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HEAT-RELATED HEALTH IMPACTS: THE RESPONSES OF LOCAL GOVERNMENTS TO CURRENT AND EMERGING HEAT EXTREMES IN THE GAUTENG PROVINCE

MSc *Final* Dissertation

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DECLARATION

I declare that this dissertation is my own unaided work. It is being submitted for the Degree of Master of Science at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University.



Bradley Riley

06 day of June 2024 at Johannesburg, South Africa.

ABSTRACT

In recent years, particularly during the last few summer seasons across the globe, there has been growing attention to the impacts of heat on human health due to unprecedented extreme heat and heatwave events. Cities and urban areas are especially at risk due to enhanced urbanisation and anthropogenic activities, leading to increased heat-related deaths and hospitalisation. Although many cities globally have developed adaptation approaches to address the current and emerging heat risks, heat adaptation strategies and planning in an African context have been poorly recognised despite the continent warming at double the rate of global temperatures. The high vulnerability of African cities due to poverty and poor socio-economic conditions, coupled with these temperature extremes, puts African societies at the forefront of future heat-related health impacts. South Africa is one African country that has recognised these growing heat risks and provided frameworks in their national and municipal policy and planning instruments. However, implementing and mainstreaming heat action across institutional structures remains a challenge. This study investigated the extent of current heat responses within three metropolitan municipalities in the Gauteng Province, South Africa, in the cities of Tshwane, Ekhuruleni and Johannesburg; to advance heat action within the local government and institutional structures of the province. In this mixed-methods research design, local officials from the municipality's Environmental Health Department in each metro were interviewed, and a perception-informed assessment of vulnerability to heat-related health impacts was developed using Principal Component Analysis. Through interviews with the local Environmental Health Officials, it was revealed that extreme heat is not a priority within the Department, as heat action is neither mandated nor budgeted for, leading to a misalignment between policy and implementation. The ability of the Department to unlock its full potential for heat action is constrained by many challenges, highlighted by three central themes: *(1) Resource capacity and the ripple effects*, *(2) Policy-implementation gap* and *(3) Interdepartmental coordination*. Despite this, the Department has the potential to unlock many opportunities for future heat responses, highlighted by four central themes: *(1) Existing systems: connecting the dots*, *(2) Power in unity: embracing a collaborative approach*, *(3) Mandated heat action* and *(4) Specialised heat action units*. Additionally, this study demonstrated how a heat vulnerability assessment tool could be created using heat-specific socio-economic variables. This reveals the spatial distribution of vulnerability throughout the metro's and highlights high levels of vulnerability within rural and informal settlements due to poverty, lack of access to resources and services and poor living conditions in these areas. Such an approach can offer valuable insights into the populations and areas most susceptible and at risk of heat-related health impacts, which can aid in developing targeted heat action responses and plans. Finally, this study contributes

a heat action framework and guideline that can assist in co-designing and developing heat action plans for the three Gauteng metropolitans and other South African and African cities.

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LIST OF ACRONYMS

CAP	Climate Action Plan
CCRS	Climate Change Response Strategy
CSIR	Council for Scientific and Industrial Research
ECD	Early childhood development
EHP	Environmental Health Practitioner
GCRO	Gauteng City-Region Observatory
GDP	Gross domestic product
HHWS	Heat Health Warning System
HVI	Heat Vulnerability Index
IDP	Integrated Development Plan
IPCC	Intergovernmental Panel on Climate Change
KMO	Kaiser-Meyer-Olkin
KPI	Key Performance Indicator
NDMC	National Disaster Management Centre
NGO	Non-governmental organization
NPO	Non-profit organization
PCA	Principal Component Analysis
QoL	Quality of Life
RCP	Representative Concentration Pathway
SAWS	South African Weather Service
UHI	Urban Heat Island
UN	United Nations
WHO	World Health Organisation
WMO	World Meteorological Organization

1 CHAPTER ONE – BACKGROUND AND INTRODUCTION

1.1 GENERAL INTRODUCTION

Climate change is a global phenomenon that comprises various climatic changes, such as the rise of average global temperatures and changes in the frequency and magnitude of extreme weather events (IPCC, 2022). The broad impacts of climate change are, however, usually starkly evident at a local level, as different regions around the world are experiencing a wide range of climatic changes and extreme weather events (Measham *et al*., 2011; Pasquini *et al*., 2013; Carter *et al*., 2015; United Nations, 2016; IPCC, 2022). Although in the past, climate change studies have mainly focused on the impacts on the physical-natural and -human environments, recently, studies have also begun to acknowledge the impacts of climate change on human health (Tan *et al*., 2009; IPCC, 2014, 2022). One such impact, which has become increasingly challenging to the health of societies around the world and also how these may be governed and dealt with in current times and the future, is the occurrence of extreme heat and heatwave events (World Health Organisation, 2008; Rosenzweig *et al*., 2011; IPCC, 2014, 2022; Garland *et al*., 2015; McGregor *et al*., 2015; Mora *et al*., 2017).

Although there are no universal definitions for heatwaves and extreme heat, heatwaves are understood to be prolonged periods of unusually hot weather lasting at least two to three days (Robinson, 2001; Perkins & Alexander, 2013; McGregor *et al*., 2015; Puley, 2022; IPCC, 2022). Extreme heat, on the other hand, is the abnormal hot temperature that surpasses the average temperature in a specific region at a particular time of the year (Robinson, 2001; Perkins & Alexander, 2013; McGregor *et al*., 2015; Puley, 2022; IPCC, 2022). Recent heat waves and hot periods have been recorded in several areas of the world, which have resulted in significant numbers of deaths and hospitalisations, with the latest press reports (*Chapter 2, Section 2.2, Figure 3*) highlighting the growing attention to and concern about extreme heat throughout the world. With the projected global temperatures expected to rise in the future, a warming climate will cause an increase in the frequency, duration and intensity of extreme heat and heatwave events, providing a setting for a rise in heat-related health impacts, especially within cities and urban area (Meehl *et al*., 2000; Patz & Khaliq, 2002; Wilby, 2003; O'Neill *et al*., 2009; Tan *et al*., 2009; Harlan & Ruddell, 2011; Revi *et al*., 2014; Bidassey-Manilal *et al*., 2016; Garland *et al*., 2015; Mora *et al*., 2017).

Urban areas are particularly at risk for climate change impacts due to the enhanced anthropogenic activities and greenhouse gas emissions in these regions, which have been further intensified by the rapid rate of urbanisation in recent decades (Hallegatte & Corfee-Morlot, 2011; Rosenzweig *et al*., 2011; Revi *et al*., 2014; United Nations, 2015, 2016; Nana *et al*., 2019; IPCC, 2022). This urbanisation has resulted in physical pressures, including the Urban Heat Island (UHI), which

intensifies the impacts of extreme heat in urban areas compared to less built-up areas and provides a setting for a dramatic increase in heat-related health challenges in the future (Grimm *et al*., 2008; World Health Organisation, 2008; Tan *et al*., 2009; McGregor *et al*., 2015; Doherty *et al*., 2016; Shirinde *et al*., 2017; Nana *et al*., 2019; Puley, 2022). Given these challenges, the development and implementation of mitigation and adaptation strategies to the current and future emerging heat impacts are needed to protect societies and human health in urban areas around the world (Pasquini *et al*., 2013; Niang *et al*., 2014; Carter *et al*., 2015; McGregor *et al*., 2015; McGregor, 2017; Girvetz *et al*., 2018; IPCC, 2022).

In the past, climate change plans and policies have mainly focused on large-scale technocratic mitigation strategies, which address the root causes of climate change on a large scale and require high economic and financial inputs. More recently, there has been a growing emergence and recognition of adaptation approaches to climate change, where resilience and adaptive capacity are enhanced at a local level, all proving to be highly effective within a low-economic context in developing countries (Hamin & Gurran, 2009; Hallegatte & Corfee-Morlot, 2011; Jabareen, 2013; IPCC, 2014, 2022; Nana *et al*., 2019; Caniglia *et al*., 2020). Adaptation approaches are thus needed alongside mitigation strategies to address the current and emerging risks experienced by local societies and populations (Hamin & Gurran, 2009; Department of Environmental Affairs, 2011; Harlan & Ruddell, 2011; IPCC, 2014, 2022). These adaptation approaches allow for localised area-specific responses, accounting for the heat severity, exposure and vulnerability of the local population (Fernandez Milan & Creutzig, 2015; Caniglia *et al*., 2020; IPCC, 2022). More suitable and effective responses can subsequently be developed within an area's specific risk context, building an adaptive capacity and resilience for future changes within the population (Caniglia *et al*., 2020; IPCC, 2022).

One adaptation approach that has become increasingly acknowledged and implemented in cities globally is the development of heatwave adaptation plans (Measham *et al*., 2011; Niang *et al*., 2014; Carter *et al*., 2015; McGregor *et al*., 2015; McGregor, 2017; Nana *et al*., 2019; IPCC, 2022; Puley, 2022). Heatwave plans are developed to prepare for the impacts of extreme heating and heatwave events, to alert the public and the affected populations of a period of heat, and to prevent the severe and avoidable impacts of these events (Ahmedabad Municipal Corporation, 2013, 2016; Public Health England, 2015; Bolitho & Miller, 2016; Nana *et al*., 2019). Effective, well-developed heatwave plans aim to increase public awareness and knowledge of heat-hazard prevention and should provide a form of effective risk responses before, during and after a heatwave or extreme heating event (Hallegatte & Corfee-Morlot, 2011; Ahmedabad Municipal Corporation, 2013, 2016; McGregor *et al*., 2015; Public Health England, 2015; Bolitho and Miller, 2016; Zografos *et al*., 2016; McGregor, 2017; Global Change Institute, 2019; Nana *et al*., 2019). These heatwave plans have

primarily been implemented within cities in the world's developed regions, but they have also been shown to be successful and highly effective towards the mitigation of heat-related illnesses and deaths within a developing country context (Ogg, 2005; Ahmedabad Municipal Corporation, 2013, 2016; Public Health England, 2015; Global Change Institute, 2019; Nana *et al*., 2019; Puley, 2022).

A highly notable heatwave plan that has been effectively implemented within a highly at-risk developing city, for example, is in Ahmedabad, India (Ahmedabad Municipal Corporation, 2013, 2016; Global Change Institute, 2019; Puley, 2022; IPCC, 2022). The Ahmedabad Heat Action Plan enhances the coordination between the different departments of government, hospitals and health care officials, emergency responders, local populations and communities, and the media outlets about an incoming heat event. This plan is a continuous process where interventions and adaptation strategies are reviewed annually to find the most effective solutions for the ongoing heat increases (Ahmedabad Municipal Corporation, 2013, 2016; Council for Scientific and Industrial Research, 2017; Global Change Institute, 2019). The Ahmedabad Heat Action Plan is just one example of how effective heatwave adaptation plans can be, especially within a highly vulnerable context such as the City of Ahmedabad, and can prove to be an essential framework to follow within the context of this study (Ahmedabad Municipal Corporation, 2013, 2016; Global Change Institute, 2019; IPCC, 2022; Puley, 2022).

The development and implementation of such adaptation plans have, however, been poorly recognised within the context of highly vulnerable African cities (Council for Scientific and Industrial Research, 2017; Global Change Institute, 2019; Kotharkar & Ghosh, 2021; Puley, 2022). Many at-risk African cities do not have these plans in place, with the local municipal authorities often having little or no heatwave considerations within their operational activities. (Bernard and McGeehin, 2004; Harlan & Ruddell, 2011; United Nations, 2016; Nana *et al*., 2019). Given that most of these regions are experiencing a rate of warming faster than the rest of the world, exacerbated by the occurrence of more frequent and intense heatwaves, as well as the developing nature of these countries and cities providing various other social, environmental, economic and political challenges, it is being recognised that more concerted adaptation efforts should be addressed within these contexts (Pasquini *et al*., 2013; Niang *et al*., 2014; Engelbrecht *et al*., 2015; Girvetz *et al*., 2018; Nana *et al*., 2019; IPCC, 2022). Southern Africa is a region of particular concern and has experienced a significant increase in temperatures over the last few decades, with average temperatures having increased by up to 1.44°C in the last 60 years, leading to more hot days per year and more frequent and intense heatwave events in the region (Ceccherini *et al*., 2017; Kruger & Nxumalo, 2017a; 2017b; Gutiérrez *et al*., 2021; IPCC, 2022). South African cities have since recognised the region's growing heat exposure and have begun action towards heat mitigation (Nana *et al*., 2019; Department of Health, 2020). Throughout South

Africa, the temperatures are projected to increase by over 5.0°C by the end of the century, under worst-case high emission scenarios (i.e., RCP 8.5), which will place many of the most vulnerable and marginalised communities in the face of more frequent and intense heatwave events resulting in heat-related mortalities and morbidities throughout (World Health Organisation, 2015; 2016). Implementing heatwave plans and strategies similar to the Ahmedabad Heat Action Plan can prove very effective in African cities in the future, and particularly cities within South Africa, which face similar heat extremes and socio-economic challenges (Council for Scientific and Industrial Research, 2017; Global Change Institute, 2019; Singh *et al*., 2019).

1.2 RATIONALE

As the impacts of climate change occur on a local scale, with different regions around the world facing different levels of extreme heat and heatwave events, some countries and cities will experience higher rates of warming and heat severities than others (Dong *et al*., 2015; Fernandez Milan and Creutzig, 2015; McGregor *et al*., 2015; Phung *et al*., 2016; McGregor, 2017; Hu *et al*., 2019; Dialesandro *et al*., 2021; IPCC, 2022). Heat-related health impacts are determined by the risk dynamics within a population, which, as described by the IPCC, is based on the interactions between the hazard, exposure and vulnerability to heat within a specific area (Dong *et al*., 2015; Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022). These dynamics are key in identifying the most at-risk populations around the world regarding future global warming and can further identify high-risk populations on a local scale (Dong *et al*., 2015; Fernandez Milan & Creutzig, 2015).

Africa and African cities have been identified as one of the most at-risk regions to the current and future impacts of global warming, as the temperatures on the continent are rising at double the rate of global temperatures, with average temperatures projected to increase by 2.0 to 3.0°C by 2050 and almost 4.5°C by 2080 (IPCC, 2014, 2022; Niang *et al*., 2014; Girvetz *et al*., 2018). In recent decades, most African countries have also recorded an increase in the annual number of hot days, hot nights and longer, more intense heatwave events, which will result in an increase in heat-related mortalities and morbidities across the continent (Bettaieb *et al*., 2010; Kynast-Wolf *et al*., 2010; Azongo *et al*., 2012; Diboulo *et al*., 2012; Egondi *et al*., 2012; Mrema *et al*., 2012; Leone *et al*., 2013; Niang *et al*., 2014; Egondi *et al*., 2015; Bunker *et al*., 2017; Wichmann, 2017; Girvetz *et al*., 2018; Scovronick *et al*., 2018; IPCC, 2022). These temperature extremes, coupled with the high vulnerability of African cities due to the increasing levels of poverty and low economic status of these populations, puts many of these societies at an increasing risk of heat-related health impacts in the near future (IPCC, 2014, 2022; Niang *et al*., 2014; Girvetz *et al*., 2018). Due to the severity of extreme heat and various socio-economic challenges faced by African societies, the continent has been classified as the most at-risk

region for future rising temperatures, with southern Africa being a particular hotspot for increasing temperatures (IPCC, 2014, 2022; Niang *et al*., 2014; Girvetz *et al*., 2018). Therefore, extreme heat and heatwave studies are critical within an African context, especially in southern Africa, which has been previously overlooked, requiring effective mitigation and adaptation strategies for African societies to cope with rising temperatures in the future.

South Africa is one African country that has identified the increasing risks associated with climate change and extreme heat, as well as the high vulnerability of their population's, and has provided frameworks within their national policies and planning instruments (i.e., National Climate Change Response White Paper of 2011, National Climate Change Adaptation Strategy of 2020, National Heat Health Guidelines of 2020 and draft Climate Change Bill of 2022). These national policies and plans outline the climate change responses and strategies needed to address the current and future climate change impacts, like the emerging heat-related health impacts, into local planning (Department of Environmental Affairs, 2011, Department of Forestry, Fisheries and the Environment, 2020; Department of Health, 2020; Republic of South Africa, 2022). Local municipalities have subsequently included climate change impacts and risks and developed adaptive strategies within their Integrated Development Plans (IDPs) (Department of Environmental Affairs, 2011; South African Cities Network, 2016; Nana *et al*., 2019; City of Johannesburg Metropolitan Municipality, 2021; City of Tshwane Metropolitan Municipality, 2021; City of Ekurhuleni Metropolitan Municipality, 2022). These IDPs guide the municipality's development in delivering services and serve as an incremental planning tool for achieving long-term goals and, in this case, climate change responses (City of Johannesburg Metropolitan Municipality, 2011, 2021; Nana *et al*., 2019; City of Tshwane Metropolitan Municipality, 2021; City of Ekurhuleni Metropolitan Municipality, 2022). Despite the adoption of these national policies and plans and the integration of climate change risk and adaptive strategies within local municipality IDPs, local governments have not effectively integrated, mainstreamed and implemented climate change adaptation strategies into their operational activities (South African Cities Network, 2016; Nana *et al*., 2019; City of Johannesburg Metropolitan Municipality, 2021; City of Tshwane Metropolitan Municipality, 2021; City of Ekurhuleni Metropolitan Municipality, 2022).

Within this South African context, a recent study by Nana *et al*. (2019) examined the architecture and implementation responses of the City of Johannesburg, a local municipality, regarding extreme heat and heatwave events. The study aimed to understand the level of attention and responses to extreme heat and heatwave events within the City of Johannesburg's Environmental Health Department (Nana *et al*., 2019). The study concluded that despite the Environmental Health Managers' understanding and awareness of current and future extreme heat and heatwave events, heatwave adaptation planning

is not a priority within the City's Environmental Health Department due to the inter-related individual, social and institutional settings in which they operate (Nana *et al*., 2019). The current study aimed to follow up and re-assess the governance of heatwaves in the City of Johannesburg to ascertain the status of preparedness and anticipatory heat action, and further expand this to the neighbouring metropolitans in the Gauteng Province.

Finally, the current study occurred when a team of diverse multidisciplinary experts, in partnership with policymakers and practitioners, began to advance responses to climate change and human health risks within African cities. This team formation, known as CASCADE[1], aims to achieve this through innovative research across natural and social sciences and transdisciplinary research engagement that acknowledges the complexity of the urban health and socio-economic challenges within these African cities. CASCADE's key entry point is human health and heat-related challenges. A systems approach, including the heat-health impacts and risk, is required to develop an understanding that can guide effective adaptation strategies for the future. Five African cities (Accra in Ghana, Harare in Zimbabwe, Kampala in Uganda, and Cape Town and Johannesburg in South Africa) have been identified and serve as the research locations for this problem-focused engagement.

The research presented in this dissertation thus builds on various local efforts focused on city-level heat health adaptations. The central intention of the research was to understand and advance the responses to heat-related health impacts within the City of Johannesburg and further expand the study area to neighbouring metropolitan municipalities (i.e., the City of Tshwane and the City of Ekurhuleni) within the Gauteng Province laying the basis for the development of adaptation strategies to protect these regions' societies and human health. This research also builds on the study done by Nana *et al*. (2019) on the responses of Environmental Health Managers within the City of Johannesburg and uses this past research as a starting point for increased understanding, gap analysis and the development and implementation of heat action plans for these municipalities.

1.3 AIM

The overall aim of this research, as outlined above, was to investigate to what extent and how three metropolitan municipalities within the Gauteng Province are responding to the current and emerging heat-related health impacts. The governance dimensions, responses and decision-making of Environmental Health Managers within these different municipalities with regard to extreme heat and heatwave events were examined. In particular, the extent of any further development made within the municipal operational activities in the City of Johannesburg since the previous study (Nana *et al*.,

[1] CASCADE is structured through three research streams: (i) Urban climate-health risk pathways, (ii) Urban climate health interventions, messaging and decision-support and (iii) Urban climate health governance.

2019) was investigated, with further expansion to concentrate on the neighbouring metropolitan municipalities within Gauteng (namely Tshwane and Ekurhuleni), on how heat health is being responded to and planned for.

Additionally, this research examined the suitability of a Heat Vulnerability Index (HVI) incorporating socio-economic variables to develop the most perception-informed assessment of vulnerability to heat-related health impacts throughout the three Gauteng metropolitans. The aim was to examine whether a tool can be developed to assist in identifying areas and populations at risk to heat extremes. From this, the potential implementation of targeted responses and strategies to reduce heat-related health impacts in these areas may emerge. Hopefully, the resulting HVI will be a valuable resource for local governments to understand and address the health impacts of extreme heat on their populations better, particularly those most at risk.

1.4 OBJECTIVES

The objectives of this study were:

1. to identify heat health adaptation policies and plans on a national (South African legislation) and municipal (local IDPS) scale to extreme heat and heatwave events;
2. to investigate the responses of the Environmental Health Managers within the local governments of three metropolitan municipalities in Gauteng (City of Johannesburg, City of Tshwane and City of Ekurhuleni) to this overarching policy environment and enhance understanding of local heat health governance dimensions;
3. to develop a socio-economic HVI, which will assist in identifying the most vulnerable areas and populations to heat-related health impacts; and
4. to provide a framework heat action plan for the metropolitans while identifying the challenges and opportunities that may arise during the development of such an adaptation plan within other South African and African cities.

The study's overview, aim and objectives have been provided in this chapter. The focus now shifts to the background and literature review aspect of this dissertation, which will be outlined in the following chapter (*Chapter 2*). In the pursuit of understanding the extent of current heat action in Gauteng and advancing city responses to extreme heat and heat-related health impacts in South Africa, it is essential to engage in a thorough research process and establish a baseline of previous studies and literatures. This includes both global and local literatures on the extent of increasing temperature and extreme heat events, the impacts of extreme heat on human health, the necessary responses and strategies to combat heat extremes in the African and South African context, as well

as the governance and institutional dynamics of mainstreaming heat action from national policies to local implementation.

2 CHAPTER TWO – LITERATURE REVIEW

Evidence of enhanced understanding of global and local literature on extreme heat and heat-related health impacts is provided in this chapter. The global context of climate change and extreme heat is initially outlined, including the rising global temperatures, the current and predicted increases of extreme heat and heatwave events, urbanisation and the vulnerability of urban landscapes, the health impacts of extreme heat exposure, the function of heat risks (i.e., heat hazard, heat exposure and heat vulnerability), global efforts in heat response strategies and adaptation, heat action planning, and lastly, the global governance dynamics of mainstreaming heat action with a primary focus on the public health sector. Secondly, this chapter outlines the African and South African heat context, including the past impacts of extreme heat events throughout Africa, the predicted increases in rising temperatures and increased extreme heat events throughout Africa and specifically for South Africa, the defined heatwave thresholds in South Africa and expanding upon recent studies in South Africa with various focal areas, including the association between temperature and mortalities, identifying heat thresholds for heat warning systems, developing heat vulnerability assessments, and heat risk modelling to identify city-level heat risks. Finally, this chapter examines the governance and institutional dimensions of climate and heat action in South Africa by reviewing the national and municipal policies and plans to address extreme heat and further explore recent local studies on the governance and institutional dynamics for mainstreaming climate action in South Africa, with particular focus on the study by Nana *et al*. (2019), which serves as the baseline study for this research dissertation.

2.1 CLIMATE CHANGE AND RISING GLOBAL TEMPERATURES

Since 1850, the average global temperature has continued to rise, with the global temperature in 2011-2020 increasing above 1.1°C from these pre-industrial levels. Global temperatures have been increasing at a faster rate since 1970 than in any 50-year period over the last 2 000 years, and this trend is predicted to continue throughout this century, with temperatures projected to increase beyond pre-industrial levels by over 2.0°C in high mitigation scenarios, and up to 4.5°C in low mitigation scenarios by 2100. This observed warming is due to natural variability and human-caused anthropogenic activities, with human society's accelerated growth and unsustainable development enhancing greenhouse gas emissions (Figure 2.1). Human activities such as burning fossil fuels, deforestation, land-use changes and industrial processes have increased the concentrations of greenhouse gas emissions in the atmosphere, which have ultimately caused accelerated warming of the earth's climate (IPCC, 2022). This human-induced global warming has resulted in multiple shifts and changes to the earth's climate system, giving rise to extreme weather and climate conditions

globally, commonly referred to as climate change (Archer *et al*., 2010; Engelbrecht *et al*., 2015; IPCC, 2022).

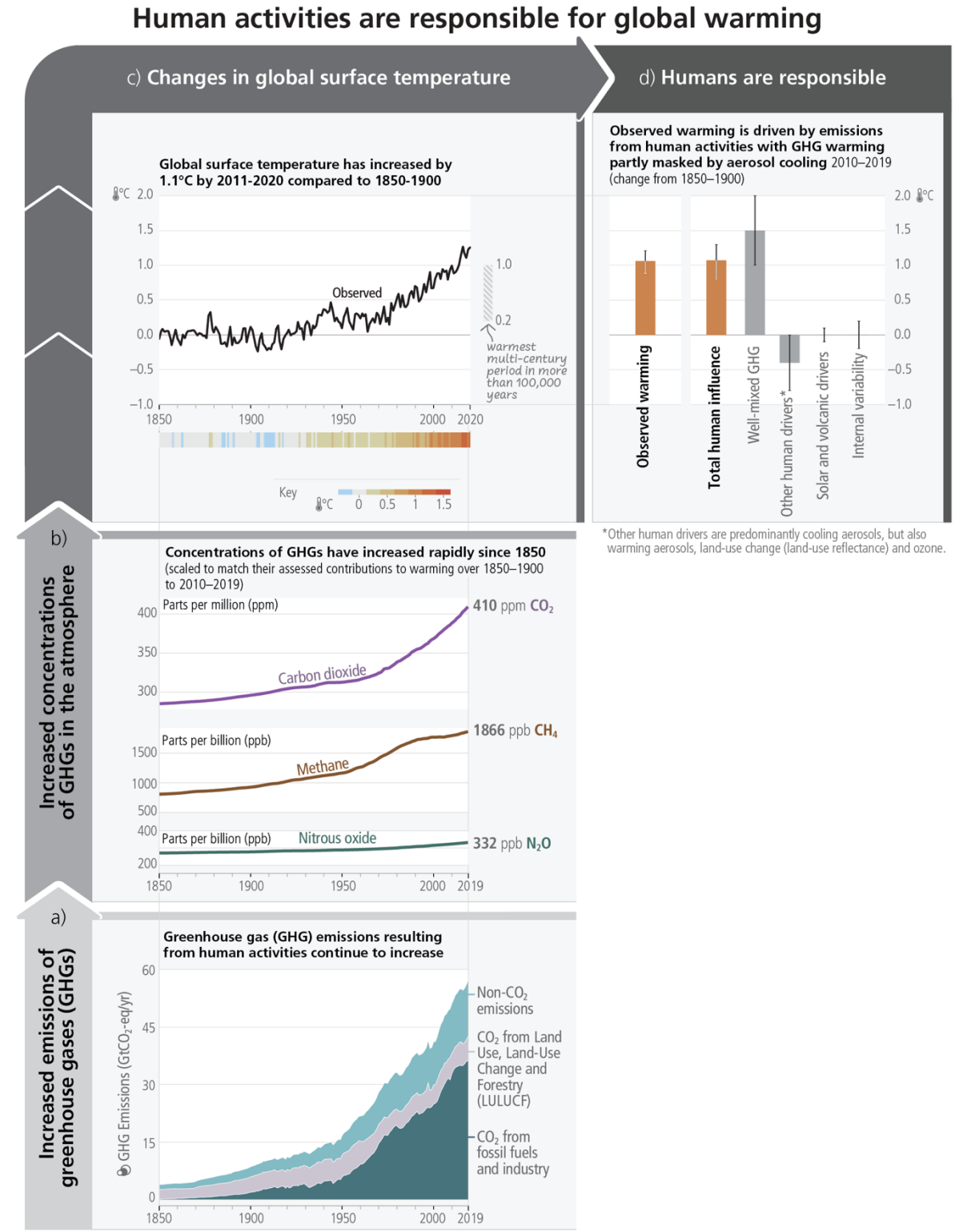


Figure 2.1: The causal chain from emissions to resulting warming of the climate system. a) Emissions of greenhouse gases (GHG) have increased rapidly over recent decades; b) These emissions have led to increases in the atmospheric concentrations of several GHGs, including CO_2, CH_4 and N_2O; c) The global surface temperature increased by around 1.1°C since 1850/1900 to 2020; and d) Formal detection and attribution

studies synthesise information from climate models and observations showing that the best estimate is that humans cause all the warming observed between 1850/1900 and 2010/2019. Source: IPCC (2022)

Although climate change is a global phenomenon causing average global temperatures to rise, the effects and impacts of climate change occur at a local level, with different regions around the world experiencing widespread adverse climatic changes and extreme weather events. These changing climates have had significant effects on food and water security, human health, society and economies, resulting in losses and damages to natural and social systems, with human populations struggling to cope with the new climatic conditions (Measham *et al*., 2011; Pasquini *et al*., 2013; Carter *et al*., 2015; United Nations, 2016; IPCC, 2022). The shift of the earth's system into a new climate has not only caused an increase in average global temperatures, but this warmer climate has resulted in more hot weather and record-breaking hot weather globally (Figure 2.2) (McMichael *et al*., 1996; Meehl *et al*., 2000; Patz & Khaliq, 2002; Wilby, 2003; Tan *et al*., 2009; IPCC, 2007, 2014, 2022). The continued increase of global temperatures throughout this century is also projected to increase the frequency, duration and intensity of extreme heat and heatwave events, leading to the increased exposure of populations to heat extremes (McMichael *et al*., 1996; Meehl *et al*., 2001; Patz & Khaliq, 2002; Wilby, 2003; Tan *et al*., 2009; IPCC 2007, 2014, 2022; Fischer & Schär, 2010; McGregor *et al*., 2015).

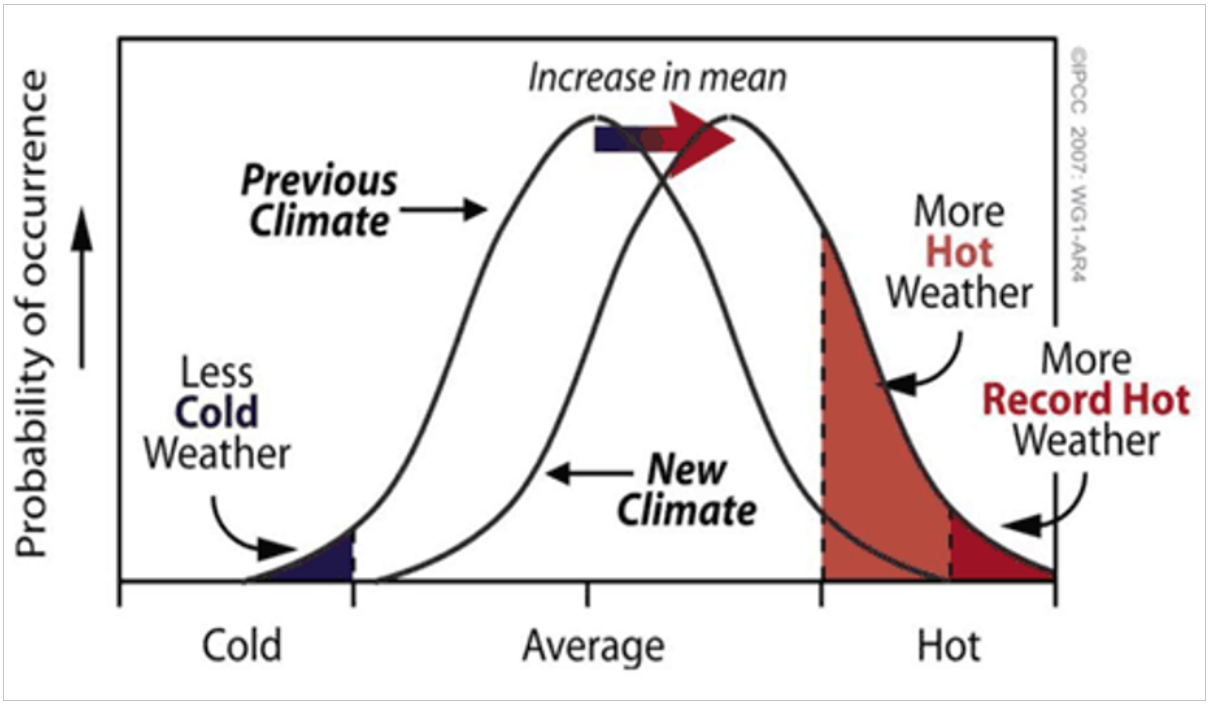


Figure 2.2: Demonstration of how a shift in average temperature influences the frequency of extreme heat. Source: IPCC (2007)

2.2 EXTREME HEAT AND HEATWAVES

Although there is no universally accepted definition for heatwaves, they are considered periods of unusually hot weather lasting at least two to three days (Robinson, 2001; Perkins & Alexander, 2013; McGregor *et al*., 2015). According to the IPCC, a heatwave is "*a period of abnormally hot weather, often defined concerning a relative temperature threshold, lasting from two days to months*" (IPCC, 2022, p. 2911). During these extreme heat periods, daytime and nighttime temperatures are significantly high, enhancing the local population's heat exposure (McGregor *et al*., 2015). The term extreme heat refers to the hazard caused by these abnormally high temperatures that surpass the average temperature for a particular region and time of the year, where extreme heat events may not necessarily last for an extended period like that of a heatwave (Robinson, 2001; Perkins & Alexander, 2013; McGregor *et al*., 2015; Puley, 2022; IPCC, 2022). Extreme heat and heatwave events are relative to the local climate, where similar temperatures can constitute a heatwave in one particular region but not another (McGregor *et al*., 2015; Puley, 2022; IPCC, 2022).

While extreme heat may not be as detrimental to the economy as other types of severe weather extremes, they are particularly dangerous to human health, especially for people living in more vulnerable contexts. Heatwaves and long periods of extreme heat do not constitute the same amount of damage and high mortality rates as other extreme weather events, like hurricanes, tornados, cyclones and flooding, as extreme heat does not result in physical damage to infrastructure and rarely identified as the direct cause of morbidities and mortalities (World Health Organisation, 2008; Boeckmann & Rohn, 2014; Zografos *et al*., 2016; Mora *et al*., 2017; Nana *et al*., 2019). Thus, until recently, extreme heat and heatwave events have been in the background of climate change studies, as their effects are not easily seen. Recent observations, press reports and current experiences have, however, propelled attention to extreme heat and heatwaves, calling attention to impacts on human health, especially within cities and urban areas (Figure 2.3) (O'Neill *et al*., 2009; Harlan & Ruddell, 2011; Revi *et al*., 2014; Bidassey-Manilal *et al*., 2016; Garland *et al*., 2015; Mora *et al*., 2017).



Figure 2.3: Recent press reports of the growing attention extreme heat and heatwaves have had throughout global media, a) News article highlighting the exposure of developing countries to extreme heat. Source: The Hindu (2023); b) News article highlighting the number of mortalities during the 2022 European heatwave. Source: CNN (2023); c) News article highlighting a recent winter heatwave that hit South America, specifically the Andes mountains, with a record-breaking heatwave. Source: The Guardian (2023); d) News article highlighting a recent heatwave warning in South Africa with temperatures reaching up to 40°C. Source: The Citizen (2023)

2.3 URBANISATION AND URBAN HEAT ISLAND

Urbanisation and urban landscapes play an interesting role in global warming trends and the impacts of extreme heat on urban populations. It is estimated that almost two-thirds of the world's population will be living within cities and urban areas by 2050, and these areas, although they cover a small proportion of the earth's surface, contribute the most to anthropogenic activities and greenhouse gas emissions (Hallegatte & Corfee-Morlot, 2010; Rosenzweig *et al*., 2011; United Nations, 2015, 2016; Revi *et al*., 2014; Nana *et al*., 2019). In addition, the effect of UHI results in significantly higher temperatures within cities and urban areas than in surrounding rural or less built-up areas (Figure 2.4) and has become one of the largest challenges associated with urbanisation (Grimm *et al*., 2008; World Health Organisation, 2008; Tan *et al*., 2009; McGregor *et al*., 2015; Doherty *et al*., 2016; Shirinde *et al*., 2017; Nana *et al*., 2019; Puley, 2022). The increased temperatures within the UHI are caused by high incidences of anthropogenic activities, high density of buildings and impervious surfaces (i.e., concrete infrastructure and roads) absorbing solar radiation, the low density of vegetation and trees providing the cooling effect, and little or no water sources providing evaporative cooling (Grimm et al., 2008; World Health Organisation, 2008; Hallegatte & Corfee-Morlot, 2011; McGregor *et al*., 2015; Nana *et al*., 2019). The UHI phenomenon leads to more hot days per year and higher than

normal nighttime temperatures, reducing the cooling capacity of urban populations (Tan *et al*., 2009; McGregor *et al*., 2015; IPCC, 2022). This effect is particularly pronounced in densely populated parts of cities with limited green spaces (McGregor *et al*., 2015; Singh *et al*., 2019; IPCC, 2022; Puley, 2022). Areas with dense buildings, fewer trees for shading, and more heat-trapping materials can experience temperatures significantly higher than leafy areas, which are more dispersed, well-shaded, and green (McGregor *et al*., 2015; Singh *et al*., 2019; IPCC, 2022; Puley, 2022). This impact is often observed in central business districts, informal settlements, and other high-density areas (McGregor *et al*., 2015; McGregor, 2017; Singh *et al*., 2019; IPCC, 2022; Puley, 2022). During extreme heat events, weaknesses in a city's systems can further exacerbate this urban vulnerability, putting strain on infrastructure and the water and energy systems (McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022; Puley, 2022). For example, cities relying on artificial cooling, such as air conditioning, may experience energy cuts due to high demand on the energy system, leaving residents exposed and vulnerable to heat-related health impacts, as well as disrupting other urban services (McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022; Puley, 2022). In addition, extreme heat events put a strain on a city's water system due to the increased need for cooling and hydration sources (McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022; Puley, 2022). However, in areas where water systems do not reach everyone, such as slums and informal settlements, residents may struggle to stay hydrated, putting them vulnerable to heat-related impacts (McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022; Puley, 2022). As global temperatures continue to rise, the UHI effect is likely to further accelerate the warming within cities and urban areas, resulting in increased frequency, duration and intensity of heatwaves, which will intensify heat exposure in cities and pose a threat to the health of these populations (McMichael *et al*., 1996; Meehl *et al*., 2001; Patz & Khaliq, 2002; Wilby, 2003; Tan *et al*., 2009; McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022). Those living in urban poverty, particularly in informal settlements, are especially at risk due to the combination of higher temperatures, increased vulnerability, and the inability to respond due to limited access to coping mechanisms (McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022; Puley, 2022). With the projected changes to global temperatures and increased frequency of heatwaves, the ongoing levels of urbanisation provide a setting for a dramatic increase in heat-related morbidities and mortalities in urban areas (Tan *et al*., 2009; Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; IPCC, 2022). Heat-related health risks have hence become widely acknowledged as one of the biggest challenges and climate change hazards to human populations, specifically in highly vulnerable urban areas (Kunst *et al*., 1993; Kalkstein and Greene, 1997; Guest *et al*., 1999; Smoyer *et al*., 2000; Tan *et al*., 2009; Fernandez Milan and Creutzig, 2015).

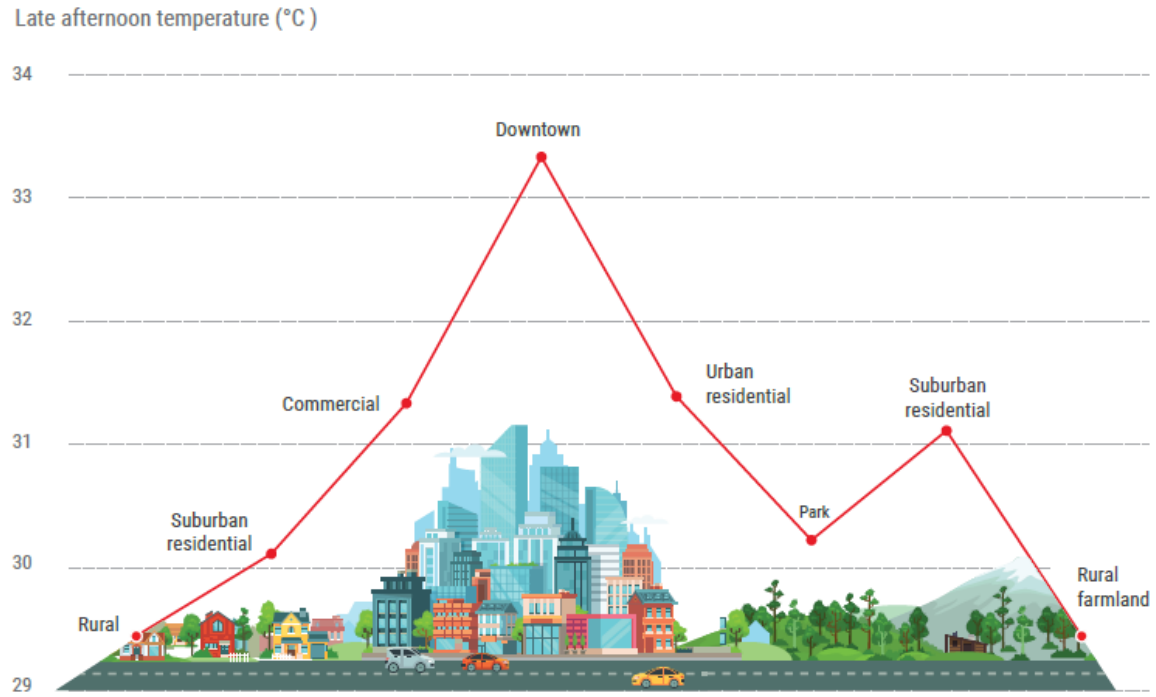


Figure 2.4: Urban Heat Island profile adapted from Heat Island Group, Lawrence Berkeley National Laboratory. Source: Puley (2022)

2.4 HEAT HEALTH IMPACTS

In the past, climate change studies have mainly focused on the impact of climate change on the physical, natural and human environment. Climate change studies have only recently acknowledged the impact of the changing climate on human health, especially considering future projected climate change and the rise of vulnerable regions at high risk from these impacts (Tan *et al*., 2009; IPCC, 2014, 2022). Heat-related health impacts are one such example that has gained increasing acknowledgement in climate change studies and has become an emerging public health concern globally (McGregor et al., 2015; IPCC, 2022). Excess heat exposure and heatwave events can significantly affect human health, both directly and indirectly (Figure 2.5). The direct impacts are caused by the heat exposure on an individual due to the body's inability to regulate its temperature, which ultimately can result in heat-related illnesses (i.e., morbidities) and deaths (i.e., mortalities) (McGregor et al., 2015; McGregor, 2017; IPCC, 2022). The indirect impacts occur due to overburdening health and emergency services due to the increased hospital admissions, particularly during intense heatwave events, as well as a strain on physical infrastructure and social services as there is an increased demand for water, electricity and cooling areas. Additionally, heatwave events can have further societal impacts, potentially affecting agriculture, food and water security, as well as an increased risk of infections and disease outbreaks (i.e., vector-borne diseases) (McGregor et al., 2015; McGregor, 2017; IPCC, 2022).

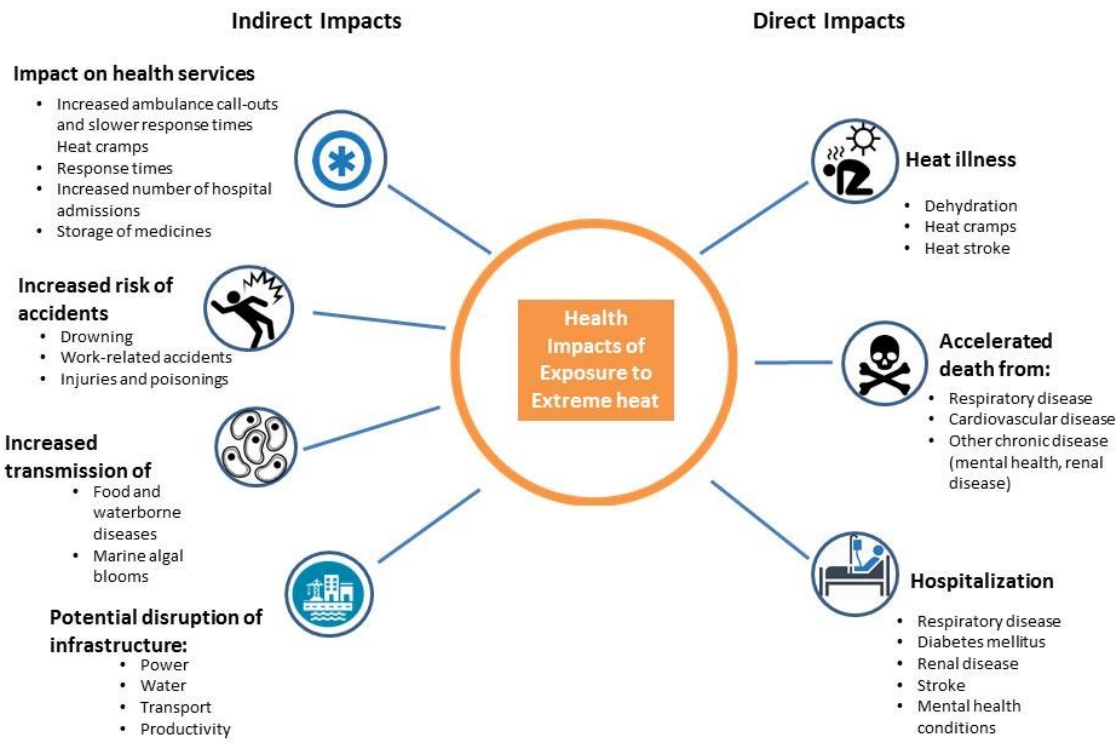


Figure 2.5: Direct and indirect health impacts of exposure to extreme heat. Source: World Health Organisation (n.d)

In recent years, extreme heat and heatwave observed mortality and morbidity impacts on human health have been well documented, with evidence of significant death tolls and hospitalisations during heatwave events (McGregor *et al*., 2015; IPCC, 2022). Historical heatwaves have accounted for some of the deadliest events on record, resulting in significant death tolls and hospitalisations, with the European heatwave of 2003 recording an excess of 70 000 deaths across 12 European countries, the Russian and Indian heatwave of 2010 accounting for over 55 000 and 1 300 deaths, respectively, and a more recent heatwave in Japan in 2018 estimating over 1 400 deaths and over 30 000 heat-related emergency hospitalisations over 11 days (Robine *et al*., 2008; Ahmedabad Municipal Corporation, 2013; Hoag, 2014; McGregor *et al*., 2015; McGregor, 2017; Hayashida *et al*., 2019; Puley, 2022; IPCC, 2022). However, the majority of mortalities and morbidities during heatwaves are not directly attributed to the heat itself; instead, the immediate cause of death or illness is recorded, leading to an underreporting of heat-related health impacts and concealing the actual effects of extreme heat (McGregor *et al*., 2015; Puley, 2022; IPCC, 2022).

Heat-related health impacts can cause a range of effects on the body, including heat rash, heat oedema, heat syncope, heat cramps, heat exhaustion and life-threatening heat strokes, while also causing severe dehydration, acute cerebrovascular accidents, thrombogenesis and further worsening pre-

existing chronic conditions such as pulmonary and cardiac issues, kidney disorders and psychiatric illnesses (World Health Organisation, 2008; McGregor *et al*., 2015). While all populations and communities are potentially exposed to heat, the severity and nature of heat-related health impacts depend on the timing, duration and intensity of the extreme heat event, as well as the level of acclimatisation, adaptation and resilience of the local populations and communities.

2.5 HEAT RISKS: HAZARD, EXPOSURE AND VULNERABILITY

Heat-related health impacts vary by location and are area-specific due to the inter-related relationships between climatic and non-climatic determinants, where regions around the world experience different levels of extreme heat and heatwave events, with some regions able to adapt to these changes, while others are more vulnerable and are at a higher risk of human health impacts (Fernandez Milan & Creutzig, 2015; Dong *et al*., 2015; McGregor *et al*., 2015; Phung *et al*., 2016; McGregor, 2017; Hu *et al*., 2019; Dialesandro *et al*., 2021; IPCC, 2022). Certain populations and communities are thus more susceptible and at a higher risk of heat morbidities and mortalities than others due to the local factors that increase heat risk (McGregor *et al*., 2015; Phung *et al*., 2016; McGregor, 2017; Hu *et al*., 2019; Dialesandro *et al*., 2021; IPCC, 2022). The health impacts of climate change are determined by the function of the risk level, which is described in terms of the interactions between the hazard (i.e., heat severity), exposure (i.e., heat stress) and vulnerability (i.e., sensitivity and adaptive capacity) of an area (Figure 2.6) (Fernandez Milan & Creutzig, 2015; Dong *et al*., 2015; McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022). The dynamics of heat hazard, exposure and vulnerability are key in identifying the most at-risk populations for heat-related health impacts at a local scale (Fernandez Milan & Creutzig, 2015; Dong et al., 2015; McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022).

