Differential vulnerabilities: Extreme heat, health and well-being of older adults in Sunbelt cities in the United States

by

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AUTHOR'S DECLARATION

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

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

STATEMENT OF CONTRIBUTIONS

Exceptions to sole authorship

Chapter 3: Dassah, C., Crank, P. J., & Jones-Crank, J. L. Heat stress and coping strategies among older adults in three Sunbelt cities in the United States. (Ready to be submitted to a journal).

I hereby declare that, as the lead author of the sole manuscript of this dissertation, I was responsible for the research conceptualization and data analysis. I was responsible for drafting and submitting the article for publication in the above peer-reviewed journal. I also addressed all the comments from peer reviewers. Dr. Leah Jones-Crank and Dr. Peter Crank, as supervisors, provided the data and significant editorial assistance.

ABSTRACT

Heat impacts vary disproportionately across geographic regions and social groups. Older adults in Sunbelt cities of the United States (US) are particularly vulnerable to localized urban warming, which threatens their health and well-being. Prevailing scientific evidence suggests that extreme heat events account for higher fatalities among older adults in the US compared to other extreme weather events. Despite existing studies on the impacts of extreme heat on older adults, limited research has addressed the specific socio-demographic, health-related conditions, and strategic coping factors influencing heat stress experiences among older urban populations. As part of a larger study examining heat and ozone-related risks in Sunbelt cities, this thesis adopts a retrospective cross-sectional study design, leveraging the strengths of mixed-methodology to examine predictors of heat stress and coping strategies among older adults in Los Angeles, Houston, and Phoenix. Utilizing a cross-sectional household survey data from 909 older adults in the three cities, the thesis sought to: (1) examine the factors affecting heat stress among older adults; and (2) explore coping strategies among older adults during extreme heat events. Qualitative data were generated from the open-ended survey questionnaire from 67 respondents across the three cities. Data was analyzed using thematic qualitative coding and multiple binary logistic regression analyses. The results reveal that marital status, income, respiratory diseases, physical activity, cool showers, and city of residence were significantly associated with a higher risk of experiencing heat stress. Also, older adults aged 80 and older were less likely to experience heat stress compared to their relatively younger counterparts. Further, the qualitative results uncovered a mix of heat-related coping behaviors adopted by older adults to protect themselves during extreme heat events. These results underscore the complex interplay of geographic, socio-demographic, behavioral and health-related factors affecting heat stress. The study makes important contributions to theory, policy and practice. First, the study contributes to the literature on the geographies of ageing and the relational processes that shape ageing across place, space and scale. Secondly, the study highlights the importance of integrating varied approaches within the geographies of health and healthcare, hence advancing the methodological diversity of the sub-discipline. Finally, the study underscores the need for policies aimed at strengthening social support for older adults, emergency heat risk warning awareness and public cooling systems in Sunbelt cities. The study recommends that urban health strategies should prioritize these demographics, fostering micro-level coping strategies to enhance resilience and reduce vulnerability to heat stress among older populations

Keywords: climate change, heat stress, extreme heat, health, binary logistic regression, socio-ecological model

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CHAPTER ONE

INTRODUCTION

1.1 Research Problem

Climate change – the long-term shift in global weather conditions due to natural or anthropogenic factors – is a major threat to health and well-being in the 21st century (Muttarak, 2021). Climate change has become a reality, as so many countries are already experiencing some of the defining impacts of extreme weather events, such as heatwaves, drought, floods, wildfires, cold waves, tornadoes, and cyclones (Curtis et al., 2017). The latest assessment report from the Intergovernmental Panel on Climate Change (IPCC) reveals that the world is warming at unsustainable levels, at a rate that has not been observed in approximately 125,000 years (IPCC, 2021). Evidence suggests that the global annual average warming is estimated to be between 2.5°C and 3°C, a figure higher than the initially assumed global average of 1.5°C to 2°C in 2015 when the Paris climate agreement was signed (Tollefson, 2021). The report further stressed that if anthropogenic activities, including greenhouse gas emissions, are not controlled, extreme weather events could become severe in the future and disproportionately impact populations. Thus, baseline temperatures are increasing rapidly, and are becoming more frequent, lasting longer and intensifying (IPCC, 2021). Although the effects of temperature extremes affect all regions, there are marked disparities across geographic regions and different population groups (Curtis & Oven, 2012). This has raised important concerns for governments and policymakers.

The IPCC projects that if global temperatures exceed 2°C above pre-industrial levels, the Earth will most likely suffer more frequent heatwaves, long-term droughts, heavy precipitation, tornadoes, flooding, and wildfires (IPCC, 2021). Exposure to environmental hazards will exacerbate acute and chronic health conditions, as well as increase the risk of vector-borne diseases (Cleland et al., 2023; Curtis et al., 2017). Among all these hazards, extreme heat is known to be the deadliest, accounting for higher rates of mortality and morbidity (Brimicombe et al., 2024). As the IPCC projects that extreme heat events will become more intense, long-lasting and frequent in the coming decades, the impacts are felt differently across space (IPCC, 2021). Particularly for urban areas, exposure to extreme heat is further exacerbated by urban-induced warming, which constitutes a major component of total urban warming – the increase in urban temperatures from multiple impacts of climate change and anthropogenic urban activities (Tuholske et al., 2021). Increased exposure to extreme heat causes heat stress or heat exhaustion – a condition which occurs when the body is unable to efficiently

dissipate heat (Khan et al., 2021). Other heat-health outcomes include heat stroke, dehydration, acute renal failure, nephritis, and cardiopulmonary diseases. Extreme heat can also exacerbate the side effects of other health conditions associated with medication, such as beta blockers used to control blood pressure (Gamble et al., 2013). These conditions are particularly severe for individuals with underlying health conditions, such as older adults.

Evidence suggests that the impact of climate-induced warming on population health is uneven, with a disproportionate impact on older adults with lower socioeconomic status whose health may have been compromised (Wilhelmi et al., 2021; Curtis and Owen, 2012; Conlon et al., 2016). The processes driving vulnerability to the risks of extreme heat are further exacerbated by the uneven distribution of the social determinants of health (conditions in which people are born, live, work, retire and die), which are often characterized by geographical, historical, political, social, economic and structural disparities outside the control of the individual (Wilhelmi et al., 2021). The recent coronavirus (COVID-19) pandemic further compounded the risks and vulnerability to weather hazards among older adults in various ways (Phillips et al., 2020). First, the pandemic disrupted access to social networks and outdoor neighbourhood resources such as public spaces, which serve as coping mechanisms and responses to indoor heat stress. Also, it aggravated the burden of self-isolation and anxiety and placed them in double jeopardy. Finally, the pandemic exacerbated socio-economic inequalities and further plunged families into the abyss of energy poverty, exposing them to the risk of extreme heat (Wang et al., 2021; Wilhelmi et al., 2021). Aside from suffering a greater burden of environmental risks, older adults also recover slowly from disasters and ill health.

The impact of extreme heat events on the health and well-being of older adults has been acknowledged in literature (Meade et al., 2020; Bell et al., 2018). Research in Los Angeles, Houston, and Phoenix has established the link between rising temperatures, and increased incidence of heat stress among older adults (Crank et al., 2024; O'Lenick et al., 2020), ambulance call outs (Mason et al., 2023; Wang et al., 2021; Turner et al., 2012), hospitalization (Bobb et al., 2014), and mortalities (Cleland et al., 2023; Khatana et al., 2022; Vaidyanathan, 2020; Anderson & Bell, 2009; Fouillet et al., 2008). In a nationwide study involving 120 cities in the US, O'Lenick and colleagues (2025) observed that heat-related hospitalizations were due to respiratory tract infection, chronic respiratory diseases, and respiratory failure among older adults. Due to declining functional limitations and the deteriorating physical health of older adults, maintaining a high quality of life amidst the rising cost of health services remains a challenge (Xu & Drew, 2015). Multiple comorbidities among older adults

increase the demand for healthcare and increase health expenditures, influencing their care-seeking behaviour (Braimah et al., 2023). Healthcare-seeking behaviour describes the actions taken by a person who is believed to have a health condition to utilize health services (Bana et al., 2016). Health-seeking behaviour among older adults has been reported in the US (Xu & Drew, 2015) and elsewhere (Atchessi et al., 2018). For example, Xu & Drew (2015) leveraged a 10-year Nationally Representative Health Interview (NRHI) series of data from the US and documented that 41% of older adults did not seek medical care for their injuries. Access to and utilization of appropriate health care are essential for older adults to maintain their health and well-being. However, the decision to seek care is influenced by several factors, including the cost of treatment, health insurance coverage, the severity of illness, wait times at the health facility, the attitude of healthcare workers, socio-demographic and cultural factors, and accessibility to health facilities (Agyemang-Duah et al., 2023; Braimah et al., 2023; Xu & Drew, 2015; Uzochukwu et al., 2004).

Older adults are at a greater risk of dehydration when exposed to prolonged and elevated levels of heatwaves compared to other age groups (Meade et al., 2020). Ageing generally comes with a decline in thermoregulatory function and increased sweat production due to heat transfer between the body and the environment (McGregor & Vanos, 2018). As such, heat exposure causes a progressive rise in body temperature and can lead to adverse health implications. Common heat stress ailments among older adults include light-headedness, dizziness, heat rash, heat cramps, heat syncope, heat exhaustion, and heat stroke (Crank et al., 2024; McGregor & Vanos, 2018). Heat stress may further exacerbate other pathophysiological health conditions unrelated to heat, such as adverse cardiovascular disease, diabetes, obesity, and acute kidney injury (Meade et al., 2020). It is estimated that extreme heat accounts for high hospitalization rates and all-cause mortalities among older adults in the US (Lavados et al., 2018; Bobb et al., 2014). Available evidence has identified advanced ageing, lack of mechanical AC, the presence of pre-existing health conditions, gender and the built environment as predictors of heat stress among older adults in Sunbelt cities in the US (Crank et al., 2024; Wilhelmi et al., 2021; O'Lenick et al., 2020). The Sunbelt describes the region of the United States that stretches across the southeastern and southwestern portions of the country from Florida to California (Wooten, 2024).

In the southwestern part of the US (the Sunbelt), the effect of extreme temperatures is felt differently. The rate at which this region is warming is particularly concerning (Moss, 2021). For instance, the fastest-warming cities in the world are located in the Sunbelt, including Las Vegas, El Paso, Tucson, Phoenix, New Mexico, Miami, Los Angeles, and Houston (American Warming, 2019).

Studies reveal that the region has been the subject of extensive investigation due to the frequency of extreme heat events and its vulnerability to climate change stressors (Yin et al., 2023; Hayden et al., 2017; Powell & Keim, 2015). There is strong evidence that extreme heat consistently accounts for annual increases in morbidity and fatalities compared to other natural disasters in the United States (Wooten, 2024; Crank et al., 2024; Meade et al., 2020; O'Lenick et al., 2020; Bobb et al., 2014). In addition to extreme heat, the region also faces unique challenges, including high volatility of climate change, poor air quality, increasing urbanization, large and expanding population, heat inequalities, and socioeconomic inequalities, owing to its geographic position (O'Lenick et al., 2024; Yin et al., 2023; Wang et al., 2021).

Studies reveal that a large proportion of urban residents in the Sunbelt are at risk of energy poverty, which affects the consistent use of air conditioning (AC), leading to an increased risk of heat stress (Crank et al.,2024; Baker & Sturn, 2024; Wang et al., 2021; Baniassadi et al., 2020). Energy poverty describes a situation where households spend a large proportion of their income on energy for cooling, heating, and lighting or the inability to afford adequate and reliable energy services, which affects their quality of life (Wang et al., 2021; Karpinska & Smiech, 2020). Due to the hot summers experienced in cities located in the Sunbelt, low-income households are prone to suffer energy poverty. Households suffer energy poverty when they are forced to optimize energy consumption by keeping their homes at unhealthy temperatures (Wang et al., 2021). In a related study, Mohr (2018) reported that, in the US, people who do not work full-time are likely to suffer from energy poverty. Compared to other groups, older adults with low income/pensions and poor access to mechanical air-conditioning are prone to suffer from energy poverty and are at an increased risk of experiencing heat stress (Crank et al., 2024; Wang et al., 2021). Anderson and Bell (2009) studied weather-related mortalities in the US and found that communities without centralized air conditioning systems reported higher heat-related mortalities. Similarly, findings by Crank et al. (2024) revealed that barriers to the use of air-conditioning increase the risk of heat stress and threaten the health and well-being of older adults in Sunbelt cities.

The urban heat island (UHI) effect refers to the phenomenon where urban temperatures are comparatively elevated relative to adjacent rural areas (Oke et al., 2017). This phenomenon occurs as a result of the compounded impacts of urban traffic, the built environment, and anthropogenic greenhouse gas emissions that retain heat within urban infrastructures (such as carbon dioxide from fossil fuels, methane from gas and oil production, and fluorinated gases from air conditioners,

refrigerators and aerosols) (O'Lenick et al., 2020). The UHI effect poses significant threats to the health and well-being of older urban populations (Sailor et al., 2015). It is estimated that urban warming contributes to approximately 52% of annual exposure to extreme heat (Tuholske et al., 2021). Evidence indicates that an increase in the global average temperature exceeding 1.5°C will significantly impact urban residents (Dahl et al., 2019). The degree of risk associated with this phenomenon relies on factors such as the levels of vulnerability, the effectiveness of adaptive capacities, urban infrastructure, and housing conditions (Martín & Paneque, 2022). Prior studies have demonstrated a correlation between climate change, urbanization, and human health (Crank et al., 2024; O'Lenick et al., 2020; Conlon et al., 2016). These studies suggest that extreme heat amplified by the UHI effect will persist and present significant threats to the health of older urban populations. Considering the projected increase in frequency and intensity of future extreme heat events, this suggests the heightened risk of older adults enduring adverse health outcomes (O'Lenick et al., 2020). Other notable urban populations that are particularly vulnerable to extreme heat include children, women, racialized populations, homeless individuals with disabilities, and other socio-economically disadvantaged groups (Tuholske et al., 2021; Wang et al., 2021; Wilhelmi et al., 2021; Conlon et al., 2016). Despite the differential vulnerability to extreme heat, there exists a notable gap in the literature regarding a globally comprehensive and/or sufficient evidence on the nexus between the projected increase in ageing population, urbanization and intensifying extreme heat events (Tuholske et al., 2021). This inadequacy obstructs the formulation of actionable solutions to address the complex challenges posed by urbanization and climate change.

Global efforts aimed at maintaining global warming at 1.5°C and below pre-industrial levels over the 21st century are visible (Tollefson, 2021). To mitigate the deleterious impacts of climate change on human health and well-being, the United Nations (UN) Agenda 2030 for Sustainable Development Goals (SDGs), the Paris Agreement, and the United Nations Framework Convention on Climate Change (UNFCCC) concomitantly commit to reducing global temperatures below pre-industrial levels. Also, the synergy between climate-related SDGS has been recognized in literature (Coenen et al., 2022; Curtis et al., 2017). Collectively, SDG 3 (good health and well-being), SDG 7 (affordable and clean energy), SDG 9 (industry innovation and infrastructure), SDG 12 (responsible production and consumption), SDG 13 (climate action), and SDG 17 (partnership for the goals) commit to tackle the impact of climate change on society. For instance, SDG 17 aims to garner global support among stakeholders in the form of knowledge and resources to address global challenges

while fostering sustainable development (Coenen et al., 2022). More recently, the 26th and 27th UN Climate Change Conference of the Parties, respectively held in Glasgow (COP26) in November 2021, and November 2022 in Egypt (COP27) re-emphasized the urgent need to meet climate change targets of limiting global temperatures to 1.5°C by 2100 (Dalton & Fleishman, 2021). However, world leaders are reluctant to implement drastic measures to curtail the emission of greenhouse gases at the expense of their economic development (Baada, 2022). In the absence of sustainable climate financing, it is unlikely that these global targets will be realized. It is also apparent that, as the United States plans to withdraw from the Paris Agreement in 2026, meeting these ambitious global climate change goals remains elusive (Executive Order, 2025). Despite these global efforts, climate change governance remains fragmented, decentralized, and lacks a centralized coordinating framework to aggregate transnational efforts (Hale, 2024).

1.2 Justification for the study

The United States, like other parts of the world, face a dual challenge of rapid population ageing and climate-induced extreme temperature events, which pose substantial threats to public health (Gyasi et al., 2019; Gamble et al., 2013). According to the World Health Organization (WHO), the population of older people has increased fivefold between 1950 and 2015 (WHO, 2015). Projections indicate that by 2030, the population of older adults will reach 1.4 billion and exceed 2 billion (representing 21.1% of the total global population) by 2050 (WHO, 2020). The UN estimates that by 2047, the population of older adults will outnumber children under 15 (UN, 2014). Consistent with global trends, the population of older adults in the US is increasing rapidly. There were 39.5 million older Americans (13% of the total population) in 2009, and by 2040, this age cohort will exceed 20% of the total American population (Pray et al., 2010). Projections indicate that by 2050, the population of older adults (aged 65 and above) will reach 88.5 million, with 19 million being older adults aged 85 years and older (Pray et al., 2010). Evidence suggests that about half the older population is concentrated in US cities, which are prone to environmental risks, including extreme heat (Filiberto et al., 2009). Consequently, evidence suggests that climate-induced extreme temperature events are on the rise and are expected to worsen in the coming years. Annual temperatures in the US are projected to increase at least 2.5 °F by 2050, irrespective of future emissions (Vose et al., 2017). There is strong evidence that the impact of these events on urban-dwelling older adults is more pronounced compared to other population groups (Crank et al., 2024; O'Lenick et al., 2024; Baniassadi et al., 2023). These studies suggest that extreme heat events disproportionately burden older urban

residents, exacerbating chronic health conditions and contributing to escalating morbidity, mortality and increasing health expenditure.

It is estimated that over 56% of the world's population resides in urban areas, and this figure is projected to increase further in the coming years (UN, 2014). Evidence suggests that by 2050, nearly 70% of the global population will be residing in urban areas (Tuholske et al., 2021). Urban morphology, including the built environment, green spaces, and city geometry, combined with anthropogenic factors, contributes to increasing urban temperatures, which poses a threat to the health and well-being of urban residents (Tuholske et al., 2021). The result of this interaction contributes to the unequal heating of urban temperatures compared to the surrounding rural areas (i.e., UHI). As cities expand, there is often a need for infrastructural development to cater to the increasing population. As such, there is encroachment on urban green spaces and expansion of impervious surfaces, creating an albedo effect (Oke et al., 2017). Also, city geometry traps daytime heat and prevents energy radiation at night, thereby increasing nighttime temperatures (Chapman et al., 2017). Combined with greenhouse gas emissions from urban traffic and other anthropogenic activities, contributes to the severity of the UHI effect (Allen et al., 2011).

Like other parts of the world, major cities account for the majority of the US population. Research has linked the UHI effect to rising temperature extremes in the US (Spencer et al., 2025; Yin et al., 2023; Dahl et al., 2019; Conlon et al., 2016; Sailor et al., 2015) and other parts of the world (Chapman et al., 2017; Santamouris et al., 2015). However, the extent to which urban heat affects residents is unequal and varies according to socio-economic status, age, gender, ethnicity, geographic location, access to information, and access to health services (Yin et al., 2023; Kreslake, Price & Sarfaty, 2016; Gamble et al., 2013). These studies also suggest that vulnerable groups, such as older adults, are disproportionately affected by the direct impacts of extreme heat and have underscored the need for tailored interventions to support equitable adaptation. While there has been increased adoption of air conditioning as an adaptation strategy against urban heat, among urban dwellers, literature suggests that there are disparities in utilization owing to energy cost, which poses a threat to sustainable use (Crank et al., 2024; Falchetta et al., 2024; Wang et al., 2021; Santamouris et al., 2015). This makes urban areas a major risk factor for extreme heat and other climate stressors.

The current and projected increase in the population of older adults in the United States raises critical concerns regarding the prevalence of environmental and age-associated chronic health conditions (such as respiratory diseases, diabetes, cardiovascular and thermoregulatory impairments)

(Meade et al., 2020). Also, the burden of exposure to these environmental hazards varies socially among various population groups due to differential susceptibility and vulnerabilities (O'Lenick et al., 2020). Older adults in urban areas are more predisposed to heat stress and ambient air pollution than their younger counterparts due to physiological decline and socio-environmental factors (Muttarak, 2021; Bunker et al., 2016). The vulnerability of older adults to extreme weather events can be explained by several factors: First, they are more likely to have impaired thermoregulatory and fluid regulation systems (Iyoho et al., 2017). Older adults are more likely to be sedentary, live alone, be socially isolated and spend most of their time indoors, which predisposes them to extreme indoor temperatures (Baniassadi et al., 2020). Also, they are more likely to suffer the burden of energy poverty or have limited access to properly functioning mechanical air conditioning and sustainable energy systems. Finally, their predisposition to multi- and co-morbidities of other health conditions places them at a higher risk (Crank et al., 2024; Khatana et al., 2022; Vaidyanathan et al., 2020; Meade et al., 2020; Bunker et al., 2016).

Older adults, in particular, are vulnerable to heat-related ailments, especially those with elevated age-related health conditions such as diabetes, hypertension, kidney, cardiovascular and respiratory disease (O'Lenick et al., 2020; Meade et al., 2020). The WHO projects that the population of older adults prone to heat-related deaths is expected to increase by 250,000 by 2050 unless drastic policies are implemented to mitigate the adverse effects of climate change (WHO, 2014). Currently, heat waves account for a majority of severe weather fatalities in the United States. According to Vaidyanathan et al. (2020), out of the 10,527 deaths attributable to the extreme heat that occurred between 2004 and 2018, 37% (4019) occurred among older adults aged 65 years and above. In a related study, Bobb et al. (2014) noted a strong association between exposure to heat waves among older adults and heat stroke, septicemia, urinary tract infection, and renal failure in the United States. As the US population continue to age rapidly, and the effects of climate change become severe, these health conditions are likely to increase. This consequently has implications for the provision of geriatric care for older adults.

The impact of extreme weather events on different demographic groups varies socially and geographically (Curtis & Oven, 2012). Prior epidemiological evidence lends credence to the burden of extreme heat on the health of older adults in Sunbelt cities of the United States (Baniassadi et al., 2020; Wilhelmi et al., 2021; O'Lenick et al., 2020). In particular, Crank et al. (2024) revealed a high prevalence of self-reported symptoms due to extreme heat and ambient air pollution in Los Angeles, Houston,

and Phoenix. Similarly, O'Lenick et al. (2019) attributed excess mortality among the elderly population in Houston, Texas, to exposure to extreme indoor heat. Sunbelt cities of Houston, Los Angeles, and Phoenix are characterized by warm and sunny climates, large and diverse populations, rapidly ageing populations, heat mortality, and widening socio-economic disparities (Crank et al., 2024; O'Lenick et al., 2020; Conlon et al., 2016). During summers, low-income households are prone to suffer energy poverty – the situation where the households spend a large proportion of their income on energy or are unable to afford energy for cooling, heating, and lighting needs, leading to adverse consequences on their health and well-being (Karpinska & Smiech, 2020). Households suffer energy poverty when they are forced to keep their homes at unhealthy temperatures to optimize energy consumption (Wang et al., 2021). In a similar study, Mohr (2018) reported that, in the US, people who do not work full-time are likely to suffer from energy poverty. Compared to other groups, older adults with low income/pensions and poor access to mechanical air-conditioning are prone to suffer from energy poverty and are at an increased risk of experiencing heat stress (Crank et al., 2024; Wang et al., 2021). For instance, Anderson and Bell (2009) studied weather-related mortalities in the US and found that communities without centralized air conditioning systems reported higher heat-related mortalities.

