Sociodemographic Vulnerabilities of Heat

A Research Report submitted in partial fulfilment of the Degree of Masters of Commerce (Inequality Studies)

In the School of Economics and Finance,

University of the Witwatersrand

Jonathan West

Student No:
1647104

Supervised by:
Professor Frederik Booysen
Fredrik.booysen@wits.ac.za

Word Count: 20 108

28 March 2025

ٱلرَّحِيمِ ٱلرَّحْمَٰنِ ٱللَّهِ سْمِ

In the Name of Allah, the Most Merciful, the Most Benevolent

ABSTRACT

Climate change and its consequences are becoming a reality that can no longer be ignored. Extreme weather events and natural disasters are becoming increasingly frequent and severe worldwide. One such extreme weather event is heatwaves. Heatwaves are becoming a hot topic, with ongoing research continually expanding our understanding of their adverse impacts. To fully understand the consequences of heat, insight is needed into the specific regional vulnerabilities that can affect adaptation. Accordingly, this research aimed to investigate the correlation between sociodemographic characteristics and self-reported impacts of a heatwave. The aim was to identify which populations are vulnerable to heatwaves due to their limited understanding of heat risk. The study evaluated not only disparities between different sociodemographic groups but also regional disparities. Research of this nature must focus on context, as vulnerability and adaptive capacity can vary significantly across different regions. As such, this research placed a specific focus on Gauteng and its various metropolitan areas within the province. The relationship between sociodemographic characteristics and heat risk perception was evaluated using quantitative analysis methods applied to the Gauteng City-Region Observatory (GCRO) Quality of Life (QoL) data. The research specifically relied on the Wave 7 data obtained from 2023 to 2024. The analysis revealed that, among all the sociodemographic characteristics evaluated, race was the most significant variable. Specifically, the lack of heat risk perception among the African population group. Further research suggests that this vulnerability is a result of social, economic and political exclusion, which has placed barriers in the path of this population group. The research also identified that regions within Gauteng have also reported impacts of a heatwave differently, and that this variance is likely a result of spatial inequality. Accordingly, it is recommended that policymakers implement HHWS and other adaptation strategies that directly address heat risk perception in African communities. It also proposes that indirect policy mechanisms be utilised to address the pre-existing inequality that contributes to the vulnerability of the African population.

Table of Contents

1. Introduction

1.1. Background

Climate change is one of the most pressing global issues, impacting all aspects of our lives, from economic stability to health. While we are all responsible for the anthropogenic activities that contribute to climate change, some are more deeply affected by its consequences than others. As anthropogenic activities continue to drive climate change, the frequency and intensity of extreme weather events are increasing, posing significant threats to ecosystems and human well-being.

The world's climate has been constantly changing, and it will continue to do so. The Earth has experienced ice ages and interglacials (warmer periods) and has sustained through them all. In fact, the past 10,000 years have been unusually stable for Earth's climate (Dansgaard et al., 1993; Petit et al., 1999; Rioual et al., 2001). However, since the 1800s, we have entered the Anthropocene, and human nature is challenging the Earth's stable climate. The Anthropocene is the period during which humanity has become the primary driver of the Earth's changes. When precisely the period began is not clear; however, it has been shown that anthropogenic activity has been changing the earth's atmosphere since 1750 (IPCC, 2023a).

Fossil fuel burning, changes in land use, industrial activity, and deforestation have all increased in the Anthropocene, contributing to the rise in atmospheric greenhouse gas concentrations. The greenhouse gas effect is not new and has been around for millennia (Kweku et al., 2018). However, the change in the quantity of greenhouse gases in the Anthropocene has led to what we now know as climate change.

The Intergovernmental Panel on Climate Change (IPCC) classifies climate change into three primary research realms: Science, Adaptation, and Mitigation. This research is focused primarily on adaptation and vulnerability. Adaptation refers to strategies used to reduce the adverse effects of climate change. However, the success of adaptation measures depends on a thorough understanding of vulnerability, which encompasses both physical exposure to climate-related risks and the socioeconomic factors that exacerbate susceptibility (H.-O. Pörtner et al., 2023). By identifying and addressing vulnerabilities, adaptation efforts can be more targeted and effectively reduce harm.

The South African National Climate Change Information System defines climate change as the 'ongoing trend of changes in the earth's general weather conditions as a result of an average rise in the temperature of the earth’s surface often referred to as global warming.’ (South African National Climate Change Information System, n.d.). With the rise in global temperatures, heatwaves—prolonged periods of excessively high temperatures—are becoming more frequent and severe (Calvin et al., 2023). The last century has shown a sharp increase in both the frequency and intensity of heatwaves (Wang et al., 2024). Estimates suggest that in 80 years, 7 billion people will be exposed to heatwaves annually with a predicted cost of $430 trillion (Yin et al., 2022).

South Africa is experiencing temperature increases at twice the rate of the global average (Scholes & Engelbrecht, 2021). More specifically, South Africa’s National Climate Change Adaptation Strategy (NCCA) emphasises Gauteng as the region with the highest settlement heat stress risk in 2050 (National Climate Change Adaptation Strategy, 2019; Van Niekerk et al., 2020).

Heat is challenging because, due to its impact and occurrence, it does not receive the same attention and mobilisation as other extreme weather events. Heat is not necessarily visible, nor is it always ‘newsworthy.’ Extreme weather events, such as fires or flooding, receive more attention due to the more explicit nature of their potential harm (Mackie, 2014; Williams et al., 2019).

The main impact of heat is on the health and well-being of individuals. The increase in global and local heat has physiological and psychological impacts on health (Ebi et al., 2021). However, the burden of this increase in heat is not being borne equally by everyone (IPCC, 2023b). The relationship between heat and health is complex, with numerous contributing factors. Accordingly, any research in the field of heat and health must attempt to understand the complexity of the different variables that affect vulnerability.

Climate Change exacerbates inequalities and disparities, creating a ‘*vicious cycle*’ that impacts marginalised groups by increasing their exposure to climate change risks and preventing further access to adaptation and mitigation resources (Islam & Winkel, 2017). Poorer communities are often forced to live in areas that are more susceptible to extreme weather events. They also have fewer resources to adapt to the impacts of climate change and are therefore not only more susceptible to climate change but also more vulnerable. As such, they do not ‘bounce back’ as quickly after extreme weather events when compared to the wealthy or more affluent. This widens the disparity, and as that gap widens, it becomes even more difficult for the poor to catch up and recover.

South Africa's long-standing social and economic inequalities aggravate the country's vulnerability to climate change. South Africa faces rising poverty, growing unemployment and a Gini coefficient that remains one of the highest in the world (Francis & Webster, 2019; Makgetla, 2020). These issues are compounded by a history of racial segregation that left most of the population socially and economically marginialised (Hoogeveen & Özler, 2005; Seekings, 2007). This has resulted in widespread poverty, inadequate access to healthcare, housing quality, and varying levels of education, all of which shape an individual's ability to respond to and cope with extreme heat.

Accordingly, sociodemographic characteristics such as race, sex, age, education, and household wealth status can affect both perceived and actual vulnerability to climate risks. In this context, sociodemographic refers to the combination of social and demographic characteristics of an individual. It can include elements such as age, sex, education, and income, and can be influenced by factors such as social class, culture, locality, and others.

1.2. Rationale & Contribution

The effects of heat stress on health has become a hot topic in academia. Much of the existing research focuses on the direct physiological impacts of heat exposure, particularly in epidemiology and meteorology (Dawson et al., 2007; Diaz, 2014a; Gasparrini et al., 2015; Gosling et al., 2009a; Ye et al., 2012). Epidemiological studies have examined heat-related mortality and morbidity, highlighting the increased risks of cardiovascular, respiratory, and heatstroke-related illnesses (Błażejczyk et al., 2018a; Deschenes, 2014; Hajat & Kosatky, 2010a; Kovats & Hajat, 2008a). Meteorological studies, on the other hand, have focused on the measurement and spatial distribution of extreme heat, mapping urban heat islands and identifying heat hot spots (Ncongwane *et al.*, 2021).

While these scientific approaches provide valuable insights, they often overlook the sociodemographic and economic dimensions that shape vulnerability to heat. An individual's susceptibility to extreme heat is not solely a matter of physiological response but is also deeply influenced by socioeconomic conditions, demographic characteristics, and structural inequalities (Reid et al., 2012).

This means looking not only at the future risks posed by climate change but also at the current risk elements that populations may already be facing. These existing risks need to consider factors such as an individual's understanding of climate change and adaptation strategies. It also requires an understanding of the factors that may influence individuals' adaptation levels (Okunola et al., 2022).

Accordingly, research that explores the sociodemographic influences on climate change vulnerability can provide ‘unique and crucial’ contributions to climate change research (Lutz & Striessnig, 2015). The move in this regard is evidenced by the inclusion of demographics such as age sex and education into the Shared Socioeconomic Pathways (SSPs) (B. C. O’Neill et al., 2017). South Africa is one of the most unequal societies in the world, with its historical and structural disparities extending beyond economic inequality to influence health, infrastructure access, and climate resilience (Francis & Webster, 2019). Climate change and its consequences unmask multiple layers of inequality, both on a global scale (Roberts, 2001) and within individual countries (Islam & Winkel, 2017).

By investigating perceived vulnerability to heat through a sociodemographic lens, this study will contribute to the growing body of research on climate justice and health equity. It will provide evidence of how sociodemographic factors are associated with perceptions of and vulnerability to heat.

Vulnerability studies are becoming increasingly prevalent, and we are beginning to understand how sociodemographic variables relate to the impact of heat. However, the relationship between these variables differs by region (Akompab et al., 2013). These differences make it essential that research is conducted in different regions to gain a more generalised understanding of their interaction (Chen, 2024). This is especially important for regions where heat is expected to increase (Howe et al., 2019).

Studies are also focusing on heat risk perception and its contribution to adaptation, behaviour, and vulnerability. These studies aim to identify what sociodemographic characteristics have the most significant influence on heat risk perception (Hass et al., 2021). However, in measuring heat risk perception, most studies ask about knowledge of the potential harm of heat (Bai et al., 2013; Liu et al., 2013a; Madrigano et al., 2018; Rauf et al., 2017). This study will take it further and ask whether individuals have actually been impacted by the consequences of extreme heat. In this way, the research adds depth to heat risk perception, as participants would have to both be aware of the impacts of heat and be able to recognise their effects.

The main contribution of this study will be the identification of different sociodemographic variables and their correlation with heat risk perception in Gauteng. Understanding the relationship between these variables will enable policymakers to make informed decisions about how to effectively communicate heat risk in Heat Adaptation Plans, Heat Health Warning Systems, and other policy decisions.

1.3. Aim and Objectives

1.3.1. Aim

The overall aim of this research is to identify the sociodemographic correlates of perceptions of the impact of heatwaves in South Africa's Gauteng province.

The focus will be on understanding vulnerability to heat in Gauteng, a province that experiences extreme temperature fluctuations and is highly urbanised. The research will explore how factors such as age, race, sex, education and household wealth correlate to an individual's heat risk perception.

The investigation into the relationship between heat risk perception and sociodemographic variables hopes to highlight how existing disparities interact with heat and the implications of these for vulnerabilities of specific population groups. This will be achieved by specifically evaluating and investigating whether individuals report on the impacts of a heatwave and how this reporting relates to different sociodemographic variables.

In this way, the research aims to provide a deeper understanding of the relationship between heat and sociodemographic variables, demonstrating that although heat does not discriminate between individuals, various sociodemographic factors can influence vulnerability through changes in heat risk perception. It will provide insight into what population groups need more targeted interventions for adaptation methods.

This will be done using a conceptual framework that emphasises the interaction between different components in heat and health adaptation. The framework will provide a basis for depicting and defining how sociodemographic variables, as axes of inequality, interact with other components, such as adaptation mechanisms and health risks. Through these interactions, the research aims to demonstrate that sociodemographic variables are part of a broader context and that their relationship in this context is significant for vulnerability and adaptation to heat.

Accordingly, the research aims to inform policymakers on how to effectively communicate heat adaptation measures. This information can be utilised to ensure that responses to heat and heat adaptation plans do not leave any population group behind. Thereby breaking the vicious cycle of inequality.

1.3.2. Objectives

1. To evaluate how Gauteng residents self-report their experience of heatwave impacts.

As heatwaves intensify and become more frequent, we aim to assess whether Gauteng residents are experiencing the impact of these events and reporting on them.

2. To evaluate how the self-reported impacts of a heatwave may vary across different regions in Gauteng.

Different regions may have distinct sociodemographic profiles. This objective examines whether the impact of heatwaves varies depending on the local population's sociodemographic characteristics.

.

3. To evaluate how sociodemographic variables are associated with self-reported impacts of a heatwave.

Sociodemographic factors such as age, sex, household wealth, education, and race can all change how individuals experience and report heatwaves. This objective examines the relationship between these sociodemographic variables and the impacts reported by individuals, helping to identify who is most vulnerable or most impacted by extreme heat.

2. Literature Review

2.1. Conceptual Framework on Adaptation to Heat

This research is situated within the context of climate adaptation and vulnerability. Numerous frameworks have been developed to evaluate and analyse how vulnerability and adaptation interrelate. There are more common frameworks, such as those focused on vulnerability risk and adaptation (Brooks, 2003) and others that applied socio-economic factors to climate change (IUCN & SEI-B, 2004). However, as climate change adaptation has developed, frameworks have become more integrated and complex. Frameworks have been designed to address intersectional vulnerability (Amorim-Maia et al., 2022) and to understand the interrelationship between different pertinent factors (Simpson et al., 2021).

While all of these frameworks may have some applicability to our study, it is essential to identify a framework that defines and explains our research questions in a way that guides them without restricting them. In light of this, our research will rely upon the 'Human Adaptation to Heat in the Context of Climate Change' conceptual framework (Navas-Martín et al., 2024). This framework aims to elucidate the complexity of various relationships within climate change adaptation, with a specific focus on the aspect of heat.

The framework comprises five components, organised into two levels and three domains. It demonstrates how each component affects heat adaptation and vulnerability in distinct ways, and how these influences can be categorised and interrelated into different domains. The framework emphasises a multidisciplinary approach.

The first component is climate change. It reflects the anthropogenic nature of climate change and the two primary responses to it: adaptation and mitigation. The component is the context within which the rest of the framework operates.

The second component is vulnerability, which refers to the capacity of communities or individuals to reduce the negative health impacts of heat. Vulnerabilities can include exposure to heat, health sensitivity, or other risk factors. Vulnerability helps identify the aspects of a system or the people in a society that need the most attention. It includes exposure, adaptive capacity and sensitivity.

The third component is health risks, specifically, the events that impact mortality and morbidity. Risks can be seen as an intersection of the first two components, as climate change brings numerous factors that can influence an individual's risk, such as food security and air quality. The main risk to health in our study is heatwaves.

The fourth component is axes of inequality, which accounts for how different distributions of power within a society impact health and climate change. Some of the different axes of inequality mentioned in the framework are social class, race, age, sex, and territory. The axes refer to access to social and economic resources that can effectively maintain good health and mitigate the adverse effects of climate change on health.

The final component is health outcomes, which effectively measure various indicators of health for either an individual or a society. The most common health outcomes are morbidity and mortality; however, the scope is not limited to these alone. In climate change and health research, there are still challenges in directly linking climate change to health outcomes; however, it is clear that they are related.

The levels are individual and social. This means that adaptation is either examined on a micro level (individual) or a macro level (social). However, the two levels are not entirely separate, and the relationship between how the individual relates to society is also essential.

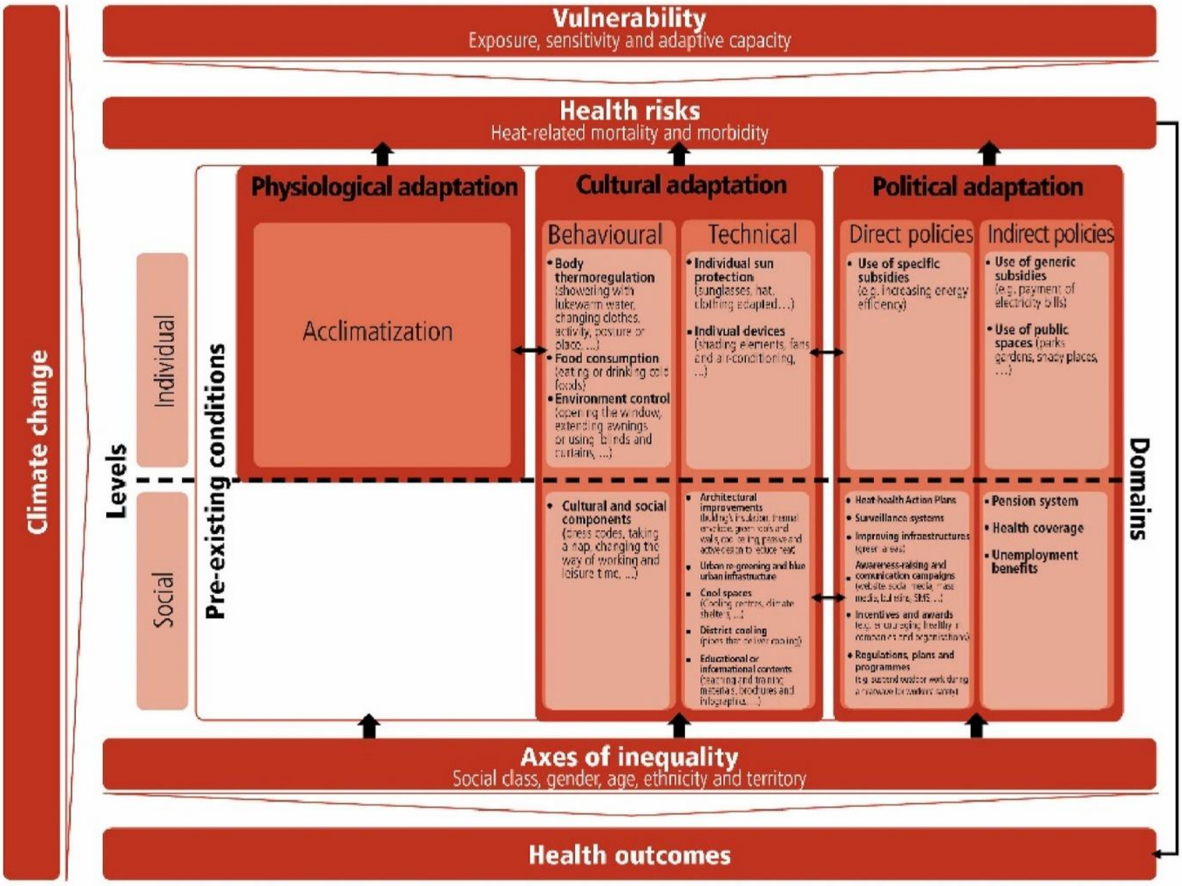
The framework encompasses three domains: physiological, cultural, and political. The domains provide ways for individuals and communities to adapt to climate change in a manner that protects their health.