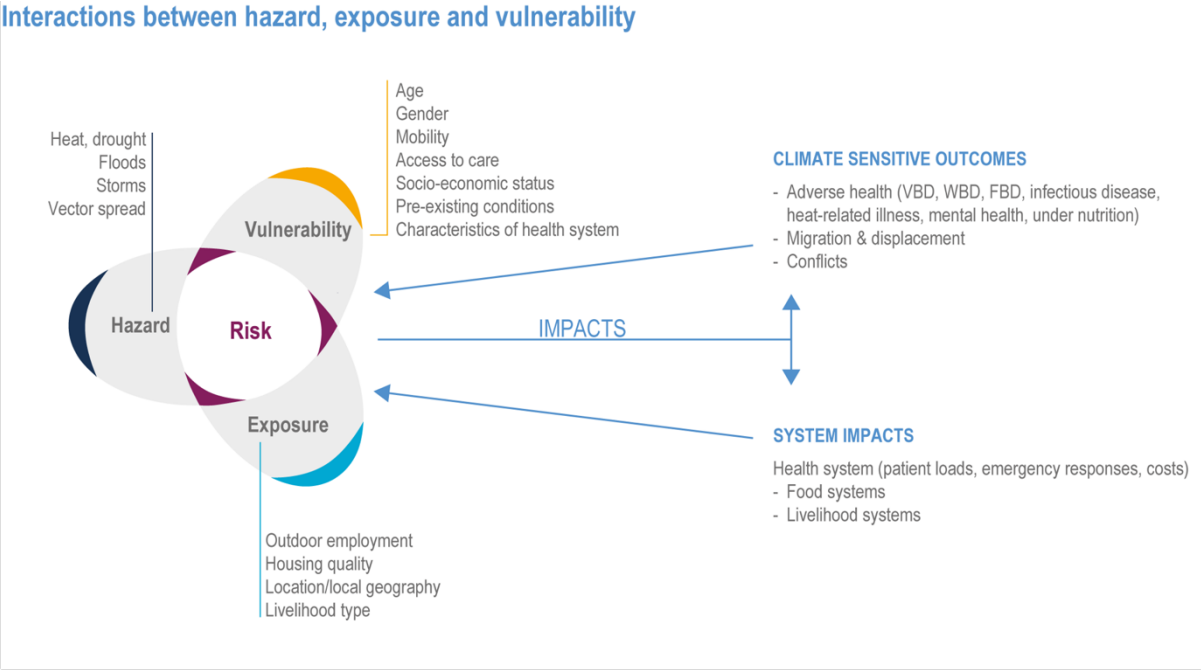


Figure 2.6: Interactions between hazard, exposure and vulnerability and how they create the risks and impacts on health systems, including selected examples to illustrate these concepts. Source: IPCC (2022)

Heat hazard refers to the severity of heat to which local populations and communities are exposed and is due to the rise in temperature of a region with increased frequency, duration and intensity of extreme heat and heatwave events. As previously discussed (*Chapter 2, Section 2.1 & 2.2*), the projected climate changes and increases in global temperatures will result in more intense and frequent heatwave events, ultimately contributing to the hazard factor of the heat risk function (Dong *et al*., 2015; McGregor *et al*., 2015; McGregor, 2017).

Heat exposure refers to the extent to which the local populations and communities are directly affected by the hazard severity, resulting in increased heat stress (Dong *et al*., 2015; McGregor *et al*., 2015; McGregor, 2017). Heat exposure is a particular concern in urban areas, where, due to the UHI effect, the regional heat load is amplified during heatwave events, thereby increasing the heat stress of these populations and communities (Grimm *et al*., 2008; World Health Organisation, 2008; Tan *et al*., 2009; McGregor *et al*., 2015; Doherty *et al*., 2016; McGregor, 2017; Shirinde *et al*., 2017; Nana *et al*., 2019; Puley, 2022). Furthermore, the importance of indoor environments has recently gained significant interest, with factors such as building materials, orientation and ventilation playing crucial roles in determining indoor thermal loads and heat exposure (McGregor *et al*., 2015; Bidassey-Manilal *et al*., 2016; Naicker *et al*., 2017; Wright *et al*., 2019; Mabuya & Scholes, 2020; IPCC, 2022). Heat stress is significantly prevalent among populations in buildings and indoor environments that are poorly ventilated or insulted and constructed with unsuitable building materials (e.g., corrugated metal housing) (Bidassey-Manilal *et al*., 2016; Naicker *et al*., 2017; Wright *et al*., 2019; Mabuya & Scholes, 2020; IPCC, 2022). These features are common to many buildings and structures in informal

settlements and slums, particularly in low-income countries, with temperatures inside these structures exceeding up to 4.0°C compared to the outdoor temperatures (Bidassey-Manilal *et al*., 2016; Naicker *et al*., 2017; Wright *et al*., 2019; Mabuya & Scholes, 2020; IPCC, 2022).

Heat vulnerability refers to the degree that a population will suffer from exposure to heat severity and is related to the sensitivity and adaptive capacity of the local populations and communities (Turner *et al*., 2003; van Vuuren *et al*., 2012; Dong *et al*., 2015; McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022). The vulnerability of an area to heat-related health impacts consists of various inter-related and dynamic factors and can be broadly categorised into demographic, health, socio-economic and behavioural factors (Dong *et al*., 2015; McGregor *et al*., 2015; McGregor, 2017):

1. *Demographic factors*

   The demographics of a population based on age and gender influence the individual's level of vulnerability and risk. The elderly (i.e., people over 65 years old) have a lower adaptive capacity to change and a higher rate of mortality to extreme heat events and have a decreased response to temperature increases, as their internal homeostatic systems cannot cope with rising temperatures and elderly-related diseases increase their mortality when faced with prolonged heat exposure (Poumadère *et al*., 2005; Vescovi *et al*., 2005; Dong *et al*., 2015; McGregor *et al*., 2015; McGregor, 2017). Infants and young children are also sensitive to the effects of high temperatures due to their dependency on others to respond to extreme heat events (Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; McGregor, 2017; Geruso & Spears, 2018; Jagarnath *et al*., 2020; Cheng *et al*., 2021; Abrar *et al*., 2022). Recent studies have also highlighted the relationship between high temperatures and increased infant mortality rates, particularly in developing countries, with greater impacts in rural areas due to limited access to healthcare facilities and resources available for adaptation measures in these areas (Geruso & Spears, 2018). Furthermore, studies have shown a significant difference in heat mortalities between men and women, with women resulting in a greater number of heat-related deaths compared to men (McGregor *et al*., 2015; McGregor, 2017).
2. *Health factors*

   The health conditions of individuals increase their vulnerability to higher temperatures and extreme heat events due to the inability of the body's physiology to regulate and respond to extreme temperatures, as well as the effect of certain medications on the body (McGregor *et al*., 2015; McGregor, 2017). Individuals with poor health or disabilities depend on others to survive, making them vulnerable to environmental changes (Wolf & McGregor, 2013; Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; McGregor, 2017; Cheng *et al*., 2021). Furthermore, recent studies have also shown that exposure to extreme heat during pregnancy increases the risk

of adverse pregnancy outcomes, such as preterm birth, low birth weight, stillbirth and other health consequences for the mother and child (Zhang *et al*., 2017; Asamoah *et al*., 2018; IPCC, 2022).

3. *Socio-economic factors*

   The conditions in which populations live may affect their exposure to heat and their sensitivity and adaptive capacity (McGregor *et al*., 2015; McGregor, 2017). Numerous socio-economic indicators are associated with heat-related health impacts, including high population densities, economic and income status, education, dwelling type, access to resources and services, etc. (Wolf & McGregor, 2013; Dong *et al*., 2015; Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; McGregor, 2017; Jagarnath *et al*., 2020; Cheng *et al*., 2021; Abrar *et al*., 2022).

4. *Behavioural factors*

   The behavioural conditions of populations and communities significantly affect heat exposure and sensitivity to heat extremes, as behaviours influence exposure to high temperatures and can also influence the vulnerability of these populations. For example, when an individual overexerts themself during physical activities or work, they may become dehydrated and, therefore, more at risk of heat-related health impacts (McGregor *et al*., 2015; McGregor, 2017). Furthermore, studies have also highlighted how changes in a person's behaviour for protective actions against heat, such as dressing lightly, using cooling techniques and having air conditioning, can significantly reduce the risks of mortalities and morbidities during heatwave events (Vandentorren *et al*., 2006; Bouchama *et al*., 2007; McGregor *et al*., 2015; McGregor, 2017).

Overall, the heat hazard, exposure and vulnerability of an area can increase the likelihood of heat-related mortalities and morbidities within a population and specifically show concerning effects on the poor, elderly, young and those with pre-existing health conditions (Rosenzweig *et al*., 2011; Dong *et al*., 2015; Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; Bolitho & Miller, 2016; Zografos *et al*. 2016; McGregor, 2017; Nana *et al*., 2019; IPCC, 2022). Heatwaves and long periods of extreme heat have also been shown to reduce peoples' working capacity during these events and are a challenge within the occupational health sector (Zografos *et al*., 2016; McGregor, 2017; Nana *et al*., 2019; IPCC, 2014, 2022). With the projected increase of global temperatures and heatwave events in the future, certain regions will be more exposed to heat extremes than others due to the hazard severity of the region, the heat exposure of the populations and the various socio-economic challenges enhancing their vulnerability (Dong *et al*., 2015; Fernandez Milan & Creutzig, 2015; McGregor, 2017; IPCC, 2022). As heat risks continue to rise into the future with more and more health challenges, especially within highly vulnerable countries and urban areas, the need to mitigate and adapt to current and future projected heat extremes is required (Niang *et al*., 2014; McGregor, 2017; Girvetz *et al*., 2018; IPCC, 2022)

Notwithstanding all of the aforementioned dimensions, it is the governance and institutional dimensions that are the focus of the research presented in this dissertation. The ability of governance and institutional structures, like that of healthcare, emergency and social services, to respond to extreme heat events significantly impacts the adaptive capacity of local populations and, therefore, their level of vulnerability. To effectively adapt and mitigate to heat-related health impacts, it is thus essential that there is effective interdepartmental co-ordination across and between all departments and agencies. These institutional structures need to have robust plans and strategies in place to effectively manage the increased demand and disruptions during extreme heat events (McGregor *et al*., 2015; McGregor, 2017).

2.6 HEAT RESPONSE STRATEGIES AND ADAPTATION

Having outlined various health impacts that can accompany heat stress, attention now turns to examining a critical part of this research, namely heat governance and adaptation and planning to reduce the risks of heat periods. In the past, climate change plans and policies have prioritised technocratic mitigation strategies, which require significant economic and financial investment. These strategies aim to address the root cause of climate change on a large scale by transitioning to more sustainable energy sources, enhancing energy efficiency and intensity, capturing carbon and driving greenhouse gas emission reductions. In recent years, however, there has been growing recognition of the importance of adaptation strategies through enhancing adaptive capacity, particularly within developing countries where there is a lack of significant financial and economic resources to respond to climate change impacts (Hamin & Gurran, 2009; Hallegatte & Corfee-Morlot, 2011; Jabareen, 2013; IPCC, 2014, 2022; Nana *et al*., 2019; Caniglia *et al*., 2020). Although mitigation strategies are necessary and important, they are often difficult to employ within developing country contexts, specifically on a local level (Hallegatte & Corfee-Morlot, 2011; Harlan & Ruddell, 2011; Jabareen, 2013; IPCC, 2014, 2022). Adaptation approaches are, therefore, needed alongside these mitigation strategies to address the current and emerging risks experienced by local societies and populations (Hamin & Gurran, 2009; Department of Environmental Affairs, 2011; Harlan & Ruddell, 2011; IPCC, 2014, 2022). These adaptation approaches allow for area-specific localised responses, accounting for the hazard severity, exposure and vulnerability of the local populations. This provides more suitable and effective responses within the specific risk context and builds adaptive capacity and resilience for future changes within the population (Caniglia *et al*., 2020; IPCC, 2022).

Research on adaptation strategies for coping with urban extreme heat and heatwaves has grown considerably in recent decades due to the increasing severity and frequency of extreme heat events (IPCC, 2014, 2022; Fernandez Milan & Creutzig, 2015; McGregor et al., 2015; McGregor, 2017).

Several effective strategies have been implemented around the world that focus on public health, public education and awareness, and urban design and planning (Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022).

Cities in North America, Europe, and Australia were the first to pioneer adaptation approaches to extreme heat that focused on public health and awareness interventions and developed the so-called Heat Health Warning System (HHWS) (Hajat *et al*., 2010; Price *et al*., 2013; Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; McGregor, 2017). HHWSs are weather-based alert systems that combine meteorological forecasts with the public health sector to reduce the impacts of extreme heat conditions on human health (Pascal *et al*., 2013; Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; McGregor, 2017; IPCC, 2022). These warning systems are designed to alert decision-makers and the local population and communities of the incoming heat event and the dangers it presents while serving as a source of information on how to reduce heat exposure and avoid the negative heat-related health impacts of these heat events (McGregor *et al*., 2015; McGregor, 2017). HHWSs include weather forecasting, determining heat thresholds that trigger warning systems and ultimately, the issuance of alert messages to the necessary stakeholders to take responsive actions (McGregor *et al*., 2015; McGregor, 2017; Puley, 2022; IPCC, 2022). An important step of these warning systems is the identification of vulnerable populations and communities to ensure that the HHWS prioritises and effectively reaches those most at risk of excessive heat exposure (McGregor *et al*., 2015; McGregor, 2017; Puley, 2022).

Ultimately, the main goal of these HHWS is to build public awareness about the impacts of extreme heat and heatwaves, educate and prepare the public about preventative behaviours and provide the public with heat avoidance actions to reduce their susceptibility to heat-related impacts (Luber & McGeehin, 2008; Fernandez Milan & Creutzig, 2015; McGregor *et al*., 2015; McGregor, 2017; Puley, 2022). Typically, HHWSs should be incorporated within the first component of a wider, multi-stakeholder action plan, which sets in motion a series of pre-agreed actions aimed at adapting and mitigating heat-related health impacts in the local populations and communities (McGregor *et al*., 2015; McGregor, 2017; Puley, 2022; IPCC, 2022).

There are, however, growing concerns with public health and awareness interventions within a low-income context due to the stratification between the rich and poor, with some communities highly exposed compared to others. For example, for heat avoidance and cooler living conditions, the strategy of air conditioning is typically used, as air conditioning is effective in reducing heat exposure (Koppe *et al*., 2004; Kovats & Kristie, 2006; Barnett, 2007; Sheridan *et al*., 2008;; Fernandez Milan & Creutzig, 2015). Access to air conditioning is, however, highly stratified between the rich and poor

within a developing country context and also requires high costs to operate (Sheridan, 2007; Rosenthal *et al*., 2014; Fernandez Milan & Creutzig, 2015). Similarly, hydration awareness to combat heat-related health problems is questionable in these contexts, as water quality, availability and affordability are not distributed equally among a population (Ruijs *et al*., 2008; Fernandez Milan & Creutzig, 2015). Furthermore, these public health and awareness strategies allow for households and individuals to cope with hazard exposure and have proven to be effective on an individual level, but these strategies are difficult to up-scale at the city level (Lankao & Qin, 2011; Fernandez Milan & Creutzig, 2015). Although these strategies play a key role in reducing individual susceptibility, they should not be overestimated in their effectiveness and require the inclusion of more city-level responses alongside them (Harlan *et al*., 2006; Kovats & Kristie, 2006; Hagerman, 2007; Harlan & Ruddell, 2011; Harlan *et al*., 2013; Wolf & McGregor, 2013; Boumans *et al*., 2014; Heaton *et al*., 2014; Fernandez Milan & Creutzig, 2015).

As urban heat and the UHI have a strong connection to the infrastructure and building structures within a city, ultimately influencing the exposure levels of a population, urban design and planning within a region can be highly effective adaptive strategies (Wang & Akbari, 2014; Fernandez Milan & Creutzig, 2015). Well-known strategies include the increase of albedo within cities through the modification of building materials, colours and reflective surfaces and the reduction of heat exposure time through shadowing and vegetation connectivity, with the cooling effect of vegetation and water bodies allowing for up to 2°C reduction in heat (Ohashi *et al*., 2007; Wilhelmi & Hayden, 2010; Armson *et al*., 2012; Hathway & Sharples, 2012; Chun & Guldmann, 2014; Sailor, 2014; Fernandez Milan & Creutzig, 2015). Studies in the cities of Seoul and Berlin have suggested that urban planning strategies to mitigate and reduce the UHI effects and urban heatwaves have been effective at a city level, with detailed urban planning focusing on specific regions that are highly vulnerable to heat-related impacts (Eum *et al*., 2013; Dugord *et al*., 2014; Schuster *et al*., 2014; Fernandez Milan & Creutzig, 2015). These strategies can assist in reducing the overall anthropogenic heat severity and exposure, and the benefits are equally distributed among the whole population of a region (Rizwan *et al*., 2008; Shashua-Bar *et al*., 2009; Fernandez Milan & Creutzig, 2015). These strategies, although providing many city-level benefits, do not specifically address populations at an individual level and have demonstrated limited effectiveness in reducing individual susceptibility to heat-related health impacts (Kjellstrom *et al*., 2007; Landry & Chakraborty, 2009; McConnachie & Shackleton, 2010; Sister *et al*., 2010; Dai, 2011; Friel *et al*., 2011; Sampson *et al*., 2013; Rosenthal *et al*., 2014; Wolch *et al*. 2014; Fernandez Milan & Creutzig, 2015). Therefore, combining public health and awareness interventions with urban planning interventions can effectively reduce individual susceptibility and exposure to extreme heat, as well as lessen the urban heat severity, exposure and UHI effects on a

city level over a longer time scale (Fernandez Milan & Creutzig, 2015). This coordinated approach can effectively address the current and future threat of extreme heat and heatwaves around the world while equally distributing the benefits throughout the population, whether rich or poor.

2.7 HEAT ACTION PLANS

A widely recognised approach for addressing extreme heat and heatwave events that combines public health and awareness interventions with city-level urban design and planning is through the development and implementation of heat action plans. (Measham *et al*., 2011; Niang *et al*., 2014; Carter *et al*., 2015; McGregor *et al*., 2015; Nana *et al*., 2019; Singh *et al*., 2019; World Health Organisation, 2021). Cities globally are developing and implementing these heatwave plans as a priority, as human health and well-being are being impacted due to increased temperatures and heatwave events (Ahmedabad Municipal Corporation, 2013, 2016; McGregor *et al*., 2015; Public Health England, 2015; Bolitho & Miller, 2016; Nana *et al*., 2019; Global Change Institute, 2019; Singh *et al*., 2019; World Health Organisation, 2021).

As cities and urban areas are highly vulnerable to the effects of extreme heating and heatwave events, the implementation of these heatwave plans is essential for the adaptation to current and future projected global warming (Kovats & Hajat, 2008; Ahmedabad Municipal Corporation, 2013, 2016; McGregor *et al*., 2015; Public Health England, 2015; Bolitho & Miller, 2016; Nana *et al*., 2019; Global Change Institute, 2019; Singh *et al*., 2019; World Health Organisation, 2021). Heatwave plans are developed to prepare for the impacts of extreme heat and heatwaves, alert people and the affected populations of the incoming period of heat and prevent the serious and avoidable impacts of these events (Ahmedabad Municipal Corporation, 2013, 2016; McGregor *et al*., 2015; Public Health England, 2015; Bolitho & Miller, 2016; Nana *et al*., 2019; Singh *et al*., 2019; World Health Organisation, 2021). Effective, well-developed heat action plans aim to increase public awareness and knowledge of heat-related health impacts, develop a formal procedure to follow before, during and after the heatwave event, develop a centralised unit or Heat Officer to coordinate and direct all heat responses, develop an early warning system and communication network to reach all the necessary stakeholders, build capacity among healthcare and emergency responders and ultimately reduce heat exposure and promote adaptive measures within the affected populations (Hallegatte & Corfee-Morlot, 2011; Ahmedabad Municipal Corporation, 2013, 2016; McGregor *et al*., 2015; Public Health England, 2015; Bolitho & Miller, 2016; Zografos *et al*., 2016; McGregor, 2017; Global Change Institute, 2019; Nana *et al*., 2019; Singh *et al*., 2019; World Health Organisation, 2021).

Although there is no single approach to developing an effective heat action plan, numerous global heat action plans have outlined the following key elements that should be incorporated within a well-developed plan:

1. Appointing a department or officer team that will coordinate, plan and direct extreme heat responses. This includes heatwave alerts, communication between other departments and affected communities and the overall implementation of the heatwave plan (Ahmedabad Municipal Corporation, 2013, 2016; Global Change Institute, 2019; Singh *et al*., 2019; Keith *et al*., 2021; Miami-Dade County, 2021; One Billion Resilient, 2021; World Health Organisation, 2021).
2. Identifying the functions of the different role-players within the heatwave adaptation plan – within and between local government departments, community members and members of society, and the different stakeholders involved (Ahmedabad Municipal Corporation, 2013, 2016; Public Health England, 2015; McGregor *et al*., 2015; McGregor, 2017; Global Change Institute, 2019; Singh *et al*., 2019; World Health Organisation, 2021).
3. Accessing real-time climate and weather forecasts to develop early warning systems (Ahmedabad Municipal Corporation, 2013, 2016; Public Health England, 2015; McGregor *et al*., 2015; McGregor, 2017; Casanueva *et al*., 2019; Global Change Institute, 2019; Singh *et al*., 2019; World Health Organisation, 2021).
4. Developing an HHWS to alert the appropriate departments and the affected populations of extreme heating events, including preventative, adaptive behaviours and heatwave preparedness to the public (Ebi *et al*., 2004; Pascal *et al*., 2006; Ahmedabad Municipal Corporation, 2013, 2016; Public Health England, 2015; McGregor *et al*., 2015; McGregor, 2017; Casanueva *et al*., 2019; Global Change Institute, 2019; Singh *et al*., 2019; World Health Organisation, 2021).
5. Identifying the highly vulnerable and at-risk areas and populations within the city/region (Ebi *et al*., 2004; Pascal *et al*., 2006; Ahmedabad Municipal Corporation, 2013, 2016; McGregor *et al*., 2015; Public Health England, 2015; McGregor, 2017; Casanueva *et al*., 2019; Global Change Institute, 2019; Singh *et al*., 2019; World Health Organisation, 2021; Abrar *et al*., 2022; Puley, 2022).
6. Improving emergency services and healthcare workers' capacity in response to heat-related illnesses to reduce the morbidity and mortality from heat stress (Ahmedabad Municipal Corporation, 2013, 2016; Public Health England, 2015; Global Change Institute, 2019; Singh *et al*., 2019; World Health Organisation, 2021).

The earliest of these heatwave plans was pioneered in the City of Philadelphia, United States, in the mid-1990s after a deadly heatwave hit the City in 1993, claiming over 100 lives (Centers for Disease

Control and Prevention, 1994; Ebi *et al*., 2004). This was the first introduction of a heat emergency plan that was centred around an HHWS and aimed to prevent mortalities and morbidities from heatwaves similar to that of 1993 by outlining strategies to identify incoming heatwaves, issuing and communicating heat alerts, setting up cooling centres and educating the public and building awareness of heat-related health impacts throughout the city (Ebi *et al*., 2004). This first heatwave plan in Philadelphia laid the foundation for the development of heat action plans throughout the world, and as more cities understood the significant impacts of extreme heat and heatwave events, it resulted in the widespread development of similar plans around the world (Ogg, 2005; Pascal *et al*., 2006; Ahmedabad Municipal Corporation, 2013, 2016; Public Health England, 2015; Puley, 2022).

Moreover, more commonly known and the first to establish the so-called "heat action plans" were those introduced by European cities, particularly in England and France in the early 2000s, after the deadly heatwave of 2003 that resulted in an estimated 70 000 deaths across Europe (Ogg, 2005; Pascal *et al*., 2006; Robine *et al*., 2008; Public Health England, 2015). Where these action plans have been adopted and backed by sufficient resourcing, they have seen highly effective results in mitigating and protecting against heat-related morbidities and mortalities within populations; these results were demonstrated during the France heatwave of 2006, which saw an estimated 4 400 fewer deaths than what would have been expected under the 2003 heatwave conditions if no heatwave plan had been implemented (Ogg, 2005; Public Health England, 2015; Nana *et al*., 2019; Puley, 2022). Furthermore, a highly notable and groundbreaking heat action plan that was the first to be implemented in a developing country particularly vulnerable to extreme heat events was the development of the Ahmedabad Heat Action Plan in India, as briefly noted in Chapter 1 (Ahmedabad Municipal Corporation, 2013, 2016; Puley, 2022).

Ahmedabad's Heat Action Plan was India's first systematic attempt at heatwave planning after a significant heatwave hit the city in 2010, which resulted in over 1 300 heat-related deaths and seriously impacted the City in several ways (Ahmedabad Municipal Corporation, 2013, 2016; Global Change Institute, 2019; Puley, 2022). This deadly heatwave event triggered the development and implementation of the Ahmedabad Heat Action Plan in 2013 by the Ahmedabad Municipal Corporation to prepare and protect the City's health systems and public against future heatwave events, which resulted in the City avoiding an estimated 1 100 annual deaths following the introduction of this Heat Action Plan (Ahmedabad Municipal Corporation, 2013, 2016; Puley, 2022). The Ahmedabad Municipal Corporation appointed a Nodal Officer who, in conjunction with the Health Department, was tasked with leading the action plan and responsible for coordinating and communicating heatwave-related activities in the City (Figure 2.7). These activities include monitoring weather forecasts and triggering the warning systems, mobilising the relevant departments

and agencies and communicating heat-health alerts to the local population and communities, with special attention paid to the vulnerable communities. The Ahmedabad Heat Action Plan aims to implement four key strategies: (i) Building Public Awareness and Community Outreach, (ii) Initiating an Early Warning System and Inter-Agency Coordination, (iii) Capacity Building Among Health Care Professionals, and (iv) Reducing Heat Exposure and Promoting Adaptive Measures. Furthermore, this action plan includes three different phases within a period of extreme heat or a heatwave event: Phase 1 – prior to the heat event; Phase 2 – during the heat event; and Phase 3 – after the heat event (Box 2.1) (Ahmedabad Municipal Corporation, 2013, 2016).

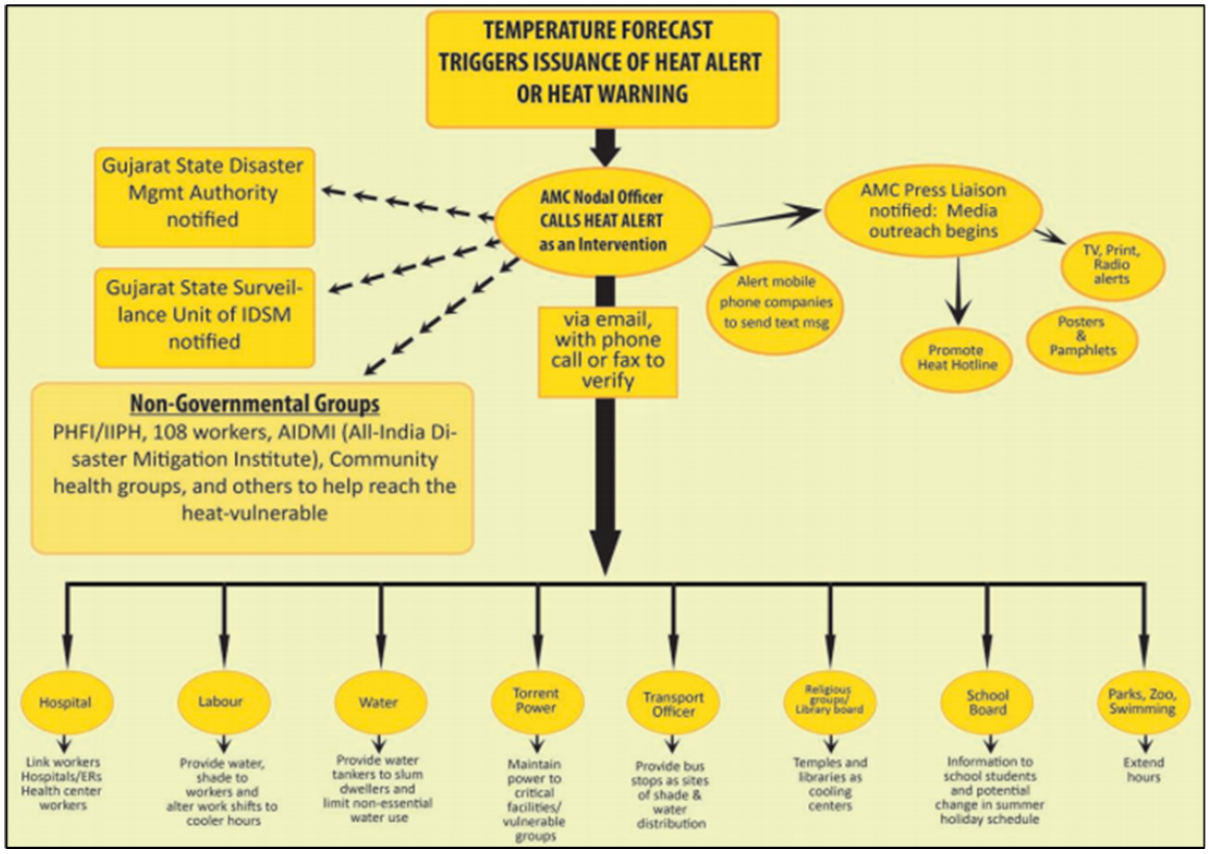


Figure 2.7: Communication plan activated by Ahmedabad Municipal Corporation's Nodal Officer in response to a heat alert or warning. Source: Ahmedabad Municipal Corporation (2016)

Box 2.1: The three phases (i.e., Pre-Heat Season, Heat Season and Post-Heat Season) of the Ahmedabad Heat Action Plan in response to an extreme heat event. Source: Ahmedabad Municipal Corporation (2016)

PHASE 1

PRE-HEAT SEASON

This phase of the action plan looks to identify the areas and communities within the city that are the most vulnerable and at-risk populations to the impact of heatwaves (Ahmedabad Municipal Corporation, 2016). The education of the public, in particular health care workers, labourers and children, about the impacts of heatwaves and preventative responses are included within this phase, as well as the use of social media, information pamphlets, advertising and the news is used to raise awareness of heatwave risks and impacts, specifically targeting the vulnerable populations and communities (Ahmedabad Municipal Corporation, 2016).

PHASE 2

HEAT SEASON

This phase includes heat warning systems and alerts, heat protection and avoidance guides, as well as city-wide responses that reduce overall heat exposure (Ahmedabad Municipal Corporation, 2016). Temperatures are constantly monitored through real-time forecasts, and access to drinking water and cool spaces is increased to reduce the impacts of heat stress on the public during the heat season (Ahmedabad Municipal Corporation, 2016). All Phase 2 operations are communicated through a formal Communication Plan (Figure 7), which is activated by AMC Nodal Officer in response to a heat alert (Ahmedabad Municipal Corporation, 2016).

PHASE 3

POST-HEAT SEASON

After the heat season, the action plan is evaluated and revised to account for all the heat-related morbidities and mortalities that occurred during the season and to identify how well the action plan worked and suggest new ways to implement it in the future (Ahmedabad Municipal Corporation, 2016).

The Ahmedabad Heat Action Plan demonstrates the importance of early warning systems and an effective communication plan with regard to extreme heat events and disaster risk management. This plan looks to enhance coordination between the different departments of government and hospitals, health care officials, emergency responders, local populations and communities and media outlets about the approaching heat event. Ahmedabad's action plan also emphasises how this adaptation plan is an ongoing process where interventions and adaptive strategies are reviewed annually to find the best possible strategies for the ongoing heat increases (Ahmedabad Municipal Corporation, 2013, 2016; Council for Scientific and Industrial Research, 2017; Global Change Institute, 2019).

The Ahmedabad Heat Action Plan is just one example of how effective heatwave adaptation plans can be, especially within a highly vulnerable context such as the City of Ahmedabad (Ahmedabad Municipal Corporation, 2013, 2016; Council for Scientific and Industrial Research, 2017; Global Change Institute, 2019; Singh *et al*., 2019). The development and implementation of these adaptation plans have been poorly recognised within an African context, with a recent review of heat action plans around the world by Kotharkar and Ghosh (2021) highlighting that no African countries have adopted such plans (Council for Scientific and Industrial Research, 2017; Global Change Institute, 2019; Kotharkar & Ghosh, 2021; Puley, 2022). Many of the most high-risk cities within Africa do not, as yet, have detailed plans in place, and many local governments do not even incorporate heatwave considerations into their operational activities (Bernard & McGeehin, 2004; Harlan & Ruddell, 2011; United Nations, 2016; Nana *et al*., 2019; Kotharkar & Ghosh, 2021; Puley, 2022). This is concerning as these regions are experiencing a rate of warming faster than the rest of the world with more frequent and intense heatwaves, as well as the developing setting of these countries and cities having various other social, environmental, economic and political challenges to deal with (Pasquini *et al*., 2013; Engelbrecht *et al*., 2015; Nana *et al*., 2019; World Health Organisation, 2021; IPCC, 2022). Implementing similar heatwave plans to the Ahmedabad Heat Action Plan could be very effective in African cities in the future, as the City of Ahmedabad faces similar heat severities and socio-economic challenges (Council for Scientific and Industrial Research, 2017; Global Change Institute, 2019; Singh *et al*., 2019).

2.8 AFRICAN HEAT CONTEXT

African cities are projected to face disproportionate heat conditions from increased temperatures compared to the temperate northern hemisphere countries, with many African regions warming at a faster rate than the global average (Ranasinghe *et al*., 2021; Carleton *et al*., 2022; IPCC, 2022). Throughout Africa, the average temperatures are projected to increase by 2.0 to 3.0°C by 2050 and over 4.5°C by 2080 under high emission scenarios (i.e., RCP 8.5). The warming potential of Africa has already resulted in the emergence of an increase in the annual number of hot days, hot nights and heatwaves, which is projected to escalate and cause more temperature-related mortalities and morbidities across the continent (Niang *et al*., 2014; Girvetz *et al*., 2018; IPCC, 2022).

Recent studies in Africa have highlighted the increase in emergency and hospital admissions during moderate- and high-temperature days, with an increase in mortalities recorded on high-temperature days in Burkina Faso, Ghana, Kenya, South Africa, Tanzania and Tunisia (Bettaieb *et al*., 2010; Kynast-Wolf *et al*., 2010; Azongo *et al*., 2012; Diboulo *et al*., 2012; Egondi *et al*., 2012; Mrema *et al*., 2012; Leone *et al*., 2013; Egondi *et al*., 2015; Bunker *et al*., 2017; Wichmann, 2017; Scovronick *et al*., 2018; IPCC, 2022). Furthermore, it is projected throughout Africa that as temperatures exceed

1.5°C, there is a significant increase in the likelihood of heat-related mortalities, with at least 15 additional deaths per 100 000 people annually across Africa, reaching 50 to 180 additional deaths for temperatures above 2.5°C and up to 200 to 600 deaths for temperatures exceeding 4.4°C (Figure 2.8, a & b) (Carleton *et al*., 2022; IPCC, 2022). Particularly in southern Africa, temperatures have rapidly increased in recent decades, with the average temperature between 1960 and 2015 increasing between 1.04°C and 1.44°C (Gutiérrez *et al*., 2021; IPCC, 2022). These increasing temperatures have also resulted in more annual hot days in these regions with more frequent and intense heatwave events (Ceccherini *et al*., 2017; Kruger & Nxumalo, 2017a; 2017b; IPCC, 2022). Furthermore, the annual number of heatwaves is projected to increase by two to four for temperatures above 1.5°C, four to eight for temperatures above 2.0°C and up to eight to 12 for temperatures above 3.0°C (Engelbrecht *et al*., 2015; Russo *et al*., 2016; Dosio, 2017; Weber *et al*., 2018; Seneviratne *et al*., 2021; IPCC, 2022). The extreme heat severity and numerous socio-economic challenges that these African societies currently face, which are projected to exacerbate, classify the African continent as the most at-risk region in the world to future rising temperatures, with southern Africa being a particular 'hotspot' for increasing temperatures (IPCC, 2014, 2022; Niang *et al*., 2014; Girvetz *et al*., 2018). Noting the highly vulnerable and at-risk contexts of African cities, it is of significant concern that climate adaptation policies and guidelines, specifically those related to extreme heat, are limited in Africa. The United Nations Framework Convention on Climate Change (UNFCC) highlighted this in a report published in 2023 on the progress and implementation of National Adaptation Plans (NAPs) in addressing the impacts of climate change throughout the least developed countries in the world (UNFCCC, 2023). This report outlines the existing climate change and adaptation policies and plans throughout the least developing countries in the world and, as at December 2023, only 21 of 54 countries in Africa had such policies in place, including Benin, Burkina Faso, Burundi, Cabo Verde, Cameroon, Central African Republic, Chad, Democratic Republic of Congo, Ethiopia, Kenya, Liberia, Madagascar, Morocco, Mozambique, Niger, Sierra Leone, South Africa, South Sudan, Sudan, Togo and Zambia (UNFCCC, 2023). This highlights the scarcity of climate change policies and plans in African countries, particularly in addressing extreme heat and heat mitigation, which has been poorly recognised in the past. It is thus critical and a necessity for extreme heat and heatwave studies to be conducted within an African context, who require effective mitigation and adaptation strategies that will help its societies cope with these rising temperatures in the future.

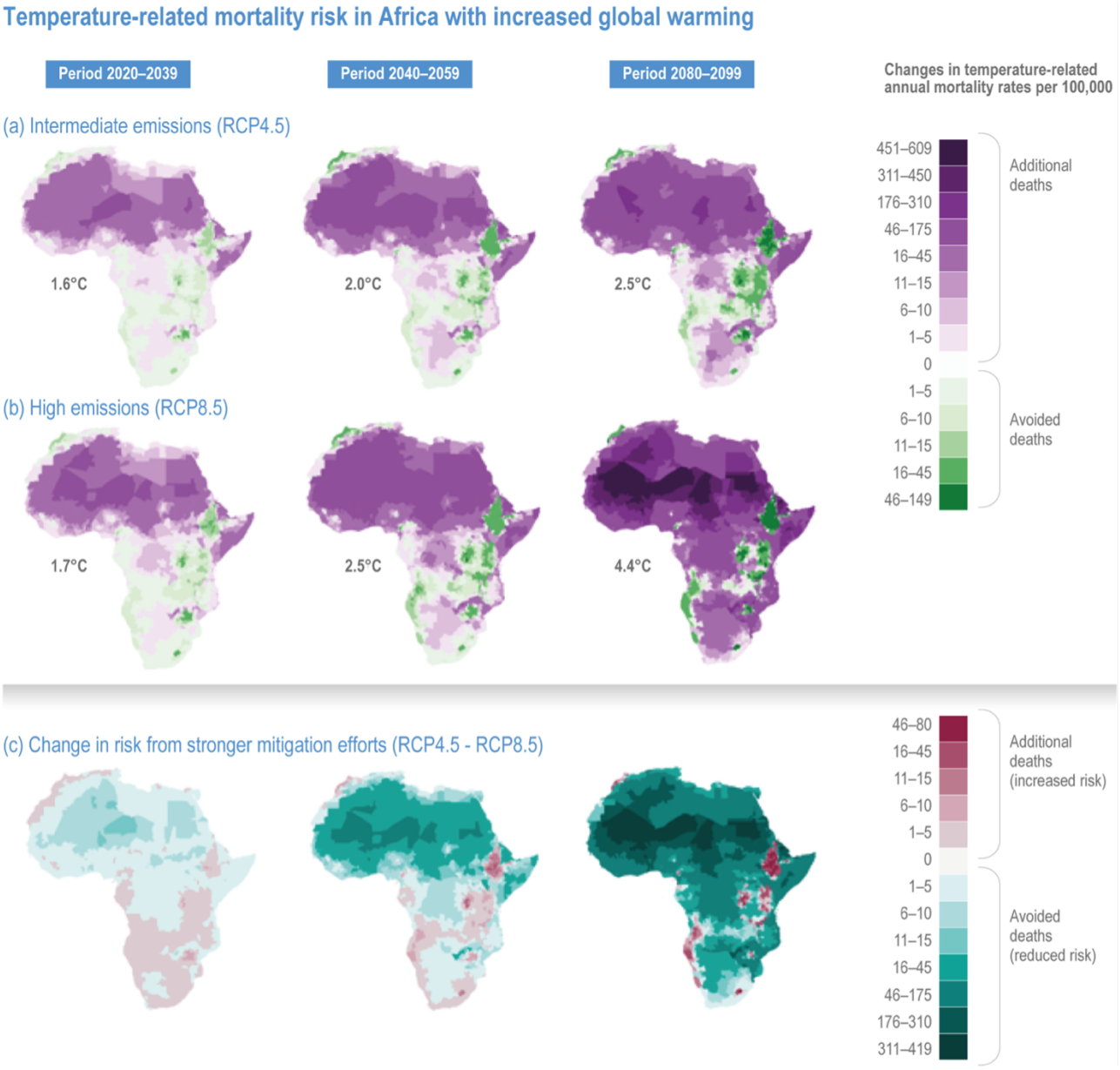


Figure 2.8: Projected temperature-related mortality risks in Africa with increasing global warming, representing changes in mortality rates in deaths per 100 000 for global warming in the years 2020 to 2039, 2040 to 2059 and 2080 to 2099, a) under intermediate emissions scenario (RCP 4.5); b) under high emissions scenario (RCP 8.5); and c) showing avoidable deaths due to increased emissions mitigation efforts to achieve a lower global warming level (RCP4.5 rather than RCP8.5). Source: IPCC (2022)

2.9 SOUTH AFRICAN CONTEXT

South Africa is one country in Africa that has recognised the region's growing heat severity and the high vulnerability of its population due to the country's developing state and the accompanying socio-economic challenges it faces, which puts its people at high risk of heat-related health impacts in the future (Nana *et al*., 2019; Department of Health, 2020). The temperature in South Africa is projected to increase over 5.0°C by the end of the century under "business as usual" high emission scenarios (i.e., RCP 8.5) and up to 1.4°C under "two-degree" low emission scenarios (i.e., RCP 2.6) (Figure 2.9) (World Health Organisation, 2015, p.2). Furthermore, the number of annual heatwave days is projected to increase to over 145 days by the end of the century under high emission scenarios (i.e.,

RCP 8.5) and, on average, about 25 days under low emission scenarios (i.e., RCP 2.6) (Figure 2.9). The rise of the average temperatures and heatwave events will also result in a projected increase in heat-related mortalities in the elderly throughout the country, with up to 116 annual deaths per 100 000 elderly people (i.e., over 65 years) by 2080 under the high emission scenarios and 18 annual deaths under low emission scenarios (World Health Organisation, 2016). The South Africa Weather Service (SAWS) has since identified the risk posed by increasing temperatures and extreme heat events and has provided a South African-specific criterion for heatwaves that can be used to identify and classify incoming periods of heatwave events. The standard criterion reads as "*if the maximum temperature at a particular town is expected to meet or exceed 5°C above the average maximum temperature of "the hottest month" for that particular area, as well as persisting in that mode for 3 days or more, then a heat wave may be declared*" (South African Weather Service, n.d). Additionally, the SAWS has provided a detailed map of the heatwave thresholds throughout the country, where the threshold represents the maximum temperature that needs to be met for a heatwave to be declared (Figure 2.10) (South African Weather Service, n.d).

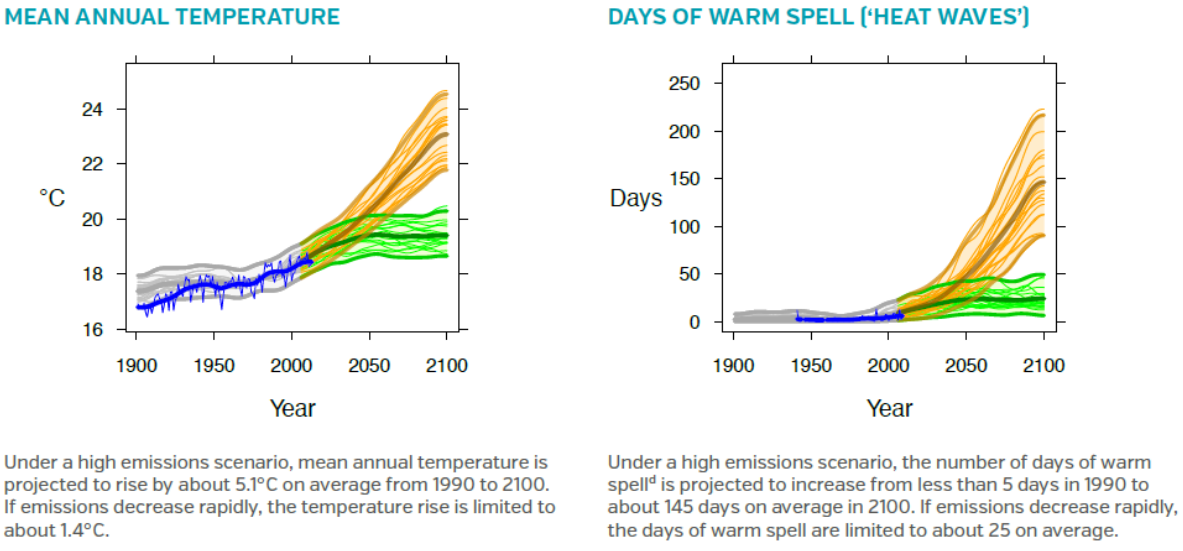


Figure 2.9: Model projections of average annual temperature and the number of days of hot days (i.e., heatwaves) in South Africa under high-emission scenarios (RCP 8.5 – orange) and low-emission scenarios (RCP 2.6 – green). Source: World Health Organisation (2015, p.2)

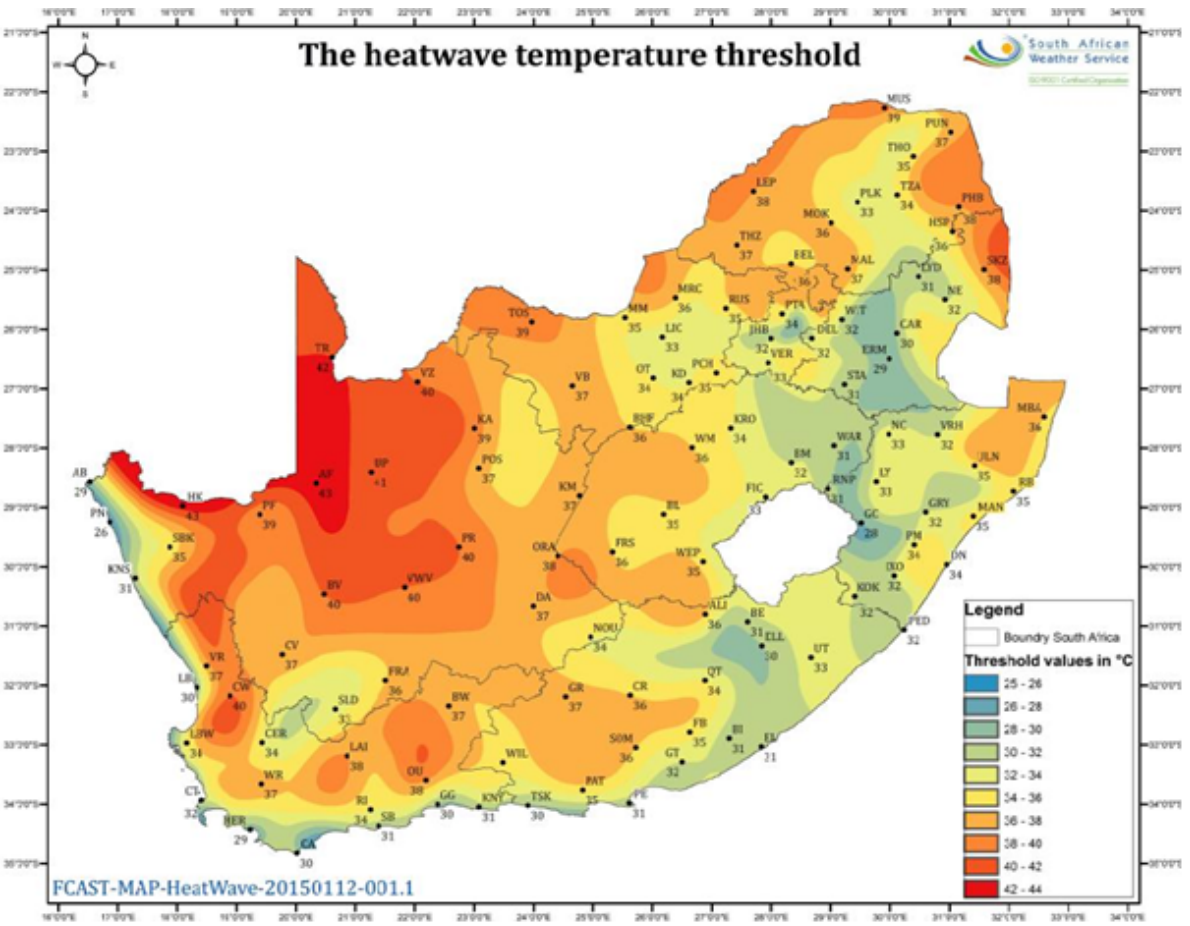


Figure 2.10: Heatwave temperature thresholds across South Africa. Source: South African Weather Service (n.d)

The projected heat extremes and high vulnerability of South African societies have led to the advancement of recent heat-health studies and the impacts of extreme heat and heatwaves on the country, highlighting the extent of increased heat extremes in future climates, the association between temperature and mortalities, identifying heat thresholds for heat warning systems, heat vulnerability assessments and neighbourhood-based heat risk modelling (Garland *et al*., 2015; Wichmann, 2017; Scovronick *et al*., 2018; Jagarnath *et al*., 2020; Mbokodo *et al*., 2020; Kapwata *et al*., 2022; Souverijns *et al*., 2022; Wright *et al*., 2023).

