildfires in Canada (e.g., the heat-dome of 2021 in BC and the 2023 wildfire season in Ontario) represent a unique opportunity to link detailed information about people's health status and adverse health outcomes. This could be done by applying the indices developed here to the active population receiving interRAI assessments at the time of the event. This linked dataset would then identify those who experienced adverse health outcomes during the extreme event and were identified as at risk by the BRI. This validation process could then inform improvements in the BRI because researchers would be able to identify the items in the index that were more important in correctly classifying people at risk.

5.7 Conclusion

Extreme weather is a new reality. Heat waves, wildfires, droughts, floods and extreme low temperatures are not rare events anymore. Added to an aging population, that are more

likely to experience adverse health outcomes because of extreme weather, an increasing number of people will need assistance. Thus, it is essential that we adapt our public health system to this new reality. Identifying individuals that could be at high risk before an extreme weather event happens is a key step in this process.

This thesis contributes to this goal by using readily available, individual-level data and producing applied knowledge that can help public health organizations to prepare for natural hazards with no additional costs. The studies presented here improve our understanding of what places older adults at higher risk of having a house with poor thermal environment, which is essential information to guide cost-effective public health initiatives to adapt homes to the new reality of extreme weather. Moreover, the thesis provides two additional tools that could be applied before natural hazards at both individual and population level. Instead of group-level risk factors, these new indices use individual information and, therefore, are likely to be more precise in identifying those at high risk. These improvements represent a unique approach to emergency preparedness and opens several new areas of research and application towards a more sustainable health system.

References

Adelman, D. S., & Legg, T. J. (2010). Caring for older adults with dementia when disaster strikes. *Journal of gerontological nursing*, *36*(8), 13-17.

Adger, W. N. (2006). Vulnerability. *Global Environmental Change*, *16*(3), 268–281. https://doi.org/10.1016/j.gloenvcha.2006.02.006

Ahmad, K., Erqou, S., Shah, N., Nazir, U., Morrison, A. R., Choudhary, G., & Wu, W.-C. (2020). Association of poor housing conditions with COVID-19 incidence and mortality across US counties. *PLOS ONE*, *15*(11), e0241327. https://doi.org/10.1371/journal.pone.0241327

Ahmed, M. (2014). *Assessing the Costs of Climate Change and Adaptation in South Asia* (Bangladesh,Bhutan,India,Maldives,Nepal,Sri Lanka). Asian Development Bank. https://www.adb.org/publications/assessing-costs-climate-change-and-adaptation-south-asia

Ahrentzen, S., Erickson, J., & Fonseca, E. (2016). Thermal and health outcomes of energy efficiency retrofits of homes of older adults. *Indoor Air*, *26*(4), 582–593. https://doi.org/10.1111/ina.12239

Akgün, K. M., Crothers, K., & Pisani, M. (2012). Epidemiology and management of common pulmonary diseases in older persons. *The Journals of Gerontology: Series A*, *67A*(3), 276–291. https://doi.org/10.1093/gerona/glr251

Alidoust, S., & Huang, W. (2023). A decade of research on housing and health: A systematic literature review. *Reviews on Environmental Health*, *38*(1), 45–64. https://doi.org/10.1515/reveh-2021-0121

Amerio, A., Brambilla, A., Morganti, A., Aguglia, A., Bianchi, D., Santi, F., Costantini, L., Odone, A., Costanza, A., Signorelli, C., Serafini, G., Amore, M., & Capolongo, S. (2020). COVID-19 Lockdown: housing built environment's effects on mental health. *International Journal of Environmental Research and Public Health*, *17*(16), Article 16. https://doi.org/10.3390/ijerph17165973

Ardagh, M. W., Richardson, S. K., Robinson, V., Than, M., Gee, P., Henderson, S., Khodaverdi, L., McKie, J., Robertson, G., Schroeder, P. P., & Deely, J. M. (2012). The initial health-system response to the earthquake in Christchurch, New Zealand, in February, 2011. *The Lancet*, *379*(9831), 2109–2115. https://doi.org/10.1016/S0140-6736(12)60313-4

Armstrong, J. J., Stolee, P., Hirdes, J. P., & Poss, J. W. (2010). Examining three frailty conceptualizations in their ability to predict negative outcomes for home-care clients. *Age and ageing*, *39*(6), 755-758.

Arsad, F. S., Hod, R., Ahmad, N., Ismail, R., Mohamed, N., Baharom, M., Osman, Y., Radi, M. F. M., & Tangang, F. (2022). The impact of heatwaves on mortality and morbidity and the associated vulnerability factors: a systematic review. *International Journal of Environmental Research and Public Health*, *19*(23), Article 23. https://doi.org/10.3390/ijerph192316356

Baccini, M., Biggeri, A., Accetta, G., Kosatsky, T., Katsouyanni, K., Analitis, A., Anderson, H. R., Bisanti, L., D'Ippoliti, D., Danova, J., Forsberg, B., Medina, S., Paldy, A., Rabczenko, D., Schindler, C., & Michelozzi, P. (2008). Heat effects on mortality in 15 European cities: *Epidemiology*, *19*(5), 711–719. https://doi.org/10.1097/EDE.0b013e318176bfcd

Balmes, J. R., & Holm, S. M. (2023). Increasing wildfire smoke from the climate crisis: impacts on asthma and allergies. *Journal of Allergy and Clinical Immunology*, *152*(5), 1081–1083. https://doi.org/10.1016/j.jaci.2023.09.008

Balmes, J. R., Hicks, A., Johnson, M. M., & Nadeau, K. C. (2025). The effect of wildfires on asthma and allergies. *The Journal of Allergy and Clinical Immunology: In Practice*, *13*(2), 280–287. https://doi.org/10.1016/j.jaip.2024.12.004

Bartholdson, S., & von Schreeb, J. (2018). Natural disasters and injuries: What does a surgeon need to know? *Current Trauma Reports*, *4*(2), 103–108. https://doi.org/10.1007/s40719-018-0125-3

Beaudoin, C. E. (2011). Hurricane Katrina: Addictive behavior trends and predictors. *Public Health Reports*, *126*(3), 400–409. https://doi.org/10.1177/003335491112600314

Beinin, L. (2012). *Medical consequences of natural disasters*. Springer Science & Business Media.

Bell, S. A., Abir, M., Choi, H., Cooke, C., & Iwashyna, T. (2018). All-cause hospital admissions among older adults after a natural disaster. *Annals of Emergency Medicine*, *71*(6), 746-754.e2. https://doi.org/10.1016/j.annemergmed.2017.06.042

Bell, S. A., Horowitz, J., & Iwashyna, T. J. (2020). Health outcomes after disaster for older adults with chronic disease: A Systematic Review. *The Gerontologist*, *60*(7), e535–e547. https://doi.org/10.1093/geront/gnz123

Belleville, G., Ouellet, M.-C., Lebel, J., Ghosh, S., Morin, C. M., Bouchard, S., Guay, S., Bergeron, N., Campbell, T., & MacMaster, F. P. (2021). Psychological symptoms among evacuees from the 2016 Fort McMurray wildfires: a population-based survey one year later. *Frontiers in Public Health*, *9*. https://www.frontiersin.org/articles/10.3389/fpubh.2021.655357

Benevolenza, M. A., & DeRigne, L. (2019). The impact of climate change and natural disasters on vulnerable populations: a systematic review of literature. *Journal of Human Behavior in the Social Environment*, *29*(2), 266–281. https://doi.org/10.1080/10911359.2018.1527739

Ben-Ezra, M., Shigemura, J., Palgi, Y., Hamama-Raz, Y., Lavenda, O., Suzuki, M., & Goodwin, R. (2015). From Hiroshima to Fukushima: PTSD symptoms and radiation stigma across regions in Japan. *Journal of Psychiatry Research*, *60*, 185–186.

Berry, P., & Schnitter, R. (2022). *Health of Canadians in a Changing Climate: Advancing our Knowledge for Action.* Government of Canada. https://changingclimate.ca/health-in-a-changing-climate/

Birkmann, J. (2006). Measuring vulnerability to promote disaster-resilient societies: conceptual frameworks and definitions. *Measuring vulnerability to natural hazards: Towards disaster resilient societies*, *1*(9), 3-7.

Black, S. A., & Rush, R. D. (2002). Cognitive and functional decline in adults aged 75 and older. *Journal of the American Geriatrics Society*, *50*(12), 1978–1986. https://doi.org/10.1046/j.1532-5415.2002.50609.x

Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (1994). *At risk: Natural hazards, people's vulnerability and disasters*. Routledge.

Bogdan, E., Krueger, R., Wright, J., Woods, K., & Cottar, S. (2024). Disaster awareness and preparedness among older adults in Canada regarding floods, wildfires, and earthquakes. *International Journal of Disaster Risk Science*, *15*(2), 198-212.