Research has established that older adults are at risk of dehydration when exposed to prolonged and elevated levels of heatwaves compared to other age groups (Crank et al., 2024; Meade et al., 2020). Ageing generally comes with a decline in functional capabilities and increased sweat production due to heat transfer between the body and the environment (McGregor & Vanos, 2018). Heat exposure causes a progressive rise in body temperature and can lead to adverse health implications. Common heat stress ailments among older adults include light-headedness, dizziness, heat rash, heat cramps, heat syncope, heat exhaustion, and heat stroke (Crank et al., 2024; McGregor & Vanos, 2018). Heat stress may further exacerbate other pathophysiological health conditions unrelated to heat, such as adverse cardiovascular disease, diabetes, obesity, and acute kidney injury (Meade et al., 2020). It is estimated that heat waves account for high hospitalization rates (Bobb et al., 2014) and mortalities (Lavados et al., 2018) among older adults. Available evidence has identified advanced ageing, lack of mechanical AC, the presence of pre-existing health conditions, gender and the built environment as predictors of heat stress and ozone risks (Crank et al., 2024; Wilhelmi et al., 2021; O'Lenick et al., 2020). Also, there is a growing consensus that increasing morbidity from extreme weather events greatly impacts healthcare systems, owing to increased demand for healthcare in Sunbelt cities.

Consistent with global trends, the proportional share of older adult residents in cities is expected to grow annually (Yin et al., 2023). In Los Angeles, Phoenix, and Houston, the proportion of older adults 65 years and above represents 12.9%, 11.1%, and 11.1%, respectively (US Census Bureau, 2021). Evidence suggests that by the mid-21st century (2040-2060, average surface air temperature (6.56ft above ground level) and the number of extreme heat days (daily maximum temperature greater than 95 °F) are projected to increase from the baseline period (1980-2000) in Los Angeles County (Kim et al., 2021). These changes will amount to almost a 20-fold increase in population exposure to heat index above 37.8 °C (100 °F) by the late century (Kim et al., 2021). Indeed, research in Los Angeles, Houston, and Phoenix has established the link between rising temperatures and increased demand for health services among older adults (Crank et al., 2024; O'Lenick et al., 2020). The consequences of extreme heat on older adults and the projected intensification of extreme heat events have gained notoriety over time. For instance, the Chicago heat waves of 1995 had a devastating effect on health systems, accounting for high mortality and morbidity rates (Karl & Knight, 1997). Over 700 people lost their lives, with a significant number of these fatalities being attributed to the harvesting effect - increased mortality among frail older adults (Zhou et al., 2021). Following major extreme heat events like the Chicago heatwave, the United States, through the National Weather Service, strengthens its emergency heat warning systems by issuing regular heat alerts/advisories during extreme heat circumstances (Kalkstein & Sheridan, 2007).

With the increasing impact of climate change driving extreme temperatures, rapid urbanization and an increasing ageing population, the proportion of older adults vulnerable to extreme temperature events in the United States is projected to increase. Given this reality, it is becoming increasingly crucial to examine heat stress experiences and coping strategies among older adults in Sunbelt cities. Studies have further shown that the burden of extreme heat on older adults is massive in the Sunbelt cities, predominantly due to the rapid ageing population, and intensifying extreme heat events (Baniassadi et al., 2023). Even though studies have examined heat risks and behavioral responses, to the best of my knowledge, literature on the association between specific socio-demographic, health-related conditions and strategic coping mechanisms influencing heat stress remains scant in Sunbelt cities. So far, there have been no qualitative or mixed-methodological studies examining heat stress and coping strategies among older adults in Sunbelt cities in the US. Therefore, a study on the association between heat stress and socio-demographic, health-related, and coping strategic factors, as well as individual-level behavioural adaptation to heat stress, is needed to inform urban planning, health policy and

programming. A deeper understanding of heat risks is crucial for urban planners, public health practitioners, and policymakers to tailor interventions aimed at reducing the burden of extreme heat on vulnerable populations whose health may have been compromised by other confounding factors. Based on the gaps identified, this study seeks to contribute to the growing discourse on climate change, ageing, and urbanization in the US.

1.3 Research objectives

This study is part of a broader project examining the impact of extreme heat among older adults in three Sunbelt cities of the United States. Building off previous work (see Crank et al., 2024; O'Lenick et al., 2020; Baniassadi et al., 2020), this study aims to understand disparities in heat risks and adaptation strategies among older adults in Phoenix, Houston and Los Angeles. First, I examined the factors influencing heat stress among older adults. Secondly, I explored coping and adaptation strategies employed by older adults during extreme heat events. Specifically, the study seeks to answer the following questions:

1. What are the factors exacerbating the risk of heat stress among older adults in Sunbelt cities?
2. What strategies do older adults adopt to cope with extreme heat in Sunbelt cities?

Based on the research questions, the specific research objectives underpinning the study are to:

1. Explore the factors influencing the risk of heat stress among older adults in Sunbelt cities.
2. Understand coping strategies among older adults against heat stress in the Sunbelt cities.

1.4 Geographies of health and climate change

Geographical research on the nexus between climate change and health falls within the ambit of health geography/geographies of health. As such, this study is grounded within the geographies of health, leveraging the strengths and major developments in the sub-discipline to contextualize the impacts of climate-driven extreme temperature events on the experiences of older adults in Sunbelt cities. Health geography evolved from medical geography in the early 1990s following major criticisms against the latter (Elliot, 2018). Medical geography focused largely on the biomedical aspects of health, adopted positivist approaches, and relied heavily on epidemiological and quantitative methods in the study of disease and healthcare (Kearns, 1993; Gatrell & Elliott, 2015). Major debates within medical geography culminated in a theoretically and methodologically nuanced sub-discipline, health geography (Kearns, 1994; Dorn & Laws, 1994; Eyles & Litva, 1996). Following this transition, health

geographers have established that health and place are inextricably linked – the environment where we are born, live, work, and retire ultimately determines our health (Gatrell & Elliott, 2015). Indeed, this argument has been long-standing following the pioneering works of geographers Relpth (1970) and Tuan (1974), who emphasized that place gives a sense of identity and "placelessness" negatively affects our experiences of health and healthcare. Again, this transition was partly in response to the WHO's conceptualization of health as a state of complete well-being, incorporating other non-medical aspects, including physical, mental, social, and emotional well-being (i.e., not merely the absence of disease) (WHO, 1984). This broader conceptualization of health stresses the influence of the social, economic, cultural, and physical environmental factors as significant determinants of health and well-being. Indeed, health geography's substantial focus on place has led to increased engagement with the socio-ecological model and the admission of multiple (social) determinants of health (Dassah, 2025).

Contrary to the assumption by medical geography that human health is generic and static, Kearns (1993) argues that human health is influenced by micro and macro-level factors, including structure and human agency. Human agency involves the capacity to act independently and affect one's health, whereas structure explains the various ways human actions are dictated by societal structures and institutions, including political, social, economic, and cultural systems (Wyness, 2015; Kalipeni & Feder, 1984). The structure/agency debates have been used by health geographers in climate change and health research to contextualize human adaptation, environmental justice, and social inequalities during extreme weather events (Curtis & Oven, 2012). For instance, the health risks presented by extreme heat are a product of human vulnerability to change, hazards presented by global environmental change, and the consequences of the physical environment (Curtis & Oven, 2012). Geographical engagement with place stems from the belief that certain places are prone to frequent climate change hazards, such as extreme temperatures, floods and tornadoes, than others, and that accounts for geographic health disparities. Other geographical work on the climate change and health nexus has argued that the emphasis must be placed on sustainability, where greater attention is paid to intergenerational equity in creating healthy conditions for all (Leach et al., 2010).

Health geography underscores the significance of multidisciplinary research and the incorporation of diverse epistemological perspectives in research. As such, health geography is distinguished by its propensity to engage multiple theoretical perspectives (Crooks et al., 2018). Earlier, Sayer (1992) clearly stated that all research in social sciences is theory-laden. Similarly, Krieger (2012) explicitly stated, "Without theory, observation is blind, and explanation is impossible." Guided by

these principles, health geographers engage with theory for three main reasons: First, theory allows researchers to ask the right questions and generate comprehensive answers (Krieger, 2012). Secondly, theory shapes how we observe phenomena and generate data scientifically through laid-down processes (Eyles & Litva, 1996; Krieger, 2012). Explicit engagement with theory guides researchers to identify gaps in the literature and enables researchers to analyze the existing theory critically (Krieger, 2012). Equally, theories allow for the systematization of knowledge, explanation and prediction of social life and the generation of new research hypotheses. Also, theories not only act as frameworks but represent how we perceive and consequently construct the social world (Eyles & Litva, 1994). Consistent with the changing meaning of health, health geographers possess the autonomy to adapt, develop, borrow, and refine diverse theories and apply them in specific studies. For instance, Mayer (1996) merged political ecology with human health to form the political ecology of the health framework, which has been utilized to understand the relationship between economy, environment, and health (King, 2010). Subsequently, Nunbogu & Elliott (2021) merged the feminist political ecology and the political ecology of health theories to form an integrated framework to understand water insecurity and gender-based violence in lower and middle-income countries.

Beyond the theoretical plurality, methodological diversity and innovation have constituted a pivotal component in the evolution of this sub-discipline. The engagement of health geographers with various theories is fundamentally supported by an array of ontological and epistemological assumptions (Vine et al., 2023). Ontology encapsulates our beliefs regarding the world and what is acknowledged as knowledge (Bryman, 2016), whereas epistemology delineates the methodologies of acquiring knowledge and understanding the world (Bryman, 2016). For instance, ontological assumptions are based on objectivism, denoting the belief that social phenomena exist independently of our perceptions, and constructivism, the perspective asserting that social phenomena are perpetually shaped by social actors and subject to continuous transformation (Knowledge is indeterminate) (Bryman, 2016). Within the realm of health geography, multiple epistemologies are present, encompassing positivism, interpretivism, and critical methodologies (Bell et al., 2023). Positivist theories utilize quantitative scientific methods to identify health patterns across both spatial and temporal dimensions, employing large sample sizes that facilitate generalization (Vine et al., 2023; Bell et al., 2023). In contrast to the positivist framework, interpretivism posits that the researcher's role is to comprehend social realities through the perceptions and lived experiences of the subjects under study (Bell et al., 2023). Alternatively, health geographers employ critical methodologies to

bridge the research-policy divide by adopting more pragmatic approaches, such as participatory action research (PAR) (Bell et al., 2023). To achieve a more holistic understanding of health, health geographers have progressively embraced multiple methodologies in a complementary manner, thereby fostering a nuanced comprehension of the interrelationship between health and place (Elliott, 1999).

Issues of climate change have been central to health geography (Gatrell & Elliott, 2015; Curtis and Oven, 2012). The sub-discipline is well-positioned to provide evidence on the complex interaction between climate change, mental health, and well-being (Martin, 2024). Health geographical research at the nexus of climate change and human health reveals social and geographic disparities in vulnerabilities (Curtis and Oven, 2012). For example, Niedzwiedz et al (2025) examined the impacts of climate change on mental health and well-being and highlighted the unequal distribution of climate-related risks, exacerbating pre-existing structural inequities. Gamble et al. (2013) noted that older adults are the most vulnerable population to climate change stressors due to the interplay of varied factors, including socioeconomic status, health status, disability and other predisposing factors. Also, health geography has a strong leaning towards critical human geography that seeks to promote social change and emancipatory politics through the use of geographic evidence to demand policy change and fight environmental injustice (Painter, 2008; Kearns & Moon, 2002). In line with this, health geographers have often adopted critical approaches, including PAR, to bridge the knowledge-policy gap (Bell et al., 2023).

In light of the foregoing, health geography presents a broader perspective for examining the climate-driven extreme heat events and the health of older adults in Sunbelt cities. Although health geography's engagement in climate change and health research has been long-standing, studies highlight that the impact of climate change stressors on population health varies socially and geographically (Curtis & Oven, 2012; Pearce et al., 2006; Maantay & McLafferty, 2011). Health geography recognizes the uniqueness of places and how that shapes exposure to environmental hazards (Curtis et al., 2017). The extent of vulnerability to environmental hazards on human health varies across demographic groups, with a disproportionate impact on vulnerable groups, including older adults, the homeless, women and children, even within geographic regions. These vulnerabilities may also be influenced by other social determinants of health (e.g., education, income, socioeconomic status), which may further compound pre-existing inequalities and expose vulnerable populations to extreme heat (Curtis & Oven, 2012). While there are global efforts to limit anthropogenic emissions

and minimize human exposure to climate change hazards, there is an urgent need to prioritize human adjustment to future environmental catastrophes, which are inevitable (IPCC, 2021). Thus far, it is important to understand socio-political and environmental processes influencing risk awareness, knowledge, perception, and behavioural processes, which collectively contribute to the vulnerability of older adults.

1.5 Geographies of ageing

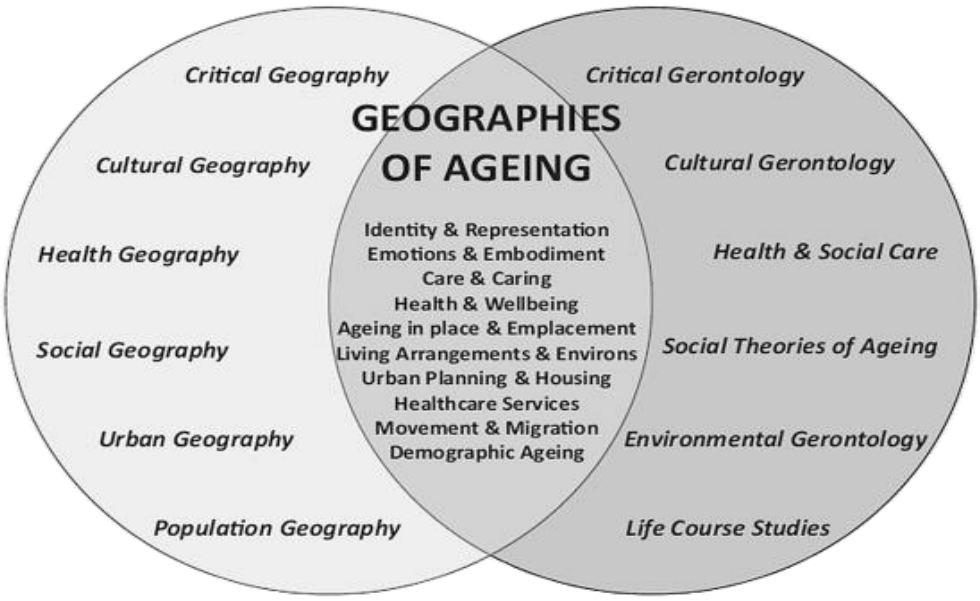


Figure 1: Geographies of ageing (Skinner et al., 2015).

Geographies of ageing (see Figure 1) encompasses work across sub-disciplines, such as health geography, population geography, social gerontology, geographical gerontology, and other gerontological works by geographers and other disciplines (including environmental gerontology, cultural gerontology, urban planning) (Skinner et al., 2015). Closely related to the evolution of this field is the longstanding, and increasingly nuanced, appreciation for the reflexive, transactional, and mutually constructive relationship between older people and the spaces and places through which ageing occurs (Cutchin, 2009). Following this evolution, research has largely focused on the spatial patterns of ageing, health care services, infrastructure, living arrangements, environments of older people, place-specific experiences of ageing, health, care, and well-being, and more recently, embodiment and representation of such experiences (Skinner et al., 2015). Within health geography,

ageing research has evolved to focus on a more cohesive, critically informed agenda that outlines the main priorities and directions of the field, both within and outside the sub-discipline (Andrews et al., 2007).

Geographers engage with ageing at multiple scales: At the microscale as a process and a suite of experiences across the life course. At the mesoscale, as a means of connecting older people to the communities and environments (places) within which they live. Globally, at the macroscale, as a way of understanding the implications of demographic ageing for policies related to pension, retirement, health and social service provision, and migration and housing (Skinner et al., 2015). Ageing research within geography has been categorized into three categories: The first category conceptualizes space as a means of describing, explaining and understanding the distribution and movement of older people in empiricist and positivist terms (Andrews & Philips, 2004). The distribution of older people across space (within cities, countries, and regions) has received considerable attention, especially as it relates to the migration of older people, healthcare, and resource distribution (Andrews et al., 2013). Others draw on the tenets of political economy to question the production and resource allocation of older people across space (Skinner et al., 2015). The second category of research examines the relationship between people and places (social, physical, built, symbolic) (Andrews et al., 2007). This strand of research draws on humanistic and social constructivist traditions to explore human experiences, subjectivity, and human agency (Andrews et al., 2013).

A third and emerging strand of research draws on contemporary theoretical developments and debates within the geographies of ageing, including relationality and non-representational theories (NRT) (Skinner et al., 2015). The relational thinking recognizes that spaces and places only emerge through connections with other spaces and places – a complex network of places and spaces (Jones, 2009). Relationality views places and spaces as a product of different places in multiple ways across multiple scales and other things associated with such places (such as people, ideas, policies). Places are incomplete at all times and are subject to an influx of ideas, objects, practices, and people and changing situations. This relational thinking has led to debates around "age relationality"-the idea of age relations between different ages and generations, particularly in geographical contexts (Skinner et al., 2015). This relational thinking can be used to explain the spatial variation in the distribution of the ageing population (Davies & James, 2016). For instance, why are more older people concentrated in Sunbelt cities than in other parts of the United States? Others have explored the relationship between people and "home places" across time and spaces of neighbourhoods and towns (Cutchin, 2013).

On the other hand, non-representational geographies of ageing argue against the oversimplification of relationality by attempting to locate places within a network. NRT emphasize that ideas and theories of space and place should be portrayed as dynamic, fluid and encountered. This view seeks to unearth the "hidden geographies of ageing" by drawing the attention of researchers to the unspoken and unacknowledged practices involved in the production of place, space, and social life among older adults (Cadman, 2009). However, it is worth noting that to date, there are limited geographical studies in ageing that have openly adopted NRT.

The relational perspective on ageing provided an avenue for increased engagement with concepts that transcend place, space, and scale, exploring socio-chronological groups through the lens of intergenerational, intersectionality, and life course issues (Sampaio et al., 2018). Ultimately, geographers perceive ageing as being geographically contingent, spatially produced, and an embodied social process (Sampaio et al., 2018). Geographers have shown increased interest in understanding how spatial inequalities exacerbate the vulnerabilities of older adults, whilst acknowledging the sensitivity to the quality of older adults and ageing places that enhance their resilience and adaptability (Skinner et al., 2015). Also, spatial variation in population ageing within cities has been examined (Davies & James, 2016). For instance, older adults tend to be concentrated in older neighbourhoods, living in homes they purchased long ago. Spatial patterning in population ageing is evident in the movement and concentration of older adults in cities located in the Sunbelt in the US (Davies & James, 2016).

A growing body of literature within the geographies of ageing has paid closer attention to older people "ageing in place." The basic assumption of ageing in place is to have older people remain in their homes and communities for as long as possible (Wiles et al., 2012). As people age, they disengage from other spaces and spend more time at home. As opposed to institutional care, the home becomes the best place for ageing (Pain, 2001). Independent living in a familiar space helps maintain and promote a sense of control, self-confidence, and positive self-esteem (Milligan, 2016). Geographers often define place in relation to the unique significance it holds in the lives of people based on the cultural and symbolic elements fostering a sense of identity and belonging (Power & Mee, 2020). Evidence suggests that the impact of extreme weather events, such as extreme heat, is minimal among older people ageing in place, as they wield greater autonomy to adapt to and adjust their lifestyle to suit changing environmental conditions (James et al., 2014).

Leveraging on the theoretical and methodological diversity and innovation of health geography, which has been touted as the greatest strength of the sub-discipline, this study adopts a mixed-methods approach to situate its findings (Crooks et al., 2018). Accordingly, this thesis is guided by the socio-ecological model (SEM), which provides a broader framework for understanding the factors influencing heat stress and coping strategies among older adults. In this study, SEM as a theoretical framework has been used to delineate the multiple factors influencing heat stress and coping strategies into five hierarchically nested and interconnected systems: microsystem, mesosystem, ecosystem, macrosystem, and chronosystem (Bronfenbrenner, 1994). SEM, therefore, provides a robust theoretical lens for systematically unpacking the complex intersecting environmental and social factors influencing heat stress, coping and adaptation mechanisms among older adults (Bernhardt & Amiri, 2024). The use of this framework offers valuable insights into the individual-level factors, socio-economic determinants, community, national, and international determinants of extreme heat, as well as the coping strategies adopted by older adults to manage the risk of extreme heat (Yao et al., 2024).

1.6 Organization of the thesis

The thesis is organized into four chapters. Chapter One presents the background and general overview of global climate change, extreme heat, and implications for older adults, narrowed down to Sunbelt cities in the US. The chapter includes the problem statement, which describes the rationale, research questions and objectives and thesis outline. The chapter also discussed how the study fits into the sub-discipline of health geography and the geographies of ageing research. Chapter Two presents a detailed research design, methods and a profile of the study context. Specifically, this chapter discusses the geographical, demographic and climatic situation of Los Angeles, Houston, and Phoenix. Although the methods are described in depth in the manuscript in Chapter Three, Chapter Two presents a summary of the broader research design and methods. Chapter Three presents an empirical manuscript on heat stress and coping strategies among older adults in Sunbelt cities. In this chapter, I describe the socio-demographic, health-related, and coping-strategic factors influencing heat stress among older adults and how older adults adapt during extreme heat events. Chapter Four concludes the thesis. In this chapter, I provided a summary of the main findings and of the research and discussion in relation to the literature and theoretical frameworks and the broader implications. This chapter highlights the implications of the research and contributions to theory, policy and

practice and concludes with directions for future research. Additional information, including references, data collection instruments, and ethical clearance, is included in the appendices.

CHAPTER TWO

METHODOLOGY

2.1 Introduction

This chapter presents a broader methodological approach adopted in this study, including the philosophical underpinning, research design, study context, data sources, data analysis procedures, and ontological and epistemological assumptions that underpin the study. While portions of the methods are presented in the associated manuscript (Chapter Three) and publications (Crank et al., 2024; O'Lenick et al., 2020; Baniassadi et al., 2020), this chapter presents a comprehensive methodology for the entire study.

2.2 Research philosophy

Health geographers have long been concerned with finding answers to broader questions, including how to identify, classify, and reduce the risk of environmental, social inequalities and behavioral determinants of health (Luginaah, 2009). To do this, health geographers adopt a range of theoretical approaches, including positivism, social constructivism, structuralism, and structuration (Gatrell & Elliott, 2015). These theoretical approaches are shaped by larger paradigms (Morgan, 2007). Paradigms are a set of assumptions that structure how a researcher approaches the research. Thus, paradigms underpin the ontology (what exists of knowledge) and epistemology (ways of knowing the world and how knowledge is acquired) of the research (Bryman, 2016). A researcher's philosophical approach defines his/her ontological and epistemological assumptions (Couper, 2015) - thus, ontology and epistemological issues are interconnected and mutually reinforcing. For instance, positivist researchers employ quantitative methods to establish health patterns, utilizing large sample sizes as the basis for generalization (Bell et al., 2023). On the other hand, interpretivism assumes that the role of the researcher is to understand multiple realities by leveraging qualitative approaches (Bell et al., 2023).