A recent study investigated the projected impacts of climate change on future extreme heat and heatwave events throughout South Africa under both low- and high-emission scenarios (i.e., RCP 4.5 and 8.5, respectively) using the Conformal Cubic Atmospheric Model, where a historical baseline to project future periods of 2010 to 2039, 2040 to 2069 and 2070 to 2099 was used. This study highlighted that maximum temperatures may rise by up to 6°C across the interior of South Africa by the end of the century under high emission scenarios, with an increase in the frequency, duration and intensity of heatwaves throughout all regions in South Africa (Mbokodo *et al*., 2020).

The projected increases in temperature and heatwaves across South Africa have sparked further studies to investigate the association between increasing temperatures and mortality in the country to understand the relationship between these and the thresholds where high temperatures result in significant heat-related mortality. Two studies in South Africa have associated the impact of high temperature and heat extremes with mortality using daily ambient temperatures and all-cause mortality data, highlighting the significance of temperature-related mortality risks and identifying the young and the elderly as particularly vulnerable groups (Figure 2.11). These studies provide significant insights for public health interventions and heat adaptation strategies in the country and the specific regions of the studies, highlighting the potential use of these temperature-mortality thresholds in present-day HHWS (Wichmann, 2017; Scovronick *et al*., 2018).

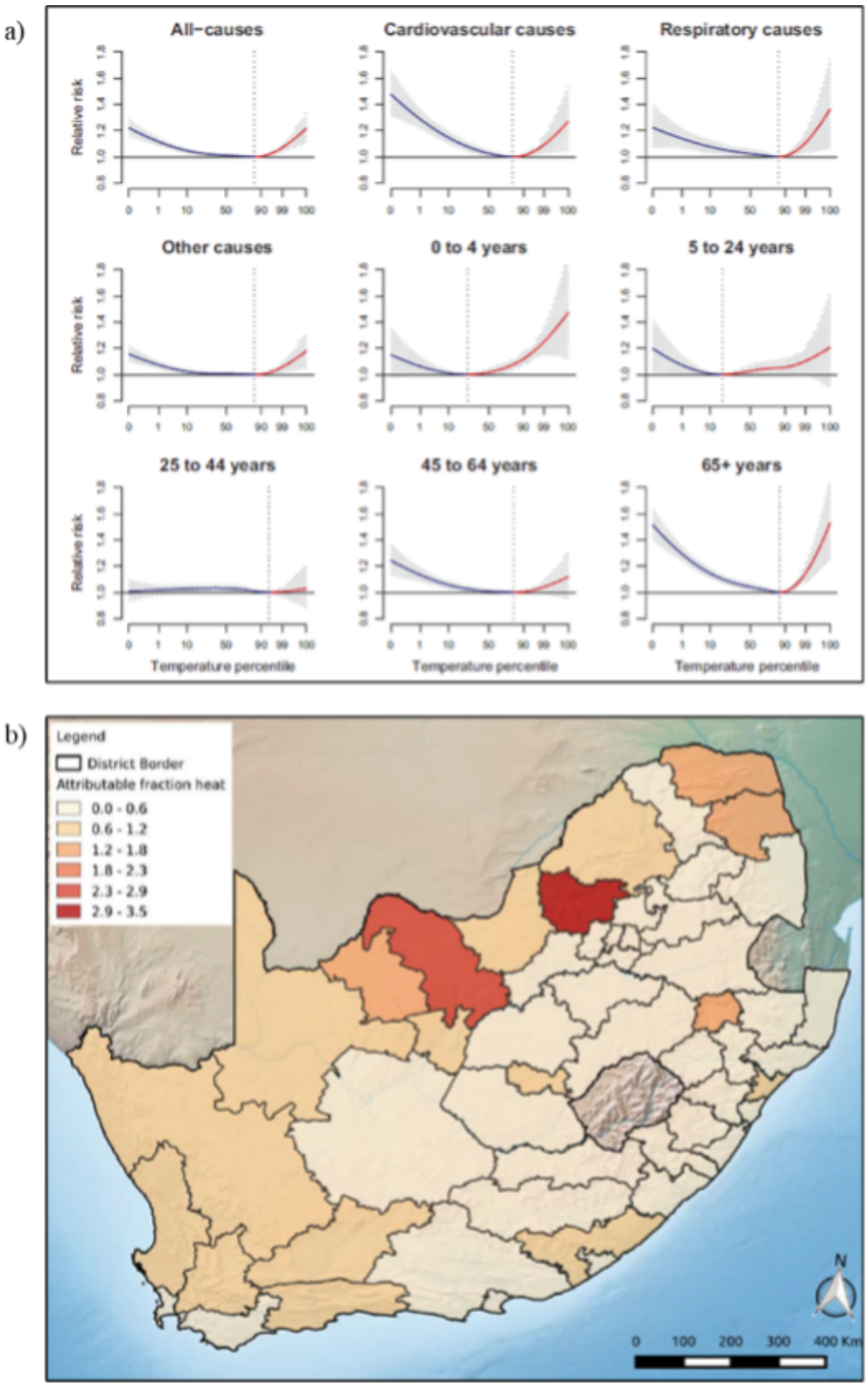


Figure 2.11: Results from the time-series analysis of the association between ambient temperature and mortality in South Africa. a) Overall relative risks of mortality associated with maximum daily temperature over a 21-day lag period for different causes and age groups. The minimum mortality temperature percentile is indicated by the vertical dotted lines; b) The proportion of heat attributable to each municipality. Source: Scovronick et al. (2018)

Before 2022, there was a lack of research on heat-based health thresholds for heat warning systems in South Africa. A recent study, however, quantified heatwave thresholds using temperature-based health impacts for past and future heatwaves (Kapwata *et al*., 2022). This study quantified heat-health thresholds using the diurnal temperature range linked to mortality impacts between 2014 and 2019, using the South African country-specific diurnal temperature range threshold of 12.8°C from Kapwata (2021), at which a significant increase in all-cause mortality was identified, and, as such, should be the threshold for triggering alerts for heat awareness (Kapwata *et al*., 2022). Furthermore, as also highlighted above by the World Health Organisation (2016) and Mbokodo *et al*. (2020), Kapwata (2022) identified that inland regions face shorter, more intense, but less frequent heatwave events, while coastal regions face longer, less intense, but more frequent heatwave events. This study observed that the most recent severe heatwaves across South Africa occurred from late 2015 to early 2016, which was the strongest El Niño event recorded to date, with record-breaking temperatures reported during this period, with the North West Province being the worst affected province in South Africa, experiencing heatwaves lasting between 12 to 77 days, based on the diurnal temperature range heatwave approach of this study. Furthermore, this North West heatwave resulted in significant impacts on the health of the local populations, with many instances of hospitalisations and reported heat stroke deaths during this period. The findings demonstrate that the identification of provinces and regions that experience intense, long-lasting heatwaves is crucial to inform the development and implementation of targeted heat-health adaptation strategies (Kapwata *et al*., 2022). These findings could also guide authorities to prioritise vulnerable population groups, such as the elderly and children living in high-risk areas, more likely to be affected by heatwaves.

The health risks associated with increasing temperatures and extreme heat events in South Africa have driven local studies to identify the heat risks at a more local level and highlight heat exposure, vulnerability and overall risks in these areas. A study conducted in the eThekwini Metropolitan (i.e., Durban) by Jagarnath *et al*. (2020) investigated the current and future heat risk of the City to identify the area's most at risk to future heat impacts by combining heat exposure and social vulnerability indices. The study spatially characterised the heat risks within the metropolitan, where the heat exposure index utilised high-resolution downscaled climate projections under high emission scenarios (i.e., RCP 8.5) using apparent temperature and increases in minimum temperatures, while the social vulnerability index used selected demographic and socio-economic variables to represent the heat vulnerability of the population by way of a Principal Component Analysis (PCA). This was one of the first studies in South Africa to successfully create a spatial map of the heat risks at a ward level (i.e., Level 4 administrative boundary level) within a municipality using both heat exposure and vulnerability aspects of risk functions. This study highlighted the projected increase in future heat

risks, which mainly resulted from the function of social vulnerability of the populations in the area (Figure 2.12). Furthermore, this study presents a heat risk framework that can be used to identify locations for targeted adaptation activities, heat action, and urban planning in other South African cities, which can further assist in addressing climate change adaptation priorities (Jagarnath *et al*., 2020).

Additionally, a recent study from the Rustenburg Local Municipality developed a Health Environment Assessment Tool to assess the heat-health risks in local communities (Wright *et al*., 2023). This study was ultimately used to identify the vulnerable populations and communities in Rustenburg at a ward level using eight indicators relating to heat-health vulnerability, including population type, level of poverty, access to education, access to medical facilities, sanitation and basic services, public transport, recreational/community centres and green spaces. The study demonstrates the importance of developing visual representations of spatial heat-health risks through a vulnerability assessment so that the relevant departments, agencies and authorities are better prepared and able to implement adaptation strategies targeted at these vulnerable populations and communities (Wright *et al*., 2023). Identifying the vulnerable and at-risk populations, like the studies conducted in eThekwini Metropolitan and Rustenburg Local Municipality, offer valuable insights into the populations and areas most susceptible and at-risk to heat-related health impacts, informing adaptation strategies for public health interventions, emergency preparedness, urban planning and aid in policy development (Jagarnath *et al*., 2020; Wright *et al*., 2023).

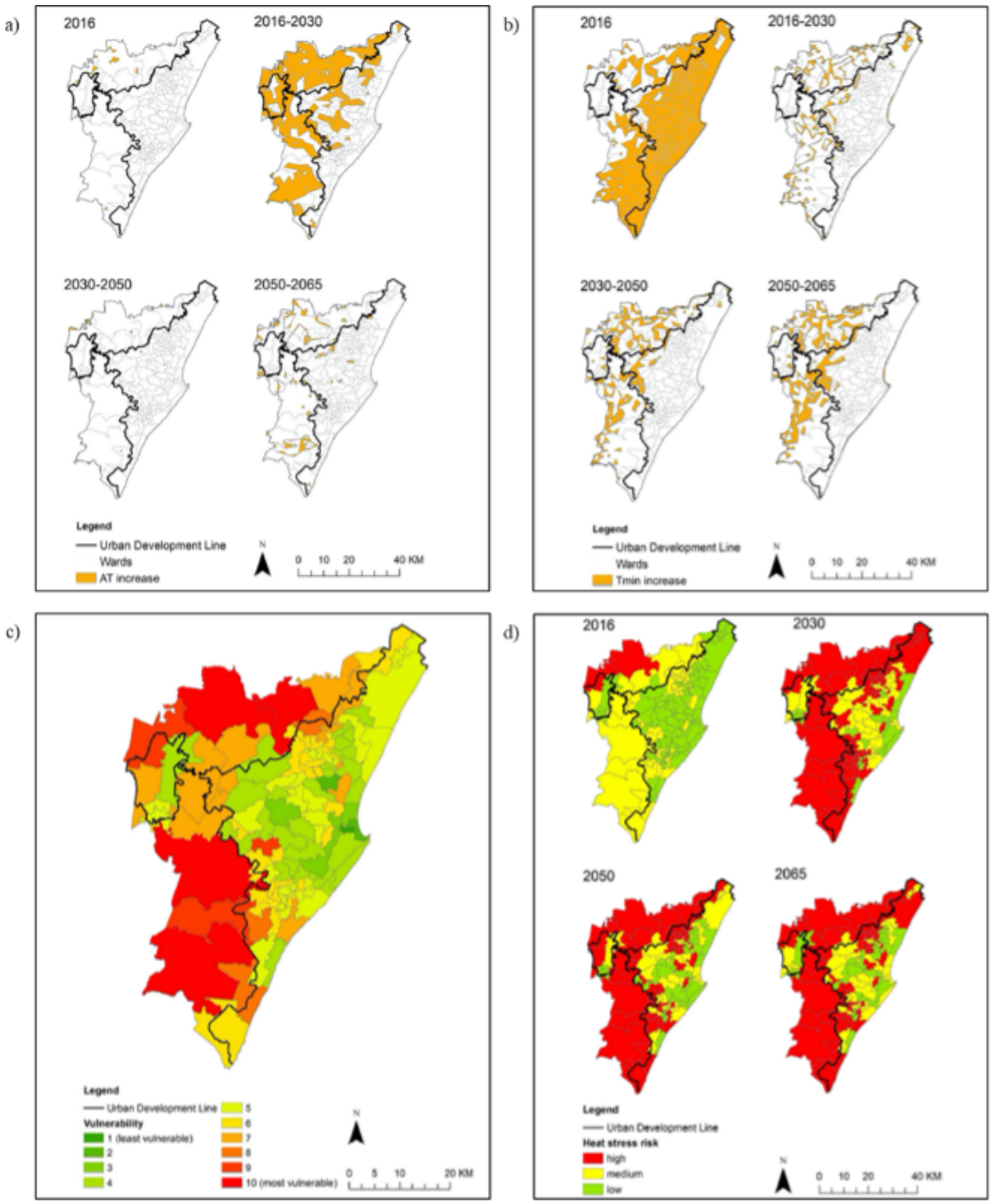


Figure 2.12: Results from the heat stress risk assessment in eThekwini Metropolitan. a) 2016 spatial extent of maximum apparent temperature exceedance and projected increases; b) 2016 spatial extent of minimum temperature exceedance and projected increases; c) Spatial distribution of social vulnerability across the eThekwini metropolitan categorised by ten vulnerability classes; d) 2016 baseline and projected spatial distribution of heat stress risk for the time periods 2030, 2050 and 2065 categorised by low-, medium- and high-risk. Source: Jagarnath et al. (2020)

In the local urban, large-metro context of the current study, within the City of Ekurhuleni and the City of Johannesburg, a recent study by Souverijns *et al*. (2022) used a numerical model (i.e., UrbClim) to simulate urban heat at a high spatial resolution for these two cities. Their study assessed the present and future heat stress throughout the two cities at a 30 m resolution to identify the

temperature projections at a local scale under low- and high-emission scenarios (i.e., RCP 4.5 and 8.5, respectively). This model accounted for the local context and UHI of the cities and highlighted the effects of the UHI on nighttime air temperatures (Figure 2.13, a & b). Additionally, on a finer scale, this study used metred-scale heat stress assessments using Wet Bulb Globe Temperature to simulate a historical heatwave event that occurred across the two cities (i.e., the heatwave of January 2016) for individual neighbourhoods to account for the spatial disparities of heat stress throughout the cities, highlighting the high heat island intensities in the informal townships (Figure 2.13, c) (Souverijns *et al*., 2022).

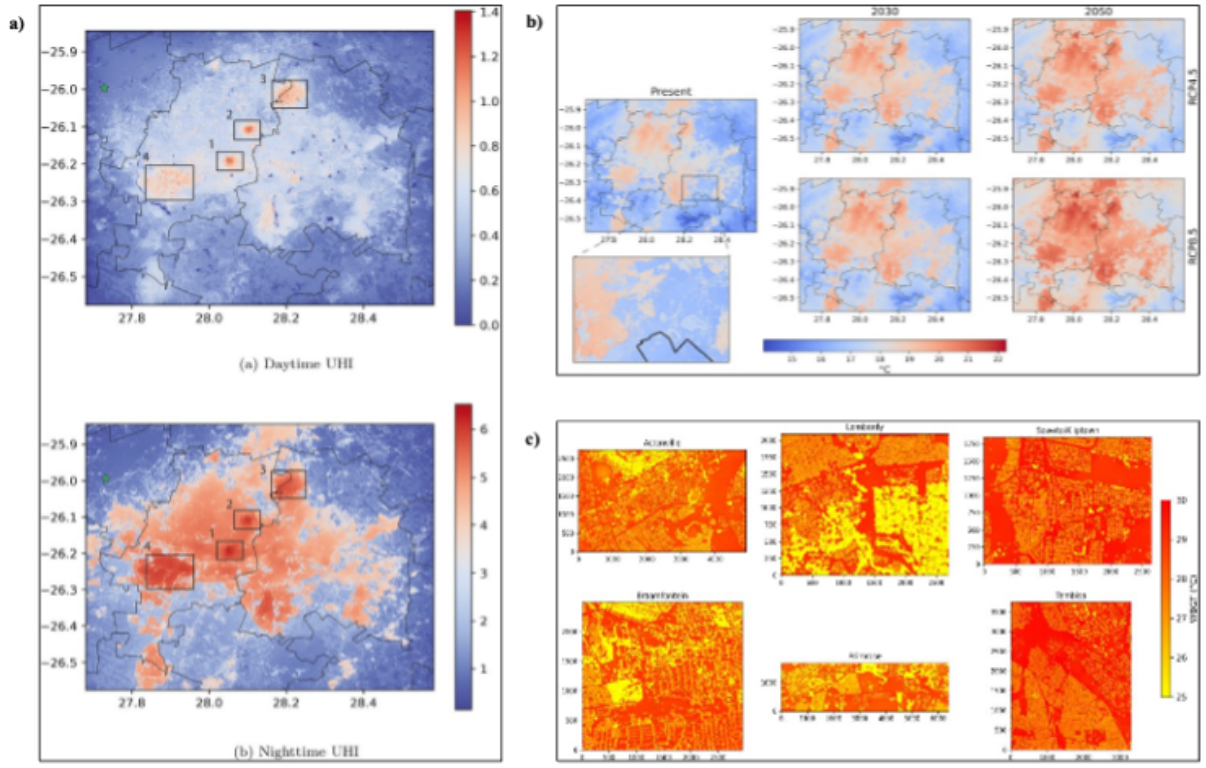


Figure 2.13: Results from the urban heat model and metred-scale assessments in Johannesburg and Ekurhuleni. a) Urban Heat Island corrected for topography in day- and night-time (1 = Central Business District; 2 = Alexandra township; 3 = Tembisa township; 4 = Soweto township; b) Average 2 m temperature for present (i.e., 2001 to 2020) and future projections (i.e., 2030 and 2050) under low- and high-emission scenarios (i.e., RCP 4.5 and 8.5, respectively); c) Heat stress levels simulated for the January 2016 heatwave for six neighbourhoods across Johannesburg (i.e., Lombardy/Alexandra, Braamfontein and Soweto/Kliptown) and Ekurhuleni (i.e., Actionville, Primrose and Tembisa), based on the Wet Bulb Globe Temperature. Source: Souverijns et al. (2022)

Lastly, it is worth noting that, in 2019, the Council for Scientific and Industrial Research (CSIR), in collaboration with the National Disaster Management Centre of South Africa, released an interactive online tool that provides evidence to assist and support local governments with the long-term planning, design and decision-making of climate-resilient settlements throughout the country, known as the Green Book (Van Niekerk *et al*., 2019). The Green Book includes future climate change projections, quantified impacts of climate change exposure for various hazards, vulnerability

assessment frameworks, population growth models, climate risk profiles and a menu of potential adaptation actions for national and local planning. In the context of this dissertation, the Green Book provides an overview of the projected temperature increases and the rise of extreme heat days and heatwaves in the future throughout South Africa at an 8-kilometre resolution and has also provided a comprehensive vulnerability assessment framework at municipal, settlement and neighbourhood levels (Van Niekerk *et al*., 2019a, 2019b). Municipal level vulnerability includes spatial mapping of four separate vulnerability indicators, including socio-economic, physical, economic and environmental, while settlement vulnerability produces a spider diagram comparing settlements within a municipality and has six overall vulnerability indicator categories, including socio-economic, growth pressure, service access, economic, regional economic connectivity and environmental. Lastly, neighbourhood-level vulnerability provides settlement hotspot maps at 500 m resolutions for two vulnerability indicators: socio-economic and settlement fabric (Le Roux *et al.*, 2019a). The vulnerability assessments developed within the Green Book utilised data sources from 1996 to 2016 and although this still offers valuable insights into the vulnerability of local populations, the use of outdated datasets raises questions as to the accuracy and quality of the assessments ((Le Roux *et al.*, 2019a). Furthermore, the Green Book itself has also highlighted some of its limitations due to the vulnerability assessments not addressing the space between settlements, which can result in an incomplete understanding of the overall risk level throughout an area (Van Niekerk *et al*., 2019).

Additionally, in 2021, the CSIR developed an additional tool called the MetroView Climate Risk and Vulnerability Profile Tool, which provides the current and future projections (i.e., 2050) of various climate change impacts, including extreme heat (Council for Scientific and Industrial Research, 2021). The Tool provides a spatial mapping of the climate risk, vulnerability and demographic settings on three levels, including municipal, planning region and ward, which ultimately assists policymakers, decision-makers and local government to make informed decisions about adaptation strategies and climate action responses (Council for Scientific and Industrial Research, 2021). This Tool provides a comprehensive overview of the current and future temperatures (i.e. 2050) (Figure 12.4, a) and the number of hot days under high emission scenarios (i.e., RCP 8.5), while also providing household-level socio-economic vulnerability compiled using four composite variables from the 2018 data, including household (i.e., household size and age dependencies), income (i.e., level of unemployment), education (i.e., literacy rates and level of education) and health (i.e., child mortality and comorbidities) (Figure 2.14, b) (Council for Scientific and Industrial Research, 2021). This MetroView Tool, however, has only effectively been rolled out in three South African cities, including the City of Tshwane, the City of eThekwini and Buffalo City, and, therefore, has limitations in its availability and accessibility for all municipalities in South Africa, specifically the City of

Johannesburg and the City of Ekurhuleni in the context of this dissertation (Council for Scientific and Industrial Research, 2021).

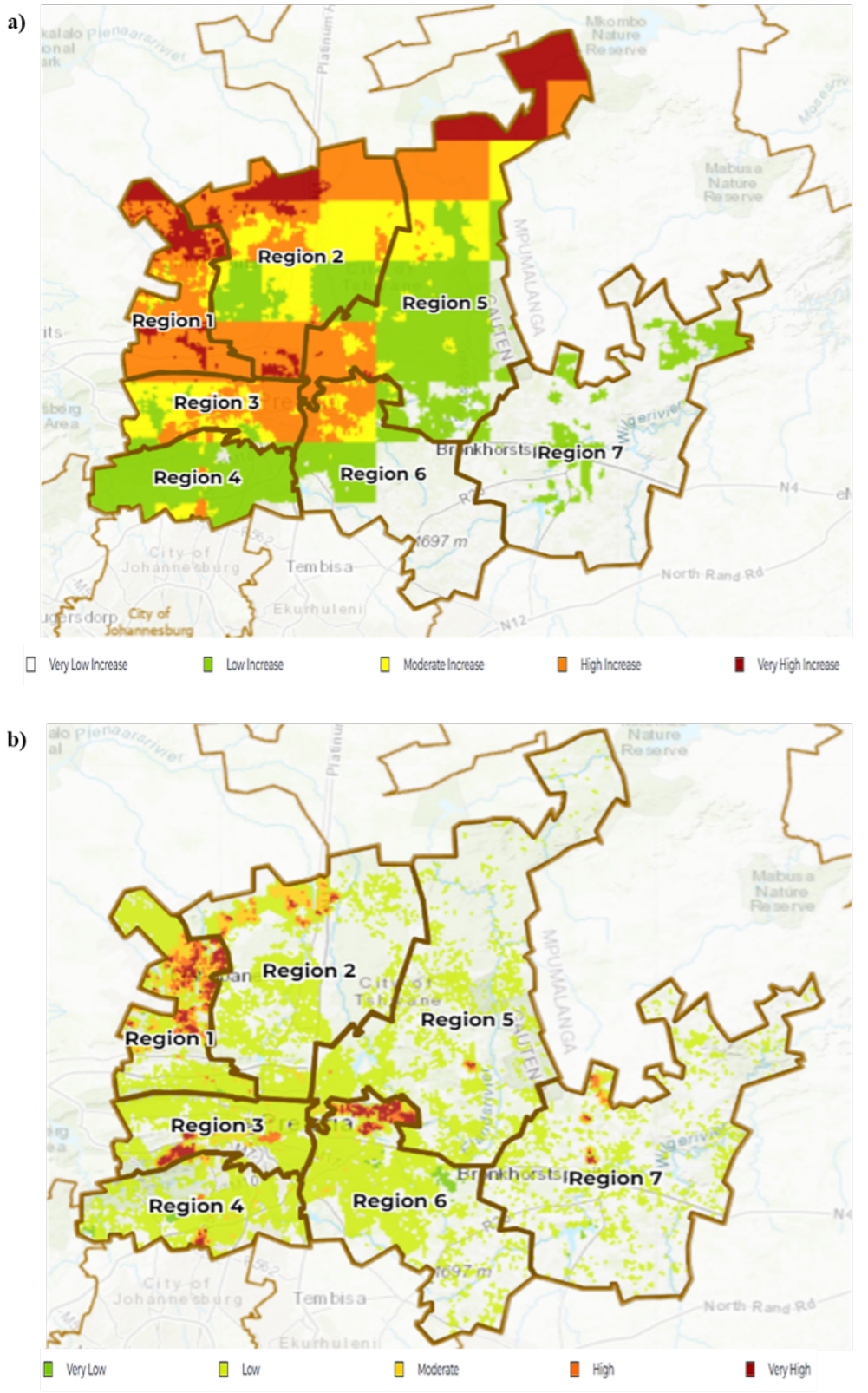


Figure 2.14: Maps of the MetroView Tool in the Green Book for the City of Tshwane. a) Map representing the 2050 projected increase in extreme heat within the City of Tshwane under the RCP 8.5 low mitigation scenario; b) Map representing the current socio-economic vulnerability for the City of Tshwane. Source: Council for Scientific and Industrial Research (2021)

2.10 CLIMATE AND HEAT ACTION GOVERNANCE IN SOUTH AFRICA

South Africa has identified the impacts and risks associated with climate change and has included a framework for addressing these challenges, as was introduced in Chapter 1. The National Climate Change Response Policy White Paper of 2011 (referred to as the Climate Change Response White Paper), the National Climate Change Adaptation Strategy of 2020 (referred to as the Climate Change Adaptation Strategy) and the draft South African Climate Change Bill of 2022 (referred to as the Climate Change Bill) outline the policies and approaches proposed to address climate change in the country. The Climate Change Bill provides the legal framework and legislative measures to "*enable the development of an effective climate change response and a long-term, just transition to a low-carbon and climate-resilient economy and society for South Africa in the context of sustainable development; and to provide for matters connected therewith*" (Republic of South Africa, 2022 p.2). Meanwhile, the Climate Change Response White Paper is a policy document that outlines South Africa's approach to addressing climate change. It describes the country's vision, goals and objectives for combatting climate change in the short, medium and long term extending to 2050, with a key focus on mitigation and adaptation approaches and serves as a roadmap and guideline for municipalities to develop and implement their own climate change policies (Department of Environmental Affairs, 2011). Furthermore, the Climate Change Adaptation Strategy is a more specific and detailed plan that solely focuses on adaptation approaches to combat climate change in the short and medium terms while offering guidance on how to achieve national adaptation goals, integrate climate priorities into development, improve coordination and ultimately fulfil international obligations (i.e., fulfils South Africa's commitment as outlined in the Paris Agreement under the United Nations Framework Convention on Climate Change). It comprises strategic objectives, interventions and outcomes with associated actions, targeting all levels of government, sectors and stakeholders, which covers various topics, such as reducing vulnerabilities and building adaptive capacity, climate risks, adaptation planning and mainstreaming, awareness and education building, governance and legislation, finance, monitoring and evaluating, as well as an implementation framework as how these topics can be addressed (Department of Forestry, Fisheries and the Environment. 2020).

The Climate Change Adaptation Strategy effectively highlights the context of increasing temperature and extreme heat in South Africa, with reference to the increasing temperatures in South Africa throughout the century in low and high mitigation scenarios, as well as the increase in the number of heatwave and hot days (Department of Forestry, Fisheries and the Environment. 2020). Additionally, it highlights the impacts of extreme heat and rising temperatures on the various sectors in South Africa while also identifying the heat stress risks throughout South Africa from the Green Book

(Engelbrecht, 2019), which is based on a combination of projected increases in heatwave and extreme heat days to produce settlement heat stress risks (Figure 2.15). Although this Adaptation Strategy effectively highlights the heat context in South Africa and the affected sectors and communities, it is noted that this strategy does not contain the necessary detail of how adaptation should and will take place in the relevant levels of governments, sectors and other stakeholders (Department of Forestry, Fisheries and the Environment. 2020). Furthermore, the Climate Change Bill and Climate Change Response White Paper do not specifically address or highlight the risks and impacts associated with extreme heat in South Africa. Although not emphasised, the effects of heat on human health and how the physical heat stresses pose particular risks to vulnerable populations, including children, the elderly and socio-economically vulnerable communities (i.e., communities living in poverty) are noted (Department of Environmental Affairs, 2011; Republic of South Africa, 2022). It is argued that South Africa will aim to integrate heat considerations into the health sector to "*design and implement Heat-Health action plans including plans in respect of emergency medical services, improved climate-sensitive disease surveillance and control, safe water and improved sanitation*" (Department of Environmental Affairs, 2011, p.20).

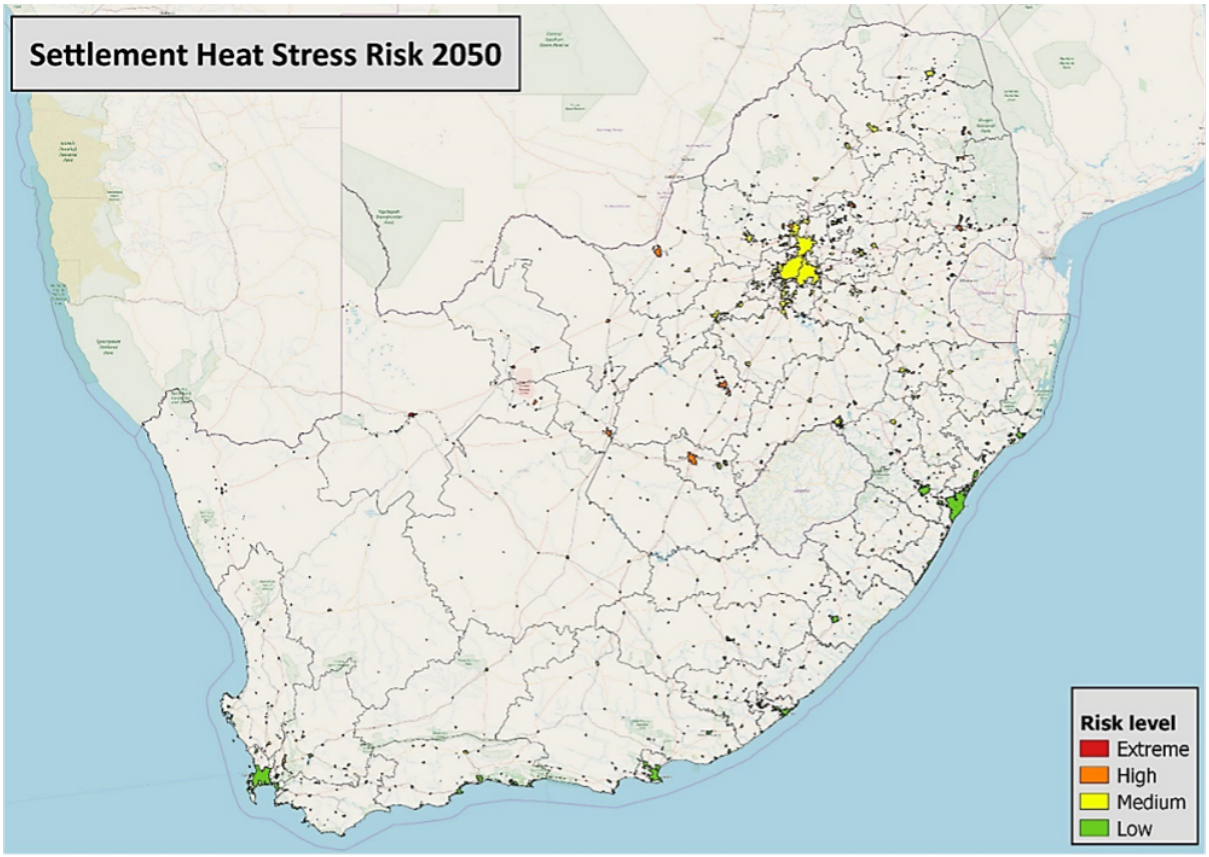


Figure 2.15: The projected impact of climate change on settlements based on a combination of the projected increase in very hot days and heatwave days to create settlement heat stress risk in four risk categories (i.e., low, medium, high or extreme) by Engelbrecht (2019). Source: Department of Forestry, Fisheries and the Environment (2020)

One particular adaptation strategy embedded within the Climate Change Response White Paper that addresses extreme heat and heatwave events is using disaster risk reduction and management approaches (Department of Environmental Affairs, 2011). The White Paper outlines disaster risk reduction and management as "*short-term adaptations to climate change because both address vulnerability to climate change-related impacts. Resilience to climate change-related extreme events, such as heat waves, floods, droughts, wildfires and storm surges, will be the basis for South Africa's future approach to disaster management*" (Department of Environmental Affairs, 2011, p.24). Disaster risk reduction and adaptation approaches address climate-related impacts and the local population's vulnerability and could be particularly useful in building resilience to climate-related extreme weather events like heatwaves. The South African Disaster Management Act 57 of 2002 and the Disaster Management Amendment Act 16 of 2015 provides a comprehensive outline of the roles and responsibilities of the departments, agencies and other key stakeholders involved in disaster management, with a centralised National Disaster Management Centre (NDMC) that coordinates disaster communication, addresses disaster prevention, and mobilises the relevant agencies and departments (Republic of South Africa, 2002, 2015). More effective disaster risk reduction and management, however, are needed to cope with the projected increased number of extreme weather events, such as droughts, flooding, heatwaves, etc., that will put strain on public resources and infrastructure. Furthermore, the Climate Change Response White Paper outlines that South Africa will try to respond to these challenges by improving early warning systems to reach the affected communities, collaborating with neighbouring states to share regional warning systems, promoting the development of vulnerability and risk research centres to support resource-constrained municipalities, maintain and enhance the use of the South African Risk and Vulnerability Atlas as a planning tool for provincial and municipal climate change adaptation, collaborating with social organisations to build a communication network and raise awareness for climate change impacts, and lastly, develop recovery mechanisms post-disaster management (Department of Environmental Affairs, 2011). In general, the Climate Change Bill, the Climate Change Response White Paper and the Climate Change Adaptation Strategy do not provide much in-depth content on the effective strategies and responses to combat extreme heat but instead provide a framework and guidelines to integrate and develop climate action within municipal policies and plans. These generic policies and plans are thus supplemented with specific heat action frameworks for more effective planning and implementation of heat responses in the country.

South Africa has since developed a comprehensive framework and guidance document for addressing the impacts of heat on public health within the National Heat Health Action Guideline of 2020 (referred to as the Heat Health Action Guideline). These guidelines provide a framework for heat

considerations within a national and municipal context and outline the direct and indirect impacts of heat on human health (Department of Health, 2020). In addition, these guidelines provide in-depth heat responses, specifically focusing on "heat health action plans", highlighting coordination and actions between various departments and agencies, including health, emergency management (i.e., disaster management), urban planning and local communities (Department of Health, 2020). The Heat Health Action Guideline has identified seven core elements that are needed to ensure an effective action plan is developed to reduce the health risks associated with extreme heat events: *"(1) Health Sector leadership and coordination of stakeholder inputs; (2) Heat-health Warning Systems; (3) A Heat-health Information Plan; (4) Reduced Exposure to Heat in Indoor Settings; (5) Particular Care for Vulnerable Groups; (6) Preparedness of Health and Social Services; and (7) Monitoring and Evaluation (including real-time surveillance)*" (Department of Health, 2020, pp.16-22). By doing so, the aim is to increase coordination between all stakeholders, develop heat early warning systems, create a heat communication network, reduce indoor heat exposure, identify and target vulnerable populations, build preparedness in healthcare and social services and lastly, monitor and evaluate the plan throughout the implementation process. This guideline serves as an important tool for planning and developing heat responses throughout all South African municipalities, specifically for key decision- and policy-makers, emergency management and healthcare professionals, and the local governments tasked with implementing these actions (Department of Health, 2020).

Overall, the Climate Change Bill, Climate Change Response White Paper, Climate Change Adaptation Strategy and Heat Health Action Guideline have set the landscape for policies and plans to combat extreme heat nationally. This provides South African municipalities with the necessary frameworks and guidelines for developing effective heat responses, enabling local governments to include heat considerations within their planning, budgeting and operational activities.

Since the inception of these policies and response strategies, many municipalities, including the larger metropolitans, have embedded climate change within their local planning and budgeting (South African Cities Network, 2016; City of Ekurhuleni Metropolitan Municipality, 2017; Nana *et al*., 2019; City of Johannesburg, 2021; City of Johannesburg Metropolitan Municipality, 2021; City of Tshwane Metropolitan Municipality, 2021; City of Ekurhuleni Metropolitan Municipality, 2022; City of Tshwane, 2022). Climate change is now a common topic within the IDPs of most South African municipalities, which are developed every five years and guide the city's development in delivering services and serve as an incremental planning tool to achieve long-term goals; in this case, climate change responses (Nana *et al*., 2019; City of Johannesburg Metropolitan Municipality, 2021; City of Tshwane Metropolitan Municipality, 2021; City of Ekurhuleni Metropolitan Municipality, 2022). Furthermore, some metropolitans have also developed localised Climate Change Response Strategies

(CCRSs) and Climate Action Plans (CAPs), highlighting particular focus areas and strategies for climate responses (South African Cities Network, 2016; City of Ekurhuleni Metropolitan Municipality, 2017; Nana *et al*., 2019; City of Johannesburg, 2021; City of Tshwane, 2022). However, despite the adoption of the Climate Change Bill, Climate Change Response White Paper, Climate Change Adaptation Strategy, Heat Health Action Guideline and the integration of climate change risk and adaptive strategies within local municipality IDPs and climate response planning, local governments have not effectively integrated and implemented climate change and heat adaptation strategies into their operational activities (South African Cities Network, 2016; Nana *et al*., 2019). Rising temperatures within South Africa, coupled with thigh vulnerability due to the socio-economic conditions of many populations throughout the country, the ineffective implementation of heat adaptation plans and strategies will leave these South African cities at high risk of increasing frequency, duration and intensity of extreme heat and heatwave events in the future (Department of Environmental Affairs, 2011; IPCC, 2014, 2022; Niang *et al*., 2014; Department of Forestry, Fisheries and the Environment, 2020).

Within the context of heat action in South Africa, specifically the Gauteng Province, a study by Nana *et al*. (2019) examined the heat-health governance process in place, particularly the responses of Environmental Health Managers within the City of Johannesburg's Environmental Health Department, to extreme heat and heatwave events. The study intended to gain an understanding of the level of attention that extreme heat and heatwave events get within the City of Johannesburg's local municipality. Although climate change impacts and risks were already acknowledged within the City's IDPs, as well as the provincial and national policies, it was found that little research had been done to investigate if effective strategies and heatwave adaptations were considered at a local operational level within the City. The study examined the awareness of extreme heat and heatwaves, their risks and impacts among the City's Environmental Health Managers, whether extreme heat and heatwave impacts are considered within Environmental Health planning, how effective implementation is at an operational level, and identifying the challenges and opportunities in developing and implementing a heatwave adaptation plan for the City of Johannesburg within the Environmental Health Department. The study concluded that despite the understanding and awareness of the Environmental Health Managers about current and future extreme heat and heatwave events, heatwave adaptations and planning are not a priority within the Environmental Health Department of Johannesburg due to the inter-related individual, social and institutional settings in which the Environmental Health Managers operate (Figure 2.16). The overall findings and reasons for the lack of heat action in the City of Johannesburg include the individual misconceptions of who is responsible for heat events within the City's Environmental Health Department and the lack of

recognition of the impacts of extreme heat and heatwave events on human health. This lack of recognition is reinforced by the community's perception of extreme heat as not being a serious issue, with the absence of societal pressure placing no demand on heatwave adaptation and planning. Lastly, the institutional and departmental settings demonstrate how climate change impacts are not mandated as priority areas of concern across departments, resulting in a lack of buy-in from higher authorities within the Environmental Health Department, as well as other operational challenges that limit the effectiveness of such heatwave planning (Nana *et al*., 2019).

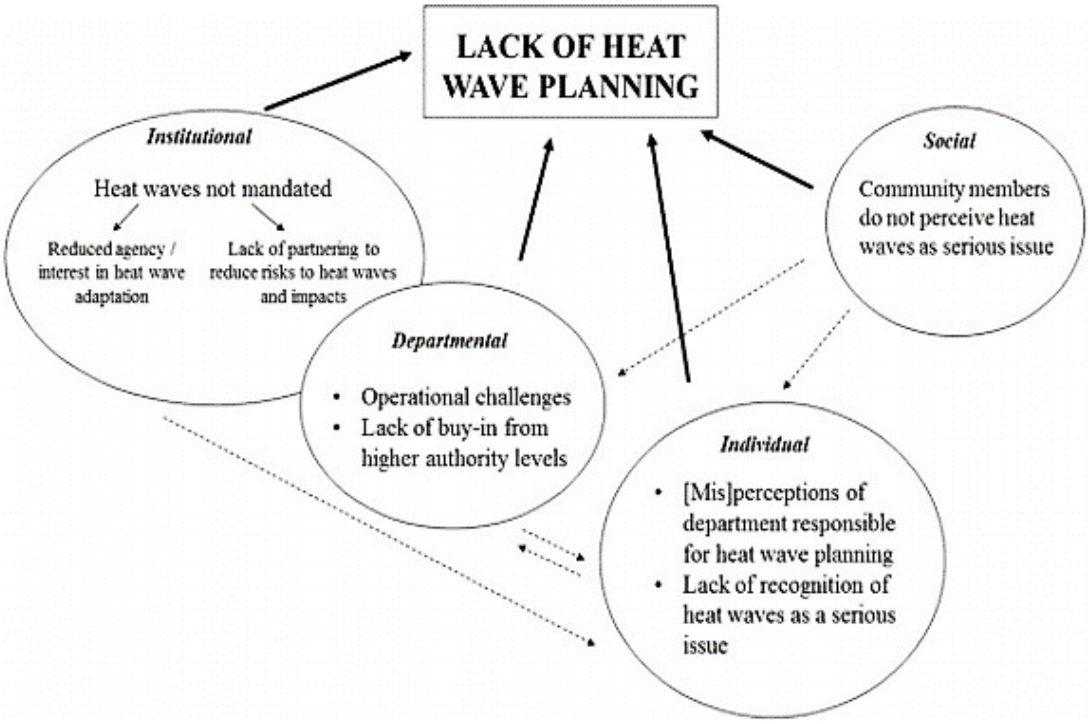


Figure 2.16: Inter-related individual, social and institutional settings of extreme heat and heatwave planning within the Environmental Health Department. Source: Nana et al. (2019)

Nana *et al*. (2019) suggested that information relating to extreme heat and heatwave events, their risks and impacts on human health, as well as precautions to take before and during a heat event, are incorporated within education programmes provided to locally affected communities by the Environmental Health Department. Future research was also proposed to continue the work with the Environmental Health Managers to provide Environmental Health Practitioners (EHPs) with basic extreme heat and heatwave training and to modify the current community health education programmes to incorporate heatwave considerations. Furthermore, it was suggested that close engagement with local communities and the Environmental Health Department is needed to develop and implement a heatwave adaptation plan for the City of Johannesburg, which can ultimately build and support adaptive capacity within the City's vulnerable populations for future extreme heat events and climate change impacts (Nana *et al*., 2019).

2.11 GOVERNANCE AND INSTITUTIONAL DYNAMICS OF CLIMATE ACTION

Similar constraints to those identified by Nana *et al*. (2019), in the case of the City of Johannesburg, have been identified elsewhere in global studies towards climate change adaptation. As mentioned previously (*Chapter 2, Section 2.4, 2.6 & 2.7*), over the last decade, many cities have scaled up and mainstreamed efforts towards climate adaptation with a primary focus on protecting public health (McGregor *et al*., 2015; Nana *et al*., 2019; Caniglia *et al*., 2020; IPCC, 2022; Sheehan *et al*., 2022). Public health could play an essential role in climate adaptation and action; however, incorporating health into planning and decision-making requires collaboration between various governance and institutions. These collaborative efforts are needed across sectors at the local, municipal and national levels, including government departments and agencies, local businesses, community-based organisations (including the local communities) and non-governmental organisations (NGOs) (Bowen & Ebi, 2015; Patz & Thomson, 2018; Macassa *et al*., 2022). Until recently, however, there was limited literature examining health-related adaptation in cities, with little attention being paid towards the public health aspects considered when developing and implementing climate adaptation plans. This has led to recent studies that examined the inclusion of public health aspects in urban and climate adaptation planning and highlighted the lack of inclusion and limited involvement of public health sectors within the preparation and development of climate adaptation plans across major global cities (Macassa *et al*., 2022; Sheehan *et al*., 2022).

In particular, Sheehan *et al*. (2022) reviewed the role of public health within the climate adaptation plans of 22 cities (Austin, Auckland, Baltimore, Barcelona, Boston, Buenos Aires, Calgary, Cape Town, Hong Kong, Kolkata, Las Vegas, Lisbon, London, Paris, Phoenix, Quezon City, Rio de Janeiro, Salt Lake City, San Francisco, Tel Aviv-Yafo, Vancouver and Washington DC) from across the globe to chart the role of public health in five health-related adaptation activities. These five health-related activity areas are "*1) hazard and vulnerability mapping, 2) heat action plans (including early warning systems), 3) other hazard early warning systems (e.g., floods and diseases), 4) preparedness and response actions, and 5) monitoring and surveillance of climate-related health impacts*" (Sheehan *et al*., 2022, p.1). They identified that 90% of the cities' adaptation plans included actions in at least three of the five health-related activity areas, but only 73% of these adaptation plans included involvement and engagement with public health agencies. It was highlighted that the integration of public health within climate adaptation planning remains a goal for the future and is not the current reality, even with the highly health-focused cities reporting limited and modest public health engagement in their climate adaptation plans. Furthermore, public health engagement is the most prevalent across the cities within heat action planning, with a little less prevalence in climate-related health surveillance. This emphasises the significance of public health aspects in heat action

planning and is particularly noteworthy in the context of the current study (Sheehan *et al*., 2022). Lastly, Sheehan *et al*. (2022) suggested several climate-health governance opportunities that could enhance climate adaptation outcomes: "*scaling up public health surveillance to guide and target adaptation planning, expanding public health engagements into vulnerability mapping, mainstreaming heat action plans across global cities, enhancing public health engagement in city preparedness, identifying barriers of health department integration into adaptation planning, and enhancing focus on under-represented cities in low- and middle-income countries, in particular Africa, Asia and Latin America*" (Sheehan *et al*., 2022, p.14).