Bolan, S., Sharma, S., Mukherjee, S., Isaza, D. F. G., Rodgers, E. M., Zhou, P., Hou, D., Scordo, F., Chandra, S., Siddique, K. H. M., & Bolan, N. (2025). Wildfires under changing climate, and their environmental and health impacts. *Journal of Soils and Sediments*. https://doi.org/10.1007/s11368-025-04020-y

Boudreault, J., Campagna, C., Lavigne, É., & Chebana, F. (2025). Projecting the overall heat-related health burden and associated economic costs in a climate change context in Quebec, Canada. *Science of The Total Environment*, *958*, 178022. https://doi.org/10.1016/j.scitotenv.2024.178022

Bourassa, K. J., Sbarra, D. A., & Whisman, M. A. (2015). Women in very low quality marriages gain life satisfaction following divorce. *Journal of Family Psychology*, *29*(3), 490–499. https://doi.org/10.1037/fam0000075

Brauer, M., Amann, M., Burnett, R. T., Cohen, A., Dentener, F., Ezzati, M., ... & Thurston, G. D. (2012). Exposure assessment for estimation of the global burden of disease

attributable to outdoor air pollution. *Environmental science & technology*, *46*(2), 652-660.

Brown, K., Ecclestone, K., & Emmel, N. (2017). The many faces of vulnerability. *Social Policy and Society*, *16*(3), 497–510. https://doi.org/10.1017/S1474746416000610

Brown, R. C., Trapp, S. K., Berenz, E. C., Bigdeli, T. B., Acierno, R., Tran, T. L., Trung, L. T., Tam, N. T., Tuan, T., Buoi, L. T., Ha, T. T., Thach, T. D., & Amstadter, A. B. (2013). Pre-typhoon socioeconomic status factors predict post-typhoon psychiatric symptoms in a Vietnamese sample. *Social Psychiatry and Psychiatric Epidemiology*, *48*(11), 1721–1727. https://doi.org/10.1007/s00127-013-0684-0

Burdette, A. M., Hill, T. D., & Hale, L. (2011). Household disrepair and the mental health of low-income urban women. *Journal of Urban Health: Bulletin of the New York Academy of Medicine*, *88*(1), 142–153. https://doi.org/10.1007/s11524-010-9529-2

Burke, M., Childs, M. L., de la Cuesta, B., Qiu, M., Li, J., Gould, C. F., Heft-Neal, S., & Wara, M. (2023). The contribution of wildfire to PM2.5 trends in the USA. *Nature*, *622*(7984), 761–766. https://doi.org/10.1038/s41586-023-06522-6

Cardona, O. D. (2013). The need for rethinking the concepts of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management. In *Mapping vulnerability* (pp. 37–51). Routledge.

Carpenter, I., & Hirdes, J. P. (2013). Using interRAI assessment systems to measure and maintain quality of long-term care. *A Good Life in Old Age*, *17*, 93–139.

Carretero, S., Garcés, J., Ródenas, F., & Sanjosé, V. (2009). The informal caregiver's burden of dependent people: theory and empirical review. *Archives of Gerontology and Geriatrics*, *49*(1), 74–79. https://doi.org/10.1016/j.archger.2008.05.004

Centers for Disease Control and Prevention. (2015). *Planning for an emergency: Strategies for identifying and engaging at-risk groups. A guidance document for emergency managers.* http://www.cdc.gov/nceh/hsb/disaster/default.htm

Chang, A. Y., Tan, A. X., Nadeau, K. C., & Odden, M. C. (2022). Aging hearts in a hotter, more turbulent world: the impacts of climate change on the cardiovascular health of older adults. *Current Cardiology Reports*, 24(6), 749–760. https://doi.org/10.1007/s11886-022-01693-6

Chen, H., Wang, J., Li, Q., Yagouti, A., Lavigne, E., Foty, R., Burnett, R. T., Villeneuve, P. J., Cakmak, S., & Copes, R. (2016). Assessment of the effect of cold and hot temperatures on mortality in Ontario, Canada: a population-based study. *Canadian Medical Association Open Access Journal*, *4*(1), E48–E58. https://doi.org/10.9778/cmajo.20150111

Chen, K., Ma, Y., Bell, M. L., & Yang, W. (2023). Canadian wildfire smoke and asthma syndrome emergency department visits in New York City. *Journal of the Medical American Association*, *330*(14), 1385–1387. https://doi.org/10.1001/jama.2023.18768

Chen, Y., Cao, C., Cao, Y., Bashir, B., Xu, M., Xie, B., & Wang, K. (2021). Observed evidence of the growing contributions to aerosol pollution of wildfires with diverse spatiotemporal distinctions in China. *Journal of Cleaner Production*, *298*, 126860. https://doi.org/10.1016/j.jclepro.2021.126860

Chen, Y., Yang, Q., Krewski, D., Shi, Y., Burnett, R. T., & McGrail, K. (2004). Influence of relatively low level of particulate air pollution on hospitalization for COPD in elderly people. *Inhalation Toxicology*, *16*(1), 21–25. https://doi.org/10.1080/08958370490258129

Cheng, W., Li, D., Liu, Z., & Brown, R. D. (2021). Approaches for identifying heat-vulnerable populations and locations: a systematic review. *Science of The Total Environment*, *799*, 149417. https://doi.org/10.1016/j.scitotenv.2021.149417

Ciurean, R. L., Schröter, D., & Glade, T. (2013). Conceptual frameworks of vulnerability assessments for natural disasters reduction. *Approaches to Disaster Management-Examining the Implications of Hazards, Emergencies and Disasters*, 1–32.

Clair, A., & Baker, E. (2022). Cold homes and mental health harm: evidence from the UK Household Longitudinal Study. *Social Science & Medicine*, *314*, 115461. https://doi.org/10.1016/j.socscimed.2022.115461

Clayton, S. (2020). Climate anxiety: Psychological responses to climate change. *Journal of Anxiety Disorders*, *74*, 102263. https://doi.org/10.1016/j.janxdis.2020.102263

Clegg, A., Young, J., Iliffe, S., Rikkert, M. O., & Rockwood, K. (2013). Frailty in elderly people. *The Lancet*, *381*(9868), 752–762. https://doi.org/10.1016/S0140-6736(12)62167-9

Clemens, S. L., Berry, H. L., McDermott, B. M., & Harper, C. M. (2013). Summer of sorrow: measuring exposure to and impacts of trauma after Queensland's natural disasters of 2010–2011. *Medical Journal of Australia*, *199*(8), 552–555. https://doi.org/10.5694/mja13.10307

Collins, K. J. (1986). Low indoor temperatures and morbidity in the elderly. *Age and Ageing*, *15*(4), 212–220. https://doi.org/10.1093/ageing/15.4.212

Cong Liu, Chen Renjie, Sera Francesco, Vicedo-Cabrera Ana M., Guo Yuming, Tong Shilu, Coelho Micheline S.Z.S., Saldiva Paulo H.N., Lavigne Eric, Matus Patricia, Valdes Ortega Nicolas, Osorio Garcia Samuel, Pascal Mathilde, Stafoggia Massimo, Scortichini Matteo, Hashizume Masahiro, Honda Yasushi, Hurtado-Díaz Magali, Cruz Julio, … Kan Haidong. (2019). Ambient particulate air pollution and daily mortality in 652 Cities. *New England Journal of Medicine*, *381*(8), 705–715. https://doi.org/10.1056/NEJMoa1817364

Conti, S., Masocco, M., Meli, P., Minelli, G., Palummeri, E., Solimini, R., Toccaceli, V. & Vichi, M. (2007). General and specific mortality among the elderly during the 2003 heat wave in Genoa (Italy). *Environmental research*, *103*(2), 267-274.

Cook, A., Watson, J., Buynder, P. van, Robertson, A., & Weinstein, P. (2008). 10th anniversary review: natural disasters and their long-term impacts on the health of communities. *Journal of Environmental Monitoring*, *10*(2), 167–175. https://doi.org/10.1039/B713256P

Cotten, S. R., Schuster, A. M., & Seifert, A. (2022). Social media use and well-being among older adults. *Current Opinion in Psychology*, *45*, 101293. https://doi.org/10.1016/j.copsyc.2021.12.005

Cunningham, C. X., Williamson, G. J., & Bowman, D. M. J. S. (2024). Increasing frequency and intensity of the most extreme wildfires on Earth. *Nature Ecology & Evolution*, 1–6. https://doi.org/10.1038/s41559-024-02452-2

Curtis, L., Rea, W., Smith-Willis, P., Fenyves, E., & Pan, Y. (2006). Adverse health effects of outdoor air pollutants. *Environment International*, *32*(6), 815–830. https://doi.org/10.1016/j.envint.2006.03.012

Cutter, S. L. (1996). Vulnerability to environmental hazards. *Progress in Human Geography*, *20*(4), 529–539. https://doi.org/10.1177/030913259602000407

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

Das, R. R., Martiskainen, M., & Li, G. (2022). Quantifying the prevalence of energy poverty across Canada: Estimating domestic energy burden using an expenditures approach. *Canadian Geographies / Géographies Canadiennes*, *66*(3), 416–433. https://doi.org/10.1111/cag.12750

De Vita, A., Belmusto, A., Di Perna, F., Tremamunno, S., De Matteis, G., Franceschi, F., & Covino, M. (2024). The impact of climate change and extreme weather conditions on cardiovascular health and acute cardiovascular diseases. *Journal of Clinical Medicine*, *13*(3), 759.

