Understanding Regional Differences in Extreme Heat Vulnerability in Aotearoa New Zealand: Demographic Sensitivity, Social Vulnerability, and Climate Justice

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Abstract

Extreme heat is an emerging climatic and population health risk in Aotearoa New Zealand, yet its demographic and spatial dimensions remain poorly understood. While international evidence demonstrates clear associations between heatwaves and excess mortality, hospitalisations, and social disruption, limited research has examined how extreme heat intersects with demographic sensitivity and social vulnerability in New Zealand's temperate climate. This thesis addresses that gap by providing the first national, spatially explicit assessment of extreme heat vulnerability in New Zealand, framed through the lenses of climate justice and intergenerational equity.

The study adopts a quantitative, cross-sectional design integrating daily maximum temperature observations from thirty representative climate stations (2009/10–2018/19 summers) with 2023 Census demographic data and the New Zealand Deprivation Index (NZDep2023) at Statistical Area 2 (SA2) level. Extreme heat is defined using station-specific 95th percentile thresholds, reflecting relative local acclimatisation. For each station, the mean number of summer days exceeding this threshold was calculated and spatially assigned to SA2s using a nearest-station approach in QGIS. Demographic sensitivity was operationalised through age structure, focusing on children (0–14 years) and older adults (65+ years), while social vulnerability was captured using ethnic composition and area-level, socioeconomic deprivation.

Results demonstrate substantial regional and interannual variability in extreme heat exposure. Warmer eastern and inland regions record higher temperature thresholds, yet relative exceedance days are not confined to traditionally hot areas, underscoring the importance of percentile-based measures in temperate climates. Exposure increased markedly in later summers, particularly in the summer of 2018/19, indicating a national upward shift in extreme heat frequency. Demographically, vulnerability is unevenly distributed. Older populations are concentrated in several South Island and coastal regions, while Māori and Pacific communities, characterised by younger age structures, are concentrated in specific North Island regions and urban areas. Overlay analysis reveals distinct spatial clusters where elevated heat exposure coincides with high proportions of either older adults or children, often alongside higher socioeconomic deprivation.

By embedding these findings within climate justice and intergenerational equity frameworks, the thesis demonstrates that extreme heat is not only a climatic hazard but also an issue of

equity. Communities least responsible for climate change may face disproportionate exposure due to structural inequities. Simultaneously, children represent a cohort with both heightened physiological sensitivity and greater lifetime exposure under continued warming.

This research contributes to knowledge by integrating climatological, demographic, and socioeconomic deprivation data into a unified national vulnerability assessment for New Zealand. It provides a policy-relevant evidence base to inform heat-health planning, housing standards, urban design, and equitable adaptation strategies. More broadly, it demonstrates the importance of embedding justice-oriented frameworks into climate and population health research to ensure adaptation responses reduce, rather than reproduce, existing inequities.

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Chapter 1: Introduction

1.1 Introduction

Climate change is one of the defining challenges of the twenty-first century (IPCC, 2022). Although historically viewed as being most important in the context of environmental domains, it will have profound implications for human health, wellbeing and social cohesion (IPCC, 2022). While its impacts will be felt across the world, they will not be distributed evenly (Charveriat, 2023). Certain populations, defined by country, age, ethnicity and socioeconomic deprivation, are disproportionately vulnerable to climate-related hazards (Owens et al., 2023; Klinenberg, 2003; Robine, et al., 2008; Randell, 2022). Rising temperatures, and particularly, extreme heat has emerged as one of these critical hazards that pose real risks to global population health (Ebi et al., 2021; Mora et al., 2017). At the international scale, heatwaves have been associated with excess mortality, hospitalisations and significant social and environmental disruption (Bell et al., 2024; Klinenberg, 2003; Robine, et al., 2008). While there has been much research concerning the impact of extreme heat in high temperature locations, it has been less explored in historically cooler climates (Harrington, 2021). New Zealand's climatology is defined as cool and maritime, which has generally made the health consequences of rising temperatures negligible (Lai et al., 2024). However, based on growing global evidence, heat is now emerging as a key concern that remains poorly understood in New Zealand (Harrington, 2021; Harrington & Frame, 2022; Ministry of Health, 2024).

This thesis explores the intersection between climate change and population health in New Zealand by identifying who, and where, is most vulnerable to extreme heat. It draws attention to demographic groups with limited or lower thermoregulation capacity, children and older adults, as well as communities who experience structural inequities (based on ethnicity or socioeconomic deprivation) that heighten exposure risk and constrain their capacity to adapt to climate change (Lai et al., 2024; Smith, 2019; Bell et al., 2024; Klinenberg, 2003; Robine, et al., 2008). By situating this analysis within frameworks of climate justice and intergenerational equity, this research highlights not only the biophysical risks posed by extreme heat, but also the social and ethical questions about fairness, responsibility and resilience.

Globally, the frequency and severity of extreme weather events are increasing (IPCC, 2022; Harrington, 2021). The Intergovernmental Panel on Climate Change (IPCC) projects with high confidence that heatwaves will continue to intensify, which will have material impacts on all populations (IPCC, 2022). The impact that heat has in New Zealand's has received little attention (Harrington, 2021). This is in part because absolute temperatures remain relatively mild, though this is changing as New Zealand's temperature warms in line with global increases (Harrington, 2021). Additionally, recent evidence from countries with historically cooler climates, such as parts of northern Europe and the United Kingdom (UK), shows that even modest relative increases in temperature have been associated with excess summer mortality during heatwaves over the past decade, which has flow-on-effects for health systems, social cohesion and overall population wellbeing (Grantham Institute, 2025; Uejio, et al., 2011).

The IPCC refers to climate change as a "stressor", or a risk amplifier, that intensifies existing social vulnerability (Bowen, et al., 2022). On the other hand, demographic trends contribute to economic realities, and are inextricably linked with poverty and inequity (Organisation for Economic Co-operation and Development [OECD], 2025). Populations ageing, changing family structures and increasing ethnic diversity are all contributing to the differences in peoples lived social and economic realities (OECD, 2025). New Zealand, as with many high-income nations, is undergoing significant demographic change (Ministry of Housing and Urban Development, [HUD], 2023; Nargund, 2009). Although Māori and Pacific communities have younger age structures, overall the national population is ageing (Statistics New Zealand, 2025). This national ageing interacts with longstanding inequities across New Zealand's social fabric, including in housing, income and health, and it raises important questions about how climate hazards, such as extreme heat, will intersect with shifting populations (HUD, 2023).

Heat, therefore, is not only a climatic problem, but also a demographic and equity problem (Randell, 2022). Understanding where climate exposure and population vulnerability overlap is crucial for informing adaptation planning. Without such evidence, there is a risk that resources will be allocated ineffectively, leaving those most in need without adequate support.

Three interrelated themes underpin this thesis:

- Extreme heat as a public health hazard: Heat stress affects cardiovascular, respiratory and renal systems, and can exacerbate existing conditions (Azan, et al., 2024; Osilla, et al., 2023).
- Demography as a driver of vulnerability: Children and older adults are more physiologically susceptible to heat, while structural population changes – such as ageing – shape how these vulnerabilities manifest across regions.

- Equity and justice: Climate justice and intergenerational equity provide frameworks for understanding how risks and responsibilities are distributed. In New Zealand, these frameworks intersect with obligations under Te Tiriti o Waitangi to ensure Māori communities are not disproportionately burdened by the impacts of extreme heat.

The overarching aim of this thesis is to assess the vulnerability of New Zealand's population to extreme heat, with a focus on demographic and geographic intersections. It seeks to:

- Identify regions most susceptible to extreme heat events, using ten years of historic summer climate data (2009-2019) and percentile-based thresholds.
- Identify the geographic distribution of children and older adults across Statistical Area 2 (SA2) regions, including their ethnic composition, as of the time of the 2023 Census.
- Analyse how age, ethnicity, and socioeconomic deprivation intersect with climate exposure, to identify where vulnerability is most concentrated.

These objectives are guided by three questions:

1. What regions in New Zealand are most susceptible to heat?
2. What is the geographic distribution of children (0-14), adults (15-64), and elderly (65+) populations and how does this intersect with ethnic composition?
3. What patterns can be identified at the intersection of geographic, age and ethnic data that illuminate where vulnerability is highest?

This research fills a critical gap. While many international studies have shown the health consequences of heatwaves, little is known about the spatial and geographic distribution of extreme heat analysed in relation to demographic characteristics (age and ethnicity) (Randell, 2022). By combining historic climate data with census and socioeconomic deprivation indicators this thesis will provide the first integrated analysis of heat vulnerability in New Zealand.

The findings will have practical implications for climate change adaptation and public health planning. Identifying at-risk regions and groups will help policymakers and agencies target interventions more effectively, ensuring that scarce resources are directed where they can have the greatest impact. More broadly, the thesis aims to demonstrates the importance of embedding equity and intergenerational justice into climate and population health research.

This thesis is organised into five chapters. This introduction section has framed the problem, situated the research and set out aims and questions. Chapter Two outlines the literature on extreme heat, demographic change, and climate justice, with a particular focus on New Zealand's context. Chapter Three outlines the methodology of this thesis, particularly the data sources, analytical framework and geospatial techniques that are used. Next, Chapter Four presents the results. That is, the findings on regional exposure to extreme heat, demographic distributions and vulnerability mapping. Finally, Chapters Five and Six are the discussion and conclusion sections, which interpret the findings, consider policy and equity implications and suggest directions for future research.

Chapter 2: Review of the literature on extreme heat and population health

2.1. A conceptual model of climate justice, extreme heat and population health

This chapter is structured around a conceptual framework that examines social vulnerability to extreme-heat through the lens of climate justice and intergenerational equity. Rather than treating heat exposure as a purely biophysical phenomenon, the framework applied recognises that the risks associated with extreme heat are shaped by demographic characteristics, social conditions and broader structural inequities (Randell, 2022; Ford, et al., 2018; Coates, et al., 2014). For the purpose of this thesis, inequities are defined as systemic, avoidable, and unfair differences in status between social groups (Marmot, 2007).

Figure 1 presents this framework and provides an organising structure for the literature reviewed in this chapter, and this thesis more broadly.

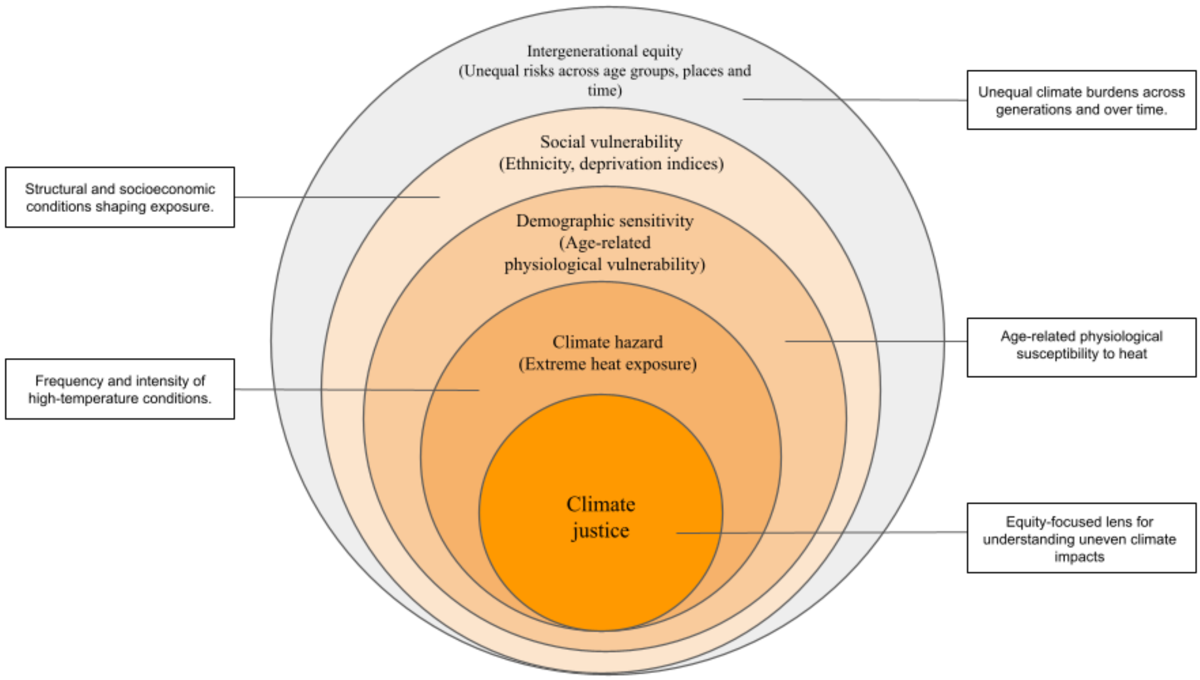

Figure 1: Conceptual model of climate justice, extreme heat and population health

Source: Author's construction based on Saunders et al., (2007) "Research Onion" and the Dahlgren-Whitehead (1991) "Rainbow model of health inequalities".

In this thesis, each layer of the conceptual model is defined and operationalised in a way that aligns with both the theoretical literature and the empirical analyses undertaken. Climate justice is positioned at the centre of the framework as an analytical lens, reflecting the premise that the exposure to, and the impacts of, climate change are not distributed evenly, but are shaped by social, political, demographic and historical contexts (Ogunbode, et al., 2024; Parsons, 2024). Climate hazard refers to the physical exposure to extreme heat, measured using percentile-based temperature thresholds derived from daily climate station data across ten summers (Harrington, 2021). Demographic sensitivity is operationalised through age-based physiological vulnerability, drawing on evidence that children (0–14 years) and older adults (65+ years) have reduced thermoregulatory capacity (Azan et al., 2024; Osilla et al, 2023). These two age groups are therefore used as a proxy to demonstrate physiological susceptibility. Social vulnerability captures the structural and socioeconomic conditions that heighten or mitigate heat risk, which can reflect historical inequities, material resources, housing quality, and access to adaptive capacity (Parsons, 2024; Howden-Chapman et al., 2023; Lawrence, et al., 2017; Atkinson & Crampton, 2019). Finally, intergenerational equity provides the temporal frame through which these layers are interpreted, emphasising that, although this analysis presents a small snapshot in time, children and future generations will face much higher lifetime exposure to extreme heat, while older adults experience immediate physiological risk (Bessant, et al., 2025; Charveriat, 2023). Together, these operational definitions ensure alignment between the conceptual model and empirical analysis, and provide a consistent set of terms for interpreting how climatic, demographic and social factors interact to shape heat-related vulnerability in New Zealand.

2.2. Heat and population health globally

The IPCC's Sixth Assessment Report affirms that global surface temperature is projected to rise by at least 1.5 °C this century, with extreme weather events becoming more frequent and intense (2022). As a result, heatwaves are virtually certain to increase in both frequency and severity (IPCC, 2022). Heat can be defined in absolute or relative terms (Harrington, 2021). In hotter climates, absolute thresholds are critical because extreme temperatures routinely exceed physiological limits and can directly threaten health; in temperate regions, relative thresholds are often more useful and relevant for understanding risks as populations may be unaccustomed to even modest increases in temperature, leading to heightened physiological and behavioural vulnerability (Robine et al., 2008; Coates et al., 2014; Harrington & Frame, 2022).

Extreme heat is increasingly recognised as a critical public health hazard worldwide, and is often highlighted as one of the key pathways through which climate change threatens human health (Mora, et al., 2017; Reid, et al., 2012; Harrington & Frame, 2022; Randell, 2022). Much of the research concerning extreme heat and its impacts on people, relate to its relationship to increases in mortality during heatwaves, with a high volume of the global literature focusing on the hottest regions (Mora, et al., 2017; Randell, 2022; Harrington, 2021).

Despite this, research has demonstrated that excess mortality can occur at extremes relative to the local climatology, even if those temperatures are low by global standards, such as in England, Wales, the Netherlands, Finland and Canada (Christidis et al., 2010; Folkerts, et al., 2020, Donaldson, et al., 2003; Gasparrini et al., 2015). Historically cooler conditions have meant that heat-related health risks have been largely overlooked in New Zealand (Harrington, 2021; Harrington & Frame, 2022). However, on the basis of these international experiences and as warming accelerates, the country may be especially sensitive to relative increases in temperature due to a lack of acclimatisation, posing potential public health and social risks (Harrington, 2021).

The public health significance of heat became widely recognised following a handful of high-profile heatwaves in the late 1990s and early 2000s. The 1995 Chicago heatwave led to more than 700 excess deaths in just a few days, exposing how urban design, poverty, and social isolation can amplify vulnerability (Klinenberg, 2003; Randell, 2022). Nearly a decade later, in 2003, Europe experienced one of the deadliest heatwaves on record, with over 70,000 excess deaths across the continent (Robine et al., 2008). Analysis revealed that mortality spikes occurred even in relatively temperate countries such as France, where populations were poorly acclimatised and public health systems were unprepared (Robine et al., 2008). In both cases, those who were most impacted were the elderly and socially isolated, underscoring that heat is not just a climatic event but a social one: its impacts depend on population vulnerability, including housing quality and design, social connectedness, urban infrastructure, and the capacity of health systems to respond to sudden onset public health risks (Robine et al., 2008; Randell, 2022; Uryu, et al., 2021; Loughnan, et al., 2013).

Heat poses a health risk as the human body relies on thermoregulation mechanisms, for example, sweating, vasodilation and behavioural adjustments, to maintain core temperatures within safe limits (Osilla et al., 2023). When external temperatures and humidity rise, these mechanisms become less effective, leading to heat stress (Osilla et al., 2023). Sustained exposure to heat can cause dehydration, electrolyte imbalance, cardiovascular strain, and kidney injury (Azan, et al., 2025 Ebi, et al., 2021; Kjellstrom, et al., 2009; Lakhoo, et al., 2025) . Excess summer mortality is most often attributed to higher levels of cardiovascular or respiratory failure across a population (Mora et al., 2017). Often heat acts as a trigger that exacerbates pre-existing conditions, many of which are age-related (Cheng, et al., 2018; Robine et al., 2008).

2.2.1. Absolute and relative thresholds

A key methodological debate concerns the best way to define "extreme" heat (Harrington, 2021). Traditional approaches set absolute thresholds, for example, days above 35°C (Harrington, 2021). In New Zealand, central and local government risk assessments identify extreme heat as being exceedances of 25°C, though there is little evidence justifying this choice (Ministry for the Environment [MfE], 2020; Harrington, 2021). Disputing this approach, research has shown that excess mortality can occur at lower absolute temperatures if they are unusually high relative to the local climate (Christidis et al., 2010; Gasparrini et al., 2015; Folkerts, et al., Donaldson, et al., 2003). This has led to the emergence of percentile-based measures when assessing the risk of heat (for example, the 95th percentile of local daily maximum temperatures), which are intended to account for local acclimatisation (Harrington, 2021; Harrinton & Frame, 2022). This debate highlights the importance of methodological choices: the way researchers define heat directly shapes conclusions about who is at risk and where.

This shift in methodological approach has major implications for countries like New Zealand, where absolute temperatures are modest by global standards but relative extremes may still be physiologically or socially stressful for local populations (Harrington, 2021; Harrinton & Frame, 2022; Muhamad, et al., 2024; Lai, et al., 2024; King & Harrington, 2018). Harrington (2021) argues that relative thresholds are more effective for capturing localised health risks and for designing context-specific warning systems. Localised health risks might be, for example, "urban heat islands" (Oke, 1982). Urban areas tend to be significantly hotter than surrounding rural regions due to dense infrastructure, limited vegetation, and heat-retaining materials, and may require a different threshold, set of warnings, and guidelines for managing the heat, as opposed to small coastal towns or rural areas, which pose different risks (Loughnan, et al., 2013; Ueijio, et al., 2011).

International examples also highlight the importance of equity in considering what temperature is hot enough to pose risks to populations: the most severe outcomes occur where vulnerable populations are concentrated or overlooked, and are not confined to exceedances of one particular high temperature threshold (Randell, 2022; Folkerts, et al., 2020; Donaldson, et al., 2003; Christidis et al., 2010; Gasparrini et al., 2015). This was evident, for example, in the marginalised communities of Chicago in 1995 or the elderly in France in 2003 (Klinenberg, 2003; Randell, 2022; Wilson et al., 2017; Fouillet et al., 2007). These insights shape the rationale for examining vulnerability to heat in the New Zealand context and inform the methodological choice of using percentile-based thresholds in this thesis.

2.3. Climate justice and intergenerational equity

2.3.1. Climate justice: Unequal responsibility, unequal impacts

The burdens of climate impacts are distributed unevenly, both within and between societies, and between present and future generations (Charveriat, 2023; Ogunbode et al., 2024). Climate change is among the most complex political challenges facing the global population (IPCC, 2021; Climate Change Commission, 2021). Scientists have assembled a significant volume of work over the past four decades, demonstrating that climate change is anthropogenic and that carbon emissions are altering planetary processes (Dolšak et al., 2022). The science is relatively settled, with an overwhelming consensus across scientific communities around the world that climate change is human induced, and causing irreparable harm (Cook et al., 2016; IPCC, 2021). In response to this evidence base, many countries, subnational governments and even major corporations have pledged to reduce carbon emissions to net zero by 2050 (Dolšak et al., 2022; Climate Change Commission, 2021). It is less clear, however, whether political action will be sufficiently mobilised to achieve this goal in any meaningful way. Decarbonisation is often stymied due to the challenges of global, collective action and domestic distributional conflicts, both of which impede and politicise action against climate change (Aklin & Midenberger, 2020; Ostrom 2010).

Climate action and inaction often reproduce existing economic, political and social inequities, making public perceptions of injustice acute (Dolšak et al., 2022; Parsons, 2024). As a result, climate change is at the centre of major political debates about who gets what, when and how. Further, decarbonisation creates a public free good, on which countries can free ride. That is, countries who make no efforts to reduce their emissions still enjoy co-benefits from international emissions reductions (Aklin & Midenberger, 2020). For example, Western critics often point to India and China, large carbon emitters on the global stage, who were not subject to mandatory emissions reductions under the Kyoto Protocol (1997; Dolšak et al., 2022). While many countries look to decommission coal-based energy plants, China and India continue to build them, providing fertile ground for other governments to opt out of international decarbonisation efforts on the basis of fairness (Dolšak et al., 2022).