In addition, and similar to the above-mentioned study, Macassa *et al*. (2022) investigated the public health aspects included within the latest climate adaptation plans, as well as the experiences and perceptions of public health considered by stakeholders in climate adaptation of three coastal cities (Söderhamn in Sweden, Porto in Portugal and Navotas in the Philippines). This study highlighted that the participant stakeholders throughout the three cities were generally aware of the major climate risks associated with their own cities, including extreme temperatures and heat island effects, rising water levels and flooding, landslides, tsunamis, wildfires and air pollution. The participants indicated some level of collaboration across various sectors and institutions during the development of climate adaptation plans, including, to some extent, public health and other health-related sectors. In particular, in Porto, there is a collaboration between city planners, NGOs, businesses and researchers, as well as the inclusion of primary health to better understand the health-related impacts of climate risks. Meanwhile, Navotas synchronised their collaboration with all city stakeholders, including the public health, economic and social sectors, during the development of their adaptation plans. However, it was noted that Söderhamn does not consider the public health sector as part of their climate adaptation efforts, which is mainly the responsibility of the city planners. Furthermore, the study highlighted that only a few public health initiatives and strategies have been embedded in the three cities' climate adaptation plans, with specific mention of water and sanitation to prevent water-borne diseases, as well as providing protection against extreme heat exposure, hence again emphasising the importance of public health aspects within heat action planning, especially significant in the context of the current study. Lastly, it is noteworthy that the participant stakeholders of this study highlighted challenges and barriers during the development and implementation of climate change adaptation within their cities, including the complexity of climate change due to the uncertainty of climate projections and future conditions of the cities, lack of funding and financial constraints limiting climate adaptation activities, lack of knowledge and understanding by local communities and vulnerable groups about the impacts of climate change and the importance of climate adaptation efforts, and ultimately the lack of full collaboration between government

departments and institutions, including the lack of involvement of the public health sector (Macassa *et al*., 2022).

These two international review studies have highlighted the lack of public health involvement and inclusion within climate adaptation planning across major cities throughout the world and have also identified the barriers and potential opportunities for climate-health governance to enhance future climate adaptation outcomes (Macassa *et al*., 2022; Sheehan *et al*., 2022). Furthermore, there have been many other studies that have examined the integration of climate science into public health practices for effective climate change adaptation, with a specific focus on the significant barriers within the public health sector and the actions needed to overcome them. Public health practices are well-suited to address climate-related health challenges due to their reliance on data and evidence to make informed decisions, experience in engaging with multiple sectors and systems beyond the primary healthcare systems and their preparedness and readiness for responding to unexpected events (Wheeler & Watts, 2018). The health-related impacts of climate change are thus challenges that the health sector has already faced and are ideally placed to cope with in the future. The public health sector is thus well-suited to enhance and strengthen the existing core functions to address the heightened previously experienced risks and further develop innovative strategies to address new and unforeseen health concerns. It has been suggested that using already existing prevention classifications of public health practices (i.e., primary, secondary and tertiary prevention) can be very effective when applied to climate change and used as guidelines to integrate public health within climate adaptation. Primary prevention relates to the prevention of diseases and health conditions from occurring and can include the reduction of exposure to climate change impacts. Secondary prevention relates to reducing the impacts diseases can have using treatments to prevent more significant risks in future and involves the avoidance of climate-related health impacts from the given exposure. Lastly, tertiary prevention relates to the reduction of the social and physical impacts of diseases and their symptoms and aims to reduce long-term health impacts (Wheeler & Watts, 2018). Furthermore, beyond just prevention, public health practices can perform other critical functions that essential public health services can be translated into climate change adaptation, as described by the US Department of Health and Human Services (Figure 2.17) (cited in Wheeler & Watts, 2018). Building on these essential services, it has been argued that there are seven key principles that characterise an effective approach when integrating public health responses within climate adaptation (Frumkin *et al.*, 2015; Wheeler & Watts, 2018): (i) a robust health system able to deliver essential health services to all populations, (ii) a clear understanding of environmental hazards, (iii) all-hazard preparedness ensuring that the health system can cope with all climate hazards, (iv) enhancing resilience to build strong systems and communities that can cope with many unprecedented changes,

(v) maximising potential co-benefits, (vi) robust interdepartmental and sectoral relationships in responding to climate change impacts, and lastly, (vii) adaptive management focused on constant institutional evaluation and improvements (Frumkin *et al.*, 2015; Wheeler & Watts, 2018).

Public health service	Translation to climate change adaptation
1. Monitor health status to identify community health problems	Surveillance for environmental risks, vulnerability and disease
2. Diagnose and investigate health problems and health hazards in the community	Vulnerability assessments and health impact assessments
3. Inform, educate and empower people about health issues	Public health communication about climate change
4. Mobilise community partnerships to identify and solve health problems	Interdisciplinary and inter-sectoral collaboration among stakeholders
5. Develop policies and plans that support individual and community health efforts	Climate-related event preparedness planning and mitigation policies maximising health co-benefits
6. Enforce laws and regulations that protect health and ensure safety	Legislation to require enhanced building code and regulations to respond to extreme weather events
7. Link people to needed personal health services	Personalised early-warning systems for patients with climate-sensitive health problems
8. Ensure presence of a competent public health and personal healthcare workforce	Training of health professionals about climate change and its health impacts
9. Evaluate effectiveness, accessibility and quality of personal and population-based health services	Evaluate preparedness plans, health communications strategies and other initiatives
10. Conduct research to attain new insights and innovative solutions to health problems	Research to provide data-based support for public health action on climate change

Figure 2.17: Ten essential public health services, described by the US Department of Health and Human Services, and their practical translation into climate change adaptation. Source: Wheeler & Watts (2018)

Notwithstanding the need for the various principles and actions that have been called for, as well as their crucial role in successfully integrating public health within climate adaptation plans; there are several barriers and limiting factors that hinder the ability of governance and institutions to effectively integrate the two. Health systems do not always have the necessary financial and organisational capacity to incorporate the above-mentioned key principles to ensure effective climate adaptation, especially within low- and middle-income contexts that are often faced with many daily challenges for the delivery of basic health services (Wheeler & Watts, 2018). Similar to that of Nana *et al*. (2019), four main barriers have been broadly defined that limit the ability of governance and institutions to effectively integrate public health into climate adaptation: (i) financial barriers, which are associated with the limited access to financial resources and a lack of funding preventing the initiation of adaptation strategies, (ii) informational barriers resulting in difficulties and hindering long-term planning due to climate modelling and analysis with health impacts being extremely resource intensive and not always available, (iii) institutional barriers limiting governmental and departmental abilities to understand and make the correct decisions when responding to changes, and lastly, (iv) social barriers can arise from the values and cultures within organisations and local communities. These barriers also interact with the broader societal challenges within low- and middle-income

countries, such as high levels of poverty increasing the vulnerability of the populations, weak social institutions and the prioritisation of other more pressing issues. Due to the complex and uncertain nature of climate change and public health, overcoming these barriers cannot arguably follow a linear approach; instead, more flexible and iterative approaches that account for unforeseen challenges are needed. Ultimately, mainstreaming climate change adaptation as a core function within public health practices provides an effective method to overcome many of these barriers to adaptation planning and implementation (Wheeler & Watts, 2018).

While mainstreaming climate change adaptation within public health practices may be an effective method for improved adaptation planning and implementation, this too poses some challenges. Recently, Rogers *et al*. (2023) reviewed 131 research articles from 2005 to 2020 to identify the trends and factors in global literature that explain the mainstreaming of climate change adaptation from municipal policy to implementation, as well as the challenges and opportunities hindering and advancing climate change adaptation mainstreaming. Firstly, of the 131 articles reviewed, 112 (85%) identified a range of barriers to municipal climate change adaptation (Figure 2.18, a). Secondly, 112 (85%) articles explored a range of enablers and drivers of municipal climate change adaptation (Figure 2.18, b). Overall, the study highlighted two overarching themes that affect the outcomes of mainstreaming climate change adaptation into implementation, both the barriers and the enablers: "*Authority to Adapt*" and "*Capacity to Adapt*" (Rogers *et al*., 2023. pp.11-14). The former refers to the authority environment and mandate at the national, municipal and or local level, which affects decision-making about the extent of local implementation of adaptation actions. Meanwhile, the latter refers to access to resources, professional networks and supportive organisational systems that enable local government adaptation. Lastly, only 30 (23%) of 131 articles referenced the policy-implementation gap and highlighted six key factors that hinder local government efforts to move from adaptation policy and planning to implementation (Figure 2.18, c) (Rogers *et al*., 2023).

a)

Position	Top 10 most frequently identified barriers	Count*	Type of barrier
1	Lack of political support (will & commitment)	86	Inadequate authority to adapt
2	Limited access to funding	72	Resourcing constraints
3	Not an immediate priority for a municipal administration	50	Organizational (cultural & structural) barriers
4	Data availability	45	Information & knowledge barriers
5	Siloed thinking and planning in a municipal administration	44	Organizational (cultural & structural) barriers
6	Municipal staff expertise *(equal 6th position)*	36	Information & knowledge barriers
6	Divergent priorities between municipal administrative units *(equal 6th position)*	36	Organizational (cultural & structural) barriers
7	A lack of community support for municipal adaptation	34	Inadequate authority to adapt
8	Unclear roles and responsibilities for local government concerning adaptation	33	Inadequate authority to adapt
9	Not knowing how to work with uncertainty in the climate science	31	Information & knowledge barriers
10	Absence of Federal/State leadership in adaptation	27	Other

b)

Position	Top 10 most frequently identified enablers	Count*	Type of enabler
1	Emphasizing co-benefits and synergies for enhanced salience	54	Information, knowledge, and communications
2	Collaborative (non-siloed) culture in a municipal administration	52	Organizational culture
3	Support of municipal elected leaders	49	Authority to adapt
4	Presence of an 'adaptation champion'	47	Authority to adapt
5	External funding	46	Enhanced access to funding
6	Active adaptation communication and scenario planning (or similar) with community	39	Information, knowledge, and communications
7	Presence of a triggering event(s)	38	Other enablers or motivators
8	External support and collaboration (broadly – articles did not elaborate)	32	Professional networks and external collaboration
8	Using substitute frames for climate change *(equal 8th position)*	32	Information, knowledge, and communications
9	Access to external expertise	30	Information, knowledge, and communications
9	Statutory requirement to adapt *(equal 9th position)*	30	Authority to adapt
9	Regional collaboration *(equal 9th position)*	30	Professional networks and external collaboration
10	Community expectation to act	29	Authority to adapt

c)

Position	Factor	Count**
1	No accountability for implementation	17
2	Simplistic language of municipal adaptation policies or plans	11
3	Insufficient understanding in a municipal council of adaptation (implementation) pathways	9
4	No resources allocated beyond adaptation planning	8
5	Competing priorities and competing policy agendas within a municipal council	7
6	Insufficient focus on the relational aspects of adaptation	5

Figure 2.18: The barriers and enablers to municipal climate change adaptation identified by Rogers et al. (2023). a) Top ten most frequently identified barriers to municipal climate change adaptation, b) Top ten most frequently identified enablers of municipal climate change adaptation, c) Key factors impeding the implementation of municipal adaptation policies and plans. Source: Rogers et al. (2023)

Specifically, within the South African context, there is limited literature on mainstreaming climate change within municipal planning instruments, like that of the IDPs. A few studies have, however, investigated the extent to which climate change strategies are embedded within the plans and IDPs of South African municipalities, specifically in Limpopo, the Eastern Cape and the Western Cape Provinces, but is somewhat lacking within the context of the Gauteng Province (Lethoko, 2016; Santhia *et al*., 2018; Pieterse *et al*., 2021). These studies highlighted the lack of effective adaptation and mitigation strategies embedded within the IDPs of the municipalities under review. These municipalities have not yet fully institutionalised and mainstreamed climate action into daily

operations, planning and decision-making. Although these municipalities recognise the impacts of climate change in urban areas and vulnerable communities, as well as the role of planning in response to these impacts, systemic and institutional approaches to addressing the long-term impacts of climate change are not well-reflected. The need for local climate change adaptation and mitigation plans to be reflected in the municipal IDPs and other planning instruments for better budgeting, planning and decision-making for climate change in the future is emphasised (Lethoko, 2016; Santhia *et al*., 2018; Pieterse *et al*., 2021).

The current study focused the lens on institutionalising and mainstreaming heat action within three Gauteng metropolitans, with a specific focus on advancing the responses of local governments to heat-related health impacts. Local and global guidance as to how heat action can be embedded within governance and institutional structures with a primary focus on public health aspects is well-documented (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; McGregor, 2017; Casanueva *et al*., 2019; Singh *et al*., 2019; Department of Health, 2020; World Health Organisation, 2021). These guides provide the necessary information and recommendations for the technical aspects of municipal and local government structures. According to the World Health Organisation and other notable global guidelines (McGregor *et al*., 2015; McGregor, 2017; Singh *et al*., 2019; Department of Health, 2020; World Health Organisation, 2021), these heat action planning aspects incorporate nine core elements:

1) Identifying the heat hazard and the impacts of heat on health;
2) Identifying a lead agency and partners in response to heat, typically led by public health;
3) Developing and integrating HHWSs within institutional structures, such as real-time weather and climate forecasts;
4) Developing a city- and local-level Heat-Health Information Plan communicating heat risks;
5) Preparedness for an incoming heat event in public health and social settings;
6) Developing strategies to reduce heat exposure;
7) Identifying and targeted care for vulnerable groups;
8) Long-term urban planning that reduces heat risks;
9) Evaluating and learning from past heatwaves and the effectiveness of heat health plans.

Ultimately, combining these aspects into an integrated guide speaks to the development and implementation of city-level heat-health action plans, which support a systematic and comprehensive public health response that consists of a portfolio of actions, as mentioned above, at different levels (World Health Organisation, n.d.). The process of heat-health action plans brings together stakeholders from multiple departments and sectors within an integrated planning strategy, including all relevant departments, agencies, NGOs, community-based organisations, vulnerable populations and local communities involved (McGregor *et al*., 2015; McGregor, 2017; Singh *et al*., 2019;

Department of Health, 2020; World Health Organisation, 2021). Furthermore, many case studies from around the world highlight effective urban heat strategies, both within a developed and developing country context, and include strategies from a simple, early warning system and public health information campaigns to more integrated and systematic climate-sensitive urban planning and heat action plans (McGregor *et al*., 2015; Public Health England, 2015; Ahmedabad Municipal Corporation, 2013, 2016; McGregor, 2017; Singh *et al*., 2019; World Health Organisation, 2021).

Managing heat risks, however, within highly populated and vulnerable cities requires inter-departmental and -sectoral collaboration. A mandate for heat action to reduce heat-related health impacts does not sit within any traditional sector or government department and needs various stakeholders to be involved. Various government departments and agencies can play a critical role in reducing heat risks at a city level and in the effective implementation of heat-health plans, including health departments, disasters and emergency management departments, weather and other meteorological forecasting agencies and city planners (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021).

The health departments ensure the preparedness and capacity building of health systems for periods of extreme heat, including upgrading physical infrastructure like hospitals, clinics and informal healthcare units, providing access to the necessary medical equipment and medication to treat patients, and training doctors, nurses and community healthcare workers on the effects, symptoms and treatments for heat-related health illnesses (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). Furthermore, the health department has been suggested to assist in the development of extreme heat and heatwave thresholds based on the association of health-related impacts of increased temperatures (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). In the context of South Africa and specifically relevant in the context of this dissertation, the Heat Health Action Guideline has tasked the health sector as the lead agency within the heat health action plans at all government levels (i.e., national, provincial and municipal). The health sector has thus been suggested to lead the coordination and collaboration across the different departments, stakeholders and institutions. In particular, within the Department of Health, the Environmental Health Department will be the key role player in leading the heat health action plan, with EHPs responsible for shaping local strategies aimed at supporting vulnerable populations to reduce extreme heat exposure. EHPs are at the interface between government and communities and are well placed with first-hand community engagement to implement heat adaptation and mitigation strategies (Department of Health, 2020).

The disaster and emergency departments are also crucial for planning for heatwave events and form part of the lead agencies within heatwave responses (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). Local emergency services, with aid from national emergency systems and community-based organisations, play a fundamental role in providing support to the local populations during extreme heat events by ensuring alerts and warnings reach the necessary populations most at risk and vulnerable to heat-related health impacts, supporting the operations of cooling centres and the overall support of response coordination (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). In the context of South Africa, the Heat Health Action Guideline has tasked the Disaster and Emergency Management Departments, along with the Department of Health, to lead the heat health action plans. As described within the Heat Health Action Guideline, many of the approaches to planning for and responding to heatwaves draw on principles of disaster management (Department of Health, 2020). Furthermore, the South African Disaster Management Amendment Act 16 of 2015 states that the Disaster Management Department aims to "*provide measures to reduce the risk of disaster through adaptation to climate change and developing of early warning mechanisms*" (Republic of South Africa, 2015, p.2). The Disaster Management Department thus plays an essential role in the development and execution of heat health action plans, including risk assessment, early warning, coordination, public awareness, infrastructure assessment, emergency response and continuous improvement to protect communities from the adverse effects of extreme heat events (Department of Health, 2020).

The weather and meteorological agencies also play an integral role in developing and issuing real-time extreme heat forecasts, which provides the basis on which heat warning systems are developed to alert the relevant departments and public on the anticipated heat risks and incoming period of extreme heat. Furthermore, they can assist not only in the development of extreme heat and heatwave thresholds based on temperature extremes but have also been suggested to assist in interpreting climate projections to inform urban planners (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). According to the South African Heat Health Action Guideline, SAWS is responsible for the issuance of alerts and warnings regarding heatwaves based on a "*Discomfort Advisory*" system that takes temperature, humidity and other weather variables into account (Department of Health, 2020, p.17). Furthermore, as previously mentioned (*Chapter 2, Section 2.8*), SAWS has already identified specific heatwave thresholds for each of the country's weather stations (Figure 2.10) (Department of Health, 2020; South African Weather Service, n.d.). As described in the Heat Health Action Guideline, when forecasted weather exceeds the stipulated thresholds for heatwave warnings, a set of actions are triggered, including alert messages that are shared with decision-makers at different levels of government, as well as the media, public and other stakeholders,

using the SAWS website and email and SMS platforms. These thresholds could include various levels of warning categories, which can be used to differentiate between (i) 'stressful' heat levels, (ii) temperature levels that may be dangerous to health, and (iii) the highest-level alarm (Department of Health, 2020).

Finally, urban planning departments play a crucial role in retrofitting and designing heat exposure reduction strategies in urban spaces, which include increasing green spaces, identifying community facilities and locations for cooling centres during periods of extreme heat, identifying and implementing cooling strategies particularly in vulnerable communities within low-cost dwellings and reducing heat exposure in indoor and outdoor public spaces (McGregor *et al*., 2015; Casanueva *et al*., 2019; Singh *et al*., 2019; Abrar *et al*., 2022). The South African Heat Health Action Guideline specifically mention the need for heat adaptation plans to focus on improving urban planning, including housing constructions and reducing UHI effects and indoor heat exposure through climate-smart urban planning. Furthermore, urban planners have been tasked to provide heat interventions for cooling public spaces, increase green spaces and increase access to water (Department of Health, 2020).

Moreover, beyond these four fundamental government departments, other departments play significant roles in supporting and managing other heat risks, including (i) environmental management departments to assist urban panners in developing urban green spaces, (ii) social service departments to assist in identifying the most at risk and vulnerable populations, (iii) education departments to ensure schools build awareness and educate children on the impacts, symptoms and treatments of heat-related illnesses, as well as ensuring schools are a safe environment for children during extreme heat events, (iv) communication departments to develop public messages and information that reaches local communities, (v) occupational and labour departments to work with the private sector to ensure occupational health and safety of workers, (vi) treasury and finance departments to budget for heat action implementation, (vii) service delivery departments to assist in response strategies and delivery of services during periods of increased demand, and lastly, (viii) higher political authorities like mayoral offices to ensure local political leadership and involvement during extreme heat events (McGregor *et al*., 2015; Singh *et al*., 2019; Department of Health, 2020; World Health Organisation, 2021;). In addition to the collaboration and cooperation between various internal government departments, collaboration and involvement among other external partners and agencies has proven key to successful heat health action plans in the past (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). These potential external stakeholders include media outlets, healthcare professionals and emergency health workers, community-based and non-governmental organisations, city residents and local communities, care centres, private sector

partners, NGOs, academic and research institutions, community and public centres and lastly, civil protection societies (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021).

Media outlets assist in delivering early warning messages to the public and can work closely with the SAWS to develop a communication network that is triggered by temperature thresholds and communicated via various media channels, including radio, newspaper, social media and SMS, among others (McGregor *et al*., 2015; Singh *et al*., 2019; Department of Health, 2020; World Health Organisation, 2021). Healthcare and emergency workers in clinics, hospitals and local communities are on the frontline for the identification, prevention and treatment of heat-related illnesses and are responsible for reporting on these heat-related impacts to assist in monitoring and evaluating the extent and impact of the heat event (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). As described in the South African Heat Health Action Guideline, an operational plan needs to set out the specific procedures that clinics and hospitals should take before and during periods of extreme heat. Health workers would also require training on how to prevent the impacts of heat and to recognise and treat patients with heat-related illnesses, such as heat exhaustion or stroke (Department of Health, 2020). Community-based organisations and NGOs can assist in providing social services to vulnerable populations and have shown to be extremely successful in disaster response actions (Singh *et al*., 2019). Furthermore, these organisations can lead public awareness to mobilise resources and disaster management responses, the development of relief programmes and advocating for policy changes (McGregor *et al*., 2015; Singh *et al*., 2019; Department of Health, 2020; World Health Organisation, 2021). Local communities and city residents are the ones who are best placed to assist and support heat exposure prevention and responses by ensuring they actively participate in and contribute to heat preparedness and response efforts, as well as adjusting their behaviours to protect themselves and their communities from heat exposure during extreme heat events (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). Care centres play a key role in providing safe shelter, health monitoring, hydration, medication management, education, emergency response, transportation services and family support to vulnerable individuals, including infants, children, the elderly and the disabled, during extreme heat events. As previously mentioned, the private sector can assist in developing safety measures and regulatory restrictions to protect workers and staff from increased heat exposure, as well as building public-private partnerships to leverage private sector resources for public use during extreme heat events (e.g., private air-conditioned buildings used as cooling centres) (McGregor *et al*., 2015; Singh *et al*., 2019; Department of Health, 2020; World Health Organisation, 2021). Academic and research institutions play fundamental roles in providing evidence-based research based on heat-related mortality and morbidity, tracking health impacts during heatwaves and facilitating data-driven decision-making.

These institutions could assist healthcare workers and authorities in better understanding the health effects of extreme heat, identifying vulnerable populations, allocating resources effectively, and improving public health interventions to reduce heat-related morbidities and mortalities (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). Furthermore, the South African Heat Health Action Guideline has identified the South African Medical Research Council, the CSIR, and institutions of higher learning (i.e., universities) as key academic and research institutions (Department of Health, 2020). Community and public centres could act as cooling centres during periods of extreme heat by ensuring they are retrofitted with cooling technologies and are open to the public while specifically targeting vulnerable populations. Lastly, civil protection societies have been suggested to be key partners in high-impact heat events, supporting the most vulnerable populations and managing emergency response strategies. Furthermore, civil society could advocate for the adoption and implementation of heat action plans on the local, regional and national levels, ensuring that these plans are well-funded, comprehensive and integrated into broader climate resilience strategies (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021).

To ensure successful coordination and collaboration within an integrated inter-departmental and -sectoral heat health action plan, all partners must have a shared vision of what they want to achieve, as well as clear objectives outlined per partner towards achieving this. It is thus fundamental to identify and clearly outline the roles and responsibilities of each partner in the process, where each role player understands what they have to achieve and the means to achieve this. An example of the key skills and roles of each role player within a heat-health action planning team is outlined in Figure 2.19. Furthermore, the decision-making process, as well as the conflict resolution measures, must be clearly outlined, with continuous communication channels between all stakeholders clearly defined to ensure constant engagement and communication about the progress and potential improvement of the heat action plan. Lastly, to ensure all the necessary skills and roles are filled at a local implementation level, it may be necessary to involve provincial and national resources and stakeholders to fill any gaps in the process (Singh *et al*., 2019).

ROLES	SKILLS	DEPARTMENTS AND PARTNERS
Developing a heat action plan	Partnership building, coordination, technical specialties, vulnerability analysis	All lead departments
Developing and issuing heat early warnings	Meteorology and public health	National meteorological service, department of health
Leading emergency response	Emergency management	Emergency management department, Red Cross Red Crescent branches
Liaising with the media	Mass communications	Central communications and the mayor's office
Liaising with city residents	Behaviour change communication, community engagement, partnership building	Social services, emergency management, community-based organizations, faith-based organizations
Strengthening health systems	Public health	Health department
Mainstreaming heat into city planning	Climate risk management, urban planning	City planning
Documenting learning	Adult learning, monitoring and evaluation	All lead departments

Figure 2.19: An example of the skills and roles critical within an integrated heat action planning team, indicating relevant partners. Source: Singh et al. (2019)

Preparing a city to reduce the impact of extreme heat is a crucial step towards decreasing climate-related fatalities. This requires a combination of long-term and seasonal, short-term planning. To ensure, however, that this effort is sustained, sufficient funding for heat action must be allocated within municipal budgets, and the mandate to reduce heat risks must be outlined within municipal policies and laws, specifically within the mandates of the key departments, agencies and partners involved in heat health action planning. Additionally, other measures to sustain heat action include working with national stakeholders to ensure that heatwaves qualify for humanitarian financing in national disaster management laws, integrating heat action into urban planning and city decisions and encouraging private sector and non-governmental partners to develop complementary heat action plans (Singh *et al*., 2019).

In summary, this chapter provided an overview and background of the global climatic impacts of extreme heat and the associated heat-related health impacts. The effective heat action responses and adaptation strategies from global literature were discussed, as well as the governance and institutional dimensions needed to achieve effective heat adaptation, with a specific focus on the public health sector. Furthermore, the heat context of the study's region and study area was highlighted, while the South African and Gauteng-specific policies and studies on extreme heat aspects were examined to further advance heat action within the local government and institutional structures of the three

metropolitans. The following chapter (*Chapter 3*) outlines and highlights the methodology used in achieving the study's aims and objectives (*Chapter 1, Sections 1.3 & 1.4*).

3 CHAPTER THREE – METHODOLOGY

A comprehensive investigation into the extent of the current responses to heat-related health impacts within three metropolitans in the Gauteng Province, as well as advancing further heat action within the local government and institutional structures of the province, is presented in this research dissertation. By doing so, this research investigates the responses of the Environmental Health Department in addressing extreme heat impacts at a local level and identifies the institutional challenges and opportunities during implementation activities. Developing a perception-informed assessment of vulnerability to heat-related health impacts throughout these three metropolitans, which can potentially assist local governments in implementing targeted responses and strategies to reduce health impacts in these areas, is also presented.

In this chapter, the methodology used to achieve the aims and objectives of the research is described, highlighting the overall methodological design of this research, including the qualitative and quantitative approaches, the study area and group, the data collection and analysis processes and finally, the ethical protocol followed.

3.1 METHODOLOGICAL DESIGN

A mixed-methods research design was followed, using qualitative and quantitative approaches. Mixed-method designs combine the strengths of qualitative and quantitative approaches to provide a more comprehensive and complete understanding of the research question (Creswell, 2003; Ivankova & Creswell, 2009). These methods have been used extensively in social and health science research, with either a quantitative or qualitative approach alone being inadequate to address the complexity of these topics. More insights can also be gained by combining qualitative and quantitative research, providing an expanded understanding of the research problems (Creswell, 2003). Moreover, these research designs have been demonstrated to provide a clearer, more societally focused understanding of climate change and its impacts on human health and well-being. Mixed-method designs could improve interdisciplinary research towards climate change studies on human health, helping to address this knowledge gap by exploring people's perceptions, experiences and attitudes towards climate change, ultimately providing a deeper understanding of the social and health implications of climate change (Furberg *et al*., 2018; Landaverde *et al*., 2022).

The mixed-method design of the current study comprised two core elements: (1) narrative approaches with local Environmental Health Officials and (2) developing a heat vulnerability assessment of the study areas. Overall, this allowed a holistic analysis and understanding of the heat context within the three metropolitan municipalities, shaping the operational context of the local Environmental Health

Department and the physical heat vulnerability of the populations and communities throughout Gauteng. The overarching goal of this research was to enable local governments to build suitable adaptive strategies that can effectively address the specific risk context of the areas, ultimately assisting in the co-designing and development of heat action plans for these cities.

3.1.1 Narrative approach

The theory and practice of narrative approaches to climate change studies have become increasingly prominent in recent years due to their ability to capture personal experiences in context and link these to larger-scale patterns of institutional change (Malena-Chan, 2019; Singh *et al*., 2019). Narrative approaches have played a fundamental role in climate change studies, as they assist in closing the knowledge gap and enhancing the understanding of local socio-ecological systems by providing potentially significant data and information that would be otherwise overlooked (Paschen & Ison, 2014; Malena-Chan, 2019). These approaches seek to provide rich insights into local environmental knowledge and perceptions of climate change, as well as a more in-depth understanding of the social-ecological constructs within the local context, which can potentially inform the design of local adaptation policies and plans while building implementation capacity (Paschen & Ison, 2014). This study employed a narrative approach through a series of semi-structured interviews. These interviews provided a comprehensive overview of the operational context of the study group, including the current heat adaptive strategies in place at a local level, as well as the challenges and opportunities involved in implementing these strategies. Overall, these interviews provided valuable insights into understanding the extent of heat action throughout the Gauteng metropolitans.

Interviews are an interactive research process that captures the participants' personal experiences and perspectives to develop an understanding and shape the local context of the participant's environment while potentially highlighting challenges and opportunities that the researcher may not consider (Young *et al*., 2018). Interview approaches have been used extensively in social science and public health research, demonstrating their ability to empower participants for policy changes and improved operational conditions (Fontana & Frey, 2005; Young *et al*., 2018). The strength of qualitative approaches in the form of interviews is that they provide a comprehensive overview and context of the research topic, stimulate innovative ideas and thoughts among participants, and include in-depth insights into each participant's experiences, perspectives and challenges (Newing, 2010). Furthermore, semi-structured interviews are typically designed around a topic guide comprising a set of key topics that form the basis of the discussion between the researcher and the participants (Edwards & Holland, 2013; Knott *et al*., 2022). This topic guide, also referred to as an interview protocol, is a pre-written guide of questions designed around the key concepts that the researcher has identified, with targeted questions aimed to elicit specific responses and consider all aspects of the

narrative, including background information, the participant's experience within the local context and the participants' various perspectives, thoughts and ideas (Newing, 2010; Edwards & Holland, 2013; Paschen & Ison, 2014; Knott *et al*., 2022). Semi-structured interviews offer flexibility in terms of when and how questions are asked, as well as how participants can respond, and allow the researcher to adapt and tailor the interview based on the context and engagement with the participants (Edwards & Holland, 2013; Knott *et al*., 2022).

To conduct a successful interview, it is important to follow a few key steps and stages, including developing a research question, creating a topic guide, completing ethical review processes and selecting appropriate interview techniques (Newing, 2010; Young *et al*., 2018; Knott *et al*., 2022). An effective interview can be simplified into nine key stages, which can be broadly divided into three fundamental categories: (1) Initial Project Design, (2) Data Gathering, and (3) Analysis and Write-up (Figure 3.1) (Young *et al*., 2018). This process was adopted and adapted during the current study, which was achieved by interviewing the Environmental Health Managers, Operational Managers and EHPs from the Environmental Health Department in the three Gauteng metropolitans. This narrative approach allowed for the capturing of the participant's personal experiences and perspectives in order to gain a better understanding of the current institutional landscape of the Environmental Health Department and its potential as the lead agency for heat-health action. These interview questions were based on previous research conducted in the City of Johannesburg and aimed to understand how extreme heat and heatwaves are understood, responded to and planned for, currently and in the future of these municipalities. A second methodological approach, interrogating data, was also followed to derive a heat vulnerability framework.

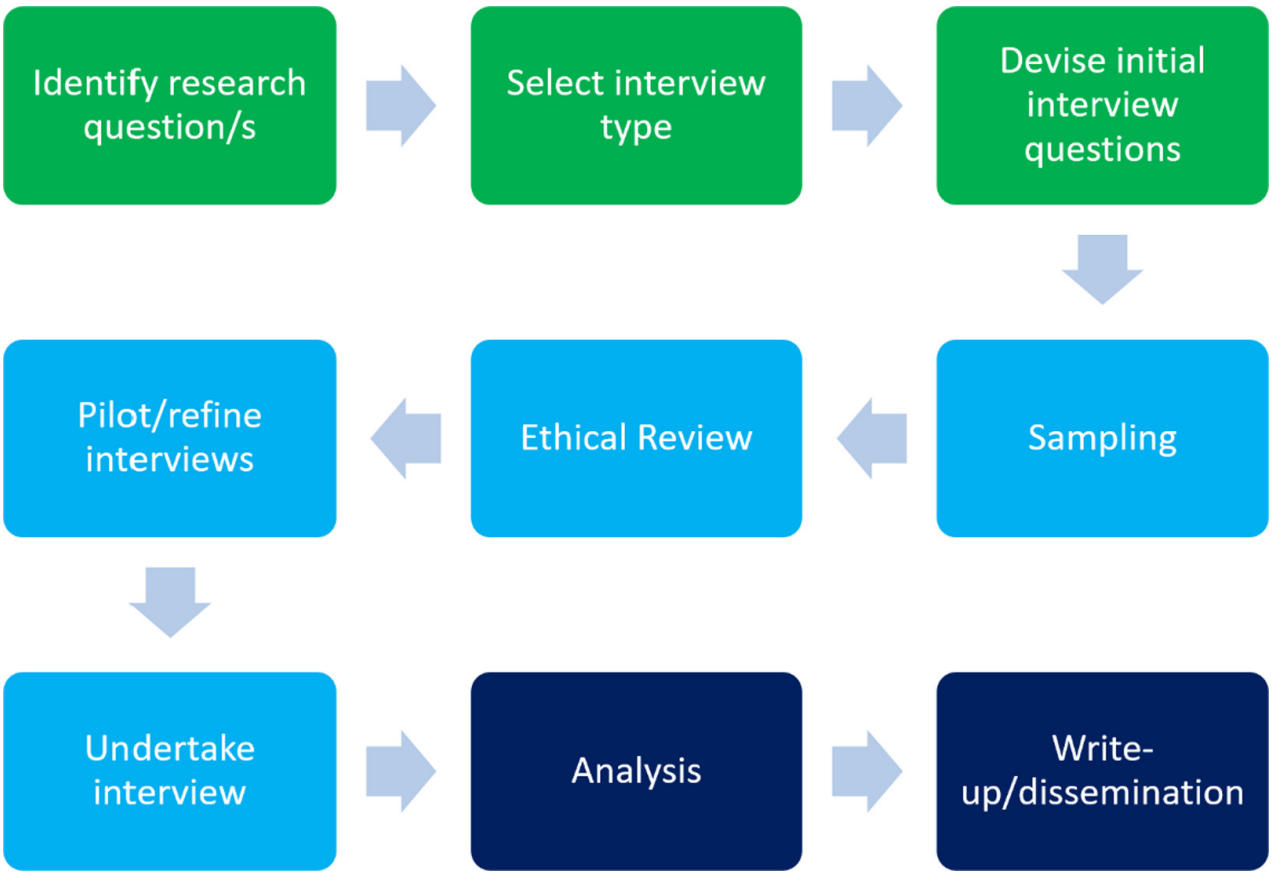


Figure 3.1: Key stages of an interview process: Initial Project Design (Stages 1 to 3; green boxes), Data Gathering (Stages 4 to 7; light blue boxes) and Analysis and Write-up (Stages 8 to 9; dark blue boxes). Source: Young et al. (2018)

3.1.2 Heat vulnerability framework

Embedded within the IPCC climate risk framework, risks are framed as a function of the hazard severity, exposure and the system's underlying vulnerability (IPCC, 2014, 2022; Fernandez Milan & Creutzig, 2015). It is widely acknowledged that vulnerability to climate change varies within populations and across communities, regions and countries, which can be attributed to a range of socio-economic factors at a macro-scale, such as education, population growth, economic development, infrastructure, technology, social behaviour and natural environments, as well as individual- and household-scale factors such as age, ethnicity, poverty status, access to basic resources and services, pre-existing health conditions and the ability to respond (US Global Change Research Program, 2016; IPCC, 2022). Vulnerability is considered an inherent characteristic that increases the likelihood of harm to a system and is represented by the concept of social vulnerability (Cutter *et al.*, 2003; Fernandez Milan & Creutzig, 2015; Jagarnath *et al.*, 2020). Identifying social vulnerability, and thereby community resilience, is fundamental for successful city- and local-level adaptation to protect communities against climate risks (IPCC, 2022).

Social vulnerability is determined by a population's sensitivity and adaptive capacity (Wolf & McGregor, 2013; Fernandez Milan & Creutzig, 2015; Jagarnath *et al*., 2020; IPCC, 2022). However, social vulnerability cannot be directly measured, and proxy variables are needed to represent the levels of vulnerability between populations and across communities and regions (Wolf & McGregor, 2013; de Sherbinin *et al*., 2019; Jagarnath *et al*., 2020). For the purpose of the current study, vulnerability to heat is conceptualised as the sensitivity of populations to heat-related health impacts and the adaptive capacity of communities to protect themselves against increasing temperatures and extreme heat exposure. Generally, social vulnerability is broadly defined; however, in the case of this study, vulnerability is related to a specific climate risk of extreme heat. Therefore, only heat-related vulnerability variables were selected.

An appropriate method for assessing vulnerability to environmental hazards was developed in the United States in 2003, which used 42 independent socio-economic variables and employed a factor analysis approach, particularly PCA, to generate an index representing vulnerability (Cutter *et al*., 2003). The PCA approach has become a popular method for developing geospatial social vulnerability indices and has since been adapted and applied in many contexts, including extensive use in heat vulnerability studies (Cutter *et al*., 2003; Boruff & Cutter, 2007; Wolf *et al*., 2009; Holand & Lujala, 2013; Wolf & McGregor, 2013; Zhou *et al*. 2014; Hummell *et al*., 2016; Nayak *et al*., 2018; Aksha *et al*., 2019; Jagarnath *et al*., 2020; Cheng *et al*., 2021). These adapted heat vulnerability methodologies have been applied in global studies at national, city and local levels to assess and identify the populations, communities and areas that are more susceptible to extreme heat and heat-related health impacts (Johnson *et al*., 2012; Wolf & McGregor, 2013; Jagarnath *et al*., 2020). Ultimately, these methodologies create an HVI, which measures and ranks the levels of vulnerability to heat across the specific study area, using selected socio-economic variables that provide valuable insights into the populations and communities most at risk to extreme heat and increasing temperatures (Johnson *et al*., 2012; Wolf & McGregor, 2013; Jagarnath *et al*., 2020; IPCC, 2022). Identifying those who are vulnerable to extreme heat can lead to further advancements in heat-related adaptations, assisting policymakers, local governments, public health officials and emergency responders in developing targeted planning and strategies to protect these vulnerable communities, ultimately enhancing resilience to extreme heat (Johnson *et al*., 2012; Wolf & McGregor, 2013; Jagarnath *et al*., 2020; IPCC, 2022).

Several key steps must be taken to create an effective and useful HVI, as illustrated in Figure 3.2. These steps include reviewing literature to identify heat risk variables linked to increased vulnerability, identifying an available data source with all the necessary variables (such as a recent census dataset), extracting and normalising all variables to ensure consistent and comparable data,

aggregating the normalised variables using a PCA method to create vulnerability scores for each geographic area of the study and lastly, visualising the resulting vulnerability scores using a geospatial platform (such as GIS) to create a heat vulnerability map (Cutter *et al*., 2003; Johnson *et al*., 2012; Wolf & McGregor, 2013; Aksha et al., 2019; Jagarnath *et al*., 2020; Cheng *et al*., 2021). The current study utilised the social vulnerability method originally developed by Cutter *et al*. (2003) and adapted it to align with the current heat vulnerability methodologies highlighted above. As a result, an HVI was generated that identifies the populations, communities and areas most susceptible to extreme heat and heat-related health impacts in the three Gauteng metropolitans.

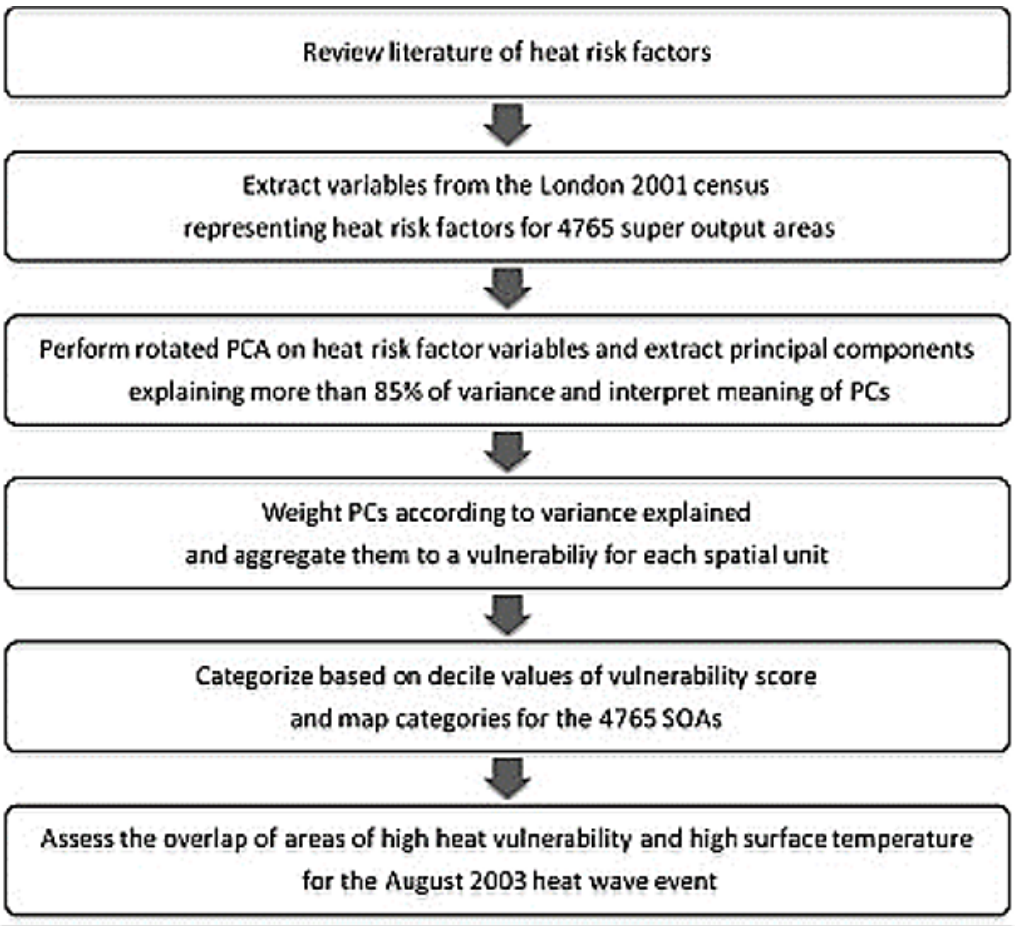


Figure 3.2: Example methodology applied in the development of the Heat Vulnerability Index. Source: Wolf and McGregor (2013)

3.2 STUDY AREA

This study was carried out in the Gauteng Province of South Africa, covering three metropolitan municipalities (Figure 3.3): the City of Johannesburg, the City of Tshwane and the City of Ekurhuleni. These three municipalities are designated as metropolitans, or Category A municipalities, because they contain a high proportion of densely populated urban areas. These municipalities are considered the economic hubs of the province and contribute significantly to South Africa's national gross domestic product (GDP) (Metropolitan Municipalities of South Africa).

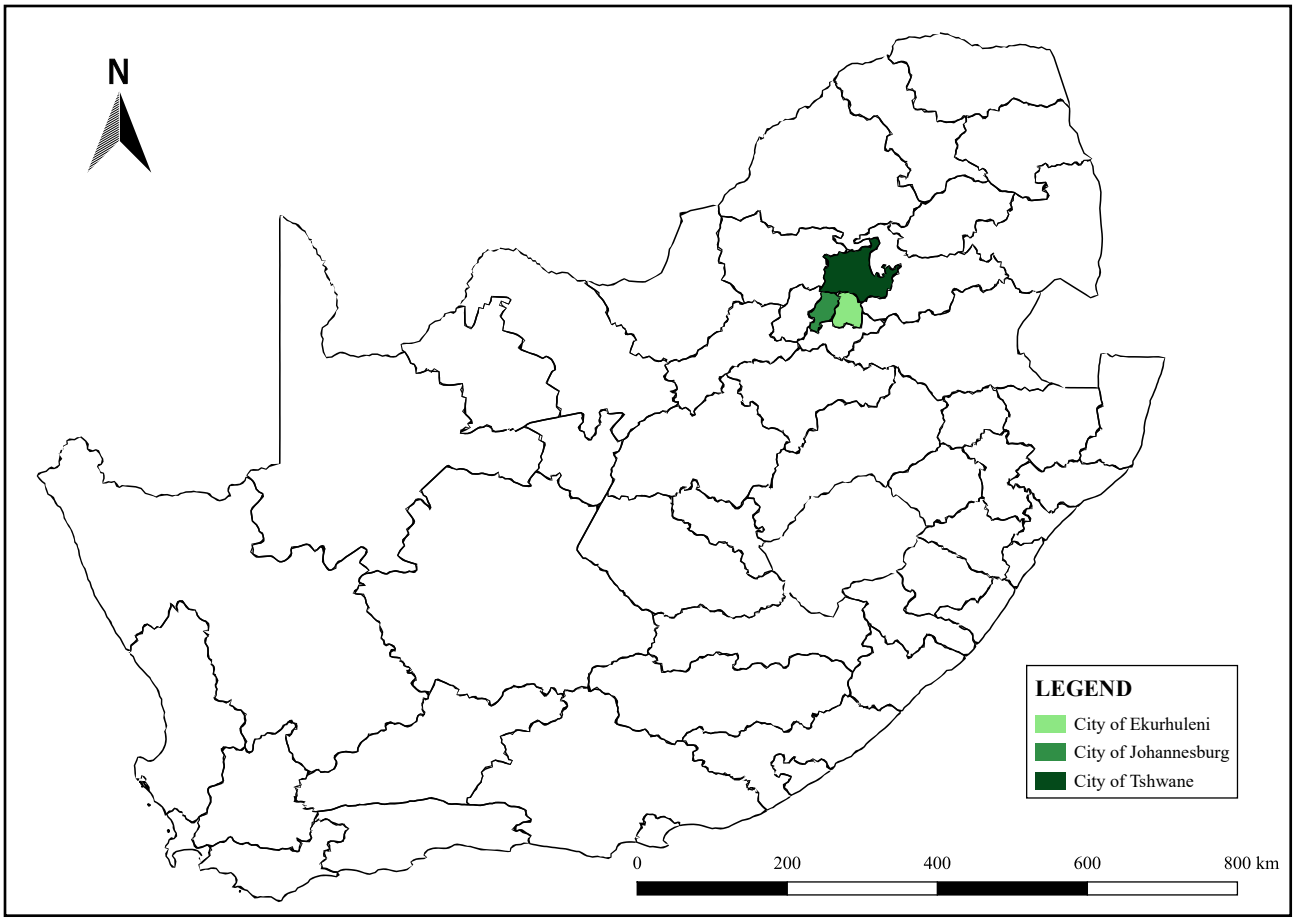


Figure 3.3: The Gauteng Province, indicating the three metropolitan municipalities, the City of Tshwane, the City of Johannesburg and the City of Ekurhuleni. Created using QGIS 3.28.1

3.2.1 City of Johannesburg

The City of Johannesburg Metropolitan Municipality (Figure 3.4) is situated centrally in the province and is divided into seven planning regions. It is the most populated city in South Africa, with a population of 5.87 million, comprising about 40% of Gauteng's total population. Moreover, Johannesburg's population is growing at twice the rate of South Africa, and it is estimated to exceed 6.8 million by 2026 (City of Johannesburg Metropolitan Municipality, 2021). Despite its high population, the City covers the smallest area of the three metropolitans, with only 1 643 km^2, demonstrating how densely populated this City is (City of Johannesburg Metropolitan Municipality, 2021). Due to the UHI effect, the temperatures in the City are on average 0.15°C higher than the surrounding areas, with these temperatures projected to increase between 2.2°C to 2.7°C by 2050, with single-day temperature extremes projected to increase by 6.0°C by the end of the century (City of Johannesburg, 2021). Due to the high population density and the nature of Johannesburg's predominantly urbanised landscape, there is a significant risk of heat-related impacts in the City. As previous research (Nana *et al*., 2019) has already been conducted in this municipality, the City of Johannesburg served as the baseline study area and a starting point from which to build.