The philosophical underpinning for this research is grounded in pragmatism. The central focus of pragmatists is to simplify human problem-solving; hence, they aim to answer the research question "What works?" (Creswell, 2006). There exists a "real world" which is subject to individual interpretations; hence, instead of focusing on methods, the important aspect of research is the problem being studied and the questions asked about the problem (Morgan, 1998; Elliott, 1999). As opposed to positivism and interpretivism philosophies, questions do not suggest which method to

adopt. Pragmatic researchers have the freedom to choose techniques, methods and procedures that best meet their needs (Creswell, 2006; Mackenzie & Knipe, 2006). Based on these assumptions, a mixed-method approach, which is underpinned by pragmatism, is employed in this study. Mixed methods research is an approach to inquiry involving both qualitative and quantitative methodologies. Integrating the two approaches using distinct designs may involve varied assumptions and theoretical frameworks (Creswell, 2014). The combined strength of both qualitative and quantitative methods of data helps to complement each other, limiting bias and strengthening objectivity. The two work side by side to check for inconsistencies in each other and generate nuanced findings (Regnault et al., 2018). A key challenge with mixed methods research is how to successfully integrate both quantitative and qualitative data during analysis and interpretation (Creswell, 2014). To this end, a mixed method provided a better understanding of the extreme heat and coping strategies and improved the quality of the study (Morgan, 1998; Creswell, 2014).

The quantitative data were used to establish a relationship between heat stress and socio-demographics, health-related factors, and coping strategies (Creswell, 2014; Morgan, 1998). A telephone survey using a questionnaire containing 60 questions was administered to 909 older adults 65 years and older in Houston, Phoenix and Los Angeles to gather data on predictors of heat stress, and the geographic distribution of heat risks among the three cities. Quantitative approaches involved establishing relationships among variables through the application of statistical methods (Creswell, 2017). In a complementary manner, qualitative data were collected to provide insight into the coping strategies employed during extreme heat among older people in the three Sunbelt cities. Data from the telephone interview were summarized to establish the extent to which responses are coherent and consistent. Although a questionnaire was administered to all 909 respondents, only responses from older adults who responded to the open-ended question on coping strategies were analyzed for the qualitative component. The qualitative data were generated from 67 older adults from Houston (29), Los Angeles (23), and Phoenix (15) who provided open-ended responses to survey Q29. These responses were coded manually by the researcher and analyzed using qualitative thematic coding.

2.3 Study context

The study was conducted in Houston, Texas; Phoenix, Arizona; and Los Angeles, California. These cities are all located in the Sunbelt of the United States (see Figure 2). The selection of these cities owes to their close similarities in terms of climate, diverse socio-demographic population, increasing aging populations, growing homelessness, widening socioeconomic disparities, and rising

heat mortality (Crank et al., 2024; Sailor et al., 2015). These cities have become hotspots for increasing temperature extremes and significant heat health challenges. The proportion of older adults in Houston, Phoenix, and Los Angeles represents 12.9%, 11.1%, and 11.1%, respectively (US Census Bureau, 2021). At the same time, the frequency, intensity and duration of heatwaves continue to pose serious threats to the health and well-being of older residents (Meade et al., 2020). More importantly, the elderly population in these cities is composed of a mix of racial and ethnic diversity (Crank et al., 2024). These cities have become hotspots for increasing ageing populations and intensifying high temperatures (Carr et al., 2025). Considering that extreme heat remains the leading cause of all weather-related mortality in the US, the choice of these cities is ideal for the study.

Houston is the fourth-largest city in the US and the largest Southern US city, considered to be sprawling at a higher rate and with a population of about 2.3 million as of 2014 (US Census Bureau, 2020). Houston is characterized by a hot, humid climate (Koppen Cfa), and summer temperatures exceeding 35°C (Hayden et al., 2017). In 2017, Houston experienced 13 days of maximum temperatures, but no heat warning was issued for a heat index of 105 °F and higher (NWS, 2018). Similarly, as a major metropolitan area in Central Arizona, Phoenix is located in the Sonoran Desert, with a hot and dry climate (BWh) and summer temperatures exceeding 37°C (NOAA 2010). The 2019 population estimate indicates that about 1.6 million inhabitants live in Phoenix (US Census Bureau, 2020). For 2017, Phoenix received 19 heat warnings for 8 distinct extreme heat events with heat index (HI) exceeding 105 °F (NWS, 2025). Finally, Los Angeles, the largest municipal government in the United States, is located in a semiarid zone influenced by Mediterranean climate (Csa). As the second most populous city in the US, with an estimated 2015 population of almost 3.8 million inhabitants, the city experiences a significant dry season (US Census Bureau, 2020; Baker & Sturm, 2024). It experiences unequal heat exposure, with a land surface temperature ranging between 36°C and 54°C (Yin et al., 2023). The background climate has a strong influence on the intensity of the UHI effect on residents (Yin et al., 2023). For instance, in 2017, the NWS issued 35 heat warnings during 114 days of maximum heat days for HI exceeding 105 °F (NWS, 2018).

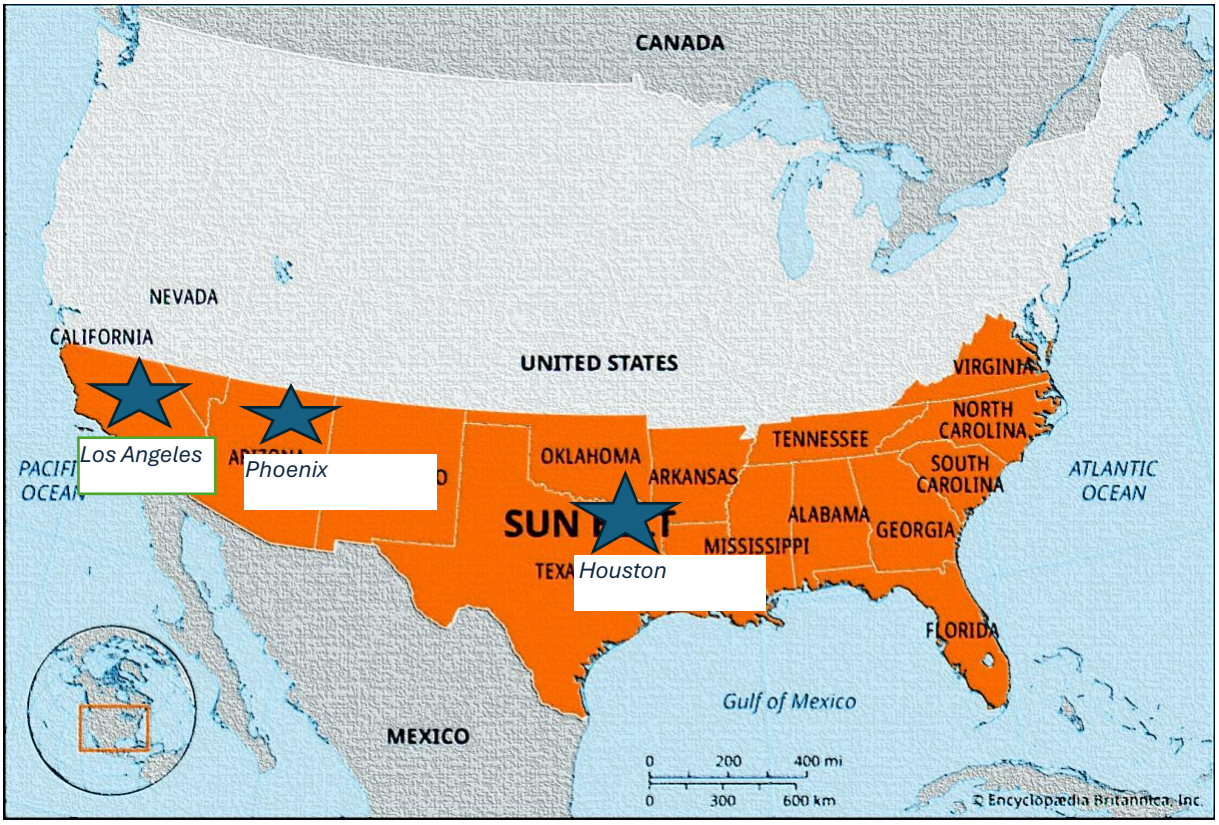


Figure 2: Map of the US and the three Sunbelt cities surveyed (Los Angeles, Phoenix, and Houston). (Britannica, 2025).

2.4 Research design

The study employed a retrospective cross-sectional study design utilizing data from a telephone survey collected between August 3, 2017, and September 20, 2017. Retrospective cross-sectional study designs are best used to measure the prevalence of a phenomenon, health status and health outcomes at a point in time (McClean et al., 2019). The study examined heat stress and coping strategies among older adults in Los Angeles, Houston, and Phoenix. This design helps reveal the determinants of heat stress and associated behavioural responses at a particular point in time (Hemed, 2017). The study initially obtained ethical approval from the University Corporation for Atmospheric Research Institutional Review Board before data collection and subsequently from the University of Waterloo Ethics Review Board to use the data in this dissertation (protocol No: #46786)

2.5 Survey development and implementation

The survey consisted of a semi-structured questionnaire developed by a joint research team from the National Science Foundation (NSF), National Center for Atmospheric Research (NCAR), and Arizona State University, which was administered by the Survey Research Lab (SRL) at Portland State University. The survey was informed by prior studies examining local climatology, social and behavioural factors, and characteristics of the urban environment, exacerbating exposure of older adults to extreme heat and ozone-related pollution (Hayden et al., 2011; Hayden et al., 2017). The survey was pre-tested by researchers from the NSF, NCAR and programmed by SRL in Voxco Virtual Call Center (VCC) 1 software. The survey was pretested to ensure its suitability for the fieldwork. The quantitative data were generated from the closed-ended questions, whilst the qualitative data were generated from the open-ended questions. The survey was conducted in English and Spanish. A detailed description of the telephone survey development and administration can be found in Crank et al. (2024), O'Lenick et al. (2020), Sailor et al. (2015) (also see Supplementary Material).

2.6 Sampling strategy

Cell phone numbers were obtained from the Marketing Systems Group, SRL, with phone numbers of households in the hope of reaching an older adult aged 65 and older. These phone numbers were randomly distributed across the three cities based on proportion. The study included all older adults who responded to phone calls and consented to the phone interview. Exclusion criteria included those older people who were mentally or physically impaired, in prison, in military barracks, in college dormitories, or in sanatoriums. The SRL called each phone number a maximum of 15 times before replacement, towards completing 300 phone surveys for each city. The detailed methodology, including sampling procedures and data collection techniques, is documented in other associated publications (Crank et al., 2024; O'lenick et al., 2020; Banaissadi et al., 2020).

2.7 Data Analysis

Quantitative Approach: This thesis employed descriptive and inferential statistical techniques to analyze older adults' experiences with heat stress. Given the dichotomous nature of the outcome variable (heat stress), a binary logistic regression model was used. The analysis began with a univariate assessment to outline the descriptive statistics. This was followed by bivariate logistic regression to investigate the individual relationships between each predictor variable, categorized into socio-demographic, health-related, and coping strategies, and heat stress. To further delineate the

effects of predictor variables, I constructed three nested models through multiple binary logistic regressions: 1) Socio-demographic Factor Model, 2) Health-Related Factor Model, and 3) Coping Strategy Factor Model. This structured approach allowed me to explore the aggregated influence of the selected predictors on heat stress across the defined categories. Following Nick et al. (2007), the mathematical formulation for the multiple binary logistic regression model is detailed as follows.

$$\pi(X) = \frac{\exp(\beta_0 + \beta_1 X_1 + \cdots + \beta_k \mathrm{X}_k)}{1 + \exp(\beta_0 + \beta_1 X_1 + \cdots + \beta_k \mathrm{X}_k)}$$

In this model, π represents the probability of an observation classified under the dichotomous variable Y, where a value of 1 corresponds to experiencing heat stress. The term "exp" denotes the exponential function. The parameter $\beta_0$is the intercept β_1, which refers to the coefficient for the first predictor, and βk signifies the coefficient for the final predictor in the model. The binary regression coefficients are expressed as odds ratios, which reflect the probability of experiencing heat stress. An odds ratio exceeding one (OR>1) suggests an increased likelihood of heat stress, while an odds ratio below one (OR<1) indicates a decreased likelihood (Akaike, 1998). To ensure the robustness of our analysis, we validated the linearity assumption for predictors and determined the continuous presence of multicollinearity. Additionally, model reliability was gauged using the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC), both of which signalled a good fit across the three models analyzed. Utilizing Stata version 18, we achieved a pseudo-R-squared value of 0.069 for Model 1, 0.089 for Model 2 and 0.125 for Model 3 (the final model), highlighting a significant variance explanation for the outcome variable. The Models' AIC (1096.91) and BIC (1255.71) values suggest a good fit.

Qualitative Approach: Qualitative data were generated from 67 older adults from Phoenix (29), Los Angeles (23), and Houston (15). This sample size comprised all responses to the open-ended option in question 29 of the survey instrument. The open-ended questions provided the respondents with an opportunity to share their experiences and coping strategies aside from the pre-programmed survey options. This approach provided a nuanced contextual understanding of how older adults adapt to and cope with extreme heat. First, the data was imported into an Excel spreadsheet, and responses from the open questionnaire options from individual cities were extracted. Inclusion criteria considered only responses that directly answered the research questions: What strategies do older adults adopt to cope with extreme heat in Sunbelt cities? The data was coded manually by a single researcher using qualitative thematic analysis. This approach follows Tesch's (1990) criteria for coding qualitative data; general ideas were categorized into similar headings. First, responses from the open-

ended questions across Houston, Phoenix, and Los Angeles were identified. Individual responses from the three cities were combined to generate codes for each city based on the study objectives. Suitable words with the same meanings and descriptions were categorized into codes. In the next stage, the codes from individual cities were collated and compared to identify duplicates. The third stage involved scaling down further to identify patterns of meaning. The various categories with similar meanings were further grouped to identify key themes. The results were presented as themes, interpreted, and discussed as a complement to the quantitative data.

Table 1: Summary of research approach to the specific objectives

Specific Objective	Data Collection Techniques	Sample Size	Analytical Framework
1. To explore the factors affecting heat stress among older adults in Sunbelt cities.	Survey	909	Logistic Regression
2. To understand coping strategies among older adults against heat stress in the Sunbelt cities.	Survey	67	Thematic analysis

Source: Authors construct, June 2025

2.8 Methodological rigour

Methodological rigour in research refers to the soundness or precision of the study, often measured in terms of specific indicators (Marquart, 2017). Following the Good Reporting of a Mixed Methods Study (GRAMMS), considerations for establishing rigour in mixed methods research were employed throughout the study (O'Cathain et al., 2008). According to Lincoln & Guba (1985), techniques for ensuring rigour in quantitative research (i.e., internal validity, reliability, and replicability) and qualitative research (i.e., credibility, dependability, transferability, and confirmability) were applied in the study.

2.8.1 Quantitative rigour

To ensure the validity, reliability, and replicability of the quantitative results, the study adhered to established procedures (Marquart, 2017). Validity pertains to the extent to which a concept is accurately measured, thereby guaranteeing the integrity of the findings (Bryman, 2019). To affirm the validity of the findings, the study established relationships between variables. For instance, through a literature review, the study established an association between heat stress and socio-demographic,

health-related, and coping strategy factors. The use of a representative sample from Houston, Los Angeles, and Houston further enhances external validity. Reliability, on the other hand, concerns the consistency of measurements over time and among different researchers (McClean et al., 2019). In evaluating internal validity, the study utilized previously validated survey instruments, modifying items as deemed appropriate for the research objectives. Replicability refers to the extent to which the study's results can be duplicated using similar methods under comparable conditions (Marquart, 2017). To facilitate replicability, the questionnaire was comprehensively explained to older adults to ensure their understanding and to elicit appropriate responses.

2.8.2 Qualitative rigour

Ensuring rigour in qualitative research means establishing the trustworthiness of the study; Lincoln and Guba (1985) proposed a criterion for establishing rigour in qualitative studies to include credibility, transferability, dependability, and confirmability. Credibility is the cornerstone of qualitative research (Baxter & Eyles, 1997). Strategies adapted to enhance the credibility of the study findings included prolonged engagement and building trust during the phone interview process, debriefing, and multiple participants' sources from across Los Angeles, Houston, and Phoenix. Also, transferability discusses the extent to which the results of the study can be replicated in other contexts (Baxter & Eyles, 1997). The phone interview generated similar findings from across the three Sunbelt cities, meaning that similar responses could be generated from other Sunbelt cities (such as Miami, Austin, Tampa, and San Diego). Cities in the Sunbelt exhibit similar characteristics, including an increasing incidence of extreme heat events, an increasing ageing population, widening inequalities, and poor air quality concerns. Older adults were asked an open-ended question: "Other than the things already discussed, during hot weather, have you done any of the following to protect yourself from the heat?" This allowed them to discuss all the strategies they adopt to cope with extreme heat. As such, the research team was able to gauge their experiences relating to extreme heat, which could be applicable in different geographic contexts (Rishworth & Elliott, 2019).

Dependability was ensured through student student-supervisor relationship as a means of checks and balances to ensure that the research is well conducted (Baxter & Eyles, 1997). Dependability refers to the consistency of interpretations of results over time. Phone interviews were recorded and transcribed verbatim. Also, extensive field notes were taken to ensure the transparency of the research process. Confirmability is the extent to which findings are determined by participants of the research and not influenced by the positionality of the researcher (Lincoln & Guba, 1985). To

ensure this, the researcher declared his positionality and how that could potentially affect the research outcomes.

2.9 Positionality

My background as a young black African man with lived experiences from Ghana in Sub-Saharan Africa ultimately influenced my understanding of extreme heat events and shaped my views on heat stress in the Global North. With my academic background in geography, planning and management, I view myself as a medical and health geographer, and that exerts an influence on my research interest in the geographies of health and healthcare, ageing, and population health. This intersectionality, as a black African doing graduate studies in North America, is reflected in the kind of research I do, the geographic location where I conduct my research, and the participants I involve in my research. My master's thesis is on heat stress and coping strategies among older adults in Sunbelt cities in the US. Within this context, I position myself as an "outsider-insider researcher" because my identities and subjective views could have had a direct bearing on my engagement with research participants owing to differences in race, gender, and other cultural differences. However, considering that the study utilized a retrospective cross-sectional study design, there was no personal engagement with study participants. This relative advantage waived the many challenges I could have encountered and ultimately shaped the research process and eliminating personal biases and conflicting perspectives. However, being an outsider-insider alone does not influence the research process if ethical protocols are adhered to (Dwyer & Buckle, 2009). From an epistemological standpoint, I view myself as a pragmatist researcher – a mix of positivism and interpretivism approaches. This is also reflected in my ontological position – idealism – because my research involves seeking the views, opinions and experiences of human participants. As a pragmatist health geographer, I appreciate the subjective meaning and diverse perspectives of issues. Accordingly, I seek to admit different methodological approaches, theoretical frameworks and techniques to understand heat stress and coping strategies among older adults in Sunbelt cities.

2.10 Summary of the chapter

The chapter outlined the methodological approach of the research. It contained the philosophical assumptions, study context, research design, and strategies for ensuring scientific rigour in the thesis and the positionality statement.

CHAPTER THREE

MANUSCRIPT

Heat stress and coping strategies among older adults in three Sunbelt cities in the United States

Dassah, C., Crank, P. J., & Jones-Crank, J. L. Heat stress and coping strategies among older adults in three Sunbelt cities in the United States (Ready to be submitted to a journal).

Abstract

Prevailing scientific evidence suggests that extreme heat poses a significant threat to the health and well-being of older adults in the Sunbelt cities of the United States. Despite existing studies on the impacts of extreme heat on older adults (65 years and older), limited research has addressed the specific socio-demographic, health-related conditions, and coping-strategic factors influencing heat stress among older urban populations. Informed by the Socio-Ecological Model (SEM), this study adopts a retrospective cross-sectional study design to investigate the predictors and experiences of heat stress among older adults. Data from older adults in Los Angeles, Houston, and Phoenix were analyzed using thematic and multiple binary logistic regression analyses. The results reveal that older adults aged 80 and above were less likely to experience heat stress compared to their relatively younger counterparts. Also, marital status, income, respiratory diseases, physical activity, taking cool showers, and city of residence were significantly associated with a higher risk of suffering heat stress. In a complementary manner, the qualitative results uncovered individual-level behavioral adjustment as an effective coping mechanism during extreme heat events. These results underscore the complex interplay of behavioral, socio-demographic, and health-related factors affecting heat stress. The study recommends that urban health strategies prioritize these demographics, enhancing support systems and coping mechanisms to reduce vulnerability to heat stress among older populations.

Keywords: Heat stress, extreme heat, health, binary logistic regression, socio-ecological model

3.1 Introduction

Amidst ongoing global climate change, extreme heat is projected to increase in intensity, frequency, and duration, with grave consequences for health and well-being (Intergovernmental Panel on Climate Change [IPCC], 2021). Extreme heat already accounts for an annual increase in emergency department visits, hospitalizations, and escalating healthcare expenditures due to heat-related ailments in the US(Clark et al., 2019) and elsewhere (Oberai et al., 2024). However, despite the prevalence of extreme heat events, the burden is unevenly distributed among population strata owing to urbanization, socioeconomic status, and demographic change (Khan et al., 2021). Marginalized populations such as older adults, children, people experiencing homelessness, racialized groups, individuals of low socioeconomic status, people with chronic health conditions, and those without an efficient household cooling system are disproportionately vulnerable to heat stress (Crank et al., 2024; Khan et al., 2021; O'Lenick et al., 2020; Bao et al., 2015). Heat stress occurs when the body is unable to effectively manage and dissipate heat when exposed to heat (Kenny et al., 2010). Common heat stress symptoms include fatigue, headache, dizziness, nausea, and, in severe cases, heat-related illnesses such as heat exhaustion or heat stroke. Older adults 65 years and older are at an elevated risk of suffering heat stress due to a weaker immune system, impaired mobility and the tendency to remain indoors most of the time (O'Lenick et al., 2020). Additionally, older adults are predisposed to multimorbidity owing to impaired health status, physiological decline, socio-demographic and economic disadvantage, exposing their vulnerability to heat stress (O'Lenick et al., 2020; Meade et al., 2020).

Urban morphology predisposes residents, particularly older adults, to heat stress partly due to the urban heat island (UHI) effect (O'Lenick et al., 2020; Sailor et al., 2015). UHI effect describes the situation where urban temperatures are relatively warmer than surrounding rural areas due to the cumulative effect of urban traffic, built environment, and emissions from anthropogenic sources that retain heat within these urban infrastructures (Oke et al., 2017). With rapid urbanization amidst climate change, the UHI effect in cities in the southern United States affects baseline temperatures, leading to frequent and more intense heat waves (McGregor & Vanos, 2018). Urbanization generally increases urban temperatures due to the loss of vegetation, increases in impervious surfaces, and a growing urban population (Moss, 2021). As a result, major cities in the United States, such as Los Angeles (LA), California, Houston (HOU), Texas, and Phoenix (PHX), Arizona, experience high ambient temperatures and hotter summers (Crank et al., 2024; Larsen et al., 2023; Conlon, 2016). Recent

epidemiological studies suggest that older adults in LA, HOU, and PHX are at an increased risk of heat stress, accounting for higher heat-related hospitalizations and mortalities (Crank et al., 2024; Yin et al., 2023; Hayden et al., 2017). Notwithstanding the use of air-conditioning to regulate indoor temperatures, older adults are also at risk of suffering energy poverty, forcing them to optimize their energy consumption (Wang et al., 2021).