This issue of fairness can be seen playing out at the national and local levels too. For example, although agricultural emissions make up the majority of New Zealand's emissions profile, primary industry groups frequently stymy efforts to introduce agricultural emissions pricing, or other polluter pays policies, on the basis of "unfair costs to farmers", while marketing New Zealand's agricultural products as clean and green abroad (Climate Change Commission, 2021; MfE and Ministry for Primary Industries [MPI], n.d.; Brodie & Sharma, 2011). They are therefore receiving the co-benefits from decarbonisation policies in place to help protect the environment, preserving the country's green image, but shielded from the costs of their own pollution.

Unlike decarbonisation (often referred to as mitigation), climate change adaptation should, in theory, face little to no public opposition. This is because it predominantly creates local public goods (Dolšak et al., 2022). In addition, adaptation does not aim to restructure the economy, impacting specific sectors and industries the way mitigation might. Despite this, progress on adaptation is generally considered costly and slow (Mendelsohn, 2012; Lawrence, et al., 2017). Adaptation efforts require long-term planning and investment that sits outside of democratic political cycles, which often make up-front costs unattractive (Lawrence, et al., 2017). This, of course, pushes the burden of responsibility for climate change adaptation into the future, and onto future generations (Dorner & Kerr, 2016).

As noted earlier, climate change acts as a "stressor", or risk amplifier (Bowen, et al., 2022). The principle of climate justice emphasises that those least responsible for greenhouse gas emissions are often, unfairly, the most vulnerable to their consequences, as it exacerbates existing risks or inequities faced by certain communities (Walker et al., 2024). Policies that ignore justice can inadvertently deepen these existing inequities, even when overall emissions fall (Ogunbode et al., 2024). In the context of adaptation these justice dynamics translate into uneven preparedness: those regions least responsible for emissions are often the least resourced to cope with escalating risks to the population (Dolšak et al., 2022; Ogunbode, et al., 2024).

This can be seen internationally, with many developing countries taking on substantial debt to cover the costs associated with extreme weather events, often only to be hit again (Mohan, et al., 2026). A similar pattern appears nationally, with regions higher in socioeconomic deprivation, such as Gisborne, repeatedly experiencing some of the most acute extreme weather events which cut off many communities access to social, health and economic support (Goode, et al., 2025; Thorpe, et al., 2025). Adaptation policies and funding must therefore recognise the unequal distribution of causal responsibility, impacts and coping capacities, and actively pursue fair outcomes for marginalised communities and regions (Ogunbode et al., 2024; Parsons, 2024; Randell, 2022).

Unequal responsibility is well established at the global scale. High-income countries account for a disproportionate share of historical carbon dioxide (CO_2) emissions, while Least Developed Countries and Small Island Developing States contribute only a fraction to global emissions, yet face outsized risks (Ritchie, 2019). Some wealthier nations may even benefit from climate change through capitalistic mechanisms, further deepening the divide (Dolšak et al., 2022). There are also important subnational differences to consider. Within countries similar patterns appear: higher-income households which have benefitted from an industrial economy typically produce greater consumption-based emissions and have more capacity to shield themselves from heat via cooling, insurance and mobility, leaving low-income groups, particularly those of colour, more exposed (Dolšak et al., 2022; Climate Change Commission, 2021; Walker et al., 2024). Within poor communities, impacts are not felt equally; the elderly and socially isolated often feel the impacts of these events most acutely (Randell, 2022; Terry, 2009; Rickards & Watson, 2020). Historic extreme heat events have clearly illustrated this dynamic (Klinenberg, 2002; Robine et al., 2008).

For New Zealand, research that frames the response to climate change as an issue of justice and equity, must highlight that Māori and Pacific peoples, who historically have contributed the least to greenhouse gas emissions, are among those most at risk from a changing climate (Reid, et al., 2019; Climate Change Commission, 2021).

Climate justice as an analytical lens

Climate justice provides an analytical lens that integrates three linked dimensions (Ogunbode et al., 2024):

1. Distributional: who benefits and who bears risks.

2. Recognitional: whose knowledge, histories and identities are acknowledged.
3. Procedural: who participates in decision-making.

In New Zealand, a justice centred-framing to climate change is essential given the legacies of colonisation (Parsons, 2024). Colonisation, dispossession and institutional racism are fundamental drivers of inequities between Māori and Europeans, shaping exposure, sensitivity and adaptive capacity to climate hazards (Reid, 2019; Health Quality and Safety Commission [HQSC], 2019). Contemporary analyses also show persistent system-level failures (for example, in primary care) that entrench unequal outcomes, reinforcing why procedural and recognitional justice (Te Tiriti-consistent governance, Māori data sovereignty, and mātauranga-informed adaptation) must sit at the centre of climate responses (Sheridan et al., 2024; Parsons, 2024).

Pacific peoples face parallel inequities, including a higher burden of chronic disease, barriers to culturally appropriate care, and lower access to quality housing which are all factors that heighten heat risk and constrain adaptive capacity (Pacific Perspectives, 2019; The Treasury, 2023; Dyer et al., 2023).

Distributionally, heat risk concentrates where substandard housing, energy hardship and limited access to cooling overlap with health vulnerabilities (Ogunbode et al., 2024; Randell, 2022; Chen, et al., 2025). These spatial and social inequities reflect broader structural conditions shaped by colonisation, labour market stratification and uneven investment in infrastructure (Loughnan, et al., 2013; Climate Change Commission, 2021; Parsons, 2024; Howden-Chapman, et al., 2023). In many cases, the same communities who endure disproportionate exposure to cold, damp housing in winter also face compounded heat stress in summer, illustrating how unequal living conditions magnify climate risk year-round (Thomas, et al., 2023; Uejio, et al., 2011; Chang-Richards, et al., 2018). Distributional justice therefore requires recognising that vulnerability is not naturally occurring but produced through historical and contemporary policy decisions that shape where people live, the quality of their housing, access to services and their capacity to adapt to challenges such as extreme heat (Parsons, 2024).

In the recognitional dimension, Indigenous knowledge and community defined-priorities (for example, Marae-based preparedness or culturally anchored mutual aid) are often sidelined in mainstream planning, despite their potential to reduce risk and address inequities (Parsons, 2024). Recognition also concerns whose experiences and needs are made visible in climate assessments: for example, overcrowded multigenerational households, Pacific networks or kaumātua living in rural areas may not be well represented in quantitative datasets (Parsons, 2024; Statistics New Zealand, 2020). Failure to incorporate these realities into planning reinforces a narrow conception of vulnerability and limits the effectiveness of adaptation measures (Ogunbode, et al., 2024). Recognitional justice therefore entails valuing diverse forms of knowledge, acknowledging lived experiences of climate risk and ensuring cultural worldviews, particularly Māori and Pacific, shape adaptation efforts from the outset (Parsons, 2024; Ogunbode et al., 2024). Centering this community knowledge, can help to avoid the unintended consequences of climate policies that can further entrench social inequities. An example of an unintended consequences is an increase in household spending associated with energy decarbonisation policies, which can impact economically strained families by increasing power costs, precluding them from using or installing cooling apparatus in their homes, perpetuating inequities (Chen, et al., 2025; Hu et al., 2022; Chen, et al., 2018).

Procedural justice, the third dimension of the analytical framework, concerns who holds decision-making power and whose voices shape adaptation policy (Ogunbode et al., 2024). Māori governance structures, including iwi authorities and hapū-based organisations, are often positioned as consultees rather than equal partners, despite Te Tiriti obligations requiring shared authority and decision-making (Parsons, 2024). Pacific communities, likewise, are frequently engaged late in regional planning processes or through narrow consultation mechanisms that do not support meaningful participation (Dyer et al., 2022). Recent national adaptation processes, including the National Adaptation Plan (NAP), reveal persistent gaps: insufficient resourcing for community participation, limited integration of Indigenous governance frameworks, and mechanisms that privilege technical expertise over lived knowledge (Climate Change Commission, 2024; Parsons, 2024). Addressing procedural inequity requires institutional shifts that embed Māori and Pacific leadership, devolve decision-making power and ensure adaptation strategies reflect community priorities, rather than top-down policy preferences (Parsons, 2024; Lawrence, et al., 2017).

What the lens of climate justice offers to this thesis, therefore, is a framework to interpret the underlying causes of unequal heat impacts, and understand how policy can close those gaps. The Climate Change Commission explicitly calls for a fair, inclusive transition; principles directly applicable to extreme heat planning and surveillance (Climate Change Commission, 2021). A climate justice lens helps prioritise interventions where risk is highest; ensure processes honour Te Tiriti o Waitangi, strengthen Māori leadership and embed Pacific perspectives and; evaluate policies by their equity impacts, not only their aggregate risk reduction (Parsons, 2024; Lawrence, et al., 2017; Ogunbode et al., 2024).

Finally, aligning heat adaptation with justice means ensuring that reduced inequities are included as a measure of success. For instance, this may be through initiatives such as cooler healthier homes in low-income suburbs; workplace protections for outdoor workers; urban greening where canopy is sparse; and strengthened community governance to sustain locally led solutions (Ogunbode et al, 2024; Randell, 2022; Zhang, et al., 2024). Without this focus, rising temperatures risk amplifying existing inequities.

2.3.2. Intergenerational equity: Unequal burdens across time

Adding intergenerational equity as another lens within which to examine extreme heat, extends the framework of climate justice across time. It helps to reframe adaptation as a duty of care, or an obligation to protect those who cannot yet protect themselves (Bessant, et al., 2025). Children, young people and future generations will live with the long-term consequences of climate change, despite contributing less to its causes (Bessant, et al., 2025; Méjean, et al., 2020). The IPCC's Impacts and Adaptation report illustrates this vividly, showing that a child born in 2020 will face "unprecedented exposure" to the number of extreme events, including heatwaves, compared with someone born in 1960, even under moderate emissions scenarios (2022). From a health perspective, this creates a double inequity for children. They are physiologically more vulnerable to heat stress due to immature thermoregulation, and they will also carry the cumulative burden of climate change over their lifetimes (Azan, et al., 2025; Lai, et al., 2024; Smith, 2019; Early Childhood Scientific Council [ECSC], 2023). Older adults today, while also vulnerable to heat stress, will experience its impacts for a shorter duration (Charveriat, 2023). This statement does not diminish the urgency of protecting older people, but it does raise ethical questions about fairness, responsibility, and the obligation to safeguard younger and future generations from the impacts of climate change.

Intergenerational equity is rooted in environmental ethics, economic modelling and legal frameworks (Bessant, et al., 2025; Méjean, et al., 2020). For example, the literature emphasises that present-day decisions around consumption, investment and environmental protection impose risks and costs on generations that cannot consent or engage in those decisions (Dolšak et al., 2022; Schoenmaker et al., 2024). An equitable approach to climate change mitigation requires the maintenance, or improvement, of environmental wellbeing for future cohorts, however standard economic models often undervalue the rights of future generations by applying discount rates that minimise long-term harm (Dolšak et al., 2022; Schoenmaker et al., 2024). Such modelling choices effectively shift economic burdens onto younger cohorts, meaning they will inherit higher costs (Dolšak et al., 2022; Schoenmaker et al., 2024). In order for economic models and policy decisions to account for the higher burdens placed on future generations, practical policy analyses must incorporate intergenerational equity as one of four core climate justice dimensions (distributive, procedural, recognitional and intergenerational) in adaptation frameworks (Barkai et al., 2024).

Applying this framework to extreme heat emphasises three interlinked concepts: temporal burden, developmental vulnerability and equity of opportunity. The temporal aspect recognises that younger cohorts will live longer into eras of increasing climatic change; children born today face far high higher lifetime exposure to hazards than previous generations (WHO, 2022; Bessant et al., 2025). Developmental vulnerability stems from early-life exposure to heat, which may hamper physiological resilience (Arpin et al., 2021; Mohamed et al., 2025; Azan, et al., 2025; Laaidi et al., 2024). Equity of opportunity refers to ensuring that children will inherit safe housing, quality infrastructure and systemic adaptive capacity; without these, heat-related exposures in childhood can become entrenched disadvantages across the life-course (Syropoulos et al., 2023).

Intergenerational equity also draws attention to how much of climate vulnerability is shaped by agency and consent (Azan, et al., 2025; WHO, 2022). Children usually do not choose where they live, the quality of their housing, the schools they attend or the environments in which they spend most of their time (Azan et al., 2025; Wang et al., 2025). Their exposure to climate hazards is therefore involuntary and structurally produced. This lack of agency intensifies the ethical responsibility on current generations: without proactive intervention, today's children will inherit built environments and social conditions that heighten their risk of exposure to extreme heat, and other hazards arising from climate change (Zhang, et al., 2024).

The framework also helps clarify the distinct position of older adults. While older adults face immediate and often severe risks from heat, their exposure to extreme heat is limited to the later stages of life (Charveriat, 2023). Children, by contrast, will live through decades of warming, including thresholds of heat that have no historical precedent (IPCC, 2022). This dual dynamic illustrates why intergenerational equity requires parallel forms of protection for both groups, and not for one at the expense of the other (Charveriat, 2023; Bessant, et al., 2025).

2.3.3. New Zealand context

In terms of absolute emissions New Zealand is a small emitter relative to major economies but is a high emitter per capita (Statistics New Zealand, 2022). Additionally, as a high-income country it has greater adaptive capacity (Climate Change Commission, 2021). Domestically, however, the picture is more complex. Māori and Pacific communities experience disproportionate vulnerability due to structural factors that may lower their overall adaptive capacity. Ensuring their needs are prioritised in adaptation planning is both an ethical obligation and a legal requirement of the Crown under Te Tiriti o Waitangi (Climate Change Commission, 2021).

At its core, intergenerational equity foregrounds the likelihood that climate change will compound existing social inequities across time, amplifying existing risks faced by some communities (Bessant, et al., 2025). For Māori and Pacific children in New Zealand, who already face structural inequities rooted in colonisation and socioeconomic marginalisation, rising temperatures risk reinforcing patterns of injustice that persist across generations (Parsons, 2024). This underscores why delayed adaptation represents a form of intergenerational harm (Parsons, 2024; Bessant, et al., 2025; Méjean, et al., 2020). Every year without sufficient action increases the likelihood of future exposure to climate hazards, raises adaptation costs and reduces the ability of future generations to live in safe, healthy environments (Schoenmaker, et al., 2024). Integrating intergenerational equity into adaptation planning therefore means prioritising preventive, anticipatory measures and building infrastructure with a long term view to support community and social wellbeing now and into the future (Lawrence, et al., 2017).

To date, few studies in New Zealand have explicitly applied climate justice or intergenerational equity frameworks to population health and climate research. Walker et al. (2024) argue that these frameworks are only beginning to influence adaptation planning and often remain more rhetorical than operational. Some non-governmental organisations have called for climate projections to integrate ageing into their analysis (Charveriat, 2023). However, there is no research that systematically links heat, demography and socioeconomic deprivation across the country, in the New Zealand context.

Equity frameworks expand the analysis of extreme heat vulnerability, emphasising fairness, responsibility, and the ethical distribution of risk (Walker et al., 2024; Bessant, et al., 2025). Together, these frameworks provide a powerful lens for analysing vulnerability in New Zealand. They demand that adaptation strategies address structural inequities, honour Te Tiriti obligations and prioritise those who are most at risk yet least responsible for climate change. In this way, they move climate and population health research from a descriptive exercise to a normative one, asking not only who is vulnerable, but also who should be protected first, and why.

2.4. Demographic sensitivity

Understanding vulnerability to extreme heat requires attention not only to climate exposure but also to the demographic characteristics of populations (Randell, 2022). Age is one of the strongest predictors of heat sensitivity: both children and older adults are physiologically less able to regulate body temperature, making them more susceptible to heat-related illness and mortality (Osilla et al., 2023; Azan et al., 2025; Cole et al., 2023). Beyond physiology, demographic structures, which are shaped by fertility rates, ageing processes, and migration, determine the relative size and distribution of vulnerable groups across regions (Randell, 2022). Both globally and nationally, demographic transitions are reshaping vulnerability profiles. These demographic dynamics at play suggest a rapidly growing population of vulnerable people to hotter temperatures, particularly as countries continue to age (Cole et al., 2023).

2.4.1. Most at risk groups

Prenatal, neonatal and young children

Infants and toddlers have limited capacity to perspire and higher surface-area-to-body-mass ratios, which make them more prone to overheating (Azan, et al., 2025; ECSC, 2023). They are also less able to communicate discomfort or seek relief, increasing their dependence on caregivers, childcare practices and structural supports such as housing quality and access to cooling (Azan et al., 2025).

International evidence links heat exposure in pregnancy and childhood to both acute and long-term health impacts (Azan, et al., 2025; Xu et al., 2014; Chersich et al., 2020; Darrow et al., 2024; Lakhoo et al., 2025). Emerging research highlights potential developmental effects, with prenatal exposure to extreme heat linked to adverse birth outcomes such as preterm birth, stillbirth, and low birth weight (Chersich et al., 2020). Large population-based studies across the United States (U.S.), China and countries in sub-Saharan Africa have shown that high ambient temperatures and multi-day heatwaves increase the risk of preterm and early term birth, low birthweight, and, in some contexts, stillbirth (Chersich et al., 2020; Darrow et al., 2024; Lakhoo et al., 2025). For example, a national case-time series of over 53 million U.S. births reported that prolonged exposure to heatwaves significantly elevated preterm delivery risk, particularly among lower socioeconomic groups and in southern states (Darrow et al., 2024). Meta-analyses across diverse climatic and socioeconomic settings have similarly found consistent associations between maternal heat exposure and shortened gestation periods, indicating that these effects are not limited to specific geographies or health systems (Chersich et al., 2020; Lakhoo et al., 2025).

Beyond pregnancy, evidence increasingly shows that heat exposure during the neonatal and post-neonatal periods elevates risks of mortality and morbidity (Lakhoo, et al., 2025). Multi-country analyses have found that high ambient temperatures during the perinatal window are associated with increased neonatal mortality, particularly in low-resource and rural settings where adaptive capacity is limited (Wang et al., 2025). Case-crossover studies in Canada and Korea have reported similar patterns, with elevated risks of sudden unexpected death in infancy and overall infant mortality during hot periods (Auger et al., 2015; Son et al., 2017). Collectively this literature highlights that the early-life vulnerability established in utero persists in infancy, amplified by limited thermoregulatory capacity and environmental context.

Global studies have consistently demonstrated that children, outside of infancy, are also vulnerable to the direct and indirect health impacts of extreme heat exposure (Azan et al., 2025; Périard et al., 2021). This could range from a mild illness like heat rash, all the way up to heat stroke, which is often fatal (Azan, et al., 2025). Extreme heat has also been associated with other morbidities in children, including asthma exacerbation, ear and enteric infections (Azan, et al., 2025). Large-scale paediatric datasets from the U.S. reveal that emergency department visits for children rise sharply on hotter days, with stronger effects for younger age groups, particularly children aged 0-4 years old (Bernstein et al., 2022). Emerging research indicates this is true for older children and adolescents as well, as across these age ranges they likely have lower cardiac output and seat production compared with adults (Périard et al., 2021). On this basis, “children” are defined as 0-14 years for the purpose of this analysis, which also aligns with the New Zealand Census data categorisation and availability.

For New Zealand, specific studies on children's heat vulnerability remain sparse, although a recent national case-time-series analyses found an association between temperature and hospital admissions for children under five, with marked increases above 24°C and an estimated 290 heat-attributable admissions per year (Lai et al., 2024; Muhamad, et al., 2024). Broader child-health reports indicate persistent disparities in hospitalisation and housing conditions for Māori and Pacific children, key modifiers of heat exposure, but do not isolate heat as a driver (Baker et al., 2012; Ministry of Social Development [MSD], 2018). Thus, although exposure pathways are demonstrably present and equity issues have been well-acknowledged, the nexus between extreme heat, age-specific health outcomes, and housing and social vulnerability remains under-explored in New Zealand.

Older adults

At the other end of the life course, ageing processes impact the body's ability to perspire, vasodilate, and affects overall cardiovascular responsiveness (Osilla et al., 2023). Older adults are also more likely to live with chronic conditions such as cardiovascular disease, diabetes, or respiratory illnesses, which, when combined with heat stress, may increase morbidity and mortality (Cole et al., 2023; Cheng et al., 2018). Additionally, many commonly prescribed medications to elderly patients, such as diuretics or beta-blockers, interfere with thermoregulation or fluid balance, heightening the risk of dehydration and heat stroke (Cole et al., 2023).

Case studies illustrate the scale of this vulnerability. In the 2003 European heatwave, excess mortality was heavily concentrated among older adults, particularly those over 75 years (Robine et al., 2008). Social factors amplified risk: many victims lived alone, in poorly ventilated housing, and lacked social support to seek help. In Australia, ambulance callouts and hospital admissions during heatwaves are disproportionately driven by older populations, especially those with pre-existing conditions (Coates et al., 2014). A decade-long time-series analysis (2010-2019) found that older adults (≥60 years) experienced markedly higher rates of heatwave-attributable mortality across multiple severity thresholds, with the strongest impacts occurring during early-season events when acclimatisation was low (Franklin et al., 2023). Similarly, in Japan during the 2017-2019 summer seasons, there were more than 95,000 emergency medical evacuations for heat-stroke, and over 1,000 confirmed deaths (Otani et al., 2021; Uryu et al., 2021). National surveillance data showed that incidence risk was overwhelmingly concentrated among people aged 65 years and older (Uryu et al., 2021).

For New Zealand, a national evidence summary by the Royal Society of New Zealand (2017) estimated that approximately fourteen deaths per year among people aged 65 years and older could be attributed to heat exposure in Auckland and Christchurch, with numbers projected to rise under future warming scenarios. Regional analyses have yielded similar indications: another pilot study in Canterbury found excess mortality during recent heatwave events, although results were not statistically significant due to small sample sizes (Environmental Health Intelligence New Zealand [EHINZ], 2023). Earlier time-series analyses in Christchurch also reported positive associations between higher daily temperatures and increased mortality (Hales et al., 2000). Consequently, understanding how ageing populations in New Zealand experience and adapt to heat remains an important and under-developed research area.

2.4.2. Demographic transitions

The improvement of human survival and the consequent explosion of population growth marked the beginning of the shift from high to low mortality and from high to low fertility, which is known as the "demographic transition" (Kirk, 2010). Demographic transitions are reshaping population structures worldwide, with important implications for climate vulnerability (Hoffmann, et al., 2025; Grace, et al., 2025). A defining feature of this transition in high-income countries is structural ageing, a population-level shift in which the proportion of older adults grows relative to younger age groups due to declining fertility and rising life expectancy (Nargund, 2009). Structural ageing changes not only the size of vulnerable older populations but also the balance of dependants to working-age populations, influencing social, economic and health system capacity to manage climate-related risks.