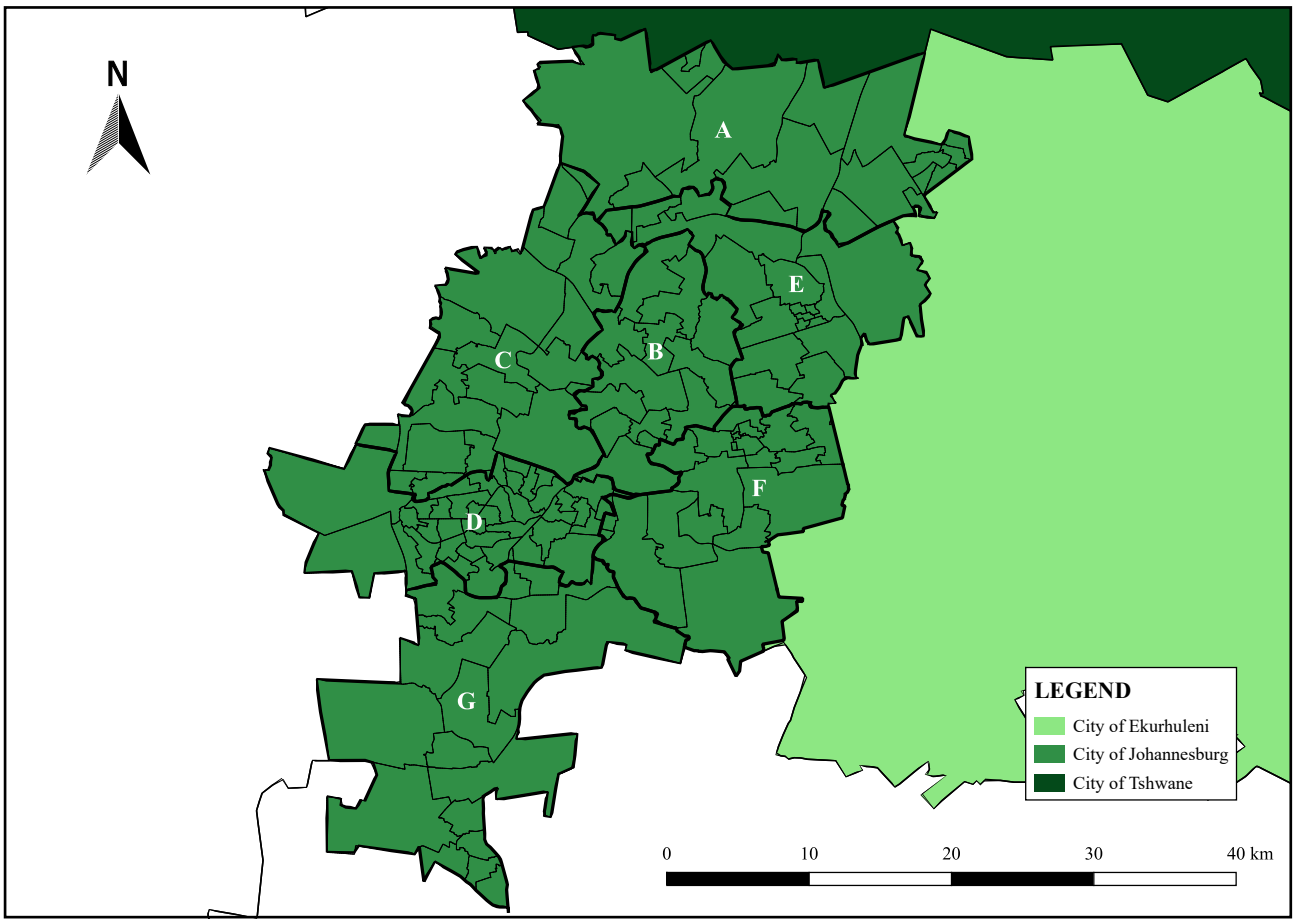


Figure 3.4: The seven planning regions (A to G) within the City of Johannesburg Metropolitan Municipality. Created using QGIS 3.28.1

3.2.2 City of Tshwane

The City of Tshwane Metropolitan (Figure 3.5), South Africa's capital city, is in the province's northern region and divided into seven planning regions. The City has an estimated population of nearly 3.7 million, with an annual growth rate of almost 2%. Tshwane is the largest of the three metropolitan areas within Gauteng and ranks the third largest city globally, covering an area of 6 345 km^2 (City of Tshwane Metropolitan Municipality, 2021). This City thus has a wider and more dispersed landscape than the other two metropolitans, comprising diverse landscapes with vast agricultural and rural land areas, resulting in varying heat contexts throughout the City (City of Tshwane Metropolitan Municipality, 2021; Municipal Demarcation Board, 2021). On average, temperatures in Tshwane have risen by 1.8°C since 1960 and are projected to increase between 2.7°C and 3.2°C by 2050 under high-emission scenarios (RCP 8.5) (City of Tshwane, 2022). Due to Tshwane's varying heat contexts, vast landscapes and diverse socio-economic contexts, there is a significant risk of heat-related health impacts throughout the City.

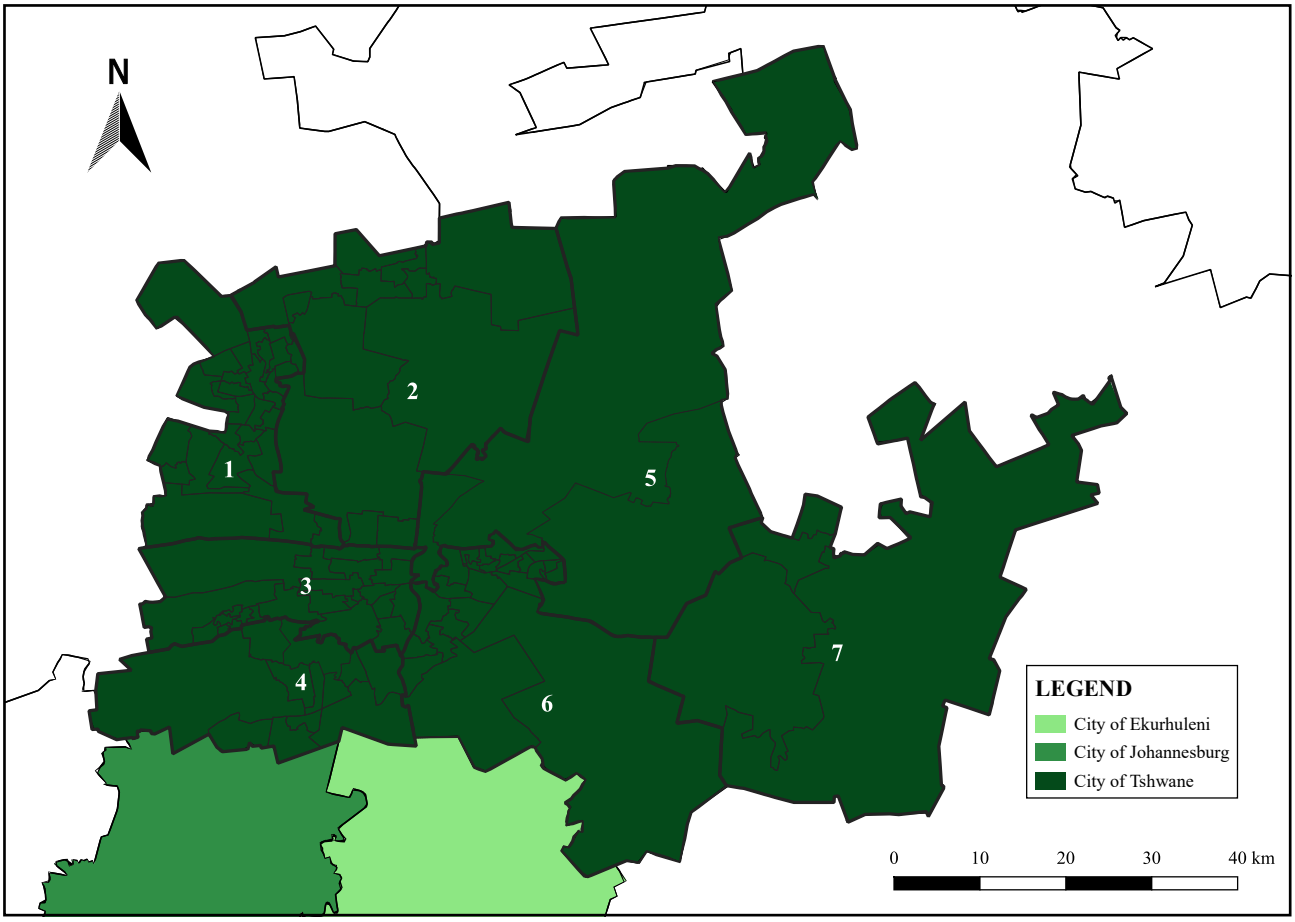


Figure 3.5: The seven planning regions (1 to 7) within the City of Tshwane Metropolitan Municipality. Created using QGIS 3.28.1

3.2.3 City of Ekurhuleni

The City of Ekurhuleni (Figure 3.6) is in the province's eastern region and is divided into six planning regions[2], covering an area of 1 975 km^2 (City of Ekurhuleni Metropolitan Municipality, 2022). Ekurhuleni has a population of 3.8 million, and although the population growth rate is slower than that of Johannesburg and Tshwane, it is estimated to have a population of over 4.0 million by 2030 and 8.8 million by 2050 (City of Ekurhuleni, 2022; City of Ekurhuleni Metropolitan Municipality, 2022). The City is a mix of landscapes with vast urban, agricultural, rural and industrial areas and is referred to as the industrial hub of Gauteng. Large clusters of informal settlements on the City's outskirts represent about 62% of the City's population, who are at significant risk of heat-related health impacts (City of Ekurhuleni Metropolitan Municipality, 2022). It is projected that Ekurhuleni's average temperatures will increase by more than 3.0°C by 2030, with extreme heat and heatwave

[2] Although Ekurhuleni is divided into six planning regions, the city's Environmental Health Department is managed at three broader planning regions (Southern, Northern and Eastern regions), and, therefore, for the qualitative approach of the study, a broader overview of these three sub-regions was assessed.

days projected to increase by 2.1°C from an average baseline of 35°C (City of Ekurhuleni Metropolitan Municipality, 2017).

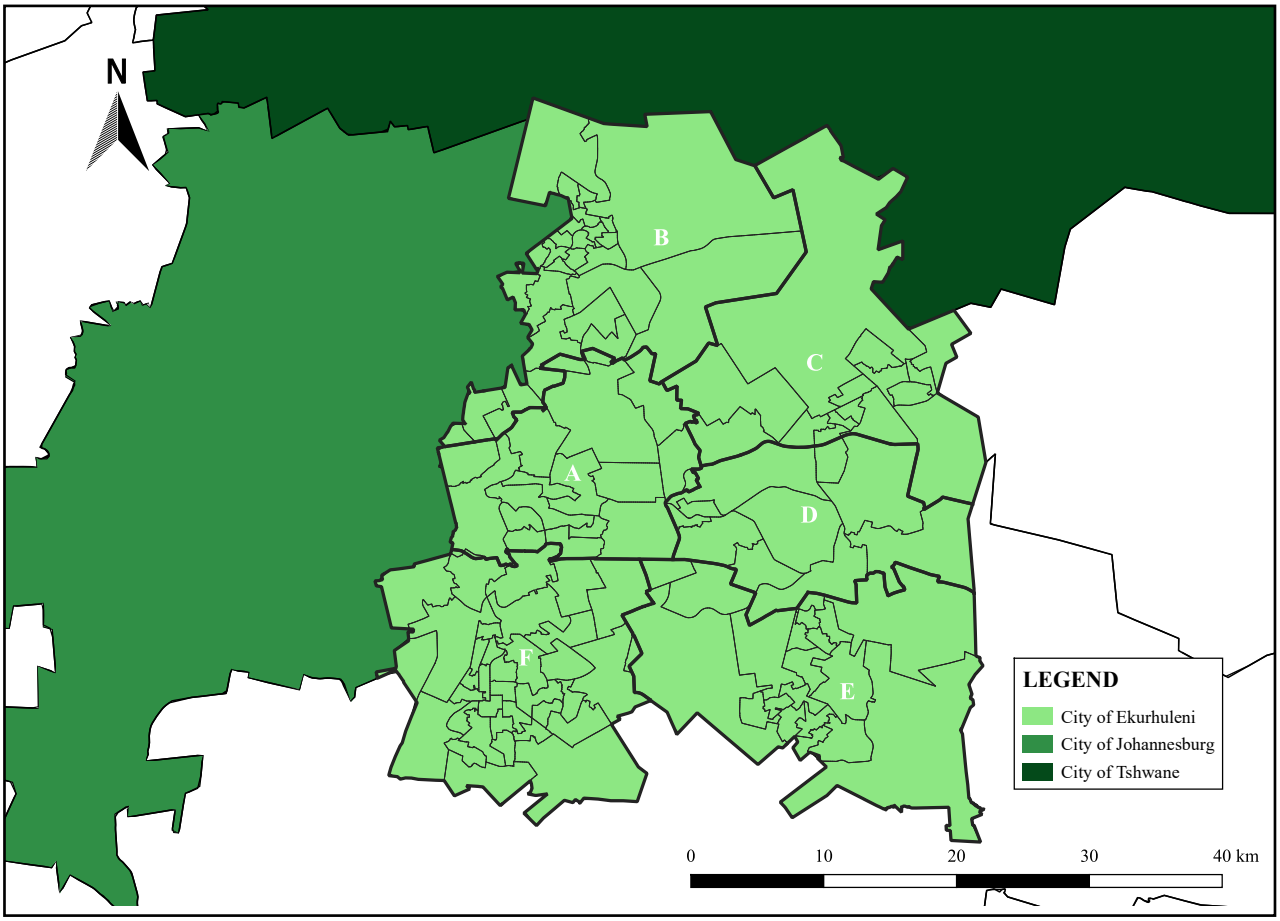


Figure 3.6: The six planning regions (A to F) within the City of Ekurhuleni Metropolitan Municipality. Created using QGIS 3.28.1

3.2.4 Regional Overview

These three municipalities are located within the Highveld region of South Africa and experience a subtropical climate with wet summers, dry winters and relatively moderate temperatures. These municipalities have similar average day temperatures of around 25°C in the summer and 17°C in winter. However, under low and high mitigation scenarios (i.e., RCP4.5 and 8.5), temperatures are predicted to increase between 2.0 to 3.0°C by 2050, including an increase in the number of heatwave days per year, with an overall increase in single-day temperature extremes (i.e. very hot days with a maximum temperature exceeding 35°C) (City of Ekurhuleni Metropolitan Municipality, 2017; City of Johannesburg, 2021; City of Tshwane, 2022). These temperature predictions, combined with the additional effects of the UHI, will significantly increase the populations' exposure to heat-related health impacts within these metropolitan cities.

The triple threat of poverty, unemployment and inequality weighs heavily on the development of these cities and provides challenges for the social, political and economic sectors. These challenges

are further intensified by unequal spatial distribution, inadequate access to basic services and needs and social exclusion of their populations, making them one of the most unequal populations globally. The gap between rich and poor and the high unemployment rates within these cities significantly strain their economies. The low economic status of these cities has improved over recent decades, and these three metropolitans account for the majority of Gauteng's overall economy and together contribute to a large portion of the national GDP. However, due to the COVID-19 pandemic of 2020, the economic state of these metropolitans has been struck, leaving them with even more challenges to deal with (City of Johannesburg Metropolitan Municipality, 2021; City of Tshwane Metropolitan Municipality, 2021; City of Ekurhuleni Metropolitan Municipality, 2022). The numerous socio-economic challenges within these cities, coupled with the future climatic projections of the region, leave these populations at an increasing vulnerability and risk level to the subsequent heat-related health impacts.

3.3 STUDY GROUP

The study group comprised the Department of Environmental Health[3], specifically the Environmental Health Managers, Operational Managers and EHPs (referred to as Environmental Health Officials) of the seventeen planning and management regions for the three metropolitan municipalities. The South African National Environmental Health Strategy of 2016-2020 (referred to as the Environmental Health Strategy) defines the practice of Environmental Health as striving to "*identify and prevent those health conditions that may be caused by people's interactions with and exposure to their environment. It aims to promote health by improving the environment in which people are born, live and work through the identification, assessment and control of those factors in the environment that may constitute a health hazard and risk*" (Department of Health, 2016, p.6). Furthermore, the National Health Act of 2003 (referred to as the Health Act) and Environmental Health Strategy outline Environmental Health Services and the Environmental Health Officials responsibilities to "*include the nine Municipal Health Services functions performed by district and metropolitan municipalities, as well as functions performed by the national and provincial Departments of Health, including food control, waste management and hygiene monitoring, surveillance and prevention of communicable diseases, water quality monitoring, chemical safety, health surveillance of premises, disposal of the dead, vector control and environmental pollution control […] in addition […] Environmental Health Services entails and is responsible for climate change and health matters, infection control, occupational health and health education and promotion functions*" (Department of Health, 2003, p.15; Department of Health, 2016, p.9).

[3] This study refers to the Environmental Health Department as a general term, but this also includes the Environmental Health Services and Municipal Health Services.

Additionally, as highlighted in the previous chapter (*Chapter 2, Section 2.11*), the South African National Heat Health Action Guideline has tasked the health sector, specifically the Environmental Health Department, to be one of the two lead agencies (i.e., including disaster management) for the coordination and collaboration of heat action across the different departments, agencies and institutions in all government spheres (Department of Health, 2020).

The Environmental Health Department's primary function is to provide comprehensive and proactive needs-based services to the public that promote a safe, healthy and clean environment while preventing diseases, and has been suggested to lead heat action in South Africa. This Department thus was identified as the key role player in the potential responses and planning of extreme heat and heatwave events within these municipalities. Each of the planning regions within these municipalities has a designated Environmental Health Manager responsible for ensuring the roles and functions of the department are fulfilled. The Environmental Health Managers are further supported by the Operational Managers, who ensure the duties of the EHPs are implemented. The Environmental Health Officials are equipped with the knowledge and awareness regarding the Department's responses, plans and priority areas and maintain a close relationship and regular engagement with local communities affected at the operational scale. Therefore, the Environmental Health Department is an ideal source of interviewing and questioning to identify and understand the local operational responses and planning for extreme heat within the cities.

3.4 DATA COLLECTION AND ANALYSIS

A comprehensive analysis of the heat context across the Gauteng metropolitans was conducted in this study using a mixed-method design, combining qualitative and quantitative approaches. Semi-structured interviews were performed with Environmental Health Officials from each of the municipalities' planning regions, as well as the inclusion of a heat vulnerability assessment to identify the most at-risk populations. This provided valuable insights into the operational landscape of the Environmental Health Department and the vulnerability of the populations and communities across these regions, enabling advancements of heat adaptation strategies and plans throughout the three metropolitans.

3.4.1 Qualitative approach: Semi-structured interviews

To understand the extent to which extreme heat is being planned for and responded to at a local level in the three municipalities, a series of semi-structured interviews between January 2022 and May 2023 were conducted with the Environmental Health Officials throughout the three Gauteng metropolitans. Environmental Health Officials were interviewed in each of the 14 planning regions within the cities of Johannesburg and Tshwane (i.e., seven regions in Johannesburg and seven regions

in Tshwane). Meanwhile, Ekurhuleni had to follow a different approach based on the structural set-up of the City's Environmental Health Department, which, due to the many vacancies of Environmental Health Managers and Officials throughout the City, is not managed at a planning region level, like that of Johannesburg and Tshwane. Ekurhuleni's Environmental Health Department is subdivided into and managed as three broad regions: the Southern, Northern and Eastern regions, with Regional Managers responsible for ensuring the Department's functions are fulfilled. Due to these three Regional Managers' broad scope of authority and the nature of the structure of the Environmental Health Department in the City, a combined regional review was conducted for Ekurhuleni[4]. Overall, fifteen interviews (n = 15) were conducted with the various Environmental Health Officials throughout the three Gauteng metropolitans.

Each interview was conducted and recorded in person or virtually (i.e., Microsoft Teams). Health Officials were provided with a brief overview of the study and the purpose of the interviews. However, they were not presented with the specific interview questions beforehand to ensure spontaneous responses. Consent forms were sent to each manager requesting permission for interviews to be recorded and declaring the confidentiality and anonymity of their responses.

The current study's interviews were informed by the results of the study conducted in the City of Johannesburg by Nana *et al*. (2019). The City of Johannesburg, therefore, served as the baseline study area for this research, using these previous results as a starting point from which to work. Also, the current study aimed to identify if any further development has been made within the municipal operations of Johannesburg since the previous study. The study area was further expanded into the neighbouring metropolitans of the City of Tshwane and the City of Ekurhuleni to identify if or how extreme heat is being responded to and planned for in these municipalities.

The current study's depth was improved by analysing Environmental Health Officials' responses in three municipalities to compare between each municipality. This analysis revealed which of the three municipalities leads the way in implementing heat adaptation strategies and planning, which can be shared with neighbouring municipalities to aid their efforts. Further comparative analysis was performed between the planning regions within each municipality. By doing so, successful and effective adaptation strategies from one region can be considered for implementation in another region with similar geographic, demographic and socio-economic contexts. By comparing both between and within the three metropolitans, valuable insights into the successful strategies for the various socio-economic contexts across the Gauteng Province were gained, focusing on assisting the

[4] Ekurhuleni's review included a combined interview with the three Regional Managers to get a comprehensive overview and context of the City's Environmental Health Department.

municipalities in developing and implementing area-specific adaptation strategies for each region's varying risk contexts, ultimately leading to the development of a framework for heat action plans for these three municipalities.

Semi-structured interviews offer flexibility in terms of when and how questions are asked, as well as how participants can respond, and allow the researcher to adapt and tailor the interview based on the context and engagement with the participants (Edwards & Holland, 2013; Knott *et al*., 2022).

The interview process followed a topic guide of questions grouped into four sections (A to D) that provided a structure and outline of the key questions, but also allowed the researcher to adapt the questions based on the participants engagement and context (refer to Appendix 1 for the topic guide of questions). The first section focused on each Health Official's brief understanding and awareness of climate change and heatwave events, as well as their knowledge of the impacts and risks associated with extreme heat. The follow-up section focused on the heat-health adaptation plans and policies in the IDPs and the municipality's climate response plans. It aimed to understand the level of attention given to extreme heat and heatwaves on a local operational level, the adaptation strategies implemented in each planning region (if any) and if vulnerable populations had been identified with targeted responses to prepare these local communities for heat events. The third section concentrated on the challenges faced by each planning region regarding the effective implementation of adaptation strategies and plans and invited suggestions for better strategy coordination and implementation. Lastly, the Environmental Health Officials were asked what they believe hinders the development of a heatwave action plan for their municipality and if they have support from higher authority officials within the department to develop and implement adaptation strategies and plans (Appendix 1).

These interview data were analysed using a thematic analysis framework, an accessible and flexible approach for identifying, organising and analysing the patterns and themes within the qualitative dataset. To successfully map out the central patterns and themes of a qualitative dataset, this framework suggests six key phases that should be included: (1) familiarise with the data; (2) code the data; (3) identify and collate the data into potential themes; (4) review themes and build thematic map; (5) define and name the themes; and (6) report the results (Braun & Clarke, 2006; Macassa *et al*., 2022). This methodology was applied during the qualitative phase of the study, during which the data was transcribed using Otter.ai, a web-based artificial intelligence-powered application that transcribes speech from audio and videos into text to present the data in a format that could be coded and analysed further (Otter.ai, 2023). This transcribed data was then coded using Microsoft Excel based on the data's specific features and topics, which were compared to identify the patterns and central themes of the study. Thereafter, the various themes were collated to create a thematic map of

the overall findings, which were related to the relevant literature and the overarching research question of the study.

3.4.2 Quantitative approach: Heat vulnerability assessment

The importance of profiling and assessing the levels of vulnerability of local populations and communities to build adaptation actions and enhance resilience has been outlined by the Sendai Framework for Disaster Risk Management, the United Nations Sustainable Development Goals, the South African Disaster Management Amendment Act of 2015 and the South African National Climate Change Response White Paper of 2011 (Department of Environmental Affairs, 2011; Republic of South Africa, 2015: UNISDR, 2015; United Nations, 2015). Therefore, identifying populations and areas most susceptible to extreme heat and related health impacts is needed to develop heat-related adaptations further and assist with targeted planning and strategies to protect vulnerable people and communities. In this study, an HVI was used, which was created using selected socio-economic variables that represent the sensitivity and adaptive capacity of the local populations to extreme heat in the three Gauteng metropolitans. These variables were extracted from the Gauteng City-Region Observatory's (GCRO) Quality of Life (QoL) dataset of 2020/2021, which is a set of surveyed data collected by GeoSpace International through in-person interviews from late October 2020 through to May 2021. This survey contains a set of 214 questions covering 15 topics:

1. Dwelling and household information
2. Access to & satisfaction of basic services
3. Moving home and migration
4. Neighbourhood or community
5. Transport
6. Household socio-economic status
7. Governance & government satisfaction
8. Social and political attitudes
9. Life satisfaction
10. Crime and safety
11. Social and civic participation
12. Health
13. Impact of COVID-19
14. Demographic details
15. Exposure to violence

The QoL survey contains the responses from 13 616 adults sampled from 529 wards in the Gauteng Province, of which 354 wards are found within the study area of the three Gauteng metropolitans. Based on previous literature and research, specific variables related to the sensitivity and adaptive capacity of heat-related health impacts were selected to represent the major socio-economic factors contributing to heat vulnerability. A list of the selected variables, their descriptions and the rationale for inclusion within the HVI has been included in Table 3.1.

Twenty proxy variables from the QoL dataset 2020/2021 were selected to develop the HVI (Table 3.1), which were extracted at the ward level (i.e., Level 4 administrative boundary level), resulting in 20 data points for each of the 135 wards in Johannesburg, 107 wards in Tshwane and 112 wards in the Ekurhuleni[5]. The 20 proxy variables were normalised using percentages prior to statistical analysis to ensure the data was comparable across the different variables. Additionally, composite categories were created before analysis to identify related variables that captured specific dimensions of heat vulnerability and were grouped into six categories: (1) Poverty, (2) Dependency, (3) Health, (4) Housing, (5) Services and (6) Resource and Communication Access (Table 3.1). A factor analysis approach was then individually applied to the six composite variables, using the PCA method in IBM Statistical Package for the Social Sciences (SPSS) Statistics version 28.0.1. This approach was used to combine the selected QoL variables into individual principal component scores for each composite variable according to the statistical relationship and spatial distributions between them. Only components with eigenvalues[6] above 1.0 were considered, and in the case where more than one component score was provided, the highest eigenvalue was used. An additive and equal weighting method was used in the absence of clear justifiable evidence for weighting heat variables differently, as has been developed in similar studies (Cutter *et al*., 2003; Hummell *et al*., 2016; Aksha *et al*., 2019). The HVI scores were calculated by summing the component scores of each of the six composite variables to reach a total HVI score per ward in the three Gauteng metropolitans[7]. The HVI scores were then classified into five categories based on the HVI scores relative to the population sample (i.e., all HVI scores of the 529 wards): Very High, High, Medium, Low and Very Low levels of vulnerability. Finally, the resulting index was transferred onto QGIS (Version 3.28.1), where the HVI was visualised to create a heat map highlighting the vulnerability levels throughout the Gauteng Province. A figurative illustration of the step-by-step process of the HVI method is illustrated in the figure below (Figure 3.7).

[5] The ward level was used as the scale of the assessment due to the spatial resolution of the QoL data; furthermore, any finer scale data would result in higher margins of error and inaccurate indices.

[6] Eigenvalues represent the amount of variance explained by each principal component, with a higher eigenvalue indicating the principal component explains more variance than a single original variable (Cutter *et al*., 2003; Jolliffe, 2010; Jagarnath *et al*., 2020).

[7] $HVI_{per\ ward}$ = Poverty PC + Dependency PC + Health PC + Housing PC + Services PC + Resource & Communication PC (where PC = Principal Component Score)

Table 3.1: Quality of Life dataset 2020/2021 vulnerability variables and their function in increasing heat vulnerability

Composite & variable		Variable definition	Rationale for inclusion
Poverty composite	**Employment**	Percentage of respondents who are unemployed	The lack of employment serves as a proxy for the level of poverty, with the inability to provide basic resources and services if unemployment continues (Wolf & McGregor, 2013; Nayak *et al*., 2018; Jagarnath *et al*., 2020; Cheng *et al*., 2021).
	Income	Percentage of respondents with monthly household income less than or equal to R3 200/month	Income serves as a proxy for the level of poverty and the ability to provide basic resources and services to the household. Wealth enables individuals/communities to absorb and recover from heat impacts more quickly due to insurance, social safety nets and entitlement programmes (Johnson *et al*., 2012; Wolf & McGregor, 2013; Dong *et al*., 2015; Nayak *et al*., 2018; Jagarnath *et al*., 2020; Cheng *et al*., 2021).
	Education	Percentage of respondents without a matric or higher	Education is linked to socio-economic status, with higher educational attainment resulting in greater lifetime earnings. Further, lower education constrains the ability to understand warning information and access recovery information (Johnson *et al*., 2012; Dong *et al*., 2015; Fernandez Milan & Creutzig, 2015; Nayak *et al*., 2018; Jagarnath *et al*., 2020; Cheng *et al*., 2021; Abrar *et al*., 2022).
	Adult skipped meal	Percentage of respondents who skipped a meal in the past 12 months because there was no money for food	The ability to feed oneself serves as a proxy for the level of poverty severe enough that meeting basic needs is not possible. An inability to meet these basic needs of nutrition is likely to substantially increase vulnerability to diseases, illness and mortality from extreme heat (Abrar *et al*., 2022).
	Children not fed	Percentage of respondents who in the past 12 could not afford to feed the children in the household	As above, the ability to feed children serves as a proxy for the level of poverty severe enough that meeting basic needs is not possible. An inability to meet these basic needs of nutrition is likely to substantially increase vulnerability to diseases, illness and mortality from extreme heat (Abrar *et al*., 2022).
Dependency composite	**Under 18**	Percentage of respondents with children in the household (under 18)	Children under the age of 18 are dependent on others and hence are limited in how they can respond to heat events. Further, recent studies have also highlighted the relationship between high temperatures and increased infant and young children mortality rates (Fernandez Milan & Creutzig, 2015; Geruso & Spears, 2018; Jagarnath *et al*., 2020; Cheng *et al*., 2021; Abrar *et al*., 2022).

Composite & variable		Variable definition	Rationale for inclusion
	Over 60	Percentage of respondents with elderly in the household (over 60)	The elderly have a lower adaptive capacity and mobility constraints, increasing the burden of care and lack of resilience. Further, the internal homeostatic systems of the elderly cannot cope with rising temperatures (Poumadère *et al*., 2005; Vescovi *et al*., 2005; Johnson *et al*., 2012; Wolf & McGregor, 2013; Dong *et al*., 2015; Fernandez Milan & Creutzig, 2015; Nayak *et al*., 2018; Cheng *et al*., 2021; Abrar *et al*., 2022).
Health composite	**Medical status**	Percentage of respondents who indicated that their medical status is poor or very poor	Respondents with poor health statuses are spatially concentrated in certain areas like townships and informal settlements. This may also reflect a higher prevalence of other illnesses and diseases in these areas and make these individuals more susceptible to future sickness (Fernandez Milan & Creutzig, 2015; Cheng *et al*., 2021).
	Illness	Percentage of respondents with member(s) of the household who have an illness (including cancer, diabetes, asthma, pneumonia, heart diseases/stroke, hypertension, HIV/AIDs and TB)	Individuals with pre-existing health conditions are particularly vulnerable to extreme heat and heat-related health impacts. Vulnerability is also increased due to the ongoing medical needs of these individuals (Wolf & McGregor, 2013; Fernandez Milan & Creutzig, 2015; Cheng *et al*., 2021).
	Disability	Percentage of respondents with member(s) of the household who have a disability (including sight, hearing, speech, physical and intellectual)	Individuals with disabilities are particularly vulnerable to extreme heat and heat-related health impacts as they are limited in their capacity to respond to heat events (Wolf & McGregor, 2013; Nayak *et al*., 2018; Cheng *et al*., 2021; Abrar *et al*., 2022).
Housing composite	**Dwelling type**	Percentage of respondents who live in an informal dwelling	The value, quality and density of housing construction and materials affect the potential losses and damages. Expensive homes on the coast are costly to replace but more robust; while mobile and informal homes are easily destroyed and less resilient to hazards (Fernandez Milan & Creutzig, 2015; Jagarnath *et al*., 2020; Abrar *et al*., 2022).
	Number of households	Percentage of respondents with more than one household sharing a single room	Household crowding is a risk to a range of health challenges due to the close nature of individuals with limited adequate sanitation. Furthermore, more individuals in a household will limit the ability of individuals to share resources and services during emergencies (Wolf & McGregor, 2013; Dong *et al*., 2015; Jagarnath *et al*., 2020; Cheng *et al*., 2021; Abrar *et al*., 2022).

Composite & variable		Variable definition	Rationale for inclusion
	Number of people in the household	Percentage of respondents with more than four people living in their household	Families with large numbers of dependents or single-parent households often have limited finances to outsource care for dependents and thus must juggle work responsibilities and care for family members (Wolf & McGregor, 2013; Dong *et al*., 2015; Jagarnath *et al*., 2020; Cheng *et al*., 2021; Abrar *et al*., 2022).
Services composite	**Water type**	Percentage of respondents who utilise water not piped into dwelling	The lack of piped water into dwellings limits individuals' immediate access to water, which is crucial in responding to extreme heat. Furthermore, non-piped water is also likely to increase the risk of poorer water quality, which may result in water-borne illnesses (Jagarnath *et al*., 2020; Cheng *et al*., 2021; Abrar *et al*., 2022).
	Electricity availability	Percentage of respondents with no access to electricity	Access to electricity is a proxy for a fundamental resource needed to respond to extreme heat, including the use of air conditioning and other cooling methods (Wolf & McGregor, 2013; Cheng *et al*., 2021; Abrar *et al*., 2022).
Resource & communication composite	**Transportation**	Percentage of respondents with no access to formal transportation (including respondents who walk or use a bicycle, minibus taxi, bus and other)	No access to formal transportation presents exposure of individuals to increased heat extreme within the conditions of these transport systems, including limited air circulation and ventilation, increased exposure to extreme heat and delayed access to healthcare services (Cheng *et al*., 2021).
	Healthcare type	Percentage of respondents who utilise public and/or informal healthcare systems	Public and informal healthcare systems are usually more crowded than private healthcare and resources are limited. This may delay access to medication and medical services needed during extreme heat events (Cheng *et al*., 2021).
	Healthcare proximity	Percentage of respondents with healthcare facilities outside the area of their household	Healthcare providers, including physicians, nursing homes and hospitals, are important sources of relief from heat-related health impacts. The lack of proximate medical services will lengthen immediate relief and longer-term recovery from heat exposure (Cheng *et al*., 2021).
	Medical aid	Percentage of respondents who are not covered by any form of medical aid or insurance	Medical aid acts as a proxy for relatively secure employment and adequate economic resources. Households with access to medical aid are also likely to have easier access to medication and medical care (Cheng *et al*., 2021).

Composite & variable		Variable definition	Rationale for inclusion
	Access to communication	Percentage of respondents whose household does not have access to a form of communication	Access to information and communication is crucial in ensuring households and individuals understand the risks, impacts and protective actions to take during extreme heat events. Furthermore, this access will also inform individuals of an incoming period of increasing temperatures and/or extreme heat (Cheng *et al*., 2021).

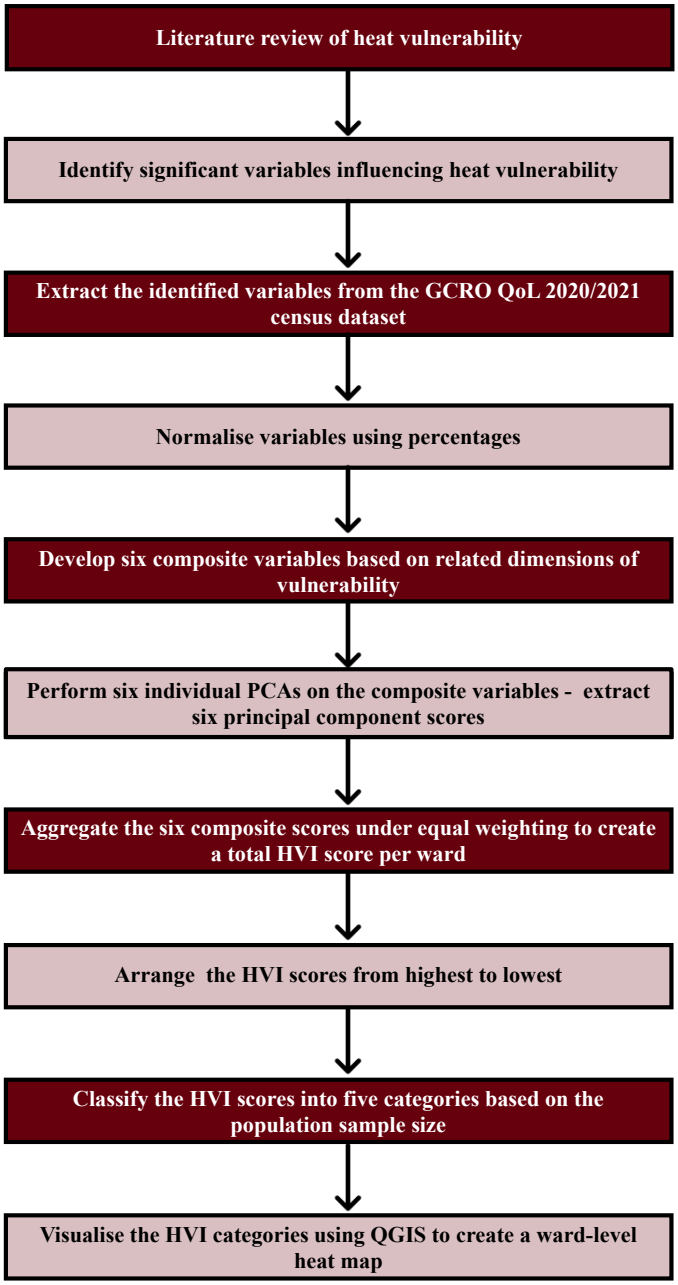


Figure 3.7: Figurative illustration of the step-by-step process of the Heat Vulnerability Index method.

Additionally, for an effective PCA, two key assumptions needed to be met before proceeding with the analysis. The first assumption was that the 'correlation matrix is an identity matrix', and the

second was that the ‘sampling adequacy’ was appropriate relative to the number of variables included (IBM Corp, 2017; Jagarnath *et al*., 2020). These two assumptions were tested on the total dataset used during the PCA before the composite variables were created to ensure the overall suitability of the dataset used in the analysis.

The first assumption was tested using Bartlett's Test of Sphericity to measure the suitability of the correlation matrix to ensure a correlation between the variables. The null hypothesis for this test was no correlation between the variables in the selected dataset, where the acceptable threshold for this test is $p < 0.005$, indicating that the dataset used is suitable for the PCA.

The second assumption was tested using the Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy to assess whether the variables were suitable for the analysis by evaluating the extent of the common variances between the variables. The KMO test provides a value from 0 to 1, where a higher value indicates better sampling adequacy, with the acceptable threshold for this test as > 0.60, verifying the suitability of the dataset.

3.5 ETHICS PROTOCOL

An application to the Wits Human Research (Non-medical) Ethics Committee was completed and accepted (Appendix 2).

An ethics protocol for the City of Johannesburg, the City of Tshwane and the City of Ekurhuleni was completed with Acceptance and Permission Letters received to conduct this study, supported by the municipalities and the various planning regions within the cities.

In summary, this chapter provided the methodological overview of the research design and approach of this study. The mixed-method approach using qualitative (i.e., narrative approach) and quantitative (i.e., heat vulnerability framework) aspects was discussed. The qualitative approach included semi-structured interviews with the Environmental Health Officials throughout the three Gauteng metropolitans to understand the extent to which extreme heat is being planned for and responded to at a local level. Furthermore, the quantitative approach included the development of a heat vulnerability assessment tool to identify the populations and areas most susceptible to extreme heat and the related health impacts. This used socio-economic indicators from the GCRO QoL 2020/2021 surveyed data as a proxy to represent the sensitivity and adaptive capacity of the local populations to extreme heat in the three Gauteng metropolitans. Having laid out the methodology of this research, the following chapter (*Chapter 4*) explores and outlines the results, which are further discussed in the subsequent chapter (*Chapter 5*).

4 CHAPTER FOUR – RESULTS

Now that the background and methodology have been clearly outlined (*Chapters 2 & 3, respectively*), results of the qualitative (i.e., narrative approach) and quantitative (i.e., heat vulnerability framework) aspects of the mixed-methods research design of this dissertation are presented. Before delving into these narrative and vulnerability approaches, it is fundamental to identify and understand the current national and municipal policies and plans to address extreme heat in South Africa and the three Gauteng metropolitans. As discussed in the literature review (*Chapter 2, Section 2.10*), the national policy and heat action landscape has already been laid, and this chapter will focus on the municipal aspects of heat action in the three metropolitans. Furthermore, as identified in the National Heat Health Action Guideline and discussed above (*Chapter 2, Section 2.11 & Chapter 3, Section 3.3*), the Environmental Health Department has been tasked with leading heat action in all spheres of government in South Africa, and it is this essential to outline the structure and functions of this department. From this critical contextual background, attention turns to the challenges and opportunities identified within the operational context of the three metropolitans' Environmental Health Officials using the semi-structured narrative interview process. Lastly, the quantitative heat vulnerability dimension results will be discussed to assist in identifying the spatial distribution of vulnerability throughout the three metropolitans. Ultimately, the results from this comprehensive research will provide a platform to advance the responses to heat-related health impacts throughout the Gauteng metropolitans by laying the basis for developing adaptation strategies working from an understanding of the vulnerability of the populations.

4.1 UNDERSTANDING THE POLICY AND CLIMATE ACTION LANDSCAPE IN SOUTH AFRICA AND GAUTENG MUNICIPALITIES

To fully understand the extent of local governments' responses to heat-related health impacts in the three Gauteng metropolitans, it is critical to identify the climate change policies and plans within South African legislation, as well as the municipal IDPs and CCRSs/CAPs that have relevance for heat health planning. By gaining a more comprehensive understanding of the broad geo-political landscape, the challenges and opportunities presented, particularly on a local level, in relation to the development and implementation of responses to heat-related health impacts can be identified. In this section of the dissertation, the dynamics between the South African policies and plans formulated at a national level, including the Climate Change Response White Paper, the Climate Change Bill, the Climate Change Adaptation Strategy and the Heat Health Action Guideline, and the corresponding municipal plans put in place within the three metropolitans to address extreme heat, including IDPs, CCRSs and CAPs, are examined. This will provide the setting of the political landscape of heat action

and assist in understanding the extent of local governments' responses to heat-related health impacts, as well as the operational challenges and opportunities presented on a local level.

The Climate Change Response White Paper, Climate Change Bill, Climate Change Adaptation Strategy and Heat Health Action Guideline outline the policies, approaches and frameworks to combat the climate crisis, with specific strategies for heat action, in the hope to build climate resilience in the country (*Chapter 2, Section 2.10*). Since the inception of these policies and response strategies, municipalities have embedded climate change in their local planning and budgeting. Climate change is now a common topic within most South African municipalities' IDPs, with some metropolitans also developing localised CCRSs and CAPs highlighting particular focus areas and strategies for heat responses.

A comprehensive outline of the political and planning context of the three Gauteng metropolitans of this study with respect to climate action and heat responses is provided below. The long-term strategic planning and broader developmental goals within the metropolitans' IDPs is firstly provided, highlighting the various cities' climate action visions, goals and objectives. This section will then further delve into the detailed plans, strategies and actions, which specifically focus on and address the impacts of extreme heat at the municipal level, within the CCRS and CAP documents.

4.1.1 City of Johannesburg

The City of Johannesburg has embedded climate change as a key focal point in its 2021-2026 IDP, with a long-term objective for climate change resilience and environmental protection in the Johannesburg 2040 Growth and Development Strategy. The objective, however, is not addressing the risks and impacts of climate change on the human population but is "*concerned with advancing towards a sustainable, resilient and liveable city, with focus on, reducing consumption of natural resources, reducing carbon emissions, minimising environmental pollution and protecting the City's natural environment*" (City of Johannesburg Metropolitan Municipality, 2021, pp.73-74).

The City of Johannesburg's IDP only mentions the impacts of climate change on the physical-natural and -human environments, with reference to the increased frequency and intensity of extreme weather events. In the context of extreme heat, the IDP assigns no particular focus on the topic besides a brief statement that "*there will be more episodes of heat waves with serious impacts on human health*" (City of Johannesburg Metropolitan Municipality, 2021, p.221), and the identification of extreme temperatures as a possible hazard in the risk assessment in the City of Johannesburg Disaster Management Plan. Additionally, the City of Johannesburg's IDP provides reference to the development of a CAP for the City to "*prioritize evidence-based transformational actions and aims*

at transitioning towards an emission neutral, and climate resilience city by 2050" (City of Johannesburg Metropolitan Municipality, 2021, p.220), but no in-depth context or detail of the plan is included. The City of Johannesburg IDP is, therefore, a planning tool with limited detailed responses and strategies to tackle climate change impacts and risks, and hence, must be supplemented with the City's climate change response strategies and action planning documents.

The City of Johannesburg has, in addition to the IDP, also developed a CAP as of March 2021 that provides the context and extent of climate change impacts on and risks to the City. This reflects the City of Johannesburg's commitment to addressing climate challenges, enhancing environmental sustainability, and creating a better future for its population. The CAP outlines the strategies and initiatives to address the impacts of climate change within the City. The plan includes a comprehensive set of actions to enhance climate resilience and adapt to climate change impacts, with key focus areas on "*enhancing water security, creating resilient human settlements, implementing flood and drought management strategies, developing resilient infrastructure and enhancing the health and wellbeing of communities*" (Figure 4.1) (City of Johannesburg, 2021, p.4). The CAP serves as an outline and guidance document for decision-making, resource allocation and policy development related to climate risks and impacts in the City of Johannesburg.

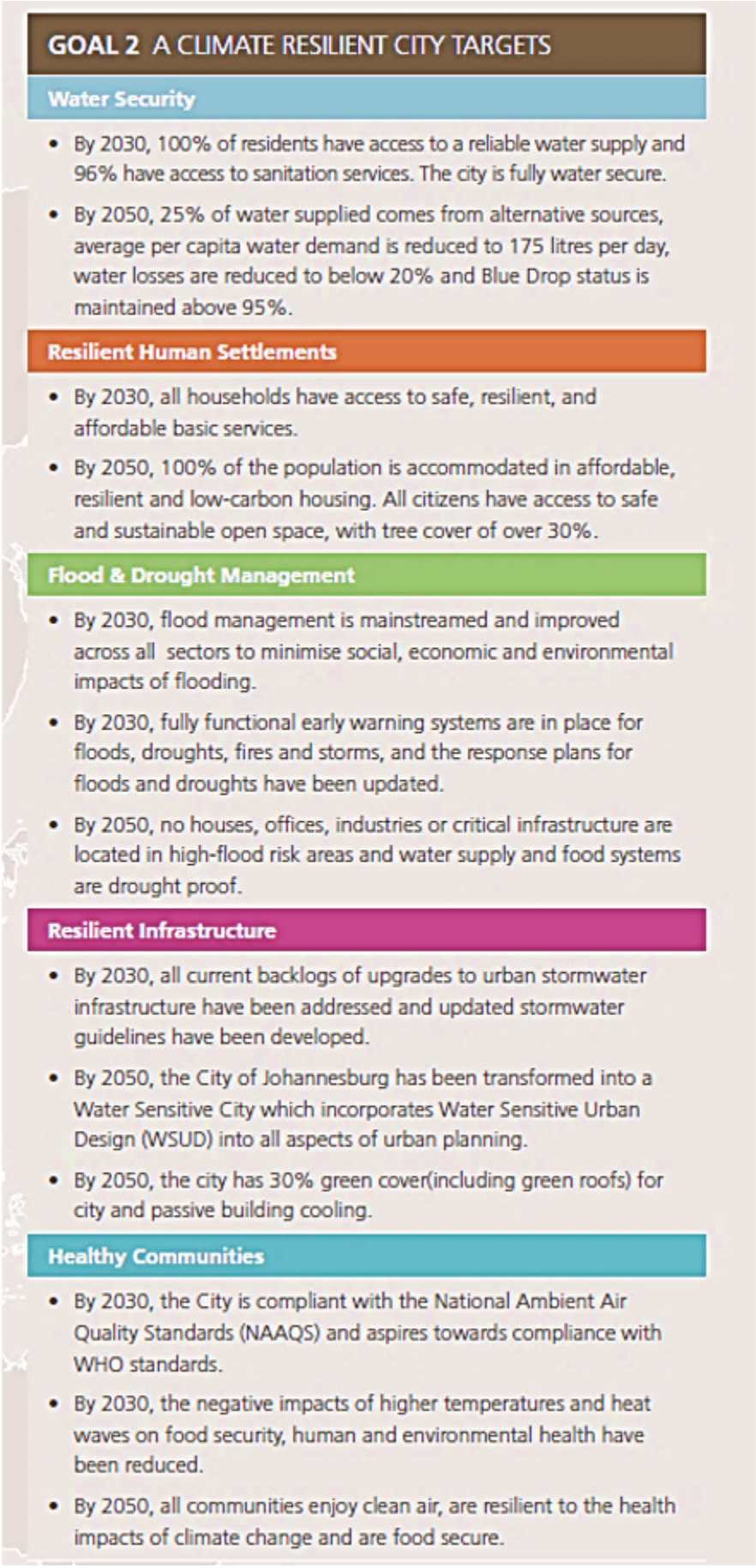


Figure 4.1: Climate-resilient adaptation targets of the Johannesburg CAP. Source: City of Johannesburg (2021, p.55)

The context of extreme heat is highlighted throughout the CAP and is identified as one of the key impacts of climate change. The CAP highlights that "*increasing temperatures are a major concern, particularly in inland areas of South Africa. Extreme and prolonged heat exposure can constitute a direct human health risk and also increases the need for additional cooling, leading to increased energy demand*" (City of Johannesburg, 2021, p.46). The identification of extreme heat as a significant risk in the City has led to the inclusion of specific adaptation actions to protect the public from heat-related health impacts. These actions and responses aim to improve human health and increase resilience to high temperatures by "*implementing awareness-raising campaigns, conducting research to improve understanding of the impacts of heat, developing mechanisms to cool health facilities and developing green infrastructure*" (City of Johannesburg, 2021, p.116). Furthermore, the CAP also builds on the national and municipal disaster risk reduction and management approach and includes disaster risk reduction and recovery as a key adaptation action area within the City, which aims to "*protect Johannesburg's residents and businesses from climate change-induced hazards such as floods, droughts, storms, heatwaves and disease by establishing early warning systems that can effectively and quickly distribute reliable, useful information to all Johannesburgers. The city will also develop preparedness and response plans to reduce damage, recovery time and cost for each of the identified hazards*" (City of Johannesburg, 2021, p.121).