DeBruin, D. A. (2004). Looking beyond the limitations of "vulnerability": reforming safeguards in research. *The American Journal of Bioethics*, *4*(3), 76–78. https://doi.org/10.1080/15265160490497579

Di, Q., Dai, L., Wang, Y., Zanobetti, A., Choirat, C., Schwartz, J. D., & Dominici, F. (2017). Association of short-term exposure to air pollution with mortality in older adults.

Journal of the Medical American Association, *318*(24), 2446–2456. https://doi.org/10.1001/jama.2017.17923

Dominski, F. H., Lorenzetti Branco, J. H., Buonanno, G., Stabile, L., Gameiro da Silva, M., & Andrade, A. (2021). Effects of air pollution on health: a mapping review of systematic reviews and meta-analyses. *Environmental Research*, *201*(Complete). https://doi.org/10.1016/j.envres.2021.111487

Durak, M. (2023). The earthquakes in Turkey and Syria remind us that long-term care residents and older adults are most affected by natural disasters. *Journal of Aging and Long-Term Care*, *6*(1), Article 1. https://doi.org/10.51819/jaltc.2023.1286010

E, J., Xia, B., Chen, Q., Buys, L., Susilawati, C., & Drogemuller, R. (2024). Impact of the Built Environment on Ageing in Place: A Systematic Overview of Reviews. *Buildings*, *14*(8), Article 8. https://doi.org/10.3390/buildings14082355

Ebi, K. L., Capon, A., Berry, P., Broderick, C., Dear, R. de, Havenith, G., Honda, Y., Kovats, R. S., Ma, W., Malik, A., Morris, N. B., Nybo, L., Seneviratne, S. I., Vanos, J., & Jay, O. (2021). Hot weather and heat extremes: health risks. *The Lancet*, *398*(10301), 698–708. https://doi.org/10.1016/S0140-6736(21)01208-3

Ebi, K. L., Vanos, J., Baldwin, J. W., Bell, J. E., Hondula, D. M., Errett, N. A., Hayes, K., Reid, C. E., Saha, S., & Spector, J. (2021). Extreme weather and climate change: population health and health system implications. *Annual Review of Public Health*, *42*(1), 293–315.

Egilson, M. (2022). *Extreme Heat and Human Mortality: A Review of Heat-Related Deaths in BC in Summer 2021. Report to the Chief Coroner of British Columbia*.

Fan, F., Zhou, Y., & Liu, X. (2017). Sleep disturbance predicts posttraumatic stress disorder and depressive symptoms: a cohort study of Chinese adolescents. *The Journal of Clinical Psychiatry*, *78*(7), 19701. https://doi.org/10.4088/JCP.15m10206

Flory, K., Hankin, B. L., Kloos, B., Cheely, C., & Turecki, G. (2009). Alcohol and cigarette use and misuse among Hurricane Katrina survivors: psychosocial risk and protective factors. *Substance Use & Misuse*, *44*(12), 1711–1724. https://doi.org/10.3109/10826080902962128

Ford, B., Val Martin, M., Zelasky, S. E., Fischer, E. V., Anenberg, S. C., Heald, C. L., & Pierce, J. R. (2018). Future fire impacts on smoke concentrations, visibility, and health in the contiguous United States. *GeoHealth*, *2*(8), 229–247. https://doi.org/10.1029/2018GH000144

Ford, J. D. (2012). Indigenous health and climate change. *American Journal of Public Health*, *102*(7), 1260–1266. https://doi.org/10.2105/AJPH.2012.300752

Forster, H. P., Emanuel, E., & Grady, C. (2001). The 2000 revision of the Declaration of Helsinki: a step forward or more confusion? *The Lancet*, *358*(9291), 1449–1453. https://doi.org/10.1016/S0140-6736(01)06534-5

Forzieri, G., Cescatti, A., e Silva, F. B., & Feyen, L. (2017). Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study. *The Lancet Planetary Health*, *1*(5), e200–e208. Scopus. https://doi.org/10.1016/S2542-5196(17)30082-7

Foster, H. D. (1988). The geography of schizophrenia: possible links with selenium and calcium deficiencies, inadequate exposure to sunlight and industrialization. *Journal of Orthomolecular Medicine*, *3*(3), 135–140.

Fothergill, A., & Peek, L. A. (2004). Poverty and disasters in the United States: a review of recent sociological findings. *Natural Hazards*, *32*(1), 89–110. https://doi.org/10.1023/B:NHAZ.0000026792.76181.d9

Fouillet, A., Rey, G., Laurent, F., Pavillon, G., Bellec, S., Ghihenneuc-Jouyaux, C., Clavel, J., Jougla, E., & Hémon, D. (2006). Excess mortality related to the August 2003 heat wave in France. *International Archives of Occupational and Environmental Health*, *80*(1), 16–24. https://doi.org/10.1007/s00420-006-0089-4

Fox, M. H., White, G. W., Rooney, C., & Rowland, J. L. (2007). Disaster preparedness and response for persons with mobility impairments. *Journal of Disability Policy Studies*. https://doi.org/10.1177/10442073070170040201

Fullerton, C. S., McKibben, J. B. A., Reissman, D. B., Scharf, T., Kowalski-Trakofler, K. M., Shultz, J. M., & Ursano, R. J. (2013). Posttraumatic stress disorder, depression, and alcohol and tobacco use in public health workers after the 2004 Florida hurricanes. *Disaster Medicine and Public Health Preparedness*, *7*(1), 89–95. https://doi.org/10.1017/dmp.2013.6

Galea, S. (2007). The long-term health consequences of disasters and mass traumas. *Canadian Medical Association Journal*, *176*(9), 1293–1295.

Galea, S., Brewin, C. R., Gruber, M., Jones, R. T., King, D. W., King, L. A., McNally, R. J., Ursano, R. J., Petukhova, M., & Kessler, R. C. (2007). Exposure to hurricane-related

stressors and mental illness after Hurricane Katrina. *Archives of General Psychiatry*, *64*(12), 1427–1434. https://doi.org/10.1001/archpsyc.64.12.1427

Gasparrini, A., Guo, Y., Hashizume, M., Lavigne, E., Zanobetti, A., Schwartz, J., Tobias, A., Tong, S., Rocklöv, J., Forsberg, B., Leone, M., Sario, M. D., Bell, M. L., Guo, Y.-L. L., Wu, C., Kan, H., Yi, S.-M., Coelho, M. de S. Z. S., Saldiva, P. H. N., … Armstrong, B. (2015). Mortality risk attributable to high and low ambient temperature: a multicountry observational study. *The Lancet*, *386*(9991), 369–375. https://doi.org/10.1016/S0140-6736(14)62114-0

Gaugler, J. E., Kane, R. L., Kane, R. A., Clay, T., & Newcomer, R. (2003). Caregiving and institutionalization of cognitively impaired older people: utilizing dynamic predictors of change. *The Gerontologist*, *43*(2), 219–229. https://doi.org/10.1093/geront/43.2.219

GBD 2015 Risk Factors Collaborators. (2016). Global, regional, and national comparative risk assessment of 79 behavioural, environmental and occupational, and metabolic risks or clusters of risks, 1990–2015: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet (London, England)*, *388*(10053), 1659–1724. https://doi.org/10.1016/S0140-6736(16)31679-8

Goessling, H. F., Rackow, T., & Jung, T. (2025). Recent global temperature surge intensified by record-low planetary albedo. *Science*, *387*(6729), 68–73. https://doi.org/10.1126/science.adq7280

Goldmann, E., & Galea, S. (2014). Mental health consequences of disasters. *Annual Review of Public Health*, *35*(1), 169–183. https://doi.org/10.1146/annurev-publhealth-032013-182435

Goldstein, R. B., Smith, S. M., Chou, S. P., Saha, T. D., Jung, J., Zhang, H., Pickering, R. P., Ruan, W. J., Huang, B., & Grant, B. F. (2016). The epidemiology of DSM-5 posttraumatic stress disorder in the United States: results from the National Epidemiologic Survey on Alcohol and Related Conditions-III. *Social Psychiatry and Psychiatric Epidemiology*, *51*(8), 1137–1148. https://doi.org/10.1007/s00127-016-1208-5

Gordon, W. J., & Catalini, C. (2018). Blockchain technology for healthcare: facilitating the transition to patient-driven interoperability. *Computational and structural biotechnology journal*, *16*, 224-230.