Physiological adaptations refer to the biological processes by which an individual's body responds to heat. This is also known as acclimatisation. Acclimatisation is specific to the individual and difficult to generalise for different population groups.

Cultural adaptation refers to the degree to which an individual or community is receptive to different adaptation techniques. Culture can dictate whether a community can adapt quickly or efficiently. Cultural adaptation is usually split into behavioural or technical adaptations. Behavioural adaptation refers to the change in how an individual or community conducts its affairs. The shift in behaviour can make them more vulnerable or more resilient. Technical adaptation refers to the implementation of technology and tools in a manner that enhances the resilience of communities or individuals.

Political adaptation refers to policy decisions made at the community or individual level to create a climate-resilient society. Policies can be direct or indirect. Direct policies intervene directly between heat and its negative impacts. Indirect policies, although not directly intended to reduce the impact of heat on health, still reduce the negative consequences.

Figure 2.1 Conceptual Framework of Human Adaptation to Heat in the Context of Climate Change (Navas-Martín et al., 2024).



Using this framework, our research will focus on how the axes of inequality relate to health risks, specifically the reported impacts of a heatwave and, consequently, vulnerability. The purpose of the framework is to illustrate this interaction in context and shed light on how the axes of inequality within heat and health influences the entire system.

2.2. Heatwaves in Context

2.2.1. Heat

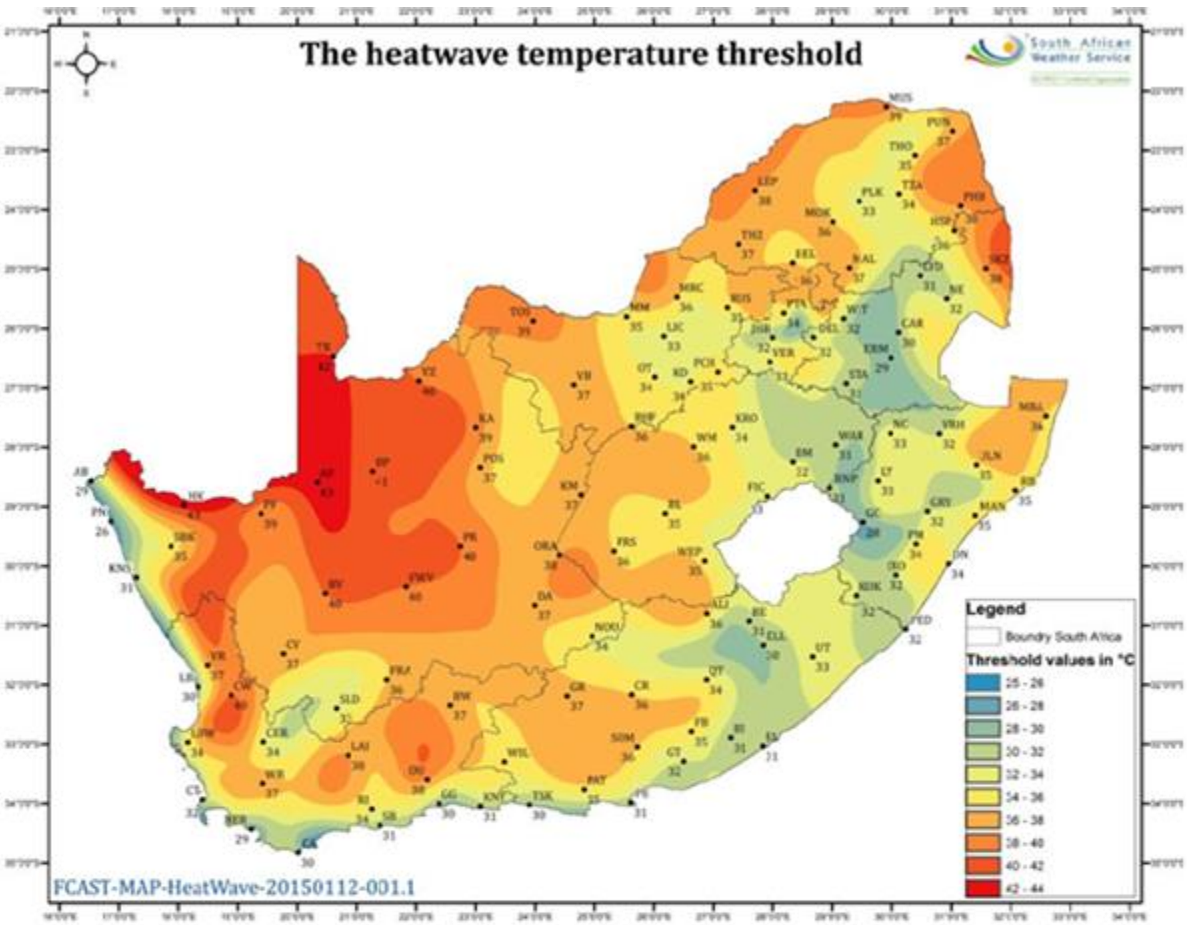
Climate change is often referred to as global warming because one of the major changes is an increase in the Earth's average surface temperature. As the global surface temperature rises, so too do extreme regional temperatures (Seneviratne et al., 2021). The regional temperature changes then also increase the likelihood of extreme 'multi-day heat events' (Hartmann et al., 2014). These multi-day heat events are often referred to as heatwaves; however, no set definition of a heatwave currently exists. This is because acclimatisation and adaptation differ per region, and therefore, heat must be understood in context.

The IPCC defines a heatwave as a period of weather that exceeds a threshold. This threshold may be determined by looking at whether the temperature exceeds the 90^{th} percentile for that calendar date or by evaluating whether the temperature exceeds an absolute maximum, such as 35°C (Seneviratne et al., 2021). However, the IPCC concedes that the determination of a threshold might change over time due to different adaptations and acclimatisation. The definition of a heatwave is important because different definitions can have an effect on the estimated impact on health (Tong et al., 2010; Xu et al., 2016, 2017). Studies do show that intensity is more important than duration and that heatwaves must be defined according to local or regional contexts (WMO, 2023; Xu et al., 2016).

2.2.2. Heat in South Africa

Regardless of which definition is used to define a heatwave, there is evidence to show that in Africa, the frequency, intensity and length of heatwaves is increasing (Seneviratne et al., 2021). In South Africa, there has been a general trend of decreasing cold extremes and increasing hot extremes (Kruger & Sekele, 2013). The World Health Organisation predicts that the number of heatwaves per year could increase by between 25 and 145 days (WHO, 2015). To mitigate the risks associated with these extreme heat events, the South African Weather Service has provided a regional definition of a heatwave: "*a prolonged period (3 days or longer) of excessively high temperatures that are 5°C or above the average maximum for a particular region*" (Werner Van Dyk, n.d.). From Figure 2.2, it is clear that the temperature thresholds for most of Gauteng are between 26°C and 36°C. Having a low threshold is not necessarily a positive thing, as it means individuals are less acclimated to extreme heat.

Figure 2.2. Map of South African Heatwave Temperature Thresholds (South African Weather Service).



Heat studies have grown in prevalence in South Africa, with studies focused on the relationship between health and heat (Scovronick et al., 2018; Wichmann, 2017) and some focused on different vulnerabilities (Souverijns et al., 2022; Wright et al., 2019). While these studies have provided the necessary foundations, more regionally specific heat vulnerabilities still need to be understood.

2.2.3. Urban Heat Islands

Urbanisation creates hotspots of heat, referred to as Urban Heat Islands (UHIs). This effect is explained by urban areas trapping heat at night, when it is meant to get cooler (Clarke, 1972), and due to the higher population densities in urban areas (Buechley et al., 1972). Urban areas also absorb more heat and usually have less space for heat to escape. The result of the UHI is that urban areas may experience the same temperature as rural areas, but their exposure to heat is more intense. However, this increased exposure does not always result in increased awareness, despite urban areas typically having more access to information (McGregor et al., 2015).

2.2.4. Impacts of Heat on Health

While studies on the relationship between heat and health have grown in the last few decades, some studies have found a relationship between heat and health going back 150 years (Ekamper et al., 2009). Heat has both direct and indirect impacts on health. While indirect impacts can cover a wide range of consequences of heat, the direct impacts are those that are felt more acutely. Some examples of direct impacts are heat stroke, heat stress, exacerbations of existing illnesses, mental health issues and hospitalisation (G. Cissé et al., 2023).

The main impact of heat on health is heat stress. Heat stress is when the body’s ability to thermoregulate gets disrupted, and thus, the individual's body temperature begins to rise, and they may experience physiological failure or even death (Błażejczyk et al., 2018b). The primary indicator of heat stress is a rise in body temperature. Thus, unless supervised by a physician, the individual must be able to monitor their temperature and be aware of when they might be experiencing heat stress.According to The Lancet, there were 50 more days of ‘health-threatening heat’ in 2024 than there were in 2023 (Romanello et al., 2024). The primary focus of the impact of heat on health has been its effect on morbidity and mortality, with an estimated increased risk of mortality by between one and three percent per change in degrees Celsius (Hajat & Kosatky, 2010b). However, one should take caution when interpreting these results, as each study is likely to use different health variables to define mortality and meteorological variables to define a heatwave (Diaz, 2014b). Thus, it becomes essential to understand the relationship in the context of the population being studied (Gosling et al., 2009b). That means looking at their unique vulnerabilities and resiliencies.

In the context of Africa, Ncongwane et al. found that there has been less research on the relationship between mortality and heat than in the developed world (Ncongwane, Botai, Sivakumar, & Botai, 2021). This is concerning due to the vulnerability of some African populations to heat (Kunda et al., 2024). However, studies show that the relationship between mortality and heat is still prevalent in Africa (Kunda et al., 2024; Ncongwane, Botai, Sivakumar, & Botai, 2021). The gaps that currently exist are vulnerability assessments in different demographics, studies on individual experiences and responses to heat, Urban Heat Island evaluations, and further research on heat adaptations (Ncongwane, Botai, Sivakumar, & Botai, 2021).

In the economics literature, there have been different methods employed in order to test or identify the relationship between heat and health. While some studies employ regression models to find relationships between heat and the actions that stem from heat, such as decision making

(Escobar Carias et al., 2024), or hospital visits (Fritz, 2022). Other studies employ econometric models in order to test how the relationship between heat and health might change due to the consideration of other factors, such as previous exposure (Barreca et al., 2015) or access to healthcare (Mullins & White, 2020). Regardless of the method employed, these studies have identified that the relationship between heat and health is not strictly linear and the importance of factoring in different variables within the research.

2.3. Heat Adaptation

Adaptation to heat does not often require structural changes; most adaptation behaviours rely on the individual to engage in minor changes. Research has found that changes such as dressing differently or drinking water (Liu et al., 2013a) or strategies such as avoiding the sun, resting, seeking cool spots or using a fan or air conditioning (Kunz-Plapp et al., 2016) have been effective in reducing the impacts of heat. While adaptation requires the adjustment of existing systems, this adjustment cannot occur unless individuals are aware of the risks and willing to respond to them. It is important to emphasise that although individual actions to adapt to heat can be beneficial, more 'all-encompassing' approaches are necessary. The 'all-encompassing' approach suggested by the authors includes education, finance, service delivery and infrastructure change as some of the relevant considerations (Wright et al., 2022).

2.3.1. Heat awareness

For an individual to engage in adaptive behaviours, they must first be aware of the heat itself and the risks it poses to their health. It was found that in the lower- and middle-income countries, one of the more common adaptation responses implemented is increased awareness and information (Scheelbeek et al., 2021).

If an individual is unaware of a heat wave or the associated risks, then it is doubtful that they will engage in health-protective behaviours (Sheridan & Allen, 2018). This is an issue where individuals do not understand that extreme temperatures are a risk to their health and are not accordingly supportive of either mitigation or adaptation strategies (DeBono et al., 2012). In Korea, the introduction of a national health warning system increased public awareness of heat waves and therefore increased heat-protecting behaviours (M. Kim et al., 2014). The impacts of heat are also more subtle than those of many other extreme weather events. In South Africa, it was found that heatwaves are not necessarily 'comprehensible', and the resulting impacts on health are therefore not understood (Manyuchi et al., 2022).

2.3.2. Thermal Comfort

Related to our awareness of heat is the concept of 'thermal comfort'. This concept describes how different individuals react and adapt to heat differently. It posits that if a change occurs that leads to discomfort, individuals will then take measures to reestablish our comfort (Nicol & Humphreys, 2002). While this concept was developed for building, it has grown in prevalence in studies on heat adaptation (Barbosa et al., 2015; Savić et al., 2022; Taleghani, 2018).

Studies on thermal comfort show that individuals who are more exposed to high temperatures have higher thermal comfort thresholds, but regardless of their threshold, the adaptive behaviour remains the same (Huang et al., 2023). Thermal comfort is one of the ways in which individuals acclimate to heat, and accordingly, individuals who are exposed to high temperatures are more acclimatised to extreme heat (Lam & Lau, 2018).

Thermal comfort is considered an adequate measure of risk as it evaluates health impacts and quality of life more comprehensively than just meteorological assessments (Savić et al., 2022). There are also studies which have evaluated vulnerabilities, such as household size and dwelling type, and how they contribute to thermal comfort (Barbosa et al., 2015). Other sociodemographic factors such as age, sex and socioeconomic status have also been found to impact thermal comfort in outdoor spaces (Lai et al., 2020).

2.3.3. Heat Risk Perception

While one's awareness and experience of heat play an essential role, they are not enough to drive adaptive behaviour (Sheridan, 2007). Individuals also need to be aware of the heat's impact and how to mitigate its effects. This 'prerequisite' to adapt is heat risk perception and is influenced by knowledge and sensitivity (Beckmann & Hiete, 2020).

While there appears to be a consensus on the effect of sociodemographic factors on heat risk perception (Hass et al., 2021; Howe et al., 2019). There are current discrepancies regarding which factors have a more significant influence on an individual's heat-risk perception. In Germany, it was found that income, education, solitude and sex did not play a role in predicting heat-risk perception (Beckmann & Hiete, 2020). In contrast, an Australian study found that income, marital status, and age were predictors of heat risk perception. (Akompab et al., 2013).

In India, research has found that prior exposure to a heatwave can increase the individual's preparedness and promote positive adaptation behaviours (Mishra et al., 2009). However, not far away in Bangladesh, it was found that despite being exposed to urban heat stress, there was limited knowledge about measures to reduce the impacts of heatwaves (Patwary et al., 2025). Therefore, the contradictions do not exist only in developed countries. One must understand that heat risk perception is not singular and varies among different populations and individuals. However, some research suggests that developing countries are more likely to change their behaviour than developed countries (Bai et al., 2013).

Heat risk perception can influence both exposure to and adaptive responses to heat (Hass et al., 2021). As such, it can also decrease an individual's vulnerability to heat by ensuring that individuals are aware of heat and its impacts and are able to act accordingly. Awareness and heat risk perception also play a role in the disparities in heat vulnerability (Lane et al., 2014). Heat risk perception and adaptation are essential components of vulnerability, and therefore, it becomes necessary to understand the factors that influence them to reduce vulnerability (Liu et al., 2013a).

2.2.4. Heat Health Warning Systems and other key Adaptations

One pathway to increased awareness and heat risk perception is the implementation of Heat Health Warning Systems (HHWS). An HHWS forecasts extreme weather and informs individuals or communities of the necessary actions to take. However, it has been found that although HHWS are effective, sociodemographic characteristics can mediate their effect (Toloo et al., 2013). Accordingly, HHWS must integrate factors that are known as effective predictors of adverse heat-related health outcomes (Kapwata et al., 2024). It is also essential that they are integrated into health systems and utilised in developing countries, with specific focus on vulnerable groups (Li et al., 2022).

HHWS not only alerts vulnerable populations but is also targeted to alert stakeholders. They are also intended to serve as a source of information on how to reduce exposure and what actions or behaviours can be taken to reduce the impacts of heat on health (McGregor et al., 2015). Their value lies in increasing heat risk perception and awareness, and if targeted correctly, they can also decrease vulnerability.

Another important aspect of adaptation to heat in relation to health is the use of air conditioning. Current literature has explored how access to air contion decreases risk and vulnerability. Some studies have found that air conditioning can decrease heat related deaths (Kouis et al., 2021; Semenza et al., 1996). There are also studies that have averred that access to air conditioning may explain a higher risk of heat stroke in people who are elderly and poor in urban spaces in the US (Klinenberg, 2015). There is also evidence to suggest that air conditioning may reduce heat acclimatisation and therefore increase vulnerability, however, evidence on this is still unclear (Kovats & Hajat, 2008a; M.

S. O'Neill, 2003). However the use of air conditioning as an adaptation mechanism must be understood in light of the increased pollution it brings (Kouis et al., 2021) and the barrier to ownership that the financial cost has (Lane et al., 2014).

2.4. Heat and Inequality

While heat does not discriminate between individuals within a location, the impacts of heat are felt differently and more acutely by different individuals or groups (H.-O. Pörtner et al., 2023). This can be due to a group's vulnerability, making them more susceptible to the negative impacts of heat. Their vulnerability can be due to physiological, social, and environmental factors (Navas-Martín et al., 2024). Therefore, we must understand these different factors and their influence.

What is concerning is that vulnerable groups are often also less aware of the risks and impacts associated with extreme heat (Lane et al., 2014). Even where individuals do display knowledge of the risk of heat, they do not have knowledge of the correct measures and behaviours to implement (Sheridan, 2007; Williams et al., 2019). This discrepancy suggests that, while the impacts of heat are becoming a growing focus and concern in the literature, society is not necessarily reflecting this attention.

2.4.1. Age

Age is a significant factor of vulnerability across studies. There are different reasons why age makes individuals vulnerable to heat. Their vulnerability can be attributed to several different factors; it could be due to their social isolation (McGeehin & Mirabelli, 2001), their ability to thermoregulate (Kovats & Hajat, 2008b) or because of the likelihood of having pre-existing medical conditions (Sherina et al., 2004).

However, regardless of their vulnerability, the elderly seem not to regard heat as impacting or threatening them. Seniors often understood that heat was dangerous for the elderly but that such danger was for others and not themselves (Abrahamson et al., 2008; Lane et al., 2014).

Some studies suggest that age is not a determinant of risk perception and that risk perception is variable within different age groups (Williams et al., 2019). The lack of trends in age groups is likely due to their distribution across different regions and sociodemographic groups, trends are easier to identify in regions where there are higher densities of either older or younger individuals (Howe et al., 2019).