Global demographic change introduces uncertainty for understanding who, and where, is most vulnerable to extreme heat: models that consider only temperature trajectories, without accounting for shifts in the population, risk substantially underestimating burdens and costs on future generations (Cole et al., 2023; Charveriat, 2023). There is also uncertainty in how demographic processes, and consequently population trends, will respond to climate change (Hoffmann, et al., 2025). Specifically, if global environmental change does influence fertility, mortality, and migration, then population estimates and forecasts need to adjust for climate feedback in population projections (Hoffmann, et al., 2025; Muttarak, 2021; Grace, et al., 2025; Jones, et al., 2018). To date, there has been significant research on the role of climate change in influencing migration trends, but much is still unknown, particularly in relation to how climate change may interact with fertility and mortality (Hoffmann, et al., 2020; Kaczan & Orgill-Meyer, 2020; Grace, et al., 2025).

New Zealand reflects many global demographic patterns, including an increase in life longevity and a structurally ageing population, but with its own distinct ethnic differentials in fertility and age structure (HUD, 2023). The general fertility rate is the number of live births per 1,000 women ages 15 to 49 in a given year (Haupt, et al., 2011). It relates births to the age-sex group at risk of giving birth, usually defined as women aged 15 to 49 (Haupt, et al., 2011). In New Zealand, the national fertility rate has fallen below replacement level (2.1 live births per woman), driven by sustained decline among all groups, but particularly European women (1.55 births per women) (Statistics New Zealand, 2025). Māori and Pacific fertility rates, while also declining, remain higher than those of European (1.97 births per woman and 2.03 births per women, respectively), producing slightly younger Māori and Pacific populations (Statistics New Zealand, 2025). This slight demographic divergence means that future vulnerability may not be evenly distributed: older adults will continue to increase in number, while Māori and Pacific children may represent a disproportionate share of younger age groups. This raises key concerns around intergenerational equity and fairness, particularly in light of the Crown's Te Tiriti o Waitangi obligations.

2.4.5. Social vulnerability

The global literature consistently demonstrates that socially marginalised groups experience disproportionate impacts during heat events (Randell, 2022; Klinenberg, 2003). In the context of heat, disparities in income, housing quality and employment conditions mean that vulnerability is unevenly distributed across populations (Randell, 2022; Hu et al, 2022; Randell, 2022; Strickland and Tong, 2025). Further, pre-existing health inequities, driven by the social determinants of health (for example, income, housing and employment) can amplify heat exposure to increase morbidity and mortality during hot periods (Braveman et al., 2011; Cheng et al., 2018). Understanding inequities is therefore essential for assessing climate-related vulnerability, as socioeconomic conditions fundamentally determine both physical exposure and adaptive capacity (Uejio, et al., 2011).

Housing is one of the most immediate determinants of adaptive capacity: poor insulation, inadequate ventilation, and limited access to cooling technologies increase indoor heat exposure, while crowding further amplifies indoor temperatures (Hu et al., 2022). International evidence from the U.S., Australia and Europe consistently shows that substandard housing is associated with higher risks of heat-related illness and death (Klinenberg, 2002; Loughnan et al., 2013; Hu et al., 2022). Built-environment features such as dwelling age, density and roof type have also been identified as key predictors of mortality during heatwaves (Uejio et al., 2011; Vandentorren et al., 2006).

In New Zealand, housing is a well-documented site of inequality (Howden-Chapman et al., 2023). Many homes remain poorly insulated or ventilated, particularly within the private rental sector, and policy interventions such as the Healthy Homes Standards have primarily targeted cold-weather risks rather than overheating (Royal Society, 2021; Baker and Howden-Chapman, 2012; MSD, 2018). Crowded housing, especially prevalent among Pacific and Māori communities, further heightens exposure and limits the ability to adapt behaviourally during heat events (Statistics New Zealand, 2020; Statistics New Zealand, 2021).

Income and employment also intersect with heat vulnerability. Higher-income households are better able to mitigate heat exposure through air conditioning, private transport and flexible work arrangements (Royal Society, 2021). By contrast, low-income households face greater to extreme heat and fewer options to adapt (Uejio, et al., 2011). Occupational exposure represents another critical dimension: outdoor workers in agriculture, construction and manufacturing are at heightened risk of heat stress, with Māori and Pacific workers disproportionately represented in these sectors (Kjellstrom et al., 2009; Denison et al., 2018).

In New Zealand, colonisation has disrupted traditional relationships with land and environment, severing adaptive practices and governance systems that historically supported resilience (Rahiri et al., 2024; Parsons, 2024). Contemporary inequities in housing, income and health are the result of ongoing structural processes, not individual behaviour (Howden-Chapman, 2018). Comparative evidence illustrates similar patterns of inequity among Indigenous Australians and Canadian First Nations populations, where poor housing and limited access to services compound climate-related vulnerabilities (Bowles, 2015; Ford et al., 2018).

Pacific peoples, while not Indigenous to New Zealand, experience parallel forms of systemic exclusion linked to migration histories and labour market segmentation (Pacific Perspectives, 2019; The Treasury, 2023; The Productivity Commission, 2021). These inequities contribute to higher rates of chronic conditions, lower life expectancy and reduced access to culturally appropriate services compared with non-Pacific populations (Pacific Perspectives, 2019).

2.5. Summary

The literature reviewed above highlights the growing body of evidence on the health impacts of extreme heat, the role of demographic and socioeconomic factors in shaping vulnerability, and the value of applying equity frameworks to climate analyses. Yet despite significant international advances, the New Zealand context remains underexplored.

Internationally, the evidence base linking heat to health outcomes is extensive. Major case studies from Europe, North America, and Australia have demonstrated clear associations between extreme heat and excess mortality, hospitalisations, and morbidity (Coates et al., 2023; Robine et al., 2008; Franklin et al., 2023; Otani et al., 2021; Uryu et al., 2021). In line with this, there is a growing body of research linking heat to health outcomes in New Zealand (Royal Society, 2017; Lai et al., 2024; EHINZ, 2023). However, while NIWA and the Ministry for the Environment provide high-quality climate datasets, few studies have examined how these data translate into population-level health risks, beyond summer mortality spikes. Harrington (2021) is one of the few to highlight that relative thresholds may be more meaningful in New Zealand than absolute thresholds to reflect local circumstances, but there is very little work linking heat to population-level socio-demographic vulnerabilities (Muhummad, et al., 2024). The lack of systematic evidence means that the social impact of extreme heat remains marginal in New Zealand's climate adaptation discourse (Ministry of Health, 2024). Policy documents often acknowledge increasing hot days but rarely identify which populations are most vulnerable in a meaningful way (Climate Change Commission, 2021; Ministry of Health, 2024; MfE, 2020). Without clear evidence, heat risks remain under-recognised and under-prioritised, and are therefore challenging to plan for.

A second gap concerns how current demographic structure can interact with extreme heat. International literature has demonstrated that demographic transitions such as ageing and fertility decline having an evolving relationship to climate change (Cole et al., 2023; Hoffman, et al., 2025). Yet New Zealand-specific research has not incorporated demographic factors into analyses of climate vulnerability (Royal Society, 2017). This omission is particularly significant given New Zealand's demographic profile: an ageing Pākehā population alongside younger Māori and Pacific communities with higher fertility and different socioeconomic realities. These shifts create a dual vulnerability at both ends of the life course. Despite their importance, these dynamics have not been systematically explored in relation to climate hazards, leaving a critical gap in knowledge.

While housing quality, socioeconomic deprivation, and ethnic inequities are well documented in New Zealand, their intersection with climate vulnerability, particularly to increasing heat, remains underexplored. International evidence consistently shows that Indigenous and minority populations experience disproportionate heat impacts, yet similar analyses are lacking in New Zealand. Moreover, the legacies of colonisation and systemic inequities mean that Māori and Pacific peoples face heightened risks. Crowded housing, high rates of chronic disease, and overrepresentation in outdoor labour all compound vulnerability (Sheridan, et al., 2024; Kjellstrom, et al., 2009; Statistics New Zealand, 2020). Despite this, there is little research linking these inequities to heat hazards, and almost no adaptation planning explicitly addresses them.

Climate justice and intergenerational equity are increasingly used internationally to frame debates about fairness and responsibility in climate adaptation (Ogunbode, et al., 2024; Bessant, et al., 2025). Yet in New Zealand, these frameworks remain largely rhetorical (Parsons, 2024). Few studies have applied them to climate and population health research, and adaptation policies often lack meaningful attention to equity (Parsons, 2024). This represents a missed opportunity, particularly given the country's Te Tirit o Waitangi obligations to Māori. By embedding climate justice and intergenerational equity into its conceptual framework, this thesis responds to calls for more normative approaches to climate and population health research. It moves beyond description to ask who, and where, bears the greatest burden in responding to extreme heat.

Chapter 3: Methodology

3.1. Research design

This study adopts a quantitative, spatially explicit, cross-sectional design. The approach integrates climate observations with demographic and socioeconomic indicators at Statistical Area 2 (SA2) level to identify where heat exposure and social vulnerability intersect. Its objective is to characterise contemporary vulnerability to extreme heat by combining climate data with current population structure and socioeconomic conditions. Particular attention is given to children (0–14 years) and older adults (65+ years), who exhibit reduced thermoregulation capacity and whose risk is further shaped by social vulnerability.

The design aligns with international climate–health vulnerability assessments (Reid et al., 2012; Hajat & Kosatky, 2010) but is adapted to New Zealand's data environment and institutional context. It is explicitly descriptive rather than causal or predictive: the goal is not to estimate temperature–mortality coefficients, but to create a spatially explicit picture of where relative heat exposure coincides with concentrations of vulnerable populations and socioeconomic deprivation. This responds to clear evidence gaps in New Zealand's extreme heat literature and climate adaptation policy.

3.2. Data sources

The analysis draws on four core datasets that together capture climatic exposure, demographic composition, socioeconomic conditions, and spatial boundaries. These datasets were selected for their national coverage, internal consistency, and suitability for linkage at SA2 level.

3.2.1. Statistical Area 2 boundaries

SA2 boundaries were sourced from the 2023 Statistical Area 2 (SA2) classification, which is the geography used for both the 2023 Census and NZDep2023. SA2 is the smallest national geography consistently available across the required datasets (typically 2,000–5,000 residents) (Statistics New Zealand, 2022). It provides sufficient granularity to capture meaningful spatial variation while maintaining disclosure protection. Statistics New Zealand concordance files were used to ensure consistent coding across datasets (Statistics New Zealand, 2023).

3.2.2. Climate data

Daily maximum temperature observations for 1909–2019 were obtained from the Ministry for the Environment (MfE), collated and quality-assured by NIWA (MfE, 2020). The dataset, prepared for the *Our Atmosphere and Climate* report, selects thirty stations across New Zealand as representative of the country's climate. To approximate contemporary conditions, a ten-summer window (December–February, 2009/10–2018/19) was extracted. Thirty stations provided national coverage; Whanganui was excluded due to missing records. Two stations had partial gaps (Hamilton 2012; Kerikeri 2014), and rather than impute values, metrics were standardised using available summers only.

Extreme heat was defined using a relative, percentile-based method (Harrington, 2021; Harrington & Frame, 2022). For each station, the 95th percentile of daily maximum summer temperature over the ten summers was calculated. For each summer, the number of days exceeding this threshold was counted, and then averaged across the available summers to derive a summer average extreme-heat days measure. This approach reflects evidence that relative, not absolute, temperature anomalies drive health impacts in temperate climates (Harrington, 2021; Harrington & Frame, 2022).

3.2.3. Demographic data

Population indicators were sourced from the 2023 Census from Statistics New Zealand at the SA2 level, using the 2023 Census national and subnational usually resident population counts and dwelling counts (Statistics New Zealand, 2024). Variables include the usually resident population; age structure (0-14, 15-64, 65+ years); and ethnic composition (Māori, Pacific Peoples, Asian, Middle Eastern, Latin America and African (MELAA) and European/Other). As multiple ethnicities can be selected in the Census, total response can add up to over 100 percent. The purpose of assessing this data was to understand the geographic distribution of children (0-14 years) and older adults (65 years and over), as well as understanding ethnic distribution across these age groups.

3.2.4. Socioeconomic deprivation data

Social vulnerability was measured by using the New Zealand Deprivation Index 2023 (NZDep2023), an area-level composite of income, employment, housing, education, and dwelling conditions (Atkinson & Crampton, 2019). NZDep is widely used as a proxy for structural disadvantage and integrates well at SA2 scale (Statistics New Zealand, 2025).

3.2.5. Data preparation

All non-spatial data processing was undertaken in R, using the tidyverse package (R Core Team, 2026). Census tables were cleaned to remove suppressed or non-residential SA2s and to calculate age-and-ethnicity-specific percentages, using population counts. As multiple ethnicities can be selected in the Census, total response can add up to over 100 percent. NZDep deciles were retained as published. The climate processing involved two steps:

1. Calculating the 95th percentile of daily maximum summer temperature per station over 2009/10-2018/19.
2. Calculating exceedance days per summer and averaging across summers to produce a unified summer average extreme-heat days measure, as well as a year-to-year picture.

Stations with one missing summer were averaged over the remaining seasons. This avoided imputation while ensuring comparability.

3.2.6. Spatial processing

The analytical dataset was assembled in QGIS by linking climate exposure metrics to SA2 boundaries and enriching them with demographic and socioeconomic attributes (QGIS Development Team, 2026).

Each SA2 was assigned exposure metrics using a nearest-station approach based on Euclidean distance between SA2 centroids and station coordinates. With a finite station network and varied terrain, nearest-station assignment provides a robust and transparent method without additional modelling assumptions. Its limitations are acknowledged in Section 3.8.

The SA2 layer was joined with census-derived age percentages via the SA2 code, producing a unified geodatabase containing:

- summer average extreme-heat days;
- age-structure.

As part of this process non-residential polygons were removed. The Chatham Islands were excluded because nearest-station assignment would have incorrectly linked them to a mainland station and overstated or understated temperatures. Ethnic composition and socioeconomic deprivation are presented in various visual formats outside of maps.

3.3. Analytical strategy

The analysis follows three sequential steps aligned with the overall conceptual model for this thesis.

1. Identifying the climatic hazard (extreme heat): Summer average extreme-heat days were mapped across SA2s to describe spatial variation in relative heat exposure.
2. Profiling social vulnerability: Age structure and ethnic composition were analysed to identify concentrations of children (0–14 years), older adults (65+ years), and Māori, Pacific, European/Other, Asian and MELAA populations. NZDep23 deciles were used to indicate social vulnerability via socioeconomic deprivation. These layers contextualise heat exposure by capturing demographic sensitivity and social vulnerability, with the inclusion of ethnicity information, allowing for equity focused analysis of extreme heat exposure.
3. Overlaying extreme heat exposure and demographic vulnerability: SA2 quintiles, climate data and demographic data were analysed both separately and together to identify areas where risk factors accumulate. That is, where heat is concentrated geographically, as well as where social vulnerability may be highest. The analysis is descriptive and exploratory, couched within climate justice and intergenerational equity frameworks, reflecting gaps in New Zealand's extreme-heat evidence base.

Percentile thresholds capture local acclimatisation and are well suited to temperate climates where moderate absolute temperatures can still be hazardous when unusually high. This approach is increasingly used in New Zealand climate-health research (Harrington, 2021; Harrington & Frame, 2022).

Given the limited station network and the aim of national coverage at SA2 scale, nearest-station assignment in QGIS offers a straightforward method, that provides an appropriate indication of regional climatology. This pairs well with regional population demography that is easily accessible via census data.

3.4. Ethical considerations

Although this analysis is based solely on publicly available data, and therefore institutional ethical approval was not required to conduct this research, ethical considerations remain important. Heat vulnerability maps may inadvertently stigmatise communities if presented without context. Results are therefore shown at SA2 level, and interpretation is explicitly framed through an equity and justice lens. No individual-level data are used.

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Chapter 4: Results

4.1. Overview

The following chapter presents the results of the spatial and demographic analyses undertaken to assess regional vulnerability to extreme heat in New Zealand. It is structured around the three core research questions central to this thesis: (1) identifying regions most susceptible to extreme heat, (2) describing the geographic distribution of key demographic and ethnic groups across the country, and (3) exploring how geographic, demographic, and socioeconomic factors intersect to indicate vulnerability to New Zealand's changing climate.

4.2. Regional susceptibility to extreme heat

Using high-quality station observations over the last ten years, the following section presents a synthesis of extreme heat in New Zealand, experienced region-by-region. When evaluating the risks associated with high temperatures across summer periods, there are complex regional differences to consider (Harrington & Frame, 2022). Although overall, the country does not experience particularly high temperatures when couched in the global context, there has been a marked increase in temperatures across most of the country, even over the relatively short time period that has been analysed (Harrington, 2021).

4.2.1. Calculation of extreme heat thresholds

The 95th percentile values define the threshold above which a day is considered an "extreme-heat" day for each of the representative twenty-seven weather stations. The values provide the baseline for the subsequent spatial analyses of exceedance frequency across the country.

Table 1: Climate summary tables per region

Region	95th Percentile of Daily Maximum Temperature (°C)	Mean extreme heat days	Extreme heat days 2009/10	Extreme heat days 2018/19
Northland	28.2	4	6	12
Auckland	27.2	4.5	5	4
Waikato	27.6	4.4	0	10
Bay of Plenty	27.1	4.4	0	15
Gisborne	30.1	4.5	2	6
Hawke's Bay	30.8	4.5	1	9
Taranaki	25.6	4.3	3	3
Manawatu-Whanganui	27.3	4.5	1	5
Wellington	27.5	4.6	0	8
Nelson	26.1	4.6	3	13
Marlborough	30.5	4.4	1	17
West Coast	26.3	4.4	4	4
Canterbury	29.6	4.4	3	7
Otago	26.9	4.4	5	5
Southland	25.7	4.3	3	8

Across New Zealand, the 95th percentile thresholds for daily maximum temperatures show some regional variation despite the country's modest geographic size. The coolest thresholds (around 25-26°C) are found in southern and high-latitude regions such as Southland, Otago and parts of the West Coast, as well as Taranaki on the West Coast of the North Island. Taranaki's comparatively low threshold is notable given its mid-latitude position and likely reflects the strong maritime influence of the Tasman Sea, which may moderate summer maximum temperatures (Chappell, 1981).

In contrast, the highest thresholds, reaching 29°C or more, occur in the warmer, drier eastern regions, including Gisborne, Hawke's Bay, Marlborough and Canterbury. These areas experience greater solar exposure, lower humidity and more inland conditions, which elevate maximum temperatures (NIWA, n.d.). Overall, this spatial pattern highlights how New

Zealand's diverse topography and coastal influences structure thermal extremes, with local climatic conditions, rather than latitude alone, driving regional variation in heat thresholds.

4.2.2 Frequency of extreme heat days

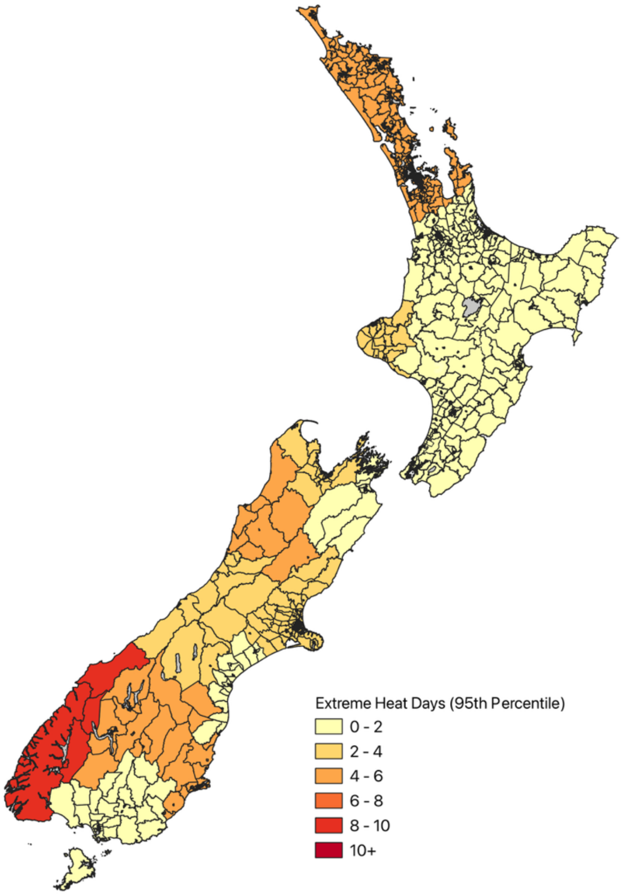

Figure 3: Number of extreme heat days, summer 2009/10

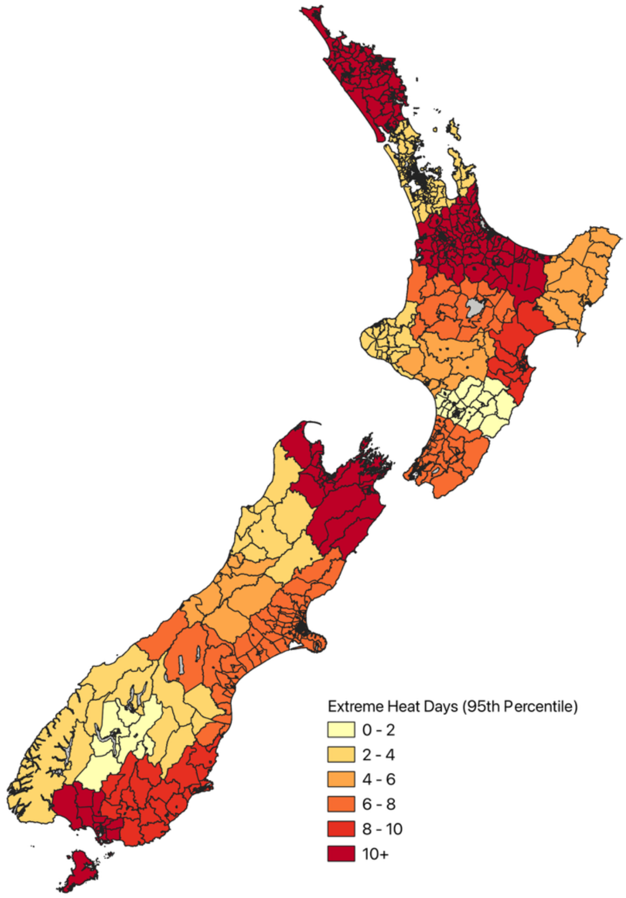

Figure 2: Number of extreme heat days, summer 2018/19

Figures 2 and 3 show the spatial distribution of extreme heat days for the two contrasting summers of 2009/10 and 2018/19. These maps offer a clear illustration of spatial and temporal variation in the frequency of extreme heat days across New Zealand between the two summer seasons.