When exposed to prolonged periods of heat, usually exceeding three continuous days of extreme temperatures, herein referred to as a heat wave, older adults are at a greater risk of dehydration and other heat-related ailments (Meade et al., 2020). Senescence is often associated with a decline in functional capabilities and decreased sweat production due to heat transfer between the body and the environment (McGregor & Vanos, 2018). As a result, prolonged heat exposure causes a progressive rise in body temperature, leading to adverse health implications. Heat stress ailments among older adults include light-headedness, dizziness, heat rash, fainting, rapid heartbeat, heat cramps, heat exhaustion, and heat stroke (Crank et al., 2024; McGregor & Vanos, 2018; Bobb et al., 2014). Heat stress may further exacerbate other pathophysiological health conditions unrelated to heat, such as adverse cardiovascular disease, diabetes, obesity, and acute kidney injury (Meade et al., 2020). It is estimated that heat stress accounts for high hospitalization rates (Bobb et al., 2024; Gronlund et al., 2015) and mortalities (Lavados et al., 2018; Baker et al., 2024) among older adults in the US. Prior empirical studies have cited old age, lack of a mechanical AC (an automatic air-conditioning system for cooling indoor spaces), the presence of pre-existing health conditions, sex, and the built environment as predictors of heat stress among older adults in the US (Baniassadi et al., 2020). There is also a growing consensus that increasing heat-related morbidities greatly impact healthcare systems owing to the increased demand for healthcare in the United States (O'Lenick et al., 2024; O'Lenick et al., 2020; Gronlund et al., 2014).

Considering the current and projected implications of extreme heat on vulnerable populations, effective coping strategies and adaptation mechanisms show great promise for mitigating the impact of extreme heat on older adults (Rohat et al., 2021). Adaptation to heat stress involves a broad range of actions individuals take to manage the symptoms of heat stress across different spatiotemporal scales (Holman et al., 2019). Older adults cope with heat stress by employing a range of strategies, such as taking allergy medication, limiting physical activity, staying indoors during hot hours of the day, using an inhaler, and having regular medical checkups (Rohat et al., 2021). These studies demonstrate that behavioral strategies such as the use of air conditioning, awareness of heat warnings,

keeping windows open during hot hours, using personal fans, and dressing appropriately to suit the weather are among a range of low-cost coping mechanisms against heat stress. Recent population-level studies suggest that the impact of extreme heat, amplified by the UHI effect, can be mitigated by adopting effective community and behavioural adaptation strategies (Mukhopadhyay & Weitz, 2022; Moss, 2021). For instance, studies by Bakhsh et al. (2018) established that in Pakistan, hospitalization due to heat-related ailments decreased by 86% due to individual adaptive behavioural adjustments.

The Sunbelt is a region of the United States that stretches across the southeastern and southwestern portions of the country from Florida to California (Wooten, 2024). Warm, sunny climates characterize cities located in the Sunbelt and are also experiencing rapid population growth. Despite significant empirical evidence on the vulnerability of older adults to heat stress in these cities, studies have seldom paid attention to individual-level coping and adaptation strategies for heat stress. As part of a larger study examining heat and ozone-related risks among older adults, this paper addresses notable gaps through a mixed-methods approach. Specifically, the paper seeks to (1) examine the predictors of heat stress among older adults, and (2) explore coping strategies against heat stress among older adults. The results of this research provide insights into individual and community-level factors affecting heat stress as well as coping strategies adopted by older adults to manage the burden of extreme heat.

3.2 Theoretical framework

This study is anchored on the socio-ecological model (SEM) to contextualize heat stress and coping strategies among older adults in three Sunbelt cities in the United States (Figure xx). Introduced in the 1970s as a conceptual model by Urie Bronfenbrenner, SEM became formalized as a theory in the 1980s (Bronfenbrenner, 1986). SEM recognizes the dynamic interrelatedness between individual and environmental factors, including personal attributes, family, and community-level resources (Bronfenbrenner, 1986; Reupert, 2017). The original SEM has been delineated into five hierarchically nested interconnected systems: microsystem, mesosystem, ecosystem, macrosystem, and chronosystem (Bronfenbrenner, 1994). At the base of SEM is the microsystem. Within the context of extreme heat, individual-level attributes, such as socio-demographic factors (age, sex, general health status, income, medical histories) that can impact individuals' experiences of heat stress. This level also considers individual behavioral responses and adaptation strategies, such as taking cool showers during hot days, wearing light clothes, reducing physical activity, and staying hydrated. Closely related is the mesosystem, which considers the influence of social determinants of health (e.g., educational

status, employment, housing, neighbourhood) that may constrain or facilitate individuals' experiences of extreme heat (Bronfenbrenner, 1994). At the ecosystem level are organizational factors such as the use of air conditioning at workplaces and office spaces, libraries, shopping centers, hospitals, and care homes, which older people frequently visit. The temperature at these facilities can greatly impact older people's experiences of extreme heat. The macrosystem comprises the physical environment in which people live and work. The nature of the environment could therefore have implications for health-related outcomes, including heat-related health conditions. Indeed, the nature of such environments has contributed to the UHI effect, and urban planners are making a conscious effort towards addressing the impacts of urban overheating and the UHI and rising air temperatures within cities. Community resources such as urban green spaces and vegetation are classical examples of the work of modern urban planners to mitigate urban overheating (Bernhardt & Amiri, 2024). At the top of the hierarchy is the chronosystem, which includes the impact of policies beyond the national level. International and national policies shape governmental responses to climate change adaptation strategies that have implications for health outcomes. For example, there have been increased calls for the use of electric and hybrid vehicles to control the emission of greenhouse gases that increase urban temperatures and heat-related health conditions (Asgardian et al., 2023). Global commitments, such as the UN Agenda 2030 and the Paris Agreement, target limiting global temperatures to below 2°C (Coenen et al., 2020; UN, 2019).

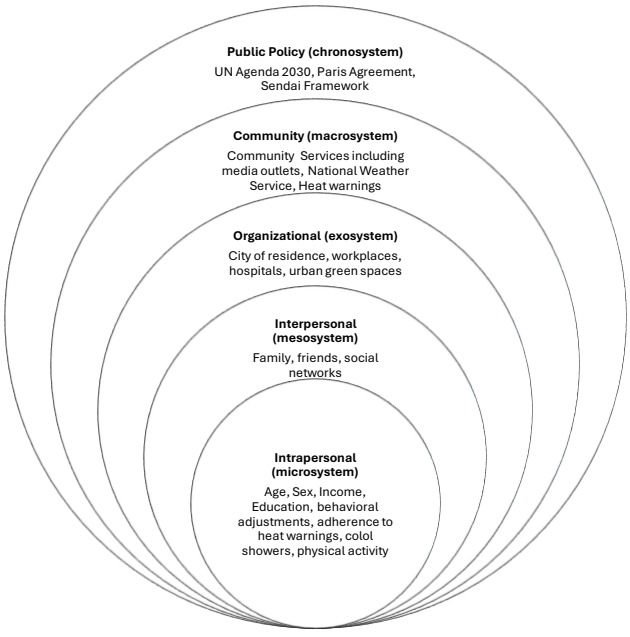


Figure 2: Social-ecological model for heat stress (Adapted from Bronfenbrenner, 1979).

SEM provides an intersectional lens for exploring the relationship between varying dimensions of heat-related health conditions among older adults (Bernhardt & Amiri, 2024; Yao et al., 2024). It underscores the influence of multiple factors operating at varied scales on health and various adaptive responses to extreme heat (Bronfenbrenner, 1994). In a recent study, Bernhardt and Amiri (2024) utilized the SEM to investigate the risks of extreme heat and recommended its applicability in addressing complex factors influencing heat stress. Similarly, Meghani et al. (2023) investigated the impact of the home environment on the physical activity and sedentary behavior of older adults. SEM, therefore, provides a robust theoretical lens for systematically unpacking the complex intersecting interventions comprising environmental and social factors influencing heat stress and associated coping and adaptation mechanisms among older adults. The framework also highlights the importance of simultaneously integrating multiple interventions in targeting heat stress vulnerability (Bernhardt & Amiri, 2024). Drawing on theoretical constructs of SEM, we examine socio-demographic factors, health-related factors, and strategic coping factors influencing heat stress among older adults in three cities in the United States. The use of this framework offers valuable insights into the individual-level factors, socio-economic determinants, community, national, and international determinants of extreme heat, as well as the coping strategies adopted by older adults to manage the risk of extreme heat (Yao et al., 2024; Bernhardt & Amiri, 2024).

3.3 Study context

The study was conducted in three Sunbelt cities: LA, HOU, and PHX. The choice of these cities is based on their hot climates characterized by high temperatures and hot summers, large and diverse populations, rapidly aging populations, increasing heat mortality, widening socio-economic disparities, and rapidly deteriorating air quality (Crank et al., 2024; Sailor et al., 2015). For instance, urbanization increases the global annual rate of exposure to extreme heat by 52% (Tuholske et al., 2021). Concomitantly, the dramatic shift in demographic distribution (with a significant increase in older populations in the Sunbelt) coincides with the projected increase in frequency, intensity and duration of extreme temperature events in the US, posing significant threats to the health and well-being of vulnerable urban populations (Meade et al., 2020; Gamble et al., 2013). In LA, HOU, and PHX, the proportion of older adults 65 years and above represents 12.9%, 11.1%, and 11.1% respectively (US Census Bureau, 2021). LA is the largest municipal government in the United States, located in a semiarid zone and with a Mediterranean climate (Csa), which predisposes the city to a significant dry season (Baker & Sturm, 2024; Yin et al., 2023). LA experiences unequal heat exposure

with a land surface temperature of between 36°C and 54 °C (Yin et al., 2023). HOU is the largest southern US city with a humid subtropical (Koppen Cfa) climate and summer temperatures exceeding 35°C (Hayden et al., 2017). Located in the Sonoran Desert, PHX is a major metropolitan area in Central Arizona, with a hot and dry climate (BWh) and summer temperatures exceeding 37°C (NOAA 2010). The temperature variation between LA, HOU, and PHX could be explained by the different background climates, which strongly influence the intensity of the UHI (Yin et al., 2023). More importantly, the elderly population in these cities is composed of a mix of racial and ethnic diversity, most of whom are within the lower economic echelon, a major factor for heat stress (Crank et al., 2024). Extreme temperatures account for a significant share of total climate-related human deaths (Kim et al., 2021). Despite the strong influence of the UHI effect on urban temperatures in these cities, AC saturation in LA is low (Crank et al., 2024).

3.4 Methodology

3.4.1 Data and sample

The study employs a retrospective cross-sectional study design utilizing data from a phone survey collected between August 3, 2017 and September 20, 2017. Retrospective cross-sectional study designs are best used to measure the prevalence of a phenomenon, health status, and health outcomes, at a specific point in time (McClean et al., 2019). The study examined heat stress and coping strategies among older adults in LA, HOU, and PHX. Thus, the design helps unravel the determinants of heat stress and associated behavioural responses at a particular point in time (Hemed, 2017). First, cell phone numbers were obtained from the Marketing Systems Group, SRL, with phone numbers of households in the hope of reaching an older adult aged 65 and older. These phone numbers were randomly distributed across the three cities based on proportion. The study included all older adults who responded to phone calls and consented to the phone interview. Older people who were mentally or physically impaired, in prison, military barracks, college dormitories, and sanatoriums were excluded from the study. The SRL called each phone number a maximum of 15 times before replacement, towards completing 300 phone surveys for each city. The detailed methodology, including sampling procedures and data collection techniques, is documented in other associated publications (Crank et al., 2024; O'lenick et al., 2020; Banaissadi et al., 2020). The study obtained approval from the University Corporation for Atmospheric Research Institutional Review Board and the University of Waterloo Ethics Review Board.

3.4.2 Measurement of variables

This is a mixed-methods study involving quantitative and qualitative analysis. The outcome variable of interest is the experience of heat stress. To measure heat stress, participants were asked how they felt during periods of extreme heat in a survey (See appendix; Q.25). The responses to these questions were then simplified into a binary coding system: a response of zero (0) indicated that the participant did not experience heat stress, while a response of one (1) signified that they did. Respondents were also asked about heat-related symptoms they experienced, such as dehydration or fatigue. This approach allows the study to quantify and analyze the prevalence and impact of heat stress among the participants (older adults), providing valuable insights for public health and environmental policies. The control variables were broadly categorized into three, including socio-demographic, heat-related and coping strategies. Details of each variable category are described in Table 1 below.

Table 1: Variables, coding, and justification for consideration

Domain	Predictors	Coding	Justification for consideration
Socio-demographic variables	Gender	0=Female 1=Male 3=Refused	Gender differences may impact vulnerability to heat stress.
	Age	0=65-69 years 1=70-79 years 2=80 and more years	Older adults are more vulnerable to heat-related health risks.
	Marital Status	0=Married 1=Single 2=Divorced 3=Widowed 4=Others	Marital status may affect social support and heat risk management.
	Employment	0=Employed 1=Retired 2=Unemployed 3=Other/Don't Know/Refused	Employment status can impact exposure to heat and access to cooling resources.
	Income	0=Less than $25k 1=$25k to <$50k 2=$50k to <$100k 3= >$100k 4=Don't know/Refused	Income level influences access to heat protection measures like air conditioning. Income was measured in USD.
	Household Size	0=one member 1=two members 2=three and more members 3=Don't know/Refused	Living alone may increase heat vulnerability due to a lack of assistance.
	City	0=Houston, 1=Phoenix 2=Los Angeles	Geographic location affects exposure to extreme heat and the availability of cooling infrastructure.
Heat-related health conditions	Diabetes	0=No 1=Yes	Past symptoms indicate vulnerability to heat-related illnesses.

	Heart disease	0=No 1=Yes	Extreme heat has been found to increase morbidity and mortality for heart diseases.
	Respiratory disease	0=No 1=Yes	High temperatures is associated with increases in respiratory diseases such as asthma, and chronic airway obstruction.
Coping strategies	Take cool shower	0=No 1=Yes	Taking a cool shower can be therapeutic and can significantly improve thermoregulation.
	Physical activity	0=No 1=Yes	Physical activity affects thermoregulation and can potentially lead to heat stress.
	Staying indoors	0=No 1=Yes	Staying indoors during periods of heat wave helps reduce the effect of extreme heat.
	Staying hydrated	0=No 1=Yes	Drinking fluids helps to replace water loss due to extreme heat.
	Stay in shade	0=No 1=Yes	Staying under shade helps reduces the effect of heat waves on the human body.
	Stay in pool	0=No 1=Yes	Staying in the pool during extreme heat situations can help reduce dehydration and improve thermoregulation.
	Loose clothes	0=No 1=Yes	Wearing loose or light cloths helps reflect sun rays and helps reduce the effect of extreme heat on the body.
	Used sunscreens	0=No 1=Yes	Sunscreens are known to protect the skin from harmful sunrays.

Source: Authors Construct (2025)

3.4.3 Data Analysis

Quantitative Approach: The study employed descriptive and inferential statistical techniques to analyze older adults' experiences with heat stress. Given the dichotomous nature of the outcome variable (heat stress), a binary logistic regression model was used. We initiated our analysis with a univariate assessment to outline the descriptive statistics. This was followed by bivariate logistic regression to investigate the individual relationships between each predictor variable, categorized into socio-demographic, health-related health conditions, and coping strategies, and heat stress. To further delineate the effects of predictor variables, we constructed three nested models through multiple binary logistic regressions: 1) Socio-demographic Factor Model, 2) Health-Related Factor Model, and 3) Coping Strategy Factor Model. This structured approach allowed us to explore the aggregated influence of the selected predictors on heat stress across the defined categories. Following Nick et al. (2007), the mathematical formulation for the multiple binary logistic regression model is detailed as follows.

$$\pi(X) = \frac{\exp(\beta_0 + \beta_1 X_1 + \cdots + \beta_k \mathrm{X}_k)}{1 + \exp(\beta_0 + \beta_1 X_1 + \cdots + \beta_k \mathrm{X}_k)}$$

In this model, π represents the probability of an observation classified under the dichotomous variable Y, where a value of 1 corresponds to experiencing heat stress. The term "exp" denotes the exponential function. The parameter β_0 is the intercept, β_1 which refers to the coefficient for the first predictor, and βk signifies the coefficient for the final predictor in the model. The binary regression coefficients are expressed as odds ratios, which reflect the probability of experiencing heat stress. An odds ratio exceeding one (OR>1) suggests an increased likelihood of heat stress, while an odds ratio below one (OR<1) indicates a decreased likelihood (Akaike, 1998). To ensure the robustness of our analysis, we validated the linearity assumption for predictors and determined the continuous presence of multicollinearity. Additionally, model reliability was gauged using the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC), both of which signalled a good fit across the three models analyzed. Utilizing Stata version 18, we achieved a pseudo-R-squared value of 0.069 for Model 1, 0.089 for Model 2, and 0.125 for Model 3 (the final model), highlighting a significant variance explanation for the outcome variable. The Models ACC (1096.91) and BIC (1255.71) values suggest a good fit.

Qualitative Approach: Qualitative data were generated from 67 older adults from PHX (29), LA (23), and HOU (15), from the phone survey. This sample size represents the number of open-ended responses to question 29 of the survey instrument (see Appendix: Q. 29). However, responses which were already captured by closed-ended survey options, such as sunblock and sunscreens, were excluded from the qualitative analysis. Respondents were asked about the actions they took during extreme heat events to protect themselves from the heat. The rationale for the open-ended questions was to provide the respondents with an opportunity to share their experiences and coping strategies. This approach provided a nuanced contextual understanding of how older adults adapt to and cope with extreme heat. Thematic analysis was used to analyze the individual responses. Following Tesch's (1990) criteria for coding qualitative data, general ideas were categorized into similar headings. First, responses from the open-ended questions across LA, HOU, and PHX were identified. Individual responses from the three cities were combined to generate codes for each city based on the study objectives. Suitable words with the same meanings and descriptions were categorized into codes. In the next stage, the codes from individual cities were collated and compared to identify duplicates. The next stage involved scaling down further to identify patterns of meaning. The various categories with

similar meanings were further grouped to identify key themes. The results were then analyzed and presented as themes, interpreted, and discussed as a complement to the quantitative data.

3.5 Quantitative results

3.5.1 Univariate results

The univariate analysis reveals key insights into the sampled population of 909 participants (see Table 2). A notable 35.2% of older adults reported experiencing extreme heat and heat stress symptoms. In terms of age distribution, the largest percentage of older adults falls within the 70-79 years category at 46.31%, followed by 25.4% aged 65-69 years, and 28.2% were 80 years or older. Gender-wise, females constituted 58.6% of respondents, whereas males represented 40.8%. The marital status breakdown indicates that 51.9% were married, with 21.3% being widowed, 11.5% single, and 10.8% divorced. Employment status shows a predominance of retirees at 77.2%, while 17.2% were actively employed, and 2.8% reported being unemployed. Regarding income levels, 22.3% of the sample either did not know their income or refused to disclose it, with 16.3% earning less than USD $25k and 18.04% earning over $100k. The household size indicates that 50.2% lived with two members, and 31.3% lived alone. Geographically, the distribution of respondents was proportionate across the three cities. Health-related factors showed that 16.6% of the respondents had mobility issues, 21.6% had diabetes, 17.7% suffered from heart disease, and 18.1% had respiratory disease. Strategic coping behaviors amidst extreme weather conditions revealed that 35.6% took cool showers, 63.3% engaged in physical activity, and 90.2% stayed indoors.

Table 2: Descriptive statistics of the older adults in the three Sunbelt cities.

Variable category	Variable	Sample (n=909)
		Frequency (Percentage)
Dependent variable	**Heat stress**	
	No	589 (64.80%)
	Yes	320 (35.20%)
Socio-demographic factors	**Age**	
	65-69 years	231(25.41%)
	70-79 years	421(46.31%)
	80 and more years	257(28.27%)
	Gender	
	Female	533 (58.64 %)
	Male	371 (40.81 %)
	Refused	5 (0.55%)
	Marital Status	
	Married	472 (51.93%)
	Single	105 (11.55%)
	Divorced	99 (10.89%)
	Widowed	194 (21.34%)

	Others	39 (4.29%)
	Employment	
	Employed	157 (17.27%)
	Retired	702 (77.23%)
	Unemployed	26 (2.86%)
	Other/Don't know/Refused	24 (2.64%)
	Income_	
	Less than $25k	149 (16.39%)
	$25k to <$50k	184 (20.24%)
	$50k to <$100k	209 (22.99%)
	>$100k	164 (18.04%)
	Don't know/Refused	203 (22.33%)
	Household Size	
	One Member	285 (31.35%)
	Two Members |	457 (50.28%)
	Three and more members	145 (15.95%)
	Don't know/Refused	22 (2.4%)
	City	
	Houston	300 (33.00%)
	Phoenix	303 (33.33%)
	Los Angeles	306 (33.66%)
Health Related Factors	**Mobility**	
	No	758 (83.39%)
	Yes	151 (16.61%)
	Diabetes	
	No	712 (78.33%)
	Yes	197 (21.67%)
	Heart Disease	
	No	748 (82.29%)
	Yes	161 (17.71%)
	Respiratory Disease	
	No	744 (81.85%)
	Yes	165 (18.15%)
Strategic Coping Behaviors	**Take Cool Shower**	
	No	585 (64.36%)
	Yes	324 (35.64%)
	Physical Activity	
	No	333 (36.63%)
	Yes	576 (63.37%)
	Stay Indoors	
	No	89 (9.7%)
	Yes	820 (90.21%)
	Drunk Water	
	No	72 (8.25%)
	Yes	834 (91.75)
	Stay in Shade	
	No	160 (17.60%)
	Yes	749 (82.40%)
	Stay in Pool	
	No	723 (79.54%)
	Yes	186 (20.46%)
	Loose Clothes	
	No	127 (13.97%)
	Yes	782 (86.03%)
	Sunscreens Use	
	No	825 (90.76%)
	Yes	84 (9.24%)

3.5.2 Bivariate results

In Table 3, the bivariate logistic regression analysis is presented. We observed that age was a significant predictor, with respondents aged 80 years and older showing less likelihood of experiencing heat stress (OR=0.566, p<0.001) compared to those aged 65-69. In terms of marital status, both single (OR=1.641, p<0.01) and divorced individuals (OR=1.616, p<0.01) were more likely to experience heat stress compared to married individuals. Regarding income, older adults earning between $50k and $100k showed less likelihood of experiencing heat stress (OR=0.608, p<0.01) compared to those earning less than $25,000. City of residence significantly influenced heat stress experience, with older adults in LA showing nearly 3 times higher likelihood of experiencing heat stress (OR=2.934, p<0.001) compared to those in HOU. Health-related factors were also notable; older adults with mobility issues were more likely to experience heat stress (OR=1.490, p<0.01), and those with respiratory diseases were nearly 2 times more likely to report heat stress (OR=1.917, p<0.001). Additionally, coping strategies had significant impacts, as taking cool showers (OR=1.937, p<0.001) and engaging in physical activity (OR=2.740, p<0.001) were associated with a higher likelihood of heat stress experiences.

Table 3: Bivariate logistic regression of older adults' experience of heat stress in three Sunbelt cities.