2.4.2. Ethnicity

In a systematic review of heat vulnerability indexes, it was found that race/ethnicity was the second most common factor used in the construction of an index (Niu et al., 2021). It is understood that the reason for race being such a prominent factor is due to access to resources, differences in culture, and marginalisation, either political, economic or social (Cutter et al., 2003). For example, a lack of access to air conditioning (Madrigano et al., 2018).

They also face vulnerability due to the lack of UGI in predominantly 'segregated' areas (Manware et al., 2022). This leads to thermal inequity, where segregated areas suffer from UHI more (Mitchell & Chakraborty, 2018). This results in ethnic minorities facing an intersectional impact of heat. That is, higher UHI exposure is due to segregation, and higher vulnerabilities are due to a lack of resources.

Few studies have sought to identify disparities in heat risk perception among ethnic minorities or racial groups. However, geographic disparities contribute to individual heat risk perceptions and adaptive behaviours (Hass et al., 2021). These geographic disparities are characterised by 'systematic disinvestment' and segregation (Benz & Burney, 2021; Mitchell & Chakraborty, 2018; Wilson, 2020).

2.4.3. Spatial Inequality

Urban areas create vulnerability through the Urban Heat Island effect (UHI). There is also disparity within urban areas where higher socioeconomic groups have more Urban Green Infrastructure (UGI) that helps lower temperatures (Chen, 2024). Marginalised communities also face similar challenges, being exposed to more heat in urban spaces due to a lack of UGI (Chen, 2024).

Urban areas also have increased access to information, which could explain an increase in heat risk perception (Gil Cuesta et al., 2017a). However, one must also take into account housing type, and socioeconomic factors also become important when evaluating UHI effects (Kovats & Hajat, 2008b).

A significant problem within urban spaces is how urban environments have been constructed and designed. That is to say that more industrial urban areas suffer higher UHI compared to more suburban areas; this design and construction contributes to 'thermal inequality' which impacts ethnic minorities more severely (Mitchell & Chakraborty, 2018). The vulnerability then compounds this thermal inequality as a result of lack of access to resources (Benz & Burney, 2021).

A history of racial segregation and spatial inequality characterises South Africa. The Apartheid government enacted this segregation to separate the African population from access to economic opportunities. The result of these laws was a restriction of not only economic power but social and political power (Shahaboonin et al., 2023). While the post-Apartheid government has attempted to address this inequality, the power disparity between regions still exists (Turok, 2018).

2.4.4. Sex

Research suggests that vulnerability to heat may differ between sex. It depends on factors such as exposure, physiology and access to resources (Hass et al., 2021). In areas where males do more outdoor work, they are more vulnerable (Alahmad et al., 2020), whereas there is evidence to suggest females are more physiologically vulnerable (Seidell et al., 1988). However, the impacts of heat are more than just physiological, and studies show that females are more sensitive to the psychological distress that comes with extreme heat events (Akompab et al., 2013).

In China, Pakistan and Australia, it was found that males had a lower risk perception of heat than females (Liu et al., 2013b; Rauf et al., 2017; Williams et al., 2019). This was understood to be because males assumed they were tough enough to bear heat more than females. This could be because males do more outdoor work or because men underestimate the risks of heat (Liu et al., 2013b). Another reason given is female's role in caring for children and households (Akompab et al., 2013).

2.4.5. Socioeconomic status

There is considerable emphasis on the living conditions of the poor and how these conditions increase their vulnerability to heat. This can be because of poor sanitation conditions, which may exacerbate already existing conditions (Hass et al., 2021), but is primarily due to their inability to adapt to situations due to a lack of economic resources (Bai et al., 2013; Hajat & Kosatky, 2010b; Schuman, 1972). In contrast, in a study in Korea, it was assumed that the main reason for socioeconomic disparity is due to the access to information (M. Kim et al., 2014).

In terms of heat risk perception, those with very high household incomes and those with very low household incomes were shown to be more aware of the harmful effects of heat (Liu et al., 2013b; Rauf et al., 2017). Whereas heat awareness was higher for lower income groups and lower for higher income groups (Lane et al., 2014; Madrigano et al., 2018). Some reasons given for this were that they have more personal experience and exposure to extreme weather

(Konisky et al., 2016; Rauf et al., 2017). In contrast, in Lhasa, it was found that higher-income groups were more aware of heat risks, despite being less vulnerable (Bai et al., 2013).

2.5.6. Education

Heat risk perception and awareness are crucial adaptation responses to heat, and thus, individuals who do not have access to information or the required education to understand it are also vulnerable to heat (Hass et al., 2021). Therefore, education's primary influence on vulnerability is on awareness and heat risk perception. The outright relationship between heat mortality and education levels is not as strong (Basu & Ostro, 2008; Voelkel et al., 2018). Instead, the impact of education on mortality is more significant for lower socioeconomic groups (Conte Keivabu, 2022).

Different studies have reached varying conclusions regarding the perception of heat and associated risks. In a study done in Lisbon and Madrid, education was less relevant than locality (Gil Cuesta et al., 2017b). Whereas in a study done in Brussels and Amsterdam, education was a significant factor in determining heat awareness (Van Loenhout & Guha-Sapir, 2016). Education was also a factor in risk perception of heat in China and Australia (Liu et al., 2013b; Williams et al., 2019). The results in Lisbon and Madrid are attributed to the population being more exposed to extreme heat, which means even less educated individuals are aware of the impacts of heat.

However, it is worth noting that most of the studies mentioned above were conducted in developed countries. In Pakistan, education was significant, with increased education leading to higher risk perception. The reason given by the researchers was that education increases access to different information sources and the content being carried by them (Rauf et al., 2017)

The above literature suggests that heat vulnerability and heat risk perception are multifaceted. Understanding this complexity and the interrelationship between different environmental, social, and physiological factors is crucial in addressing the impacts of heat.

2.5. Gauteng in Context

2.5.1. Population density

The South African government has identified Gauteng as the region with the highest settlement heat stress risk in its 2050 forecasts (National Climate Change Adaptation Strategy, 2019). These forecasts are not just based on meteorological data but also consider the vulnerability of the Gauteng population. This vulnerability is intensified by the projection that Gauteng's population is expected to increase by over 8.1 million by 2050. Of this growth, 99.99% is likely to occur in the Gauteng City Region, a region that encompasses the metropolitan areas of Johannesburg, Tshwane, Ekurhuleni, Sedibeng, and West Rand. Sedibeng comprises Emfuleni, Lesedi and Midvaal municipalities. West Rand comprises of the Merafong, Mogale and Rand West municipalities. Johannesburg, Tshwane, and Ekurhuleni are all anticipated to be the fastest-growing municipalities within the region (Le Roux, Arnold, et al., 2019).

Figure 2.3. Map of Gauteng City Region Metropoles and Municipalities.

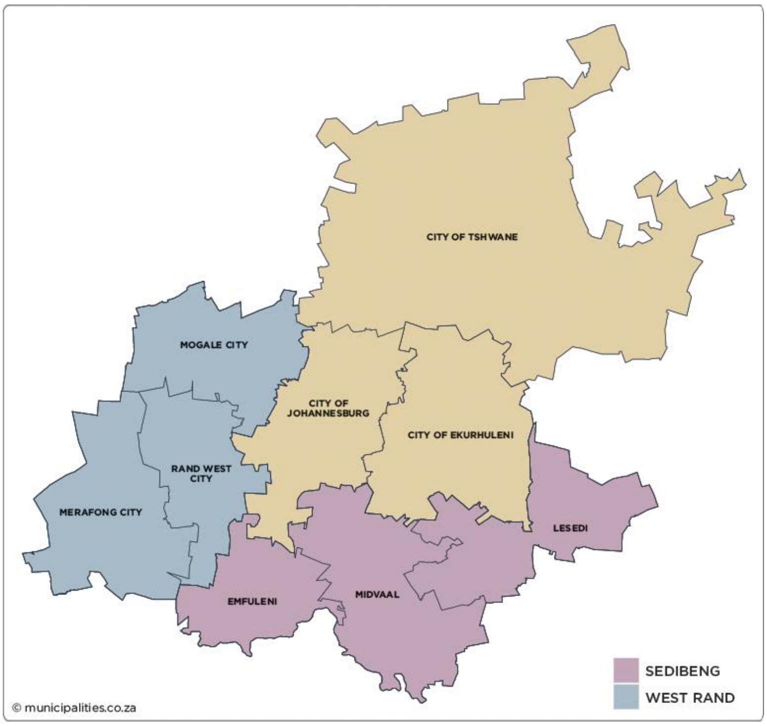
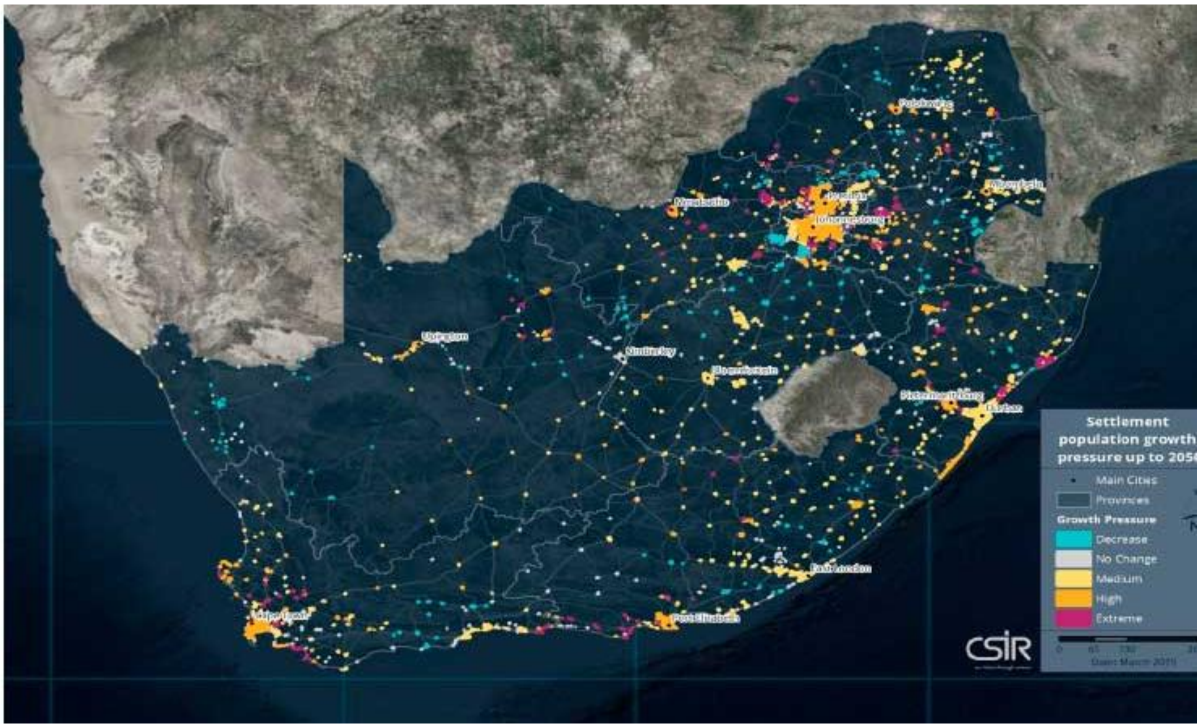
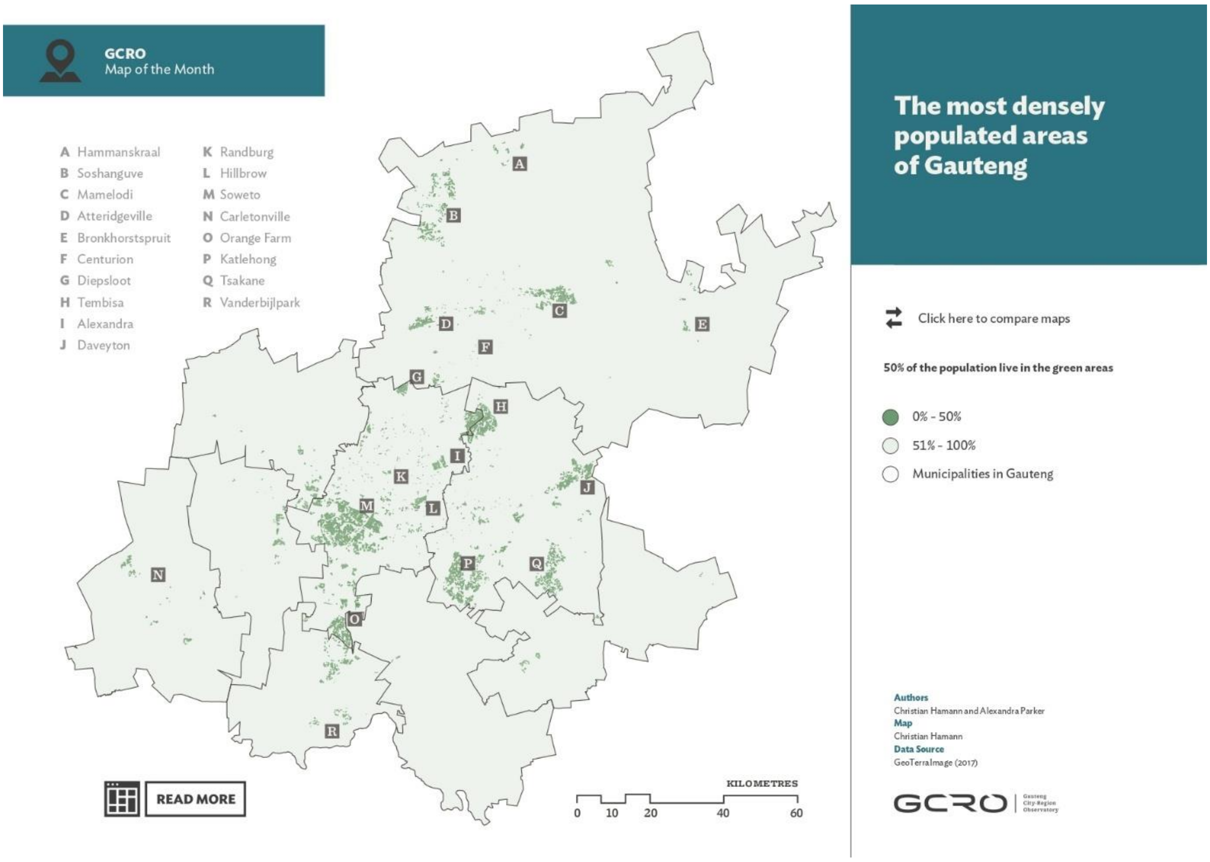


Figure 2.4. Population growth pressure of South African Settlements (Le Roux, Arnold, et al., 2019).



Population growth is concerning because as areas get more densely populated, the environmental and health risks multiply. Densely populated regions put a strain on service provisioning, sanitation, housing, and public spaces, such as parks or schools. Johannesburg ranks as one of the most densely populated cities in the world, although Tshwane and Ekurhuleni still play host to a significant portion of the Gauteng population (Parker & Hamann, 2020).

Figure 2.5. Map of 50% of the Gauteng Population (Parker & Hamann, 2020).



2.5.2. Environmental Vulnerability

These metropoles in Gauteng are not only vulnerable due to their expected population growth, but they also face increased environmental vulnerability due to land use, air pollution, strained watercourses, and Urban Heat Island (UHI) effects. As such, Ekurhuleni and Johannesburg are ranked in the top four most environmentally vulnerable cities in South Africa (Le Roux, van Huyssteen, et al., 2019). The vulnerability of urban areas is amplified by the lack of Urban Green Infrastructure (UGI), which is designed to produce green carbon. The effect of green carbon is twofold; it mitigates and counteracts harmful GHG, but it also has been shown to lower urban temperatures (Chen, 2024).

Figure 2.6. Total green Carbon per Municipality by Hectare (Naidoo et al., 2022).

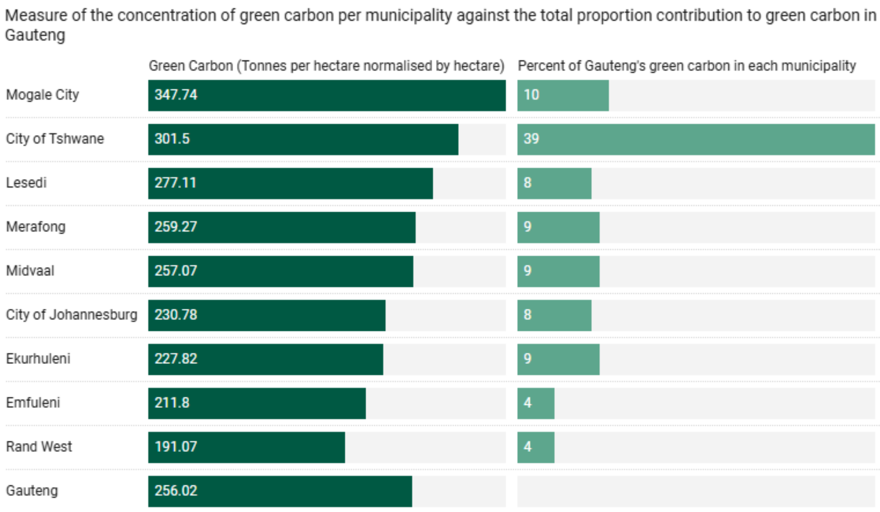
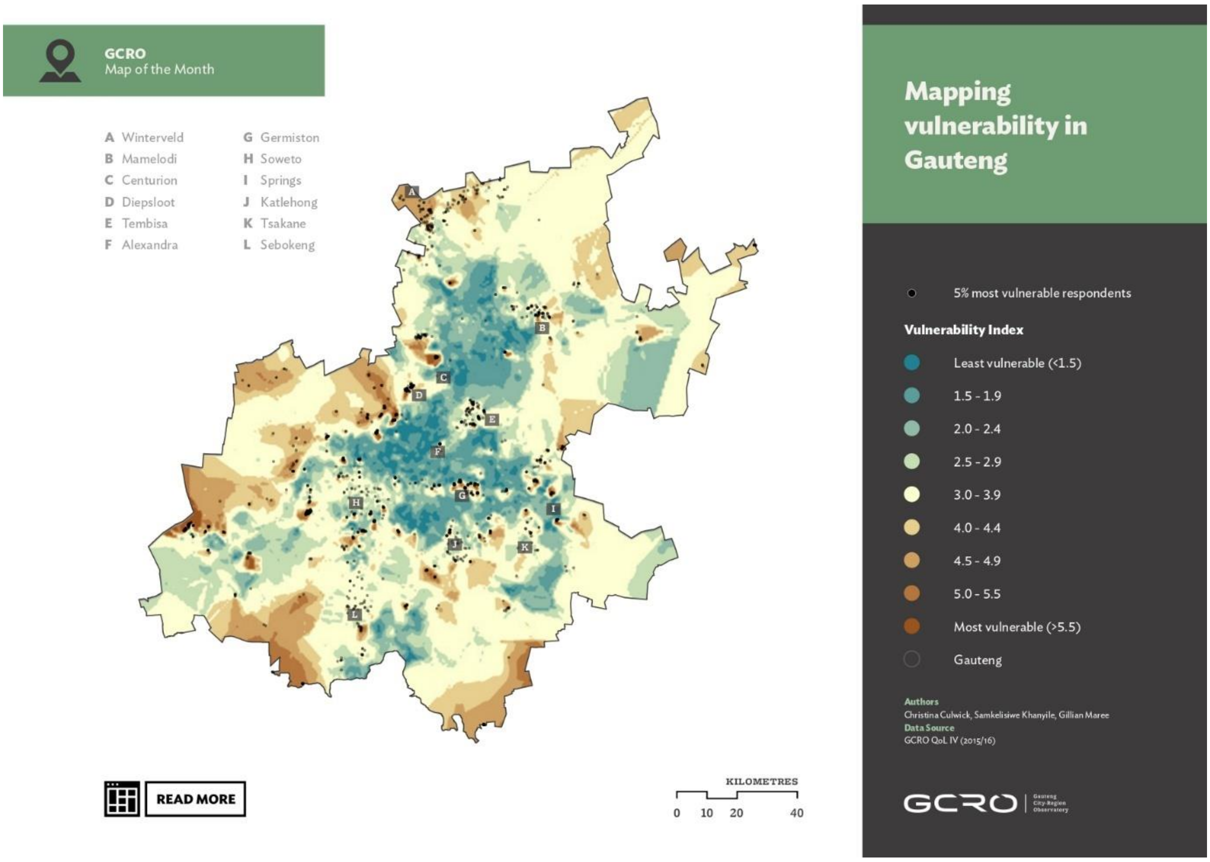


Figure 2.6. shows the different levels of green carbon in Gauteng Municipalities. Notably, some of the lowest levels are observed in Johannesburg and Ekurhuleni, while the highest levels are found in Tshwane. Mogale City in the West Rand exhibits a high concentration of green carbon, which is likely due to the region's abundance of largely unpopulated conservation areas.