In the summer of 2009/10, most regions experienced relatively low-to-moderate numbers of extreme heat days, with large areas of the North Island and coastal South Island falling within the 0-4 day range. Higher frequencies were concentrated in parts of the South Island, particularly Otago and coastal Southland, where several areas recorded between 6 and 10 extremely hot days. By contrast, the West Coast and Canterbury generally experienced fewer exceedances.

The summer of 2018/19 shows a markedly different national pattern, with substantially higher frequencies of extremely hot days across the entire country. Large portions of the North Island, including Northland, Waikato, Bay of Plenty and Hawke's Bay experienced between 6 and 10 extreme heat days, with some areas exceeding 10 days. In the South Island, elevated exceedance frequencies include Canterbury, Otago, Southland and Marlborough, indicating a more widespread and intense summer compared with that of 2009/10.

Comparing the two summers highlights interannual variability in climate. Inland and eastern regions of the South Island consistently exhibit higher frequencies of extreme heat days, reflecting greater temperature variability and continental influences (NIWA, n.d.). However, the extent and intensity of extreme heat exposure increased substantially in 2018/19 across both islands, with many regions shifting into higher exceedance categories relative to 2009/10.

As these maps are based on a relative temperature, the observed patterns differ from those based on absolute temperatures alone. Regions that are warm in absolute terms do not necessarily experience frequent extreme heat days if their summer temperatures are relatively stable or their thresholds are high (for example, Gisborne). Conversely, some cooler regions experienced a relatively high number of exceedance days, likely due to slightly lower thresholds (for example, Southland). Overall, the comparison between summers demonstrates that relative extreme heat exposure in New Zealand varies not only spatially, but also from year to year. These differences underscore the importance of considering interannual variability when assessing population exposure to unexpectedly hot conditions, rather than relying on long-term averages.

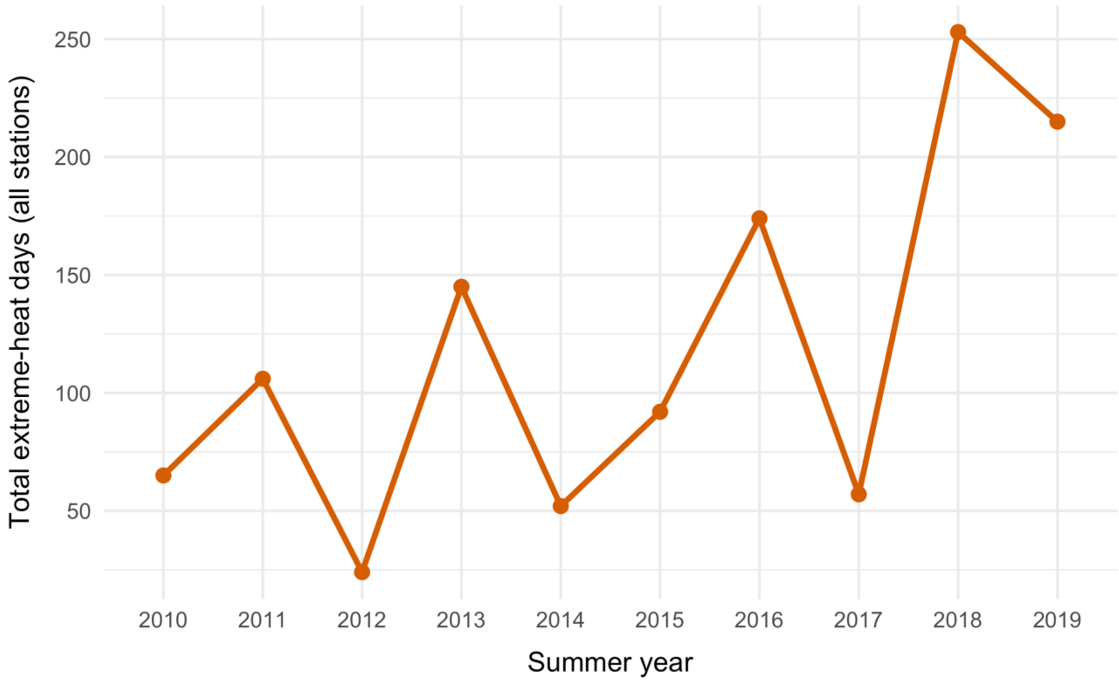

Figure 4: Days exceeding station-specific 95th percentile thresholds nationally per summer, 2009/10-2018/19.

Figure 4 illustrates considerable interannual variability in national extreme heat days, but with a clear shift upward over the decade. Summers early in the period (2010-2012) recorded relatively low national totals, typically 60 to 110 extreme heat days across all stations, before a marked increase from 2013 onward. While individual summers fluctuate substantially, the later years show notably higher totals, with 2016, 2018 and 2019 standing out as extreme years, reaching approximately 175, 250, and 215 days, respectively.

Although the series is short, the overall pattern is consistent with a rising incidence of extreme heat conditions nationally. The fact that these values are based on relative, station-specific 95th percentile thresholds means that the increase reflects more frequent exceedances of historically extreme local temperatures rather than changes driven by one or two particularly hot regions. The trend aligns with documented national warming of 0.1-0.3°C per decade (MfE, 2020), suggesting that extreme-heat events are becoming more common across New Zealand's diverse climates rather than being confined to isolated anomalous summers.

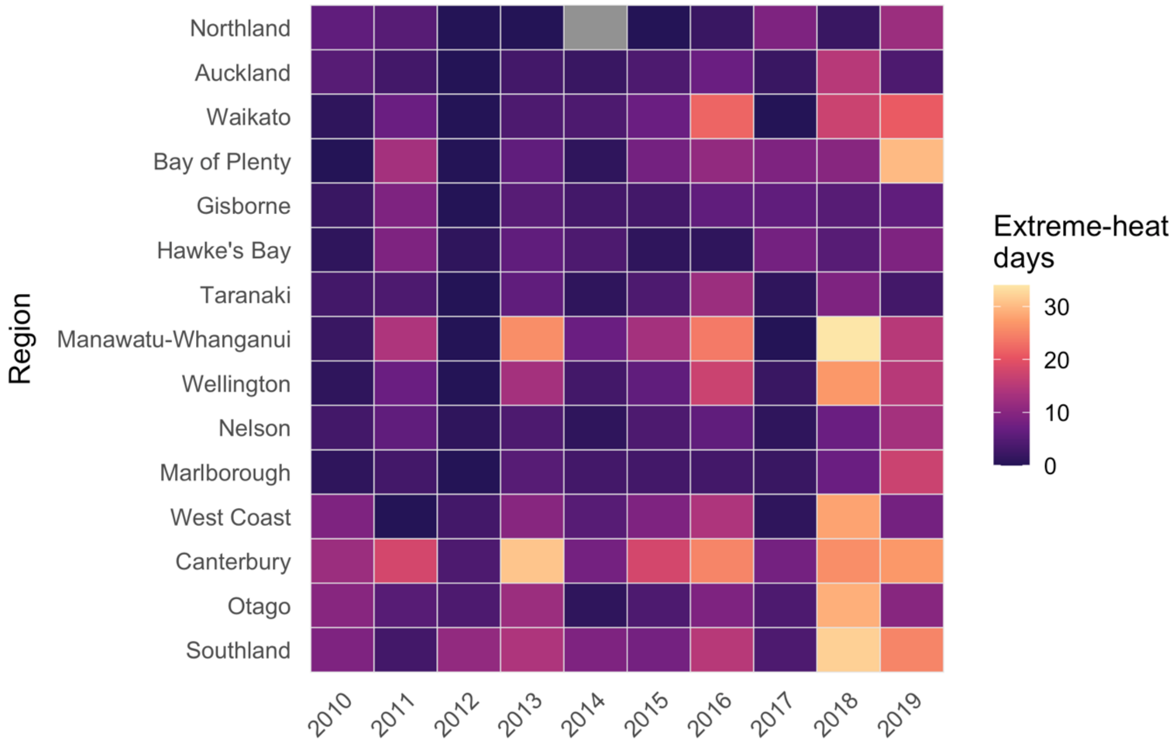

Figure 5: Heatmap of regional extreme heat days per summer (December-February, 2009/10-2018/19

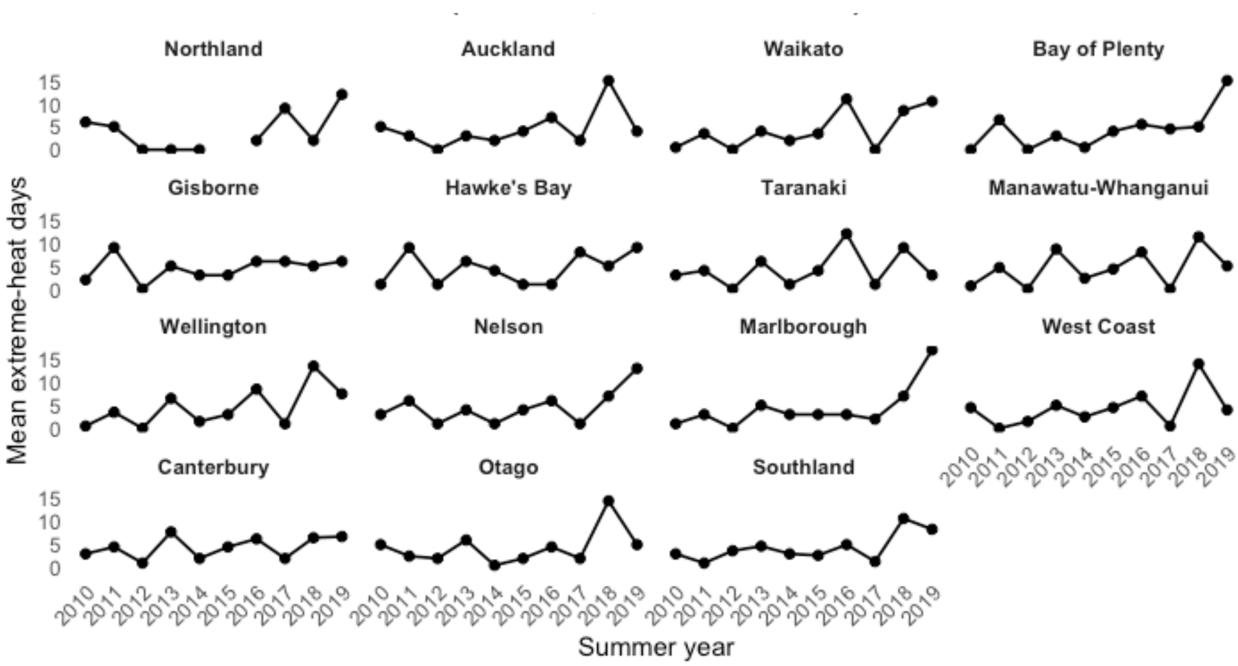

Figure 6: Faceted line chart of regional extreme heat days per summer (December-February, 2009/10-2018/19

Figure 5 displays regional extreme-heat days per summer (December–February) from 2009/10 to 2018/19. The heatmap highlights substantial spatial and interannual variability. Regional exposure to extreme heat is uneven but not strictly latitudinal. Some regions, including Manawatū–Whanganui, West Coast, Canterbury, and Otago frequently record higher counts of extreme-heat days across multiple summers, while others, such as Waikato and Bay of Plenty tend to record lower counts in many years but experience pronounced spikes during nationally warm summers. However, heat exposure is not monotonic over time; instead, distinct high-heat summers are visible across multiple regions. Several years stand out nationally, particularly 2013/14, 2015/16 and 2017/18–2018/19, which appear as vertical bands of intensified colour across the country. This indicates that extreme heat during these summers was geographically widespread rather than confined to isolated regions. In contrast, some regions, most notably Gisborne, Hawkes Bay and Marlborough show consistently low exceedance counts across the decade. This is notable as all three of these regions record the highest temperature threshold (all above 30°C).

A single gap is visible for Northland in 2013/14 (shown in grey), reflecting missing observations at Kerikeri station for that summer. This absence represents unavailable data rather than zero extreme heat days. Waikato also includes a station with a missing year (Hamilton 2011/12), but because regional values are averaged across multiple contributing stations, no visual gap appears for Waikato..

Figure 6 presents the same regional dataset in line-plot form to emphasise year-to-year variation within each region. Rather than demonstrating uniformly increasing trends, most regions exhibit variability punctuated by episodic peaks. For example, Manawatū–Whanganui, Southland and Wellington show pronounced spikes in 2017/18 and 2018/19, while Gisborne and Hawke's Bay appear comparatively stable across much of the period, aside from isolated higher years. The Northland gap in 2013/14 is again visible, reinforcing that this is a data absence rather than a climatic signal.

Taken together, Figures 5 and 6 show that extreme-heat exposure in New Zealand during 2009/10–2018/19 is characterised less by steady linear intensification and more by geographically uneven, episodic escalation. This spatial heterogeneity is central to understanding how climatic hazard interacts with demographic sensitivity and social vulnerability in subsequent analyses.

4.3. Demographic and ethnic distribution

This section outlines the spatial distribution of key demographic characteristics across New Zealand, focusing on age structure and ethnic composition. Understanding where different population groups are concentrated provides essential context for subsequent analyses that integrate demographic patterns with extreme heat exposure.

4.3.1. Age structure

This section examines the spatial distribution of children aged 0-14, and older adults aged 65 years and over, in each SA2, at the national level, using 2023 Census data from Statistics New Zealand.

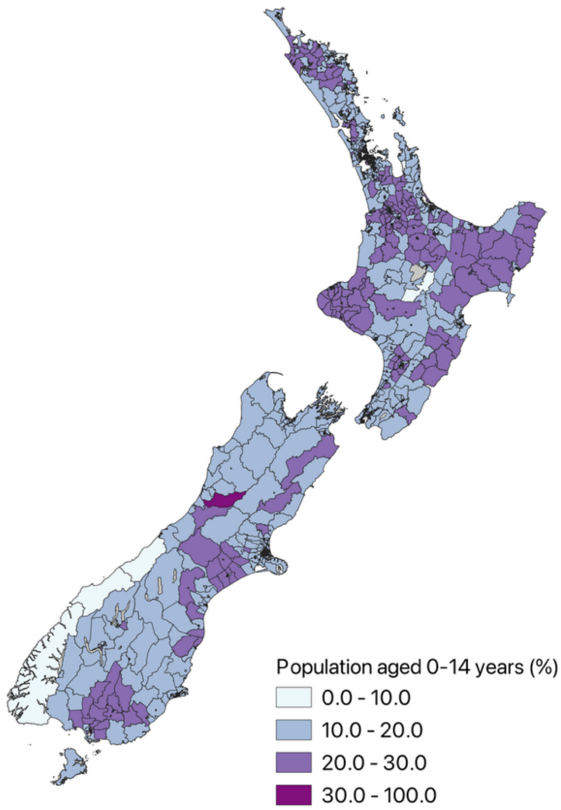

Figure 7: Percentage of population aged 0-14 years by SA2 (2023 Census)

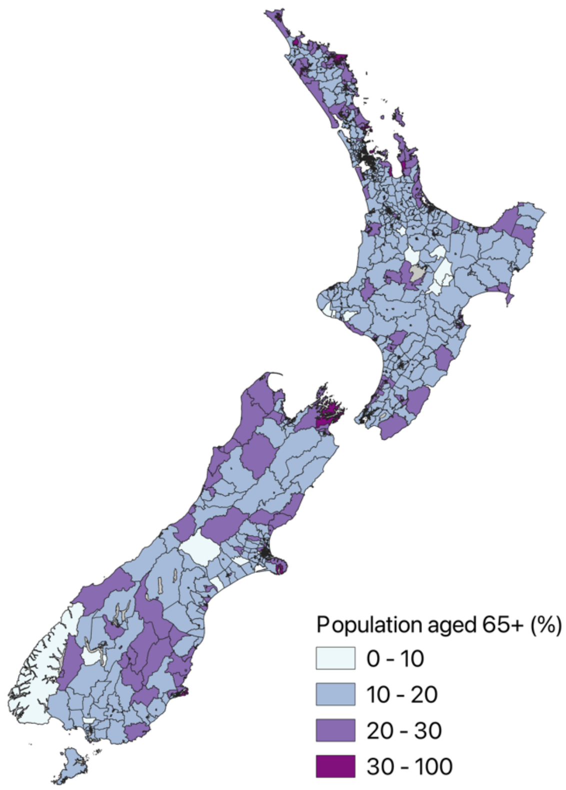

Figure 8: Percentage of population aged 65 years and over by SA2 (2023 Census)

Figure 7 illustrates that the highest proportions of children (30 percent and above) are concentrated in Northland, Gisborne, inland Bay of Plenty and parts of Waikato. By contrast, urban and higher income areas such as central Auckland, Wellington and Christchurch record the lowest shares of children (under 10-15 percent). Figure 8 shows the percentage of the population aged 65 years and older. Here, the opposite pattern emerges: older populations are heavily concentrated in the South Island and along coastal areas of the lower North Island, including Tasman, Marlborough, Canterbury and the Coromandel, where older residents account for over 30 percent of local populations. Younger and high-growth areas such as Auckland and Northland remain below 15 percent.

Together, the two maps highlight show a north-south gradient in age structure: northern and eastern regions are relatively young, while southern and some coastal regions are markedly older. This demographic divergence provides interesting insights into potential climate and population health vulnerability, as it shapes both exposure and adaptive capacity to extreme heat.

4.3.2. Ethnic Composition

To contextualise subsequent analyses on the social vulnerability to extreme heat in New Zealand, it is important to understand and describe the regional ethnic composition of the country. As regions differ substantially in total population size, this section focuses on within-region ethnic composition, rather than absolute counts. Presenting ethnicity as a percentage of each region's usual resident population allows for consistent comparison across regions and highlights relative demographic structure.

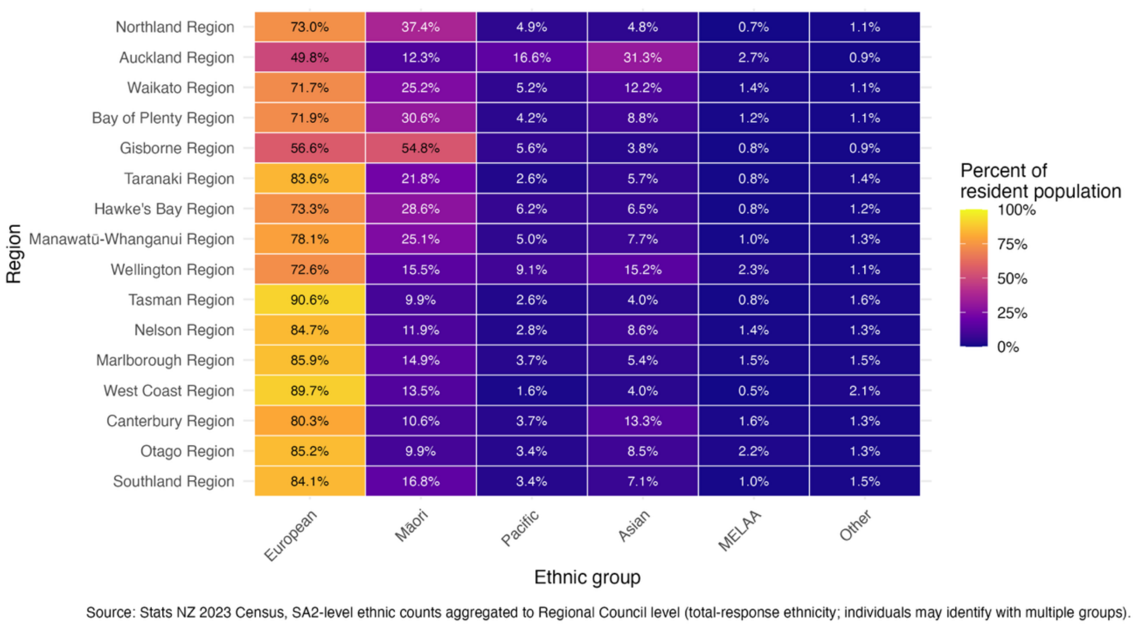

Figure 7: Regional ethnic composition in New Zealand – total response ethnicity. Percentage of usual resident population identifying with each ethnic group, aggregated from SA2 level (2023 Census).Row totals may exceed 100%.

Figure 9 presents a heatmap of regional ethnic composition based on total-response ethnicity from the 2023 Census. Ethnic counts were aggregated from SA2 to Regional Council level and expressed as the percentage of the usual resident population identifying with each ethnic group. Because ethnicity is reported on a total-response basis, individuals may identify with more than one ethnic group; consequently, percentages within a region may sum to more than 100 percent. This representation preserves the standard Census definition of total-response ethnicity while illustrating regional differences in the proportion of residents identifying with each group.

The heatmap shows clear regional variation in ethnic composition across New Zealand. Populations identifying as European comprise the largest share of residents in most regions, particularly across the South Island. Tasman, Nelson, Marlborough, Canterbury, Otago, Southland and the West Coast all have European proportions of approximately 80–90 percent. Similarly high proportions are observed in several central North Island regions, including Taranaki, Manawatū-Whanganui and Hawke's Bay. In contrast, Auckland has the lowest European share nationally (approximately 50 percent), reflecting its highly diverse demographic profile.

Māori population shares display a strong regional gradient, with the highest proportions observed in the upper and eastern North Island. Gisborne records the highest Māori share (approximately 55 percent), followed by Northland, Bay of Plenty and Waikato, where Māori account for roughly 25–37 percent of the resident population. Comparatively, several South Island regions have the lowest Māori proportions, including Tasman and Otago (approximately 10 percent).