Variable category	Variable	Bivariate Logistic Regression	
		OR(SE)	**[95% conf. interval]**
Socio-demographic factors	**Age** (ref: 65-69 years)		
	70-79 years	0.873(0.146)	0.628-1.213
	80 and more years	0.566(0.109)***	0.387-0.827
	Gender (ref: female)		
	Male	0.822(0.117)	0.621-1.087
	Refused	6.877(7.714)	0.763-61.968
	Marital Status (ref: married)		
	Single	1.641(0.361)**	1.066-2.526
	Divorced	1.616(0.364)**	1.039-2.514
	Widowed	0.988(0.180)	0.691-1.414
	Others	1.626(0.549)	0.839-3.152
	Employment (ref: employed)		
	Retired	0.862(0.157)	0.602-1.235
	Unemployed	1.937(0.826)	0.839- 4.470
	Other/Don't know/Refused	0.683(0.327)	0.267-1.746
	Income (ref: Less than $25k)		
	$25k to <$50k	0.787(0.178)	0.504-1.229
	$50k to <$100k	0.608(0.136)**	0.391-0.945
	>$100k	0.971(0.223)	0.618-1.526

		Don't know/Refused	0.694(0.155)	0.447-1.078
		Household Size (ref: one member)		
		Two members	1.034(0.164)	0.757-1.412
		Three or more members	1.116(0.237)	0.735-1.695
		Don't know/Refused	1.938(0.861)	0.811-4.630
		City (ref: Houston)		
		Phoenix	1.204(0.220)	0.841-1.723
		Los Angeles	2.934(0.512)***	2.083-4.132
Health Factors	**Related**	**Mobility** (ref: no)		
		Yes	1.490(0.270)**	1.044-2.127
		Diabetes (ref: no)		
		Yes	1.238(0.205)	0.894-1.714
		Heart Disease (ref: no)		
		Yes	1.228(0.219)	0.864-1.743
		Respiratory Disease (ref: no)		
		Yes	1.917(0.334)***	1.362-2.698
Strategic Behaviors	**Coping**	**Take Cool Shower** (ref: no)		
		Yes	1.937(0.278)***	1.461-2.567
		Physical Activity (ref: no)		
		Yes	2.740(0.431)***	2.012-3.731
		Stay Indoors (ref: no)		
		Yes	1.354(0.330)	0.839-2.185
		Drunk Water (ref: no)		
		Yes	1.437(0.383)	0.851-2.425
		Stay in Shade (ref: no)		
		Yes	1.197(0.222)	0.831-1.724
		Stay in Pool (ref: no)		
		Yes	0.956(0.165)	0.682-1.342
		Loose Clothes (ref: no)		
		Yes	1.507(0.319)	0.994-2.284
		Sunscreen Use (ref: no)		
		Yes	0.761(0.1890	0.466-1.241

p<0.1, *p<0.05, **p<0.01, ***p<0.001 OR (Odds Ratio), SE (Standard Error), CI (Confidence interval), Dependent variable (Heat Stress).

3.5.3 Multivariate results

Table 4 presents the multiple binary logistic regression (nested) analyses in different models. In all three models, age emerged as a significant predictor of experiencing heat stress. Particularly, older adults aged 80 and older were less likely to experience heat stress (OR=0.545, p<0.001 in Model 1; OR=0.526, p<0.001 in Model 2; OR=0.575, p<0.01) compared to those aged 65-69 years. Marital status also significantly impacts heat stress experiences. Single older adults (OR =1.839, p<0.01 in Model 3) and divorced older adults (OR = 1.781, p<0.01 in Model 1; OR = 1.748, p<0.05 in Model 2; OR = 1.848, p<0.01 in Model 3) were more likely to experience heat stress compared to married older adults. Income levels emerged as a predictor of heat stress only in the socio-demographic model, where older adults earning $50k to <$100k were less likely to experience heat stress (OR=0.608, p<

0.01) compared to older adults earning less than $25k. Also, the city of residence significantly affects heat stress experiences, with older adults living in Los Angeles more likely to experience heat stress across all models (OR=2.872, $p<0.001$ in Model 1; OR=2.931, $p<0.001$ in Model 2; OR=2.489, $p < 0.001$ in Model 3) compared to those in Houston. Health-related conditions also demonstrated a relationship with heat stress. Older adults with respiratory diseases were more likely to experience heat stress (OR=2.160, $p<0.001$ in Model 1; OR=2.137, $p<0.001$ in Model 2). Coping strategies were also significant predictors. Surprisingly, older adults taking cool showers show an increased likelihood of experiencing heat stress (OR=1.370, $p<0.05$) in the health-related model.

Table 4: Multiple Binary Logistic Regression of older adults' experience of heat stress in three Sunbelt cities.

Variable	Sociodemographic Model		Health conditions Model		Coping Strategies Model	
	Multiple Logistic Regression		Multiple Logistic Regression		Multiple Logistic Regression	
	OR(SE)	[95% conf. interval]	OR(SE)	[95% conf. interval]	OR(SE)	[95% conf. interval]
Age (ref: 65-69 years)						
70-79 years	0.893(0.161)	0.626-1.274	0.920(0.169)	0.642-1.320	1.016(0.193)	0.700-1.475
80 and more years	0.545(0.119)***	0.354(0.838)	0.526(0.117)***	0.339-0.815	0.575(0.132)**	0.366-0.903
Gender (ref: female)						
Male	0.879 (0.138)	0.645-1.197	0.863(0.139)	0.628-1.1846	0.958(0.162)	0.687-1.335
Refused	13.5280(15.658)	1.399-130.758	16.651(19.470)	1.683-164.721	18.072(21.328)	1.788-182.629
Marital Status (ref: married)						
Single	1.639(0.470)	0.934-2.878	1.650(0.480)	0.932-2.920	1.839(0.558)**	1.015-3.333
Divorced	1.781(0.500)**	1.027-3.091	1.748(0.498)*	0.999-3.058	1.848(0.552)**	1.028-3.320
Widowed	1.290(0.331)	0.780-2.133	1.199(0.313)	0.719-2.001	1.275(0.346)	0.749-2.172
Others	1.172(0.503)	0.505-2.719	1.211(0.527)	0.515-2.844	1.312(0.587)	0.545-3.158
Employment (ref: employed)						
Retired	1.039(0.206)	0.703-1.535	0.975(0.196)	0.656-1.448	0.907(0.189)	0.602-1.365
Unemployed	2.112(0.977)	0.852-5.231	2.152(1.016)	0.853-5.430	2.255(1.112)	0.857-5.932
Other/Don't know/Refused	0.628(0.360)	0.204-1.933	0.510(0.298)	0.161-1.609	0.478(0.286)	0.147-1.547
Income (ref: Less than $25k)						
$25k to <$50k	0.819(0.199)	0.509-1.320	0.9393(0.234)	0.576-1.531	0.939(0.242)	0.566-1.557
$50k to <$100k	0.608(0.150)**	0.374-0.989	0.695(0.176)	0.422-1.142	0.641(0.168)	0.383-1.073
>$100k	0.817(0.217)	0.486-1.376	1.014(0.278)	0.592-1.738	1.084(0.310)	0.618-1.901
Don't know/Refused	0.716(0 .175)	0.442-1.158	0.837(0.211)	0.510-1.372	0.820(0.213)	0.491-1.367
Household Size (ref: one member)						
Two members	1.479(0.343)	0.938-2.333	1.533(0.363)	0.963-2.4395	1.574(0.387)	0.971-2.551
Three and more members	1.420(0.380)	0.840-2.399	1.414(0.385)	0.828-2.414	1.549(0.438)	0.890-2.697
Don't know/Refused	3.192(1.920)	0.982-10.378	3.802(2.345)	1.135-12.737	4.676(2.963)	1.350-16.192
City (ref: Houston)						
Phoenix	1.261(0.238)	0.870-1.828	1.192(0.230)	0.816-1.7423	1.055(0.211)	0.712-1.563
Los Angeles	2.872(0.527)***	2.004-4.116	2.931(0.548)***	2.032-4.2293	2.489(0.480)***	1.705-3.632
Mobility (ref: no)						
Yes			1.288(0.2622)	0.864-1.919	1.247(0.262)	0.826-1.883
Diabetes (ref: no)						
Yes			1.383(0.255)	0.962-1.987	1.251(0.239)	0.859-1.821

Heart Disease (ref: no)					
Yes		1.059(0.217)	0.707-1.584	0.983(0.209)	0.647-1.492
Respiratory Disease (ref: no)					
Yes		2.160(0.422)***	1.472-3.171	2.137(0.433)***	1.436-3.179
Take Cool Shower (ref: no)					
Yes				1.370(0.225)*	0.992-1.891
Physical Activity (ref: no)					
Yes				2.490(0.464)***	1.728-3.590
Stay Indoors (ref: no)					
Yes				0.783(0.232)	0.438-1.400
Drunk Water (ref: no)					
Yes				1.192(0.372)	0.646-2.199
Stay in Shade (ref: no)					
Yes				0.922(0.201)	0.600-1.415
Stay in Pool (ref: no)					
Yes				1.129(0.223)	0.766-1.664
Loose Clothes (ref: no)					
Yes				1.355(0.335)	0.833-2.202
Sunscreens Use (ref: no)					
Yes				0.714(0.200)	0.412-1.237
Log-likelihood	-548.8767	-536.972		-515.452	
R-Square	0.069	0.089		0.125	
AIC	1139.753	1123.945		1096.906	
BIC	1240.813	1244.254		1255.713	

p<0.1, *p<0.05, **p<0.01, ***p<0.001 OR (Odds Ratio), SE (Standard Error), CI (Confidence interval), Dependent variable (Heat Stress)

3.6 Qualitative results

A broad range of activities of daily living emerged as heat coping strategies adopted by older adults to protect themselves during extreme heat events. These include various individual-level coping strategies and environmental adjustment strategies.

3.6.1 Individual-level behavioural coping strategies

Heat-related behavioural adjustments emerged as a key theme in coping with extreme heat among older urban populations. Heat coping behaviours included sleeping, reducing intense physical activity, staying indoors, controlling their diet, putting their feet in a kiddie pool, or regulating indoor temperatures using fans and air conditioning. Staying hydrated by drinking water also emerged as an essential measure adopted by older adults to cope with heat stress. These strategies are known used to maintain thermal comfort within the home environment during periods of extreme temperatures. For instance, one participant echoed, "I wet a towel and wrap it around my body to keep me refreshed." Another participant noted, "I exercise indoors rather than outdoors and late evenings."

3.6.2 Environmental adjustment strategies

To ensure acclimatization to weather conditions outside the home, older adults resorted to the use of heat-protective accessories, such as umbrellas, parasols, and sunglasses, when they needed to go out. Some older adults also reported travelling out of town during periods of extreme heat to cooler locations, such as visiting the beach to cool off. For instance, some older adults stated that "they usually travelled to cooler places" during extreme heat events. To maintain comfortable temperatures in cars, older adults reported using various strategies, including allowing cars to cool down before getting moving, filling cars with freon, and utilizing the air conditioning system. For instance, respondents stated, "I usually allow the car to cool down before getting into it. "

Table 5: Thematic analysis of coping strategies among older adults during extreme heat

Theme	Sub-themes	Codes	Justification
Individual-level behavioural coping strategies	Reduced Physical activity/ mobility control	I sleep Take breaks during activities Exercised indoors rather than outdoors and late evening I try to do things in the early morning Worked inside My rides usually pull up close to the door so I can avoid being in the sun for too long	Individual activities of daily living to control internal temperatures, reduce exposure to heat or minimize the effect of extreme heat within the home environment.
	Diet control	I eat lighter Ate frozen food	
	Dressed appropriately	Wore a bandeau around the neck I don't wear dark clothing Evaporate neck cloth I wet a towel and wrapped it around my body to keep me refreshed.	
	Stayed hydrated	Drank Gatorade Drank a lot of beer Drank iced tea	
	Cooled off	Use a fan Indoor dehumidifier Wet towel around neck I put a container of water behind my electric fan Turned on the outdoor fountain Sit with feet in a kiddie pool Used water mister	
Environmental adjustments strategies	Heat protection accessories	Umbrella Parasol Sunglasses	A range of coping mechanisms employed by older adults to protect themselves against harmful heat exposure outside the home environment
	Relocated	Left town. Went to the mall Travelled to a cooler place	
	Car cooling measures	Cools car down before getting into it Put freon in my car Used car AC	

Source: Authors Construct (2025)

3.7 Discussion

Recent studies have highlighted the vulnerability of older adults to extreme heat events linked to climate change. As a result, understanding the predictors and coping mechanisms of older adults in response to heat stress has become increasingly relevant for effective policy intervention. The current and projected growth in the population of older adults living in Sunbelt cities across the United States raises critical concerns about their health and ability to withstand and adjust to extreme heat. This study explored the factors affecting heat stress and the coping mechanisms among older adults in LA, HOU, and PHX. The results reveal that socio-demographic factors such as age, marital status, income, city of residence, and health-related factors such as respiratory diseases and physical activity are significant predictors of heat stress among older adults. Also, behavioral adjustment, including altering activities of daily living and taking cool showers, emerged as significant coping mechanisms.

Our quantitative results indicate that older adults aged 80 years and above were less likely to experience heat stress compared to their relatively younger counterparts. This appears counterintuitive given the prevailing evidence of increasing vulnerability to heat stress with advanced age, mainly due to diminished thermoregulatory responses and impaired health status (McKenna et al., 2023; O'Lenick et al., 2024). This finding contradicts some previous research on the association between age and heat stress. For instance, Fouillet and colleagues (2006) reported that in France during the 2003 heat wave in Europe, mortality due to heat stress was consistent with increasing age. Notwithstanding this contradiction, evidence suggests that older adults become acclimatized to temperature changes over time and can adapt to environmental conditions compared to their younger counterparts (Kenny et al., 2010). This finding, however, validates similar epidemiological studies by Wilhelmi et al. (2021), who reported that the oldest adults (80+ years) were less likely to suffer heat stress compared to their relatively younger counterparts. Although surprising, several factors could be advanced to explain this phenomenon. This could be attributed to sampling bias, as it is possible for the phone interview to unintentionally sample a generally healthier population of the oldest adults. Another challenge might result in more of the oldest respondents (80+ years) spending more time indoors (see Table 2). Older adults aged 80 years and older are less likely to engage in rigorous physical activity, which has been linked to increased risk of heat stress. Also, it is possible that due to the socio-economic status of this age group, they can afford the consistent use of functional air conditioning systems to regulate indoor temperatures (Baniassadi et al., 2023).

The quantitative results also highlighted that single and divorced older adults were more likely to experience heat stress compared to their married counterparts. This finding aligns with previous

research, which identified social isolation as a significant determinant of heat stress and mortality among older adults (Orlando et al., 2021). In a similar study, Gronlund et al. (2014) utilized death records between 1990 and 2007 of older adults in Michigan and found that older adults who were not married and living alone were associated with increased vulnerability to extreme heat mortality. The presence of a supportive partner has proven to be an effective measure of reducing vulnerability through the provision of emotional support and burden sharing during extreme heat events. Loneliness has been identified as a key social determinant of health, particularly for older adults who require assistance in performing activities of daily living. Hence, living alone could reduce the quality of life for older adults and their capacity to cope with heat stress. Being single or divorced can exacerbate experiences of heat stress, particularly for older adults who do not have children or family members who visit regularly (Malmquist et al., 2022).

Consistent with earlier studies, we found that older adults earning between $50k and $100k were less likely to experience heat stress (Kang et al., 2024). Socio-economic status has been shown to compound vulnerability to heat stress among older adults in different settings. A study by Kim and Joh (2006) in Korea found that the mortality rate among low-income elderly people was 1.7-fold higher compared to the whole high-income group. The relationship between financial capacity and vulnerability to heat stress can be explained by several factors. First, older adults with strong financial capacity can afford to live a higher quality of life in healthy neighbourhoods and have access to parks and green spaces, reducing their exposure to extreme heat (Walter et al., 2023). Also, financial security increased accessibility to properly functioning air-conditioning systems, fans and other cooling systems, increasing their ability to mitigate extreme heat exposures. Financially stable older adults can afford to live in their own homes, giving them greater autonomy and control over decisions regarding their indoor temperatures. On the other hand, low-income older adults and those living in care homes may be vulnerable during extreme heat conditions due to their limited autonomy over indoor temperature control (James et al., 2014).

Across the three models, quantitative findings indicate that older adults residing in LA were more likely to experience heat stress. In 2017, LA experienced about 114 days of maximum temperatures, and the NWS issued 35 heat warnings compared to Phoenix (19) and Houston (0), (NWS, 2018). This indicates the elevated levels of heat risks in LA compared to HOU and PHX. Consistent with previous research, Kim et al. (2021) and Mitchell & Chakraborty (2015) reported unequal heat exposure within the LA. For instance, summer temperatures in the Coastal areas like Santa Monica are projected to increase less than 3.6°F, whereas inland areas, including Palmdale and

downtown LA, may experience an increase in summer temperatures of between 4.8°F and 5.4°F and 3.7°F and 4.0°F, respectively, by 2050 (Kim et al., 2021). The unique position, local climate, diverse population, and varied topography of the city predispose residents to unequal heat. The Urban ecology and diverse physiography significantly influence the unique and heterogeneous local climate of LA County. This shapes the spatial pattern of heat vulnerability to the disadvantage of marginalized groups who are already subject to racially discriminatory practices and the background Mediterranean climate (Yin et al., 2023). LA is located in a semiarid landscape, which makes it experience a significantly long dry season and extended drought (O'Lenick et al., 2020). This spatial location defines the UHI effect in a uniquely complex manner, where the oceanic effect provides a moderating effect on summer temperatures on the adjacent landmass, to the neglect of the city core, mostly inhabited by minority groups (Yin et al., 2023). Also, although many older adults in LA have access to air conditioning, utilization reflects socio-economic disparities, with a significant number underutilizing it due to the high cost of energy (Baker & Sturn, 2024). With a diverse population and a high proportion of older adults and other vulnerable populations, energy insecurity is pervasive (Xie et al., 2024). Compared to LA, PHX experiences a reverse UHI effect where temperatures in the urban areas are generally lower than in the surrounding rural areas (Moss, 2021). Owing to the relative location in the Sonoran Desert, PHX experiences the "oasis effect", which provides a moderating effect on extreme summer heat experienced in the city (Kim et al., 2018).

Our analysis indicates that older adults with respiratory illnesses are more prone to heat stress. Those reporting symptoms such as coughing, throat irritation, chest tightness, or shortness of breath are especially at risk. This supports earlier research by O'Lenick et al. (2024), which highlighted the vulnerability of older adults in major U.S. cities with pre-existing respiratory conditions to heat stress. A systematic review by Bouchama and colleagues (2007) also found that older individuals with pulmonary disorders faced higher risks of heat-related fatalities during extreme heat events. Similarly, Anderson et al. (2013) identified a strong link between heat stress and chronic respiratory conditions in the elderly across the U.S.

We also observed that older adults who engage in physical activity were more likely to experience heat stress. A normal body strives to maintain a steady temperature of 37°C (Kenny et al., 2010). However, the ability of the human body to thermoregulate and maintain a normal temperature depends largely on maintaining a physiological balance between internal heat generation and heat loss to the environment (Gagge & Gonzalez, 2010). During warm temperatures, the body absorbs heat from the environment, creating excess heat, thereby prompting heat loss through sweat production to

maintain a normal temperature. Therefore, physical activity in hot ambient temperature situations not only increases heat production levels and places the body under greater physiological strain, but also increases heat energy stored in the body, which can potentially be dangerous. As a result, to maintain heat balance, rapid heat loss is necessary through increased sweat production. Considering the impaired thermoregulatory system of an aging body, intense physical activity in humid conditions could result in heat stress disorders or fatality (Kang et al., 2024). For older adults, especially those 80 years and older, engaging in physical activity amidst high temperatures, the ability to dissipate heat is diminished, and the risk of heat stress is elevated (Balmain et al., 2018). Other researchers have also highlighted that older adults are more capable of adapting to extreme heat situations amidst moderate exercise during hot temperatures compared to their younger counterparts (Tyler et al., 2016).

Furthermore, older adults who took cool showers demonstrated an increased likelihood of experiencing heat stress. Taking a cool shower on a hot day is a significant coping mechanism against vulnerability to heat stress. This finding is in alignment with prior research conducted in the US (Sampson et al., 2013) and elsewhere (Malmquist & Weitz, 2022). For example, a study by Mukhopadhyay and Weitz (2022), examining heat-related symptoms and coping strategies among older adults in West Bengal, India, reported that taking a shower or bath was a common behavioral practice among older adults against heat stress. Also, in a similar study in the US, White-Newsome and colleagues (2011) identified taking cool showers as one of the adaptive behaviors against high ambient temperatures. Taking a quick bath during extreme heat events can significantly improve thermoregulation, fluid regulation, and cardiovascular and nervous system function (Mukhopadhyay & Weitz, 2022).

Due to the apparent heat intolerance and other physiological, psychological and social vulnerabilities, older adults used a variety of heat coping behaviours to protect themselves from or adapt to the adverse effects of extreme heat. This is consistent with the findings of Sampson et al. (2013) and Malmquist et al. (2022), who found behavioural adjustments as significant coping strategies among older adults in the US and India during extreme heat events. These protective behaviours included travelling to cooler locations, reducing physical activity, appropriate dressing, increased use of fans and air-conditioning and staying hydrated. Extreme heat could have adverse physical and psychological consequences, leading to heat-related mortality and morbidities (Sampson et al., 2013). As such, micro-level protective behavioral that aim to lower heat exposure and reduce heat fatalities among older adults. This finding underscores the importance of adjusting activities of daily living to suit weather conditions, such as limiting intense physical activity during hot hours, remaining indoors

and staying hydrated during hot hours of the day. Our study supports previous adaptive thermal studies that highlighted the potential of narrow heat-coping behaviors such as wearing light clothes, using fans, and drinking a lot of water (Mukhopadhyay & Weitz, 2022; Haque et al., 2013). Studies have established that the body loses excess water rapidly due to extreme heat, which can only be replaced by eating food that contains water or drinking fluids (Sampson et al., 2013). Individual behavioural adjustment and adaptive strategies have been tested in different settings and have proven to increase resilience against extreme heat among older adults.

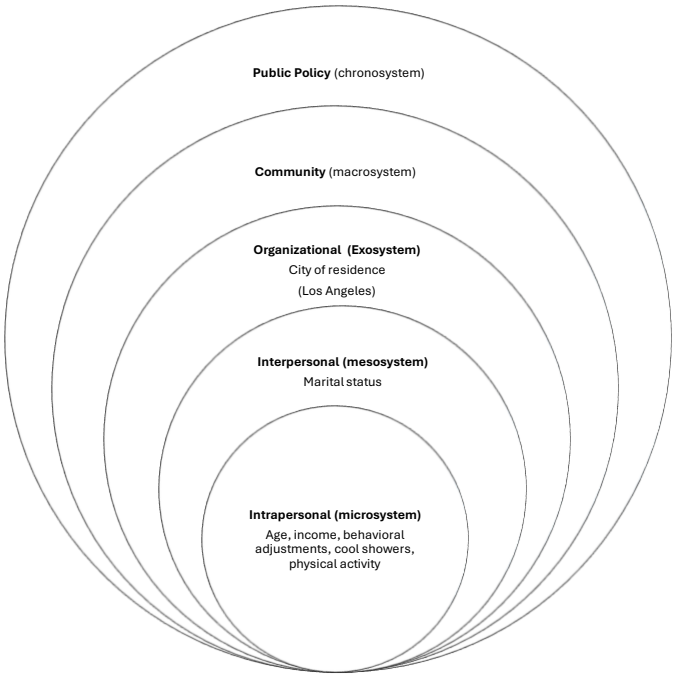


Figure 3: Social-ecological model for heat stress based on factors identified in the results (Adapted from Bronfenbrenner, 1979).

These findings fall directly under the purview of major constructs of SEM. The microsystem, embodying physical attributes including age and marital status, influences extreme heat experiences (Kilanowski, 2017). Social support is a crucial component of adaptability and resilience in the face of extreme heat (Rohat et al., 2021). SEM highlights the importance of the interpersonal environment, such as social systems and networks, on older people's experiences of extreme heat. Also, income as a social determinant of health may facilitate or constrain older adults' ability to deal with pre-existing health challenges in the presence of extreme heat circumstances. The physical environment where we live and work influences our experiences of heat stress and other health-related conditions (Bernhardt & Amiri, 2024). LA displays unequal heat exposure, which exposes older residents to heat risks compared to HOU and PHX. Further, the interrelationship between the various levels of SEM is facilitated by effective communication between the actors. However, our findings did not identify

factors in the macrosystem or chronosystem. These levels are still important considerations for heat adaptation, as community-level resources can facilitate the timely dissemination of heat warning messages to inform heat hazard preparedness, and the role of public policy remains crucial in mitigating extreme weather conditions (Bernhardt & Amiri, 2024). These findings underscore the importance of personal awareness and the potential risks of heat stress and adverse health outcomes among specific demographic groups while highlighting opportunities for future analysis of factors in the macrosystem and chronosystem of the SEM.