Vulnerability to extreme weather events is often determined by examining factors beyond just environmental ones. Access to services, transport, communication, education and social capital can all decrease disaster vulnerability. The areas within the Gauteng City Region each have different vulnerability profiles due to their varying sociodemographic compositions. Figure 2.7. below shows the vulnerability of various regions in Gauteng. Notably, West Rand and Sedibeng exhibit the most vulnerability, likely due to their relative position, which is further from the main cities where services and opportunities are more abundant. Closer to the center of Gauteng, in Johannesburg and north of Johannesburg towards Tshwane, appears to be where vulnerability is lowest.

Figure 2.7. Map of Vulnerability to Natural Disasters in Gauteng. (Maree et al., 2018).



2.5.3. Diversity and Segregation

Although South Africa no longer has segregation laws, there are still significant disparities in the racial composition of different areas. This fact is true for the Gauteng City Region as well as numerous other regions in South Africa. It appears that the racial patterns currently in place are primarily a result of affordability and socioeconomic status (Hamann, 2024).

Figure 2.8. illustrates how different areas of Gauteng have been diversified, examined through a socioeconomic lens. Johannesburg shows the highest diversity but also the highest socioeconomic status. Very few areas remain high-income and undiversified. However, on the outskirts of the Gauteng City Region, we see very low diversity and low incomes. This is especially true for the West Rand, the North of Tshwane and East of Sedibeng. Figure 2.9. further supports the lack of racial diversity in areas such as Sedibeng, West Rand and Tshwane, with Johannesburg and Ekurhuleni showing the most diversity.

Figure 2.8. Map of Segregation and Socioeconomic Distribution in Gauteng (Hamann, 2024).

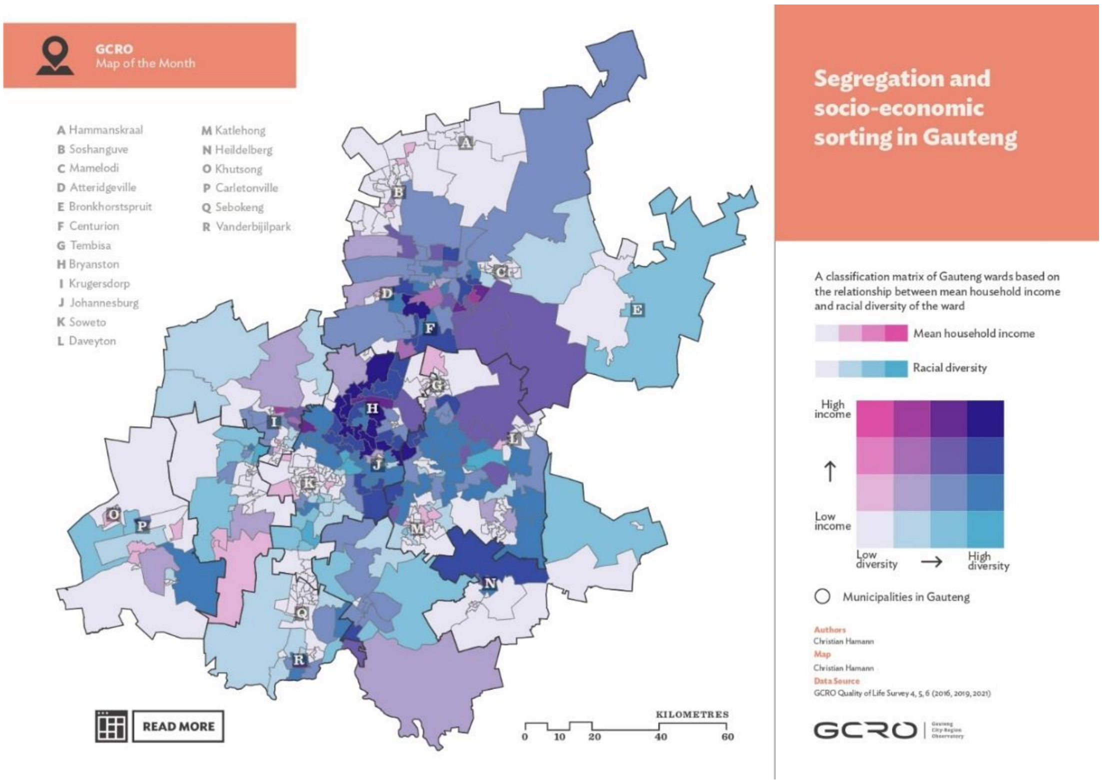
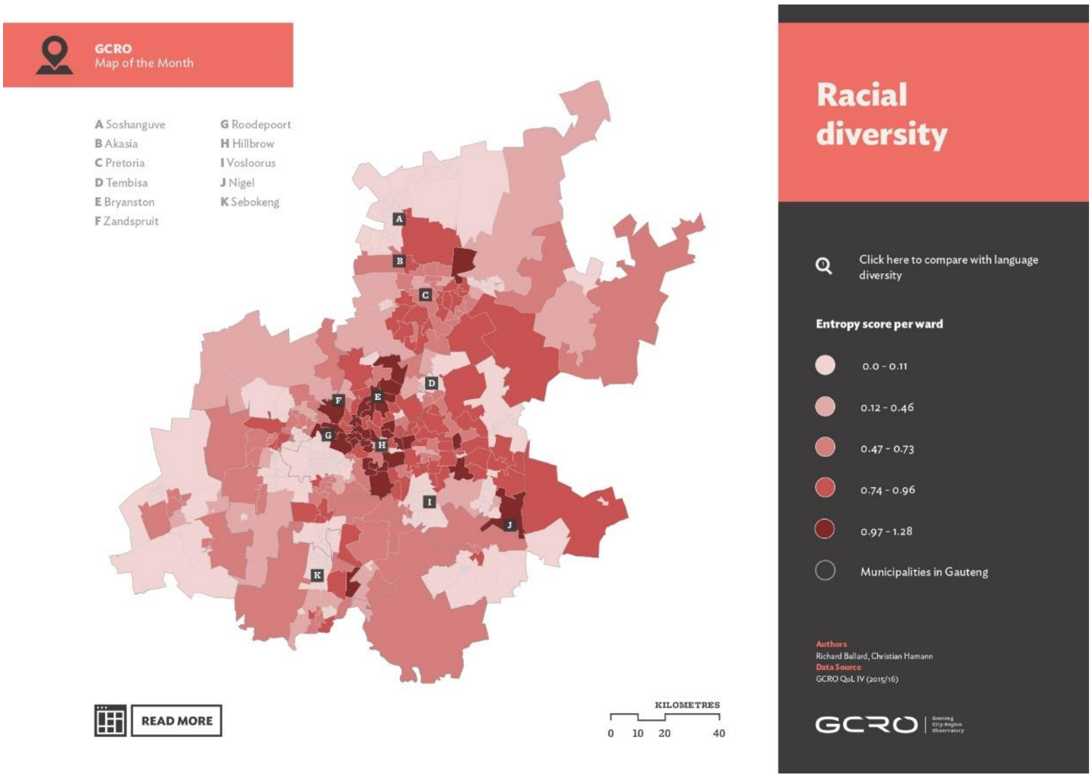
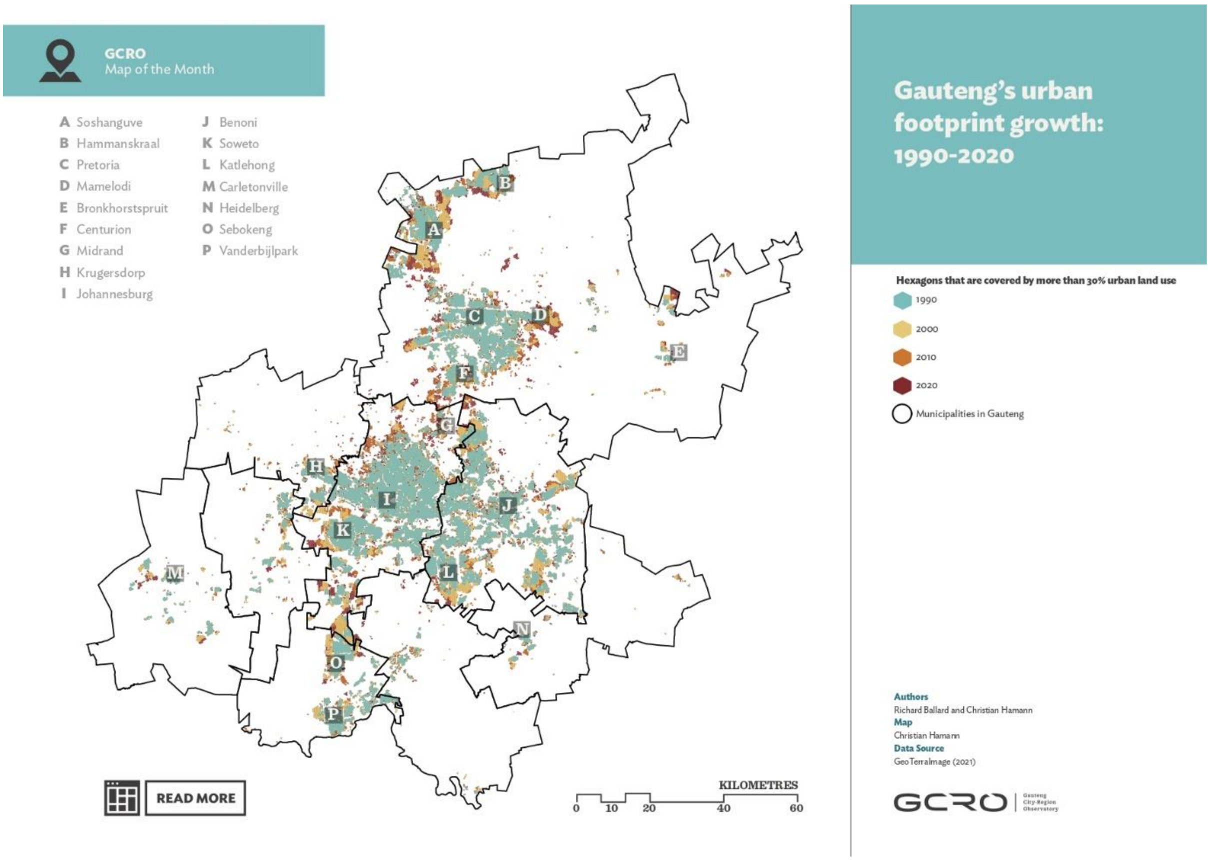


Figure 2.9. Map of Racial Diversity in Gauteng. (Hamann & Ballard, 2017).



2.5.4. Urbanisation

Figure 2.10. Map of Urbanisation of Gauteng (1990-2020) (Ballard & Hamann, 2022).



Since 1990, Gauteng has been rapidly expanding its urban footprint. The result of this expansion is an increase in population density and a decrease in urban green infrastructure. The majority of this increase in urban development has been in residential infrastructure, indicating that urbanisation is likely a result of internal migration to cities for employment opportunities (Ballard & Hamann, 2022).

3. Methodology

3.1. Methodological Design

The research used quantitative tools and the Stata platform to analyse the data and variables from the Gauteng City-Region Observatory (GCRO) Quality of Life (QoL) survey data.

Our first stage of analysis involved identifying the frequency of reported impacts of a heatwave and variations across different regions and sociodemographic factors. By evaluating the frequency we were able to begin evaluating how Gauteng residents self-report their experience of heatwave impacts.

Then, in order to effectively assess how these reported impacts change across both regions and sociedemographics , bivariate analyses were employed.. The utility of bivariate analysis lies in its ability to identify variances in the self-reported impacts of a heatwave across different regions and within various sociodemographic groups. In this research, the bivariate analyses were used for their descriptive purpose. The research relied specifically on one-way analysis of variances (ANOVA) and t-tests.

Based on the observations from the bivariate analyses, we constructed a regression model. The research relied upon a probit regression analysis. Probits are explicitly used for binary dependent variables. In this case, the dependent variable was the reported impact of a heatwave, which was either a “yes” or “no”, making a probit analysis suitable. The dependent variable was then modelled against independent variables.

3.1.1. Model Specification

The probit regression model takes the following form:

$P(Y = 1 \mid X) = \Phi (X \beta)$

Where:

$P(Y = 1 \mid X)$	represents the probability that the dependent variable takes the value 1 (e.g., experiencing a heatwave, having a pre-existing condition, or reporting poor mental health), given a set of explanatory variables.
Φ	denotes the standard normal cumulative distribution function.
X	is a vector of independent variables, including race, sex, education, age, wealth,
β	represents the vector of coefficients to be estimated.

A probit model was used to examine the probability that individuals report being affected by a heatwave, based on their sociodemographic characteristics. The outcome or dependent variable is binary; individuals either reported being impacted or didn't. Therefore, the probit model is best suited because it shows that there's a constant chance of being affected by a heatwave. This chance is influenced by things like race, sex, age, wealth, and education.

The coefficients of a probit do not represent the effect, but they do show the direction and statistical significance of the relationship between the independent variable and the predictor variables. Accordingly, we also did marginal analyses on the regressions.

The marginal effects analysis was used to show how a one-unit change in each sociodemographic characteristic is expected to change the probability of reporting heatwave impact. This method makes it easier to understand the results and how they relate to policies. For example, we can check if low-income families or the elderly are more likely to report negative impacts from heatwaves.

The model will be used to identify how the second component of our conceptual framework; vulnerability, relates to the fourth component of the framework; axes of inequality. This is done by showing the interaction between the independent variables, such as race, sex, education, age, and wealth, and the dependent variable; self-reported impacts of a heatwave.3.2. Data

The research will rely on the Gauteng City-Region Observatory (GCRO) Quality of Life (QoL) survey for the data. The GCRO was established in 2008 and has been conducting its quality-of-life survey since 2009, repeating the survey every two to three years. The QoL collects data on various aspects of livelihoods, including administration, environment and sustainability, demographics, crime and safety, health, social mobility, economics, life satisfaction, and more. Our research will analyse data from the 7th wave of the QoL survey that was conducted in 2023/2024.

3.2.1. Study Area

The GCRO QoL survey encompasses the entire Gauteng province, typically spanning various urban, peri-urban, and rural areas to capture a comprehensive range of living conditions and experiences. Conducted across nine municipalities and 529 wards, the survey provides valuable insights into the diverse socio-economic and environmental factors that influence the quality of life in South Africa.

3.2.2. Sampling Methods

The Quality of Life (QoL) survey utilised a stratified, multi-stage sampling design to ensure representation across all 529 wards in Gauteng province. Wards were used as the primary sampling unit, and a minimum of 20 interviews were conducted per ward. They also ensured that 600 interviews were conducted per municipality. Each ward had designated enumeration areas randomly selected using a probability proportional size approach based on the number of residences within the ward.

The primary interview points/households were then randomly chosen using the GeoTerraImage Building-Based Land Use dataset, and three substitution points were generated in case the chosen household decided not to participate. In places where the primary household contained multiple dwelling units, the interviewer randomly selected one for the interview.

The final sample size was 13,795 respondents. This amount surpassed the targeted sample size and also exceeded municipality targets. Ward-level targets were mostly met or exceeded, bar a few wards, which only managed 95% of the target.

3.2.3. Survey Design

The data is obtained through structured questionnaires conducted by an external service provider. The survey conducts over 13,000 interviews with individuals over the age of 18 at their homes. The survey comprises over 200 questions translated into 8 different languages, some of which were asked of the individual and others of the household.

The interviews were conducted face-to-face with data capturers, who used tablets to record responses that were sent directly to the Kobo Toolbox software. The interviews usually took 35 minutes to administer. Sensitive questions were answered by the participants themselves directly onto the tablet.

Data was then subjected to quality control, beginning with strictly recruiting fieldworkers and subjecting them to high-quality training. Challenges in the field were reported, and approaches adjusted were necessary. Surveys that did not meet the requirements were rejected without discretion.