The City of Johannesburg's CAP provides a comprehensive outlook of the City's climate change impacts and risks, with specific adaptation actions proposed to address extreme heat. It is essential for the CAP to be supplemented within the context of the IDP for more effective planning, budgeting and implementation of climate responses in the City. The combination of the two will ensure that the broader development goals are outlined in the IDP, while the CAP provides specific focus on the adaptation strategies and plans to address heat action throughout the City.

4.1.2 City of Tshwane

Unlike the City of Johannesburg, the City of Tshwane's 2022-2026 IDP provides a more detailed outline and approach for climate action, built from the City's 2022 CAP. Tshwane's IDP provides a comprehensive summary of the City's newly developed CAP, which highlights the CAP's ten outcomes, each outcome's goals, the 36 programmes proposed to achieve these outcomes and the targets used to assess the performance of the CAP outcomes and goals.

The IDP in this case still, however, serves as a planning tool with limited clear responses and strategies to combat climate change impacts, with a brief reference to mitigation efforts to the overall effects of climate change through "*the use of green infrastructure; organisation of space that reduced urban heat island effect; protecting minimally developed or undeveloped areas and biodiversity,*

through compaction, densification, and infill of already developed area; technological advances in various sectors to reduce greenhouse gas emissions; being proactive with regards to water and energy demand management, water harvesting and retention; and being proactive with regards to alternative energy sources" (City of Tshwane Metropolitan Municipality, 2021, pp.137-138). Tshwane's IDP, however, does provide more focus on the impacts of climate change on human health, including "*higher temperatures, more erratic rainfall patterns and more frequent and intense extreme climate events*" (City of Tshwane Metropolitan Municipality, 2021, p.239); and has since embraced an evidence-based approach to climate action where "*the city regularly updates its Greenhouse Gas emissions inventory, has developed and will regularly update a climate risk and vulnerability assessment and has identified areas that require more in-depth understanding*" (City of Tshwane Metropolitan Municipality, 2021, p.239). The City of Tshwane has also provided an alignment of climate change and risk reduction within its Disaster Management Plan, highlighting that "*the city has made a long-term institutional commitment to tackling climate change. It has established a dedicated unit and equipped it with the resources required to mainstream climate change in the City*" (City of Tshwane Metropolitan Municipality, 2021, p.239).

Furthermore, Tshwane's IDP has a comprehensive review of the CAP, outlining the risks and impacts of climate change, as well as an overview of the goals and mechanisms for effective climate action. This review also highlights the impacts of extreme heat and increasing temperatures on human health within the City but provides no further mention of the strategies and responses needed for heat action. Therefore, although Tshwane's IDP appears to be a more detailed planning tool for climate action than Johannesburg's IDP, it must be supplemented with the City's CAP and other action planning documents for a more comprehensive approach for specific climate change and heat responses.

As outlined within Tshwane's IDP, Tshwane's CAP as of June 2022 highlights measures for climate change adaptation, mitigation and resilience building, expanding upon the Tshwane CCRS of 2017. The CAP outlines a comprehensive list of climate actions and strategies to "*address climate risks, build climate resilience, and promote net-zero carbon emissions*" with co-benefits to "*promote equity and a just transition, and ensure health and resilience of people, natural resources and the economy*" (City of Tshwane, 2022, p.52). The CAP is divided into ten thematic areas (Figure 4.2), each with strategic actions and targets, and collectively deliver the vision of Tshwane's CAP.



Figure 4.2: The ten thematic areas of the Tshwane CAP, with the goal of each area highlighted. Source: City of Tshwane (2022, p.56)

Like Johannesburg's CAP, Tshwane has embedded extreme heat as a priority throughout the CAP and has identified heat as a current and future risk in the City. The CAP highlights that "*exposure to high temperatures can lead to heat stress and increased morbidity and mortality, and as temperatures rise due to climate change, the risk of heat stress will also increase*" (City of Tshwane, 2022, p.42). Furthermore, the CAP has not only identified the impact of extreme heat but has mapped out the City's current and future heat hazards from the Green Book (*Chapter 2, Section 2.9, Figure 2.14a*), highlighting the areas at a higher risk of heat-related impacts.

Unlike the City of Johannesburg's CAP, which provides specific actions and responses to heat-related health impacts, Tshwane's CAP embeds heat risks throughout the programmed action and response plans of five of the ten thematic areas (Figure 4.3). As part of the thematic area of "*Safe, healthy, prosperous and climate-resilient communities*", Tshwane has also built on the national and municipal disaster risk reduction and management approach and aims to "*investigate, identify and map climate-related disaster risk for each key hazard; develop disaster risk reduction and management plans and systems, using exposure and vulnerability indicators as guidance, and update emergency protocols; and identify and develop measures to reduce the identified risks of climate hazards to informal settlements and informal traders*" (City of Tshwane, 2022, p.61). Although Tshwane's CAP does not specifically highlight extreme heat as one of the ten thematic areas, heat action is embedded throughout the strategic programmes, responses and targets of the CAP, which has been addressed as a priority focal point.

Thematic area 1: Safe, healthy, prosperous and climate-resilient communities.

Thematic area 2: Climate-smart urban planning and design.

Thematic area 4: Climate-proof infrastructure.

Thematic area 5: Net-zero carbon, efficient and climate-resilient buildings and public facilities.

Thematic area 6: Climate-resilient ecological infrastructure and protected natural resources.

Figure 4.3: Thematic areas that include programmed actions and responses for heat risks in the Tshwane CAP. Source: City of Tshwane (2022, pp. 60-88)

As with Johannesburg, Tshwane's CAP provides a comprehensive breakdown of the climate change risks and impacts, with the goals, programmes and targets of climate action clearly outlined throughout. Although Tshwane's IDP provides a more detailed view of the specific climate change responses and actions than the City of Johannesburg's IDP, it is still limited in the details of the responses and strategies to combat climate change and extreme heat impacts, and Tshwane's IDP must be supplemented with its CAP for improved climate action planning, budgeting and implementation.

4.1.3 City of Ekurhuleni

Like Tshwane's IDP, the City of Ekurhuleni's 2022-2026 IDP has a comprehensive section regarding the impacts and risks of climate change, built from the City's 2017 CCRS. The IDP highlights the impacts of climate change in the three dimensions of sustainability, including "*Economic, Environmental, and Social*" (City of Ekurhuleni Metropolitan Municipality, 2022, p.50), and identifies the key risks, vulnerabilities and impacts of climate change for the City, including

> "*increasing temperatures affecting social welfare and natural assets; increased rainfall, which could lead to infrastructure damage, particularly about road infrastructure; water service disruption due to increasing rainfall overburdening existing system capacity, and concerns pertaining to the potential contamination to potable water because of ineffective and under capacitated service infrastructure; increased dry spells will lead to a heightened need for water and again the over-capacitating of an already strained resource network; and changing weather patterns will greatly affect the agricultural sector of the EMM leading to inter alia reduced agricultural production*" (City of Ekurhuleni Metropolitan Municipality, 2022, p.52).

However, although a comprehensive outline of the risks and impacts of climate change is given, Ekurhuleni's IDP provides limited responses and strategies to combat the impacts of climate change but focuses on strategically mainstreaming climate change into the City's overall operations and departmental targets and objectives, including

> "*voluntary disclosure reporting platforms (i.e., Carbon Disclosure Program – CDP) to share cities action and progress towards tackling climate change; sharing climate change information, commenting on technical document and ensuring coordination of climate change and resilience initiatives in the city; the development of guiding documents in alignment with sector department's targets and commitments; integrating climate change indicators into the city and strengthening the cities resilience by making efforts towards institutionalizing climate resilience into city systems, structures, strategic documents and creating strategic programs*" (City of Ekurhuleni Metropolitan Municipality, 2022, p.52).

In the context of extreme heat, the IDP briefly mentions that increasing temperatures will affect society and the natural environment in the City, and "*the predicted effects of climate change include extreme weather events, increased frequency of disease, and heat stress*" (City of Ekurhuleni Metropolitan Municipality, 2022, p.51). However, extreme heat and the increase in temperatures are not considered a risk within the City's Disaster Management Plan and, therefore, are not within the planning capacity of disaster risk reduction and management approaches. Ekurhuleni's IDP is thus limited in the responses and strategies to tackle climate action, specifically regarding heat extremes, and must be supplemented with the City's CCRSs and action planning documents.

Similarly to the City of Johannesburg's and Tshwane's CAPs, Ekurhuleni's CCRS of 2017 provides a framework for climate action and highlights the extent of climate change impacts and risks in the City. It outlines the climate actions and strategies aimed at "*building resilience and climate proofing the city*" (City of Ekurhuleni Metropolitan Municipality, 2017, p.31). Ekurhuleni has identified the City's climate change context and has highlighted various climate risks, impacts and vulnerabilities in the CCRS for the current and future periods. The priority impact areas of climate change are "*higher temperatures; reduction in average rainfall; increase in intensity and frequency of storm events; reduced water availability; and the strain on agricultural production*" (City of Ekurhuleni Metropolitan Municipality, 2017, p.26).

The CCRS outlines the strategies and responses to address the impacts of climate change within the City and includes a comprehensive list of potential climate actions that combine adaptation and mitigation approaches. The adaptation approaches focus on key developmental areas: "*(1) Water sector; (2) Agricultural; (3) Human health; (4) Biodiversity and Ecosystems; (5) Human settlement; (6) Disaster risk and early warning; and (7) Waste*" while the mitigation approaches focus on *"(1) [The] Energy sector; (2) Transport sector improvement; (3) Industry and commerce; and (4) Infrastructure*" (City of Ekurhuleni Metropolitan Municipality, 2017, pp.32-42).

Similarly to the CAPs of Johannesburg and Tshwane, Ekurhuleni's CCRS embeds extreme heat as a priority throughout the response plans and has also provided a comprehensive section relating to the risks of heatwave events and heat-related health impacts. The CCRS highlights that "*both increased average temperatures and increasingly frequent and severe extreme heat events produce increased risks of heat-related illness and death that can be significant*" (City of Ekurhuleni Metropolitan Municipality, 2017, p.211). Furthermore, the adaptation and mitigation approaches outlined in the CCRS to reduce overall heat-related health impacts include "*aggressive public health actions and widespread physiologic and behavioural adaptations such as robust heat early warning systems and other health communications, increased air conditioning use, decreased time spent outdoors, and increased wearing of sun-shielding clothing*" (City of Ekurhuleni Metropolitan Municipality, 2017, p.212). The CCRS also builds on the national and municipal disaster risk reduction and management approach and outlines a detailed section for integrating disaster risk and management within climate change adaptation with key focus areas (Figure 4.4) (City of Ekurhuleni Metropolitan Municipality, 2017).

1. Understanding vulnerabilities to existing patterns of disaster risks, especially climate related hazards
2. Working with vulnerable groups to understand and prioritize their existing concerns
3. Compiling information on future changes in climate and how these are likely to affect historical disaster patterns of occurrence and/or create new patterns and locations of disaster occurrences
4. Analyzing less visible climate changes, such as seasonal shifts, persistent drought, extended periods of extreme weather and temperature, and other slow-onset or incremental changes that can be nonetheless destructive
5. Ensuring enhanced levels of preparedness for current patterns of climate risks and all hazards
6. Ensuring that planning and decision making include strategies for dealing with disasters and climate hazards of both today and tomorrow
7. Ensuring structural measures are designed for future climate risks, based on likely climate change scenarios

Figure 4.4: The areas in which an integrated Disaster Risk Reduction and Climate Change adaptation approach would look at in the City of Ekurhuleni. Source: City of Ekurhuleni Metropolitan Municipality (2017, p.233)

As with Johannesburg and Tshwane, and due to the limited nature of Ekurhuleni's IDP, the responses and strategies to tackle climate action within Ekurhuleni's CCRS must be supplemented within the context of the City's IDP for better planning, budgeting and implementation of climate action responses on the ground.

Overall, the three metropolitans' policies and plans (i.e., IDP and CAP or CCRS) have, to some extent, provided the necessary planning capacities to develop and implement heat adaptation strategies on a local level. Johannesburg and Tshwane are a step ahead of Ekurhuleni due to the recent development of their CAP documents, which specifically address extreme heat with proposed actions and strategies to address heat action. Furthermore, these two cities have identified extreme heat as a risk in their Disaster Management Plans, whereas Ekurhuleni has not and only provides an outline for potentially integrating disaster risk and management within climate change adaptation. Lastly, it should also be highlighted that although the CAP and CCRS of all three metropolitans provide more insights into heat risk and adaptation actions, there is still minimal reference to actual heat adaptation strategies in the metropolitans' IDPs. Heat action must reflected in the municipal IDPs for better budgeting, planning and decision-making in the future. Table 4.1 outlines the policy and planning context of extreme heat throughout the three metropolitans.

Table 4.1: Summary of the policy and planning for extreme heat and heat-related health impacts in the three Gauteng metropolitans, highlighting the heat context, disaster risk management approaches and the proposed adaptation actions to extreme heat

Element	City of Johannesburg	City of Tshwane	City of Ekurhuleni
Heat context in the IDP	The IDP assigns no particular focus on extreme heat but acknowledges that there will be more heatwaves that could impact human health, as well as identifying extreme temperatures as a possible hazard in the risk assessment in the City's Disaster Management Plan.	The IDP places the greatest emphasis on the impacts of climate change on human health, particularly rising temperatures, taking an evidence-based approach to climate action (i.e., regular updates to the climate risk and vulnerability assessment). Furthermore, the City has integrated climate change and risk reduction into its Disaster Management Plan.	The IDP briefly mentions that increasing temperatures will impact both society and the natural environment in the City, with the predicted impacts of climate change including extreme weather events and increased heat stress.
Reference to CAP or CCRS in the IDP	The IDP provides reference to the development of the City's 2021 CAP to prioritise transformational actions and transition towards an emission-neutral and climate-resilient City by 2050. However, no in-depth context or detail of the CAP is included.	The IDP provides a comprehensive summary of the City's 2022 CAP, highlighting its outcomes, goals, actions and targets. It also highlights the impacts of extreme heat and increasing temperatures on human health within the City, with no further mention of the strategies and responses needed for heat action.	The IDP includes a comprehensive section on the impacts and risks of climate change, developed based on the City's 2017 CCRS.
Heat context in the CAP or CCRS	Extreme heat is highlighted throughout the CAP and is identified as one of the key impacts of climate change. It highlights increasing temperatures as a significant risk, particularly in inland areas where prolonged heat exposure can constitute a direct human health risk and result in the increased need for additional cooling, leading to high energy demands.	Tshwane has embedded extreme heat as a top priority throughout the CAP and has identified heat as a current and future risk in the City. It has also recognised that high temperatures can lead to health concerns and mortality rates. Furthermore, the CAP maps out the current and future heat hazards throughout the City.	The CCRS embeds extreme heat as a priority, providing a comprehensive section on the risks of heatwaves and their health impacts. Furthermore, it highlights that rising temperatures and increasing extreme heat events pose significant risks for heat-related illness and death.

Element	City of Johannesburg	City of Tshwane	City of Ekurhuleni
Disaster risk reduction	The IDP identifies extreme temperatures as a possible hazard in the risk assessment in the City's Disaster Management Plan. Furthermore, the CAP includes disaster risk reduction as a key adaptation action area within the City, with a focus on protecting the public from climate-related hazards, including heatwaves, by establishing early warning systems. The City will also further enhance preparedness and response plans to reduce damage, recovery time and cost for these hazards.	Tshwane has included climate change and risk reduction within the Disaster Management Plan of the IDP. Furthermore, Tshwane has identified and mapped climate-related disaster risks, which will assist in enhancing emergency protocols and developing plans to reduce the impacts of climate hazards in high-risk areas.	Extreme heat and the increase in temperatures are not considered a risk within the Disaster Management Plan of the IDP and, therefore, are not within the planning capacity of disaster risk reduction and management approaches at a municipal level. However, the CCRS outlines a detailed section for potentially integrating disaster risk and management within climate change adaptation.
Adaptation actions to heat	The CAP includes specific adaptation actions to protect the public from heat-related health impacts. These actions and responses aim to improve human health and increase resilience to high temperatures through awareness-raising campaigns, research to better understand the impacts of heat, and develop mechanisms to cool health facilities and green infrastructure.	Tshwane has embedded heat risks throughout the programmed actions and response plans of five of the ten thematic areas in the CAP. Although this does not specifically highlight extreme heat as one of the ten thematic areas, heat action is included in the CAP's strategic programmes, responses and targets.	The CCRS outlines adaptation and mitigation approaches to reduce heat-related health impacts, including aggressive public health actions, physiologic and behavioural adaptations (i.e., heat early warning systems), increased use of air conditioning, decreased outdoor heat exposure and increased use of sun-shielding clothing.

CAP: Climate Action Plan; CCRS: Climate Change Response Strategy; IDP: Integrated Development Plan

In summary, an overview of and insights into the current national and municipal policies and plans to address extreme heat throughout the study's three metropolitans has been provided (*Chapter 2, Section 2.10 & Chapter 4, Section 4.1*). In South Africa, various policies, plans and frameworks are in place for municipalities to include heat considerations in their planning, budgeting and operational activities, with evidence of some specific heat action guidelines for local governments. Furthermore, the three metropolitans have, to some extent, included heat action in their planning capacity, which has enabled them to develop specific responses and strategies aimed at targeting extreme heat and heat-related health impacts. Now that the political and heat action landscape has been set, the following section delves deeper into the operational activities and implementation of the above-

mentioned policies and plans to identify the extent of local governments' responses to heat-related health impacts.

4.2 ENVIRONMENTAL HEALTH DEPARTMENT: CONTEXT, FUNCTIONS AND STRATEGIC OBJECTIVES

Having laid the foundation of the policy and climate action context of South Africa and the three metropolitans, the focus now shifts to the departments and individuals responsible for implementing these plans and policies at a local level. For this research and based on the South African National Heat Health Action Guideline, as well as previous research conducted in the City of Johannesburg by Nana *et al*. (2019), the Environmental Health Department was selected as one of the key role players in implementing responses and strategies for climate-related health impacts. It is thus critical to have a comprehensive understanding of the Environmental Health Department and its primary functions and roles to effectively implement the plans and strategies for heat-related health impacts.

4.2.1 Structure and functions of the Environmental Health Department

According to the World Health Organisation (WHO), Environmental Health is defined as "*addressing all the physical, chemical, and biological factors external to a person, and all the related factors impacting behaviours. It encompasses the assessment and control of those environmental factors that can potentially affect health*" (as cited by Mathee & Wright, 2013, p.106), while Environmental Health Services are defined as "*those services which implement environmental health policies through monitoring and control activities. They also carry out that role by promoting the improvement of environmental parameters and by encouraging the use of environmentally friendly and healthy technologies and behaviours. They also have a leading role in developing and suggesting new policy areas*" (Mathee & Wright, 2013, p.106). Similarly, as highlighted in the previous chapter (*Chapter 3, Section 3.3*), the Environmental Health Strategy outlines that the practice of Environmental Health strives to

> "*identify and prevent those health conditions that may be caused by people's interactions with and exposure to their environment. It aims to promote health by improving the environment in which people are born, live and work through the identification, assessment and control of those factors in the environment that may constitute a health hazard and risk*" (Department of Health, 2016, p.6).

Furthermore, the Health Act and Environmental Health Strategy define Environmental Health Services, and specifically EHPs' functions to

> "*include the nine Municipal Health Services functions performed by district and metropolitan municipalities, as well as functions performed by the national and provincial Departments of Health, including food control, waste management and*

> *hygiene monitoring, surveillance and prevention of communicable diseases, water quality monitoring, chemical safety, health surveillance of premises, disposal of the dead, vector control and environmental pollution control […] in addition […] Environmental Health Services entails and is responsible for climate change and health matters, infection control, occupational health and health education and promotion functions*" (Department of Health, 2016, p.9).

Within the local context of South African municipalities, specifically the study's three Gauteng metropolitan municipalities, the Environmental Health Department is managed at an operational level within the municipalities' planning regions and involves resources management, services delivery, policy implementation, stakeholder engagement, performance monitoring and ensuring that the Department effectively fulfils its mandates and functions at the local level. Each planning region has an Environmental Health Manager responsible for ensuring that the roles and functions of the Environmental Health Department are fulfilled. The Environmental Health Managers are further supported by the Operational Managers, who ensure the EHPs' duties are implemented. The EHPs thus provide a bridge between the Department and the local communities by maintaining a direct relationship with the general public and responding to the needs and concerns presented by the local communities.

Moreover, the EHPs play a fundamental role in identifying, assessing and controlling all the risks related to human health and are responsible for leading the development, coordination and implementation of community health strategies and responses. Additionally, embedded within the Heat Health Action Guideline and identified in previous chapters (*Chapter 2, Section 2.11 & Chapter 3, Section 3.3*), the health sector has been identified as the lead agency on the heat health action plan, by coordinating and collaborating mechanisms across all departments, institutions and stakeholders, with the implementation of local responses if a disaster or emergency occurs. The Heat Health Action Guideline highlight Environmental Health as one of the two key departments – the other is Disaster Management – to lead this action plan with the EHPs at the forefront of heat-health responses. The Guideline outlines that,

> "*with first-hand community engagement, they [EHPs] are potentially well positioned in relation to climate change adaptation and mitigation implementation. These Practitioners can contribute to the shaping of local strategies aimed at supporting vulnerable communities to adapt to extreme heat exposure. They will require additional training to optimise their contribution to the Heat Health Action Plan*" (Department of Health, 2020, p.17).

The Environmental Health Department, specifically the EHPs, thus play a pivotal role in combatting the impacts of extreme heat on human health and are tasked with the effective coordination, collaboration and implementation of heat-health strategies and responses on a local level.

Although the Environmental Health Department has been identified as one of the key departments for the effective implementation of climate change responses and strategies and has been tasked to carry out specific heat-health action plans, this is not the case when investigating the roles, functions and objectives of the department in the local planning regions. This became clear during interviews with the 17 planning regions' Health Officials (refer to Appendix 3 for the interview responses), as the implementation of heat strategies and responses were not observed in any of the regions across the three metropolitans (n = 0), and according to these officials, climate change responses are not considered within the operational activities of their department:

> "W*e study micro and macro environments, but […] it's [climate change responses] not our primary focus; it's not an MHS focus; we deal with it as it comes.*" **[EC][8]**

The Health Officials throughout the 17 planning regions explained how they purely focus on the nine Municipal Health Services, which have been laid out within their mandate and are budgeted for, with specific strategic objectives and targets:

> "*From the high level, our seniors will give us the strategic objectives and then develop the KPIs [key performance indicators], and from the lower level, I must ensure that operational activities are done for us to accomplish that.*" **[J3]**; "W*ith us, we would need to have a mandate in enforcing that type of thing [climate and heat action], so we don't have that particular mandate.*" **[J5]**

The understanding and knowledge of the CCRSs, CAPs and heat health action plans were limited throughout the regions, with only a few Health Officials having knowledge of these plans. None (n = 0) knew of their supposed role and function for the effective coordination, collaboration and implementation of heat-related responses and strategies. Many of the Health Officials (n = 10) indicated that the policies and plans developed at a national and municipal level do not align with the Department's implementation ability and are not always 100% achievable at a local level:

> "*Some of the policies are not always that applicable on the ground; it is a challenge to 100% comply [with] these policies.*" **[J4]**

Health Officials have limited influence and involvement in the decision-making processes when it comes to policy development:

> "*We are struggling because the people that are involved [policy development] are mostly in national office, so in the local government, we struggle a lot because they are not in relation to what we* have *[…] we were talking about the shortage of staff*

[8] Reference codes have been used to indicate the metropolitan and planning region number for Health Official's responses, where J refers to Johannesburg, T refers to Tshwane, and EC refers to Ekurhuleni Combined. Furthermore, in the case of Johannesburg and Tshwane, to maintain the Health Officials' confidentiality and anonymity, random numbers were applied and, therefore, cannot be traced to specific regions (e.g., T1 does not indicate a response from Tshwane Planning Region 1).

> *[…] they're not looking at that; they are just developing the policies, and you find that with us, it's very difficult to implement.*" **[T6]**

Furthermore, the Health Officials indicated that, even if heat response strategies were mandated and budgeted for within their department, they are limited with the number of EHPs working on the ground to effectively include heat responses in their operational activities:

> "*You see, that is something that needs to be considered as well in the implementation of such an event. There should be people [a team for heat responses], but […] there are not enough EHPs […] we cannot take them out of the service, to withdraw them from MHS, and tell them to look at heat issues.*" **[EC]**

According to the World Health Organisation Guidelines and the National Environmental Health Policy of 2013 (referred to as the Environmental Health Policy), local governments are advocated to "*deploy at least 1(one) EHP for every ten thousand population 1:10 000 for provision of EHS. To ensure equity of environmental health in the country, the government must ensure conformance to the WHO [World Health Organisation] guideline for operational EHPs*" (Department of Health, 2013, p.24). However, this is not the case at the local level, and EHPs are significantly limited throughout the three metropolitan's regions, even within the areas of considerable demand. This highlights a significant gap and disconnect between the policies and plans set out nationally and municipally with the implementation abilities on the ground on a local level.

4.2.2 Operational context and response strategies of the Environmental Health Department

The Environmental Health Department, specifically the EHPs, are currently not achieving the Department's full capabilities of sustaining the nine Municipal Health Services and unlocking the potential to play a fundamental role in climate change response strategies in instances related to health. The EHPs' daily interactions with the local communities provide a line and network of communication between the Department and the local populations, which can prove extremely effective for building awareness and education on the impacts and risks of climate change.

The Environmental Health Officials across the three metropolitans showed a comprehensive understanding and knowledge of climate change and its impacts on society, with all officials (n = 17) able to recognise examples of current climate change impacts within the local context of their planning regions. However, it must be noted that extreme heat and heat-related health impacts are only considered a significant risk in a few planning regions (n = 5), with local communities rarely complaining and highlighting problems and difficulties from increased temperatures and extreme heat:

> "*I cannot remember that we've ever received a heat complaint.*" **[T7]**

Heat is simply viewed as natural and a normal occurrence by local communities, and it is an expectation that temperatures will increase with some days exhibiting intense heat:

> "*I think because they [local communities] are used to heat; they don't usually complain about it.*" **[T6]**; "*Heat? No, not from the communities; it's almost as if […] the community sort of expect it [extreme heat].*" **[T7]**.

This is significant for the Environmental Health Department; it is not considered a priority focus area or a direct health hazard and risk if the local communities don't raise these issues. As outlined in the Environmental Health Strategy, the Environmental Health Department will only identify, assess and control those factors in the environment that may constitute a health hazard and risk (Department of Health, 2016).

Although the local Environmental Health Departments and Environmental Health Officials are not currently fulfilling the function of implementing climate change responses, they are well positioned and have built the foundations for effective coordination, collaboration and implementation of these responses in the future. Throughout the three metropolitans, the majority of the regions (n = 15) have already identified the vulnerable populations and communities that are at a higher risk of climate change impacts:

> "*The focus is on the elderly, like the old age homes, and then also early childhood centres like our ECDs [early childhood developments].*" **[J2]**; "*We do prioritise […] the vulnerable groups, which is the ECDs, old age homes, schools, mental institutions and places like that.*" **[T7]**.

Most of these regions (n = 12) have also developed outreach campaigns for education and awareness drives for various topics in these communities, including health and hygiene, law enforcement, disease and pest control, land and water pollution, housing and development and fire management:

> "*We do awareness and health education for a lot of different things […]; we [do] also do education, and then awareness in schools, primary school, high schools, […] because […] the who is most affected [the most vulnerable] is elderly, the people above 65, and also children.*" **[J2]**; "*We have a component […] called health promotion, so they also look at such activities or services in terms of informing mainly or promoting the health awareness campaigns.*" **[J7]**

The continuous community engagement of the Environmental Health Officials throughout the three metropolitans provides opportunities to develop an effective communication network between the Department and the local populations for the coordination, collaboration and implementation of heat-health strategies and responses in the future.

4.2.2.1 City of Johannesburg

The context of the City of Johannesburg is unique compared to the neighbouring Tshwane and Ekurhuleni cities because Johannesburg is South Africa's largest populated city but covers the least amount of land of the three metropolitans (City of Johannesburg Metropolitan Municipality, 2021). The City's urban density is significantly larger than the other two cities, highlighting how densely populated the municipality is (City of Johannesburg Metropolitan Municipality, 2021). This provides a setting for significant heat extremes presented from the UHI effect due to the density and nature of the landscape and urban areas found within the City (Grimm *et al*., 2008; World Health Organisation, 2008; Hallegatte & Corfee-Morlot, 2011; Nana *et al*., 2019). However, these heat extremes are not identified or seen as a risk within the City, with only two (n = 2) of the planning regions highlighting the effects of extreme heat on their region and its communities during the summer months in the past few years:

> "*We've heard […] about people collapsing due to heat [i.e., in the past few years during the summer months]; people collapsing due to dehydration as a result of extreme heat.*" **[J6]**.

In both cases, the Environmental Health Officials identified these heat risks, which were not raised by the local communities. From these two regions, only one region had identified the health-related impacts of heat extremes, as they noticed individuals collapsing due to heat exhaustion and dehydration, while the other region highlighted the lack of cooling and ventilation in the City, which will likely increase heat exposure for the region's communities.

Although heat-related health impacts are not considered a priority within the City, the different regions have the structures and foundations to build on for effective heat responses and strategies in the future. All the planning regions (n = 7) have ensured continuous community engagement, having established good relationships with relevant stakeholders in their respective communities. Environmental Health Officials are continually interacting with the local communities, and all the regions (n = 7) have identified the vulnerable populations in their area:

> "*The most vulnerable people are identified […] you find those, especially in informal settlements […]; so those are identified, and those are the people who receive more attention, of course, because of their vulnerability.*" **[J6]**

The majority of the regions (n = 5) also implement outreach campaigns to create awareness and educate the local communities about a range of health risks and concerns:

> "*We do a lot of […] training at nursery schools; we're trying to get to the kids because that's where you get [the] most learning.*" **[J1]**

The Environmental Health Officials in the City's seven planning regions have demonstrated that although no heat action and response strategies are currently being implemented, the existing structures and processes are in place to build a network for effective communication, coordination and collaboration to fulfil this function in the future.

Previous research by Nana *et al*. (2019), which similarly examined the responses of Environmental Health Officials within the Environmental Health Department of the City of Johannesburg with regard to extreme heat and heatwave events and called for action, has not seemed to gain any traction in the City with no further developments or inclusions of heat action planning and responses being made on a local level. Nana *et al*. (2019, p.253) identified that "*heat waves are absent from the local Department's mandate, with unclear legislative requirements blurring the responsibility for heat wave planning. Service delivery backlogs relegate heat wave considerations, as do the Department's constituencies for whom heat waves are not yet of concern"*.

Notwithstanding heat actions at local metropolitans, there have been developments in terms of national and municipal legislative requirements, as well as the policies, plans and guidelines developed, which outline the responsible departments and agencies needed for heat action planning and the implementation of response strategies (*Chapter 2, Section 2.10 and Chapter 4, Section 4.1*). However, although the legislative and political landscape has been contoured, this has not filtered down and reached the local governments and key stakeholders who implement these policies and plans on the ground. No heat action or heat response strategies have been included in the Johannesburg Environmental Health Department's mandate, and hence, no further developments have been made.

Furthermore, Nana *et al*. (2019, pp.253 & 262) emphasised the importance of education and awareness in heat action plans, highlighting this as a particular role that the Environmental Health Department could lead in future: "*heat wave planning supports community health education; raising public awareness of associated health risks and should be considered in future 'climate proofing' the City*" and " *[public awareness] aligns closely with the role that the City's Environmental Health Department suggested they could play in heat wave adaptation planning; one that can be tied to their core mandates of public health advice and associated awareness-raising and training programmes*". Despite this, there is still no inclusion of heat-health awareness and education campaigns in the local communities to raise public awareness of the related health risks associated with extreme heat and increasing temperatures.

4.2.2.2 City of Tshwane

The City of Tshwane is physically broader and a lot more dispersed than the City of Johannesburg, with Tshwane covering the most amount of land of the three metropolitans (City of Tshwane Metropolitan Municipality, 2021; Municipal Demarcation Board, 2021). Tshwane consists of a wide range of geographical and land use features and is not predominantly urbanised like Johannesburg, with many vast areas of agricultural and rural land (City of Tshwane Metropolitan Municipality, 2021). Tshwane is thus subjected to very different temperature extremes from one region to the next. The northern regions of Tshwane (n = 3) have identified the heat risks of their areas, but like Johannesburg, this has come internally from the Environmental Health Officials, and limited complaints are received from community members:

> "*We have the area [informal settlement]; I know that's the area that they are complaining [Environmental Health Officials' complaints] […] that, that area is hot. During the summer, it's very hot.*" **[T6]**

The rest of the Tshwane regions do not consider heat as a risk in their areas, with three regions highlighting that the local communities believe heat is a natural occurrence and it is an expectation for temperatures to increase:

> "*The community sort of expect that [extreme heat and increasing temperatures].*" **[T7]**

Similarly to the City of Johannesburg, Tshwane's seven planning regions have the fundamental structures and processes for effective heat responses in the future. The regions ensure constant engagement and communication with the local communities, with six of the seven regions having identified the vulnerable populations in their areas:

> "*We do prioritise as well as the vulnerable groups, which is the ECDs, old age homes, schools, mental institutions and places like that.*" **[T7]**

The majority of the regions (n = 5) already engage communities with outreach programmes focusing on education and awareness campaigns for specific issues and risks presented in the communities:

> "*We identify the areas, and we are aware of […] all the situations; […] we know where the need is for certain awareness campaigns, or whatever the case might be, which is more associated for certain areas or for a certain community group, and then we will target them.*" **[T2]**

Although heat-related health impacts are not considered a priority in the City of Tshwane, the local Environmental Health Officials have the structures and foundations to build on for effective heat responses and strategies in the future.

4.2.2.3 City of Ekurhuleni

The City of Ekurhuleni is a bit larger than the City of Johannesburg in terms of land cover but is not as highly urbanised and densely populated (City of Ekurhuleni Metropolitan Municipality, 2022). Ekurhuleni consists of mixed land use types, from urban, agricultural, rural and industrial areas, and is referred to as the industrial heartland of Gauteng and South Africa (City of Ekurhuleni Metropolitan Municipality, 2022). The City of Ekurhuleni's Environmental Health Officials, to some extent, identified the heat context of their City, identifying recent heat waves and increasing temperatures, as recent as February 2023, in their regions:

> "*Not so long ago […] within the last six weeks, we actually had a heatwave that persisted, which was at first indicated to be a week-long, and I actually tried to manage trends of occurrence.*" **[EC]**

Furthermore, unlike the City of Johannesburg and Tshwane, Ekurhuleni has not only identified the heat context and the vulnerable populations in the City but has already engaged with local communities on the impacts of heat stress, recently holding heat-health outreach programmes for the education and awareness of vulnerable populations:

> "A*s recently as February 2023, we actually had a heat stress, health education and awareness drive. So where communities, primarily schools [and] creches […] were informed of heat-related effects and the rest of it.*' **[EC]**

This demonstrates that the Environmental Health Officials in the City of Ekurhuleni are already unlocking their potential to play a fundamental role in heat-health responses and highlights the opportunities for further development and involvement of the Environmental Health Department in heat action in the City.

Overall, Environmental Health Officials in the three metropolitans have a comprehensive understanding and knowledge of climate change and its impacts on society and are well-equipped to manage extreme heat responses. They have, to some extent, identified the increasing risk extreme heat is having within the local communities; however, extreme heat and heat-related health impacts are only considered a significant risk in a few regions because the local communities rarely complain about concerns of increased temperatures, and heat is simply viewed as a normal occurrence. The Environmental Health Department is thus currently not fully unlocking its capabilities for responding to extreme heat events and heat-related health impacts. The Environmental Health Officials in Ekurhuleni have shown to be a step further ahead of those in Johannesburg and Tshwane, as they have already held awareness and education campaigns on extreme heat targeting the vulnerable groups after a heatwave in the City in early 2023. However, there is still much to be done for heat considerations to be embedded in the institutional dynamics of the Environmental Health Department

in all three metropolitans. As outlined in Table 4.2, the three metropolitans already have the structures and foundations to build on for effective heat responses and strategies in the future.

Table 4.2: Summary table of the heat context and existing structures for effective heat response strategies throughout the three Gauteng metropolitans, representing the identified heat concerns, community engagement, identified vulnerable populations, and current awareness and education campaigns.

Element	City of Johannesburg	City of Tshwane	City of Ekurhuleni
Identified heat concerns	Only two planning regions highlighted the effects of extreme heat.	Only the three northern regions of Tshwane have identified the heat risks of their areas, while many highlighted that local communities believe heat is a natural occurrence and is expected.	The Environmental Health Officials have, to some extent, identified the heat context of their City, identifying a recent heatwave (February 2023) in the City.
Community engagement	All seven planning regions have continuous community engagement and have established good relationships with relevant local stakeholders.	All seven regions ensure that there is constant engagement and communication with the local communities.	Environmental Health Officials constantly communicate and engage with local communities.
Identified vulnerable populations	All seven planning regions have identified their area's vulnerable populations.	Six of the seven regions have identified their area's vulnerable populations.	The Environmental Health Officials have identified the City's vulnerable populations.
Awareness and education campaigns	Five of the regions have implemented outreach campaigns to create awareness and educate local communities about a range of health risks. ***Not specific to heat.***	Five of the regions are already engaging communities with outreach programmes focusing on education and awareness campaigns for specific risks presented in the communities. ***Not specific to heat.***	Ekurhuleni has engaged with local communities on the impacts of heat stress and held heat-health outreach programmes for the education and awareness of vulnerable populations. ***Specific to heat.***

In summary, this section has highlighted that although the Environmental Health Department has been identified as the lead agency in heat health action plans throughout all government spheres, it is currently not achieving its full capabilities to unlock this potential. The implementation of heat strategies is not considered within the Department's operational activities, with the Environmental Health Officials not even aware of their supposed role in heat action planning. Furthermore, they indicated that even if heat was mandated and budgeted, they are limited in the number of EHPs to effectively include this within their operational activities. Additionally, although the Department is currently not fulfilling its capabilities to include heat action, it is well set up to develop and implement

these in future. Now that both the political and operational contexts have been set, the following section will identify the implementation challenges and opportunities presented to the local Environmental Health Department's Officials to ultimately assist in developing and implementing future heat considerations within the department.

4.3 TACKLING IMPLEMENTATION: LESSONS LEARNED AND OPPORTUNITIES FOR HEAT CONSIDERATIONS

This study's qualitative approach mainly focused on identifying the institutional context of the Environmental Health Department on a local level by understanding the challenges limiting the implementation abilities of the Environmental Health Officials, as well as recognising areas for potential improvement and opportunities for future heat considerations. These were identified by interviewing Environmental Health Officials in the three Gauteng metropolitans and were reviewed at both a city and regional level to identify the settings both within and between the three cities.

4.3.1 Implementation challenges and operational limitations in the Environmental Health Department

The Environmental Health Department is not currently fulfilling and unlocking its full potential and the implementation of climate change response strategies on a local level. As already mentioned in the previous section (*Chapter 4, Section 4.2*), this is due to a wide variety of factors, including the disconnection and misalignment of policies and plans with implementation abilities, climate change responses not embedded within the Department's mandate and budget, the lack of knowledge of the Department's involvement in heat-related responses, and limited staff and capacity to fulfil additional duties not within their already challenging mandate of the nine Municipal Health Services. The eight key categories identified as the overall challenges of the Environmental Health Official's operational activities (outlined in Appendix 3) throughout the three Gauteng metropolitans are outlined in Box 4.1 and Figure 4.5.

Box 4.1: The eight operational challenges observed and identified by the Environmental Health Officials in the study's three Gauteng metropolitans

(i)	**Resource capacity**
(ii)	**Policy misalignment with implementation ability**
(iii)	**Communication and cooperation with departments**
(iv)	**Distance and time constraints of area coverage**
(v)	**Reactive and not proactive**
(vi)	**Lack of knowledge and understanding of other departments**
(vii)	**Lack of responsibility and accountability**
(viii)	**Safety of Health Officials**

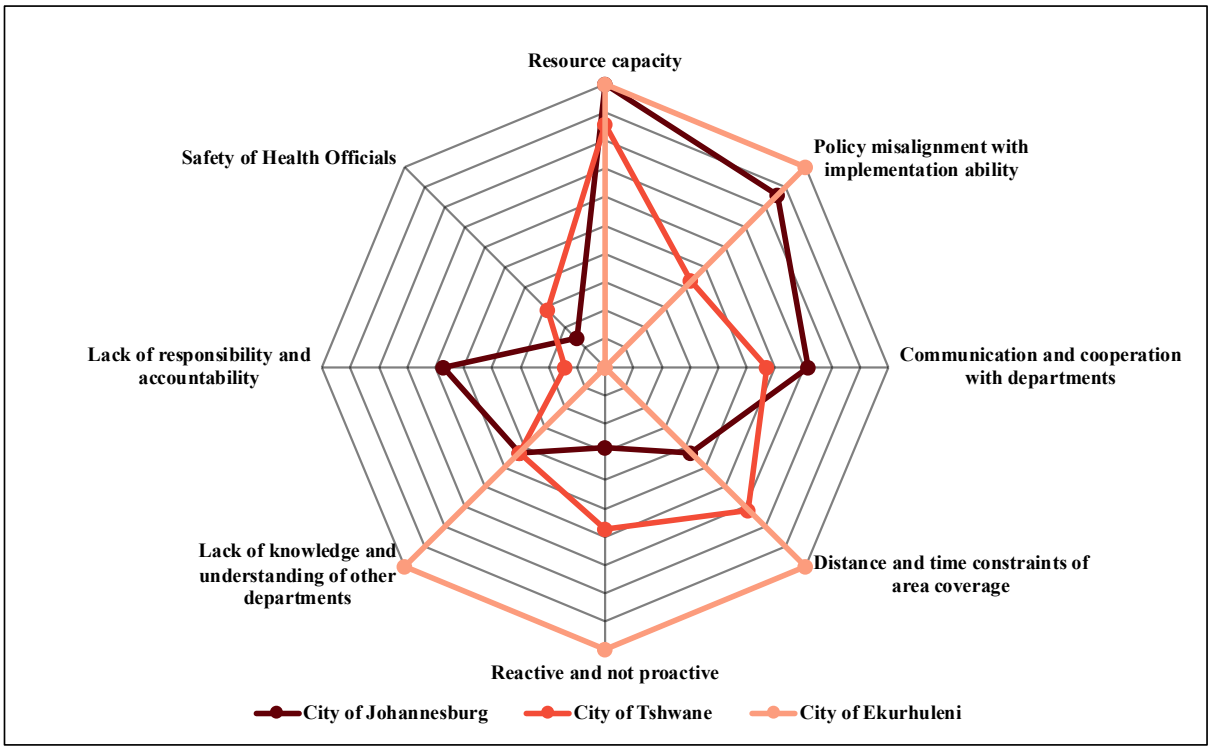


Figure 4.5: Radar Chart representing the percentage of operational challenges identified by the Environmental Health Officials in the study's three Gauteng metropolitans[9]

[9] The City of Ekurhuleni is a combined review; hence, only a single response is represented for the City (i.e., one response is equivalent to 100%), and thus is not comparable to Johannesburg and Tshwane.

(i) Resource capacity

"*Resource capacity*" was identified as the most common challenge in the three metropolitans, with almost all Environmental Health Officials (n = 14) highlighting resourcing constraints as a significant challenge in their region, compromising their ability to implement their daily operations effectively.

> "*I think most of the problems that we do encounter is* ***budget [and] under-resourcement*** *in terms of the items that we'll* ***need to effectively render our services.***" **[J4]**[10]

Resourcing constraints varied from understaffing and underfunding to the lack of physical resources available for officials to carry out their duties:

> "*The threat is that we are so* ***outnumbered****, we don't have much* ***personnel and budgets*** *for running all these tasks.*" **[J5]**; "*You* ***can't make copies****. You can't submit a single copy […] half of my staff […] doesn't have access to a computer […]* ***no ICT, no phones, no nothing.***" **[EC]**

(ii) Policy misalignment with implementation ability

Most Environmental Health Officials (n = 10) highlighted "*Policy misalignment with implementation ability*" as the second most prominent challenge in the three metropolitans, limiting their ability to achieve their set out mandate and to fulfil and implement these policies on the ground:

> "*There are some of the* ***policies*** *that have been drafted, but they are* ***not always that applicable on the ground****; it is a* ***challenge to 100% comply [with] these policies.***" **[J4]**; "*The* ***lack of really thought through policy, lacklustre policy.***" **[EC]**

(iii) Communication and cooperation with departments

Most Environmental Health Officials (n = 9) highlighted that poor communication and cooperation between departments hindered their ability to effectively implement their duties on a local level:

> "*Our* ***communication, general communication*** *of who's doing what, that thing with the left hand is not knowing what the right hand is doing, that's happening a lot. It's just the general communication.*" **[T4]**.