Pacific populations are more spatially concentrated and strongly associated with major urban centres. Auckland stands out, with approximately 17 percent of its population identifying with Pacific ethnicities, substantially higher than any other region. Wellington has the second highest proportion (approximately nine percent), while most other regions have Pacific shares below six percent. Asian populations also show a clear metropolitan concentration. Auckland has the highest regional proportion identifying as Asian (approximately 31 percent), followed by Wellington (approximately 15 percent) and Canterbury (approximately 13 percent). In most other regions, Asian population shares remain below ten percent. Populations identifying with MELAA ethnicities remain small across all regions, generally accounting for one to three percent of resident populations, with the highest proportions observed in Auckland and

Wellington. The "Other" ethnic category also represents a small share nationally, with slightly higher proportions in several South Island regions.

Overall, this heatmap illustrates the spatial differentiation in ethnic composition across New Zealand. Northern and metropolitan regions tend to be more ethnically diverse, with higher proportional representation of Māori, Pacific, Asian and MELAA communities, while many South Island regions remain predominantly European. Establishing this regional demographic baseline is critical for interpreting subsequent analyses of heat exposure and vulnerability, as ethnic composition intersects closely with age structure, socioeconomic conditions and historical patterns of marginalisation, and help illustrate a picture of potential social vulnerability to extreme heat.

Ethnicity and age structure

As the threat posed by heat is highly age-sensitive, understanding the age composition of New Zealand's major ethnic groups is key as it helps to further develop the picture of the country's potential social vulnerability (Azan et al., 2025).

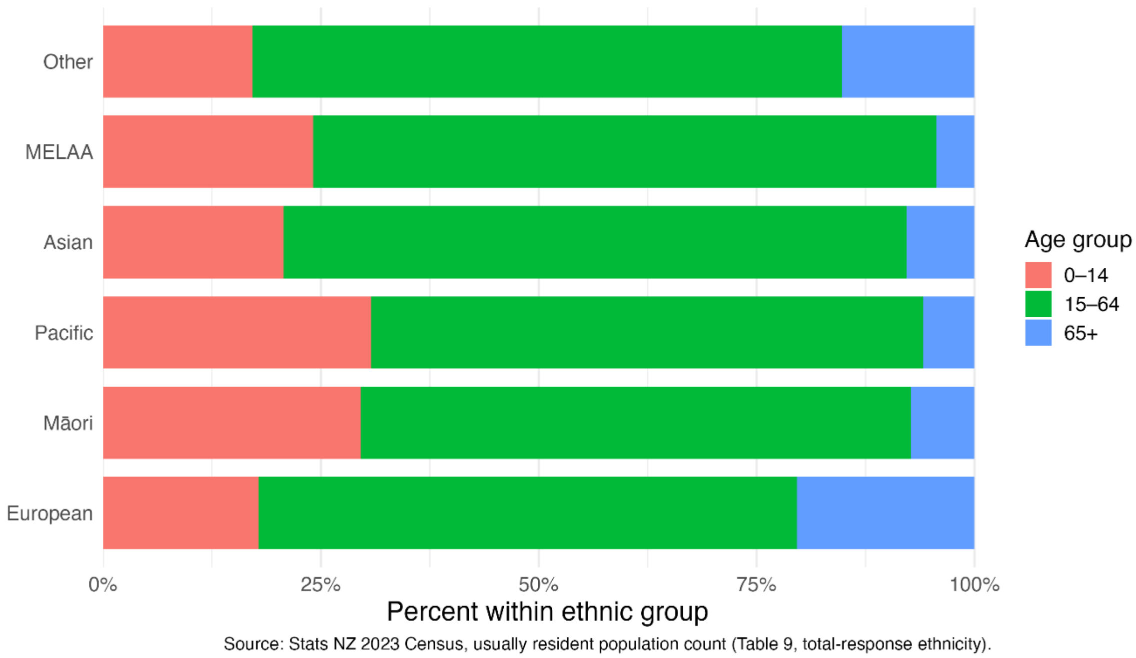

Figure 8: Age-ethnicity breakdown (2023 Census, total-response ethnicity)

Figure 10 presents the age-ethnicity composition of New Zealand's population as recorded in the 2023 Census. Each bar represents the proportion of people within each ethnic group belonging to three broad age bands: 0-14 years, 15-64 years and 65 years and over. The figure highlights the differences between ethnic groups in terms of age distribution. For example, populations identifying as Māori and Pacific peoples are markedly younger, with children (0-14) comprising roughly a quarter to a third of these populations, and comparatively small shares aged 65 years and over. In contrast, European populations are considerably older on average, with a large proportion of people aged 65 and over and a smaller population of children. Asian and MELAA groups display a more concentrated working-aged structure (15-64 years), perhaps reflecting more recent migration patterns and a relatively low proportion of older adults (Productivity Commission, 2021).

In Figure 11, the smoothed age-distribution ridge plot offers a more detailed view of how age is distributed within each ethnic group across the full life course.

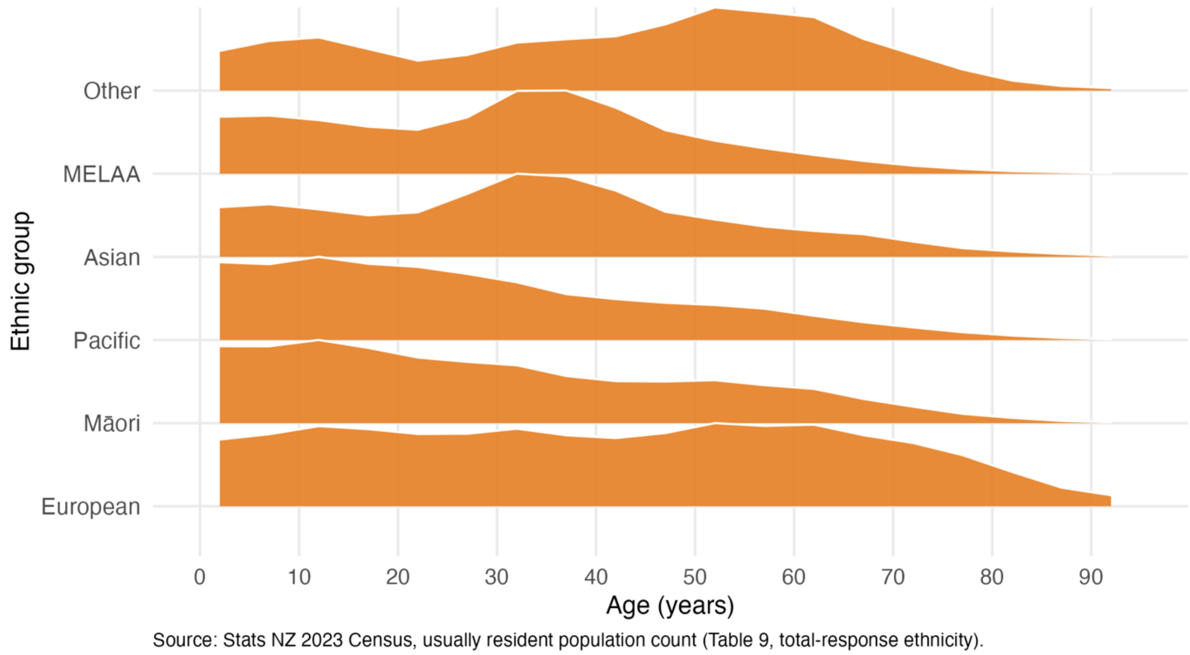

Figure 9: Age-ethnicity stacked bar chart (2023 Census, total-response ethnicity)

Figure 11 shows the relative concentration of populations at each five-year age interval. Māori and Pacific populations display relatively larger sized populations in the childhood and young adulthood years, with a much smaller proportion of people in the older age groups, reflecting their youthful population structures and lower proportion of older adults. Asian and MELAA groups exhibit a much larger proportion of people in the 25-45 age range. By contrast, the European population shows a more even spread across the middle and older ages, with a higher proportions in the 60-75 age range, indicative of sustained demographic ageing. The "Other" ethnicity category presents a mixed profile but similarly shows a higher proportion in older adulthood than Māori, Pacific, Asian or MELAA groups. Overall, Figure 11 reinforces the structural differences in age distribution between ethnic groups, illustrating how some populations, particularly Māori and Pacific children, and older European adults, are more heavily represented at ages associated with increased vulnerability to heat.

4.4. Intersection of heat exposure and vulnerability

4.4.1. Overview

This section overlays heat exposure with demographic structure to identify where physical and social vulnerability to extreme heat may intersect by examining the spatial co-distribution of mean summer extreme heat days (2009-2019) with the number and proportion of children (aged 0-14 years) and older adults (aged 65 years and over) within each SA2. This integrated approach highlights regions where both heat exposure and susceptibility coincide, signalling potential hotspots of climate-related health risk.

4.4.2. Intersection of heat exposure and age-based vulnerability in New Zealand

To examine how extreme heat exposure intersects with population vulnerability, Figures 12-15 present a series of quadrant plots comparing regional mean summer extreme heat exposure with the proportion of children (aged 0-14 years) and older adults (aged 65 years and over). Plots are shown for two contrasting summers: 2009/10 and 2018/19. In each plot, dashed vertical and horizontal lines indicate the national values for heat exposure and demographic composition, for that particular year, respectively. Regions positioned in the upper-right quadrant therefore represent areas with above-average heat exposure and above-average demographic vulnerability, while those in the lower-left quadrant experience below-average heat exposure and lower vulnerability. The size of each point reflects the total size of each regional population, allowing highly populated regions to be visually distinguished from smaller regions when interpreting potential population-level risk.

Heat exposure and child populations (2009/1 and 2018/19)

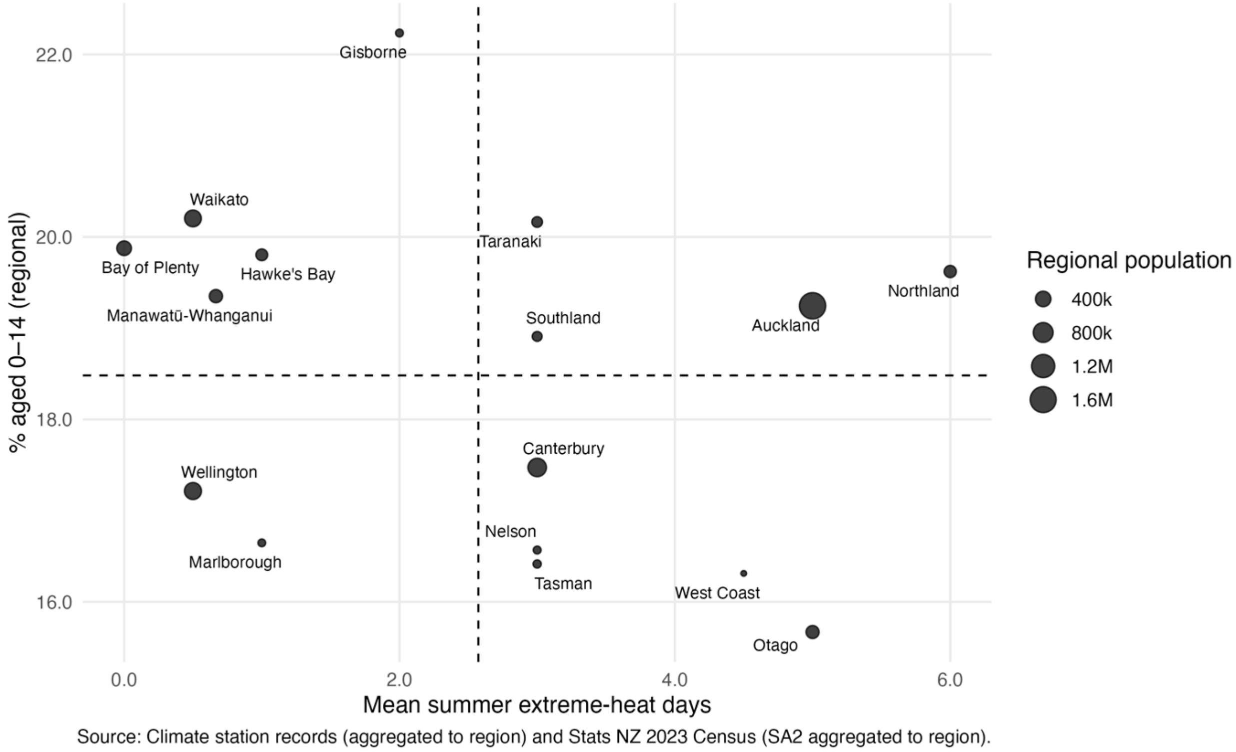

Figure 10: Heat exposure and vulnerability by region (summer, 2009/10), children 0-14 years

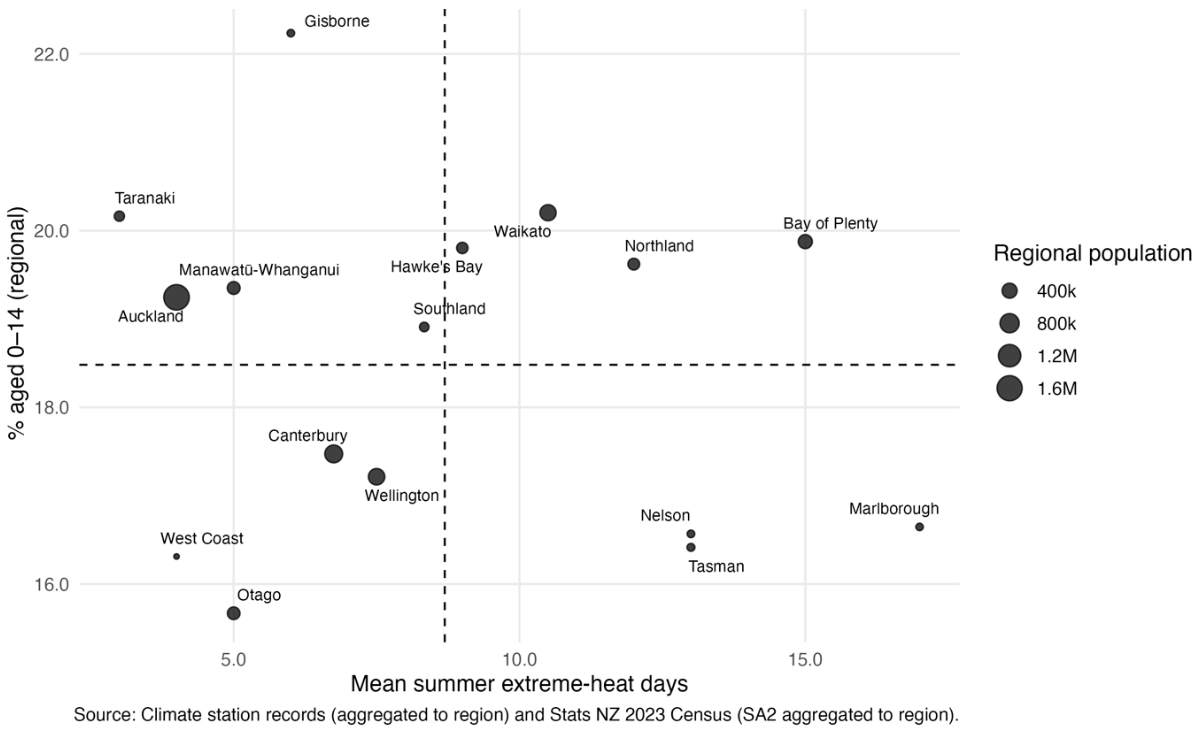

Figure 11: Heat exposure and vulnerability by region (summer, 2018/19), children 0-14 years

In the summer of 2009/10, most regions cluster just above or below average levels of mean summer extreme heat days, with modest separation along the exposure axis. However, there is considerable variation in the proportion of children across regions. Several North Island regions, including Gisborne, Waikato, Bay of Plenty and Hawke's Bay, are above the national mean for the proportion of children reflecting their younger age structures.

Despite this, only a small number of regions combine above-average child populations with above-average heat exposure in 2009/10. Northland, while experiencing higher heat exposure than most regions, sits closer to the national mean for child population share. Auckland, which has the largest total population, is positioned below the national mean for child population proportion despite moderate heat exposure, reflecting its comparatively older and more diverse age structure. South Island regions generally fall below the national mean for child population share, even where heat exposure is moderate to high, such as in Otago and Canterbury. Overall, the 2009/10 plot suggests limited overlap between high heat exposure and high child population vulnerability at the regional scale during this summer season.

By the summer of 2018/19, there is a shift in this pattern. Heat exposure is increased across nearly all regions, producing a clear rightward shift in the distribution of points (note the x axis is slightly different to accommodate the increase in days of exposure between the two years). Several northern and eastern North Island regions, including Bay of Plenty, Waikato and Northland, occupied the upper-right quadrant, combining above-average heat exposure with above-average proportions of children. Gisborne continued to exhibit the highest child population share nationally, although its relative heat exposure remained closer to the national mean compared with other northern regions. Note that the temperature threshold in Gisborne is one of the highest in the country (30.1°C), and so only using exceedance days as a proxy for heat vulnerability may obscure some potential vulnerability. Auckland experienced moderate to high-heat exposure but remains below the national mean for the proportion of children. Nevertheless, its large total population suggests that substantial absolute numbers of children may still be exposed to any extreme heat events, despite lower proportional vulnerability.

Overall, comparison across summers indicates an increase in the spatial overlap between higher child populations and higher heat exposure, particularly in the North Island, between the two years.

Heat exposure and older adult populations (2009/10 and 2018/19)

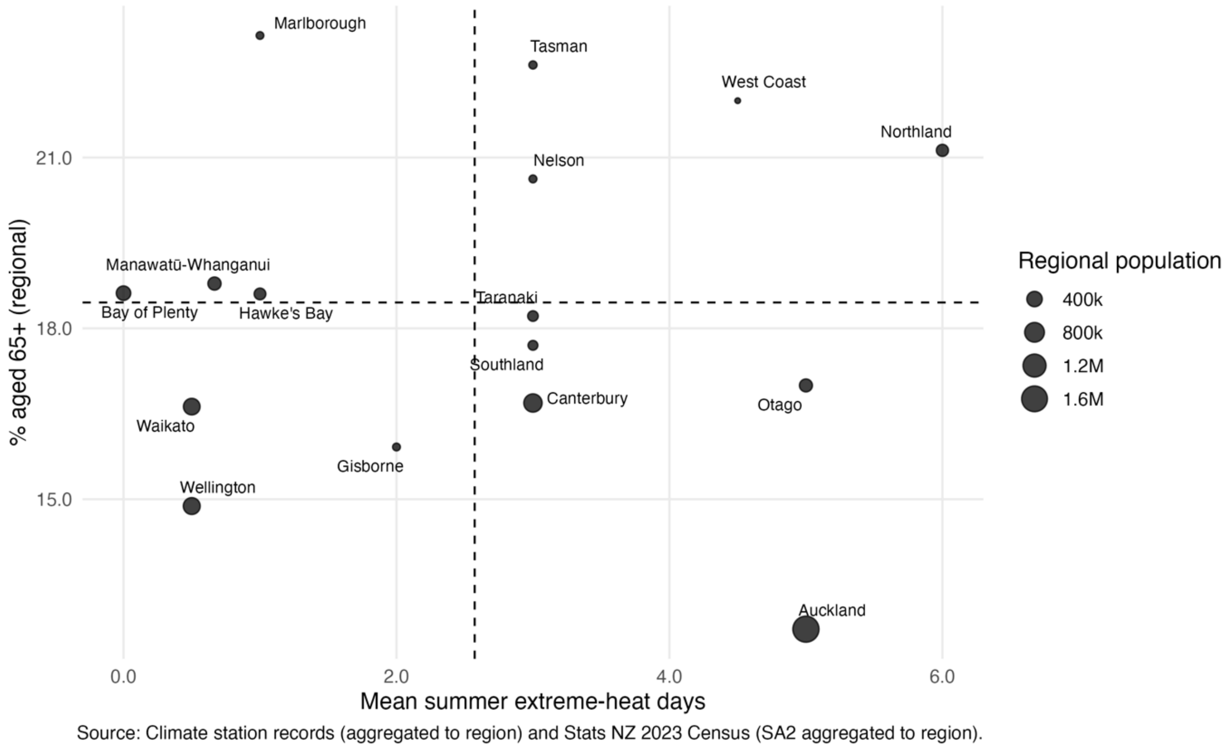

Figure 12: Heat exposure and vulnerability by region (summer, 2009/10), 65 years and over

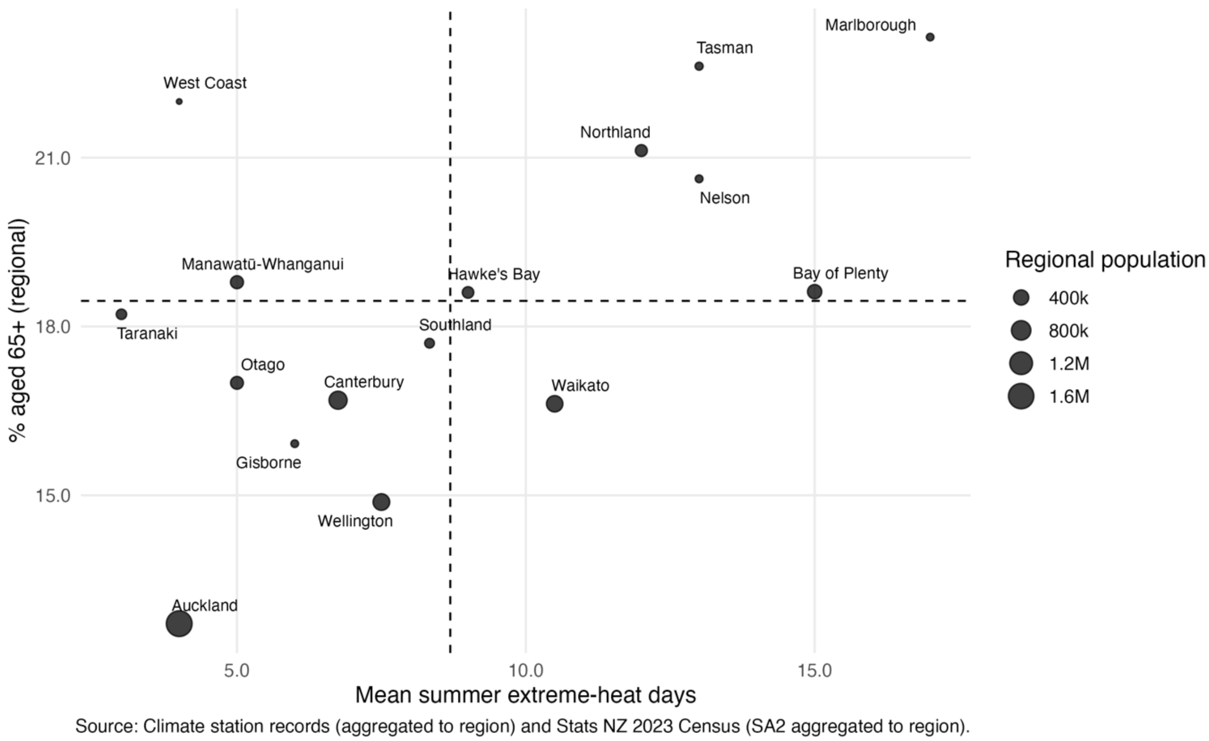

Figure 13: Heat exposure and vulnerability by region (summer, 2018/19), 65 years and over

Patterns for older adults differ notably from those observed for children. In 2009/10, regions with above-average proportions of older residents were primarily concentrated in the South Island and lower North Island. Marlborough, Tasman, Nelson and the West Coast all exhibited older population shares above the national mean, but these regions generally experienced low to moderate heat exposure. As a result, they were predominantly located in the upper-left-to-middle quadrant, indicating higher demographic vulnerability but lower exposure to heat.