3.3. Data Analysis

The data analyses used in this study were run on Stata/SE 17 for Windows. The following variables will be used to run our analysis:

Table 3.1. Dependent Variables, Measurement and Reasons for Selection (Gauteng City Region Observatory, 2024)

Variable	*GCRO QoL* question *and Measurement*	Details and Reason for selection
Self-reported impact of a heatwave	*Q1.19_4: Has your household been severely affected (e.g., experienced damage, injury or harm) by a heatwave in the last 12 months?* No = 0 Yes = 1	Self-reported impact of a heatwave is a proxy to heat risk perception as it captures not only individuals' physical exposure, but also their subjective awareness and interpretation of heat-related harm, ie did they experience damage, injury or harm. It therefore identifies whether an individual experienced a heatwave and then perceived that the heatwave had severe implications. While it is not a direct measure of risk perception, it allows us to assess who is most likely to recognise and report heat-related impacts.

Table 3.2. Independent Variables, Measurement and Reasons for Selection (Gauteng City Region Observatory, 2024)

Variable	*GCRO QoL* question and Measurement	Details and Reason for selection
Socioeconomic Status	*Two variables will be used to measure socioeconomic status:*	Socioeconomic status has been shown in the literature to increase vulnerability to heat and affect heat risk perception (Hass et al., 2021; S. Kim et al., 2020).

	1. *wealth_index (continuous)* 2. *wealth_quintile (ordinal)* Wealth_index variable constructed into five quintiles.	The wealth index is constructed using multiple-correspondence analysis (MCA), drawing on data on dwelling type, structure and ownership, access to water, sanitation and electricity, energy sources for cooking and lighting, indebtedness, the ownership of ten household assets, and access to social grants and indigent status. The *wealth_index* variable will be used specifically in the regression analyses, whereas the *wealth_quintile* variable will be used in the bivariate analysis to see how heat risk perception varies across socioeconomic quintiles.
Education	*Q14.1: What is the highest level of education you have completed?* No/Primary= 1 Secondary = 2 Tertiary = 3	Higher education levels are associated with higher heat risk perception (Rauf et al., 2017). Education is correlated to heat vulnerability through awareness and access to information (Hass et al., 2021). Education has been coded to simplify our analysis; the regression analysis utilised the dummy variables: *Education_3* – Secondary Education compared to No/Primary and Tertiary Education *Education_5* – Tertiary Education compared to No/Primary and Secondary Education
Sex	*A2: What is the sex of the respondent?* Male = 1 Female = 2	Caregiving roles often expose females to a higher heat risk perception (Akompab et al., 2013). There is also evidence that suggests women are more physiologically vulnerable (Seidell et al., 1988).

Race	*A1_pop_group: To which population group does the respondent belong?* Black African = 1 Coloured = 2 Indian/Asian = 3 White = 4 Other = 5	Historical patterns of racial discrimination and segregation have resulted in a prolific racial inequality. We aim to investigate whether racial inequality is associated with a disparity in heat risk perception, as suggested by other studies (Benz & Burney, 2021; Mitchell & Chakraborty, 2018). The reporting of race excludes the variable group "other" due to the small sample size.
African	*Recoded race variable.* Black African = 1 [Coloured, Indian/Asian, White, Other] = 2	The *race* variable was recoded to place a specific focus on the African population group, due to the bivariate results and Gauteng demographic patterns
Age	*Q14.2: How old are you?* Min 18 Max 107	Age is a critical factor in vulnerability studies, particularly in the context of older populations (Kovats & Hajat, 2008b). We aim to assess whether this vulnerability is associated with a higher heat risk perception.

Table 3.3. Other Variables, Measurement and Reasons for Selection (Gauteng City Region Observatory, 2024).

Variable	*GCRO QoL* question and Measurement	Details and Reason for selection
Region	*municipality_coded* Ekurhuleni = 1 Johannesburg = 2 Tshwane = 3 Sedibeng = 4 West Rand = 5	Comparisons across different regions will provide insight into the spatial disparities of heat. Regions are divided into five metropoles, each with distinct characteristics and demographic compositions.

4. Results

4.1. Self-Reported Impact of Heat

Table 4.1. Self-Reported Impacts of a Heatwave (2023/24).

Region	Mean	Frequency	CI Interval
Ekurhuleni	17.02%	460	[0.16, 0.18]
Johannesburg	36.48%	1,432	[0.35, 0.28]
Tshwane	26.98%	708	[0.25, 0.29]
Sedibeng	25.49%	574	[0.24, 0.27]
West Rand	27.22%	607	[0.25, 0.29]
Total	27.53%	3,781	[0.27, 0.28]

The total for Gauteng showed that over one-quarter of respondents (27.53%) reported being impacted by a heatwave. In evaluating the variance between different regions reporting the impacts of a heatwave, the ANOVA found a stark disparity between Johannesburg and Ekurhuleni. The results showed that residents of Johannesburg were more than twice as likely to report being impacted by a heatwave than those in Ekurhuleni.

This could be due to differences in the sociodemographic composition of the regions, or it could be a result of the different experiences of heat in the regions. For example, Johannesburg might have more reported impacts of heat because it's more crowded and suffers from the urban heat island effectAlthough Sedibeng, West Rand, and Tshwane had a minimal difference in their means, the ANOVA F-statistic was still relatively high (79.95), with a p-value < 0.001. The p-value and F-statistic indicate that, despite the minimal difference, there is still statistically significant variance across all regions. This suggests that the region where you live may play a significant role in how individuals report the impacts of heat.

4.2. Bivariate Analysis on sociodemographic factors

4.2.1. Socioeconomic status

Table 4.2. ANOVA between Self-Reported Impacts of a Heatwave and Wealth Quintiles (2023/24).

Wealth_Quintile	Mean	Frequency	CI Interval
Quintile one	25.94%	630	[0.24, 0.28]
Quintile two	25.26%	653	[0.24, 0.27]
Quintile three	24.97%	692	[0.23, 0.27]
Quintile four	29.89%	863	[0.28, 0.32]
Quintile five	30.80%	943	[0.29, 0.32]

With a p-value of 0.000 and an F-statistic of 10.86, the ANOVA results indicated a statistically significant association between socioeconomic status and self-reported impact of heatwaves. Individuals with a higher socioeconomic status were more likely to report having been impacted by a heatwave. The F-statistic is expected due to the proximity between quintiles one to three. However, quintile five is still 20% more likely to report heat than quintile one.

4.2.2. Age

Table 4.3. t-test between Self-Reported Impacts of a Heatwave and Age (2023/24).

Reported impact	Mean	CI Interval
Yes	42.87%	[0.42, 0.43]
No	42.59%	[0.42, 0.42]

The t-test for age, examining the self-reported impact of a heatwave, yielded a p-value of 0.365 and a t-value of -0.9106. These statistics indicate that there is no statistically significant relationship between the variables and minimal variance between age groups.

4.2.3. Education

Table 4.4. ANOVA between Self-Reported Impacts of a Heatwave and Education (2023/24).

Education	Mean	Frequency	CI Interval
None or Primary	24.33%	312	[0.22, 0.27]
Secondary	26.52%	2,242	[0.27, 0.27]
Tertiary	30.61%	1,196	[0.29, 0.32]

The ANOVA between education and self-reported impacts of a heatwave found that more educated individuals were more likely to report an impact of a heatwave. The p-value was <0.001, and the F-statistic was 14.79. The results are, therefore, statistically significant, with moderate variance between education levels.

4.2.4. Sex

Table 4.5. ANOVA between Self-Reported Impacts of a Heatwave and Sex (2023/24).

Sex	Mean	Frequency	CI Interval
Male	27.51%	1,838	[0.26, 0.29]
Female	27.55%	1,943	[0.27, 0.29]

The ANOVA test on male and female self-reported impacts of a heatwave found nearly no difference between the genders. The p-value was 0.9522, and the F-statistic was 0.00.

4.2.5. Race

Table 4.6. ANOVA between Self-Reported Impacts of a Heatwave and Race (2023/24).

Race	Mean	Frequency	CI Interval
African	25.59%	2,760	[0.25, 0.26]
Coloured	33.91%	197	[0.30, 0.38]
Indian/Asian	35.54%	134	[0.31, 0.40]
White	34.80%	686	[0.33, 0.37]

Race excludes “other” (n=20).

The ANOVA for the different racial groups and self-reported impact of a heatwave revealed a significant difference, primarily in the African group. The p-value < 0.001, and the F-statistic was 24.45. The F-statistic was high, and the African racial group stands out when compared to all the other racial groups.

When the relationship between the race variable and wealth quintile variable was measured, it was found that there was a strong association between the variables. Quintile one is 97.3% African, whereas Quintile 5 is more diverse and only 47.5% African.

4.3. Bivariate Analysis on sociodemographic factors by Region

4.3.1. Socioeconomic status

Table 4.7. ANOVAs between Wealth Quintiles and Self-Reported Impacts of a Heatwave per Region (2023/24).

	Quintile 1	Quintile 2	Quintile 3	Quintile 4	Quintile 5	p-value
Ekurhuleni	18.27%	15.30%	14.42%	19.12%	17.95%	0.17
Johannesburg	39.38%	35.35%	32.64%	36.91%	37.87%	0.09
Tshwane	21.87%	23.71%	26.65%	27.27%	33.39%	<0.001
Sedibeng	22.02%	20.28%	24.44%	28.91%	31.41%	<0.001
West Rand	24.43%	27.85%	24.39%	34.45%	22.99%	<0.001
Total	25.94%	25.26%	24.97%	29.89%	30.80%	<0.001

Pearson chi2(4) = 43.2992   Pr = 0.000

Tshwane, Sedibeng, and the West Rand all showed a statistically significant relationship between the self-reported impacts of heat across different wealth quintiles. Tshwane showed the highest variance (F-statistic = 5.58), with self-reported impacts of a heatwave increasing consistently across each quintile. Sedibeng exhibited a similar trend in reporting to Tshwane with an F-statistic of 4.68.

The West Rand showed the least variance between the quintiles (F-statistic = 4.70); however, the trend across quintiles differed from those in Tshwane and Sedibeng. For quintiles one to four, there was a consistent increase in self-reported impacts of a heatwave. However, there was a sudden decrease going from quintile four (34.45%) to quintile five (22.99%).

4.3.2. Age

Table 4.8. t-tests between Age and Self-Reported Impacts of a Heatwave per Region (2023/24).

Region	No	Yes	P-value
Ekurhuleni	41.59%	43.07%	0.07
Johannesburg	42.62%	41.86%	0.13
Tshwane	42.66%	44.84%	0.00
Sedibeng	44.38%	43.93%	0.58
West Rand	41.99%	41.78%	0.77
Total	42.59%	42.87%	0.36

Pearson chi2(79) = 63.9837 Pr = 0.890

Only Tshwane showed statistical significance across age groups for the self-reported impacts of a heatwave; the F-statistic for Tshwane was -3.01, indicating an inverse relationship. Ekurhuleni was only marginally significant with a low F-statistic of -1.84.

4.3.3. Education

Table 4.9. ANOVAs between Education and Self-Reported Impacts of a Heatwave per Region (2023/24).

	Education Level			
Region	None/Primary	Secondary	Tertiary	p-value
Ekurhuleni	14.93%	15.95%	20.24%	0.03
Johannesburg	32.82%	35.425	38.56%	0.08
Tshwane	25.38%	26.14%	29.10%	0.25
Sedibeng	19.71%	23.91%	32.73%	0.00
West Rand	27.80%	28.41%	23.72%	0.11
Total	24.43%	26.52%	30.61%	<0.001

Pearson chi2(2) = 29.5155 Pr = 0.000

Sedibeng showed a statistically significant relationship between education levels. The F-statistic for Sedibeng was moderately high (11.07), indicating that the variance between education levels shifts substantially. Ekurhuleni and Johannesburg showed moderate statistical significance. However, their F-statistic was much lower than Sedibeng's, 3.56 and 2.54, respectively.

4.3.4. Sex

Table 4.10. ANOVAs between Sex and Self-Reported Impacts of a Heatwave per Region (2023/24).

	Sex		
Region	Male	Female	p-value
Ekurhuleni	16.97%	17.06%	0.95
Johannesburg	36.86%	36.12%	0.63
Tshwane	25.53%	28.34%	0.11
Sedibeng	26.96%	24.12%	0.12
West Rand	26.49%	27.91%	0.45
Total	27.51%	27.55%	0.95

Pearson chi2(1) = 0.0036 Pr = 0.952

None of the regions showed a statistically significant relationship between sex and self-reported impacts of a heatwave. These findings confirm those done in the bivariate analysis for the entire Gauteng region.

4.3.5. Race

Table 4.11. ANOVAs between Race and Self-Reported Impacts of a Heatwave per Region (2023/24).

	Race				
Region	African	Coloured	Indian/Asian	White	p-value
Ekurhuleni	15.52%	22.22%	12.20%	25.21%	<0,001
Johannesburg	35.81%	35.91%	41.29%	38.98%	0.42
Tshwane	24.82%	20.00%	30.88%	37.72%	<0,001
Sedibeng	22.22%	40.00%	42.11%	37.83%	<0,001

West rand	25.43%	51.25%	35.42%	30.66%	<0,001
Total	25.59%	33.91%	35.54%	34.80%	<0.001

Pearson chi2(4) = 97.1495 Pr = 0.000

Race excludes "other" (n=20).

All four regions, except for Johannesburg, showed a statistically significant relationship between race and the self-reported impacts of heat.

Ekurhuleni had the least variance across the different regions. Notably, in Ekurhuleni, the racial group with the lowest reporting of heatwave impacts was Indian/Asian (12.20%), followed closely by African (15.52%). The higher racial groups were Coloured (22.22%) and White (25.21%).

In Tshwane, the racial group with the highest reported impacts was White (37.73%), with a relatively decent sample size (448). The lowest group was Coloured (20%) with a sample size of 65, followed by African (24.82%) with the largest sample size of 2,035. The Indian/Asian group had a small sample size (68) with a high likelihood of reporting impacts (30.88%).

Sedibeng exhibited the highest variance (12.70). The high likelihood of reports by Indians/Asians (42.11%) could be due to the small sample size in Sedibeng (19). The Coloured racial group had a high likelihood (40%), but similarly had a low sample size (30). Africans (1,787) and Whites (415) had a higher sample size in Sedibeng, with a large variance in reporting, at 22.22% and 37.83%, respectively.

In the West Rand, the Coloured group had a very high likelihood of reporting (50%), which is likely due to the sample size of 80. The second highest likelihood was Indian/Asian (35.42%), with a sample size of 48. Followed closely by White (30.66%) with a sample size of 287. The lowest likelihood was observed in the African group (25.42%), with the largest sample size (1,813).

4.4. Regression Analysis on sociodemographic factors by Region

This regression analysis for all of Gauteng revealed that only African was statistically significant ($p < 0.001$). The negative coefficient of the African variable indicates that being African reduces your likelihood of reporting an impact of a heatwave The significance of the constant variable ($p < 0.001$) and the low pseudo-R-squared value (0.0347) for the regression indicate that there are likely other significant factors that have not been included in the model.

The regression for Gauteng also showed that all regional dummy variables were statistically significant and positively associated with the likelihood of reporting heatwave impacts. Compared to Ekurhuleni (the reference region), individuals living in Johannesburg (region 2) were 21.3% more likely to report heatwave impacts, the highest marginal effect observed among the regional categories. Tshwane (region 3), Sedibeng (region 4), and West Rand (region 5) also showed increased likelihoods of 11.87%, 8.00%, and 12.42%, respectively..

The regional regression analyses revealed that race was the only sociodemographic variable with statistical significance in more than one region. African showed high statistical significance in Sedibeng ($p<0.001$) and moderate statistical significance in Tshwane and Ekurhuleni ($p<0.05$). Sedibeng showed the highest marginal effect (-13.72) out of the other two regions, Tshwane (-6.22) and Ekurhuleni (-5.80).

In Tshwane, the wealth variable was statistically significant ($p < 0.05$) and had a marginal effect of 3.64%, indicating that a change in wealth results in only a slight change in self-reported impacts of a heatwave. Tshwane, being the only region to show statistical significance for wealth, is noteworthy as it also reported the highest F-statistic in the bivariate analysis of wealth and self-reported impacts between regions.

Age was also statistically significant ($p<0.05$) in Tshwane, although its coefficient was very low (0.00), and the marginal effects were also minor (0.16%). The small marginal effects indicate that the relationship, although moderately statistically significant, is not strong.

Sex was found to be moderately statistically significant ($p < 0.05$) in Sedibeng. The negative coefficient (-0.26) indicates that males are less likely to report being impacted by a heatwave. The marginal effects show that being male increases the likelihood of reporting impacts of a heatwave by 7.69%.

A similar level of effect was observed in Ekurhuleni with tertiary education. The coefficient was 0.29, with moderate statistical significance ($p<0.05$) and marginal effects of 7.03%. The positive coefficient indicates that obtaining a tertiary education will increase your likelihood of reporting heatwave impacts by 7.03%.

It was notable that no sociodemographic variables showed statistical significance in Johannesburg, and the LR chi-squared for Johannesburg was insignificant ($p = 0.2580$), as was the case for West Rand ($p = 0.0162$). These were the only two regions whose regressions were not a good fit. However, their likelihood ratios were still lower than those of Gauteng, indicating that each region makes its own unique contributions to the self-reported impacts of a heatwave, which the models did not account for.

Table 4.12. Regression Results.

	City of Ekurhuleni		City of Johannesburg		City of Tshwane		Sedibeng		Total	
	coefficients	marginal effects(%)	coefficients	marginal effects(%)	coefficients	marginal effects(%)	coefficients	marginal effects(%)	coefficients	marginal effects(%)
Wealth_index	-0.04(0.03)	-0.91(0.01)	-0.07(0.05)	-2.65(0.02)	0.11**(0.05)	3.64**(0.02)	-0.02(0.05)	-0.55(0.02)	-0.02(0.02)	-0.54(0.01)
Age	0.00(0.00)	0.03(0.00)	-0.00(0.00)	-0.11(0.00)	0.00**(0.00)	0.16**(0.00)	-0.00(0.00)	-0.07(0.00)	0.00(0.00)	0.02(0.00)
Education_3	0.07(0.13)	1.71(0.03)	-0.10(0.15)	-3.84(0.06)	0.04(0.14)	1.28(0.04)	0.02(0.16)	0.48(0.05)	0.00(0.07)	0.03(0.02)
Education_5	0.29**(0.15)	7.03**(0.03)	0.03(0.16)	1.05(0.06)	0.11(0.16)	3.47(0.05)	0.21(0.19)	6.29(0.06)	0.19(0.08)	3.84(0.03)
Sex	0.03(0.07)	0.71(0.02)	0 .01(0.06)	0.44(0.02)	0.11(0.07)	3.57(0.02)	-0.26**(0.09)	-7.69**(0.02)	0.02(0.04)	0.73(0.01)
African	-0.24**(0.09)	-5.80**(0.02)	-0.12(0.08)	-4.48(0.03)	-0.19**(0.09)	-6.22**(0.03)	-0.47***(0.12)	-13.72***(0.04)	-0.22***(0.05)	-7.10***(0.01)
Region_2									0.66***(0.05)	21.30***(0.02)
Region_3									0.37***(0.05)	11.87***(0.02)
Region_4									0.25***(0.06)	8.00***(0.02)
Region_5									0.38***(0.51)	12.42***(0.02)
Constant	-1.02***(0.23)		-0.09(0.24)		-0.89***(0.24)		-0.06(0.30)		-0.90***(0.13)	
Log Likelihood	-1606.59		-2877.94		-2068.91		-539.64		-7658.17	
LR chi-squared	18.58**		7.74		33.31***		29.30***		263.07***	
Pseudo R^2	0.0098		0.0040		0.0216		0.0267		0.0347	
Sample (n)	2,691		3,900		2,606		2,225		13,644	

***p<0.01; **p<0.05; *p<0.1

Standard errors are given in parentheses.