3.8 Limitations of the study

Despite the contributions of the study, some limitations are worth noting. The cross-sectional data limit the establishment of causality. Utilizing a retrospective cross-sectional study design could potentially result in recall bias (McClean et al., 2019). As such, older adults self-reported their experience of past exposure to extreme heat. Their present circumstances could influence their responses, leading to underreporting or overreporting past exposure experiences (Mason et al., 2023). Sampling bias in the selection of older adults could result in some age categories being oversampled against others. Additionally, the qualitative component did not follow conventional qualitative protocols, such as purposive sampling procedures and data collection instruments, such as interviews and focus group discussions, which could have resulted in limited responses relative to the quantitative sample survey. Furthermore, due to the nature of the phone survey, which was based on including all older adults who answered and consented to the interview, it is possible that proper randomization was not achieved.

3.9 Conclusion

This paper explored predictors of heat stress and coping strategies among older adults in three Sunbelt cities in the United States. The study found that older adults 80 years and above, single and divorced, residents of Los Angeles, and those earning between $50-100k were less likely to experience heat stress. Additionally, older adults with pre-existing health conditions such as respiratory diseases and those taking cool showers were more susceptible to heat stress. Our findings also identified the individual-level behavioural adjustments in response to heat warning signals as effective coping and adaptive mechanisms against extreme heat. It is recommended that urban health strategies prioritize these demographics, strengthening social support systems and enhancing effective adaptation mechanisms to mitigate the impacts of extreme heat on vulnerable older populations. Considering the strong influence of place of residence and socio-economic factors on heat stress experiences, city

planners and policymakers should design sustainable interventions to reduce heat vulnerability and ensure environmental equity through addressing issues of access and consistent use of AC and accessibility to public cooling spaces to meet the needs of vulnerable older adults.

CHAPTER FOUR

DISCUSSION AND CONCLUSION

4.1 Introduction

The goal of this thesis is to examine disparities in heat risk vulnerabilities and coping strategies among older adults residing in Phoenix, Houston, and Los Angeles. Specifically, this research aimed to address two objectives: 1) to examine the factors influencing heat stress among older adults in Sunbelt cities and 2) to explore coping strategies among older adults in Sunbelt cities. The study uses a retrospective cross-sectional study design to explore heat stress and coping strategies among older adults. This thesis is organized into four chapters comprising one empirical manuscript. Following Chapter One, Chapter Two presented a detailed methodology and an outline of the study area. This chapter provided a comprehensive summary of the findings and outlines the contributions of the thesis to the literature, methodology, policy and practice. Chapter Three consists of an empirical manuscript on heat stress experiences and coping strategies among older adults in Sunbelt cities. The chapter conceptualized the factors influencing heat stress within the socio-ecological model, recognizing the impact of multiple determinants of heat stress. Chapter Four presents a summary of findings and concludes the dissertation. Chapter Four also outlines the theoretical and methodological contributions of the study, as well as implications for policy and practice. The chapter further discusses the limitations of the study and directions for future research.

4.2 Summary of key findings

Findings from this thesis demonstrate that older adults in Sunbelt cities disproportionately suffer a greater burden of extreme heat. The study highlights the importance of geography, behavioural, socio-demographic, and health-related factors as significant factors influencing heat stress. First, the results reveal that older adults (80 years and older) were less likely to experience heat stress compared to their relatively younger counterparts. While this finding sounds counterintuitive, evidence suggests that the oldest (80+ years) may have been acclimatized to climatic changes over time compared to relatively younger counterparts, among other possible sources of this result (Wilhelmi et al., 2021; Kenny et al., 2010). Given the sensitivity and susceptibility of older adults to heat risks, it is also possible that they are adhering to heat warning communication and adjusting their activities of daily living to suit weather changes. Second, older adults experiencing social isolation, including single and divorced older adults, were at a greater risk of suffering heat stress. This finding is consistent with prior epidemiological studies conducted in the US by Gronlund et al. (2014) and

elsewhere (Orlando et al., 2021). Loneliness is a prime social determinant of health, particularly for older adults who require assistance in performing activities of daily living and as such, living alone could reduce the quality of life for older adults and their capacity to cope with extreme weather conditions.

Also, income emerged as a predictor of heat stress among older adults. Older adults earning between $50,000 and $100,000 were less likely to experience heat stress. Older adults with a higher disposable income can afford to live a higher quality of life in healthy neighbourhoods and have access to parks and green spaces, can afford the consistent use of air-conditioning systems, have greater autonomy and control over their indoor temperatures, reducing their exposure to extreme heat. Further, older adults living in Los Angeles were more likely to experience heat stress compared to those in Houston and Phoenix. As the largest municipal government in the United States, the diverse physiography and location of Los Angeles in a semiarid zone with a Mediterranean climate (Csa), strongly influence the intensity of the UHI effect. Aside from experiencing a significant dry season, LA has low AC saturation compared to PHX and HOU, potentially contributing to higher heat risk (Crank et al., 2024). Also, summertime temperatures in LA are unequal, with a land surface temperature of between 36°C and 54°C varying disproportionately across the city (Yin et al., 2023). This phenomenon exposes vulnerable older populations in the inland areas to differential heat hazards (Mitchell & Chakraborty, 2015).

The multivariate results indicated that individuals with preexisting health conditions, including respiratory diseases, were a significant determinant of heat stress. Similar findings were reported by O'Lenick et al. (2024), who highlighted that heat stress experiences are further accentuated for older adults with pre-existing respiratory conditions. Additionally, it was observed that older adults who engaged in physical activity were more likely to suffer heat stress. This finding validates previous literature on thermoregulation and maintaining a physiological balance among older adults in ambient temperature environments (Kang et al., 2024; Tyler et al., 2016). Also, older adults who took cool showers were significantly more likely to experience heat stress. This finding, however, remains unclear as to whether older adults take cool showers as a response mechanism against extreme heat or whether the cool showers exacerbate their heat stress experiences. It is well noted that taking a quick bath is a significant coping mechanism. Previous studies have highlighted the potential of taking cool showers to significantly improve thermoregulatory functioning (Mukhopadhyay & Weitz, 2022; Malmquist & Weitz, 2022).

The second section of Chapter Three addresses the second objective, which explores coping strategies against extreme heat among older adults. This objective was achieved through a qualitative approach by coding responses from open-ended survey questions and conducting a thematic analysis. The results revealed that older adults adjusted their activities of daily living (ADLs) to suit the weather conditions in several ways. This finding corroborates previous studies, which suggest that behavioural adjustments, such as wearing light clothing, reducing physical activity, staying hydrated, opening windows, visiting cooling centers, and travelling out of town, can significantly reduce vulnerability to extreme heat (Mukhopadhyay & Weitz, 2022; Haque et al., 2013). These behavioural adjustments could be that older people stay informed of impending heat waves by monitoring and adhering to heat warning announcements, emphasizing the importance of heat warning systems in keeping the public informed to facilitate appropriate behavioural change. Similar findings have been reported in the literature by Brimicombe et al. (2024) and Oberai et al. (2024).

4.3 Contributions of the study

The study makes important contributions to the discourse at the nexus of climate change, urbanization, and human health, highlighting the implications of urban-induced extreme heat on vulnerable older adults. Despite previous research examining the impact of extreme heat on older adults in Sunbelt cities (Crank et al., 2024; O'Lenick et al., 2020; Conlon et al., 2016), there is a dearth of studies examining the predictors of heat stress and coping strategies among older adults across scales in the United States. This study, therefore, expands our understanding of specific socio-demographic, health-related and strategic coping factors affecting heat stress among older adults using a mixed-methods approach. By adopting a mixed-methods methodology, the study provided a more nuanced understanding of heat stress experiences and coping strategies – a gap identified in the literature. The findings highlight the importance of geography, individual factors, as well as societal factors as significant determinants of heat stress among older adults.

4.4 Theoretical Contributions

This research makes important contributions to the literature on the geographical dimensions of ageing by enhancing our understanding of ageing, place and health. With climate change and ageing now an axiomatic backdrop for much of the global health research in the 21st century, the implication of this research is crucial for advancing population health and well-being (Skinner et al., 2015; Curtis et al., 2012). Employing the socio-ecological model provides a useful framework for examining the health and well-being of older adults and how this varies across place, space and scales (major

constructs of SEM). Opportunities for health vary between the three cities of Los Angeles, Houston, and Phoenix, which are further dictated by micro (including socio-demographic attributes) and macro factors (environment, social structures, public policies). For example, older adults' experiences of extreme heat varied across the cities in the Sunbelt, although they all experienced the urban heat island effect. The study advances research within the domains of geographies of ageing by theorizing the recursive relationship between ageing, health and place relations. This relationship defines the places where ageing occurs and the implications for the health and well-being of older adults. For example, impaired health conditions and a decline in functional limitations influence where and how someone ages. These health conditions influence the places where older people live and access to opportunities for health, including supportive neighbourhoods that promote healthy ageing.

Secondly, this research sheds light on the social determinants of health and subjective well-being among older adults. By examining multiple socioeconomic, health, and strategic coping determinants of health, I expanded the operational understanding of the WHO's Commission on Social Determinants of Health and highlighted the factors that shape the social and environmental vulnerabilities to extreme heat. In this regard, health is understood not as the absence of disease, but as the presence of an enabling environment and the reduction of vulnerabilities. Although ageing accentuates vulnerabilities to extreme heat by elevating the risk of multiple comorbidities, impaired immunity, and reduced thermoregulatory functions, the presence of social support systems, access to properly functioning air conditioning services, and adequate resources helps mitigate the effects of extreme temperatures.

This study established that the heat stress vulnerability varies socially and geographically, with certain demographic and geographic populations disproportionately affected by extreme heat. Examining specific socio-demographic, health-related and strategic coping factors influencing heat stress among older adults in Sunbelt cities provides evidence of heat stress vulnerabilities. Theorizing explicitly on multiple influences shaping heat stress vulnerabilities (along the main constructs of SEM) across the three cities provides evidence for policy and practice that arguably hold authority. Examining individual and context-specific realities affecting older adults brings to light how city planners and policy makers can retool emergency response mechanisms to respond to the specific needs of older adults across individual cities.

This study contributes to the understanding of the applicability of the socio-ecological model in examining heat stress among older adults in Sunbelt cities. The specific theoretical contribution of this study is that it discusses the determinants of heat stress and coping strategies along the SEM

framework within the context of Sunbelt cities by offering possible recommendations that strengthen it. This serves as the basis for future research to employ the SEM to contextualize heat stress dynamics in the US and elsewhere. To the best of my knowledge, this study is the first to employ SEM in heat stress research within the context of the US. The application of SEM in this study provides useful pathways for addressing specific vulnerabilities across scales.

4.5 Methodological contributions

The study makes important methodological contributions to the literature. First, the research contributes to methodological diversity in addressing complex socio-demographic and environmental health issues. By adopting a mixed-methods approach, the study provided a nuanced understanding of social vulnerability and human agency during an environmental crisis. This study adopted a novel approach of generating qualitative data from the pre-programmed quantitative survey. This was done through the use of open-ended questions, which allowed respondents to provide more details outside of the options contained in the questionnaire. These responses were collated and analyzed using thematic analysis to generate the qualitative component of this study. Through this process, I was able to identify patterns and themes relevant to answering the research questions. This aligns with the methodological innovation and diversity of health geography. Despite copious literature theorizing the health implications of extreme heat in Sunbelt cities, no study has utilized mixed-method approaches, a notable gap in the literature. This advances the methodological diversity and the relevance of integrating varied approaches within the geographies of health and healthcare.

4.6 Substantive contributions

This thesis offers several substantive contributions. First, this study contributes to the geographies of ageing discourse by expanding our understanding of disparities in heat stress vulnerabilities among older adults (Skinner et al., 2015). In part, this study demonstrates how place and space influence the health and well-being of older populations by exposing the vulnerabilities of older adults in Sunbelt cities to extreme temperatures. Health geographers have long been interested in the significance of place and space in the lives of older adults, depicting place as problematic, complicated and contested (Skinner et al., 2015). Much of the geographies of ageing literature in high-income countries is focused on theorizing the relationship between ageing-health-place (Rishworth et al., 2019), with little effort to uncover the "hidden geographies of ageing" as it relates to their coping strategies during extreme weather events. Hence, this research expands knowledge on the scope and

nature of ageing by appreciating the reflexive and mutually constitutive relationship between older adults and the places where ageing occurs within the context of Sunbelt cities in the US.

In line with the United Nations' "Decade of Healthy Ageing (2021-2030)," it is imperative to utilize scientific evidence to demand urgent policy interventions aimed at protecting the ageing population from the exigencies of climate-induced extreme heat events. Research addressing specific knowledge gaps in the literature among older adults and offering tangible solutions is exceedingly relevant (Baniassadi et al., 2023). Developing age-friendly cities and communities is a priority among other important targets of the UN Decade of Healthy Ageing (WHO, 2021). Evidence from this study highlights particular vulnerabilities of older adults and the primacy of behavioural responses during extreme heat events. Evidence from the study provides a benchmark for measuring progress and contributes to developing age-friendly cities and communities that foster the abilities of older people.

Further, this study extends the literature on the influence of urban environments on older adults through the UHI effect by elevating pre-existing vulnerabilities. This study directly responds to calls for increased investigation into the health implications of urban-induced heating on vulnerable populations owing to the projected increase in population ageing, rapid urbanization, and intensifying climate change. The UHI effect makes urban location a major risk factor for increased vulnerability to climate change stressors due to the exacerbation of summer heat. The study re-emphasized that, as much of the ageing population in America is concentrated in the Sunbelt, a region prone to increased intensification of extreme heat events, evidence on effective coping and adaptation mechanisms can significantly improve resilience among older adults (Gamble et al., 2013).

4.7 Implications for theory and practice

Health geographers are instrumental in bridging the knowledge-action gap in the areas of evidence-based research. Following Luginaah's (2009) call for health geographers to highlight the implications of their research on health policy and practice, this research highlights how study findings can improve health outcomes of older adults in Sunbelt cities. International frameworks on ageing, such as the United Nations Principles for Older Persons and the Madrid International Plan of Action on Ageing, aim to ensure that older people live in dignity, self-fulfilment, and participate actively in their society (Rishworth & Elliott, 2019; UN, 2002). Concomitantly, the Sendai Framework of 2015 commits to reducing environmental risks and losses by outlining the roadmap for safer and more resilient communities. Within the context of heat stress and coping strategies, findings from this thesis offer useful insights into how the health of older adults can be protected by mitigating the impact of

extreme heat. Possible pathways for enhancing the health and well-being of older adults are discussed below.

4.7.1 Strengthening emergency heat risk warning systems

In line with this, the National Weather Service should intensify heat risk warning awareness in Sunbelt cities, particularly Los Angeles, where heat risk is high. Heat warning messages need to be explicit and target specific socio-demographic groups and highlighting individual adaptive behaviours. Case studies suggest that to enhance compliance with heat warnings and adaptive behaviours, heat alerts should spell out the particular behaviour to undertake by the different socio-demographic groups. Also, evidence suggests that people are more likely to comply with heat warnings if such warnings are accompanied by clear instructions, such as drinking plenty of water, relocating to cooler areas, improving ventilation, and wearing lightweight clothing (Oberai et al., 2024; Kiarsi et al., 2023).

4.7.2 Strengthening social support systems

The study underscores the importance of creating supportive social structures to enhance the health and well-being of older adults. This is particularly important for older adults who are single, divorced, or whose partners are deceased. Social networks are instrumental in providing guidance and encouraging adaptive behaviour (Baniassadi et al., 2023). Social interaction can enhance longevity, improve quality of life and act as a buffer against functional decline (Ramlagan et al., 2013). As a policy alternative, social prescribing could potentially target the unmet needs of older adults experiencing social isolation. This involves referring older adults to community-based resources to meet their non-medical health-related social needs, to improve their mental health and well-being. Social prescribing enhances social integration, social inclusivity and improves mental health by addressing the unique needs of older adults, such as loneliness, through person-centred programmes and activities based on individual preferences (Mulligan et al., 2023).

4.7.3 Strengthening economic opportunities

Also, the study advocates for policies aimed at enhancing economic security, which have been linked to subjective well-being in old age (Rishworth & Elliott, 2019). Addressing economic disparities and financial barriers to AC utilization is necessary, as older adults with lower incomes are most likely to suffer heat stress (Baniassadi et al., 2023). Policymakers should implement strategies such as strengthening economic security for older adults, subsidized cooling centers, direct outreach through healthcare providers, and targeted media campaigns to improve accessibility to heat-related information for low-income groups.

4.7.4 An effective public cooling system

Further, access to public cooling systems is imperative to ensure equitable access to adequate cooling for older adults. In light of the increasing vulnerability of older adults and the projected rise in extreme heat events, community-based cooling systems can be a cost-effective intervention against heat stress among older adults. As part of a comprehensive heat response strategy for urban areas experiencing rapid heating, public cooling centers should be a crucial component of urban design (Dearman et al., 2024).

4.8 Limitations of the study

Despite the contributions of this thesis to knowledge, several limitations warrant attention. First, the retrospective cross-sectional study design may introduce the potential for recall bias. This could be attributed to cognitive dissonance, as older adults self-reported their past exposure to extreme heat, and their current circumstances may influence their recollections, resulting in either underreporting or overreporting of past exposure experiences. Furthermore, the retrospective cross-sectional design restricts the determination of causality; while associations have been identified, it cannot be ascertained whether certain factors directly resulted in disparities in heat stress experiences. Consequently, future longitudinal studies are imperative to understand how these variables evolve. Secondly, the study is susceptible to sampling bias in the selection of older adults, which could lead to an overrepresentation of particular socio-demographic groups. To optimize the response rate, all older adults who responded to the phone call, satisfied the inclusion criteria, and consented to the interview were included in the study. It is conceivable that due to self-selection, the phone interview might have disproportionately reached certain socio-demographic groups, resulting in oversampling. Additionally, the qualitative component of the study was derived from a pre-programmed quantitative survey, thereby deviating from the conventional sampling protocols utilized in qualitative research. Qualitative studies typically employ non-probability sampling methods to recruit participants possessing extensive knowledge, a comprehensive understanding, and the ability to provide valuable insights to enhance the study (Denscombe, 2010). However, the trustworthiness of the study's findings can be evaluated based on the credibility, dependability, confirmability, and transferability of this approach, as detailed in Chapter Two (Lincoln & Guba, 1985).

4.9 Directions for future research

This research has made significant contributions to knowledge but has also revealed the need for further research on ageing and heat health in Sunbelt cities. First, although the study adopted a

mixed method to examine heat stress and coping strategies among older adults, the survey instrument did not give room to explore in-depth into older experiences of heat stress and coping strategies. The inherent limitation of this qualitative approach warrants that future research should employ conventional qualitative instruments such as interview guides, focus group discussions, or sharing circles to understand the nuanced heat-related experiences of older adults. Such an approach will provide an in-depth and comprehensive understanding of the lived experiences of older adults. Secondly, given the limitations of the study, future research should employ a prospective cohort study design to overcome major challenges such as recall bias, inability to establish causality, and minimize the potential of confounders. A prospective study will offer insights into older adults at risk of heat stress at the baseline and with a follow-up to examine if the risk has increased or decreased. The advantage of such a methodological approach is to have greater control of standard procedures that produce robust data, reduce or minimize the influence of confounding factors and minimize recall bias by not relying on study participants recalling past experiences. Finally, it will be beneficial for additional research to focus on the effectiveness of heat warnings in mitigating the heat stress vulnerabilities among older adults. Understanding how heat warnings influence adaptive behavioural adjustments among older adults, thereby reducing their vulnerabilities.

REFERENCES

Agyemang-Duah, W., Asante, D., Oduro Appiah, J., Morgan, A. K., Mensah, I. V., Peprah, P., &Mensah, A. A. (2023). System, institutional, and client-level factors associated with formal healthcare utilization among older adults with low income under a social protection scheme in Ghana.

Akaike, H. (1998). Information theory and an extension of the maximum likelihood principle. In *Selected Papers of Hirotugu Akaike* (pp. 199-213). New York, NY: Springer New York.

Allan, R. P., Arias, P. A., Berger, S., Canadell, J. G., Cassou, C., Chen, D., ... & Zickfeld, K. (2023). Intergovernmental panel on climate change (IPCC). Summary for policymakers. In *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 3-32). Cambridge University Press.

Allen, L., Lindberg, F., & Grimmond, C. S. B. (2011). Global to city-scale urban anthropogenic heat flux: model and variability. *International Journal of Climatology*, *31*(13), 1990.

American Warming: The Fastest-Warming Cities and States in the U.S. (2019). https://www. Climate central.org/news/report-American-warming-us-heats-up-earth-day

Anderson, B. G., & Bell, M. L. (2009). Weather-related mortality: how heat, cold, and heat waves affect mortality in the United States. *Epidemiology*, *20*(2), 205-213.

Anderson, G. B., Dominici, F., Wang, Y., McCormack, M. C., Bell, M. L., & Peng, R. D. (2013). Heat-related emergency hospitalizations for respiratory diseases in the Medicare population. *American journal of respiratory and critical care medicine*, *187*(10), 1098-1103.

Andrews, G. J., & Phillips, D. R. (Eds.). (2004). *Ageing and place* (Vol. 9). London: Routledge.

Andrews, G. J., Cutchin, M., McCracken, K., Phillips, D. R., & Wiles, J. (2007). Geographical gerontology: The constitution of a discipline. *Social Science & Medicine*, *65*(1), 151-168.

Andrews, G. J., Evans, J., & Wiles, J. L. (2013). Re-spacing and re-placing gerontology: Relationality and affect. *Ageing & Society*, *33*(8), 1339-1373.

Asgarian, F., Hejazi, S. R., & Khosroshahi, H. (2023). Investigating the impact of government policies to develop sustainable transportation and promote electric cars, considering fossil fuel subsidies elimination: A case of Norway. *Applied Energy*, *347*, 121434.

Baada, J. N. (2022). Being Pushed And Pulled: Understanding How Climate Change And Multilateral Investment Interact To Influence Rural-to-rural Migration In Sub-Saharan Africa.

Baker, L., & Sturm, R. (2024). Mortality in extreme heat events: an analysis of Los Angeles County Medical Examiner data. *Public Health*, *236*, 290-296.

Bakhsh, K., Rauf, S., & Zulfiqar, F. (2018). *Adaptation strategies for minimizing heat wave-induced morbidity and its determinants. Sustain. Cities Soc. 41, 95–103.*

Balmain, B. N., Sabapathy, S., Louis, M., & Morris, N. R. (2018). Aging and thermoregulatory control: the clinical implications of exercising under heat stress in older individuals. *BioMed research international*, *2018*(1), 8306154.

Bana, S., Yakoob, J., Jivany, N., Faisal, A., Jawed, H., & Awan, S. (2016). Understanding health-seeking behaviour of health care professionals in tertiary care hospitals in Pakistan. *Journal of Ayub Medical College Abbottabad*, *28*(3), 545-549.

Baniassadi, A., Lipsitz, L. A., Sailor, D., Pascual-Leone, A., & Manor, B. (2023). Heat waves, climate change, and implications for an aging population. *The Journals of Gerontology: Series A*, *78*(12), 2304-2306.

Baniassadi, A., Sailor, D. J., O'lenick, C. R., Wilhelmi, O. V., Crank, P. J., Chester, M. V., & Reddy, A. T. (2020). effectiveness of mechanical air conditioning as a protective factor against indoor exposure to heat among the elderly. *journal of engineering for sustainable buildings and cities*, *1*(1), 011005.