Regions with higher heat exposure during 2009/10, such as Otago and Canterbury tended to have older population shares that were close to or below the national mean. Auckland again stood out as a highly populated region with relatively low proportions of older adults and moderate heat exposure. This configuration suggests limited overlap between heat exposure and older age-based vulnerability during this summer.

In 2018/19, increased heat exposure altered this relationship. Many regions with high proportions of older adults experienced substantially higher exposure to extreme heat, shifting several closer to, or into, the upper-right quadrant. Marlborough, Nelson and Tasman, in particular, combined high older population shares with elevated heat exposure, while the West Coast also experienced increased exposure relative to 2009/10. Marlborough is particularly noticeable as representing a significant share of 65's and over, as well as being the region with the second highest threshold in the country, behind Hawke's Bay, at 30.5°C. This centres it as a critical meeting point of climatic hazard in terms of extreme heat, and social vulnerability, due to its aged population. Bay of Plenty and Northland also emerge as regions of interest, combining above-average heat exposure with an older population share close to, or slightly above, the national mean. Overall, the comparison between summers indicates that interannual variability in heat exposure can substantially alter the degree of overlap between climatic risk and older population vulnerability, particularly in regions that are historically cooler but demographically older.

Taken together, the quadrant plots highlight that the intersection of extreme heat exposure and age-based vulnerability is both spatially uneven and temporally dynamic. Child vulnerability is most strongly concentrated in northern and eastern North Island regions, while older adult vulnerability is more prominent in the top of the South Island. Warmer summers, such as 2018/19, amplify these patterns by increasing heat exposure across all regions, bringing some historically lower-risk areas closer to conditions of combined vulnerability.

4.5. Socioeconomic deprivation and social vulnerability

This section examines the social vulnerability dimension of the conceptual model by examining the regional composition of socioeconomic deprivation using NZDep2023 quintiles. While Sections 4.2-4.4 mapped the climatic hazard (extreme heat exposure) and demographic sensitivity via age and ethnicity, NZDep provides a structural indicator of adaptive capacity. Figure 16 presents the regional distribution of socioeconomic deprivation using row-normalised percentages, showing the proportion of each region's population living in NZDep quintiles one (least deprived) through five (most deprived).

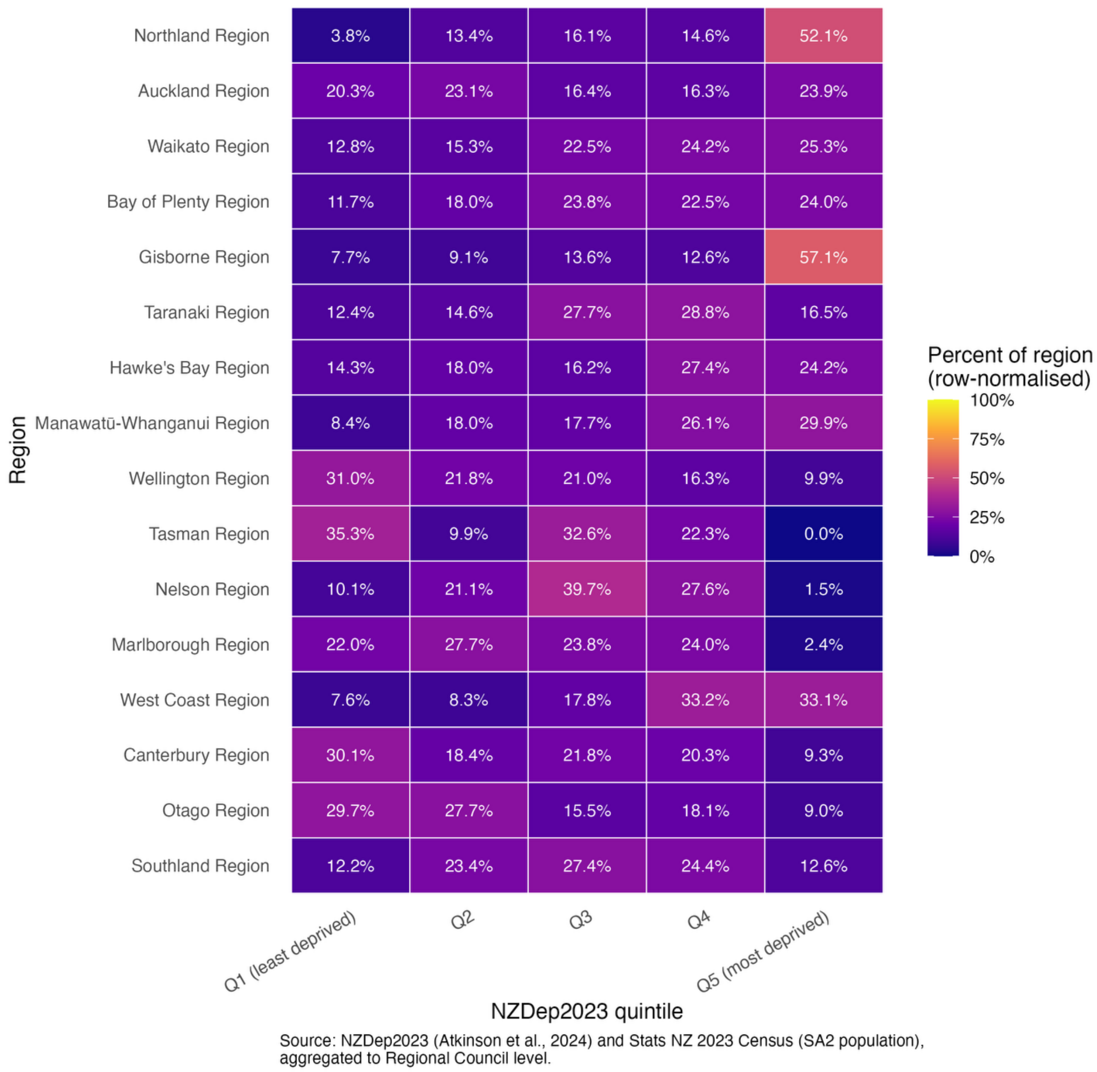

Figure 14: Regional deprivation composition in New Zealand (quintiles aggregated from SA2 level 2023)

4.5.1. Regional composition of socioeconomic deprivation

Figure 16 reveals marked regional variation in socioeconomic deprivation structure across New Zealand. Several northern and eastern North Island regions are characterised by high concentrations of population in the most deprived quintile (Q5). Northland and Gisborne stand out in particular, with over half of their populations residing in Q5 areas (52.1 percent and 57.1 percent respectively). Manawatū-Whanganui and the West Coast also show substantial proportions in Q5 (29.9 percent and 33.1 percent respectively). These regions exhibit relatively small shares in the least deprived quintile (Q1), indicating limited internal socioeconomic buffering.

In contrast, Wellington, Tasman, Canterbury and Otago display starkly different profiles. Wellington and Tasman have high proportions of residents in Q1 (31 percent and 35.3 percent respectively, and very small Q5 shares. Canterbury and Otago also show relatively high Q5 shares (30.1 percent and 29.7 percent respectively) and comparatively low Q5 concentrations (9.3 percent and 9.0 percent). These patterns suggest stronger regional socioeconomic advantage and potentially greater capacity to adapt to climate change at the area, or individual household level.

Auckland presents a more evenly distributed socioeconomic deprivation profile, with almost even populations across the five quintiles. While 23.9 percent of Auckland's population resides in Q5 areas, similar proportions are distributed across Q1 and Q2. This heterogeneity reflects Auckland's internal socioeconomic stratification and underscores the value of intraregional analysis when interpreting heat vulnerability in large metropolitan areas, particularly when considering urban heat islands (Oke, 1982).

4.5.2. Socioeconomic deprivation in relation to climatic hazard and demographic sensitivity

When considered alongside earlier findings on extreme heat exposure and demographic structure, the socioeconomic deprivation heatmap sharpens the picture of social vulnerability. Several regions identified as having elevated mean summer extreme heat days, including Northland, Bay of Plenty, and Gisborne, also have high concentrations of population in the most deprived quintile. In these areas, climatic hazard and structural disadvantage co-locate, suggesting the potential for constrained adaptive capacity in the face of increasing summer heat.

This overlap is particularly significant in regions that also have younger age structures and higher proportions of Māori residents, such as Northland, Bay of Plenty and Gisborne. Within the conceptual framework, these regions represent convergence zones where climatic hazard (extreme heat), demographic sensitivity (age and ethnicity), and social vulnerability (socioeconomic deprivation) intersect. The cumulative presence of these factors may amplify heat-related health risks for these populations.

In contrast, several South Island regions with high proportions of older adults, such as Tasman, Marlborough and Otago, tend to exhibit lower socioeconomic deprivation profiles. Although these regions demonstrate demographic sensitivity due to ageing populations, their relatively higher shares of Q1 and Q2 areas suggest potentially stronger socioeconomic buffering capacity. However, as shown in Section 4.4, warmer summers such as 2018/19 increase heat exposure even in these historically cooler regions, narrowing the spatial separation between hazard and vulnerability.

Overall, Figure 16 reinforces that heat vulnerability in New Zealand is a layered interaction of physical hazard, demographic composition and structural socioeconomic conditions. NZDep functions here as a proxy for adaptive capacity within the social vulnerability domain of the conceptual model, highlighting where limited material resources, housing quality and economic constraints may compound health risks posed by intensifying summer heat.

Chapter 5: Discussion

5.1. Overview

This thesis set out to examine how extreme heat exposure intersects with demographic and socioeconomic vulnerability across New Zealand, with a particular focus on age structure, ethnicity and socioeconomic deprivation at the regional level. Using integrated analyses of climate, census and socioeconomic deprivation data, the study aimed to identify the following research questions:

1. What regions in New Zealand are most susceptible to heat?
2. What is the geographic distribution of children (0-14), adults (15-64), and elderly (65+) populations and how does this intersect with ethnic composition?
3. What patterns can be identified at the intersection of geographic, age and ethnic data that illuminate where vulnerability is highest?

The results demonstrate that there is spatial variability in extreme heat exposure across New Zealand, both between regions and between summers. While long-term average exceedance frequencies varied within a relatively narrow range, analyses of contrasting summers revealed substantial interannual vulnerability, with the 2018/19 summer producing an increase in extreme heat exposure across both islands from the 2009/10 base summer. Inland and eastern regions of the South Island consistently experienced higher exceedance frequencies, while northern and central regions of the North Island also exhibited elevated exposure during hotter years. These findings underscore the importance of considering temporal variability, rather than relying solely on long-term means, when assessing heat-related risk.

Demographic analyses revealed strong geographic patterning in age structure and ethnicity. Children and Māori populations were concentrated in northern and eastern regions, while older populations were more prevalent in the South Island and coastal areas of the lower North Island. These patterns were shown to intersect with heat exposure in different ways across summers. In cooler years, overlap between high exposure and age-based vulnerability was limited, whereas in warmer summers, several regions shifted into conditions where above-average heat exposure coincided with higher proportions of children or older adults. Large urban regions such as Auckland remerged as distinct cases, where proportional vulnerability was lower, but absolute population exposure remained substantial due to population size.

The incorporation of socioeconomic deprivation added a further dimension to these patterns. Areas of higher socioeconomic deprivation were spatially clustered in several northern and eastern regions many of which had younger population structures, although heat exposure varied, and exceedance frequencies were lower (for example, in Gisborne and Northland). In contrast, many older and predominantly European regions in the South Island exhibited lower socioeconomic deprivation, and some of these regions experienced historically high heat exposure (for example, Canterbury and Marlborough). These results indicate that vulnerability to extreme heat in New Zealand is not evenly distributed, but instead shaped by the interaction of climatic exposure, demographic composition and socioeconomic conditions.

These findings both confirm and extend existing international research on climate-related vulnerability in temperate, high-income settings. Consistent with studies from comparable contexts, the results highlight the importance of social and demographic factors in shaping heat risk, even in regions with relatively moderate climates (Harrington, 2021; Paterson et al., 2020). At the same time, this thesis extends the literature by demonstrating how interannual variability in extreme heat can rapidly alter the geography of vulnerability, brining historically lower-risk areas into closer alignment with conditions of compounded exposure and susceptibility.

The remainder of Chapter Five interprets these findings in greater depth. Section 5.2 explores the spatial and demographic patterns observed, situating them within broader climatological and population contexts. Sections 5.3 and 5.4 apply climate justice and intergenerational equity frameworks to interpret the implications of these patterns, while Section 5.5 synthesises intersection inequities and compounded risks. The chapter then considers policy and planning implications, methodological limitations, and directions for future research, before concluding with reflections on the significance of these findings for climate-related population health risk in New Zealand.

5.2. Interpreting spatial and demographic patterns

5.2.1. Regional differences in extreme heat exposure

New Zealand's climate is fundamentally shaped by its position within mid-latitude westerlies and complex topography, leading to spatial heterogeneity in temperature variability (Renwick, 2011; Harrington & Frame, 2022). Synoptic circulation has been shown to produce coherent surface climate anomalies that vary regionally across the country, reflecting the influence of larger circulation patterns on local temperature and precipitation (Renwick, 2011; Krishna, et al., 2024). Climate classification studies indicate that while much of New Zealand falls within the temperate oceanic (Cfb) zone under the Köppen classification, orographic features and differential exposure to prevailing winds contribute to regional distinctions in vulnerability (Krishna, et al., 2024). National climatic summaries report that inland areas, particularly to the east of major ranges, exhibit larger daily and seasonal temperature variations than coastal locations, consistent with a relative reduction in maritime moderation (NIWA, n.d.). Observational examples, such as the inland town of Reefton, illustrate higher summer temperatures and greater diurnal temperature ranges compared with nearby coastal areas, further demonstrating these inland-coastal constraints (Macara, 2015).

The spatial distribution of extreme heat exposure observed in this study reflects both New Zealand's broad climatic gradients and more localised geographic influences (Macara, 2015). Across the analyses, inland and eastern regions of the South Island, particularly Canterbury and Otago, consistently exhibited higher frequencies of extreme heat days. These patterns align with established climate classifications, which identify these regions as more continental in character, with greater diurnal and seasonal temperature variability compared with coastal and western areas (Renwick, 2011; NIWA, n.d.). Reduced maritime moderations, combined with inland basin and plains topography, contributes to more frequent departures from local temperature norms during summer months (Renwick, 2011; NIWA, n.d.).

In contrast, western and southern coastal regions, including the West Coast and Fiordland, consistently experienced fewer extreme heat exceedances. These areas are strongly influenced by oceanic climates, with high cloud cover, frequent precipitation and relatively stable summer temperatures (NIWA, n.d.). Northern regions of the North Island, including Northland and parts of Gisborne, also displayed lower exceedance frequencies in some summers despite being among the warmest regions in absolute terms.

Urban areas present more complex patterns. Large metropolitan regions such as Auckland, Wellington and Christchurch did not consistently record the highest exceedance frequencies at the regional scale, although intraurban variation, is likely masked by regional aggregation. International literature highlights the role of urban heat islands in elevating local temperatures, particularly in densely built environments with limited vegetation and high impervious surface cover (Oke, 1982). While this study does not isolate urban microclimates, the results suggest that regional-scale analyses may understate heat exposure risks within cities, particularly for neighbourhoods characterised by dense housing, limited green space of high socioeconomic deprivation (Oke, 1982; Uejio, et al., 2011).

Importantly, the comparison between summers demonstrates that interannual variability substantially alters the geographic distribution of heat exposure. Warmer summers, such as 2018/19, produced widespread increases in exceedance frequency across both islands, reducing the distinction between historically cooler and warmer regions. That the summer of 2018/19 was much warmer than that of 2009/10, is consistent with national warming trends that show New Zealand's temperate is rising in line with global trends (Harrington & Frame, 2022; Climate Change Commission, 2021), but also highlights the merit of comparing specific years across time, not just long-term averages, in order to account for year-to-year variability.

Demographic vulnerability and age-based exposure

Patterns of demographic vulnerability intersect with heat exposure in ways that vary across space and time (Randell, 2022). Children and older adults, groups recognised as physiologically more sensitive to heat are unevenly distributed across New Zealand, creating different regional risks (Arpin et al., 2021; Mohamed et al., 2023; Osilla et al., 2023; Azan et al., 2023; Cole et al., 2023). Younger populations, including higher proportions of children, are concentrated in northern and eastern regions such as Northland, Bay of Plenty, Waikato and Gisborne. Older populations are more prevalent in the South Island and along coastal areas of the lower North Island, including Tasman, Marlborough, Canterbury and Wellington.

During the 2009/10 summer, the overlap between high heat exposure and age-based vulnerability was limited. Regions with younger populations did not consistently experience the highest exceedance frequencies, although absolute temperatures were still highest in these regions, while many older regions remained relatively cool. However, during the warmer summer assessed (2018/19), this separation is diminished. Several northern regions with younger age structures shifted into conditions of above-average heat exposure, increasing the potential for heightened risk among child populations. Similarly, some South Island regions with high proportions of older adults, experienced substantially higher heat exposure during warmer years, narrowing the historical exposure gap between north and south. In fact, some of the highest exceedance days, and absolute temperatures, were experienced across Tasman and Marlborough, both of which have high concentrations of older people.

These findings align with international evidence showing that heat-related vulnerability is not static, but is highly sensitive to temporal variability and exposure (Randall, 2022; Pearce, et al., 2020). For example, Auckland consistently exhibited lower proportions of children and older adults relative to other regions, yet its large population size implies that substantial numbers of vulnerable individuals may still be exposed to extreme heat during warmer summers. This distinction is critical for interpreting risk in urban settings and informing population-level health planning (Randall, 2022; Uejio, et al., 2011).

Socioeconomic context and exposure to extreme heat

Socioeconomic deprivation in New Zealand tends to be concentrated spatially, and is especially prevalent in Northland, Gisborne and South Auckland, as reflected in NZDep (Atkinson & Crampton, 2019). Each of these areas has a high concentration of Māori and Pacific peoples (Atkinson & Crampton, 2019). These regions also tend to have high rental costs relative to average income; in Gisborne for example, the rent share of income from an average job was consistently around 50-55 percent between 2020 and 2025 (Faulkner & Squires, 2025).

These spatial patterns of socioeconomic deprivation align closely with the distribution of demographic vulnerability and, in several regions, with elevated exposure to heat. Areas of higher socioeconomic deprivation are concentrated in northern and eastern regions of the North Island that also exhibit younger age structures and high proportions of Māori populations (Atkinson & Crampton, 2019). During warmer summers, many of these areas experience relatively high frequencies of extreme heat days, increasing the potential for compounded vulnerability (Randell, 2022).

Studies from Australia, Europe and North American demonstrate that socially disadvantaged communities are at much higher risk of poor health outcomes when exposed to higher ambient temperatures, due to their inability to mitigate or adapt to the heat because of factors such as housing quality, limited access to cooling and constrained health and social resources (Ogunbode et al, 2024; Klinenberg, 2003; Robine et al., 2008; Coates et al., 2014). Although New Zealand's climate is comparatively temperate, the results of the study indicate that similar social gradients in exposure and vulnerability may be replicated here and are key to public health planning.

In contrast, many regions with older populations, particularly across the South Island and coastal lower North Island, tend to exhibit lower levels of socioeconomic deprivation. These areas are predominantly European in composition and many of these areas experienced lower levels of extreme exposure, and lower absolute temperatures. As a result, demographic vulnerability associated with older age is somewhat moderated by lower levels of socioeconomic deprivation and cooler climatic conditions. Examining data relating to the 2018/19 summer it appears that hotter summers narrow this separation, bringing some older, less deprived regions closer to conditions of elevated exposure, particularly in inland and eastern areas.

Highly urbanised regions present more complex and heterogeneous patterns. In cities such as Auckland and Wellington, areas of high socioeconomic deprivation are spatially embedded within broader metropolitan regions that experience moderate to high heat exposure. This intra-urban variation mirrors international findings that neighbourhood-level socioeconomic conditions shape heat risk within cities, often more so than regional climate alone (Oke, 1982; Randell, 2022). As such, regional-scale analyses may obscure fine-scale inequities in exposure that are concentrated in spatially small, deprived urban communities, such as neighbourhoods within South Auckland (Zhao, et al., 2024).

Overall, the alignment between higher socioeconomic deprivation, younger age structures and elevated heat exposure in several regions highlights the importance of considering social context when assessing climate-related health risk (Randell, 2022; Lawrence, et al., 2017). The results reinforce evidence from other high-income settings that socioeconomic deprivation acts as a key modifier of heat vulnerability, shaping both exposure and capacity to respond (Uejio, et al., 2011; Zhang, et al., 2024) . In the New Zealand context, these patterns suggest that heat-related risk is likely to be experienced unevenly, with socially disadvantaged communities facing disproportionate challenges as extreme heat events become more frequent and/or intense (Zhang, et al., 2024).

Housing and infrastructure

The spatial patterns of heat exposure and demographic vulnerability identified in this thesis must be understood within the context of New Zealand's housing stock and supporting infrastructure, which play a critical role in mediating exposure to temperature extremes. Housing quality, thermal performance and access to energy are well-established social determinants of health, shaping the extent to which households are able to maintain safe indoor temperatures during extreme weather events (Howden-Chapman et al., 2023; Chen, et al., 2025). In the New Zealand context, longstanding deficiencies in housing quality, due to a nationally low replacement rate and lack of maintenance, mean that climatic exposure is unlikely to translate uniformly into experienced heat stress across different populations (Chang-Richards, et al., 2018).