Government of Canada, S. C. (2023, July 19). *The prevalence of household air conditioning in Canada*. https://www150.statcan.gc.ca/n1/pub/82-003-x/2023007/article/00002-eng.htm

Grant, E., & Runkle, J. D. (2022). Long-term health effects of wildfire exposure: a scoping review. *The Journal of Climate Change and Health*, *6*, 100110. https://doi.org/10.1016/j.joclim.2021.100110

Gray, L. C., Berg, K., Fries, B. E., Henrard, J.-C., Hirdes, J. P., Steel, K., & Morris, J. N. (2009). Sharing clinical information across care settings: the birth of an integrated assessment system. *BMC Health Services Research*, *9*(1), 71. https://doi.org/10.1186/1472-6963-9-71

Hahn, M. B., Wyck, R. V., Lessard, L., & Fried, R. (2022). Compounding effects of social vulnerability and recurring natural disasters on mental and physical health. *Disaster Medicine and Public Health Preparedness*, *16*(3), 1013–1021. https://doi.org/10.1017/dmp.2020.476

Hallman, S. (2022). *A Portrait of Canada's Growing Population Aged 85 and Older from the 2021 Census: Census of Population, 2021*. Statistics Canada= Statistique Canada.

Hassanzad, M., & Hajian-Tilaki, K. (2024). Methods of determining optimal cut-point of diagnostic biomarkers with application of clinical data in ROC analysis: an update review. *BMC Medical Research Methodology*, *24*, 84. https://doi.org/10.1186/s12874-024-02198-2

Hawley, A. H. (1986). *Human Ecology: A Theoretical Essay*. University of Chicago Press.

Heckman, G. A., Turcotte, L., & Hirdes, J. P. (2021). The crying need for validated consensus frailty measurement standards: will the real frailty please stand up? *Canadian Journal of Cardiology*, *37*(11), 1702–1704. https://doi.org/10.1016/j.cjca.2021.09.027

Health New Zealand (2011). *HIQ technology assists Earthquake recovery.* https://www.tdhb.org.nz/news/documents/media_release_2011_05_10.shtml

Henderson, S. B., Brauer, M., MacNab, Y. C., & Kennedy, S. M. (2011). Three measures of forest fire smoke exposure and their associations with respiratory and cardiovascular health outcomes in a population-based cohort. *Environmental health perspectives*, *119*(9), 1266-1271.

Henderson, S. B., McLean, K. E., Lee, M. J., & Kosatsky, T. (2022). Analysis of community deaths during the catastrophic 2021 heat dome: early evidence to inform the public

health response during subsequent events in greater Vancouver, Canada. *Environmental Epidemiology*, *6*(1), e189. https://doi.org/10.1097/EE9.0000000000000189

Hendrickson, L. A., Vogt, R. L., Goebert, D., & Pon, E. (1997). Morbidity on Kauai before and after Hurricane Iniki. *Preventive Medicine*, *26*(5), 711–716. https://doi.org/10.1006/pmed.1997.0196

Henning-Smith, C. (2016). Quality of life and psychological distress among older adults: the role of living arrangements. *Journal of Applied Gerontology: The Official Journal of the Southern Gerontological Society*, *35*(1), 39–61. https://doi.org/10.1177/0733464814530805

Hilhorst, D., & Bankoff, G. (2022). Introduction: why vulnerability still matters. In *Why Vulnerability Still Matters* (pp. 1–12). Routledge.

Hirdes, J. P., Fries, B. E., Morris, J. N., Steel, K., Mor, V., Frijters, D., LaBine, S., Schalm, C., Stones, M. J., Teare, G., Smith, T., Marhaba, M., Perez, E., & Jonsson, P. (1999). Integrated health information systems based on the RAI/MDS series of instruments. [erratum appears in Healthc Manage Forum 2000 Summer;13(2):41]. *Healthcare Management Forum*, *12*(4), 30–40. https://journals.sagepub.com/doi/pdf/10.1016/S0840-4704%2810%2960164-0

Hirdes, J. P., Ljunggren, G., Morris, J. N., Frijters, D. H., Finne Soveri, H., Gray, L., Björkgren, M., & Gilgen, R. (2008). Reliability of the interRAI suite of assessment instruments: a 12-country study of an integrated health information system. *BMC Health Services Research*, *8*(1), 277. https://doi.org/10.1186/1472-6963-8-277

Hirdes, J. P., Poss, J. W., Mitchell, L., Korngut, L., & Heckman, G. (2014). Use of the interRAI CHESS Scale to predict mortality among persons with neurological conditions in three care settings. *PLOS ONE*, *9*(6), e99066. https://doi.org/10.1371/journal.pone.0099066

Højsgaard, S., Halekoh, U., & Yan, J. (2006). The R Package geepack for generalized estimating equations. *Journal of Statistical Software*, *15*, 1–11. https://doi.org/10.18637/jss.v015.i02

Hopton, J. L., & Hunt, S. M. (1996). Housing conditions and mental health in a disadvantaged area in Scotland. *Journal of Epidemiology and Community Health*, *50*(1), 56–61. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1060205/

Hospers, L., Dillon, G. A., McLachlan, A. J., Alexander, L. M., Kenney, W. L., Capon, A., ... & Mavros, Y. (2024). The effect of prescription and over-the-counter medications on core temperature in adults during heat stress: a systematic review and meta-analysis. *EClinicalMedicine*, *77*.

Howden-Chapman, P., Crane, J., Chapman, R., & Fougere, G. (2011). Improving health and energy efficiency through community-based housing interventions. *International Journal of Public Health*, *56*(6), 583–588. https://doi.org/10.1007/s00038-011-0287-z

Howden-Chapman, P., Roebbel, N., & Chisholm, E. (2017). Setting housing standards to improve global health. *International Journal of Environmental Research and Public Health*, *14*(12), 1542. https://doi.org/10.3390/ijerph14121542

Hufschmidt, G. (2011). A comparative analysis of several vulnerability concepts. *Natural Hazards*, *58*(2), 621–643. https://doi.org/10.1007/s11069-011-9823-7

Hurst, S. A. (2008). Vulnerability in research and health care; describing the elephant in the room? *Bioethics*, *22*(4), 191–202. https://doi.org/10.1111/j.1467-8519.2008.00631.x

Ibrahim, D. (2016). Canadians' experiences with emergencies and disasters, 2014. *Juristat: Canadian Centre for Justice Statistics*, 1.

IEP. (2020). *Ecological threat register 2020: Understanding ecological threats, resilience and peace*. Institute for Economics & Peace. http://visionofhumanity.org/reports

Inouye, S. K., Studenski, S., Tinetti, M. E., & Kuchel, G. A. (2007). Geriatric syndromes: clinical, research, and policy implications of a core geriatric concept. *Journal of the American Geriatrics Society*, *55*(5), 780–791. https://doi.org/10.1111/j.1532-5415.2007.01156.x

IPCC. (2023). *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]*. (p. 184). doi: 10.59327/IPCC/AR6-9789291691647

Isaac, F., Toukhsati, S. R., Di Benedetto, M., & Kennedy, G. A. (2021). A systematic review of the impact of wildfires on sleep disturbances. *International Journal of Environmental Research and Public Health*, *18*(19), Article 19. https://doi.org/10.3390/ijerph181910152

Jain, P., Barber, Q. E., Taylor, S. W., Whitman, E., Castellanos Acuna, D., Boulanger, Y., Chavardès, R. D., Chen, J., Englefield, P., Flannigan, M., Girardin, M. P., Hanes, C. C., Little, J., Morrison, K., Skakun, R. S., Thompson, D. K., Wang, X., & Parisien, M.-A. (2024). Drivers and impacts of the record-breaking 2023 wildfire season in

Canada. *Nature Communications*, *15*(1), 6764. https://doi.org/10.1038/s41467-024-51154-7

Janssen, H., Ford, K., Gascoyne, B., Hill, R., Roberts, M., Bellis, M. A., & Azam, S. (2023). Cold indoor temperatures and their association with health and well-being: a systematic literature review. *Public Health*, *224*, 185–194. https://doi.org/10.1016/j.puhe.2023.09.006

Johnston, F. H., Henderson, S. B., Chen, Y., Randerson, J. T., Marlier, M., DeFries, R. S., ... & Brauer, M. (2012). Estimated global mortality attributable to smoke from landscape fires. *Environmental health perspectives*, *120*(5), 695-701.