This refers to the lack of communication between departments about the work they have done and or are doing, as well as supporting and cooperating with each other to solve issues and address challenges effectively:

> "*I would say* ***cooperation from other departments.***" **[J3]**; "*The other sister departments are not very prompt to respond to queries or to complaints […] it is*

[10] Bold text has been applied to add emphasis to keywords and phrases to highlight the important aspects of the Environmental Health Official's dialogue.

difficult to get assistance and support *from the sister departments; it's very difficult*." **[T1]**

(iv) Distance and time constraints of area coverage

Aligned with capacity constraints, both in the form of personnel and resources and due to the vast range of area and land cover in some regions, "*Distance and time constraints of area coverage*" were commonly identified by most environmental Health Officials (n = 9) as a challenge in the three metropolitans:

"*One of the* ***challenges is the distance****, […]; you* ***travel a long distance.***" **[T1]**

This refers to the distance travelled across the various regions, with limited travel allowances available to effectively cover the whole area:

"*The* ***vast area of the region****, with the* ***allowances, they get travelling allowances****; it's not always feasible for them to go to all the areas. You will find that the amount of the allocated kilometres is exhausted, and they are not prepared to travel anymore.*" **[T2]**

It also refers to the ability to achieve their duties and targets attached to limited timeframes:

"*With norms and standards, we have targets [..], and it also has timeframes attached to it, […] which might* ***not be able to cover all the premises within that [timeframe].***" **[J2]**

(v) Reactive and not proactive

Also aligned to the regions' capacity constraints and limited staffing, the concept of being "*Reactive and not proactive*" was identified by many Environmental Health Officials (n = 7) throughout the three metropolitans:

"*As we [have] a very serious shortage of staff, we are* ***no more proactive*** *[…]; we can't manage all those things [duties and responsibilities] […] so as I'm saying, we are* ***not proactive; we just wait and then see.***" **[T6]**; "*The way it is now, we are working like we're responding to when a problem is there already,* ***not being proactive and doing preventative [preventative action]*** *[…] we* ***only now reacting; we are reactive*** *now.*" **[J2]**

(vi) Lack of knowledge and understanding of other departments

Similar to the challenge of communication and cooperation between departments, there is a "*Lack of knowledge and understanding of other departments*", with many Environmental Health Officials (n = 7) identifying this as a challenge. This refers to the knowledge of the roles and responsibilities of other departments:

"*[referring to other departments] I think even the* ***scope of work also is a problem that we don't know what they are doing; they don't know what we are doing.****"* **[T6]**

It also refers to the scope of work within their department:

> "*I think what one should just consider is that you must look at the **scope of work** and sometimes […] **they [EHPs] lose scope** with Environmental Management [Environmental Management Department] […]; so I think the **lack is knowledge of our department**, where our mandates begin and where our mandates end. The **EHPs lose the scope of what is their role** and what is Environmental Management's role.*" **[T2]**

Furthermore, higher authorities and senior management also lack the understanding and knowledge of which department is responsible for what and where a specific department sits within the mandate and constitution:

> "*I don't think that the **City completely understands the role and responsibilities that [go] with that particular Department** […]; so if the City understood the functions and what resources they have, then there won't be duplication, because **there's duplication of work.***" **[J4]**; "*There's this **perception amongst HR [human resources] and politicians and senior management** that Environmental Health is also an **unfunded mandate**. But we are **constitutionally mandated** to render Municipal Health Services.*" **[EC]**

(vii) Lack of responsibility and accountability

Although not commonly raised throughout the three metropolitans, with the City of Johannesburg making up the majority, five Environmental Health Officials raised the "*Lack of responsibility and accountability*". This refers to the lack of accountability both within the Environmental Health Department and the other sister departments:

> "***Somebody has to take responsibility**, and I think that's where the problem comes in. Because some people, when they get to a certain stage, they lose connection with what's going on on the ground.*" **[J1]**; "***Accountability is just nowhere** […] I'm [referring to theoretical individual/department] responsible for a certain function, I don't perform it.*" **[T7]**

(viii) Safety of Environmental Health Officials

Lastly, the "*Safety of Environmental Health Officials*" was highlighted as the least of the concerns throughout the three metropolitans, but three Environmental Health Officials still identified this as a challenge in their regions:

> "*We've got challenges in terms of **safety issues** […]; certain areas have become **actually unsafe for environmental practitioners** to enter and sometimes, they are **threatened […] life threatening's** […] so it places a service delivery hamper obstacle for us to really perform the functions everywhere.*" **[T2]**

4.3.1.1 City of Johannesburg

The Environmental Health Officials in the City of Johannesburg identified various factors limiting their ability to achieve their implementation duties and constraining them from further unlocking the potential to include climate change response strategies in their operations. Figure 4.6 highlights the eight key categories and the frequency of reference by the City of Johannesburg's Environmental Health Officials. In order of highest to lowest frequency, the City of Johannesburg highlighted the most common implementation challenges as (i) Resource capacity, (ii) Policy misalignment with implementation ability, (iii) Communication and cooperation with departments, (iv) Lack of responsibility and accountability, (v) Distance and time constraints of area coverage, (vi) Lack of knowledge and understanding of other departments, (vii) Reactive and not proactive, and (viii) Safety of Environmental Health Officials.

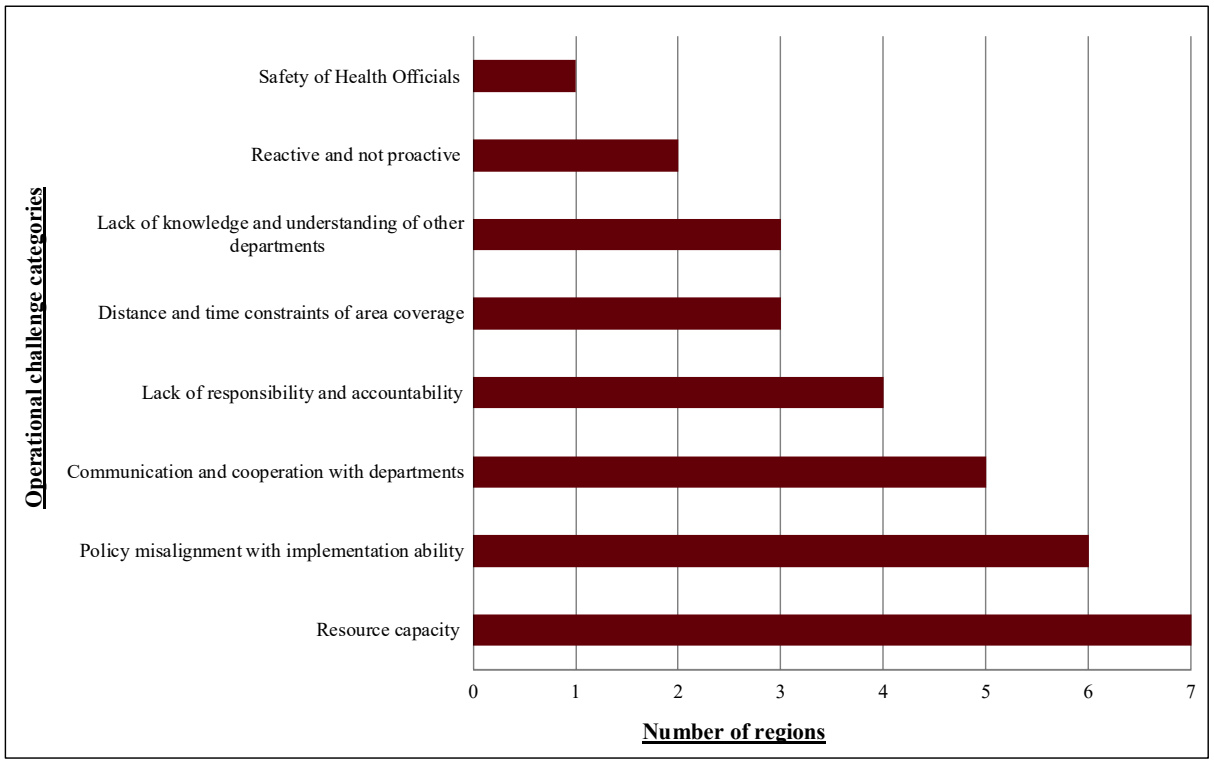


Figure 4.6: Bar graph representing the frequency of operational challenges identified by the Environmental Health Officials in the seven regions of the City of Johannesburg

As identified as the most common challenge throughout the three Gauteng metropolitans, "*Resource capacity*" was also highlighted by all the Environmental Health Officials (n = 7) in the City of Johannesburg as one of the largest constraints limiting effective implementation in the City:

> "*I think most of the problems that we do encounter is* ***budget*** *[and]* ***under-resourcement in terms of the items*** *that we'll need to effectively render our services […]; but now it becomes a challenge of fully doing the tasks that we are required to do under the* ***budgetary constraints*** *that we do have within the City.*" **[J4]**; "***Regarding our resources […] in conducting awareness campaigns****, we don't have [any]. So one*

> *is to struggle, sometimes to even use our own resources, […] in order to reach out to the communities […], but yeah, it's things that we have to do, so yeah,* ***resources are an issue*** *as well.*" **[J2]**

"*Policy misalignment with implementation ability"* was highlighted as the second most prominent challenge within the City of Johannesburg, with most Environmental Health Officials (n = 6) highlighting this element as an issue in their region:

> "*There are* ***some of the policies*** *that have been drafted, but they* ***are not always that applicable on the ground****;* ***it is a challenge to 100% comply [with] these policies.***" **[J4]**; "*When they input and who is part of it all [policy development]; like I don't know how far do they extend an invite for people to be part of it. And* ***once the policy is promulgated, the legislation*** *[…], they just send it down and* ***tell you, you must implement****. The challenge is they don't workshop these things either.*" **[J2]**

Five Environmental Health Officials identified that "*Communication and cooperation with departments*" is an underlying problem in their region, with most highlighting the limitations of effective implementation due to other departments:

> *"[referring to improvements in the city]* ***Inter-collaboration between departments*** *[…] then I think that can help a lot so that we know how to plan the same. [We] have the same strategies and have the same goals because [for example] Pikitup have their own goals, [and] we have our own goals. We are responsible for waste management [and] they are also responsible for waste management. So our goals, I don't think they really gel together. Hence, our activities somewhere, somehow, they don't complement each other.*" **[J3]**; "*I would say* ***cooperation from other departments.***" **[J3]**; "*It's a massive monster [Environmental Health Department and 'allied' departments], and* ***I don't even know who to contact sometimes*** *[…]; I don't know who's who anymore because there's so many people.*" **[J1]**

Although not highlighted as a common factor in the other two metropolitans, the "*Lack of responsibility and accountability*" was commonly mentioned throughout the City of Johannesburg, with four Environmental Health Officials (n = 4) identifying this factor as a concern:

> "***Somebody has to take responsibility****, and I think that's where the problem comes in. Because some people, when they get to a certain stage, they lose connection with what's going on on the ground.*" **[J1]**; *"[referring to people understanding their roles and responsibilities] […] and for the* ***accountability****, then I think that will be the start before we could go and explore other avenues.*" **[J4]**

To effectively cover the entire region was commonly highlighted in the larger regions of Johannesburg, with the "*Distance and time constraints of area coverage*" factor identified by three of the City's Environmental Health Officials:

> "*The work that they [EHPs] are expected to do* ***cannot always be done*** *[…]* ***because of the broadness of the area.****"* **[J6]**; "*With norms and standards, we have targets […], and it also has timeframes attached to it, so like how often you're supposed to go there,*

> *[…] our CBD [central business district] area is where the bulk of our formal […] and also our informal food traders are, so a person that's working in that area might* ***not be able to cover all the premises within that [timeframe]****, but you're supposed to be doing them every quarter.*" **[J2]**

The "*Lack of knowledge and understanding of other departments*" in terms of their overall scope of work and roles and responsibilities was identified by three Environmental Health Officials:

> "*The City does not understand […] in terms of the capacity. For instance, if they were talking about Environmental Health, I don't think that the* ***City completely understands the role and responsibilities that goes with that particular Department****. So if there was an understanding, first of the resources that the City has […] 'cause of now the problem is, people jump[s] on other people's area of jurisdiction, duties or functions. So if the City understood the functions and what resources they have, then there won't be duplication because* ***there's duplication of work*** *[…]. If the city can start by understanding the resources that they have in the ground, and then how to fully utilise it.*" **[J4]**; "*If all departments* ***better understood their roles and functions****, they would be better aligned in terms of planning, like Disaster Management, Environmental Management, Environmental Health, […] if* ***everyone understood their functions, and what they can do to enhance the other departments' function instead of duplication****, then we can plan better on a strategic level, then that information will be better filtered to the people with the most resources on the ground.*" **[J4]**

In contrast to the other two metropolitans, the concept of being "*Reactive and not proactive*" was not commonly identified in the City of Johannesburg and was only raised by two of the City's regions:

> "*In relation to [the] disaster management […] I think we are* ***not much that proactive****; we are* ***more reactive*** *with the department; we will only come in after the disaster [has] already happened.*" **[J4]**; "*If we were doing our job 100%, to our full capacity, then our clinics should be empty because we should be preventing people from getting ill. But the way it is now, we are working like we're responding to when a problem is there already,* ***not being proactive and doing preventative [actions]*** *[…]; what we are supposed to be doing? That is the challenge because we [are] only now* ***reacting; we are reactive now.***" **[J2]**

Lastly, the "*Safety of Environmental Health Officials*" was not identified as an area of particular concern in the City but was still highlighted by one Environmental Health Official (n = 1):

> "*Others* ***threaten you with your life****, [they say] you will not come into my shop and tell me what to do, I will get to you […] I've got a young lady here who goes into these places, where do you draw the line,* ***your life or … [their duties]***" **[J1]**

4.3.1.2 City of Tshwane

Although similar at first glance to the City of Johannesburg, the City of Tshwane's Environmental Health Officials highlighted significantly different factors that commonly limit implementation abilities and potential climate change, such as heat health considerations in the City. The eight overall implementation challenges and the frequency of reference by the Tshwane Health officials are

presented in Figure 4.7. In order of highest to lowest frequency, the City of Tshwane's Environmental Health Officials highlighted the most common implementation challenges as (i) Resource capacity, (ii) Distance and time constraints of area coverage, (iii) Reactive and not proactive, (iv) Communication and cooperation with departments, v) Policy misalignment with implementation ability, (vi) Lack of knowledge and understanding of other departments, (vii) Safety of Environmental Health Officials, and (viii) Lack of responsibility and accountability.

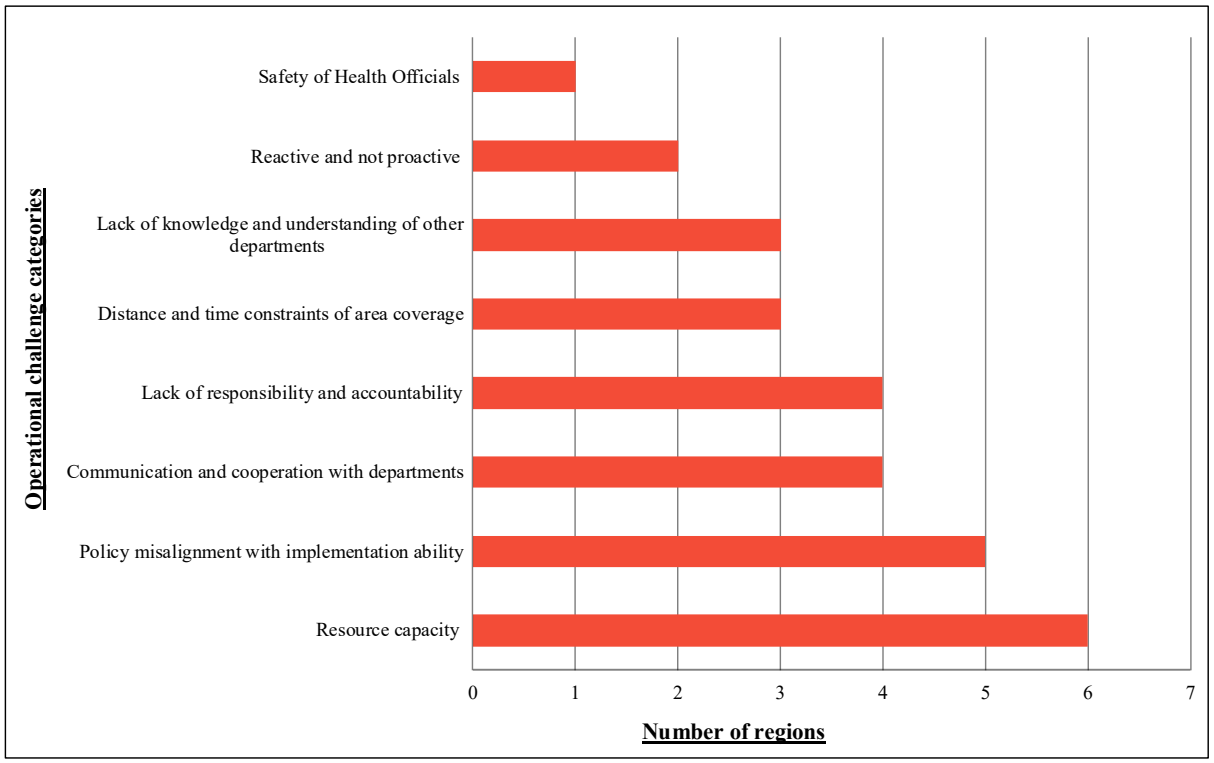


Figure 4.7: Bar graph representing the frequency of operational challenges identified by the Environmental Health Officials in the seven regions of the City of Tshwane

Similarly to the City of Johannesburg, the City of Tshwane Environmental Health Officials identified "*Resource capacity*" as the most common challenge limiting effective implementation in the City, with most (n = 6) of them highlighting this issue:

> "*We do have a problem with the necessary* ***budget available****. […]; currently, we haven't even accomplished to get our adjustment budget approved, which means that* ***nothing is being paid, nothing is being done.***" **[T7]**; *"[…] our ratio [EHPs per person ratio] is quite bad […]; its worse than the other regions. […] we're struggling with human [staff capacity], and then they've combined three regions […]; I think we are about* ***one to 90 000 if not almost 100 000****, so* ***we really are understaffed****, and then also it's a growing region.*" **[T2]**; "*At this moment, in our region, it's* ***one per 65 000*** *of the population [EHPs per person ratio], so* ***totally understaffed.***" **[T4]**

As discussed in the previous section (*Chapter 4, Section 4.2.2.2*) regarding the City's operational context, Tshwane is more dispersed and a lot larger, covering more land than the other two Gauteng metropolitans. This has resulted in the "*Distance and time constraints of area coverage*" factor

identified as the second most prominent challenge within the City of Tshwane, with most (n = 5) Environmental Health Officials highlighting this issue as hindering their ability to effectively implement their duties:

> "*The **distances that the people [have] to travel** […] from our office to the border of our region. The people who have to go the round trip is about 120 kilometres per day, and so we have **limited resources in the sense of travel allowances** that's allocated to the EHPs, so it makes it very difficult for them to do all the inspections that they need to do to attend to everything.*" **[T4]**; "*The **vast area of the region**, with the **allowances, they get travelling allowances**, it's not always feasible for them to go to all the areas. You will find that the amount of the allocated kilometres [is] exhausted, and they are not prepared to travel anymore.*" **[T2]**; "***One of the challenges is the distance**, […] you **travel a long distance**. I mean, from the office to […] [area within the region] is about 45 kilometres. That's a one-way trip […], so that, that is a challenge for us.*" **[T1]**

Unlike the City of Johannesburg, being "*Reactive and not proactive*" in their duties was highlighted as a common area of concern amongst most (n = 4) Environmental Health Officials in the City of Tshwane:

> "A*s we [have] a very serious shortage of staff, we are **no longer proactive**. […] we can't manage all those things, all this nine KPIs […] so as I'm saying, **we are not proactive**, we just wait and then see.*" **[T6]**; *"[education and awareness campaigns] In terms of outreach, […] we've been sort of **reactive** in some instances in terms of, like, communicable diseases outbreaks.*" **[T1]**

Four Environmental Health Officials identified that "*Communication and cooperation with departments*" is an underlying problem in their region, with most of them highlighting the limitations of effective implementation due to other departments:

> *"Our **communication** [communication with other departments]**, general communication** of who's doing what, that thing with the left hand is not knowing what the right hand [is] doing; that's happening a lot. It's just the general communication. I think it's just too big; it's too many things happening.*" **[T4]**; "*The other sister departments are not very prompt to respond to queries or to complaints. So, as such, we find ourselves having to be the middle person between the complainant and the other departments. […] it is **difficult to get assistance and support from the sister departments**; it's very difficult.*" **[T1]**; "*The challenge here is that **we don't communicate**, […] for example, we go out and take some samples, and others go out also and take some samples. We must have the information, or we share the results so that we must know what is happening, which samples they took, and then what says the results […]; we need to communicate [with] each other so that we give each other information.*" **[T6]**; "*I think that's one of the reasons I wanted to be very clear in terms of the **communication between departments**. A team effort is the only thing that takes us forward.*" **[T7]**

Three Environmental Health Officials highlighted "*Policy misalignment with implementation ability*" in the City, which challenges their ability to achieve their set mandates:

> "*We are struggling because the people […] that are involved are mostly in national office, so in the local government, we struggle a lot because they are not in relation to what we have. […]; we were talking about the shortage of staff […] they're not looking at that,* ***they are just developing the policies,*** *and you find that with us, it's* ***very difficult to implement.***" **[T6]**; "*I think even the* ***issue of the alignment with the City's policies.***" **[T3]**

Similarly to the City of Johannesburg, the "*Lack of knowledge and understanding of other departments*" in terms of the overall scope of work and roles and responsibilities was identified by three Environmental Health Officials:

> "*I think even the* ***scope of work also is a problem that we don't know what they [other departments] are doing, they don't know what we are doing****, or what we supposed to do […]; and then we do our part, and then they must do their part. So you find that we don't know what they are doing. They don't know what we are doing."* **[T6]**; "*I think what one should just consider is that you must look at the* ***scope of work*** *and sometimes […] they [EHPs] lose scope with Environmental Management […]; so I think the* ***lack is knowledge of our department****, where our mandates begin and where our mandates end. The EHPs* ***lose the scope of what is their role*** *and what is Environmental Management's role.*" **[T2]**

The "*Safety of Environmental Health Officials*" was more commonly identified in the City of Tshwane than in the City of Johannesburg. However, it is not a particular area of concern in the City as it was only highlighted by two Environmental Health Officials:

> "W*e've got challenges in terms of* ***safety issues****, which we didn't have in the past. Certain areas have become* ***actually unsafe for environmental practitioners*** *to enter, and sometimes they are* ***threatened […] life threatenings*** *[…] so it places a service delivery hamper obstacle for us to really perform the functions everywhere.*" **[T2]**; "*The* ***risk [safety of EHPs] in the area****, because it's a rural area, and you have these informal settlements; we have a lot of female EHPs, and what we usually do is we have to [send] out two people [EHPs] or you have to have metro police accompany you to some of these areas.*"**[T4]**

Lastly, although it was a common concern in the City of Johannesburg, the "*Lack of responsibility and accountability*" was only raised by one Environmental Health Official in the City of Tshwane and is not an area of high concern:

> "***Accountability is just nowhere*** *[…]; I'm [theoretical individual/department] responsible for a certain function, I don't perform it.*" **[T7]**.

4.3.1.3 City of Ekurhuleni

The review of the City of Ekurhuleni took a different approach to that of Johannesburg and Tshwane due to the current structure of the City's Environmental Health Department; hence, the results are not comparable. However, an overview of the City of Ekurhuleni was assessed and can be compared to that of the other two metropolitans. From the combined review of the three City of Ekurhuleni

Environmental Health Officials, the key challenges identified as limitations for the effective implementation abilities of the Environmental Health Department were (in no particular order) (i) Resource capacity, (ii) Policy misalignment with implementation ability, (iii) Lack of knowledge and understanding of other departments, and (iv) Reactive and not proactive (Figure 4.8).

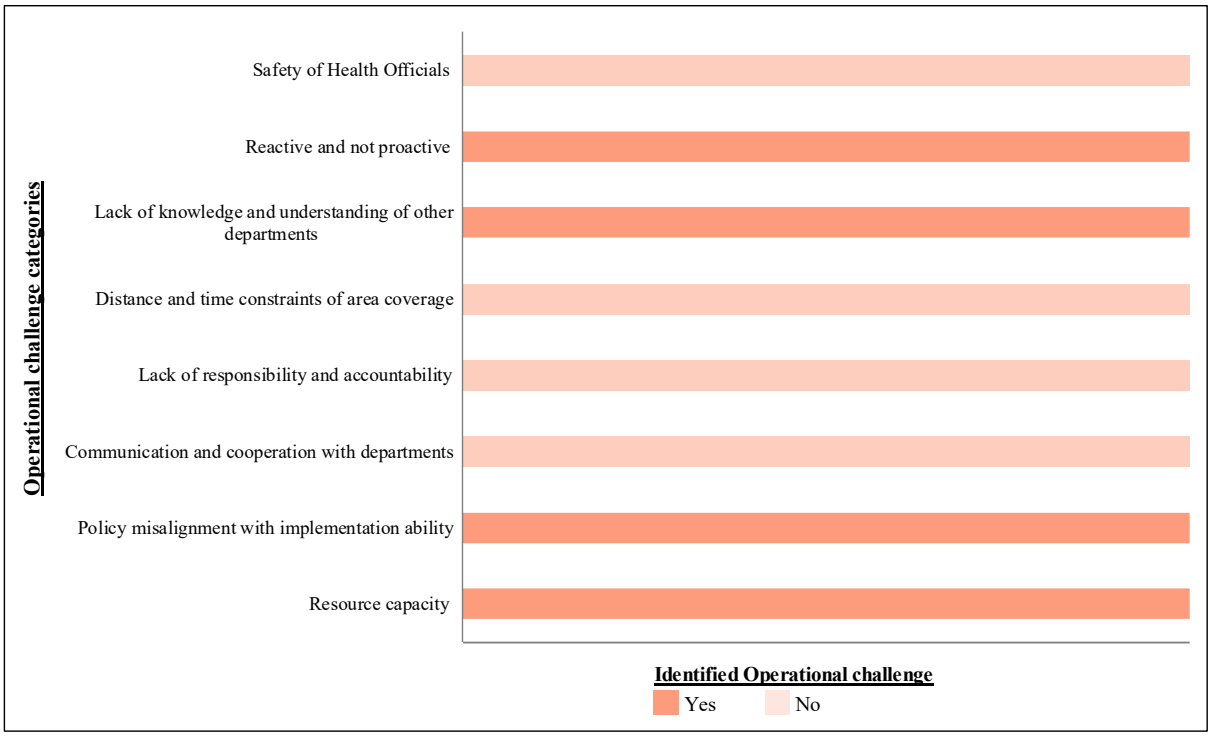


Figure 4.8: Bar graph representing the operational challenges identified by the Environmental Health Officials in the City of Ekurhuleni

Similarly to Johannesburg and Tshwane, the City of Ekurhuleni identified "*Resource capacity*" as one of the underlying challenges limiting effective implementation in the City, with all three Regional Managers highlighting this issue:

> "***Finance*** *but linked to that then comes* ***ICT****, and the rest of it because resources as a whole, as a package,* ***start with resources as a package****, that is our biggest concern. […] say, for example, now we have these to disseminate [heat awareness posters], beautiful posters with all of the information that you want, […] but you can't make copies. You can't submit a single copy […] half of my staff […] doesn't have access to a computer […]* ***No ICT, no phones, no nothing.****"; "[We don't] have a* ***full complement of EHPs*** *[…]; my figures is* ***one in 42 000*** *[EHP per person ratio] […] one* ***EHP is doing almost 1.45 EHPs*** *work; in terms of workload,* ***one EHP is doing up to seven to eight to nine to ten*** *depending on the area EHPs work, so there's no way that you're going to get all your bases covered.*" **[EC]**

The Environmental Health Officials highlighted "*Policy misalignment with implementation ability*" in the City, which inhibits their ability to achieve the set mandates;

> "*The* ***lack of [a] really thought through policy****,* ***lacklustre policy****, [and]* ***changing policy when you have political change****, because focal areas differ.*" **[EC]**.

The City of Ekurhuleni's Environmental Health Officials identified the "*Lack of knowledge and understanding of other departments*" as a challenge because higher authority officials and senior management are not aware of their mandate and where they sit in the constitution:

> "*We sit with a situation where in Health Departments, […] the primary health care section is **viewed as an unfunded mandate**. It's actually [a] provincial service we render; the service on behalf of [the] province, and now there's this **perception amongst HR [human resources] and politicians and senior management that Environmental Health is also an unfunded mandate**. But we are constitutionally mandated to render Municipal Health Services.*" **[EC]**

Lastly, the concept of being "*Reactive and not proactive*" in their duties was highlighted as a common area of concern amongst the Environmental Health Officials in Ekurhuleni:

> "*That makes sense to have a proactive [proactive responses]; **we have a reactive** […], but once there's incidents, then there is action.*" **[EC]**

As discussed previously (*Chapter 4, Section 4.2*), the Environmental Health Department is not currently fulfilling and unlocking its full potential for the implementation of climate change response strategies, specifically heat responses. This is due to various factors: (i) disconnection and misalignment of policies and plans with implementation abilities; (ii) climate change responses not embedded within the mandate and budget of the Department; (iii) the lack of knowledge of the Department's involvement of heat-related responses; and (iv) the limitation of staff and capacity to fulfil additional duties not within their already challenging mandate of the nine Municipal Health Services. Furthermore, the local Environmental Health Officials identified specific implementation challenges limiting their operational abilities, including resource constraints, policy misalignment, lack of communication and cooperation between departments, distance and time constraints, reactive instead of proactive approaches, lack of knowledge and understanding of other departmental mandates and functions, the lack of accountability and responsibility, and lastly, their safety when trying to implement their duties. Table 4.3 summarises these challenges as highlighted by the Environmental Health Officials in the three metropolitans.

Table 4.3: Summary of the implementation challenges and operational limitations in the Environmental Health Department throughout the three Gauteng metropolitans

Element	City of Johannesburg	City of Tshwane	City of Ekurhuleni
Resource capacity	**Ranked 1st** Identified by all the Environmental Health Officials (n = 7) with reference to budgeting constraints, understaffing and lack of physical resources to carry out their duties.	**Ranked 1st** Identified as the most common challenge, highlighted by most of the Environmental Health Officials (n = 6) with reference to under-funding and the lack of Environmental Health Practitioners on the ground.	**No rank** Identified by all three Regional Managers with reference to financial constraints, the lack of Environmental Health Practitioners on the ground and the physical resources needed to carry out their duties.
Policy misalignment	**Ranked 2nd** Identified as the second most prominent challenge, highlighted by most Environmental Health Officials (n = 6) with reference to the inability to 100% comply with policies as they are not always that applicable on the ground.	**Ranked 5th** Three Environmental Health Officials highlighted this because higher authorities develop policies that are very difficult to implement.	**No rank** The Environmental Health Officials highlighted that there is policy misalignment, which inhibits their abilities to achieve the set mandates, with reference to lacklustre policy and policy changes when there is political change.
Communication and cooperation with departments	**Ranked 3rd** Five Environmental Health Officials identified this as an underlying problem with reference to the lack of cooperation and inter-collaboration between departments.	**Ranked 3rd** Four Environmental Health Officials have identified this with reference to the lack of communication and difficulties in getting support from other departments.	**No mention**
Distance and time constraints	**Ranked 5th** The ability to effectively cover the entire region was commonly highlighted in the larger regions and identified by three Environmental Health Officials with reference to the vastness of the area and the limited timeframes to achieve their duties.	**Ranked 2nd** Because Tshwane's land area is vastly larger than the other two cities, this element was identified as the second most prominent challenge highlighted by five Environmental Health Officials with reference to the distance of travel and limited travel allowances.	**No mention**

Element	City of Johannesburg	City of Tshwane	City of Ekurhuleni
Reactive and not proactive	**Ranked 7th** In contrast to the other two metropolitans, this has not been commonly identified and was only raised by two Environmental Health Officials with reference to not being proactive nor performing preventative actions.	**Ranked 3rd** Unlike the City of Johannesburg, this element was highlighted as a common area of concern amongst most Environmental Health Officials (n = 4) because they are no longer proactive in their duties.	**No rank** Highlighted as a common area of concern amongst the Environmental Health Officials because they have a reactive response approach.
Lack of knowledge and understanding of other departments	**Ranked 5th** Identified by three Environmental Health Officials with reference to the lack of understanding of other department's roles and responsibilities, resulting in the duplication of work.	**Ranked 5th** Identified by three Environmental Health Officials with reference to the lack of knowledge of their department, as well as the Environmental Health Practitioners losing the scope of their roles.	**No rank** Identified as a challenge due to the fact that higher authority officials and senior management are not aware of their mandate and where they sit in the constitution.
Lack of responsibility and accountability	**Ranked 4th** Although not highlighted as a common factor in the other two cities, this was commonly mentioned by four Environmental Health Officials with reference to the lack of responsibility and the loss of connection with what is happening on the ground.	**Ranked 8th** Although this was a common concern in Johannesburg, it was only raised by one Tshwane Environmental Health Official because accountability does exist.	**No mention**
Safety of Environmental Health Officials	**Ranked 8th** This element was not identified as an area of particular concern as it was only highlighted by one Environmental Health Official with reference to some instances of being threatened by local communities.	**Ranked 7th** The Environmental Health Officials' safety was more commonly identified than in the City of Johannesburg but is still not a particular area of concern and only highlighted by two Environmental Health Officials with reference to the unsafe environment and because they are threatened by local communities.	**No mention**

4.3.2 Opportunities for improved implementation and heat-health responses

Although the local Environmental Health Department is currently facing many challenges limiting its ability to fulfil its primary mandated duties, including climate change responses in its operation activities, it is well positioned and has the fundamental structures in place to effectively implement heat strategies in the future (outlined in Appendix 3). The three metropolitans' Environmental Health Officials identified ten key opportunities (Box 4.2 & Figure 4.9).

Box 4.2: The ten opportunities for improved implementation and possible heat considerations highlighted by the Health officials throughout the three Gauteng metropolitans

(i)	**Building on education and awareness campaigns**
(ii)	**Multi-sectoral communication, collaboration and cooperation**
(iii)	**Build on existing structures**
(iv)	**Community ownership**
(v)	**Mandated heat action embedded within the IDP**
(vi)	**Heat Action Task Force**
(vii)	**Specialisation of Health Officials**
(viii)	**Early warning systems**
(ix)	**Training Health Officials with mandated duties**
(x)	**Involving private companies**

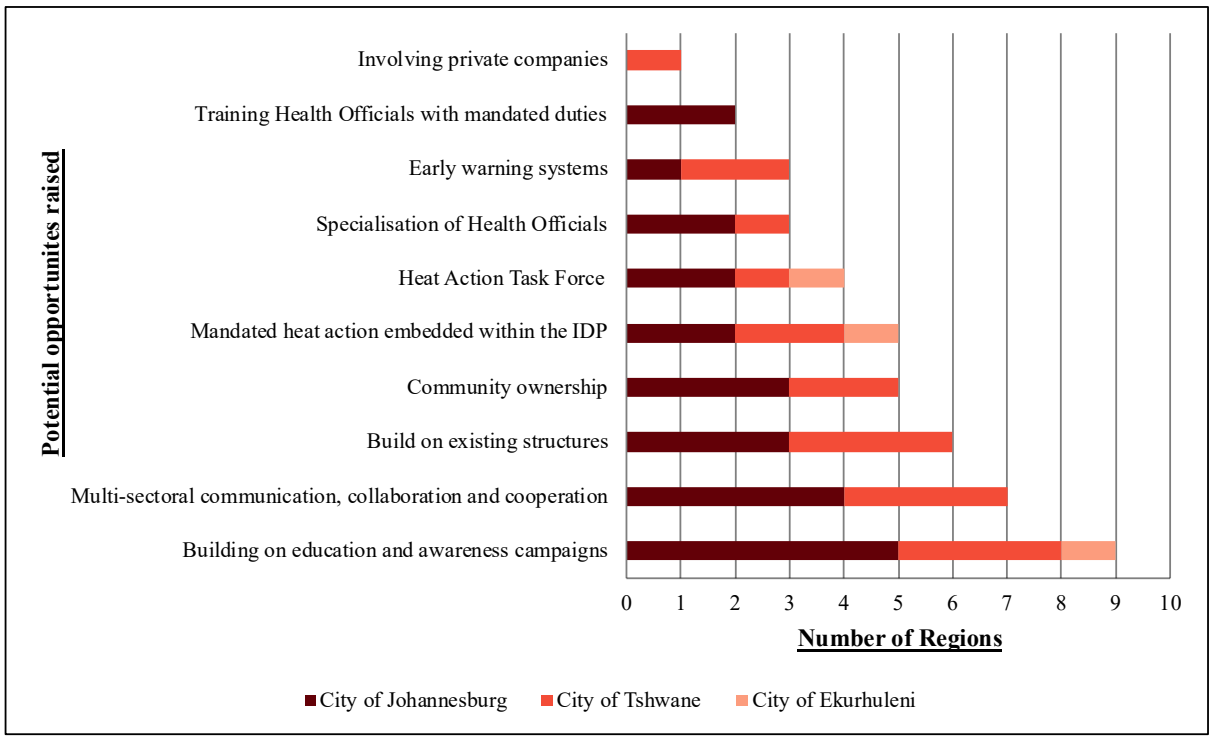


Figure 4.9: Bar graph representing the opportunities for improved implementation and possible heat considerations identified by the Environmental Health Officials in the three Gauteng metropolitans

(i) Building on education and awareness campaigns

"*Building on education and awareness campaigns*" was identified as the most common (n = 9) opportunity throughout the three metropolitans to implement future heat-health responses. This refers to the enhancement of existing education and awareness structures within the departmental activities into outreach programmes specifically to increase heat knowledge and adaptations in local communities:

> "*[referring to areas of opportunity in the region] We do **awareness and health education** for a lot of different things […] so like, yeah, we can do that. And then maybe people are not aware […] we also do **education, and then awareness in schools, primary school, high schools**, […] because I see also who is most affected [vulnerable to heat]; it's elderly, the people above 65, and also children.*" **[J2]**; "*[We] have a component […] called **health promotion**, so they also look at such activities or services in terms of **informing mainly, or promoting the health awareness campaigns** […]; so we will use a **loud hailing truck** in order to spread the message if there's an event coming or campaign coming in order to inform them; [we also] use **pamphlets.***" **[J7]**; "A*s recently as February 2023, we actually had a **heat stress, health education and awareness drive**. So where communities, primarily schools [and] creches […] were **informed of heat-related effects** and the rest of it.*' **[EC]**

(ii) Multi-sectoral communication, collaboration and cooperation

Although highlighted as one of the key challenges throughout the three cities, improved "*Multi-sectoral communication, collaboration and cooperation*" was identified as an area of potential opportunity to better provide effective implementation of the department's duties and further unlock

future heat response strategies. Seven Environmental Health Officials highlighted this opportunity, and it refers to various departments working together to achieve collective goals and targets aligned with one another and to support and assist each other in better implementing their mandates:

> "*To **learn from one another** and to not make the same mistakes. That is that crucial because I think, to a very big extent, we **all share exactly the same problems.***" **[T7]**; "*[referring to heat responses in the future] You get to know it through **multi-sectoral collaboration**, […] how we then get to know that [heat periods are incoming], the **multi-sectoral cooperation, collaboration**; that's how we will then learn of it.*" **[J5]**; "Y*ou also alerting us to say, let's **not sit in silos, or also in silence**, but rather make sure that whatever gains are made at a **national level, it also become[s] localised.***" **[J5]**

(iii) Build on existing structures

Six Environmental Health Officials highlighted the opportunity to "*Build on existing structures*", which aligns with other identified opportunities, including "*Building on education and awareness campaigns*", "*Multi-sectoral communication, collaboration and cooperation*" and "*Early warning systems*". This refers to the enhancement of the current resources and activities already carried out within the department and includes other structures and processes, which may not be within the Environmental Health Department mandate (i.e., early warning systems) for future response:

> "*We **don't have to reinvent the wheel**; if the wheel is already there, even best practices, you will learn from others, and if it worked for them, you can always adopt it on your side.*" **[J2]**; "*I think in future, if we do have heat situations or heat wave situations [to] such an extent that it will start threatening the health and wellbeing of the population, they will incorporate those stations [existing temperature and air quality stations] to **monitor it, and then have a warning signal sent out.***" **[T4]**

(iv) Community ownership

Another key opportunity highlighted by many Environmental Health Officials is the inclusion of "*Community ownership*" within heat-related responses. This will ensure sufficient community buy-in and allow for better strategy implementation, which will be more sustainable over time:

> "*If you can just **get the people to buy-in** because if we **do it alone and the community don't buy-in, you will never win**. […]; if you don't also speak to the people because you will think it's the issue [theoretical issue] […] but for them that is not the issue […].*" **[J2]**; "*Better interaction between […] the community and not always be dependent on the city council but also **come up with initiatives and working together with us**, […] where they also **take responsibility [for] the environment. They, as the community**, […] they need to **come up initiatives and work with us and assisting us and not just depending on us all the time**; so there's definitely more opportunity in a change of mindset which can come forward.*" **[T2]**; "*I think, you know, the big thing is if you can **get your champions in every informal settlement** […] and you **start small, and you see people see the advantage of it.***" **[J1]**

(v) Mandated heat action embedded within the IDP

Five Environmental Health Officials identified the opportunity for "*Mandated heat action embedded within the IDP*" as heat responses are not embedded within the Department's operational mandate and KPI structure; therefore, they are not within the allocated budget to achieve these targets:

> "*It will be effective [heat strategies] if […] it's* ***included in our IDP*** *[…];* ***in our budget****, […] we need to have those items that talk to heat […]; it should be* ***specific, it should not be a generic*** *[…]* ***KPI, it should be specific****. If it's* ***specific****, then it's easy to monitor […], unlike if it's just a* ***generic thing*** *[…]. If you're going to say heat-related key performance indicator, then it's possible to be achieved.*" **[J3]**; "*How do we* ***change our policies****? And how do we fine-tune our policies? How do we* ***add this thing [heat] into our bylaws as a City where the City endorses [it]*** *[…]; some of these changes into its own* ***immediate space and legislation*** *that way.*" **[J5]**

(vi) Heat Action Task Force

A common trend mentioned by a few Environmental Health Officials (n = 4) is the development of a "*Heat Action Task Force*", which is a centralised unit that proactively responds to incoming extreme heat events and mobilises the relevant departments and agencies associated with the implementation of heat strategies:

> "*What really helps is, you, if you have […]* ***a team and you have a close team of people communicating with each other****, knowing what's happening, but you have to have* ***specific teams working on a project, like a project team*** *[…] where you have your reliable and general contacts that you have to deal with on a daily basis […] so the only way that you can improve that [communication and cooperation of response strategies] is to have the* ***specific operational teams or task teams working on specific problems; where you have a close team communicating with each other****.*" **[T4]**; "*You see that, that is something that needs to be considered as well in the implementation of such an event. There should be* ***people [a unit or task force]****, but […] there are not enough EHPs […]; we cannot take them out of the service, to withdraw them from MHS, and tell them to look at heat issues.*" **[EC]**; "*Even if* ***somebody can just champion it, someone to champion this*** *and bring it down [heat action].*" **[J5]**

(vii) Specialisation of Environmental Health Officials

Three Environmental Health Officials identified the opportunity for "*Specialisation of Environmental Health Officials*", which similarly refers to a specialised focus on heat, similar to the "Heat Task Force", but more focused internally within the Environmental Health Department, as well as the specialisation of EHP's skills to focus on specific aspects of Environmental Health instead of a generalist approach:

> "*If people can […]* ***focus, and you specialise; specialisation****, you do one of the things and you do everything, […] because at the moment, we have so many things that you do, because each inspector is in every area or district that they are allocated to, so you do everything in there, from food to noise to […]communicable diseases […] so you* ***don't really have time to focus on one specific thing****, because you just go as the things come in.*" **[J2]**; "***We also need people to specialise*** *because, at the present moment, the heat action plan and the guidance we have not yet implemented because*

of the vastness of our scope and the nine KPIs that we have to implement on a daily basis." **[T6]**

(viii) Early warning systems

Included in "*Build on existing structures*" is using existing "*early warning systems*", which three Environmental Health Officials identified as an opportunity. This refers to the better communication and spreading news of incoming events:

> "*An atmospheric monitoring station that they have put down and get the information automatically sent to them via computer. So that's* ***monitoring the temperature and air pollution*** *[…]; so I think in future, if we do have heat situations or heat wave situations, [to] such an extent that it will start threatening the health and wellbeing of the population, they will incorporate those stations [existing temperature and air quality stations] to* ***monitor it, and then have a warning signal sent out.***" **[T4]**

(ix) Training Environmental Health Officials with mandated duties

Aligned with the "*Specialisation of Environmental Health Officials*" opportunity, two Environmental Health Officials identified that improvements can be made by "*Training Environmental Health Officials with mandated duties*", specifically when new duties are mandated or included within the Department. This refers to including regional heads and EHPs in training and workshops to effectively implement and fully achieve their duties on the ground:

> "*Once the policy is promulgated, the legislation […], they just send it down and tell you, you must implement. The challenge is they* ***don't workshop these things*** *[…]they* ***need to workshop it and then explain*** *and […] discuss it so that we have the* ***same understanding****; so that even going forward, for me to implement it, I know exactly when they draw up the policy. This was the intention, and this is what they aim to get out of it. If we're all on the same page, that is the start; if we don't have the start right, I don't think our outcome is going to be what was expected in the long run. But if we can approach [it] right from the beginning, then I think we can move in the right direction.*" **[J2]**

(x) Involving private companies

Lastly, "*Involving private companies*" was highlighted by one Environmental Health Official throughout the three metropolitans and refers to the inclusion of private companies, Non-Governmental Organisations (NGOs), Non-Profit Organisations (NPOs) and other agencies within the operations and the assistance of implementation activities on a local level:

> "*[referring to possible opportunities and ways of moving forward] There [are] a lot of* ***private companies*** *that's jumped on the bandwagon, and we know there's* ***money to be made****. […] that's why we have in the new […] industry in South Africa with recycling [informal waste pickers in cities].*" **[T7]**

Despite the challenges faced by local Environmental Health Officials in fulfilling their mandated duties and incorporating climate change responses into their operations, they have the necessary

structures in place to effectively implement heat strategies in the future. Throughout the three metropolitans, they identified specific opportunities for improved implementation and future heat considerations, including building on education and awareness campaigns, multi-sectoral communication, collaboration and cooperation, building on existing structures, community ownership, mandated heat action, a Heat Action Task Force, specialisation of Environmental Health Officials, early warning systems, training Environmental Health Officials and lastly, involving the private sector. Table 4.4 summarises these opportunities.

Table 4.4: Summary of the identified opportunities for improved implementation and heat-health responses throughout the three Gauteng metropolitans, highlighting the number of Environmental Health Officials who identified these opportunities in each metropolitan, with Ekurhuleni only consisting of a Yes/No consideration due to the combined nature of the study's City approach and the potential of each identified opportunity for future considerations

Element	City of Johannesburg	City of Tshwane	City of Ekurhuleni	Identified potential
Building on education and awareness campaigns	Five Environmental Health Officials	Three Environmental Health Officials	Yes	Identified as the most common opportunity throughout the three metropolitans and refers to the enhancement of the already existing education and awareness structures in place within the Department's operational activities into outreach programmes specifically to increase heat knowledge and adaptations in local communities.
Multi-sectoral communication, collaboration and cooperation	Four Environmental Health Officials	Three Environmental Health Officials	No	Identified as an area of potential opportunity to better provide effective implementation of the Department's duties and further unlock future heat response strategies. This refers to various departments working together to achieve collective goals and targets aligned with one another and to support and assist each other in better implementing their mandates.
Build on existing structures	Three Environmental Health Officials	Three Environmental Health Officials	No	This refers to enhancing the current resources and activities carried out within the Department and including other structures and processes that may not be within the Environmental Health Department's mandate (i.e., early warning systems) in future response.
Community ownership	Three Environmental Health Officials	Two Environmental Health Officials	No	Including community ownership within heat-related responses will ensure sufficient community buy-in and allow for better implementation of the strategies, which will be more sustainable over time.

Element	City of Johannesburg	City of Tshwane	City of Ekurhuleni	Identified potential
Mandated heat action embedded within the Integrated Development Plan	Two Environmental Health Officials	Two Environmental Health Officials	Yes	Highlighted as a key aspect in the future, as heat responses are currently not embedded within the Department's operational mandate and key performance indicator structure; therefore, it is not within the allocated budget to achieve these targets.
Heat Action Task Force	Two Environmental Health Officials	One Environmental Health Official	Yes	A common trend that was mentioned is the development of a Heat Action Task Force, which is a centralised unit that proactively responds to incoming extreme heat events and mobilises the relevant departments and agencies associated with the implementation of heat strategies.
Specialisation of Environmental Health Officials	Two Environmental Health Officials	One Environmental Health Official	No	This refers to a specialised focus on heat, similar to the "Heat Task Force", but this is focused internally within the Environmental Health Department, and the specialisation of the EHP skills to focus on specific aspects of Environmental Health.
Early Warning Systems	One Environmental Health Official	Two Environmental Health Officials	No	Included in the "*Building of existing structures*" opportunity, which includes using existing early warning systems and refers to better communication and widespread alerts of warnings for incoming heat events.
Training Environmental Health Officials with mandated duties	Two Environmental Health Officials	No	No	Aligned with the "*Specialisation of Environmental Health Officials*" opportunity, training Environmental Health Officials with mandated duties is needed, specifically when new duties are mandated or included within the Department. This includes regional heads and EHPs in training and workshops to effectively implement and fully achieve their duties on the ground.
Involving private companies	No	One Environmental Health Official	No	This opportunity refers to including private companies, Non-Governmental Organisations, Non-Profit Organisations and other agencies within the operations and the assistance of implementation activities on a local level.

In summary, this section focused on the qualitative aspect of this research, which highlighted the operational context of the Environmental Health Department on a local level by identifying and understating the challenges limiting their implementation abilities and recognising the potential opportunities for improved implementation and including heat considerations within their duties in the future. This section identified the institutional settings at both a city level by comparing the three metropolitans and at a regional level by comparing within each metropolitan. This revealed which of the three municipalities has the necessary structures and functions in place for future heat considerations that can be shared with the neighbouring metropolitans to assist in their efforts. Furthermore, comparing within each metropolitan can further assist the different planning regions throughout each metropolitan by sharing successful and effective adaptation strategies from one region, which can be considered for implementation in another region with similar geographic, demographic and socio-economic contexts. By comparing both between and within the three metropolitans, we gained valuable insights into the successful strategies, the implementation challenges and the opportunities for improved implementation to ultimately lead to developing future heat considerations and a framework for heat action plans for the three metropolitans. Now that the qualitative approach of this research has been laid out, the following section will delve into the quantitative aspect by looking at the results of the heat vulnerability assessment to further identify vulnerable populations and assist with targeted heat adaptation strategies.