New Zealand's housing stock is old, with a large proportion built prior to the introduction of modern insulation and thermal performance standards (Chang-Richards, et al., 2018; Howden-Chapman, et al., 2023). Poor insulation, inadequate ventilation and limited shading are widespread, particularly within the private rental sector, which is disproportionately occupied by Māori, Pacific peoples and low-income households (Statistics New Zealand, 2020; Howden-Chapman et al., 2023). While much of the national discourse has historically focused on cold and damp housing, the same structural deficiencies also increase vulnerability to extreme heat by limiting a dwellings ability to buffer outdoor temperature fluctuations. Housing that performs poorly in winter is similarly ill-equipped to maintain safe indoor conditions during hot weather (Chen, et al., 2025).

These issues are particularly relevant in regions identified in this thesis as experiencing both elevated heat exposure and higher socioeconomic deprivation, such as Northland, Gisborne and parts of Bay of Plenty. In these areas, younger populations and higher proportions of Māori and Pacific households are more likely to live in rental or overcrowded housing with limited capacity for cooling (Statistics New Zealand, 2020; Statistics New Zealand 2020; Chen, et al., 2025). During warmer summers, this creates conditions in which children may be exposed to prolonged indoor heat stress, even where absolute outdoor temperatures are moderate by international standards (ECSC, 2023; Gao, et al., 2014).

Energy hardship further compounds these risks. Households experiencing financial strain may be unable to afford electricity for cooling, or may limit use of fans or air conditioning during heat events in order to manage costs (Chen, et al., 2025). This constraint is most pronounced among low-income renters and households already experiencing high housing cost burdens, which are spatially concentrated in many of the same regions identified as highly deprived (Chen, et al., 2025; Hu, et al., 2022). As a result, the capacity to adapt to extreme heat through behavioural or technological means is unevenly distributed, reinforcing the patterns of compounded vulnerability observed in this study (Hu, et al., 2022).

Older populations face a different but related set of challenges. While many older New Zealanders live in regions that have lower heat exposure, warmer summers increasingly expose these populations to unfamiliar heat stress. Age-related physiological vulnerability, combined with housing that lacks effective cooling or ventilation, may increase risks for older adults, particularly those living alone or in poorly maintained dwellings. Although many older populations reside in less deprived areas overall, there are many pockets of older renters and energy-poor households that remain vulnerable, particularly in regional centres as well as rural areas (Chen, et al., 2025). Overcrowded homes are often multigenerational, so elderly people living in these environments are also at elevated risk of heat stress (Allen, et al., 2025). This is particularly dangerous as it can exacerbate common health problems in older people such as diabetes, kidney disease and heart disease, and puts pressure on often already stretched health systems (Osilla et al., 2023; Cole et al., 2023).

Taken together, these findings suggest that housing and infrastructure act as critical mediators between climatic exposure and health risk in New Zealand. Extreme heat does not occur in a social vacuum; rather, its impacts are shaped by the thermal quality of dwellings, tenure security, affordability and access to energy. The spatial alignment of higher heat exposure, socioeconomic deprivation and the potential exposure to substandard housing conditions indicates that existing housing inequities are likely to amplify the health impacts of extreme heat as temperatures continue to rise.

Comparative insight from similar temperate contexts

The climatic patterns identified in this thesis align closely with international evidence from other temperate countries who are also experiencing warming over time, indicating that New Zealand is not an outlier, but rather at an earlier point in a trajectory that is already documented elsewhere. In nations historically characterised by cooler climates, such as the UK, northern Europe, and parts of both Japan Australia, extreme heat has transitioned from an episodic anomaly to a persistent public-health risk (Uryu, et al., 2021; Coates et al., 2014; Grantham Institute, 2025; Vicedo-Cabrera et al., 2023). The ways these countries have experienced, responded to, or struggled with this shift, provide insight into preparedness gaps in New Zealand that must be addressed.

A central finding across international studies is that even modest increases in summer temperatures can trigger significant excess morbidity and mortality in populations physiologically unaccustomed to heat (Randell, 2022; Paterson, et al., 2020;). The UK and northern Europe offer a clear analogue for New Zealand: both regions have temperate climates, ageing populations and historically limited community-level acclimatisation (Paterson, et al., 2020; Clarke, et al., 2025). During critical heatwaves of this century, in Europe, Australia and the United States, excess mortality was concentrated among older adults and those with pre-existing health conditions, despite absolute temperatures that would be considered moderate in warmer global regions (Robine, et al., 2008; Clarke, et al., 2025; Grantham Institute, 2025; Randall, 2022; Cheng, et al., 2018) . This mirrors the pattern observed in this analysis, where small relative departures from local climatology, not extreme absolute temperatures, are sufficient to elevate exposure and push vulnerable groups, especially older adults, into risk conditions. The parallel suggests that New Zealand's cool maritime profile does not confer meaningful protection once temperatures begin to exceed locally normal thresholds, particular as the country warms in line with global climate change (Cui, et al., 2020; Harrington, 2021).

Research from Australian cities shows that ageing interacts with socioeconomic inequalities, particularly housing quality and air-conditioning access, to produce concentrated pockets of vulnerability, even where national adaptation systems are relatively mature (King & Harrington, 2009; Loughnan, et al., 2013; Coates, et al., 2014). This resonates strongly with the findings in this analysis for New Zealand. That is, areas with higher socioeconomic deprivation, poorer housing stock and higher proportions of Māori and Pacific households correspond closely with areas of elevated exposure in warm summers. The Australian experience demonstrates that structural factors, and not only heat intensity, determine the scale of harm, strengthening the argument that New Zealand cannot rely on its historically milder climate for protection (King & Harrington, 2009).

Japan provides another relevant comparison point, particularly for understanding how demographic ageing magnifies heat-related risk. Despite substantial investment in heat-health warning systems, public education and urban cooling strategies, Japan continues to record high rates of heat-related emergency callouts and mortality among older adults (Uryu, et al., 2021). This pattern reflects the physiological and social dimensions of ageing and indicates that adaptation cannot fully offset the increased burden created by demographic change (Uryu, et al., 2021; Cheng, et al., 2018). In New Zealand, as the European population continues to structurally age, regions currently exhibiting low exposure during cooler summers may still face increasing health, and health systems, impacts simply because their population profiles are shifting.

Across these international cases, it is notable that nations, even if relatively temperate, can be disproportionately affected by heat because their infrastructure, housing, public-health systems and social norms were not designed for warmer conditions (Uryu, et al., 2021; Cheng, et al., 2018; Loughnan, 2013). New Zealand displays many of the same features. Housing built for cold, damp winters performs poorly in summer heat; air-conditioning is uncommon outside commercial buildings; and national guidance on heat-health protection remains fragmented or provisional (HUD, 2023; Royal Society, 2021; Baker & Howden-Chapman, 2012; Ministry of Health, 2024). Comparative evidence suggests that once relative heat exposure increases, these structural characteristics sharply elevate risk, particularly in deprived communities and among children and older adults (Randell, 2022; Azan, et al., 2025; Cheng, et al., 2018). This supports the argument that New Zealand must proactively develop heat-health strategies before exposure intensifies further.

As with all countries, New Zealand has its own spatial patterns of vulnerability, which are shaped by its own ethnic and socioeconomic inequalities. The findings of this thesis show that Māori and Pacific populations, already experiencing material socioeconomic deprivation and poorer housing conditions, are located in regions where warm-summer exposure can climb rapidly (Parsons, 2024). Comparable patterns are evident in Indigenous communities in Australia and First Nations communities in Canada where structural inequities often magnify heat vulnerability (King & Harrington, 2009; Ford, et al., 2018). New Zealand therefore aligns with broader international evidence while underlining the specific need for Te Tiriti-consistent, equity-focused adaptation approaches (Climate Change Commission, 2021; Parsons, 2024; Sheridan, et al., 2024).

Taken together, international experience reinforces that New Zealand is entering a phase already visible in other high-income temperate countries, where demographic change, inequity, and rising temperatures interact in ways that substantially elevate heat-related health risk. What distinguishes countries that have mitigated heat-related harm is the strength of their public-health infrastructure, housing quality, urban design, and capacity to incorporate equity into adaptation planning (Loughnan, et al., 2013; Cheng, et al., 2018; Lawrence et al., 2017; Spangler, et al., 2019). New Zealand's early-stage position presents an opportunity to learn directly from international trajectories, implementing critical policy and infrastructure now, to avoid repeating the severe health burdens documented elsewhere.

These findings demonstrate that extreme heat vulnerability in New Zealand emerges not from climate alone, but the interaction of climate variability, demographic structure and socioeconomic conditions, including access to quality housing. Understanding these intersecting drivers provides a foundation for the subsequent discussion, which reframes these results through the lens of climate justice and intergenerational equity, and considers their implications for adaptation planning and public health in a warming climate.

5.3. Applying a climate-justice framework

The spatial and demographic patterns identified in this analysis lend themselves strongly to interpretation through a climate-justice framework. Climate justice provides a lens for examining how risks are distributed, whose experiences and knowledge systems are recognised, and who participates in shaping adaptation responses (Ogunbode, et al., 2024; Dolšak, et al., 2022). As outlined in the literature review, climate justice is typically conceptualised through three interconnected dimensions: distributional justice (who bears the risks and who benefits from protection), recognitional justice (whose identities, histories and forms of knowledge are acknowledged and valued), and procedural justice (who has decision making power) (Ogunbode, et al., 2024; Parsons, 2024; Dolšak, et al., 2022). Applying this framework to extreme heat in New Zealand highlights that vulnerability is not only a function of climatic exposure, but a product of structural inequities, institutional arrangements and political choices.

5.3.1. Distributional justice: unequal exposure and capacity to cope

Distributional justice concerns the equity of risk and protection (Ogunbode, et al., 2024; Bessant, et al., 2025). This is critically important in the context of this analysis, given the spatial alignment between socioeconomic deprivation, Māori and Pacific populations, and higher levels of heat exposure in several regions. Younger, more socioeconomically deprived populations are concentrated in Northland, Bay of Plenty and Gisborne in particular, all of which have experienced elevated exceedance frequencies as the temperature has risen over time. These geographic patterns echo the structural inequities identified in the literature that demonstrate that heat risk concentrates where poor housing, limited green space and economic disadvantage converge (Randell, 2022; Klinenberg, 2002; Robine et al., 2008; Rickards &

Watson, 2020 Reid, 2019; Auckland Council, 2024). The findings in this thesis ground this dynamic in a real world context. That is, the clustering of socioeconomic deprivation across the country, higher proportions of Māori and Pacific families, and younger age structures often overlap with higher heat exposure.

In contrast, many older populations live in regions with historically cooler temperatures, lower socioeconomic deprivation, and higher proportions of Europeans. Under typical conditions, this offers a degree of climatic buffering. However, the 2018/19 summer demonstrates that this protection is fragile. Regions such as Tasman and Marlborough, both with high proportions of older adults, experienced significantly higher exceedance frequencies during the warmer summer of 2018/19. This underscores the justice concern that older adults, despite living in comparatively more advantaged areas across the country, may still face acute vulnerability during extreme summers. However, on the whole, this is due primarily to physiological sensitivity and geographic concentration, as opposed to structural inequities (Cheng, et al., 2018). There is also precedent to suggest that this group is more likely to experience governmental protection in the face of heightened risk, than younger, more disadvantaged communities of colour (Randell, 2022).

The distributional patterns observed across this analysis are therefore not incidental; they reflect embedded social and economic structures that determine where people live, the quality of infrastructure available to them and their capacity to adapt. Extreme heat interacts with these structures in ways that reinforce pre-existing inequities, which is a hallmark of unjust climate impacts (Ogunbode et al., 2024; Klinenberg, 2002; Robine et al., 2008; Randell, 2022).

5.3.2. Recognitional justice: knowledge, histories and values that shape adaptation

Recognitional justice examines who is acknowledged in planning processes, whose experiences are centred, and whose ways of knowing are considered legitimate (Ogunbode et al., 2024; Bessant, et al., 2025). The patterns identified in this study highlight several recognitional gaps in current climate and population health adaptation responses. Although Māori and Pacific peoples are disproportionately represented among populations residing in regions with higher socioeconomic deprivation and higher heat exposure during warmer summers, their voices remain inconsistently integrated into national and local adaptation planning (Climate Change Commission, 2021; Parsons, 2024). This aligns with broader patterns of neglect across different facets of national and regional policy in New Zealand (Sheridan, et al., 2024). The literature review emphasised that climate change in New Zealand must be understood through the legacies of colonisation, dispossession and systematic racism, as these forces continue to shape exposure, sensitivity and adaptive capacity today (Parsons, 2024; Reid, et al., 2019; Climate Change Commission, 2021). Despite this, meaningful engagement and partnership with Māori in designing policy responses to climate change remain limited (Parsons, 2024).

National policy documents, including the Health National Adaptation Plan (HNAP), signal the need for partnership with Māori and the importance of Te Tiriti o Waitangi (Ministry of Health, 2024). However, recognitional justice requires that Māori and Pacific worldviews are prioritised, ensuring their knowledge systems genuinely inform adaptation strategies (Ogunbode, et al., 2024; Parsons, 2024). The absence of Māori data sovereignty structures in heat-health surveillance, the limited involvement of iwi-Māori partnership in planning for climate and population health risks, and the under-recognition of community-defined adaptation strategies all indicate that recognitional justice is only partially embedded (Climate Change Commission, 2021). Similarly, Pacific communities, particularly those living in areas of high socioeconomic deprivation in Auckland, are central to the observed patterns of risk, yet their cultural perspectives, collective living arrangements and climate-related concerns are not systematically incorporated into planning frameworks (Pacific Perspectives, 2019). Without these recognitional dimensions, adaptation policy risks reproducing the same inequities that shape vulnerability to heat in the first place (Dolšak et al., 2022).

5.3.3. Procedural justice: voices that shape decision making

Procedural justice concerns the fairness of governance processes, who participates, whose voices are empowered, and whose concerns drive policy decisions (Ogunbode, et al., 2024). Despite significant demographic and social differences across regions, heat adaptation planning remains largely top down (Ministry of Health, 2024; Climate Change Commission, 2021). National frameworks, such as the HNAP, provide important direction but limited operational clarity, resulting in fragmented local responses. Where communities face the highest compounded vulnerabilities, for example, in Northland or Gisborne, procedural pathways for meaningful participation remain limited (Parsons, 2024). In contrast, in areas with older, whiter populations, there are much higher reported rates of participation in local and national government processes and representation (Statistics New Zealand, 2018).

Local government processes often privilege technical expertise and established planning structures, which may inadvertently exclude Māori, Pacific and low-income communities (Zhang, et al., 2024). Procedural inequity, also reflects who is not visible in data. The absence of systematic heat-health surveillance means that those most affected, young children, older adults, people in substandard housing or experiencing energy hardship, are not identifiable in current monitoring systems, reducing their ability to influence adaptation priorities (Ministry of Health, 2024). Procedural justice requires institutional mechanisms that ensure Māori governance structures, Pacific organisations, local communities and groups representing children and older adults are systematically involved in shaping climate and population health responses (Ogunbode et al., 2022; Parson, 2024). Without these mechanisms, adaptation planning risks reinforcing existing inequities rather than addressing them.

Positioning New Zealand within global climate-justice dynamic

Viewed collectively, the spatial patterns observed in this thesis show clear evidence of climate-justice concerns emerging even within a temperate, high-income context.

- Distributionally, regions with high socioeconomic deprivation and higher concentrations of Māori and Pacific populations coincide with elevated heat exposure during warmer summers.
- Recognitionally, the communities most exposed to risk are not fully centred in national and local adaptation processes, despite strong evidence of their vulnerability.
- Procedurally, key decision-making structures have yet to develop inclusive, culturally anchored, equity-focused adaptation pathways.

These findings support the argument that extreme heat in New Zealand is not only a climatic hazard but also a social and political one, influenced by the same structural inequities that shape health more broadly (Sheridan, et al., 2024).

Although a small emitter in global, absolute terms, New Zealand is a high per capita emitter with significant adaptive capacity relative to many countries (Climate Change Commission, 2021). Yet within its borders, vulnerability is unevenly distributed, and those who have contributed least to emissions face some of the greatest risks (Parsons, 2024). This mirrors global patterns in which marginalised populations bear the brunt of climate impacts despite limited responsibility (Dolšak, et al., 2022). In this sense, New Zealand embodies both sides of the global struggle for climate justice: a wealthy nation with high per-capita emissions, as well as a society where colonial legacies and socioeconomic inequities shape unequal climate burdens (Dolšak et al, 2022; Parsons, 2024).

5.4. Applying an intergenerational-equity framework

Intergenerational equity extends the justice framing across time, emphasising that the burdens of climate change are not only unevenly distributed across space and social groups, but also across generations (Bessant, et al., 2025; Schoenmaker, et al., 2024). It draws attention to the ethical reality that children and future generations will live with the consequences of present-day emissions and policy choices, despite contributing the least to their cause (Méjean, et al., 2020). In climate and population health terms, this temporal dimension is particularly important for extreme heat: heat risk is shaped by immediate physiological vulnerability, but also by cumulative exposure over a lifetime and by the social infrastructural conditions that will determine whether future populations can live safely in a warm climate (ECSC, 2023; Schoenmaker, et al., 2024; Méjean, et al., 2020).

A central concept within intergenerational equity is the 'temporal burden' (Bessant, et al., 2025). As outlined by the IPCC, a child born in 2020 is projected to experience substantially higher lifetime exposure to extreme events, including heatwaves, than older cohorts, even under moderate emissions scenarios (IPCC, 2022). This framing is useful for interpreting the results of this thesis, which demonstrate that extreme heat exposure in New Zealand is already variable across summers, and that warmer summers can rapidly expand the geography of elevated exposure. The implication is that children living in New Zealand today are likely to encounter not only more frequent extreme heat episodes across their lives, but also more intense and spatially widespread exposure as warming progresses.

The comparison in Chapter Four between cooler and warmer summers across the ten year period, illustrates how exposure patterns can shift significantly over short timeframes. If warmer summers, such as 2018/19, increase in frequency, younger cohorts of the population will experience these expanded exposure conditions repeatedly over their lifetimes. Intergenerational equity therefore strengthens the argument that heat-health planning must not only respond to present risk, but also anticipate cumulative exposure and evolving vulnerability over time (Walker, et al., 2024).

Developmental vulnerability and early life exposure

A key pillar of intergenerational equity is developmental vulnerability (Walker et al., 2024; Méjean, et al., 2020). The results in Chapter Four show that child populations are disproportionately concentrated in regions that, during warmer summers, experienced elevated heat exposure concurrent with higher socioeconomic deprivation. In other words, many children are already living in areas where the social and environmental conditions for heat harm overlap. While the results do not directly measure health outcomes, the literature emphasises that heat exposure during infancy and childhood can influence physiological resilience across the life course (ECSCE, 2023; Smith, 2019; Son et al., 2017; Azan, et al., 2025). The risk is that children exposed to repeated heat stress in early life may carry long-term disadvantages that compound other forms of inequity.

These dynamics also underscore why intergenerational equity cannot be separated from current socioeconomic contexts. The results indicate that areas with higher proportions of children often coincide with higher socioeconomic deprivation and, in many cases, higher Māori and Pacific representation. If access to quality housing (including, energy access and indoor thermal conditions) remain unequal, then the climate-related burdens placed on today's children are likely to reinforce intergenerational cycles of disadvantage (Walker et al., 2024; Chen et al., 2025). This is particularly concerning given the high representation of Māori in vulnerable regions, as this poses a breach of the Crown's obligations to Māori under Te Tiriti o Waitangi (Parsons, 2024).

Policy foresight and intergenerational fairness

In applying an intergenerational equity lens, policy should consider whether current adaptation measures are designed with future generations in mind, and whether they protect children not only now, but over the long term (Syropoulos, et al., 2023). New Zealand's adaptation architecture is still at an early stage in this regard (Climate Change Commission, 2024; Ministry of Health, 2024). National frameworks increasingly acknowledge health risks, but the operational detail, surveillance infrastructure and regulatory standards needed to prevent harm remain extremely limited (Ministry of Health, 2024). From an intergenerational perspective, this is not merely a gap in planning; it represents a form of temporal injustice, where the costs of inaction are deferred to those who will live longest with the consequences (Syropoulos, et al., 2023).

The absence of robust heat-health monitoring is a particularly clear example (Harrington, 2021). Without systematic surveillance of heat-related morbidity and mortality, it is difficult to define thresholds, trigger warnings, regulate indoor environments, or evaluate the effectiveness of interventions over time. This limits the ability to protect children in settings where they spend significant time, for example, in early childhood centres, schools and homes, and makes it harder to design durable, long-term policy responses without the evidence base (Chen et al., 2025). Similarly, if housing standards and urban infrastructure are not adapted proactively, children may inherit built environments that lock in overheating risk for decades (Howden-Chapman, et al., 2023). Intergenerational equity therefore implies that adaptation cannot rely primarily on short-term behavioural responses, such as advice to "stay cool" or "drink water", when the structural determinants of exposure remain unchanged (Te Whatu Ora, 2024).

A further consideration is that fairness across generations requires investing in conditions of resilience, not simply crisis response (Syropoulos, et al., 2023). This includes strengthening housing thermal performance, expanding urban tree canopy and shade, ensuring access to affordable cooling, and building community preparedness systems that can be sustained over time (Uejio, et al., 2011; Chen, et al., 2025; Zhang, et al., 2024). These investments have long lifespans and therefore directly shape the future climate and population health landscape that children will inherit. In this way, intergenerational equity bridges public health and planning, and asks whether current decisions are creating resilient futures or entrenching preventable risk (Walker, et al., 2024).

The moral obligation to act preventatively

Intergenerational equity ultimately involves a moral claim, that societies have obligations to protect those who cannot consent to the risks imposed upon them (Charveriat, 2023). In the context of extreme heat, this moral obligation is sharpened by two features of the hazard. First, the most severe heat impacts are often preventable through appropriate infrastructure, housing standards and early warning systems (Smith, 2019; Cheng, et al., 2018). Second, delays in adaptation can produce path dependency, where vulnerable communities remain exposed as risks intensify (Ministry of Health, 2024; Randell, 2022). From this perspective, the cost of delayed adaptation is not only measured in future health burdens but in foregone opportunities to reduce harm. If children spend successive summers in overheated homes, schools and communities, the cumulative impacts may extend beyond acute illness to broader wellbeing, educational outcomes and long-term health trajectories (Azan et al., 2025; ECSC, 2023). Acting preventatively is therefore an ethical necessity as well as a pragmatic one as early investment in adaptation reduces future burdens and avoids shifting costs onto younger generations.