Johnston, D., Standring, S., Ronan, K., Lindell, M., Wilson, T., Cousins, J., Aldridge, E., Ardagh, M. W., Deely, J. M., Jensen, S., Kirsch, T., & Bissell, R. (2014). The 2010/2011 Canterbury earthquakes: context and cause of injury. *Natural Hazards*, *73*(2), 627–637. https://doi.org/10.1007/s11069-014-1094-7

Jones, M. W., Smith, A. J. P., Betts, R., Canadell, J. G., Prentice, I. C., & Le Quéré, C. (2020). Climate change increases the risk of wildfires: January 2020. *ScienceBrief*. https://ueaeprints.uea.ac.uk/id/eprint/77982/

Kailes, J. I., & Enders, A. (2007). Moving beyond "special needs": A function-based framework for emergency management and planning. *Journal of Disability Policy Studies*, *17*(4), 230–237. https://doi.org/10.1177/10442073070170040601

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental Pollution*, *151*(2), 362–367. https://doi.org/10.1016/j.envpol.2007.06.012

Karim, M. Z., Al-Mamun, M., Eva, M. A., Ali, M. H., Kalam, A., Uzzal, N. I., & Das, P. K. (2024). Understanding mental health challenges and associated risk factors of post-natural disasters in Bangladesh: a systematic review. *Frontiers in Psychology*, *15*, 1466722.

Kassambara, A. (2021). *survminer: Drawing Survival Curves using "ggplot2* (Version 0.4.9) [Computer software]. <https://CRAN.R-project,org/package=survminer>

Keim, M. E. (2020). The epidemiology of extreme weather event disasters (1969-2018). *Prehospital and Disaster Medicine*, *35*(3), 267–271. https://doi.org/10.1017/S1049023X20000461

Kenny, G. P., Wilson, T. E., Flouris, A. D., & Fujii, N. (2018). Heat exhaustion. *Handbook of Clinical Neurology*, *157*, 505–529. https://doi.org/10.1016/B978-0-444-64074-1.00031-8

Kessler, R. C., Galea, S., Jones, R. T., & Parker, H. A. (2006). Mental illness and suicidality after Hurricane Katrina. *Bulletin of the World Health Organization*, *84*(12), 930–939. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1852424/

Khatoon, S., Asif, A., Hasan, M. M., & Alshamari, M. (2022). Social media-based intelligence for disaster response and management in smart cities. In P. M. Pardalos, S. Th. Rassia, & A. Tsokas (Eds.), *Artificial Intelligence, Machine Learning, and Optimization Tools for Smart Cities: Designing for Sustainability* (pp. 211–235). Springer International Publishing. https://doi.org/10.1007/978-3-030-84459-2_11

Kim, J., Schiavon, S., & Brager, G. (2018a). Personal comfort models–A new paradigm in thermal comfort for occupant-centric environmental control. *Building and Environment*, *132*, 114-124.

Kim, J., Zhou, Y., Schiavon, S., Raftery, P., & Brager, G. (2018b). Personal comfort models: predicting individuals' thermal preference using occupant heating and cooling behavior and machine learning. *Building and environment*, *129*, 96-106.

Kim, S., Jeong, W., Jang, B. N., Park, E.-C., & Jang, S.-I. (2021). Associations between substandard housing and depression: insights from the Korea welfare panel study. *BMC Psychiatry*, *21*(1), 12. https://doi.org/10.1186/s12888-020-03011-2

Klinenberg, E. (2013). *Going solo: The extraordinary rise and surprising appeal of living alone*. Penguin.

Kojima, G., Taniguchi, Y., Kitamura, A., & Fujiwara, Y. (2020a). Is living alone a risk factor of frailty? A systematic review and meta-analysis. *Ageing Research Reviews*, *59*, 101048. https://doi.org/10.1016/j.arr.2020.101048

Kojima, G., Walters, K., Iliffe, S., Taniguchi, Y., & Tamiya, N. (2020b). Marital status and risk of physical frailty: a systematic review and meta-analysis. *Journal of the American Medical Directors Association*, *21*(3), 322–330. https://doi.org/10.1016/j.jamda.2019.09.017

Kõlves, K., Kõlves, K. E., & De Leo, D. (2013). Natural disasters and suicidal behaviours: a systematic literature review. *Journal of Affective Disorders*, *146*(1), 1–14. https://doi.org/10.1016/j.jad.2012.07.037

Kosatsky, T. (2005). The 2003 European heat waves. *Eurosurveillance*, *10*(7), 3–4. https://doi.org/10.2807/esm.10.07.00552-en

Krieger, J., & Higgins, D. L. (2002). Housing and health: time again for public health action. *American Journal of Public Health*, *92*(5), 758–768. https://doi.org/10.2105/AJPH.92.5.758

Landrigan, P. J., Fuller, R., Acosta, N. J. R., Adeyi, O., Arnold, R., Basu, N. (Nil), Baldé, A. B., Bertollini, R., Bose-O'Reilly, S., Boufford, J. I., Breysse, P. N., Chiles, T., Mahidol, C., Coll-Seck, A. M., Cropper, M. L., Fobil, J., Fuster, V., Greenstone, M., Haines, A., … Zhong, M. (2018). The Lancet Commission on pollution and health. *The Lancet*, *391*(10119), 462–512. https://doi.org/10.1016/S0140-6736(17)32345-0

Lawrance, E. L., Thompson, R., Newberry Le Vay, J., Page, L., & Jennings, N. (2022). The impact of climate change on mental health and emotional wellbeing: a narrative review of current evidence, and its implications. *International Review of Psychiatry*, *34*(5), 443–498. https://doi.org/10.1080/09540261.2022.2128725

Lee, K. K., Bing, R., Kiang, J., Bashir, S., Spath, N., Stelzle, D., Mortimer, K., Bularga, A., Doudesis, D., Joshi, S. S., Strachan, F., Gumy, S., Adair-Rohani, H., Attia, E. F., Chung, M. H., Miller, M. R., Newby, D. E., Mills, N. L., McAllister, D. A., & Shah, A. S. V. (2020). Adverse health effects associated with household air pollution: a systematic review, meta-analysis, and burden estimation study. *The Lancet Global Health*, *8*(11), e1427–e1434. https://doi.org/10.1016/S2214-109X(20)30343-0

Lee, K., & Lee, D. (2015). the relationship between indoor and outdoor temperature in two types of residence. *Energy Procedia*, *78*, 2851–2856. https://doi.org/10.1016/j.egypro.2015.11.647

Lee, Y., & Tang, F. (2015). More caregiving, less working: caregiving roles and gender difference. *Journal of Applied Gerontology*, *34*(4), 465–483. https://doi.org/10.1177/0733464813508649

Leppold, C., Gibbs, L., Block, K., Reifels, L., & Quinn, P. (2022). Public health implications of multiple disaster exposures. *The Lancet Public Health*, *7*(3), e274–e286. https://doi.org/10.1016/S2468-2667(21)00255-3

Levine, C. (2004). The concept of vulnerability in disaster research. *Journal of Traumatic Stress*, *17*(5), 395–402. https://doi.org/10.1023/B:JOTS.0000048952.81894.f3

Liao, K. M., & Hu, Y. J. (2025). Factors influencing disaster preparedness behaviors of older adults. *PloS one*, *20*(2), e0315617.

Lima, F., Ferreira, P., & Leal, V. (2020). A review of the relation between household indoor temperature and health outcomes. *Energies*, *13*(11), Article 11. https://doi.org/10.3390/en13112881

Liu, G., Chen, H., Yuan, Y., & Song, C. (2024). Indoor thermal environment and human health: a systematic review. *Renewable and Sustainable Energy Reviews*, *191*, 114164. https://doi.org/10.1016/j.rser.2023.114164

Lulham, N., Warren, F. J., Walsh, K. A., & Szwarc, J. (2023). *Canada in a changing climate: Synthesis report*. https://doi.org/10.4095/332326

Madianos, M. G., & Evi, K. (2010). Trauma and natural disaster: the case of earthquakes in Greece. *Journal of Loss and Trauma*, *15*(2), 138–150. https://doi.org/10.1080/15325020903373185

Masselot, P., Mistry, M., Vanoli, J., Schneider, R., Iungman, T., Garcia-Leon, D., Ciscar, J.-C., Feyen, L., Orru, H., Urban, A., Breitner, S., Huber, V., Schneider, A., Samoli, E., Stafoggia, M., de'Donato, F., Rao, S., Armstrong, B., Nieuwenhuijsen, M., … Aunan, K. (2023). Excess mortality attributed to heat and cold: a health impact assessment study in 854 cities in Europe. *The Lancet Planetary Health*, *7*(4), e271–e281. https://doi.org/10.1016/S2542-5196(23)00023-2