Weighted results

Note: The results of the West Rand probit regression were insignificant with a chi-squared p-value of 0.0162 and accordingly left out of reported findings above.

5. Discussion:

The findings above provide an analysis of how sociodemographic variables correlate with heat risk perceptions. In the discussion that follows, the relationships will be summarised and compared to the existing literature. Thereafter, the findings will be integrated into the conceptual framework to illustrate the implications of these findings for heat and health, followed by a discussion of the limitations and recommendations of this research.

5.1. Heat Risk Perception

The first observations aimed to evaluate the number of individuals who reported an impact of a heatwave in the Wave 7 GCRO data. The results show that 27.5% of participants reported having been impacted by a heatwave. These results appear low when compared to other studies that reported between 60-80% of participants knew of heatwaves and their impacts on human health (Bai et al., 2013; Liu et al., 2013a; Rauf et al., 2017). They were also low when compared to studies that asked about individuals' concerns about heatwaves, where the response rate was 68% (Madrigano et al., 2018).

Our findings indicate that less than one-third of respondents reported the impact of a heatwave. However, the question in the GCRO QoL was more specific than those used in other studies. The question explicitly asked if a heatwave *had* impacted the individual. The question was, therefore, primarily concerned with whether individuals were aware of actual impacts, rather than potential impacts. Thus, considering the nature of heat and the subtlety of its actual impacts, a 27.5% report rate could be considered relatively high.

According to the South African Weather Service, Gauteng also has a low threshold for heatwaves. A threshold is used as a trigger point for when to declare a heatwave, specifically to prevent its harmful effects. A low threshold indicates lower thermal comfort, and accordingly lower acclimatisation (Lam & Lau, 2018). Therefore, the low threshold in Gauteng, combined with the low report rate, suggests a need for a higher heat risk perception. Especially as research suggests that temperatures as low as 24°C could still have negative impacts on health in urban areas (Beckmann & Hiete, 2020).

Most adaptation strategies are informed by scientific methods that seek to understand the future risk of climate hazards (Garschagen et al., 2021). Accordingly, the policies and strategies that flow from these assessments do not give a full picture (Okunola et al., 2022). While currently the City of Johannesburg has a Climate Change Action Plan, this plan does not include any mention of how they plan to increase heat risk perception. The Ekurhuleni Climate Change Response Strategy is slightly more inclusive of sociodemographic factors, citing access to resources in rural areas as an adaptation action area. Similarly, the Tshwane Climate Change Action Plan recognises vulnerabilities, but fails to recognise race as an aspect of vulnerability that needs to be looked at. Sedibeng and West Rand do not yet have any climate change policy. What these policies show is that while sociodemographic vulnerabilities are recognised, their contribution to risk perception are not being planned and accounted for.

These results are important because heat risk perception plays a crucial role in determining vulnerability. It influences both exposure and adaptive capacity (Beckmann & Hiete, 2020; Hass et al., 2021). As such, our findings suggest that to reduce the vulnerability of the Gauteng population, greater emphasis should be placed on increasing heat risk perception. To effectively do this, an appreciation for the various correlations between heat risk perception and other factors is also necessary. Accordingly, the discussion that follows unpacks the results of the analyses done between heat risk perception and sociodemographic variables. Essentially, seeking to identify which populations are most vulnerable.

5.2. Sociodemographic Factors and Heat Risk Perception

The literature review suggests that factors such as education, age, sex, race, and socioeconomic status can all affect heat risk perception. However, our findings show that not all these sociodemographic variables were significant either regionally or in the greater Gauteng.

5.2.1. Sex and age

Our results show no direct trend in the variation across different age and sex groups. This lack of significance is also evident in the regressions for Gauteng and its respective regions. Only two regions showed statistical significance for age or sex in the regression analyses. That being said, an evaluation of these findings reveals that, although the variables were moderately significant ($P < 0.05$), their marginal effects and coefficients were relatively low. Accordingly, these results indicate that the relationship between heat risk perception and age and sex is not strong for the Gauteng region.

While other literature indicates a higher heat risk perception in females (Liu et al., 2013a; Rauf et al., 2017; Williams et al., 2019), our findings suggest that this disparity between genders may not be as prevalent in Gauteng. The results for age are more consistent with the literature that suggests that although age influences vulnerability, this does not necessarily increase heat risk perception (Abrahamson et al., 2008; Lane et al., 2014; Williams et al., 2019).

5.2.2. Socioeconomic status and education

A clear trend was observed between socioeconomic status and the self-reported impacts of a heatwave in the bivariate analyses. Higher quintiles were all more likely to report being impacted by a heatwave, whereas the lower quintiles were less likely. A similar trend was observed across education levels, with higher education levels more likely to report the impacts of a heatwave.

Similar results can be found in bivariate analyses with socioeconomic status in other studies (Madrigano et al., 2018). However, the lack of statistical significance in the regression analysis suggests that although heat risk perception varies across socioeconomic status, this variation is not attributed solely to changes in socioeconomic status.

Education also showed no significance in any of the regression analyses, except for Ekurhuleni, which showed statistical significance for tertiary education. The lack of prevalence in the regressions indicates that the variance across education levels is not solely due to education and is likely a result of other variables. Other studies suggest that the effect of education on vulnerability is better understood when it is seen in conjunction with other variables (Conte Keivabu, 2022; Voelkel et al., 2018).

5.2.3. Race

Race was statistically significant in every region's bivariate analysis and in the probit analysis performed using all sociodemographic variables. These results indicate that the relationship between the self-reported impacts of a heatwave and race is strong in Gauteng. It was also the only variable to show statistical significance in the regional regression analyses.

Although there are few studies which evaluate racial disparities in heat risk perception, the research is evident in demonstrating how access to resources influences heat risk perception (Bai et al., 2013; Cutter et al., 2003; Hajat & Kosatky, 2010b; Schuman, 1972). Accordingly, our results must be understood in the context of South Africa’s racialised history. A history in which the African racial group was intentionally restricted from economic, social and political resources (Shahaboonin et al., 2023). Thus, the variance observed between racial groups in our findings is indicative of a disparity in access to resources, which affects heat risk perception.

The studies that have investigated how race and heat risk perception have identified that spatial inequality is the main contributor to any racial disparity in heat risk perception (Benz & Burney, 2021; Mitchell & Chakraborty, 2018; Wilson, 2020). As such, our findings, in conjunction with the literature, suggest that the vulnerability of racial groups is likely due to racial segregation and economic, social and political exclusion.

5.2.4. Who is most vulnerable?

These results suggest that the most significant sociodemographic variable in self-reported impacts of a heatwave is race. Our results differ from the results of *Rauf et al.*, who found that age, education, gender, and income were all significant predictors in their logit model (Rauf et al., 2017). One reason for this difference could be the higher levels of reported heat awareness in the *Rauf et al.* study (70-80%) compared to the lower reports in our study (27.5%).

While socioeconomic status and education both show trends in heat risk perception, this relationship does not explain the reported impacts of heat. Age and sex show no relationship in our analysis, which could be due to the dominance of the other variables. Of all the variables, race shows significance far above the others, indicating that racial disparities in Gauteng make the most significant contribution to how individuals report the impacts of a heatwave.

Race, being the most significant sociodemographic factor, may also contribute to the variance observed across both education and socioeconomic status. According to the GCRO data, 97% of individuals who reported no education or only primary school level education were African. Similarly, 97% of individuals belonging to quintile one were African, compared to only 47.45% in quintile five (Gauteng City Region Observatory, 2024). Accordingly, the African racial group likely faces the greatest vulnerability to heat in Gauteng due to the lack of access to resources.

This lack of access to resources is more evident when we use the GCRO data to evaluate the percentage of respondents living in informal dwellings for each race group. This analysis was conducted using a chi-squared test for independence. The analysis yielded a chi-square statistic of 510.09 with 4 degrees of freedom and a p-value < 0.001. We can therefore conclude that the relationship between race and informal dwelling is statistically significant. Of the 1,857 respondents who live in an informal dwelling, 1,826 (98.3%) were African (Gauteng City Region Observatory, 2024).

When a similar analysis was conducted with medical aid, the results showed a chi-square statistic of over 3000, with 4 degrees of freedom, and a p-value < 0.001. Therefore, the relationship between medical aid and race was statistically significant, and the very high chi-squared statistic is evidence of a very strong relationship between the variables. A total of 9,043 respondents without medical aid were African, comprising 65.84% of the total sample. While medical aid is not necessarily evidence of low heat risk perception, it is evidence of the lack of access to resources for the African population (Gauteng City Region Observatory, 2024).

This is likely a result of discriminatory laws which were designed to exclude Africans from the economy and the state in general. Part of this discrimination was the intentional development of apartheid spatial planning, a tool for systematic segregation in more urbanised areas. The effects of this will be discussed in the subsequent section.

5.3. Spatial Inequality and Heat Risk Perception

Our findings on the regional relationships between heat risk perception revealed variance across different regions in Gauteng. Participants from Johannesburg were nearly twice as likely to report being impacted by a heatwave as those from Ekurhuleni.

Johannesburg is notable because neither the bivariate nor the regression analysis identified any sociodemographic variables as significant in explaining the higher number of reports of heatwave impacts. Accordingly, other variables must contribute to Johannesburg's higher reports of heatwave impacts compared to the other regions. One of these reasons could be the density of the population in Johannesburg (Parker & Hamann, 2020), the increase of which is expected to make Johannesburg vulnerable to heat stress risk (Le Roux, Arnold, et al., 2019).

One explanation for the disparity between Johannesburg and Ekurhuleni's reported heat impacts is the Urban Heat Island (UHI) effect, which suggests that more urban areas get higher heat exposure. Figure 2.8 indicates that both Johannesburg and Ekurhuleni have experienced the most significant increase in urbanisation since 1990. Accordingly, the disparity between the regions is unlikely to be due to UHI. This is further supported by Figure 2.5, which shows that Johannesburg and Ekurhuleni both produce low levels of green carbon per hectare.

In other studies that have evaluated racial disparities in heat risk perception, the suggestion was that the most significant contributors to racial disparities in heat are segregation and geographic disparities (Benz & Burney, 2021; Manware et al., 2022; Mitchell & Chakraborty, 2018). Accordingly, when interpreting the results of our analysis, we must consider South Africa's history of segregation and spatial inequality—the spatial disparity resulting from apartheid-era spatial planning.

In Gauteng, Johannesburg has been identified by GCRO research as the city with the most diversity (Hamann & Ballard, 2017). The diversity of Johannesburg is not by chance. It is closely linked to the employment opportunities and, accordingly, the socioeconomic status in the region (Hamann, 2024). This could explain why it is the only municipality without race as a significant variable in the regression analysis and further shows the inextricable link between racial and spatial inequality in Gauteng.

The regional analysis revealed that the different regions within Gauteng have varying relationships between sociodemographic variables and perceptions of heat risk. The only variable that shows some consistency across the different regions was race. Therefore, race remains the most significant sociodemographic variable in relation to heat risk perception. The variance across regions may be a result of spatial disparity, a legacy of apartheid spatial planning.

5.4. Our Findings in the Context of Human Adaptation to Heat

Our conceptual framework, "Human Adaptation to Heat in the Context of Climate Change," identifies how different components of heat and health adaptation interact and relate to each other. Figure 2.1. depicts the interaction between the various components. The framework emphasises the complexity of heat and health adaptation, and often, the components overlap.

For example, sociodemographic factors (classified as axes of inequality within the framework) are closely linked to vulnerability, as they impact individuals' adaptive capacity and exposure. As such, the effect of sociodemographic variables on health risks is twofold: one through their relationship with vulnerability and another through their relationship with the axis of inequality.

Placing the findings within the conceptual framework, we see that race, as an axis of inequality, contributes to health risks, such as heatwaves, through cultural and political adaptation rather than physiological adaptation, as race does not directly impact physiological processes. We also know from the literature that these sociodemographic variables are associated with vulnerability and an individual's capacity to adapt to heat. Therefore, through our framework and findings, we can see the importance of sociodemographic factors in the context of heat adaptation, as they are related to both vulnerability and health risks.

Accordingly, the framework indicates how race, in the context of Gauteng, is a critical factor to consider in understanding adaptation to heat in the context of climate change. It must, therefore, be given due attention through political and cultural adaptation at both individual and social levels.

Cultural adaptation can be encouraged through the use of Heat Health Warning Systems, which can address behavioural and technical changes in African communities to increase their heat risk perception. This adaptation measure aims to raise awareness and encourage individuals to undertake health-seeking behaviour (McGregor et al., 2015). Accordingly, the state should implement HHWS in areas and languages that will reach the African population. Doing so has the potential to increase heat risk perception and reduce vulnerability.

It would also be helpful to address the current barriers preventing cultural adaptations. This can be achieved through political adaptation, as outlined in the framework. The barriers are most likely those created by spatial disparity and apartheid planning. Addressing this spatial disparity would require the state to implement policies which address spatial inequality. One such mechanism could be addressing UHI effects by increasing the use of UGI in public spaces that are still mainly occupied by individuals of African ethnicities (Manware et al., 2022). This is especially important for regions such as Johannesburg and Ekurhuleni, where there are low green carbon levels and high population densities.

The state should also realise the effects that our history of economic, political and social exclusion is having on vulnerability to heat. As such, the state can implement policies that indirectly reduce vulnerability to heat and ensure more equitable adaptation. These indirect policies aim to address economic, political, and social exclusion. Policies of this nature will have the effect of increasing access to resources for Africans, which could increase their heat risk perception and their adaptive capacity.

5.5. Limitations and Recommendations

Our study was limited by the sociodemographic variables selected by the GCRO for the QoL survey. From the pseudo-R-squared values in our regressions, it appears that other factors are contributing to individual heat risk perception. Future studies should expand the scope of sociodemographic characteristics and identify variables beyond race that may relate to heat risk perception in Gauteng. Variables left out of this research but prevalent in other studies are: access to services, the use of air conditioning and access to information.

There are also no environmental variables or factors included in the GCRO data. That means it is not possible to correlate how environmental factors such as temperature may interact with heat risk perception or the sociodemographic variables.

Further studies could also extend the scope of this research to investigate how heat risk perception and sociodemographic variables influence adaptive behaviour. This research did not have access to data on adaptive behaviour. However, it is a crucial element in understanding heat vulnerability. Further studies can also investigate how the relationship between variables in these findings may vary in other locations in South Africa. There is also room to increase the number of sociodemographic variables used in the analysis.

Other limitations include the fact that data obtained by the GCRO QoL is self-reported, and there may be discrepancies in how individuals recall and remember their experiences. There may also be discrepancies in the ways individuals understand the questions being asked. There may also have been social barriers, such as participants fabricating responses out of concern for embarrassment.

Despite these limitations, our results suggest that the findings of this study still underscore the need for greater emphasis on addressing racial inequality in Gauteng. This is due to the relationship between racial inequality and heat risk perception, as well as its contribution to heat vulnerability. If this issue is not addressed, it may continue to perpetuate the 'vicious cycle' that climate change can have on inequality.

Therefore, it is recommended that policies be implemented to directly increase heat risk perception through Heat Health Warning Systems targeted at African communities. It is also recommended that indirect policies be implemented to address both spatial and racial disparities. These indirect policies aim to increase access to resources, thereby enhancing adaptive capacity and mitigating the adverse effects of UHI, ultimately reducing exposure. These can both decrease vulnerability and increase heat risk perception. The realities of spatial and racial inequality in Gauteng should guide these policies.

6. Conclusion

Developing countries, such as South Africa, are expected to be disproportionately affected by climate change compared to developed countries. We, therefore, have fewer state resources to raise awareness and implement different adaptation and mitigation measures. This, coupled with our high poverty and inequality, makes the South African population especially vulnerable to the impacts of heat.

These findings show that some of the more vulnerable populations have very low reporting of the impacts of heatwaves. This is concerning because reporting impacts of a heatwave indicates that an individual has both experienced heat and interpreted its effects as potentially dangerous or harmful. Therefore, the low reporting rate of vulnerable groups is a sign that they have lower heat risk perception. What is most alarming about these findings is that they reveal the most significant source of inequality in perceptions of heat to be race, proving that the scars of our past remain ever-present.

Therefore, these findings should inform adaptation policies that address not only the issues related to heat but also the racial disparities in heat vulnerability. Current policies are silent on plans to reduce heat risk perception, and by understanding how racial disparities may affect heat vulnerability, strategies and policies that seek to implement adaptation measures in Gauteng can be more targeted and accordingly provide meaningful protection and equitable relief to vulnerable population groups.

The government needs to tackle some underlying issues like spatial inequality and unequal access to public services. These issues that stem from a history of unequal treatment before the law have great potential to increase climate vulnerability, specifically in the context of heat in Gauteng. The current policies that exist in each region need to be updated to include these aspects of inequality and ensure that the most vulnerable are not left behind.

Adaptation planning shouldn't just focus on technical fixes; it should actively involve the communities, direct funds to the areas at the highest risk, and include historic inequalities when evaluating policies. If they don't take these steps, their adaptation efforts might end up making the existing inequalities even worse instead of helping to solve them.

This requires a multidimensional approach because the racial disparity in South Africa affects various aspects of heat and health adaptation. Therefore, policies should be implemented that recognise the various ways in which race influences vulnerability to heat risk perception, both directly and indirectly. Such policies must recognise the underlying sources of heat vulnerability among the African population, including both spatial inequality and a lack of access to resources.