Baxter, J., & Eyles, J. (1997). Evaluating qualitative research in social geography: Establishing "rigour" in interview analysis. *Transactions of the Institute of British Geographers*, *22*(4), 505–525. https://doi.org/10.1111/j.0020-2754.1997.00505.

Bell, J. E., Brown, C. L., Conlon, K., Herring, S., Kunkel, K. E., Lawrimore, J., ... & Uejio, C. (2018). Changes in extreme events and the potential impacts on human health. *Journal of the Air & Waste Management Association*, *68*(4), 265-287.

Bell, R., Miranda, J. J., Woo, J., & Marmot, M. (2023). Social determinants of health and NCDs. In *Noncommunicable Diseases* (pp. 127-133). Routledge.

Bernhardt, J. M., & Amiri, A. (2024). Application of the socioecological model to mitigate risks of heat illness. *Nursing Outlook*, *72*(3), 102150.

Bobb, J. F., Obermeyer, Z., Wang, Y., & Dominici, F. (2014). Cause-specific risk of hospital admission related to extreme heat in older adults. *Jama*, *312*(24), 2659-2667

Bouchama, A., Dehbi, M., Mohamed, G., Matthies, F., Shoukri, M., & Menne, B. (2007). Prognostic factors in heat wave–related deaths: a meta-analysis. *Archives of internal medicine*, *167*(20), 2170-2176.

Braimah, J. A., & Rosenberg, M. W. (2022). An ecological systems analysis of food access barriers and coping strategies adopted by older adults in Ghana. *The Canadian Geographer/Le Geographer Canadian*, 66(1), 107-118.

Braun, V., & Clarke, V. (2024). Thematic analysis. In *Encyclopedia of quality of life and well-being research* (pp. 7187-7193). Cham: Springer International Publishing.

Brimicombe, C., Runkle, J. D., Tuholske, C., Domeisen, D. I., Gao, C., Toftum, J., & Otto, I. M. (2024). Preventing heat-related deaths: The urgent need for a global early warning system for heat. *PLOS Climate*, *3*(7), e0000437.

Bronfenbrenner, U. (1979). *The ecology of human development: Experiments by nature and design*: Harvard university press.

Bronfenbrenner, U. (1986). Ecology of the family as a context for human development: Research perspectives. *Developmental Psychology*, *6*(22), 723–742. https:// doi.org/https:/ /doi.org/10.1037/0012-1649.22.6.723

Bronfenbrenner, U. (1994). Ecological models of human development. *International encyclopedia of education*, *3*(2), 37-43.

Bryman, A. (2016). *Social research methods*. Oxford University Press.

Bunker, A., Wildenhain, J., Vandenbergh, A., Henschke, N., Rocklöv, J., Hajat, S., & Sauerborn, R. (2016). Effects of air temperature on climate-sensitive mortality and morbidity outcomes in the elderly: a systematic review and meta-analysis of epidemiological evidence. *EBioMedicine*, *6*, 258-268.

Cadman, L. (2009). Nonrepresentational theory/nonrepresentational geographies.

Carr, D., Wing, I. S., Falchetta, G., & De Cian, E. (2024). Population Aging and Heat Exposure in the 21st Century: Which World Regions Are at Greatest Risk?. *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences*, *79*(4), glae053.

Chambers, J. (2020). Global and cross-country analysis of exposure of vulnerable populations to heatwaves from 1980 to 2018. *Climatic Change*, *163*(1), 539-558.

Chapman, S., Watson, J. E., Salazar, A., Thatcher, M., & McAlpine, C. A. (2017). The impact of urbanization and climate change on urban temperatures: a systematic review. *Landscape Ecology*, *32*, 1921-1935.

Clark, S. S., Chester, M. V., Seager, T. P., & Eisenberg, D. A. (2019). The vulnerability of interdependent urban infrastructure systems to climate change: could Phoenix experience a Katrina of extreme heat? *Sustainable and Resilient Infrastructure*, *4*(1), 21-35.

Cleland, S., Steinhardt, W., Neas, L., West, J., & Rappold, A. (2023). Urban Heat Island Impacts on Heat-Related Cardiovascular Morbidity: A Time Series Analysis of Older Adults in US Metropolitan Areas. *Environment International. Elsevier BV, Amsterdam, Netherlands*, *178*(108005), 1.

Coenen, J., Glass, L. M., & Sanderink, L. (2022). Two degrees and the SDGs: a network analysis of the interlinkages between transnational climate actions and the Sustainable Development Goals. *Sustainability Science*, *17*(4), 1489-1510.

Conlon, K., Monaghan, A., Hayden, M., & Wilhelmi, O. (2016). Potential impacts of future warming and land use changes on intra-urban heat exposure in Houston, Texas. *PloS one*, *11*(2), e0148890.

Couper, P. (2014). A student's introduction to geographical thought: theories, philosophies, methodologies.

Crank, P. J., O'Lenick, C. R., Baniassadi, A., Sailor, D. J., Wilhelmi, O., & Hayden, M. (2024). Sociodemographic Determinants of Extreme Heat and Ozone Risk Among Older Adults in 3 Sun Belt Cities. *The Journals of Gerontology: Series A*, *79*(8).

Creswell, J. W. (2014). A concise introduction to mixed methods research, Sage Publications.

Creswell, J. W., & Creswell, J. D. (2017). *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage Publications.

Creswell, J. W., Shope, R., Plano Clark, V. L., & Green, D. O. (2006). How interpretive qualitative research extends mixed methods research. *Research in the Schools*, *13*(1), 1-11.

Crooks, V. A., Andrews, G. J., Pearce, J., & Snyder, M. (2018). Introducing the Routledge handbook of health geography. In *Routledge Handbook of Health Geography* (pp. 1-8). Routledge

Curtis, S. E., & Oven, K. J. (2012). Geographies of health and climate change. *Progress in Human Geography*, *36*(5), 654-666.

Curtis, S., Fair, A., Wistow, J., Val, D. V., & Oven, K. (2017). Impact of extreme weather events and climate change for health and social care systems. *Environmental Health*, *16*, 23-32.

Cutchin, M. P. (2009). Geographical gerontology: New contributions and spaces for development.

Dahl, K., Licker, R., Abatzoglou, J. T., & Declet-Barreto, J. (2019). Increased frequency of and population exposure to extreme heat index days in the United States during the 21st century. *Environmental Research Communications*, *1*(7), 075002.

Dalton, M. M., & Fleishman, E. (2021). Fifth Oregon climate assessment.

Dassah, C. (2025). Towards global health equity: the contributions of health geography to global health, policy and practice. Environment and Planning F, DOI: 10.1177/26349825251350711

Davies, A., & James, A. (2016). *Geographies of ageing: Social processes and the spatial unevenness of population ageing*. Routledge.

Day, J. W., Hall, C., Day, J. W., & Hall, C. (2016). Global climate change: a warmer and more unpredictable future. *America's Most Sustainable Cities and Regions: Surviving the 21st Century Megatrends*, 137-166.

Dearman, C., Adams, N., Sousa, A., Pearce-Smith, N., & Petrokofsky, C. (2024). Public health effectiveness of cooling centres in adverse hot weather events: a systematic review. *European Journal of Public Health*, *34*(Supplement_3), ckae144-1367.

Denscombe, M. (2017). *EBOOK: The good research guide: For small-scale social research projects*. McGraw-Hill Education (UK).

Dorn, M., & Laws, G. (1994). Social theory, body politics, and medical geography: extending Kearns's invitation. *The Professional Geographer*, *46*(1), 106-110.

Dwyer, S. C., & Buckle, J. L. (2009). The space between: On being an insider-outsider in qualitative research. *International journal of qualitative methods*, *8*(1), 54-63.

Elliott, S. J. (1999). And the question shall determine the method. *The Professional Geographer*, *51*(2), 240-243.

Elliott, S. J. (2018). Fifty years of medical health geography (ies) of health and wellbeing. Social Science & Medicine, 196(C), 206-208.

Epp, J. 1986. Achieving Health for All: A Framework for Health Promotion (Ottawa: Health and Welfare Canada).

Executive Order (2025). "Putting America First in International Environmental Agreements." The official designation for this agreement is the "Paris Agreement" (PA). 90 *Federal Register* 8455, https://www.federalregister.gov/documents/2025/01/30/2025-02010/putting, america-first-in-international-environmental-agreements

Eyles, J., & Litva, A. (1996). Theory: calming, you can only get there from here. Health & Place, 2(1), 41-43.

Falchetta, G., Cian, E. D., Pavanello, F., & Wing, I. S. (2024). Inequalities in global residential cooling energy use to 2050. *Nature communications*, *15*(1), 7874.

Filiberto, D., Wethington, E., Pillemer, K., Wells, N., Wysocki, M., & Parise, J. T. (2009). Older people and climate change: Vulnerability and health effects. *Generations*, *33*(4), 19-25

Fouillet, A., Rey, G., Laurent, F., Pavillon, G., Bellec, S., Guihenneuc-Jouyaux, C., ... & Hémon, D. (2006). Excess mortality related to the August 2003 heat wave in France. *International archives of occupational and environmental health*, *80*, 16-24.

Gagge, A. P., & Gonzalez, R. R. (2010). Mechanisms of heat exchange: biophysics and physiology. *Comprehensive physiology*, 45-84.

Gamble, J. L., Hurley, B. J., Schultz, P. A., Jaglom, W. S., Krishnan, N., & Harris, M. (2013). Climate change and older Americans: state of the science. *Environmental health perspectives*, *121*(1), 15-22.

Gatrell, A. C. & Elliott, S. J. (2015). Explaining Geographies of Health. *Geographies of health: An introduction. Third ed. Sussex, UK: John Wiley & Sons*, 25-49.

Gatrell, A. C. & Elliott, S. J. (2015). Explaining Geographies of Health. *Geographies of health: An introduction. Third ed. Sussex, UK: John Wiley & Sons*, 25-49.

Gronlund, C. J., Berrocal, V. J., White-Newsome, J. L., Conlon, K. C., & O'Neill, M. S. (2015). Vulnerability to extreme heat by socio-demographic characteristics and area green space among the elderly in Michigan, 1990–2007.

Gronlund, C. J., Zanobetti, A., Schwartz, J. D., Wellenius, G. A., & O'Neill, M. S. (2014). Heat, heat waves, and hospital admissions among the elderly in the United States, 1992–2006. *Environmental health perspectives*, *122*(11), 1187-1192.

Gyasi, R. M. Ageing, health and health-seeking behaviour in Ghana.

Hale, T. (2024). Long problems: Climate change and the challenge of governing across time.

Haque, M. A., Budi, A., Azam Malik, A., Suzanne Yamamoto, S., Louis, V. R., & Sauerborn, R. (2013). Health coping strategies of the people vulnerable to climate change in a resource-poor rural setting in Bangladesh. *BMC Public Health*, *13*, 1-11.

Hayden, M. H., Brenkert-Smith, H., & Wilhelmi, O. V. (2011). Differential adaptive capacity to extreme heat: a Phoenix, Arizona, case study. *Weather, Climate, and Society*, *3*(4), 269-280.

Hayden, M. H., Wilhelmi, O. V., Banerjee, D., Greasby, T., Cavanaugh, J. L., Nepal, V., ... & Gower, S. (2017). Adaptive capacity to extreme heat: results from a household survey in Houston, Texas. *Weather, climate, and society*, *9*(4), 787-799.

Hemed, M. (2017). *Cross-sectional studies. Training course in sexual and reproductive health research, Geneva*.

Holman, I. P., Brown, C., Carter, T. R., Harrison, P. A., & Rounsevell, M. (2019). Improving the representation of adaptation in climate change impact models. *Regional Environmental Change*, *19*, 711-721.

Hondula, D. M., Balling, R. C., Vanos, J. K., & Georgescu, M. (2015). Rising temperatures, human health, and the role of adaptation. *Current Climate Change Reports*, *1*, 144-154.

IPCC. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2021. doi:10.1017/9781009157896

Iyoho, A. E., Ng, L. J., & MacFadden, L. (2017). Modelling of gender differences in thermoregulation. *Military medicine*, *182*(suppl_1), 295-303.

James, I., Blomberg, K., & Kihlgren, A. (2014). A meaningful daily life in nursing homes place of shelter and a space of freedom: a participatory appreciative action reflection study. *BMC Nursing*, *13*, 1-13.

James, I., Blomberg, K., & Kihlgren, A. (2014). A meaningful daily life in nursing homes-a place of shelter and a space of freedom: a participatory appreciative action reflection study. *BMC nursing*, *13*, 1-13.

Jones, R. (2009). Categories, borders and boundaries. *Progress in Human Geography*, *33*(2), 174-189.

Kalipeni, E., & Feder, D. (1999). A political ecology perspective on environmental change in Malawi with the Blantyre Fuelwood Project Area as a case study. *Politics and the Life Sciences*, *18*(1),

Kalkstein, A. J., & Sheridan, S. C. (2007). The social impacts of the heat–health watch/warning system in Phoenix, Arizona: assessing the perceived risk and response of the public. *International journal of biometeorology*, *52*, 43-55.

Kang, Y., Park, J., & Jang, D. H. (2024). Compound impact of heatwaves on vulnerable groups considering age, income, and disability. *Scientific Reports*, *14*(1), 24732.

Karpinska, L., & Śmiech, S. (2020). Invisible energy poverty? Analyzing housing costs in Central and Eastern Europe. *Energy Research & Social Science*, *70*, 101670

Kearns, R. (1994). To reform is not to discard: a reply to Paul. *Professional Geographer,* 46(4): 505-507.

Kearns, R. A. (1993). Place and health: towards a reformed medical geography. *The Professional Geographer*, *45*(2), 139-147.

Kearns, R., & Moon, G. (2002). From medical to health geography: novelty, place and theory after a decade of change. Progress in Human Geography, 26(5), 605–625

Kenney, W. L., & Munce, T. A. (2003). Invited review: aging and human temperature regulation. *Journal of applied physiology*, *95*(6), 2598-2603.

Kenny, G. P., Yardley, J., Brown, C., Sigal, R. J., & Jay, O. (2010). Heat stress in older individuals and patients with common chronic diseases. *Cmaj*, *182*(10), 1053-1060.

Khan, A. M., Finlay, J. M., Clarke, P., Sol, K., Melendez, R., Judd, S., & Gronlund, C. J. (2021). Association between temperature exposure and cognition: a cross-sectional analysis of 20,687 aging adults in the United States. *BMC Public Health*, *21*, 1-12

Khan, A. M., Finlay, J. M., Clarke, P., Sol, K., Melendez, R., Judd, S., & Gronlund, C. J. (2021). Association between temperature exposure and cognition: a cross-sectional analysis of 20,687 aging adults in the United States. *BMC public health*, *21*, 1-12

Khatana, S. A. M., Werner, R. M., & Groeneveld, P. W. (2022). Association of extreme heat with all-cause mortality in the contiguous US, 2008-2017. *JAMA Network Open*, *5*(5), e2212957-e2212957.

Kiarsi, M., Amiresmaili, M., Mahmoodi, M. R., Farahmandnia, H., Nakhaee, N., Zareiyan, A., & Aghababaeian, H. (2023). Heat waves and adaptation: a global systematic review. *Journal of thermal biology*, *116*, 103588.

Kilanowski, J. F. (2017). Breadth of the socio-ecological model. *Journal of agromedicine*, *22*(4), 295-297.

Kim, S., Sun, F., & Irazábal, C. (2021). Planning for climate change: implications of high temperatures and extreme heat for Los Angeles County (CA). *Journal of the American Planning Association*, *87*(1), 34-44.

Kim, Y., & Joh, S. (2006). A vulnerability study of the low-income elderly in the context of high temperature and mortality in Seoul, Korea. *Science of the total environment*, *371*(1-3), 82-88.

King, B. (2010). Political ecologies of health. *Progress in Human Geography*, *34*(1), 38-55.

Klepeis, N.E., Nelson, W.C., Ott, W.R., Robinson, J.P., Tsang, A.M., Switzer, P., Behar, J.V., Hern, S.C., Engelmann, W.H., 2001. The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. Journal of Exposure Analysis and Environmental Epidemiology 11, 231–252.

Kreslake, J. M., Price, K. M., & Sarfaty, M. (2016). Developing effective communication materials on the health effects of climate change for vulnerable groups: a mixed methods study. *BMC Public Health*, *16*, 1-15

Krieger, B. N. (2012). Epidemiology and the People's Health. *Am. J. Epidemiol*, *175*(8), 854-856.

Larsen, L., Gronlund, C. J., Ketenci, K. C., Harlan, S. L., Hondula, D. M., Stone Jr, B., ... & O'Neill, M. S. (2023). Safe at home? A comparison of factors influencing indoor residential temperatures during warm weather among three cities. *Journal of the American Planning Association*, *89*(3), 363-375.

Lavados, P. M., Olavarría, V. V., & Hoffmeister, L. (2018). Ambient temperature and stroke risk: evidence supporting a short-term effect at a population level from acute environmental exposures. *Stroke*, *49*(1), 255-261

Leach, M., Stirling, A. C., & Scoones, I. (2010). *Dynamic sustainability: technology, environment, social justice* (p. 232). Taylor & Francis.

Lin, S., Luo, M., Walker, R. J., Liu, X., Hwang, S. A., & Chinery, R. (2009). Extreme high temperatures and hospital admissions for respiratory and cardiovascular diseases. *Epidemiology*, *20*(5), 738-746.

Lincoln, Y. S. & Guba, E. G. (1985). Naturalistic inquiry. New York: Sage

Luginaah, I. (2009). Health geography in Canada: where are we headed? *The Canadian Geographer/Le Géographe canadien*, *53*(1), 91-99.

Maantay, J. A., & McLafferty, S. (Eds.). (2011). *Geospatial analysis of environmental health* (Vol. 4). Springer Science & Business Media.

Mackenzie, N., & Knipe, S. (2006). Research dilemmas: Paradigms, methods and methodology. *Issues in educational research*, *16*(2), 193-205.

Malmquist, A., Hjerpe, M., Glaas, E., Karlsson-Larsson, H., & Lassi, T. (2022). Elderly people's perceptions of heat stress and adaptation to heat: an interview study. *International Journal of Environmental Research and Public Health*, *19*(7), 3775.

Marquart, F. (2017). Methodological rigor in quantitative research. *The international encyclopedia of communication research methods*, 1-9.

Martin, G. (2024). Climate change and mental health and wellbeing: Reflections from a health geography lens. *Geography Compass*, *18*(1), e12734.

Martín, Y., & Paneque, P. (2022). Moving from adaptation capacities to implementing adaptation to extreme heat events in urban areas of the European Union: Introducing the U-ADAPT! research approach. *Journal of Environmental Management*, *310*, 114773.

Mason, H. M., King, J. C., Peden, A. E., Watt, K., Bosley, E., Fitzgerald, G., ... & Franklin, R. C. (2023). Determining the impact of heat waves on emergency ambulance calls in Queensland: a retrospective population-based study. *International journal of environmental research and public health*, *20*(6), 4875.

McClean, S., Bray, I., Pilkington, P., Bird, E., & de Viggiani, N. (2019). Research methods for public health.

McGregor, G. R., & Vanos, J. K. (2018). Heat: a primer for public health researchers. *Public Health*, *161*, 138-146.

McKenna, Z. J., Foster, J., Atkins, W. C., Belval, L. N., Watso, J. C., Jarrard, C. P., ... & Crandall, C. G. (2023). Age alters the thermoregulatory responses to extreme heat exposure with accompanying activities of daily living. *Journal of Applied Physiology*, *135*(2), 445-455.

Meade, R. D., Akerman, A. P., Notley, S. R., McGinn, R., Poirier, P., Gosselin, P., & Kenny, G. P. (2020). Physiological factors characterizing heat-vulnerable older adults: a narrative review. *Environment International*, *144*, 105909. 21st century. *Science*, *305*(5686), 994-997.

Meade, R. D., Akerman, A. P., Notley, S. R., McGinn, R., Poirier, P., Gosselin, P., & Kenny, G. P. (2020). Physiological factors characterizing heat-vulnerable older adults: a narrative review. *Environment International*, *144*, 105909. 21st century. *Science*, *305*(5686), 994-997

Meghani, N. A. A., Hudson, J., Stratton, G., & Mullins, J. (2023). Older adults' perspectives on physical activity and sedentary behaviour within their home using socio-ecological model. *Plos one*, *18*(11), e0294715.

Milan, B. F., & Creutzig, F. (2015). Reducing urban heat wave risk in the 21st century. *Current Opinion in Environmental Sustainability*, *14*, 221-231.

Milligan, C. (2016). There's no place like home: Place and care in an ageing society. Routledge.

Mitchell, B. C., & Chakraborty, J. (2015). Landscapes of thermal inequity: disproportionate exposure to urban heat in the three largest US cities. *Environmental Research Letters*, *10*(11), 115005.

Morgan, D. L. (1998). Practical strategies for combining qualitative and quantitative methods: Applications to health research. *Qualitative health research*, *8*(3), 362-376.

Moss, T. E. (2021). *Reducing Heat Exposure in Phoenix: A Proposal for School-Based Cooling Centers* (Doctoral dissertation, Brandeis University).

Mukhopadhyay, B., & Weitz, C. A. (2022). Heat exposure, heat-related symptoms and coping strategies among elderly residents of urban slums and rural villages in West Bengal, India. *International Journal of Environmental Research and Public Health*, *19*(19), 12446.

Mulligan, K., Bhatti, S., Rayner, J., & Hsiung, S. (2020). Social prescribing: creating pathways towards better health and wellness. *Journal of the American Geriatrics Society*, *68*(2), 426-428.

Mulligan, K., Hsiung, S., Bloch, G., Park, G., Richter, A., Stebbins, L., & Talat, S. (2023). Social Prescribing in Canada: A Tool for Integrating Health and Social Care for Underserved Communities. *Healthcare Quarterly (Toronto, Ont.)*, *25*(4), 17-22.

Muttarak, R. (2021). Demographic perspectives in research on global environmental change. *Population Studies*, *75*(sup1), 77-104

National Weather Service (2018). Historical Heat risk data for 2017. https://www.wpc.ncep.noaa.gov/heatrisk/historical/

National Weather Service (2025). Historical Heat Risk Data. https://www.weather.gov/psr/heat

Nick, T. G., & Campbell, K. M. (2007). Logistic regression. *Topics in biostatistics*, 273-301

Niedzwiedz, C., Olsen, J., Habte, T. A., Hill-Harding, C., Shaw, R., Thomas, R., ... & Papies, E. K. Coming to terms with climate change: a glossary for climate change impacts on mental health and wellbeing.

NOAA National Centers for Environmental Information, Monthly Global Climate Report for Annual 2010, published online January 2011, retrieved on July 4, 2025 from https://www.ncei.noaa.gov/access/monitoring/monthlyreport/global/201013.doi**:** https://www.ncei.noaa.gov/access/metadata/landing-page/bin/iso?id=gov.noaa.ncdc:C00672

Nunbogu, A. M., & Elliott, S. J. (2021). Towards an integrated theoretical framework for understanding water insecurity and gender-based violence in Low-and middle-income countries (LMICs). *Health & place*, *71*, 102651.

O'cathain, A., Murphy, E., & Nicholl, J. (2008). The quality of mixed methods studies in health services research. *Journal of health services research & policy*, *13*(2), 92-98.

O'lenick, C. R., Baniassadi, A., Michael, R., Monaghan, A., Boehnert, J., Yu, X., ... & Wilhelmi, O. V. (2020). A case-crossover analysis of indoor heat exposure on mortality and hospitalizations among the elderly in Houston, Texas. *Environmental health perspectives*, *128*(12), 12700

O'Lenick, C. R., Cleland, S. E., Neas, L. M., Turner, M. W., Mcinroe, E. M., Hill, K. L., ... & Rappold, A. G. (2024). Impact of Heat on Respiratory Hospitalizations among Older Adults in 120 Large US Urban Areas. *Annals of the American Thoracic Society*, (ja).