Matz, C. J., Egyed, M., Xi, G., Racine, J., Pavlovic, R., Rittmaster, R., Henderson, S. B., & Stieb, D. M. (2020). Health impact analysis of PM2.5 from wildfire smoke in Canada (2013–2015, 2017–2018). *Science of The Total Environment*, *725*, 138506. https://doi.org/10.1016/j.scitotenv.2020.138506

Mavrouli, M., Mavroulis, S., Lekkas, E., & Tsakris, A. (2023). an emerging health crisis in turkey and syria after the earthquake disaster on 6 february 2023: risk factors, prevention and management of infectious diseases. *Healthcare*, *11*(7), Article 7. https://doi.org/10.3390/healthcare11071022

McArdle, C. E. (2023). asthma-associated emergency department visits during the canadian wildfire smoke episodes-United States, April– August 2023. *MMWR. Morbidity and Mortality Weekly Report*, *72*. https://doi.org/10.15585/mmwr.mm7234a5

McClatchey, R., McClymont, K., Griffin, E., & Carmichael, L. (2025). Community led housing, health and wellbeing: A comprehensive literature review. *International Journal of Housing Policy*, *25*(1), 18–55. https://doi.org/10.1080/19491247.2023.2232200

Mehta, K. M., Yaffe, K., & Covinsky, K. E. (2002). Cognitive impairment, depressive symptoms, and functional decline in older people. *Journal of the American Geriatrics Society*, *50*(6), 1045–1050. https://doi.org/10.1046/j.1532-5415.2002.50259.x

Melton, C. C., De Fries, C. M., Smith, R. M., & Mason, L. R. (2023). Wildfires and Older Adults: A Scoping Review of Impacts, Risks, and Interventions. *International Journal of Environmental Research and Public Health*, *20*(13), Article 13. https://doi.org/10.3390/ijerph20136252

Morganstein, J. C., & Ursano, R. J. (2020). Ecological disasters and mental health: causes, consequences, and interventions. *Frontiers in Psychiatry*, *11*. https://www.frontiersin.org/articles/10.3389/fpsyt.2020.00001

Morris, J. N., Carpenter, I., Berg, K., & Jones, R. N. (2000). Outcome measures for use with home care clients. *Canadian Journal on Aging/La Revue Canadienne Du Vieillissement*, *19*(S2), 87–105. https://doi.org/10.1017/S071498080001391X

Morris, J. N., Fries, B. E., Frijters, D., Hirdes, J. P., & Steel, R. K. (2013). interRAI home care quality indicators. *BMC Geriatrics*, *13*(1), 127. https://doi.org/10.1186/1471-2318-13-127

Morris, K. A., & Deterding, N. M. (2016). The emotional cost of distance: geographic social network dispersion and post-traumatic stress among survivors of Hurricane Katrina. *Social Science & Medicine*, *165*, 56–65. https://doi.org/10.1016/j.socscimed.2016.07.034

Mouratidis, K. (2021). Urban planning and quality of life: a review of pathways linking the built environment to subjective well-being. *Cities*, *115*, 103229. https://doi.org/10.1016/j.cities.2021.103229

Mulliner, E., Riley, M., & Maliene, V. (2020). Older people's preferences for housing and environment characteristics. *Sustainability*, *12*(14), Article 14. https://doi.org/10.3390/su12145723

Navaie-Waliser, M., Spriggs, A., & Feldman, P. H. (2002). Informal caregiving: differential experiences by gender. *Medical Care*, *40*(12), 1249–1259. https://www.jstor.org/stable/3767944

Neria, Y., Nandi, A., & Galea, S. (2008). Post-traumatic stress disorder following disasters: a systematic review. *Psychological Medicine*, *38*(4), 467–480. https://doi.org/10.1017/S0033291707001353

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

Nguyen, A.-M., Kim, Y., & Abramson, D. M. (2023). Neighborhood socioeconomic status and women's mental health: a longitudinal study of Hurricane Katrina survivors, 2005–2015. *International Journal of Environmental Research and Public Health*, *20*(2), Article 2. https://doi.org/10.3390/ijerph20020925

Nguyen, J. L., Schwartz, J., & Dockery, D. W. (2014). The relationship between indoor and outdoor temperature, apparent temperature, relative humidity, and absolute humidity. *Indoor Air*, *24*(1), 103–112. https://doi.org/10.1111/ina.12052

Nikitin, G. (2021). *Tackling climate change could be the greatest global health opportunity of the 21st century*. The Global Climate and Health Alliance. https://climateandhealthalliance.org/wp-content/uploads/2021/05/GCH-Climate-Change-paper.pdf

Noji, E. K. (2000). The public health consequences of disasters. *Prehospital and Disaster Medicine*, *15*(4), 21–31. https://doi.org/10.1017/S1049023X00025255

Norris, F. H., Friedman, M. J., Watson, P. J., Byrne, C. M., Diaz, E., & Kaniasty, K. (2002). 60,000 disaster victims speak: Part I. An empirical review of the empirical literature, 1981—2001. *Psychiatry*, *65*(3), 207–239. https://doi.org/10.1521/psyc.65.3.207.20173

North, C. S. (2017). Epidemiology of disaster mental health response. *Textbook of Disaster Psychiatry*, 27–43.

North, C. S., Ringwalt, C. L., Downs, D., Derzon, J., & Galvin, D. (2011). Postdisaster course of alcohol use disorders in systematically studied survivors of 10 disasters. *Archives of General Psychiatry*, *68*(2), 173–180. https://doi.org/10.1001/archgenpsychiatry.2010.131

Novia, K., Hariyanti, T., & Yuliatun, L. (2020). The impact of natural disaster on mental health of victim's lives: systematic review. *International Journal of Science and Society*, *2*(3), Article 3. https://doi.org/10.54783/ijsoc.v2i3.128

Ojo, A. V., & Juba, A. (2024) Safety Challenges in the care of dementia patients during natural disasters: preparing care homes for climate events. *Journal for Multidisciplinary Research*, *1*(02), 60-72.

Ontario. (2024). *Paying for long-term care*. http://www.ontario.ca/page/paying-long-term-care

Patel, L., Conlon, K. C., Sorensen, C., McEachin, S., Nadeau, K., Kakkad, K., & Kizer, K. W. (2022). Climate change and extreme heat events: how health systems should prepare. *NEJM Catalyst*, *3*(7), CAT.21.0454. https://doi.org/10.1056/CAT.21.0454

Pavanello, F., De Cian, E., Davide, M., Mistry, M., Cruz, T., Bezerra, P., Jagu, D., Renner, S., Schaeffer, R., & Lucena, A. F. (2021). Air-conditioning and the adaptation cooling deficit in emerging economies. *Nature Communications*, *12*(1), 6460.

Pausas, J. G., & Keeley, J. E. (2021). Wildfires and global change. *Frontiers in Ecology and the Environment*, *19*(7), 387–395. https://doi.org/10.1002/fee.2359

Paxson, C., Fussell, E., Rhodes, J., & Waters, M. (2012). Five years later: recovery from post traumatic stress and psychological distress among low-income mothers affected by Hurricane Katrina. *Social Science & Medicine*, *74*(2), 150–157. https://doi.org/10.1016/j.socscimed.2011.10.004

Pebesma, E. J. (2018). Simple features for R: standardized support for spatial vector data. *R Journal*, *10*(1), 439.

Peterson, L. J., Hackett, S. E., Dobbs, D., & Haley, W. E. (2024). Dementia caregivers' perspectives on disaster preparedness: barriers, resources, and recommendations. *The Gerontologist*, *64*(3), gnad076.

Petkova, E. P., Dimitrova, L. K., Sera, F., & Gasparrini, A. (2021). Mortality attributable to heat and cold among the elderly in Sofia, Bulgaria. *International Journal of Biometeorology*, *65*(6), 865–872. https://doi.org/10.1007/s00484-020-02064-y

Poss, J. W., Jutan, N. M., Hirdes, J. P., Fries, B. E., Morris, J. N., Teare, G. F., & Reidel, K. (2008). A review of evidence on the reliability and validity of minimum data set data. *Healthcare Management Forum*, *21*(1), 33–39. https://doi.org/10.1016/S0840-4704(10)60127-5

Proietti, M., & Cesari, M. (2020). Frailty: What Is It? In N. Veronese (Ed.), *Frailty and Cardiovascular Diseases: Research into an Elderly Population* (pp. 1–7). Springer International Publishing. https://doi.org/10.1007/978-3-030-33330-0_1

R Core Team. (2024). *R: A Language and Environment for Statistical Computing* [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/

Ragini, J. R., Rubesh Anand, P. M., & Bhaskar, V. (2018). Mining crisis information: a strategic approach for detection of people at risk through social media analysis. *International Journal of Disaster Risk Reduction*, *27*, 556–566. https://doi.org/10.1016/j.ijdrr.2017.12.002

Raker, E. J., Lowe, S. R., Arcaya, M. C., Johnson, S. T., Rhodes, J., & Waters, M. C. (2019). Twelve years later: the long-term mental health consequences of Hurricane Katrina. *Social Science & Medicine*, *242*, 112610. https://doi.org/10.1016/j.socscimed.2019.112610

Reher, D., & Requena, M. (2018). Living Alone in Later Life: A Global Perspective. *Population and Development Review*, *44*(3), 427–454. https://www.jstor.org/stable/26622850

Rhodes, J., Chan, C., Paxson, C., Rouse, C. E., Waters, M., & Fussell, E. (2010). The impact of hurricane Katrina on the mental and physical health of low-income parents in New Orleans. *American Journal of Orthopsychiatry*, *80*(2), 237. https://www.proquest.com/docview/1492511853?parentSessionId=JU81KjhAGCjswdwc339%2Fs4YhYWBMm32XHoxF9nm5S6s%3D&pq-origsite=primo&

Richards, D.A., Bower, P., Pagel, C., Weaver, A., Utley, M., Cape, J., Pilling, S., Lovell, K., Gilbody, S., Leibowitz, J. & Owens, L. (2012). Delivering stepped care: an analysis of implementation in routine practice. *Implementation Science*, *7*, 1-11.