7. References

Abrahamson, V., Wolf, J., Lorenzoni, I., Fenn, B., Kovats, S., Wilkinson, P., Adger, W. N., & Raine, R. (2008). Perceptions of heatwave risks to health: Interview-based study of older people in London and Norwich, UK. *Journal of Public Health*, *31*(1), 119–126. https://doi.org/10.1093/pubmed/fdn102

Akompab, D., Bi, P., Williams, S., Grant, J., Walker, I., & Augoustinos, M. (2013). Heat Waves and Climate Change: Applying the Health Belief Model to Identify Predictors of Risk Perception and Adaptive Behaviours in Adelaide, Australia. *International Journal of Environmental Research and Public Health*, *10*(6), 2164–2184. https://doi.org/10.3390/ijerph10062164

Alahmad, B., Shakarchi, A. F., Khraishah, H., Alseaidan, M., Gasana, J., Al-Hemoud, A., Koutrakis, P., & Fox, M. A. (2020). Extreme temperatures and mortality in Kuwait: Who is vulnerable? *Science of The Total Environment*, *732*, 139289. https://doi.org/10.1016/j.scitotenv.2020.139289

Amorim-Maia, A. T., Anguelovski, I., Chu, E., & Connolly, J. (2022). Intersectional climate justice: A conceptual pathway for bridging adaptation planning, transformative action, and social equity. *Urban Climate*, *41*, 101053. https://doi.org/10.1016/j.uclim.2021.101053

Bai, L., Cirendunzhu, Pengcuociren, Dawa, Woodward, A., Liu, X., Baimaciwang, Dazhen, Sang, S., Wan, F., Zhou, L., Xu, J., Li, X., Wu, H., Yu, B., Xiraoruodeng, & Liu, Q. (2013). Rapid warming in Tibet, China: Public perception, response and coping resources in urban Lhasa. *Environmental Health*, *12*(1), 71. https://doi.org/10.1186/1476-069X-12-71

Ballard, R., & Hamann, C. (2022). *Gauteng's urban land cover growth: 1990-2020* (Map of the Month) [Map of the Month]. Gauteng City-Region Observatory. https://doi.org/10.36634/BMTK9909

Barbosa, R., Vicente, R., & Santos, R. (2015). Climate change and thermal comfort in Southern Europe housing: A case study from Lisbon. *Building and Environment*, *92*, 440–451. https://doi.org/10.1016/j.buildenv.2015.05.019

Barreca, A., Clay, K., Deschênes, O., Greenstone, M., & Shapiro, J. S. (2015). Convergence in Adaptation to Climate Change: Evidence from High Temperatures and Mortality, 1900–2004. *American Economic Review*, *105*(5), 247–251. https://doi.org/10.1257/aer.p20151028

Basu, R., & Ostro, B. D. (2008). A Multicounty Analysis Identifying the Populations Vulnerable to Mortality Associated with High Ambient Temperature in California. *American Journal of Epidemiology*, *168*(6), 632–637. https://doi.org/10.1093/aje/kwn170

Beckmann, S., & Hiete, M. (2020). Predictors Associated with Health-Related Heat Risk Perception of Urban Citizens in Germany. *International Journal of Environmental Research and Public Health*, *17*(3), 874. https://doi.org/10.3390/ijerph17030874

Benz, S. A., & Burney, J. A. (2021). Widespread Race and Class Disparities in Surface Urban Heat Extremes Across the United States. *Earth's Future*, *9*(7), e2021EF002016. https://doi.org/10.1029/2021EF002016

Błażejczyk, A., Błażejczyk, K., Baranowski, J., & Kuchcik, M. (2018a). Heat stress mortality and desired adaptation responses of healthcare system in Poland. *International Journal of Biometeorology*, *62*(3), Article 3. https://doi.org/10.1007/s00484-017-1423-0

Błażejczyk, A., Błażejczyk, K., Baranowski, J., & Kuchcik, M. (2018b). Heat stress mortality and desired adaptation responses of healthcare system in Poland. *International Journal of Biometeorology*, *62*(3), 307–318. https://doi.org/10.1007/s00484-017-1423-0

Brooks, N. (2003). Vulnerability, risk and adaptation: A conceptual framework. *Tyndall Centre for Climate Change Research*, *38*.

Buechley, R. W., Van Bruggen, J., & Truppi, L. E. (1972). Heat island = death island? *Environmental Research*, *5*(1), 85–92. https://doi.org/10.1016/0013-9351(72)90022-9

Calvin, K., Dasgupta, D., Krinner, G., Mukherji, A., Thorne, P. W., Trisos, C., Romero, J., Aldunce, P., Barrett, K., Blanco, G., Cheung, W. W. L., Connors, S., Denton, F., Diongue-Niang, A., Dodman, D., Garschagen, M., Geden, O., Hayward, B., Jones, C., … Péan, C. (2023). *IPCC, 2023: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland.* (First). Intergovernmental Panel on Climate Change (IPCC). https://doi.org/10.59327/IPCC/AR6-9789291691647

Chen, P. (2024). Inequality in heat: The role of spatial patterns of urban green infrastructure. *Urban*

Climate, *53*, 101820. https://doi.org/10.1016/j.uclim.2024.101820

Clarke, J. F. (1972). Some effects of the urban structure on heat mortality. *Environmental Research*, *5*(1), 93–104. https://doi.org/10.1016/0013-9351(72)90023-0

Conte Keivabu, R. (2022). Extreme Temperature and Mortality by Educational Attainment in Spain, 2012–2018. *European Journal of Population*, *38*(5), 1145–1182. https://doi.org/10.1007/s10680-022-09641-4

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

Dansgaard, W., Johnsen, S. J., Clausen, H. B., Dahl-Jensen, D., Gundestrup, N. S., Hammer, C. U., Hvidberg, C. S., Steffensen, J. P., Sveinbjörnsdottir, A. E., Jouzel, J., & Bond, G. (1993). Evidence for general instability of past climate from a 250-kyr ice-core record. *Nature*, *364*(6434), 218–220. https://doi.org/10.1038/364218a0

Dawson, J., Weir, C., Wright, F., Bryden, C., Aslanyan, S., Lees, K., Bird, W., & Walters, M. (2007). Associations between meteorological variables and acute stroke hospital admissions in the west of Scotland. *Acta Neurologica Scandinavica*, *0*(0), Article 0. https://doi.org/10.1111/j.1600-0404.2007.00916.x

DeBono, R., Vincenti, K., & Calleja, N. (2012). Risk communication: Climate change as a human-health threat, a survey of public perceptions in Malta. *The European Journal of Public Health*, *22*(1), 144–149. https://doi.org/10.1093/eurpub/ckq181

Deschenes, O. (2014). Temperature, human health, and adaptation: A review of the empirical literature. *Energy Economics*, *46*, 606–619. https://doi.org/10.1016/j.eneco.2013.10.013

Diaz, J. (2014a). Heat Waves' Influence on Health: Some Uncertainties about Their Impact. *Journal of Earth Science & Climatic Change*, *05*(03), Article 03. https://doi.org/10.4172/2157-7617.1000186

Diaz, J. (2014b). Heat Waves' Influence on Health: Some Uncertainties about Their Impact. *Journal of Earth Science & Climatic Change*, *05*(03), 186. https://doi.org/10.4172/2157-7617.1000186

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

Ekamper, P., Van Poppel, F., Van Duin, C., & Garssen, J. (2009). 150 Years of temperature-related excess mortality in the Netherlands. *Demographic Research*, *21*, 385–426. https://doi.org/10.4054/DemRes.2009.21.14

Escobar Carias, M., Johnston, D. W., Knott, R., & Sweeney, R. (2024). Temperature's Toll on Decision-Making. *The Economic Journal*, *134*(663), 2746–2771. https://doi.org/10.1093/ej/ueae036

Francis, D., & Webster, E. (2019). Inequality in South Africa. *Development Southern Africa*, *36*(6), 733–734. https://doi.org/10.1080/0376835X.2019.1699397

Fritz, M. (2022). Temperature and non-communicable diseases: Evidence from Indonesia's primary health care system. *Health Economics*, *31*(11), 2445–2464. https://doi.org/10.1002/hec.4590

G. Cissé, R. McLeman, H. Adams, P. Aldunce, K. Bowen, D. Campbell-Lendrum, S. Clayton, K.L. Ebi, J. Hess, C. Huang, Q. Liu, G. McGregoro, J. Semenza, & M.C. Tirad. (2023). Chapter 7: Health, Wellbeing and the Changing Structure of Communities. In *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009325844

Garschagen, M., Doshi, D., Reith, J., & Hagenlocher, M. (2021). Global patterns of disaster and climate risk—An analysis of the consistency of leading index-based assessments and their results. *Climatic Change*, *169*(1–2), 11. https://doi.org/10.1007/s10584-021-03209-7

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

Gauteng City Region Observatory. (2024). *Quality of Life Survey 2023-2024, Round 7* [Dataset].

DataFirst. https://doi.org/10.25828/V2KY-V879

Gil Cuesta, J., Van Loenhout, J., Colaço, M., & Guha-Sapir, D. (2017a). General Population Knowledge about Extreme Heat: A Cross-Sectional Survey in Lisbon and Madrid. *International Journal of Environmental Research and Public Health*, *14*(2), 122. https://doi.org/10.3390/ijerph14020122

Gil Cuesta, J., Van Loenhout, J., Colaço, M., & Guha-Sapir, D. (2017b). General Population Knowledge about Extreme Heat: A Cross-Sectional Survey in Lisbon and Madrid. *International Journal of Environmental Research and Public Health*, *14*(2), 122. https://doi.org/10.3390/ijerph14020122

Gosling, S. N., Lowe, J. A., McGregor, G. R., Pelling, M., & Malamud, B. D. (2009a). Associations between elevated atmospheric temperature and human mortality: A critical review of the literature. *Climatic Change*, *92*(3–4), Article 3–4. https://doi.org/10.1007/s10584-008-9441-x

Gosling, S. N., Lowe, J. A., McGregor, G. R., Pelling, M., & Malamud, B. D. (2009b). Associations between elevated atmospheric temperature and human mortality: A critical review of the literature. *Climatic Change*, *92*(3–4), 299–341. https://doi.org/10.1007/s10584-008-9441-x

Hajat, S., & Kosatky, T. (2010a). Heat-related mortality: A review and exploration of heterogeneity. *Journal of Epidemiology & Community Health*, *64*(9), Article 9. https://doi.org/10.1136/jech.2009.087999

Hajat, S., & Kosatky, T. (2010b). Heat-related mortality: A review and exploration of heterogeneity. *Journal of Epidemiology & Community Health*, *64*(9), 753–760. https://doi.org/10.1136/jech.2009.087999

Hamann, C. (2024). *Segregation and socio-economic sorting in Gauteng* (Map of the Month) [Map of the Month]. Gauteng City-Region Observatory. https://doi.org/10.36634/MIJV2656

Hamann, C., & Ballard, R. (2017). *Dimensions of diversity in Gauteng* (Map of the Month) [Map of the Month]. Gauteng City-Region Observatory. https://doi.org/10.36634/UOCW6758

Hartmann, D. L., A.M.G. Klein Tank, M. Rusticucci, L.V. Alexander, S. Brönnimann, Y. Charabi, F.J. Dentener, E.J. Dlugokencky, D.R. Easterling, A. Kaplan, B.J. Soden, P.W. Thorne, M. Wild, & P.M. Zhai. (2014). Observations: Atmosphere and Surface. In *Climate Change 2013 – The Physical Science Basis* (1st ed., pp. 159–254). Cambridge University Press.

https://doi.org/10.1017/CBO9781107415324.008

Hass, A. L., Runkle, J. D., & Sugg, M. M. (2021). The driving influences of human perception to extreme heat: A scoping review. *Environmental Research*, *197*, 111173. https://doi.org/10.1016/j.envres.2021.111173

H.-O. Pörtner, D.C. Roberts, E.S. Poloczanska, K. Mintenbeck, M. Tignor, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, & V. Möller. (2023). IPCC, 2022: Summary for Policymakers. In *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009325844

Hoogeveen, J. G., & Özler, B. (2005). *Not separate, not equal: Poverty and inequality in post-apartheid South Africa*.

Howe, P. D., Marlon, J. R., Wang, X., & Leiserowitz, A. (2019). Public perceptions of the health risks of extreme heat across US states, counties, and neighborhoods. *Proceedings of the National Academy of Sciences*, *116*(14), 6743–6748. https://doi.org/10.1073/pnas.1813145116

Huang, X., Yao, R., Xu, T., & Zhang, S. (2023). The impact of heatwaves on human perceived thermal comfort and thermal resilience potential in urban public open spaces. *Building and Environment*, *242*, 110586. https://doi.org/10.1016/j.buildenv.2023.110586

IPCC. (2023a). *Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009157896

IPCC. (2023b). *Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (1st ed.). Cambridge University Press. https://doi.org/10.1017/9781009325844

Islam, N., & Winkel, J. (2017). Climate Change and Social Inequality. *United Nation Department of Economic & Social Affairs, 152*.

IUCN, I., & SEI-B, I. (2004). *Sustainable Livelihoods & Climate Change Adaptation–A Review of Phase One Activities for the Project on "Climate Change, Vulnerable Communities and*

Adaptation".[Online] International Institute of Sustainable Development.

Kapwata, T., Abdelatif, N., Scovronick, N., Gebreslasie, M. T., Acquaotta, F., & Wright, C. Y. (2024). Identifying heat thresholds for South Africa towards the development of a heat-health warning system. *International Journal of Biometeorology*, *68*(2), 381–392. https://doi.org/10.1007/s00484-023-02596-z

Kim, M., Kim, H., & You, M. (2014). The role of public awareness in health-protective behaviours to reduce heat wave risk. *Meteorological Applications*, *21*(4), 867–872. https://doi.org/10.1002/met.1422

Kim, S., Kim, S.-Y., Oh, J., Chae, Y., Park, J., Kim, D., & Kim, Y.-M. (2020). Effects of the 2018 heat wave on health in the elderly: Implications for adaptation strategies to climate change. *Environmental Analysis Health and Toxicology*, *35*(4), e2020024. https://doi.org/10.5620/eaht.2020024

Klinenberg, E. (2015). *Heat wave: A social autopsy of disaster in Chicago*. University of Chicago press.

Konisky, D. M., Hughes, L., & Kaylor, C. H. (2016). Extreme weather events and climate change concern. *Climatic Change*, *134*(4), 533–547. https://doi.org/10.1007/s10584-015-1555-3

Kouis, P., Psistaki, K., Giallouros, G., Michanikou, A., Kakkoura, M. G., Stylianou, K. S., Papatheodorou, S. I., & Paschalidou, A. K. (2021). Heat-related mortality under climate change and the impact of adaptation through air conditioning: A case study from Thessaloniki, Greece. *Environmental Research*, *199*, 111285. https://doi.org/10.1016/j.envres.2021.111285

Kovats, R. S., & Hajat, S. (2008a). Heat Stress and Public Health: A Critical Review. *Annual Review of Public Health*, *29*(1), Article 1. https://doi.org/10.1146/annurev.publhealth.29.020907.090843

Kovats, R. S., & Hajat, S. (2008b). Heat Stress and Public Health: A Critical Review. *Annual Review of Public Health*, *29*(1), 41–55. https://doi.org/10.1146/annurev.publhealth.29.020907.090843

Kruger, A., & Sekele, S. (2013). Trends in extreme temperature indices in South Africa: 1962–2009. In *International Journal of Climatology*. https://doi.org/10.1002/joc.3455

Kunda, J. J., Gosling, S. N., & Foody, G. M. (2024). The effects of extreme heat on human health in tropical Africa. *International Journal of Biometeorology*, *68*(6), 1015–1033.

https://doi.org/10.1007/s00484-024-02650-4

Kunz-Plapp, T., Hackenbruch, J., & Schipper, J. W. (2016). Factors of subjective heat stress of urban citizens in contexts of everyday life. *Natural Hazards and Earth System Sciences*, *16*(4), 977–994. https://doi.org/10.5194/nhess-16-977-2016

Kweku, D., Bismark, O., Maxwell, A., Desmond, K., Danso, K., Oti-Mensah, E., Quachie, A., & Adormaa, B. (2018). Greenhouse Effect: Greenhouse Gases and Their Impact on Global Warming. *Journal of Scientific Research and Reports*, *17*(6), 1–9. https://doi.org/10.9734/JSRR/2017/39630

Lai, D., Lian, Z., Liu, W., Guo, C., Liu, W., Liu, K., & Chen, Q. (2020). A comprehensive review of thermal comfort studies in urban open spaces. *Science of The Total Environment*, *742*, 140092. https://doi.org/10.1016/j.scitotenv.2020.140092

Lam, C. K. C., & Lau, K. K.-L. (2018). Effect of long-term acclimatization on summer thermal comfort in outdoor spaces: A comparative study between Melbourne and Hong Kong. *International Journal of Biometeorology*, *62*(7), 1311–1324. https://doi.org/10.1007/s00484-018-1535-1

Lane, K., Wheeler, K., Charles-Guzman, K., Ahmed, M., Blum, M., Gregory, K., Graber, N., Clark, N., & Matte, T. (2014). Extreme Heat Awareness and Protective Behaviors in New York City. *Journal of Urban Health*, *91*(3), 403–414. https://doi.org/10.1007/s11524-013-9850-7

Le Roux, A., Arnold, K., Makhanya, S., & Mans, G. (2019). South Africa's urban future: Growth projections for 2050. *Green Book*.

Le Roux, A., van Huyssteen, E., Arnold, K., & Ludick, C. (2019). *Green Book. The vulnerabilities of South Africa's settlements*. Pretoria: CSIR. Available at: https://pta-gis-2-web1. csir. co. za/portal2 ….

Li, T., Chen, C., & Cai, W. (2022). The global need for smart heat–health warning systems. *The Lancet*, *400*(10362), 1511–1512. https://doi.org/10.1016/S0140-6736(22)01974-2

Liu, T., Xu, Y. J., Zhang, Y. H., Yan, Q. H., Song, X. L., Xie, H. Y., Luo, Y., Rutherford, S., Chu, C., Lin, H. L., & Ma, W. J. (2013a). Associations between risk perception, spontaneous adaptation behavior to heat waves and heatstroke in Guangdong province, China. *BMC Public Health*, *13*(1),

913. https://doi.org/10.1186/1471-2458-13-913

Liu, T., Xu, Y. J., Zhang, Y. H., Yan, Q. H., Song, X. L., Xie, H. Y., Luo, Y., Rutherford, S., Chu, C., Lin, H. L., & Ma, W. J. (2013b). Associations between risk perception, spontaneous adaptation behavior to heat waves and heatstroke in Guangdong province, China. *BMC Public Health*, *13*(1), 913. https://doi.org/10.1186/1471-2458-13-913

Lutz, W., & Striessnig, E. (2015). Demographic aspects of climate change mitigation and adaptation. *Population Studies*, *69*(sup1), S69–S76. https://doi.org/10.1080/00324728.2014.969929

Mackie, B. (2014). *Warning fatigue: Insights from the Australian bushfire context*.