Intergenerational equity also provides a way to reconcile competing vulnerabilities. Older adults face immediate physiological risk, and protecting them is urgent (Charveriat, 2023; Vandentorren, et al., 2006). However, policy approaches that focus only on present-day acute risk may miss the longer horizon of child vulnerability and lifetime exposure (Smith, 2019). Intergenerational fairness therefore requires the dual focus of addressing current risk among older adults, while building long-term protective systems for children and future populations. This includes ensuring that institutions such as aged-care providers, schools and public health services have robust heat protocols, and that built environments are progressively redesigned to remain safe under future climatic conditions (Cheng et al., 2018; Zhang, et al., 2024).

Māori intergenerational concepts and kaitiakitanga

Integrating intergenerational equity in New Zealand also requires grounding the framework in Te Tiriti o Waitangi and Māori worldviews. Western framings of intergenerational equity often focus on future populations, whereas Māori perspectives emphasise genealogical continuity, collective wellbeing and obligations to past and future generations (Kawharu, 2000). Concepts such as kaitiakitanga foreground stewardship, reciprocity and care for the environment as an inheritance and responsibility, rather than a resource to be managed solely for present benefit (Kawharu, 2000). In this sense, intergenerational equity resonates strongly with Māori understandings of time, responsibility and wellbeing, but it also raises questions about whose values and governance structures shape adaptation.

For Māori communities, intergenerational vulnerability is inseparable from the legacy of colonisation, land dispossession and structural inequity (Parsons, 2024). The results of this thesis show that many regions with high Māori populations also experience higher socioeconomic deprivation and elevated heat exposure. Intergenerational equity therefore cannot be framed solely as a universal moral obligation as it must specifically confront how historical injustice shapes the starting point from which different communities face future risk (Syropoulos, et al., 2023). Policies that fail to honour Māori governance, Māori data sovereignty and mātauranga Māori risk reproducing inequity across generations.

5.5. Policy and planning implications

Nationally, climate change adaptation is guided by the National Adaptation Plan (NAP), and the National Climate Change Risk Assessment (NCCRA), which are tools born out of the Climate Change Response Act 2002 (Climate Change Commission, 2024). Both recognise climate-related health risks and the need for cross-sectoral collaboration to address the determinants of health. In line with recommendations from the NAP, the Ministry of Health released the Health National Adaptation Plan (HNAP), published in 2024. The HNAP is New Zealand's first framework for preparing the health sector for the impacts of climate change, and provides an overarching vision for a climate resilient health system and acknowledges that adaptation requires coordinated action across agencies, sectors and communities. It identifies priority populations in line with this thesis: Māori, Pacific peoples, children and older adults, outdoor workers and those living in socioeconomic deprivation (Ministry of Health, 2024). It also emphasises the need to develop climate and population health policy in line with the foundational principles set out in Te Tiriti o Waitangi.

However, while the HNAP marks an important step forward, notable gaps remain. The plan provides high-level direction but limited operational detail on how health services, local government, iwi-Māori governance structures and community organisations should coordinate responses to specific hazards, including extreme heat. Consistency across regional and sectoral plans are still uneven, and heatwaves are not yet recognised as hazards of national significance within emergency management frameworks (Te Whatu Ora, 2023). Furthermore, as the HNAP highlights, there is an absence of qualified national assessments of climate attributable health impacts, such as heat-related morbidity and mortality, continues to limit the system's ability to prioritise interventions or anticipate future burdens (Ministry of Health, 2024). As a result, despite emerging national frameworks, implementation remains fragmented, with substantial work required to translate high-level commitments into place-based action, in order to reduce overall vulnerability (Royal Society, 2017). Although it is a more mature policy approach than previous high level documents, setting out actionable directions and aligning health adaptation with both national climate policy and health system priorities, the HNAP acts as a foundational framework, and not a set of policies or legislation, capable of directly addressing gaps within the system.

A central challenge identified through this research, and echoed in the HNAP, is the absence of a robust national evidence base linking temperature exposure to health outcomes.

Monitoring exists almost exclusively for winter temperatures in New Zealand, as this has been a long established public health risk and concern. At present, New Zealand does not have systematic national surveillance for heat-related morbidity and mortality, nor integrated datasets linking climate metrics to hospitalisations or primary care (Ministry of Health, 2024). This is a significant barrier to effective adaptation: without reliable data on when, where and for whom heat causes harm, it is challenging to design effective, targeted interventions, evaluate risk and develop meaningful or enforceable standards (Royal Society, 2017). Solutions to address this gap could include:

- Development of a national heat-related mortality register to monitor excess summer mortality (Ministry of Health, 2024);
- Mandated reporting of heat events in aged care, healthcare facilities and schools, where vulnerable populations are concentrated (Bassey, et al., 2025); and
- Linkage of daily temperature data with national hospitalisation records, enabling identification of heat-sensitive conditions and regional hotspots.

Such data would enable the Ministry of Health to identify actionable temperature thresholds at which health risks sharply increase. These thresholds could then inform evidenced-based regulatory standards, such as:

- Maximum indoor temperatures in rest homes, hospitals and early-childcare centres, consistent with best international practice (Kenny, et al., 2018);
- Mandatory heatwave response protocols for aged-care facilities, including hydration monitoring, staffing ratios and indoor cooling environments (Scalley, et al., 2015);
- Heat exposure guidelines for outdoor workers; and
- Trigger thresholds for public heat warnings and community outreach, particularly in areas of high demographic vulnerability.

Strengthening partnerships with iwi-Māori governance structures is also essential. The HNAP recognises that iwi-Māori Partnership Boards, mana whenua and Māori health providers must be active partners in designing climate and population health strategies (Ministry of Health, 2024). At the local government level, this includes supporting mana whenua leadership in adaptation planning, investing in Māori-led data governance, and ensuring that adaptation actions align with kaupapa Māori approaches to housing, water and community wellbeing.

Embedding these partnerships is central to meeting Te Tiriti obligations and ensuring that adaptation reinforces, rather than undermines, Māori health and sovereignty.

Aligning New Zealand's approach with global adaptation best practice is equally important. Internationally, public health agencies, including the UK Health Security Agency (UKSA), the European Environment Agencies (EEA), and Australia's state-level heat-health units, emphasise integrated heat-health warning systems, mandated heatwave response plans for aged-care facilities, routine epidemiological monitoring of heat impacts, and community outreach targeted to vulnerable groups (UKSA, 2025.; EEA, 2024; Australian Bureau of Meteorology, n.d.). Many jurisdictions also employ detailed urban heat maps and building-level overheating assessments to guide investment in cooling infrastructure. The results of this thesis suggest that similar approaches would be valuable in New Zealand, particularly in urban centres and regions of high socioeconomic deprivation.

Overall, the policy implications of this research point to a clear conclusion: while New Zealand has established high-level frameworks for climate and population health adaptation, significant gaps remain between national ambition and operational implementation. Addressing these gaps requires stronger local–national coordination, Māori leadership, and a commitment to developing the data systems and regulatory structures that enable evidence-based decision-making. As temperatures continue to rise, embedding heat-health resilience across planning, housing, and public health systems will be essential for protecting vulnerable communities, and for ensuring that adaptation efforts keep pace with the scale and urgency of climate risk.

5.6. Methodological reflection and limitations

This thesis took an integrated spatial approach to examine the intersection of climatic exposure, population structure and socioeconomic context in shaping vulnerability to extreme heat across New Zealand. A key methodological strength of this approach lies in its ability to synthesise climate observations, census demographics and socioeconomic deprivation indices, and analyse within a climate justice and equity framework. By analysing climate exposure through ten years of summer seasons, and linking this to current, census SA2-level demographic data and socioeconomic information, the study provides a novel picture of where exposure and susceptibility coincide. This spatial integration enhances both the interpretability and policy relevance of the findings, allowing vulnerability to be understood not just in absolute terms, but relative to the communities who inhabit these places.

Despite these strengths there are several key limitations to this study that must be acknowledged. First, the climate data in this thesis are derived from station-based observations interpolated to regional summaries. While the dataset is comprehensive and widely used in climate research, the spatial distribution of the climate stations is uneven. Station coverage is denser in some regions (for example, Canterbury and Auckland) and sparse in others (for example, Gisborne/Tairāwahiti and Otago). Although interpolation methods help mitigate these gaps, the resulting estimates may still smooth over local microclimates or notable temperature variations, particularly in topographically complex areas. This limitation may underrepresent exposure in some inland valleys or urban heat pockets, suggesting that the spatial patterns observed here should be interpreted at the regional rather than neighbourhood scale.

Second, the climate exposure metrics used in this thesis are derived from a ten year period of summer temperature data, providing a robust empirical basis for characterising typical patterns of extreme heat exposure across regions. This temporal coverage strengthens the analysis by smoothing short-term anomalies and capturing a range of climatic conditions. However, while individual summers (2009/10 and 2018/19) are presented in the Results to illustrate interannual variability and contrast, the analysis does not explicitly model long-term trends or future climate trajectories. As a result, the findings should be interpreted as reflective of recent historical conditions rather than projections of future exposure under continued warming. Incorporating longer observational records or downscaled climate projections would allow future research to assess how the spatial distribution of extreme heat exposure may evolve under different emissions scenarios, and how this may interact with changing demographic patterns.

A further limitation relates to the static nature of the demographic data. Census data represent populations at a single point in time (2023), while climate exposure analyses span earlier years (2009-2019). Although demographic change at the SA2 level tends to be gradual, some regions, particularly Auckland, Waikato and parts of Canterbury, have experienced significant population turnover, migration and housing development over the last decade (Stats NZ, 2025). The demographic patterns mapped here therefore reflect current population distributions (as of the country's most recent census), rather than those present at the time of historic heat exposure. This mismatch does not invalidate the analysis but highlights the need to consider demographic dynamism in longitudinal climate and population health research.

The study is also limited by the absence of housing quality, infrastructure and indoor temperature data, which are central to understanding how climatic exposure translates into experienced heat stress. Housing characteristics, such as insulation, shading, ventilation, overcrowding and the ability to afford cooling, are well-documented modifiers of heat vulnerability (Chen, et al., 2025), however linking these variables at the SA2 scale are limited. As a result, vulnerability inferred from demographic or socioeconomic variables alone may underestimate risk in areas with poor housing stock or concentrated energy hardship. Future research would benefit from integrating datasets such as Healthy Homes compliance records, Building Research Association New Zealand (BRANZ) housing condition surveys or high-resolution land surface temperature data to better capture built-environment influences.

Another important gap concerns the absence of health outcome data. This thesis focuses on exposure and susceptibility, but does not directly measure heat-related morbidity or mortality due to the lack of publicly accessible, fine-scale health data for New Zealand. The analysis does not link extreme heat days to hospital admissions, ambulance callouts or mortality limits, as it was out of scope. A more integrated climate–health dataset would enable researchers to quantify risk, estimate attributable burdens and identify priority populations with far greater precision. Likewise, key vulnerable groups, such as pregnant people, outdoor workers, people experiencing homelessness or those taking medications that affect thermoregulation, are not captured within demographic variables used here, suggesting that vulnerability may be systematically underestimated.

These methodological limitations have implications for interpretation. While the findings provide a robust indication of where exposure and demographic vulnerability intersect, they should be viewed as indicative rather than definitive. The study identifies relative patterns of vulnerability, not absolute risk, and should be interpreted alongside local knowledge, health datasets and urban planning contexts. At the same time, the limitations highlight promising avenues for future research, including longitudinal climate–health linkage studies, microclimate modelling in urban centres, integration of indoor temperature monitoring and explicit inclusion of additional vulnerable groups. Despite these constraints, the methodological approach taken here provides a strong foundation for understanding how extreme heat intersects with demographic and social factors in Aotearoa, and offers a transparent, spatially grounded basis for future climate–health research.

5.7. Future research directions

The findings of this thesis highlight several priority areas for future research to strengthen understanding of extreme heat vulnerability in New Zealand and to support evidence-based adaptation planning. While the present study focuses on exposure and susceptibility, extending this work to include health outcomes, longitudinal perspectives and lived experience would allow for a more complete assessment of climate-related health risk (Ministry of Health, 2024).

A key avenue for future research is the integration of health outcome data, such as hospital admissions, ambulance callouts and mortality records, paired with climatic exposure metrics (Ministry of Health, 2024). Linking extreme heat days to heat-sensitive outcomes, including cardiovascular events, renal disease and adverse pregnancy-related outcomes, would enable direct validation of vulnerability patterns identified in this thesis. Such linkage would also allow estimation of heat-attributable health burdens and identification thresholds effects, providing stronger empirical evidence for public health interventions (Ministry of Health, 2024; EIHNZ, 2023; Folkerts, et al., 2020; Hales, et al., 2000). While access to fine-scale health data presents some ethical challenges, collaborative approaches with health agencies and iwi-led research partnerships may offer promising pathways (Ministry of Health, 2024).

Closely related is the need for longitude and cohort-based analyses, particularly for children and older adults (Xu, et al., 2014; Arpin, et al., 2021; Auger, et al., 2015). The present study demonstrates that age-based vulnerability intersects with interannual variability in heat exposure, but it does not capture cumulative or life-course effects. Longitudinal data would allow researchers to examine how repeated exposure to extreme heat influences long-term health trajectories, educational outcomes and functional decline (Azan, et al., 2025). For children, this could include investigating associations between early-life heat exposure and developmental or respiratory outcomes (Azan, et al., 2025). For older adults, cohort studies could explore how chronic conditions, medication use and social isolation modify heat sensitivity over time (Charveriat, 2023). These approaches would strengthen causal inference and help distinguish acute from cumulative impacts.

Future research would also benefit from mixed-methods approaches that integrate quantitative spatial analyses with qualitative insights from affected communities. While geospatial data can identify where vulnerability is concentrated, it cannot fully capture how people experience heat, adapt to it or perceive risk (Ministry of Health, 2024). Qualitative research, such as interviews and focus groups, could provide critical insight into household-level coping strategies, barriers to adaptation and culturally specific understandings of heat and wellbeing. This is particularly important for Māori and Pacific communities, whose experiences of climate risk are shaped by collective living arrangements, cultural obligations and historical inequities that may not be visible in census data alone (Parsons, 2024).

Another important direction is the integration of climate projections with socio-demographic change scenarios (Randell, 2022). This thesis focuses on historical exposure, but future vulnerability will be shaped by both climatic change and population dynamics, including ageing, urbanisation and migration (Randell, 2022; Charveriat, 2023). Combining climate projections with projected demographic shifts would allow researchers to identify emerging hotspots of risk and to assess whether current patterns of vulnerability are likely to intensify, shift or attenuate under different scenarios (Charveriat, 2023). Such modelling would be especially valuable for central, regional and local governments tasked with long-term infrastructure and health planning.

Finally, future studies should seek to better incorporate built-environment and housing data, including indoor temperature measurements, housing quality indicators and energy hardship metrics (Chen, et al., 2025). Understanding how outdoor heat translates into indoor exposure is essential for assessing real-world risk, particularly in a country with an ageing and often poorly insulated housing stock (Howden-Chapman, et al., 2023).

Together, these future research directions point toward a more integrated climate and population health evidence base for New Zealand, one that links exposure, vulnerability and health outcomes across time, space and social context. Building on the spatial and descriptive foundation established in this thesis, such work would support more equitable and anticipatory approaches to managing the health impacts of extreme heat in a warming climate.

Chapter 6: Conclusion

This thesis set out to examine who in New Zealand is most vulnerable to extreme heat, where these vulnerabilities are geographically concentrated, and why such patterns emerge. Through the integration of climate observations, demographic distributions and socioeconomic indicators at Statistical Area 2 (SA2) level, the research demonstrates that vulnerability to extreme heat is neither random nor evenly spread. Rather, it reflects the interaction of climatic exposure, demographic sensitivity, and structural inequities that shape the conditions in which people live, work and age. By applying the dual analytical lenses of climate justice and intergenerational equity, the thesis advances a multidimensional understanding of heat-related risk that moves beyond climatology alone and foregrounds questions of fairness, responsibility and long-term wellbeing.

A central empirical finding of this study is that extreme heat exposure varies substantially across New Zealand's regions. While exposure to extreme heat varies across regions, the results show that exceedance days are not consistently concentrated in any single part of the country. Instead, extreme summers produce geographically widespread spikes, temporarily elevating exposure across both historically warmer and cooler regions. This aligns with Chapter Five's emphasis that exposure is dynamic and sensitive to shifts in baseline temperatures. Such findings point to a need for adaptive, forward-looking planning that accounts for variable heat patterns and the possibility that historically cooler regions may face increasing summer extremes.

The thesis also shows that demographic sensitivity to heat, particularly among children and older adults, is unevenly distributed across the country. Children (0–14 years) are highly concentrated in regions that also exhibit higher socioeconomic deprivation and, in warmer summers, higher exposure levels (Atkinson & Crampton, 2019). Older adults (65+ years), by contrast, are overrepresented in parts of the South Island and lower North Island, where climatic buffering has historically reduced heat risk but where this buffering becomes less reliable as conditions warm (see Chapter Four). These insights reinforce that vulnerability is not just a matter of physiology but is social, and spatial: children and older adults are not equally distributed, and their vulnerability interacts with regional exposure gradients in ways that require geographically differentiated policy responses.

A third major insight concerns the role of socioeconomic deprivation, housing quality and ethnic inequities in shaping vulnerability. This thesis demonstrates clear spatial clustering of socioeconomic deprivation, poor-quality housing, and higher proportions of Māori and Pacific households in many northern and eastern regions. These clusters align closely with areas that experience elevated heat exposure during warmer summers, resulting in what Chapter Five describes as "conditions for compounded vulnerability". International literature shows that social inequality not temperature alone drives the most severe heat-related harms (Osilla et al, 2023; Randell, 2022; Charveriat et al, 2023). This thesis confirms that pattern in the New Zealand context: SA2s with higher socioeconomic deprivation are often those with more children, poorer housing conditions, limited cooling capacity and historically inadequate public investment (Atkinson & Crampton, 2019). Adaptation strategies that rely solely on communication, behavioural advice or short-term emergency responses will therefore be insufficient without structural improvements to housing quality, urban infrastructure, energy access and public investment. (Climate Change Commission, 2024).

When viewed through a climate justice lens, these patterns reveal deep inequities in who is most exposed and who has the least capacity to cope. The thesis shows that many regions with high Māori populations also experience higher socioeconomic deprivation and warmer summer exposures, meaning historical and structural inequities continue to shape present-day climate vulnerability (Parsons, 2024; Reid, et al., 2019). Pacific peoples, similarly, are disproportionately represented in crowded housing and lower-income urban areas, heightening indoor heat stress and limiting feasible adaptation (Pacific Perspectives, 2019; Statistics New Zealand, 2020). These findings mirror global evidence that climate hazards disproportionately affect communities already marginalised by socioeconomic, political or historical disadvantage (Randell, 2022; Chen, et al., 2025). As the discussion makes clear, adaptation that does not acknowledge these realities risks reinforcing inequities rather than reducing them.

The study's second analytical lens, intergenerational equity, further sharpens these concerns. Children today will experience far more heat exposure across their lifetimes than previous generations, and this thesis shows that high-child-population SA2s often overlap with higher socioeconomic deprivation and higher exposure during warm summers (IPCC, 2021). Older adults also face heightened risk in many southern regions, where even modest increases in summer temperatures can strain thermoregulation in ageing bodies (Vandentorren, et al., 2006; Cheng, et al., 2018). The results highlight a moral imperative: adaptation decisions made now must protect those least able to shield themselves, physiologically, financially or socially, from escalating climatic change (Randell, 2022; Ogunbode, et al., 2024; Charveriat, 2023). In the New Zealand context, intergenerational equity must also engage with Te Tiriti o Waitangi and Māori concepts of stewardship, ensuring that strategies do not simply prepare for future conditions but also address historical inequities that would otherwise be passed on (Parsons, 2024).

From a policy perspective, the thesis finds that New Zealand's national adaptation frameworks, while evolving, remain insufficiently operationalised. The National Adaptation Plan and Health National Adaptation Plan offer high-level direction and identify priority populations, yet still lack the monitoring systems, hazard recognition and implementation detail required to address extreme heat as a public-health concern (Ministry of Health, 2024). The discussion chapter underscores the continued absence of robust national surveillance of heat-related morbidity and mortality and the limited recognition of heatwaves as hazards of national significance. This research directly addresses these evidence gaps in part, by providing the first integrated, population-level analysis of heat exposure and demographic vulnerability in New Zealand, offering a foundational evidence base upon which more targeted adaptation policy can be built.

Methodologically, the study demonstrates the value of integrating climate records with demographic and socioeconomic data at a regional spatial scale. The approach provides a robust starting point for national-scale climate and population health assessment. It also establishes a framework that can be extended as health outcome datasets (for example, hospitalisation or mortality) and improved climate projections become available.

Overall, this thesis makes several key contributions to climate–health research and public-health planning in New Zealand. It provides the first national, spatially explicit assessment of heat exposure using a relative climatological definition tailored to New Zealand's temperate conditions, establishing a foundation for context-specific analysis. Demographic and socioeconomic sensitivity are mapped at SA2 level, revealing clear regional patterns of age, ethnicity, and socioeconomic deprivation that shape differential vulnerability. By examining the intersection of exposure and vulnerability, the analysis identifies spatial clusters of compounded risk that call for targeted, place-based adaptation. Climate justice and intergenerational equity are employed as guiding analytical frameworks, foregrounding how historical and structural inequities influence who is most at risk both now and in the future.

Together, these contributions generate a policy-relevant evidence base capable of informing housing standards, heat-health surveillance, urban planning, and resource allocation decisions.Taken together, the findings show that extreme heat poses an emerging but unevenly distributed public-health risk in New Zealand. Vulnerability is shaped not only by climate but by demography, infrastructure, and inequality (Randell, 2022; Reid, et al., 2019; Parsons, 2024; Ogumbode, et al., 2024; Chaveriat, 2023). Recognising that vulnerability is layered, spatially structured and socially produced is essential for designing adaptation strategies that are both effective and just. As temperatures continue to rise, understanding who is exposed, who is sensitive, and why vulnerabilities cluster where they do will be critical for protecting communities today and safeguarding the wellbeing of generations to come.

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