Oberai, M., Baker, S., Bach, A. J., Forbes, C., Jackman, E., Binnewies, S., ... & Rutherford, S. (2024). Towards Improvement of Heatwave Warnings for Older Adults: The Case of Queensland Australia. *Journal of Primary Care & Community Health*, *15*, 21501319241286584.

Oke, T.R., Mills, G., Christen, A., Voogt, J.A., 2017. Urban climates, Urban Climates. Cambridge University Press. https://doi.org/10.1017/9781139016476

Orlando, S., Mosconi, C., De Santo, C., Emberti Gialloreti, L., Inzerilli, M. C., Madaro, O., ... & Liotta, G. (2021). The effectiveness of intervening on social isolation to reduce mortality during heat waves in aged population: a retrospective ecological study. *International Journal of Environmental Research and Public Health*, *18*(21), 11587.

Pain, R. (2001). Gender, race, age and fear in the city. *Urban studies*, *38*(5-6), 899-913.

Painter, J. E., Borba, C. P., Hynes, M., Mays, D., & Glanz, K. (2008). The use of theory in health behavior research from 2000 to 2005: a systematic review. *Annals of behavioral medicine*, *35*(3), 358-

Park, Y. S., Konge, L., & Artino Jr, A. R. (2020). The positivism paradigm of research. *Academic medicine*, *95*(5), 690-694.

Pearce, J., Kingham, S., & Zawar-Reza, P. (2006). Every breath you take. Environmental justice and air pollution in Christchurch, New Zealand. *Environment and Planning A*, *38*(5), 919-938.

Powell, E. J., & Keim, B. D. (2015). Trends in daily temperature and precipitation extremes for the southeastern United States: 1948–2012. *Journal of Climate*, *28*(4), 1592-1612.

Power, E. R., & Mee, K. J. (2020). Housing: an infrastructure of care. *Housing studies*, *35*(3), 484-505.

Pray, L., Miller, E. A., Boon, C., & Pillsbury, L. (Eds.). (2010). *Providing healthy and safe foods as we age: Workshop summary*. National Academies Press.

Ramlagan, S., Peltzer, K., & Phaswana-Mafuya, N. (2013). Social capital and health among older adults in South Africa. *BMC geriatrics*, *13*, 1-11.å

Regnault, A., Willgoss, T., Barbic, S., & International Society for Quality-of-Life Research(ISOQOL) Mixed Methods Special Interest Group (SIG). (2018). Towards the use of mixed methods inquiry as best practice in health outcomes research. *Journal of patient-reported outcomes*, *2*(1), 19.

Relph, E. (1976). *Place and placelessness* (Vol. 67, p. 45). London: Pion.

Reupert, A. (2017). A socio-ecological framework for mental health and well-being. *Advances in Mental Health*, *15*(2), 105-107.

Richmond, C., Elliott, S. J., Matthews, R., & Elliott, B. (2005). The political ecology of health: perceptions of environment, economy, health and well-being among 'Namgis First Nation. *Health & place*, *11*(4), 349-365

Rishworth, A., & Elliott, S. J. (2019). Global environmental change in an aging world: The role of space, place and scale. *Social Science & Medicine*, *227*, 128-136.

Rohat, G., Wilhelmi, O., Flacke, J., Monaghan, A., Gao, J., van Maarseveen, M., & Dao, H. (2021). Assessing urban heat-related adaptation strategies under multiple futures for a major US city. *Climatic Change*, *164*, 1-20.

Ryan, G. (2018). Introduction to positivism, interpretivism and critical theory. *Nurse researcher*, *25*(4), 41-49.

Sailor, D. J., Hu, H., Wilhelmi, O., & Banerjee, D. (2015, July). Indoor-outdoor environmental coupling and exposure risk to extreme heat and poor air quality during heat waves. In *Proceedings of the 9th International Conference on Urban Climate jointly with 12th Symposium on the Urban Environment* (pp. 20-24)

Sailor, D. J., Hu, H., Wilhelmi, O., & Banerjee, D. (2015). Indoor-outdoor environmental coupling and exposure risk to extreme heat and poor air quality during heat waves.

Sampaio, D., King, R., & Walsh, K. (2018). *Geographies of the ageing-migration nexus: An introduction. Area, 50 (4), 440–443*.

Sampson, N. R., Gronlund, C. J., Buxton, M. A., Catalano, L., White-Newsome, J. L., Conlon, K. C., ... & Parker, E. A. (2013). Staying cool in a changing climate: Reaching vulnerable populations during heat events. *Global Environmental Change*, *23*(2), 475-484.

Santamouris, M., Cartalis, C., Synnefa, A., & Kolokotsa, D. (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings—A review. *Energy and Buildings*, *98*, 119-124.

Skinner, M. W., Cloutier, D., & Andrews, G. J. (2015). Geographies of ageing: Progress and possibilities after two decades of change. *Progress in Human Geography*, *39*(6), 776-799.

Spencer, R. W., Christy, J. R., & Braswell, W. D. (2025). Urban Heat Island Effects in US Summer Surface Temperature Data, 1895–2023. *Journal of Applied Meteorology and Climatology*.

Tesch, R. (1990). Qualitative research. Analysis types and software tools. New York: Falmer.

The Editors of Encyclopedia Britannica (2025, July 25). Sun Belt. Encyclopedia Britannica. https://www.britannica.com/place/Sun-Belt

Tollefson, J. (2021). IPCC climate report: Earth is warmer than it's been in 125,000 years. *Nature*, *596*(7871), 171-172.

Tompkins, E. L., & Eakin, H. (2012). Managing private and public adaptation to climate change. *Global environmental change*, *22*(1), 3-11.

Tuan, Y. F. (1977). *Space and place: The perspective of experience*. U of Minnesota Press.

Tuholske, C., Caylor, K., Funk, C., Verdin, A., Sweeney, S., Grace, K., ... & Evans, T. (2021). Global urban population exposure to extreme heat. *Proceedings of the National Academy of Sciences*, *118*(41), e2024792118.

Turner, L. R., Connell, D., & Tong, S. (2013). The effect of heat waves on ambulance attendances in Brisbane, Australia. *Prehospital and disaster medicine*, *28*(5), 482-487.

Tyler, C. J., Reeve, T., Hodges, G. J., & Cheung, S. S. (2016). The effects of heat adaptation on physiology, perception and exercise performance in the heat: a meta-analysis. *Sports medicine*, *46*, 1699-1724.

U.S. Census Bureau. (2020). https://www.census.gov/quickfacts/fact/table/ Houston county, Texas, Phoenix city, Arizona, California/PST045224

U.S. Census Bureau. *2017–2021 American Community Survey 4-Year Population 65 Years and Over in the United States.* 2021. https://data.census.gov/table?q=S0103&tid=ACSST5Y2021. S0103

United Nations (2014) World urbanization prospects: the 2014 revision—highlights. United Nations, New York

United Nations (2019). Climate and SDG synergies knowledge platform. https://sustainable development. un. org/ climate- sdgs-synergies2019 home

Vaidyanathan, A. (2020). Heat-related deaths—United States, 2004–2018. *MMWR. Morbidity and mortality weekly report*, *69*.

Varpio, L., & MacLeod, A. (2020). Philosophy of Science series: harnessing the multidisciplinary edge effect by exploring paradigms, ontologies, epistemologies, axiologies, and methodologies. *Academic Medicine*, *95*(5), 686-689.

Vine, M. M., Mulligan, K., Harris, R., & Dean, J. L. (2023). The Impact of Health Geography on Public Health Research, Policy, and Practice in Canada. *International Journal of Environmental Research and Public Health*, *20*(18), 6735.

Vose, R. S., Easterling, D. R., Kunkel, K. E., LeGrande, A. N., & Wehner, M. F. (2017). Temperature changes in the United States. *Climate science special report: Fourth national climate assessment*, *1*(GSFC-E-DAA-TN49028).

Walter, M., Bagozzi, B. E., Ajibade, I., & Mondal, P. (2023). Social media analysis reveals environmental injustices in Philadelphia urban parks. *Scientific Reports*, *13*(1), 12571.

Wang, Q., Kwan, M. P., Fan, J., & Lin, J. (2021). Racial disparities in energy poverty in the United States. *Renewable and Sustainable Energy Reviews*, *137*, 110620.

White-Newsome, J. L., Sánchez, B. N., Parker, E. A., Dvonch, J. T., Zhang, Z., & O'Neill, M. S. (2011). Assessing heat-adaptive behaviors among older, urban-dwelling adults. *Maturitas*, *70*(1), 85-91.

Wiles, J. L., Leibing, A., Guberman, N., Reeve, J., & Allen, R. E. (2012). The meaning of "aging in place" to older people. *The gerontologist*, *52*(3), 357-366.

Wilhelmi, O. V., Howe, P. D., Hayden, M. H., & O'lenick, C. R. (2021). Compounding hazards and intersecting vulnerabilities: experiences and responses to extreme heat during COVID-19. *environmental research letters*, *16*(8), 084060.

intersecting vulnerabilities: experiences and responses to extreme heat during COVID-19. *Environmental Research Letters*, *16*(8), 084060.

Wilhelmi, O. V., Howe, P. D., Hayden, M. H., & O'Lenick, C. R. (2021). Compounding hazards and intersecting vulnerabilities: experiences and responses to extreme heat during COVID-19. *Environmental Research Letters*, *16*(8), 084060.

Wooten, M. E. (2024). Growing Sunbelt Cities Are the Future of Urban Life. They Need a Resilient Power Infrastructure.

World Health Organization. (2015). *World report on ageing and health*. World Health Organization.

World Health Organization. (2020). Decade of healthy ageing: Plan of action. Geneva, Switzerland: World Health Organization.

World Health Organization. (2021). *Decade of healthy ageing: baseline report*. World Health Organization.

Wyness, M. G. (2015). Conceptualizing agency. In M. G. Wyness (Ed.), Childhood (pp. 7-33). Polity Press.

Xie, D., Cai, S., & Gui, X. (2024). Reclaiming justice for energy-vulnerable populations: Evidence from the city of Los Angeles. *Energy Strategy Reviews*, *51*, 101317.

Xu DongJuan, X. D., & Drew, J. A. R. (2016). Cause, nature and care-seeking behaviour for injuries among community-dwelling older adults, USA, 2004-2013.

Yao, X., Jin, S., Zhao, Z., Sun, R., Wang, C., & Yu, Z. (2024). A novel integrated socio-ecological-economic index for assessing heat health risk. *Ecological Indicators*, *169*, 112840.

Yin, Y., He, L., Wennberg, P. O., & Frankenberg, C. (2023). Unequal exposure to heatwaves in Los Angeles: Impact of uneven green spaces. *Science Advances*, *9*(17), eade8501

Yin, Z., Liu, Z., Liu, X., Zheng, W., & Yin, L. (2023). Urban heat islands and their effects on thermal comfort in the US: New York and New Jersey. *Ecological Indicators*, *154*, 110765

Zhou, H., Geng, H., Dong, C., & Bai, T. (2021). The short-term harvesting effects of ambient particulate matter on mortality in Taiyuan elderly residents: A time-series analysis with a generalized additive distributed lag model. *Ecotoxicology and Environmental Safety*, *207*, 111235

APPENDIX A: SURVEY INSTRUMENT

Title: Socio-demographic determinants of extreme heat and ozone risk among older adults in three Sunbelt cities

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Supplementary File: Survey Questionnaire

Survey Instrument

1. Do you live in a:
    1) Detached single-family house
    2) Townhouse
    3) Duplex
    4) Triplex or fourplex
    5) Apartment (with 5 or more units)
    6) Condominium
    7) Mobile or manufactured home
    8) Other (Please specify)
    9) Don't know
    10) Refused
2. Do you have a basement?
    1) Yes
    2) No
    8) Don't know
    9) Refused
3. What is the physical size of your entire residence <including the basement>? Your best guess is fine.
    1) Less than 1000 square feet
    2) 1000 to 2000 square feet
    3) 2001 to 3000 square feet
    4) More than 3000 square feet
    8) Don't know
    9) Refused
4. What is the physical size of your basement? Your best guess is fine.
    1) Less than 500 square feet
    2) 500 to 1000 square feet
    3) 1001 to 1500 square feet
    4) 1501 to 2000 square feet
    5) More than 2000 square feet
    8) Don't know
    9) Refused
5. What type of windows do you currently have in your home?
    1) Single-paned
    2) Double-paned
    3) Other (Please specify)
    8) Don't know
    9) Refused
6. What year was your home built?
    1) Before 1976
    2) 1976 to 1990

3) 1991 to 2005
4) After 2005
8) Don't know
9) Refused

7. Has your home been weatherized to improve insulation or reduce air leakage?
   0) No
   1) Yes
   8) Don't know
   9) Refused
8. Which of the following weatherization options are in your home?
   0) Air vents
   1) Insulation in the roof or attic
   2) Insulation in walls
   3) Weather-stripping for windows or doors
   4) Anything else
   5) Waterproofing or weatherproofing paint
   6) Solar screens on windows
   7) Tinting on windows
   8) Don't know
   9) Refused
9. Do you have any solar panels (PV or thermal) on your roof?
   0) No
   1) Yes
   8) Don't know
   9) Refused
10. What percentage of your roof is covered by panels?
   1) 25% or less
   2) Between 26 and 50%
   3) Between 51 and 75%
   4) More than 75%
   8) Don't know
   9) Refused
11. Do you have a vegetated green roof?
   0) No
   1) Yes
   8) Don't know
   9) Refused
12. What percentage of your roof is covered by vegetation?
   1) 25% or less
   2) Between 26 and 50%
   3) Between 51 and 75%
   4) More than 75%
   8) Don't know

9) Refused

13. Would you characterize your (exposed) roof surface material as being:
    1) Dark or black in color
    2) Medium in color
    3) Light in color
    4) White or having a cool roof (or high albedo) coating
    7) Other
    8) Don't know
    9) Refused
14. To what extent is your home shaded from the sun? This includes shading from trees or other buildings.
    1) Not shaded at all
    2) Somewhat shaded
    3) Completely shaded
    8) Don't know
    9) Refused
15. Which of the following are you using to cool your home?
    01) Central air conditioner
    02) Window-mounted air conditioners
    03) Fans
    04) Awnings, shades, shutters, or blinds
    05) Anything else? (Please specify)
    55) Ductless air conditions (DHP, mini-splits, etc.)
    66) Evaporative swamp coolers
    77) None of the above
    88) Don't know
    99) Refused
16. How many working air conditioning units do you have?
    1) One
    2) Two
    3) Three
    4) Four
    5) Five
    6) Six or more (Please specify)
    8) Don't know
    9) Refused
17. What room do you have the air conditioner in?
    1) Living or family room
    2) Bedroom
    3) Kitchen
    4) Bathroom
    5) Office
    6) Anywhere else? (Please specify)

8) Don't know
9) Refused

18. Do you spend the majority of your time in <this room/these rooms>?
    0) No
    1) Yes
    8) Don't know
    9) Refused
19. At what temperature do you usually set the air conditioner(s)?
    1) Less than 70 degrees
    2) 70-80 degrees
    3) Greater than 80 degrees
    6) Don't have a thermostat/Can't set the temperature
    7) Other (please specify, e.g. low/medium/high or 1-10 settings)
    8) Don't know
    9) Refused
20. Does anything prevent you from using your air conditioner(s)?
    0) No
    1) Yes
    8) Don't know
    9) Refuse
21. What would that be?
    1) Cost of electricity
    2) Saving energy or being sustainable
    3) Air conditioner(s) not working
    4) Cost of repairs
    5) Anything else? (Please specify)
    8) Don't know
    9) Refused
22. This summer, did you open windows or doors in your home to increase ventilation or otherwise cool down your home?
    0) No
    1) Yes
    7) Sometimes
    8) Don't know
    9) Refused
23. Did you open them during the day, or night, or both?
    01) Day
    02) Night
    03) Both
    8) Don't know
    9) Refused
24. About how long did you usually keep your windows or doors open?
    1) Less than 1 hour

2) 1 to 2 hours
3) More than 2 hours
8) Don't know
9) Refused

25. This summer, did you ever feel too hot inside your home?
    0) No
    1) Yes
    8) Don't know
    9) Refused
26. When the weather is very hot, places like libraries and community centers allow residents to cool-off in their buildings. This summer, when you felt too hot in your home, did you go somewhere else to cool-off?
    0) No
    1) Yes
    8) Don't know
    9) Refused
27. Did any of the following reasons prevent you from going somewhere else to cool-off?
    1) A disability
    2) Lack of transportation
    3) Not sure where to go
    4) Anything else? (Please specify)
    7) Nothing
    8) Don't know
    9) Refused
28. On a TYPICAL day this summer, how much time did you spend outdoors?
    1) Less than 30 minutes
    2) From 30 minutes to 2 hours
    3) More than 2 hours
    4) Rarely or did not outdoors
    8) Don't know
    9) Refused
29. Other than the things we´ve already discussed, during hot weather, have you done any of the following to protect yourself from the heat?
    00) Took cool showers
    01) Reduced physical activity
    02) Stayed indoors during the hottest part of the day
    03) Drank plenty of water
    04) Stayed in the shade
    05) Used a swimming pool
    06) Wore a hat, light or loose-fitting clothing
    07) Anything else? (Please specify)
    55) Used sunscreen

66) Changed daily routine (outdoor activities before it gets too hot or after it cools off)
77) None of the above
88) Don't know
99) Refused

30. This summer, do you recall seeing or hearing warnings about excessive heat?
    0) No
    1) Yes
    8) Don't know
    9) Refused
31. Where did you see or hear these warnings?
    1) 311 City Info
    2) Family, friends, or neighbors, either in-person or on Facebook
    3) At community-based organizations
    4) Internet website
    5) Local TV news station
    6) Notices received on a mobile device, such as a smartphone
    7) Newspaper
    8) Radio
    9) The TV Weather Channel
    10) Caregiver or medical staff
    11) Road sign
    12) E-mail
    13) Magazine
    77) Other (please specify)
    88) Don't know
    99) Refused
32. This summer, did you have symptoms such as fainting, rapid heartbeat, confusion, dizziness or muscle cramps that you believe were heat-related?
    0) No
    1) Yes
    8) Don't know
    9) Refused
33. Did you seek medical attention for these symptoms?
    0) No
    1) Yes
    8) Don't know
    9) Refused
34. This summer, did you take any of the following actions to protect yourself from ozone or smog?
    0) Take allergy medication
    1) Reduced physical activity outdoors
    2) Stayed indoors during certain times of the day
    3) Kept windows or doors closed
    4) Carried an inhaler

5) Something else? (Please specify)
6) Checked vital signs (pulse or respiration rate, temperature, blood pressure)
7) Did nothing different
8) Don't know
9) Refused

35. This summer, do you recall seeing or hearing warnings about ozone action days?
    0) No
    1) Yes
    8) Don't know
    9) Refused
36. Where did you see or hear these warnings?
    1) 311 City Info
    2) Family, friends, or neighbors, either in-person or on Facebook
    3) At community-based organizations
    4) Internet website
    5) Local TV news station
    6) Notices received on a mobile device, such as a smartphone
    7) Newspaper
    8) Radio
    9) The TV Weather Channel
    10) Caregiver or medical staff
    11) Road sign
    12) E-mail
    13) Magazine
    77) Other (please specify)
    88) Don't know
    99) Refused
37. This summer, did you have symptoms such as coughing, throat irritation, chest tightness, or shortness of breath that you believe were related to air pollution?
    0) No
    1) Yes
    8) Don't know
    9) Refused
38. Did you seek medical attention for these symptoms?
    0) No
    1) Yes
    8) Don't know
    9) Refused
39. Could any of the following things prevent or delay you from seeking medical attention during a heat or air pollution-related illness.
    1) Not having health insurance
    2) The insurance deductible is too high
    3) Impaired physical mobility
    4) Limited access to transportation

5) Caring for someone else who cannot be left alone
6) Anything else? (Please specify)
77) No, nothing prevents me
88) Don't know
99) Refused

40. In general, is there a family member, friend, or neighbor you would feel comfortable asking for help?
    0) No
    1) Yes
    8) Don't know
    9) Refused
41. Were there any power outages at your home this summer?
    0) No
    1) Yes
    8) Don't know
    9) Refused
42. On average, for how long was the power out?
    1) A few minutes
    2) A few minutes to less than an hour
    3) About 1 to 2 hours
    4) Several hours
    5) All day
    6) Several days
    8) Don't know
    9) Refused
43. What did you do when the power went out?
    1) Reported outage to the local power company
    2) Turned on a generator
    3) Went to a different location with power
    4) Just waited for power to come back on
    5) Anything else? (Please specify)
    8) Don't know
    9) Refused
44. This summer, <other than during possible power outages,> did your air conditioner(s) stop working?
    0) No
    1) Yes
    8) Don't know
    9) Refused
45. On average, for how long did your air conditioner stop working?
    1) Less than a day
    2) 1 to 2 days
    3) 3 to 5 days
    4) About a week

5) 2 to 3 weeks
6) About a month or more
8) Don't know
9) Refused

46. What did you do?
1) Paid a professional to fix the air conditioner
2) Replaced the air conditioner immediately
3) Fixed the air conditioner myself (or someone I know fixed it)
4) Something else? (Please specify)0
8) Don't know
9) Refused

47. Just to verify, what is your gender?
0) Male
1) Female
2) Other (Please specify)
9) Refused

48. In what year were you born? [Record four-digit year between 1900-1952] 9999) Refused

49. What is your marital status?
1) Single
2) Living with a partner
3) Married
4) Divorced
5) Separated
6) Widowed
8) Other (Please specify)
9) Refused

50. Including yourself, how many people live in your home? [Record exact number of people 01-20]
01) One (I live alone)
99) Refused

51. Do you have any of the following health issues?
1) Impaired mobility
2) Diabetes
3) Heart problems
4) Respiratory issues, such as asthma, COPD, or Emphysema
7) None of the above
8) Don't know
9) Refused

52. What is your occupational status?
1) Employed full-time
2) Employed part-time
3) Retired
4) Unemployed, looking for work
5) Unemployed, not looking for work

7) Other (Please specify)
8) Don't know
9) Refused

53. On average, do you spend more than 20 hours outside of your home each week?
0) No
1) Yes
8) Don't know
9) Refused

54. What languages are spoken in your home?
1) English
2) Spanish
3) Vietnamese
4) Chinese
5) French
6) Russian
7) Korean
8) Hindi
9) Other (Please specify)
88) Don't know
99) Refused

55. Which of the following races or ethnicities do you identify with? Please select all that apply.
1) White or Caucasian
2) Black or African American
3) Asian
4) Hispanic or Latino
5) Native Hawaiian or Other Pacific Islander
6) American Indian or Alaska Native
7) Other (Please specify)
8) Don't know
9) Refused

56. Do you own or rent your home?
1) Own
2) Rent
3) Other arrangement (Please specify)
8) Don't know
9) Refused

57. Do you live in a retirement community or assisted living facility?
0) No
1) Yes
8) Don't know
9) Refused

58. In 2016, what was your total household income before taxes?
0) Less than $10,000
1) $10,000 to less than $15,000

2) $15,000 to less than $25,000
3) $25,000 to less than $35,000
4) $35,000 to less than $50,000
5) $50,000 to less than $75,000
6) $75,000 to less than $100,000
7) $100,000 or more
8) Don't know
9) Refused

59. Would you be willing to provide us your street address?
    1) Yes (willing to provide)
    9) Refused
60. Would you be comfortable telling us just your zip code? [Enter 5-digit zip code] 9999) Refused