Madrigano, J., Lane, K., Petrovic, N., Ahmed, M., Blum, M., & Matte, T. (2018). Awareness, Risk Perception, and Protective Behaviors for Extreme Heat and Climate Change in New York City. *International Journal of Environmental Research and Public Health*, *15*(7), 1433. https://doi.org/10.3390/ijerph15071433

Makgetla, N. (2020). Inequality in South Africa: An overview. *Pretoria, South Africa: Trade and Industrial Policy Strategies Working Paper*.

Manware, M., Dubrow, R., Carrión, D., Ma, Y., & Chen, K. (2022). Residential and Race/Ethnicity Disparities in Heat Vulnerability in the United States. *GeoHealth*, *6*(12), e2022GH000695. https://doi.org/10.1029/2022GH000695

Manyuchi, A. E., Vogel, C., Wright, C. Y., & Erasmus, B. (2022). The self-reported human health effects associated with heat exposure in Agincourt sub-district of South Africa. *Humanities and Social Sciences Communications*, *9*(1), 50. https://doi.org/10.1057/s41599-022-01063-1

Maree, G., Leroy, M., Phoka, M., Sebei, N., Bakwunye, N., Taviv, R., Khanyile, S., & Culwick Fatti, C. (2018). *Mapping vulnerability in Gauteng* (Map of the Month) [Map of the Month]. Gauteng City-Region Observatory. https://doi.org/10.36634/VKNX9633

McGeehin, M. A., & Mirabelli, M. (2001). The potential impacts of climate variability and change on temperature-related morbidity and mortality in the United States. *Environmental Health Perspectives*, *109*(suppl 2), 185–189. https://doi.org/10.1289/ehp.109-1240665

McGregor, G., Bessemoulin, P., Ebi, K., & Menne, B. (2015). *Heatwaves and Health: Guidance on*

Warning-System Development [Text]. Humanitarian Library. https://www.humanitarianlibrary.org/resource/heatwaves-and-health-guidance-warning-system-development

Mishra, S., Suar, D., & Paton, D. (2009). Is Externality a Mediator of Experience–Behaviour and Information–Action Hypothesis in Disaster Preparedness? *Journal of Pacific Rim Psychology*, *3*(1), 11–19. https://doi.org/10.1375/prp.3.1.11

Mitchell, B. C., & Chakraborty, J. (2018). Exploring the relationship between residential segregation and thermal inequity in 20 U.S. cities. *Local Environment*, *23*(8), 796–813. https://doi.org/10.1080/13549839.2018.1474861

Mullins, J. T., & White, C. (2020). Can access to health care mitigate the effects of temperature on mortality? *Journal of Public Economics*, *191*, 104259. https://doi.org/10.1016/j.jpubeco.2020.104259

Naidoo, L., Main, R., Cho, M., Maree, G., Naidoo, Y., & Petersen, C. (2022). *Distribution of Green Carbon across the GCR* (Map of the Month) [Map of the Month]. Gauteng City-Region Observatory. https://doi.org/10.36634/YJWK5182

National Climate Change Adaptation Strategy, 94 (2019).

Navas-Martín, M. Á., Cuerdo-Vilches, T., López-Bueno, J. A., Díaz, J., Linares, C., & Sánchez-Martínez, G. (2024). Human adaptation to heat in the context of climate change: A conceptual framework. *Environmental Research*, *252*, 118803. https://doi.org/10.1016/j.envres.2024.118803

Ncongwane, K. P., Botai, J. O., Sivakumar, V., & Botai, C. M. (2021). A Literature Review of the Impacts of Heat Stress on Human Health across Africa. *Sustainability*, *13*(9), 5312. https://doi.org/10.3390/su13095312

Ncongwane, K. P., Botai, J. O., Sivakumar, V., Botai, C. M., & Adeola, A. M. (2021). Characteristics and Long-Term Trends of Heat Stress for South Africa. *Sustainability*, *13*(23), 13249. https://doi.org/10.3390/su132313249

Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings*, *34*(6), 563–572. https://doi.org/10.1016/S0378-7788(02)00006-

3

Niu, Y., Li, Z., Gao, Y., Liu, X., Xu, L., Vardoulakis, S., Yue, Y., Wang, J., & Liu, Q. (2021). A Systematic Review of the Development and Validation of the Heat Vulnerability Index: Major Factors, Methods, and Spatial Units. *Current Climate Change Reports*, *7*(3), 87–97. https://doi.org/10.1007/s40641-021-00173-3

Okunola, O. H., Simatele, M. D., & Olowoporoku, O. (2022). The influence of socioeconomic factors on individual and household adaptation strategies to climate change risks in Port Harcourt, Nigeria. *Journal of Integrative Environmental Sciences*, *19*(1), 273–288. https://doi.org/10.1080/1943815X.2022.2143821

O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., Van Ruijven, B. J., Van Vuuren, D. P., Birkmann, J., Kok, K., Levy, M., & Solecki, W. (2017). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, *42*, 169–180. https://doi.org/10.1016/j.gloenvcha.2015.01.004

O'Neill, M. S. (2003). Air conditioning and heat-related health effects. *Appl Environ Sci Public Health*, *1*(1), 9–12.

Parker, A., & Hamann, C. (2020). *The most densely populated areas of Gauteng* (Map of the Month) [Map of the Month]. Gauteng City-Region Observatory. https://doi.org/10.36634/FMLV8486

Patwary, M. M., Disha, A. S., Sikder, D., Hasan, S., Hossan, J., Bardhan, M., Billah, S. M., Hasan, M., Hasan, M., Haque, M. Z., Imran, S. A., Kabir, M. P., Pitol, M. N. S., Ritu, M. R., Saha, C., Browning, M. H. E. M., & Salahuddin, M. (2025). Urban heat stress and perceived health impacts in major cities of Bangladesh. *International Journal of Disaster Risk Reduction*, *116*, 105066. https://doi.org/10.1016/j.ijdrr.2024.105066

Petit, J. R., Jouzel, J., Raynaud, D., Barkov, N. I., Barnola, J.-M., Basile, I., Bender, M., Chappellaz, J., Davis, M., Delaygue, G., Delmotte, M., Kotlyakov, V. M., Legrand, M., Lipenkov, V. Y., Lorius, C., PÉpin, L., Ritz, C., Saltzman, E., & Stievenard, M. (1999). Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature*, *399*(6735), 429–436. https://doi.org/10.1038/20859

Rauf, S., Bakhsh, K., Abbas, A., Hassan, S., Ali, A., & Kächele, H. (2017). How hard they hit? Perception, adaptation and public health implications of heat waves in urban and peri-urban Pakistan. *Environmental Science and Pollution Research*, *24*(11), 10630–10639. https://doi.org/10.1007/s11356-017-8756-4

Reid, C. E., Mann, J. K., Alfasso, R., English, P. B., King, G. C., Lincoln, R. A., Margolis, H. G., Rubado, D. J., Sabato, J. E., West, N. L., Woods, B., Navarro, K. M., & Balmes, J. R. (2012). Evaluation of a Heat Vulnerability Index on Abnormally Hot Days: An Environmental Public Health Tracking Study. *Environmental Health Perspectives*, *120*(5), 715–720. https://doi.org/10.1289/ehp.1103766

Rioual, P., Andrieu-Ponel, V., Rietti-Shati, M., Battarbee, R. W., De Beaulieu, J.-L., Cheddadi, R., Reille, M., Svobodova, H., & Shemesh, A. (2001). High-resolution record of climate stability in France during the last interglacial period. *Nature*, *413*(6853), 293–296. https://doi.org/10.1038/35095037

Roberts, J. T. (2001). Global Inequality and Climate Change. *Society & Natural Resources*, *14*(6), 501–509. https://doi.org/10.1080/08941920118490

Romanello, M., Walawender, M., Hsu, S.-C., Moskeland, A., Palmeiro-Silva, Y., Scamman, D., Ali, Z., Ameli, N., Angelova, D., Ayeb-Karlsson, S., Basart, S., Beagley, J., Beggs, P. J., Blanco-Villafuerte, L., Cai, W., Callaghan, M., Campbell-Lendrum, D., Chambers, J. D., Chicmana-Zapata, V., … Costello, A. (2024). The 2024 report of the Lancet Countdown on health and climate change: Facing record-breaking threats from delayed action. *The Lancet*, *404*(10465), 1847–1896. https://doi.org/10.1016/S0140-6736(24)01822-1

Savić, S., Trbić, G., Milošević, D., Dunjić, J., Ivanišević, M., & Marković, M. (2022). Importance of assessing outdoor thermal comfort and its use in urban adaptation strategies: A case study of Banja Luka (Bosnia and Herzegovina). *Theoretical and Applied Climatology*, *150*(3–4), 1425–1441. https://doi.org/10.1007/s00704-022-04237-8

Scheelbeek, P. F. D., Dangour, A. D., Jarmul, S., Turner, G., Sietsma, A. J., Minx, J. C., Callaghan, M., Ajibade, I., Austin, S. E., Biesbroek, R., Bowen, K. J., Chen, T., Davis, K., Ensor, T., Ford, J. D., Galappaththi, E. K., Joe, E. T., Musah-Surugu, I. J., Alverio, G. N., … Berrang-Ford, L. (2021).

The effects on public health of climate change adaptation responses: A systematic review of evidence from low- and middle-income countries. *Environmental Research Letters*, *16*(7), 073001. https://doi.org/10.1088/1748-9326/ac092c

Scholes, R., & Engelbrecht, F. (2021). *Climate impacts in southern Africa during the 21st Century*. https://cer.org.za/wp-content/uploads/2021/09/Climate-impacts-in-South-Africa_Final_September_2021.FINAL_.pdf

Schuman, S. H. (1972). Patterns of urban heat-wave deaths and implications for prevention: Data from New York and St. Louis during July, 1966. *Environmental Research*, *5*(1), 59–75. https://doi.org/10.1016/0013-9351(72)90020-5

Scovronick, N., Sera, F., Acquaotta, F., Garzena, D., Fratianni, S., Wright, C. Y., & Gasparrini, A. (2018). The association between ambient temperature and mortality in South Africa: A time-series analysis. *Environmental Research*, *161*, 229–235. https://doi.org/10.1016/j.envres.2017.11.001

Seekings, J. (2007). *Poverty and inequality after apartheid*.

Seidell, J. C., Oosterlee, A., Deurenberg, P., Hautvast, J. G., & Ruijs, J. H. (1988). Abdominal fat depots measured with computed tomography: Effects of degree of obesity, sex, and age. *European Journal of Clinical Nutrition*, *42*(9), 805–815.

Semenza, J. C., Rubin, C. H., Falter, K. H., Selanikio, J. D., Flanders, W. D., Howe, H. L., & Wilhelm, J. L. (1996). Heat-Related Deaths during the July 1995 Heat Wave in Chicago. *New England Journal of Medicine*, *335*(2), 84–90. https://doi.org/10.1056/NEJM199607113350203

Seneviratne, S. I., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S. M., Wehner, M., & Zhou, B. (2021). Weather and Climate Extreme Events in a Changing Climate. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change[Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B.*

Zhou (eds.)]. (pp. 1513–1766). Cambridge University Press.

Shahaboonin, F., David, O. O., & Wyk, A. V. (2023). Historic Spatial Inequality and Poverty along Racial Lines in South Africa. *International Journal of Economics and Financial Issues*, *13*(1), 102–111. https://doi.org/10.32479/ijefi.13803

Sheridan, S. C. (2007). A survey of public perception and response to heat warnings across four North American cities: An evaluation of municipal effectiveness. *International Journal of Biometeorology*, *52*(1), 3–15. https://doi.org/10.1007/s00484-006-0052-9

Sheridan, S. C., & Allen, M. J. (2018). Temporal trends in human vulnerability to excessive heat. *Environmental Research Letters*, *13*(4), 043001. https://doi.org/10.1088/1748-9326/aab214

Sherina, M. S., Rampal, L., & Mustaqim, A. (2004). Factors Associated with Chronic Illness among the Elderly in a Rural Community in Malaysia. *Asia Pacific Journal of Public Health*, *16*(2), 109–114. https://doi.org/10.1177/101053950401600206

Simpson, N. P., Mach, K. J., Constable, A., Hess, J., Hogarth, R., Howden, M., Lawrence, J., Lempert, R. J., Muccione, V., Mackey, B., New, M. G., O'Neill, B., Otto, F., Pörtner, H.-O., Reisinger, A., Roberts, D., Schmidt, D. N., Seneviratne, S., Strongin, S., … Trisos, C. H. (2021). A framework for complex climate change risk assessment. *One Earth*, *4*(4), 489–501. https://doi.org/10.1016/j.oneear.2021.03.005

South African National Climate Change Information System. (n.d.). *What is Climate Change?* Retrieved March 14, 2025, from https://nccis.environment.gov.za/climate-information/what-is-climate-change

Souverijns, N., De Ridder, K., Veldeman, N., Lefebre, F., Kusambiza-Kiingi, F., Memela, W., & Jones, N. K. W. (2022). Urban heat in Johannesburg and Ekurhuleni, South Africa: A meter-scale assessment and vulnerability analysis. *Urban Climate*, *46*, 101331. https://doi.org/10.1016/j.uclim.2022.101331

Taleghani, M. (2018). Outdoor thermal comfort by different heat mitigation strategies- A review. *Renewable and Sustainable Energy Reviews*, *81*, 2011–2018. https://doi.org/10.1016/j.rser.2017.06.010

Toloo, G., FitzGerald, G., Aitken, P., Verrall, K., & Tong, S. (2013). Are heat warning systems effective? *Environmental Health*, *12*(1), 27. https://doi.org/10.1186/1476-069X-12-27

Tong, S., Wang, X. Y., & Barnett, A. G. (2010). Assessment of Heat-Related Health Impacts in Brisbane, Australia: Comparison of Different Heatwave Definitions. *PLoS ONE*, *5*(8), e12155. https://doi.org/10.1371/journal.pone.0012155

Turok, I. (2018). *Worlds Apart: Spatial Inequalities in South Africa* (pp. 159–182).

Van Loenhout, J. A. F., & Guha-Sapir, D. (2016). How resilient is the general population to heatwaves? A knowledge survey from the ENHANCE project in Brussels and Amsterdam. *BMC Research Notes*, *9*(1), 499. https://doi.org/10.1186/s13104-016-2305-y

Van Niekerk, W., Amy Pieterse, & Alize Le Roux. (2020). Introducing the Green Book: A practical planning tool for adapting South African settlements to climate change. *Town and Regional Planning*, *77*. https://doi.org/10.18820/2415-0495/trp77i1.8

Voelkel, J., Hellman, D., Sakuma, R., & Shandas, V. (2018). Assessing Vulnerability to Urban Heat: A Study of Disproportionate Heat Exposure and Access to Refuge by Socio-Demographic Status in Portland, Oregon. *International Journal of Environmental Research and Public Health*, *15*(4), 640. https://doi.org/10.3390/ijerph15040640

Wang, C., Li, Z., Chen, Y., Li, Y., Ouyang, L., Zhu, J., Sun, F., Song, S., & Li, H. (2024). Changes in Global Heatwave Risk and Its Drivers Over One Century. *Earth's Future*, *12*(10), e2024EF004430. https://doi.org/10.1029/2024EF004430

Werner Van Dyk. (n.d.). Understanding Heat Waves: Climate Change Averages and Strategies for Managing Extreme Hot Weather. *The Sustainability Initiative of South Africa (SIZA)*. Retrieved March 14, 2025, from https://siza.co.za/climate-change-averages-and-strategies-for-managing-extreme-hot-weather/

WHO. (2015). Climate and health country profile 2015: South Africa. In *Climate and health country profile 2015: South Africa*.

Wichmann, J. (2017). Heat effects of ambient apparent temperature on all-cause mortality in Cape Town, Durban and Johannesburg, South Africa: 2006–2010. *Science of The Total Environment*, *587–*

588, 266–272. https://doi.org/10.1016/j.scitotenv.2017.02.135

Williams, S., Hanson-Easey, S., Nitschke, M., Howell, S., Nairn, J., Beattie, C., Wynwood, G., & Bi, P. (2019). Heat-health warnings in regional Australia: Examining public perceptions and responses. *Environmental Hazards*, *18*(4), 287–310. https://doi.org/10.1080/17477891.2018.1538867

Wilson, B. (2020). Urban Heat Management and the Legacy of Redlining. *Journal of the American Planning Association*, *86*(4), 443–457. https://doi.org/10.1080/01944363.2020.1759127

WMO. (2023, May 23). *Guidelines on the definition and characterization of extreme weather and climate events*. https://reliefweb.int/report/world/guidelines-definition-and-characterization-extreme-weather-and-climate-events

Wright, C. Y., Dominick, F., Kapwata, T., Bidassey-Manilal, S., Engelbrecht, J. C., Stich, H., Mathee, A., & Matooane, M. (2019). Socio-economic, infrastructural and health-related risk factors associated with adverse heat-health effects reportedly experienced during hot weather in South Africa. *Pan African Medical Journal*, *34*. https://doi.org/10.11604/pamj.2019.34.40.17569

Wright, C. Y., Wernecke, B., Kapwata, T., Kunene, Z., Mathee, A., Vande Hey, J., & Theron, L. (2022). Perceptions of thermal comfort and coping mechanisms related to indoor and outdoor temperatures among participants living in rural villages in Limpopo province, South Africa. *South African Journal of Psychology*, *52*(4), 449–459. https://doi.org/10.1177/00812463221129363

Xu, Z., Crooks, J. L., Black, D., Hu, W., & Tong, S. (2017). Heatwave and infants' hospital admissions under different heatwave definitions. *Environmental Pollution*, *229*, 525–530. https://doi.org/10.1016/j.envpol.2017.06.030

Xu, Z., FitzGerald, G., Guo, Y., Jalaludin, B., & Tong, S. (2016). Impact of heatwave on mortality under different heatwave definitions: A systematic review and meta-analysis. *Environment International*, *89–90*, 193–203. https://doi.org/10.1016/j.envint.2016.02.007

Ye, X., Wolff, R., Yu, W., Vaneckova, P., Pan, X., & Tong, S. (2012). Ambient Temperature and Morbidity: A Review of Epidemiological Evidence. *Environmental Health Perspectives*, *120*(1), Article 1. https://doi.org/10.1289/ehp.1003198

Yin, C., Yang, Y., Chen, X., Yue, X., Liu, Y., & Xin, Y. (2022). Changes in global heat waves and its socioeconomic exposure in a warmer future. *Climate Risk Management*, *38*, 100459. https://doi.org/10.1016/j.crm.2022.100459