Ritchie, H., Rosado, P., & Roser, M. (2022). Natural Disasters. *Our World in Data*. https://ourworldindata.org/natural-disasters

Riva, M., Kingunza Makasi, S., Dufresne, P., O'Sullivan, K., & Toth, M. (2021). Energy poverty in Canada: Prevalence, social and spatial distribution, and implications for research and policy. *Energy Research & Social Science*, *81*, 102237. https://doi.org/10.1016/j.erss.2021.102237

Riva, A., Rebecchi, A., Capolongo, S., & Gola, M. (2022). Can homes affect well-being? a scoping review among housing conditions, indoor environmental quality, and mental health outcomes. *International Journal of Environmental Research and Public Health*, *19*(23), Article 23. https://doi.org/10.3390/ijerph192315975

Robin, X., Turck, N., Hainard, A., Tiberti, N., Lisacek, F., Sanchez, J.-C., & Müller, M. (2011). pROC: an open-source package for R and S+ to analyze and compare ROC curves. *BMC Bioinformatics*, *12*, 1–8.

Rockwood, K. (2005). What would make a definition of frailty successful? *Age and Ageing*, *34*(5), 432–434. https://doi.org/10.1093/ageing/afi146

Romanello, M., Napoli, C. di, Green, C., Kennard, H., Lampard, P., Scamman, D., Walawender, M., Ali, Z., Ameli, N., Ayeb-Karlsson, S., Beggs, P. J., Belesova, K., Ford, L. B., Bowen, K., Cai, W., Callaghan, M., Campbell-Lendrum, D., Chambers, J., Cross, T. J., … Costello, A. (2023). The 2023 report of the Lancet Countdown on health and climate change:tThe imperative for a health-centred response in a world facing irreversible harms. *The Lancet*, *402*(10419), 2346–2394. https://doi.org/10.1016/S0140-6736(23)01859-7

Ruopp, M. D., Perkins, N. J., Whitcomb, B. W., & Schisterman, E. F. (2008). Youden Index and optimal cut-point estimated from observations affected by a lower limit of detection. *Biometrical Journal. Biometrische Zeitschrift*, *50*(3), 419–430. https://doi.org/10.1002/bimj.200710415

Russell, L. (2018). Emmeans: estimated marginal means, aka least-squares means. *R Package Version*, *1*(2).

Saeed, S. A., & Gargano, S. P. (2022). Natural disasters and mental health. *International Review of Psychiatry*, *34*(1), 16–25. https://doi.org/10.1080/09540261.2022.2037524

Sanyal, S., Rochereau, T., Maesano, C. N., Com-Ruelle, L., & Annesi-Maesano, I. (2018). Long-term effect of outdoor air pollution on mortality and morbidity: a 12-year

follow-up study for metropolitan france. *International Journal of Environmental Research and Public Health*, *15*(11), Article 11. https://doi.org/10.3390/ijerph15112487

Schluter, P. J., Ahuriri-Driscoll, A., Anderson, T. J., Beere, P., Brown, J., Dalrymple-Alford, J., David, T., Davidson, A., Gillon, D. A., Hirdes, J., Keeling, S., Kingham, S., Lacey, C., Menclova, A. K., Millar, N., Mor, V., & Jamieson, H. A. (2016). Comprehensive clinical assessment of home-based older persons within New Zealand: an epidemiological profile of a national cross-section. *Australian and New Zealand Journal of Public Health*, *40*(4), 349–355. https://doi.org/10.1111/1753-6405.12525

Schroeder, D., & Gefenas, E. (2009). Vulnerability: too vague and too broad? *Cambridge Quarterly of Healthcare Ethics*, *18*(2), 113–121. https://doi.org/10.1017/S0963180109090203

Sinn, C.-L. J., Heckman, G., Poss, J. W., Onder, G., Vetrano, D. L., & Hirdes, J. (2020). A comparison of 3 frailty measures and adverse outcomes in the intake home care population: a retrospective cohort study. *Canadian Medical Association Open Access Journal*, *8*(4), E796–E809. https://doi.org/10.9778/cmajo.20200083

Sinn, C.-L. J., Hirdes, J. P., Poss, J. W., Boscart, V. M., & Heckman, G. A. (2022). Implementation evaluation of a stepped approach to home care assessment using interRAI systems in Ontario, Canada. *Health & Social Care in the Community*, *n/a*(n/a). https://doi.org/10.1111/hsc.13784

Skou, S. T., Mair, F. S., Fortin, M., Guthrie, B., Nunes, B. P., Miranda, J. J., Boyd, C. M., Pati, S., Mtenga, S., & Smith, S. M. (2022). Multimorbidity. *Nature Reviews Disease Primers*, *8*(1), 1–22. https://doi.org/10.1038/s41572-022-00376-4

Statistic Canada. (2022). In the midst of high job vacancies and historically low unemployment, Canada faces record retirements from an aging labour force: number of seniors aged 65 and older grows six times faster than children 0-14. *The Daily*, *11*.

Stepler, R. (2016). *Smaller share of women ages 65 and older are living alone*. Pew Research Center. http://pewrsr.ch/1QLTnsf

Stewart, S. L., Celebre, A., Semovski, V., Hirdes, J. P., Vadeboncoeur, C., & Poss, J. W. (2022). The interrai child and youth suite of mental health assessment instruments: an integrated approach to mental health service delivery. *Frontiers in Psychiatry*, *13*, 710569. https://doi.org/10.3389/fpsyt.2022.710569

Suglia, S. F., Duarte, C. S., & Sandel, M. T. (2011). housing quality, housing instability, and maternal mental health. *Journal of Urban Health*, *88*(6), 1105–1116. https://doi.org/10.1007/s11524-011-9587-0

Sun, Z., & Zhu, D. (2019). Exposure to outdoor air pollution and its human-related health outcomes: an evidence gap map. *BMJ Open*, *9*(12), e031312. https://doi.org/10.1136/bmjopen-2019-031312

Tang, J., Galbraith, N., & Truong, J. (2019). *Insights on Canadian society living alone in Canada.* Statistics Canada.

Tang, W., Lu, Y., & Xu, J. (2018). Post-traumatic stress disorder, anxiety and depression symptoms among adolescent earthquake victims: comorbidity and associated sleep-

disturbing factors. *Social Psychiatry and Psychiatric Epidemiology*, *53*(11), 1241–1251. https://doi.org/10.1007/s00127-018-1576-0

Tardy, F., & Lee, B. (2019). Building related energy poverty in developed countries – Past, present, and future from a Canadian perspective. *Energy and Buildings*, *194*, 46–61. https://doi.org/10.1016/j.enbuild.2019.04.013

Terayama, T., Shigemura, J., Kobayashi, Y., Kurosawa, M., Nagamine, M., Toda, H., & Yoshino, A. (2021). Mental health consequences for survivors of the 2011 Fukushima nuclear disaster: a systematic review. Part 2: emotional and behavioral consequences. *CNS Spectrums*, *26*(1), 30–42. https://doi.org/10.1017/S1092852920000115

Tham, S., Thompson, R., Landeg, O., Murray, K. A., & Waite, T. (2020). Indoor temperature and health: a global systematic review. *Public Health*, *179*, 9–17. https://doi.org/10.1016/j.puhe.2019.09.005

Therneau, T. M. (2023). *A package for survival analysis in R.* (Versions 5-7) [Computer software]. <https://CRAN.R-project.org/package=survival>

Thiele, C., & Hirschfeld, G. (2021). cutpointr: improved Estimation and Validation of Optimal Cutpoints in R. *Journal of Statistical Software*, *98*, 1–27. https://doi.org/10.18637/jss.v098.i11

Thompson, J., & Vasefi, M. (2025). Natural disaster-induced dementia and cognitive decline: a meta-analysis and systematic review. *Social Science & Medicine*, 117898.

Thompson, R., Lawrance, E. L., Roberts, L. F., Grailey, K., Ashrafian, H., Maheswaran, H., Toledano, M. B., & Darzi, A. (2023). Ambient temperature and mental health: a

systematic review and meta-analysis. *The Lancet Planetary Health*, *7*(7), e580–e589. https://doi.org/10.1016/S2542-5196(23)00104-3

Thomson, H., Thomas, S., Sellstrom, E., & Petticrew, M. (2013). Housing improvements for health and associated socio-economic outcomes. *Cochrane Database of Systematic Reviews*, *2*. https://doi.org/10.1002/14651858.CD008657.pub2

Thywissen, K. (2006). Core terminology of disaster reduction: a comparative glossary. *Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies*, 448–496.

Trevisan, C., Veronese, N., Maggi, S., Baggio, G., De Rui, M., Bolzetta, F., Zambon, S., Sartori, L., Perissinotto, E., Crepaldi, G., Manzato, E., & Sergi, G. (2016). Marital status and frailty in older people: gender differences in the progetto veneto anziani longitudinal study. *Journal of Women's Health*, *25*(6), 630–637. https://doi.org/10.1089/jwh.2015.5592

Turner, B. L., Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., Eckley, N., Kasperson, J. X., Luers, A., Martello, M. L., Polsky, C., Pulsipher, A., & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences*, *100*(14), 8074–8079. https://doi.org/10.1073/pnas.1231335100

Umishio, W., Ikaga, T., Kario, K., Fujino, Y., Hoshi, T., Ando, S., Suzuki, M., Yoshimura, T., Yoshino, H., Murakami, S., & SWH Survey Group. (2019). Cross-sectional analysis of the relationship between home blood pressure and indoor temperature in winter: a

nationwide smart wellness housing survey in Japan. *Hypertension, 74*(4), 756–766. https://doi.org/10.1161/HYPERTENSIONAHA.119.12914

UN DESA. (2023). *World population prospects 2022: Summary of results*. UN. https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/wpp2022_summary_of_results.pdf

United Nations. (2023). *Sustainable Development Goals Report 2023: Special Edition*. UN. https://unstats.un.org/sdgs/report/2023/

Ursano, R. J., Fullerton, C. S., Weisaeth, L., & Raphael, B. (2017). Individual and community responses to disasters. *Textbook of Disaster Psychiatry*, 1–25.

van den Berg, B., Grievink, L., Yzermans, J., & Lebret, E. (2005). Medically unexplained physical symptoms in the aftermath of disasters. *Epidemiologic Reviews*, *27*(1), 92–106. https://doi.org/10.1093/epirev/mxi001

Van der Kolk, B. (2000). Posttraumatic stress disorder and the nature of trauma. *Dialogues in Clinical Neuroscience*, *2*(1), 7–22.

van Riet, E. E. S., Hoes, A. W., Wagenaar, K. P., Limburg, A., Landman, M. A. J., & Rutten, F. H. (2016). Epidemiology of heart failure: the prevalence of heart failure and ventricular dysfunction in older adults over time. A systematic review. *European Journal of Heart Failure*, *18*(3), 242–252. https://doi.org/10.1002/ejhf.483

van Solm, A. I. T., Hirdes, J. P., Eckel, L. A., Heckman, G. A., & Bigelow, P. L. (2017). Using standard clinical assessments for home care to identify vulnerable populations before, during, and after disasters. *Journal of Emergency Management*, *15*(6), 355–366. https://doi.org/10.5055/jem.2017.0344

Vandentorren, S., Bretin, P., Zeghnoun, A., Mandereau-Bruno, L., Croisier, A., Cochet, C., Ribéron, J., Siberan, I., Declercq, B., & Ledrans, M. (2006). August 2003 heat wave in France: risk factors for death of elderly people living at home. *European Journal of Public Health*, *16*(6), 583–591. https://doi.org/10.1093/eurpub/ckl063

Vesentini, L., Van Eenoo, L., Vanneste, D., Declercq, A., Mello, J. D. A., & Almeida, D. (2011). Elderly care: The interRAI-instruments in Belgium-Feasibility to use BelRAI across settings (home care, nursing home care and acute hospital care). *International Psychogeriatrics*, *23*(1), 162.

Vogel, C., & O'Brien, K. (2004). *Vulnerability and global environmental change: Rhetoric and reality*. https://idl-bnc-idrc.dspacedirect.org/handle/10625/39859

Wang, C., Zhang, F., Wang, J., Doyle, J. K., Hancock, P. A., Mak, C. M., & Liu, S. (2021). How indoor environmental quality affects occupants' cognitive functions: a systematic review. *Building and Environment*, *193*, 107647. https://doi.org/10.1016/j.buildenv.2021.107647

Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., Chaytor, S., Colbourn, T., Collins, M., Cooper, A., Cox, P. M., Depledge, J., Drummond, P., Ekins, P., Galaz, V., Grace, D., Graham, H., Grubb, M., Haines, A., … Costello, A. (2015). Health and climate change: policy responses to protect public health. *The Lancet*, *386*(10006), 1861–1914. https://doi.org/10.1016/S0140-6736(15)60854-6

Wei, T., Simko, V., Levy, M., Xie, Y., Jin, Y., & Zemla, J. (2013). corrplot: visualization of a correlation matrix. *R Package Version 0.73*, *230*(11).

Weilnhammer, V., Schmid, J., Mittermeier, I., Schreiber, F., Jiang, L., Pastuhovic, V., Herr, C., & Heinze, S. (2021). Extreme weather events in europe and their health consequences – a systematic review. *International Journal of Hygiene and Environmental Health*, *233*, 113688. https://doi.org/10.1016/j.ijheh.2021.113688

World Health Organization. (2021). *Ambient (outdoor) air pollution*. https://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health

World Health Organization. (2023a). *Overview of methods to assess population exposure to ambient air pollution*. World Health Organization. https://www.who.int/publications/i/item/9789240073494

World Health Organization. (2023b). *WHO flash appeal: Earthquake response in Türkiye and Whole of Syria*. https://www.who.int/publications/m/item/who-flash-appeal--earthquake-response-in-t-rkiye-and-whole-of-syria

World Health Organization. (2024). *WHO Results Framework: Delivering a measurable impact in countries*. https://www.who.int/publications/m/item/who-results-framework--delivering-a-measurable-impact-in-countries-Jan-15-2024

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S. M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., … Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software*, *4*(43), 1686. https://doi.org/10.21105/joss.01686

Wisner, B. (2016). Vulnerability as Concept, Model, Metric, and Tool. In *Oxford Research Encyclopedia of Natural Hazard Science*. https://doi.org/10.1093/acrefore/9780199389407.013.25

Wolf, S. (2010). *From vulnerability formalization to finitely additive probability monads*. (Doctoral dissertation). https://doi.org/10.17169/refubium-9300

Wolf, S., Hinkel, J., Hallier, M., Bisaro, A., Lincke, D., Ionescu, C., & Klein, R. J. T. (2013). Clarifying vulnerability definitions and assessments using formalisation. *International Journal of Climate Change Strategies and Management*, *5*(1), 54–70. https://doi.org/10.1108/17568691311299363

Yen, I. H., Michael, Y. L., & Perdue, L. (2009). Neighborhood environment in studies of health of older adults. *American Journal of Preventive Medicine*, *37*(5), 455–463. https://doi.org/10.1016/j.amepre.2009.06.022

Zarulli, V., Barthold Jones, J. A., Oksuzyan, A., Lindahl-Jacobsen, R., Christensen, K., & Vaupel, J. W. (2018). Women live longer than men even during severe famines and epidemics. *Proceedings of the National Academy of Sciences*, *115*(4), E832–E840. https://doi.org/10.1073/pnas.1701535115

Zhao, J., Liu, Y. W. J., Tyrovolas, S., & Mutz, J. (2023). Exploring the concept of psychological frailty in older adults: a systematic scoping review. *Journal of Clinical Epidemiology*, *159*, 300–308. https://doi.org/10.1016/j.jclinepi.2023.05.005

Zuñiga, R. A. A., Reyes, G. G., Murrieta, J. I. S., & Villoria, R. A. M. G. (2019). Posttraumatic stress symptoms in people exposed to the 2017 earthquakes in Mexico. *Psychiatry Research*, *275*, 326–331. https://doi.org/10.1016/j.psychres.2019.04.003

Zunin, L. M., & Myers, D. (2000). *Training manual for human service workers in major disasters*. Department of Health and Human Services Administration.