4.4 HEAT VULNERABILITY ASSESSMENT

Having discussed the results of the qualitative interviews and engagements, attention now turns to the quantitative dimension of the research. As previously described (*Chapter 3, Sections 3.1 and 3.4*), this study's quantitative approach was based on the preliminary heat vulnerability assessment of the three Gauteng metropolitans, which included developing an HVI using PCA. Surveyed data from the 2020/2021 GCRO QoL was used to develop this HVI from selected heat-specific variables associated with increased vulnerability levels through past literature (Table 3.1). The HVI was then visualised to represent the spatial distribution of the levels of vulnerability throughout the three Gauteng cities at a city and regional level. This assessment further identifies the spatial distribution of the areas and communities at a higher risk of current and future heat extremes in the three cities using insights drawn from previous studies (*Chapter 2, Sections 2.5, 2.7, 2.9 & 2.10*) and provides a platform to begin to develop heat response strategies working from an understanding of these populations' potential risks.

4.4.1 Heat Vulnerability Index and Principal Component Analysis

The HVI was developed using PCA methodology, which combined the selected QoL variables into individual principal component scores for six composite variables according to the statistical relationship and spatial distributions between them. Before proceeding with the analysis, the two key assumptions for effective PCA had to be met.

The first assumption (*Chapter 3, Section 3.4.2*) that the "*correlation matrix is an identity matrix*" was tested using Bartlett's Test of Sphericity to ensure a correlation between the variables. The acceptable threshold of this test is $p < 0.005$, and the result of this test was $p = 0$, which suggests that there is a significant rejection of the null hypothesis, which is no correlation between the variables, indicating that the dataset was suitable for the analysis.

The second assumption (*Chapter 3, Section 3.4.2*) of the appropriateness of the "*sampling adequacy"* was tested using the KMO Measure of Sampling Adequacy to assess the extent of the common variances between the variables. The acceptable threshold for this test is > 0.60, and the KMO test provided a score of 0.891, verifying the suitability of the dataset.

The results from both these tests provide confidence in the QoL variables selected and the dataset used in the analysis and are thus suitable for the PCA assessment. Following the validation of the dataset and variables' suitability, individual PCA was performed to produce principal components for the six composite variables. Each of the six PCAs produced individual principal component scores, with their loadings[11] and variance explained[12] (Table 4.5). The resulting six composite principal components were summed to calculate the total HVI score per ward, ranging from -9.89 (i.e., lowest vulnerability) to 8.08 (i.e., highest vulnerability) (Appendix 4). These HVI scores were then relatively classified into the five levels of vulnerability: Very High (HVI>2.46), High (2.46>HVI>0.92), Medium (0.92>HVI>-0.81), Low (-0.81>HVI>-4.28) and Very Low (-4.28>HVI). These HVI scores were subsequently visualised using QGIS to create a heat vulnerability map for each of the three Gauteng metropolitans.

[11] Loadings represent the correlation between the original variables and the principal components and indicate the level of contribution of each variable to the formation of a principal component, where a high loading (positive or negative) indicates a strong relationship between the variable of the component (Cutter *et al*., 2003; Jolliffe, 2010).

[12] Explained variance is how much variation in the dataset is accounted for by each principal component in the PCA and represents the overall variability contributed by each component, with a higher explained variance indicating that the component contributes a large proportion of the total variability of the dataset (Cutter *et al*., 2003; Jolliffe, 2010).

Table 4.5: Heat vulnerability composite variables and their principal component loadings and variance explained by each principal component from the six individual PCAs

Composite	Variable	Loadings	Variance explained
Poverty	Income	0.867	66.12%
	Skip meal	0.856	
	Education	0.821	
	Child skip meal	0.810	
	Unemployment	0.701	
Dependency	Under 18	0.724	52.48%
	Over 60	0.724	
Health	Disability	0.719	49.34%
	Medical status	0.717	
	Illness	0.671	
Housing	Dwelling type	0.811	37.66%
	Number of households	0.486	
	Number of people in the household	-0.485	
Service	Water type	0.920	84.70%
	Electricity availability	0.920	
Resource and Communication Access	Medical aid	0.966	71.31%
	Healthcare	0.964	
	Transportation	0.941	
	Communication access	0.905	
	Healthcare proximity	-0.014	

4.4.2 Heat vulnerability mapping

To assess and identify the extent of heat vulnerability throughout the three Gauteng metropolitan, the PCA-developed HVI was visualised to represent the spatial distribution and levels of vulnerability within the City of Johannesburg, the City of Tshwane and the City of Ekurhuleni, at both a city- and regional-level (i.e., per planning region). This visualisation or vulnerability mapping highlights the spatial distribution of the higher-risk areas and communities to current and future heat extremes, allowing for identifying and targeting heat responses for these populations.

Figure 4.10 represents the spatial distribution of the HVI across the three Gauteng metropolitans. The HVI scores (Appendix 4) and Figure 4.10 reveal that the highest levels of vulnerability are located in the southern regions of Johannesburg, the northern and eastern regions of Tshwane and the southern regions of Ekurhuleni. The least vulnerable populations and communities are located in the central regions of Johannesburg, the southern and central regions of Tshwane and the western and central regions of Ekurhuleni.

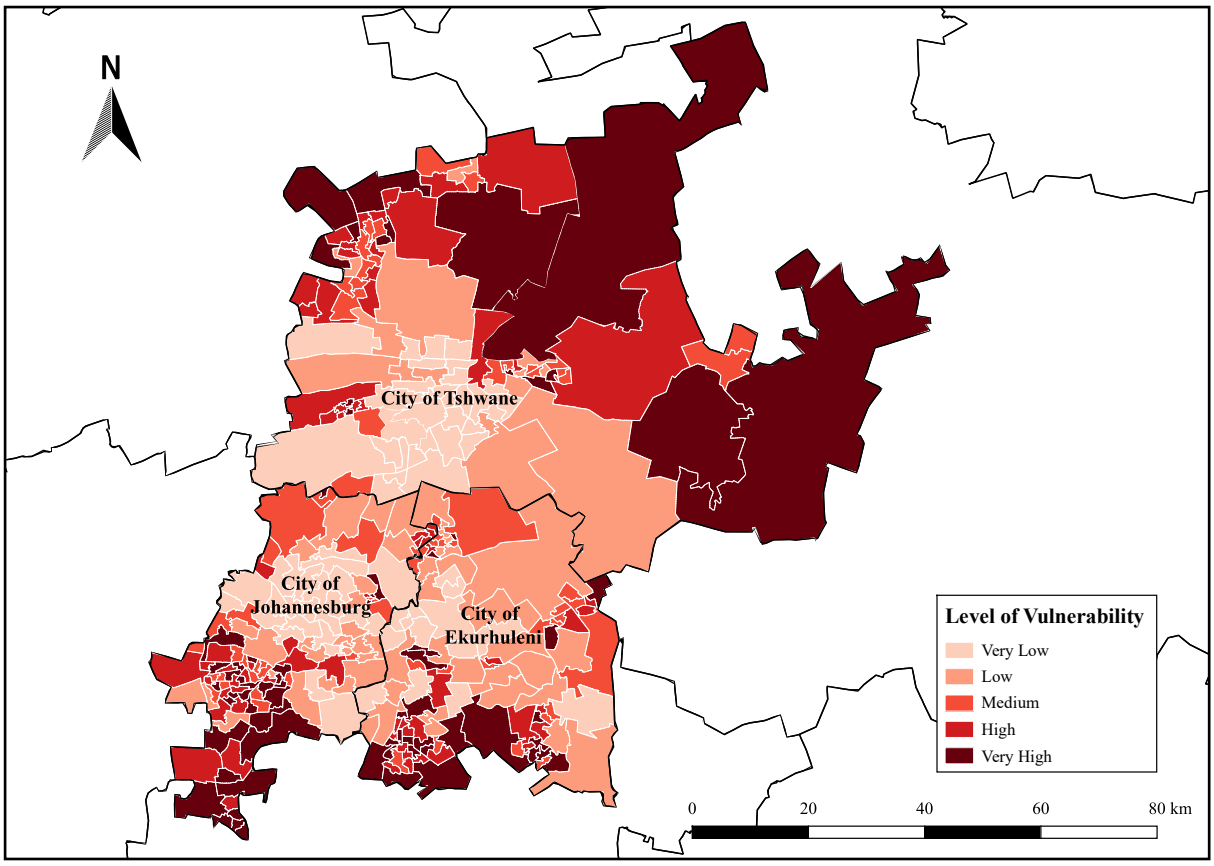


Figure 4.10: Spatial visualisation of heat vulnerability throughout the three Gauteng metropolitans. Developed using a Heat Vulnerability Index to categorise vulnerability into five levels, i.e., Very Low, Low, Medium, High and Very High (Created using QGIS 3.28.1)

The areas identified as "hotspots" of vulnerability are characterised by high poverty levels, limited access to adequate healthcare services, lack of access to basic services, high-dependency populations, poor living conditions, and lack of communication and access to resources. As expected, most identified hotspots occur within the informal settlements and rural areas throughout the Gauteng metropolitans, where poor socio-economic conditions are found. Furthermore, when comparing the three metropolitans by assessing the average HVI scores (i.e., the higher the score, the more vulnerable the population) across the three metropolitans, Ekurhuleni (average HVI score = −0.14346) is the most vulnerable of the cities, with Johannesburg (average HVI score = −0.37692) the second most vulnerable and Tshwane (average HVI score = −1.10081) as the least vulnerable. A detailed breakdown of the HVI per metropolitan is highlighted in the subsequent sections (*Chapter 4, Sections 4.4.2.1, 4.4.2.2 & 4.4.2.3*).

4.4.2.1 City of Johannesburg

Figure 4.11 represents the spatial distribution of vulnerability throughout the City of Johannesburg, highlighting the regions and populations more vulnerable to extreme heat based on the HVI scores. As demonstrated in this vulnerability heat map and outlined in Appendix 4, Regions D and G

demonstrate the highest levels of vulnerability throughout the City, and actioned responses should be targeted to prioritise these regions. Furthermore, all the regions (A to G) indicate particular hotspots of vulnerability embedded in the regions' wards and should be used as a planning tool within each region to identify and develop targeted response strategies aimed at these specified vulnerable areas and populations. Table 4.6 provides an overview of the City of Johannesburg's 31 most vulnerable wards with a 'Very High' level of vulnerability.

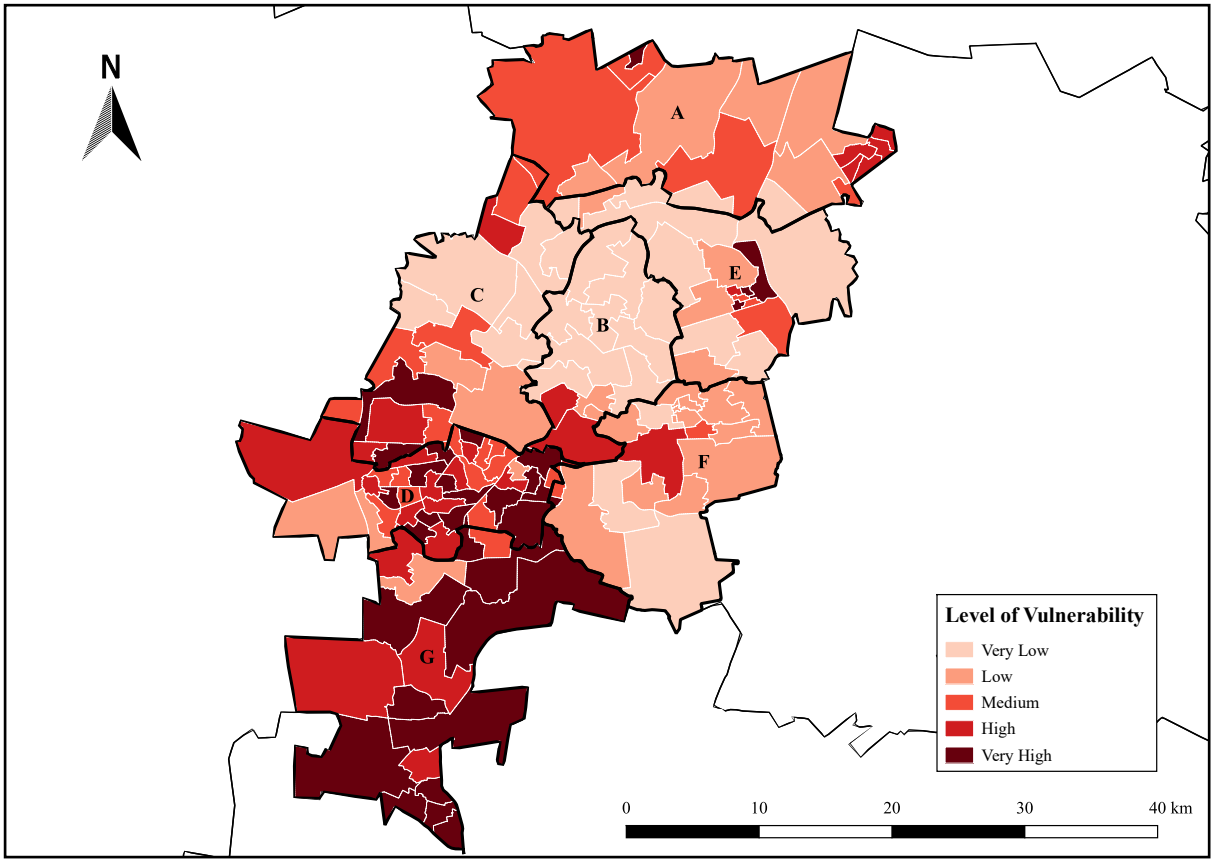


Figure 4.11: Spatial visualisation of heat vulnerability throughout the City of Johannesburg's seven regions (A to G). Developed using a Heat Vulnerability Index to categorise vulnerability into five levels, i.e., Very Low, Low, Medium, High and Very High (Created using QGIS 3.28.1)

Table 4.6: The most vulnerable City of Johannesburg wards ranked by the High Vulnerability Index (HVI) with 'Very High' vulnerability

	Metropolitan	Planning region	Ward ID	HVI score	Level of vulnerability
1	City of Johannesburg	Johannesburg A	79800095	5.40749	Very High
2	City of Johannesburg	Johannesburg C	79800127	5.30591	Very High
3	City of Johannesburg	Johannesburg G	79800001	5.25002	Very High
4	City of Johannesburg	Johannesburg D	79800035	5.11914	Very High
5	City of Johannesburg	Johannesburg G	79800005	5.01095	Very High
6	City of Johannesburg	Johannesburg G	79800131	4.83624	Very High
7	City of Johannesburg	Johannesburg G	79800122	4.63580	Very High
8	City of Johannesburg	Johannesburg D	79800019	4.60827	Very High
9	City of Johannesburg	Johannesburg D	79800025	4.32424	Very High
10	City of Johannesburg	Johannesburg D	79800037	4.28323	Very High
11	City of Johannesburg	Johannesburg G	79800119	4.08489	Very High

	Metropolitan	Planning region	Ward ID	HVI score	Level of vulnerability
12	City of Johannesburg	Johannesburg D	79800046	3.91869	Very High
13	City of Johannesburg	Johannesburg G	79800017	3.79746	Very High
14	City of Johannesburg	Johannesburg C	79800129	3.79229	Very High
15	City of Johannesburg	Johannesburg E	79800075	3.73131	Very High
16	City of Johannesburg	Johannesburg D	79800043	3.55280	Very High
17	City of Johannesburg	Johannesburg G	79800007	3.42766	Very High
18	City of Johannesburg	Johannesburg D	79800029	3.31906	Very High
19	City of Johannesburg	Johannesburg G	79800003	3.31845	Very High
20	City of Johannesburg	Johannesburg D	79800026	3.31243	Very High
21	City of Johannesburg	Johannesburg G	79800008	3.29126	Very High
22	City of Johannesburg	Johannesburg D	79800028	3.11313	Very High
23	City of Johannesburg	Johannesburg D	79800047	2.95517	Very High
24	City of Johannesburg	Johannesburg D	79800012	2.93147	Very High
25	City of Johannesburg	Johannesburg G	79800002	2.90366	Very High
26	City of Johannesburg	Johannesburg D	79800024	2.81140	Very High
27	City of Johannesburg	Johannesburg E	79800105	2.78311	Very High
28	City of Johannesburg	Johannesburg D	79800020	2.72461	Very High
29	City of Johannesburg	Johannesburg G	79800006	2.70732	Very High
30	City of Johannesburg	Johannesburg E	79800116	2.67967	Very High
31	City of Johannesburg	Johannesburg D	79800015	2.58190	Very High

4.4.2.2 City of Tshwane

Figure 4.12 represents the spatial distribution of vulnerability throughout the City of Tshwane, highlighting the regions and populations more vulnerable to extreme heat. As demonstrated in this heat map and outlined in Appendix 4, Regions 1 and 6 demonstrate the City's highest levels of vulnerability, and actioned responses should be targeted to prioritise these regions. Furthermore, all regions (1 to 7) indicate particular hotspots of vulnerability embedded in the regions' wards and should be used as a planning tool within each of the regions to identify and build targeted response strategies aimed at these specified vulnerable areas and populations. Table 4.7 provides an overview of the City of Tshwane's 15 most vulnerable wards with 'Very High' vulnerability.

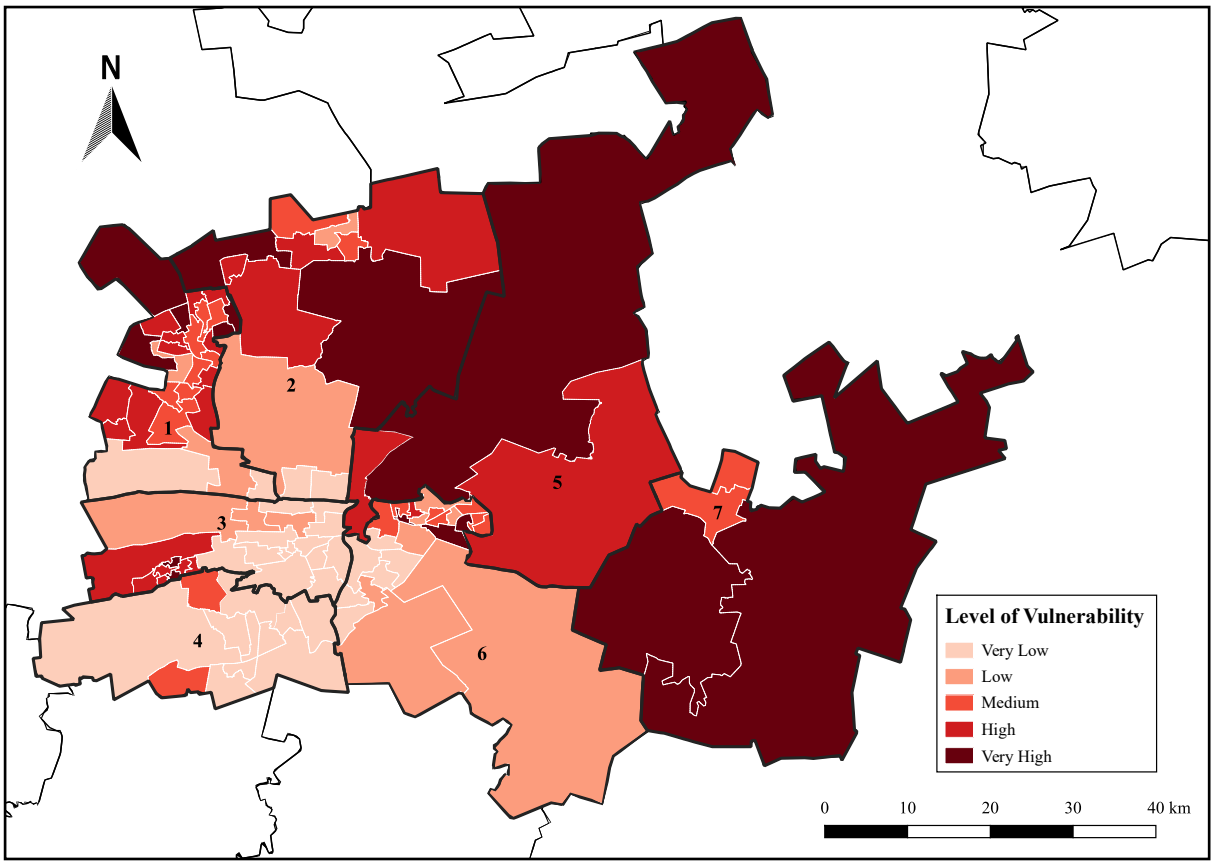


Figure 4.12: Spatial visualisation of heat vulnerability throughout the City of Tshwane's seven regions (1 to 7). Developed using a Heat Vulnerability Index to categorise vulnerability into five levels, i.e., Very Low, Low, Medium, High and Very High (Created using QGIS 3.28.1)

Table 4.7: The City of Tshwane's most vulnerable wards ranked by the High Vulnerability Index (HVI) with 'Very High' vulnerability.

	Metropolitan	Planning region	Ward ID	HVI score	Level of vulnerability
1	City of Tshwane	Tshwane 7	79900102	7.70007	Very High
2	City of Tshwane	Tshwane 2	79900049	5.12042	Very High
3	City of Tshwane	Tshwane 1	79900009	4.64509	Very High
4	City of Tshwane	Tshwane 6	79900015	4.51008	Very High
5	City of Tshwane	Tshwane 7	79900105	4.27994	Very High
6	City of Tshwane	Tshwane 6	79900040	4.17352	Very High
7	City of Tshwane	Tshwane 6	79900038	3.94909	Very High
8	City of Tshwane	Tshwane 3	79900063	3.41100	Very High
9	City of Tshwane	Tshwane 3	79900072	3.04079	Very High
10	City of Tshwane	Tshwane 5	79900099	3.01725	Very High
11	City of Tshwane	Tshwane 1	79900088	2.81879	Very High
12	City of Tshwane	Tshwane 1	79900024	2.77313	Very High
13	City of Tshwane	Tshwane 1	79900027	2.61892	Very High
14	City of Tshwane	Tshwane 1	79900022	2.53705	Very High
15	City of Tshwane	Tshwane 2	79900013	2.47732	Very High

4.4.2.3 City of Ekurhuleni

Figure 4.13 represents the City of Ekurhuleni's spatial distribution of vulnerability, highlighting the particular regions and populations more vulnerable to extreme heat. As demonstrated in this heat map

and outlined in Appendix 4, Regions E and F demonstrate the City's highest levels of vulnerability, and actioned responses should be targeted to prioritise these regions. Furthermore, all the regions (A to F) indicate particular hotspots of vulnerability embedded in the region's different wards and should be used as a planning tool within each of the regions to identify and develop targeted response strategies aimed at these specified vulnerable areas and populations. Table 4.8 provides an overview of the City of Ekurhuleni's 25 most vulnerable wards with a 'Very High' level of vulnerability.

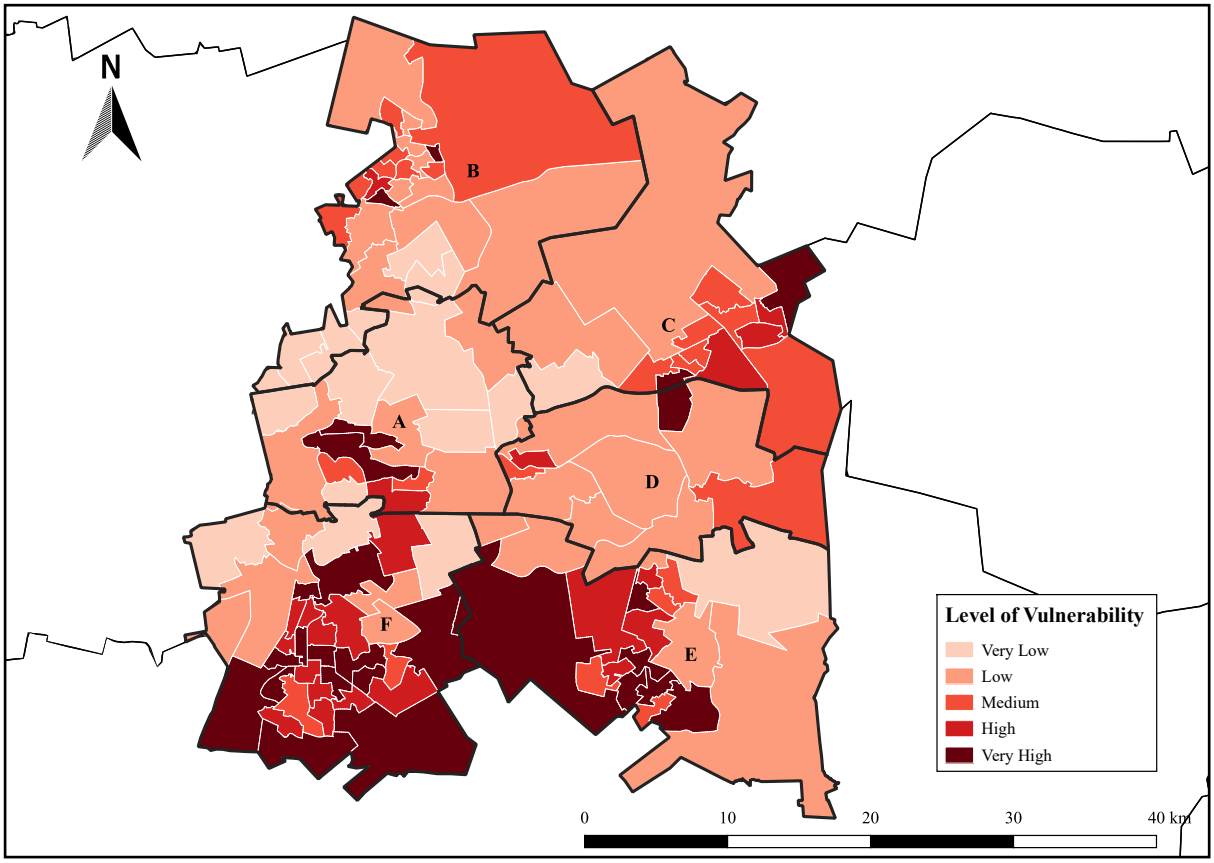


Figure 4.13: Spatial visualisation of heat vulnerability throughout the City of Ekurhuleni's seven regions (A to F). Developed using a Heat Vulnerability Index to categorise vulnerability into five levels, i.e., Very Low, Low, Medium, High and Very High (Created using QGIS 3.28.1)

Table 4.8: The City of Ekurhuleni's most vulnerable wards ranked by the Heat Vulnerability Index (HVI) with a 'Very High' level of vulnerability

	Metropolitan	Planning region	Ward ID	HVI score	Level of vulnerability
1	City of Ekurhuleni	Ekurhuleni F	79700056	8.08433	Very High
2	City of Ekurhuleni	Ekurhuleni F	79700062	6.68298	Very High
3	City of Ekurhuleni	Ekurhuleni F	79700060	5.99389	Very High
4	City of Ekurhuleni	Ekurhuleni C	79700065	5.63355	Very High
5	City of Ekurhuleni	Ekurhuleni A	79700021	5.46597	Very High
6	City of Ekurhuleni	Ekurhuleni F	79700053	5.45740	Very High
7	City of Ekurhuleni	Ekurhuleni E	79700083	5.36692	Very High
8	City of Ekurhuleni	Ekurhuleni E	79700098	5.07001	Very High
9	City of Ekurhuleni	Ekurhuleni F	79700061	4.29672	Very High
10	City of Ekurhuleni	Ekurhuleni E	79700079	4.14247	Very High
11	City of Ekurhuleni	Ekurhuleni F	79700040	3.84828	Very High

	Metropolitan	Planning region	Ward ID	HVI score	Level of vulnerability
12	City of Ekurhuleni	Ekurhuleni F	79700048	3.78939	Very High
13	City of Ekurhuleni	Ekurhuleni B	79700100	3.77977	Very High
14	City of Ekurhuleni	Ekurhuleni F	79700055	3.24801	Very High
15	City of Ekurhuleni	Ekurhuleni A	79700093	3.16290	Very High
16	City of Ekurhuleni	Ekurhuleni E	79700099	3.11536	Very High
17	City of Ekurhuleni	Ekurhuleni F	79700047	2.99287	Very High
18	City of Ekurhuleni	Ekurhuleni F	79700045	2.95060	Very High
19	City of Ekurhuleni	Ekurhuleni B	79700090	2.92053	Very High
20	City of Ekurhuleni	Ekurhuleni F	79700057	2.90872	Very High
21	City of Ekurhuleni	Ekurhuleni F	79700051	2.71765	Very High
22	City of Ekurhuleni	Ekurhuleni E	79700084	2.67450	Very High
23	City of Ekurhuleni	Ekurhuleni D	79700071	2.61671	Very High
24	City of Ekurhuleni	Ekurhuleni F	79700044	2.59423	Very High
25	City of Ekurhuleni	Ekurhuleni E	79700086	2.48471	Very High

Overall, although similar socio-economic vulnerability assessments have been developed in the CSIR's Green Book, both within the municipal risk profiles and within the MetroView Tool, the current study's heat vulnerability mapping specifically looks at socio-economic vulnerability from a heat perspective, and only indicators related to increased sensitivity and lower adaptive capacity to heat extremes were used. In doing so, this provides a specific heat vulnerability profile of the wards in the three Gauteng metropolitans, which have not been produced in Gauteng previously, allowing for ward-level planning and management of heat-related risks using these heat vulnerabilities as a proxy.

Additionally, the QoL surveyed datasets used to develop the current study's heat vulnerability assessment consists of more up-to-date datasets, as the Green Book source data ranges from 1996 to 2016, and the use of more updated datasets results in more accurate and valuable results (Le Roux *et al.*, 2019a). Furthermore, although the Green Book provides settlement and neighbourhood-level vulnerability assessments, some questions are raised about the quality of the data available to map vulnerability at this scale, which has potential biases and may affect the vulnerability assessments' accuracy. The Green Book also highlights limitations due to the vulnerability assessments not addressing the space between settlements, which can result in an incomplete understanding of the overall risk level throughout an area where the spatial interactions, resource allocation and planning can become compromised, potentially hindering the effectiveness of disaster management and heat responses strategies (Van Niekerk *et al*., 2019). Overall, the current study's spatial vulnerability assessment is the first of its kind to successfully map heat vulnerability at a ward level in three neighbouring cities. The consistency of the vulnerability assessment approach allows for comparability among and within the metropolitans to identify the hotspots of vulnerability to be used as a valuable tool for implementing targeted heat adaptation strategies.

In summary, this section has highlighted the results of the study's quantitative approach based on the heat vulnerability assessment of the three Gauteng metropolitans. This assessment has identified the spatial distribution of the populations and areas at a higher risk of current and future heat extremes and provides a valuable resource for local governments to better understand and address extreme heat in their areas. Ultimately, this allows for targeted heat responses to be developed, with a particular focus on these high-risk areas. This vulnerability assessment has revealed that the highest levels of vulnerability are located within the southern regions of Johannesburg, the northern and eastern regions of Tshwane and the southern regions of Ekurhuleni. These areas of high vulnerability are associated with high levels of poverty, limited health access, lack of basic services and resources, poor living conditions and limited communication access and are mainly characterised by informal settlements and rural areas, which present significantly higher levels of vulnerability due to the poor socio-economic conditions in these populations and communities.

To conclude, this chapter has highlighted the results of the study's qualitative and quantitative aspects and has provided a setting for further developments of heat adaptation and response strategies in the future. The chapter outlined policy and climate action planning at the national and municipal level, the structures and operational context of the Environmental Health Department, the implementation challenges and opportunities for improved implementation and heat considerations, and lastly, the spatial distribution of heat vulnerability throughout the three Gauteng metropolitans. Ultimately, the result from this comprehensive research provides a platform to advance the responses to heat-related health impacts throughout the Gauteng metropolitans by laying the basis for the development of adaptation strategies working from an understanding of the operational context of the lead heat agency (i.e., Environmental Health Department) and the level of heat vulnerability throughout these populations. Having laid out the study's results, the following chapter (*Chapter 5*) discusses these results further.

5 CHAPTER FIVE – DISCUSSION

In this chapter, a comprehensive review of the results will be presented. The details of implications for bridging the gap between policies and action for successful implementation are explored, as well as the operational challenges, the opportunities for improved implementation and future heat considerations within the Environmental Health Department, and lastly, the preparedness and resilience of local populations and communities through the identification of heat vulnerabilities.

5.1 TRANSFORMING POLICY INTO ACTION: BRIDGING THE GAP FOR SUCCESSFUL IMPLEMENTATION

The development of the Climate Change Response White Paper, the Climate Change Bill and the Climate Change Adaptation Strategy (*Chapter 2, Section 2.10 & Chapter 4, Section 4.1*) have provided potentially effective policies and plans to address the country's climate risks, which have set out the vision, goals and objectives to combat climate change in the short-, medium- and long-term, and serve as reference documents for the development of response plans and strategies at a municipal level. Furthermore, the Heat Health Action Guideline provides specific focus and guidance on heat adaptation approaches, with a roadmap for developing municipal heat action plans. The development of these national policies and plans has laid the foundation for integrating and developing climate change strategies, and specifically heat action, within municipal planning and implementation.

At the local city level, the City of Johannesburg, the City of Tshwane, and the City of Ekurhuleni have embedded climate action, with varying levels of 'mainstreaming' as a key topic and focal point within their local planning, particularly relating to the city's IDPs. Furthermore, the three municipalities have developed localised climate change response strategies and climate action planning documents, including the City of Ekurhuleni's CCRS of 2017, the City of Johannesburg's CAP of 2021 and the City of Tshwane's CAP of 2022, that supplement these IDPs and have identified extreme heat as a significant risk, both currently and in the future. Despite the development of these national and municipal plans and policies, the local governments have, however, not successfully integrated and implemented heat response strategies into their operational activities.

5.1.1 Governance and heat planning: What is missing?

As highlighted in the Heat Health Action Guideline, the health sector is the lead agency in the development and implementation of heat action planning, with the Department of Health, led by Environmental Health and Disaster Management, identified as the key role player for the integration and implementation of heat action plans at the local level. The EHPs from the Environmental Health

Department are situated between government and the local communities, with continuous engagement and daily interactions providing a direct line and network of communication for potentially effective coordination, collaboration and implementation of heat health strategies and responses at the local level. The Environmental Health Department has, therefore, been tasked with "the *shaping of local strategies aimed at supporting vulnerable communities to adapt to extreme heat exposure*" (Department of Health, 2020, p.17). This is not the case, however, when investigating the Department's mandate and operational activities at a local level. This became notably clear during the study, and although the Environmental Health Department has been tasked with coordinating, collaborating and implementing heat-health strategies, this is not the reality when investigating the roles, functions and objectives of the department within the local planning regions of the three Gauteng metropolitans.

According to the Environmental Health Officials in the Gauteng metropolitans engaged in this research, climate change, specifically extreme heat, is not considered within the operational context of the Environmental Health Department, and it is neither mandated nor budgeted for. The Officials further explained how their primary focus is on the nine Municipal Health Services, which aim to achieve specific strategic objectives and targets. These strategic objectives and targets, in the form of KPIs, are developed by senior management and communicated to the regional offices, where the local Environmental Health Officials align their operational activities with these KPIs to ensure the objectives and targets are reached. Although, the Environmental Health Strategy states that "*in addition, […] Environmental Health Services entails and is responsible for climate change and health matters, infection control, occupational health and health education and promotion functions*" (Department of Health, 2016, p.9), climate change and climate-related health matters have not been included in the Environmental Health Official's mandate and operational activities at the local level. If these matters have not been embedded within the operational mandate of the Department, then there is no allocated budget to achieve these targets, and if climate and heat responses are not mandated and budgeted for, then implementation on the ground will not be possible. As discussed earlier (*Chapter 2, Section 2.11*), heat action must be outlined in the key departmental mandates to ensure that heat-related responses and strategies are implemented and sustained at a local level. This will ensure that sufficient financial and human resources are aligned to this mandate to ultimately develop operational activities with specific KPIs to achieve the set-out objectives and targets (Singh *et al*., 2019; World Health Organisation, 2021). Additionally, there is limited reference and focus on extreme heat and heat responses within the three cities' IDPs, and although the IDPs are supplemented with CCRS and CAP documents, which address heat impacts, there is no specific planning and budgeting directly focused on heat-health impacts. It has been highlighted throughout global and local

literature (*Chapter 2, Section 2.11*) that if climate action is not specifically mandated and budgeted for within the local municipal planning instruments, it will not be effectively implemented within the operational activities in the key departments on the ground (Lethoko, 2016; Santhia *et al*., 2018; Singh *et al*., 2019; Pieterse *et al*., 2021; World Health Organisation, 2021.). It has, therefore, been suggested that there is a need for climate adaptation and mitigation plans to be reflected in the cities' local policies and planning instruments, with specific reference to the IDPs, which will allow for better budgeting, planning and decision-making for climate and heat action in the future (Lethoko, 2016; Santhia *et al*., 2018; Pieterse *et al*., 2021).

5.1.2 Misalignment of policy and implementation capacity

Despite the National Health Act stating that climate change and climate-related health matters be included in Environmental Health operational activities, as well as that the Department is tasked with shaping local strategies to support communities to adapt to extreme heat, the Environmental Health Officials do not know their roles and functions in the effective coordination, collaboration and implementation of heat-related responses and strategies. A common issue they raised is the misalignment of policy development with the implementation ability of the Environmental Health Department and the limited involvement of local governments during policy and plan development. The Officials further explained that they rarely communicated about new roles and responsibilities they were tasked with and were merely instructed to implement without further background or training on the desired outcomes and targets. This has led to a significant gap between policy development and actual implementation, as the national and municipal policy does not always align with the capacity and abilities of the local governments on the ground. It has been emphasised (*Chapter 2, Section 2.11*) that to ensure successful coordination and collaboration of climate adaptations, specifically heat action, it is essential that all departments, agencies and partners have a shared vision of the desired outcome for a particular plan, as well as the objectives and targets on how to achieve this. It is thus fundamental to include all the necessary departments in the development process of these adaptation strategies and plans to ensure they have the necessary capacities or capabilities on the ground for implementation. If not, possible alternatives and solutions should be developed (i.e., using national and provincial resources where necessary) (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021).

Finally, the lack of capacity and ability of the local Environmental Health Department remains a significant stumbling block to effective heat planning, and even if heat action was mandated and budgeted for, the Department lacks the resources to effectively include heat responses in its operational activities. According to the World Health Organisation Guidelines and the Environmental Health Policy, local governments are expected to include at least one EHP for every ten thousand

population to ensure the country's environmental health objective is effectively achieved (Department of Health, 2013). In the local government cases presented in this research, this is not the reality, and the study demonstrated that EHPs are significantly limited and highly outnumbered throughout all three metropolitans. This significantly constrains the Environmental Health Department from achieving their already challenging Municipal Health Service objectives and to include heat responses in their operational activities.

5.1.3 From policy to action: Paving the way forward

This research reveals the gaps between the policy development of climate change strategies and the implementation ability of departments in the three metropolitans of Gauteng. This can be related to many other South African, African and global cities (*see review Chapter 1*). To effectively implement heat response strategies and any climate change-related strategies at the local level, it is essential that these activities not only have dedicated departments responsible for carrying out these tasks but also include specific strategic objectives and targets laid out in the departmental mandates (Singh *et al*., 2019; World Health Organisation, 2021). In addition, these mandates must be supported by sufficient budgets to carry out the tasks associated with achieving the desired objectives and targets (Singh *et al*., 2019). In the case of the Environmental Health Department, these budgets should also include more EHPs and operational officials to successfully incorporate heat action within their operational activities. Furthermore, for heat considerations to be successfully mandated with a sufficient budget in place, it is suggested to provide a more in-depth focus and specifically address heat-related health impacts within the municipal IDP context for better planning, budgeting and implementation measures (Lethoko, 2016; Santhia *et al*., 2018; Singh *et al*., 2019; Pieterse *et al*., 2021). Once heat responses are included in the necessary mandate and budgeting, officials on the ground must be informed about their functions and roles in the overall planning, as well as the desired outcomes and targets of said plan. In addition, the officials implementing these activities on the ground must be provided with sufficient knowledge and training on their new roles and how to successfully achieve the objectives and targets of the set-out mandate.

Many global studies have reviewed and highlighted the barriers and limitations to mainstreaming efforts towards climate adaptation, with a specific focus on integrating the public health sector within climate adaptation plans. As discussed previously (*Chapter 2, Section 2.11*), health systems do not always have the necessary financial and organisational capacity to incorporate climate adaptation within their operational activities, especially within a low-income context, like South Africa, faced with many other socio-economic and health service delivery challenges. Furthermore, other barriers limit the ability of governance and institutions to integrate public health within climate adaptation, including financial (as mentioned), informational, institutional and social, which also interact with

broader societal challenges such as high poverty levels, weak social institutions and the prioritisation of more pressing issues. It has thus been suggested that to overcome many of these barriers, mainstreaming climate adaptation as a primary function of the public health systems is needed to improve adaptation planning and ultimately enhance local implementation abilities (Wheeler and Watts, 2018; Macassa *et al*., 2022; Rogers *et al*., 2023).

5.2 OPERATIONAL CHALLENGES IN THE ENVIRONMENTAL HEALTH DEPARTMENT

The Environmental Health Department is currently not fulfilling and unlocking its full potential to include climate change, specifically heat responses, in its operational activities. The Environmental Health Officials throughout the Gauteng metropolitans are limited in achieving their current mandate of the nine Municipal Health Services without further including heat responses in their duties. Many operational challenges constrain their ability to fulfil their mandated functions, including heat response strategies. The most significant and commonly raised challenges and limitations throughout the three metropolitans were highlighted in the previous chapter (*Chapter 4, Section 4.3.1*) and include:

(i) the lack of resources in terms of staff and budget;
(ii) the area of coverage is too broad to successfully achieve objectives and targets throughout (i.e., linked to capacity constraints);
(iii) reactive and not proactive in their duties (i.e., also linked to capacity constraints and the inability to be proactive due to the lack of sufficient staff);
(iv) the disconnection and misalignment of policies and plans with implementation abilities;
(v) the lack of communication, cooperation and collaboration between departments and other agencies; and
(vi) the misunderstanding and lack of knowledge of their and other departments' scope of work (i.e., linked to the lack of communication, cooperation and collaboration between departments).

5.2.1 Resource capacity and the ripple effects

As already highlighted (*Chapter 5, Section 5.1*), the lack of sufficient budgeting and planning has led to significant constraints on the ability of the Environmental Health Department to successfully achieve its mandated functions. This has been identified as the most significant challenge throughout the local governments in the three Gauteng metropolitans, and despite the Environmental Health Department's potential to unlock heat responses in their operational activities, they are currently limited in terms of human and financial capacity. A recent study by Rogers *et al*. (2023) identified the trends in global literature that explain the challenges hindering climate change adaptation mainstreaming (*Chapter 2, Section 2.11*) and highlighted resource constraints as one of the most common barriers hindering effective climate change implementation, with specific reference to

limited access to funds and the lack of sufficient staff dedicated to implementing adaptation strategies. Within the public health sector context, Macassa *et al*. (2022) investigated the extent of public health aspects that are considered by the stakeholders involved in developing climate adaptation plans for three global cities (*Chapter 2, Section 2.11*). These stakeholders identified challenges and barriers faced during the development and implementation of climate adaptation plans with a public health focus and highlighted the lack of funding and financial constraints limiting climate adaptation activities. In addition, Rogers *et al*. (2023) discuss how a local government's capacity to implement adaptation strategies depends on access to financial and human resources, and they highlight the importance of prioritising these during the policy development stage, with specific emphasis placed on providing the relevant departments with the necessary prerequisites to achieve their targets.

This lack of resources and resource constraints in the form of staffing further cripples the Environmental Health Department's ability to effectively cover the entirety of its area, resulting in reactive responses, which have been raised as areas of particular concern in the various operating contexts of the Environmental Health Officials throughout the Gauteng metropolitans. Both of these issues are directly correlated and related to the lack of sufficient budgeting and limited staff capacity to achieve and implement their operational activities effectively. The limitation of staffing within the Environmental Health Department provides a setting where it is almost impossible to build proactive strategies and carry out these activities, especially in areas with extremely large populations (e.g., northern regions of the City of Tshwane). This has resulted in the delayed, and hence reactive approach, of the local Environmental Health Department. According to Rogers *et al*. (2023), one of the most important enablers for improved implementation is the inclusion of a proactive and reflective planning culture within the relevant departments, and hence, the inability of the Environmental Health Department to be proactive in their responses puts a huge strain and limitation on the effectiveness of their strategising and implementation abilities.

5.2.2 Policy-implementation gap

As already explored (*Chapter 5, Section 5.1*), the disconnection and misalignment of policies with the Environmental Health Department’s implementation ability has been raised as a significant outcome of this study. Not only has this been highlighted externally during the review of the national and municipal policy and implementation gap, but it has been raised as a common challenge by the Environmental Health Officials throughout the Gauteng metropolitans. They expressed concern that they are neither involved in policy development nor instructed on their supposed roles and functions to effectively implement climate change, specifically heat responses, within the local communities. The difficulty of policy-implementation alignment is not uncommon, and the misalignment and disconnection of policy with implementation have been highlighted as areas of particular concern

throughout global literature focused on climate adaptation (Wheeler & Watts, 2018; Macassa *et al*., 2022; Sheehan *et al*., 2022; Rogers *et al*., 2023). The policy-implementation gap in climate adaptation approaches is due to a range of barriers and challenges, including governmental inefficiencies, resource constraints, lack of departmental and intersectoral coordination, and resistance from implementation departments, as well as communities on the ground (Wheeler & Watts, 2018; Hudson *et al*., 2019; Macassa *et al*., 2022; Sheehan *et al*., 2022; Rogers *et al*., 2023). To overcome this policy-implementation gap (*Chapter 5, Section 5.1.2*), it is essential for local governments, specifically the public health sector, to be actively involved in policy and planning development, as well as the presence of political support throughout the implementation journey (Wheeler & Watts, 2018; Singh *et al*., 2019; Macassa *et al*., 2022; Sheehan *et al*., 2022; Rogers *et al*., 2023). Furthermore, it is essential to not only include the local governments but also to address and include the departments, agencies and partners involved in the implementation of the policies and plans within the development process (Singh *et al*., 2019; Macassa *et al*., 2022; Sheehan *et al*., 2022; Rogers *et al*., 2023). This will ensure these key stakeholders are aware of their duties and objectives in the implementation process and identify whether or not they have the necessary capabilities and capacities to align with the set-out policies and plans (Singh *et al*., 2019; Rogers *et al*., 2023).

5.2.3 Interdepartmental coordination

The lack of effective communication, cooperation and collaboration between departments has not only been identified as a common challenge throughout the local Environmental Health Department but has also been highlighted as a potential opportunity for improvement and one that would enable effective implementation. The Environmental Health Officials throughout the Gauteng metropolitans highlighted that there are no shared objectives and targets with other departments, which inhibits the building of combined strategies to achieve common goals. Macassa *et al*. (2022) further highlighted that the lack of full collaboration between government departments and institutions, including the lack of involvement of the public health sector, limits effective climate change adaptation and is a significant challenge, particularly during the implementation phase (Macassa *et al*., 2022). Key enablers for enhanced climate adaptation implementation within local municipalities include active communication and collaboration, with robust intersectoral relationships throughout all municipal departments. This is further expanded to highlight the need for emphasising the co-benefits of climate change with other departments, thereby having a common goal to build combined strategies by reframing climate change to include other local concerns or areas of focus. This includes the need for a collaborative culture within municipal departments for open communication and cooperation across departmental planning and implementation (Wheeler & Watts, 2018; Macassa *et al*., 2022; Rogers *et al*., 2023). The need for effective communication, cooperation and collaboration is particularly

critical in the context of this research, as heat action does not sit within any traditional governmental departments or sectors and needs various stakeholders to be involved (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). The collaboration between the various government departments and agencies is thus essential in reducing heat-related health impacts at a city level and for the effective implementation of heat-health plans (McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021).

Relating to the ineffective communication, cooperation and collaboration between departments, local Environmental Health Officials also identified misunderstandings and lack of knowledge of departmental scopes of work as an area of concern. The lack of communication, cooperation and collaboration between departments has resulted in an ineffective system where there is duplication of work in some areas and areas where the scope of work slips through the cracks and is not covered by any relevant departments. This has been highlighted at the operational level. Furthermore, higher authorities do not completely understand the roles and responsibilities of the various departments. Active communication and collaboration between municipal departments are critical for enhancing implementation at the local level and will ensure that all relevant stakeholders are aware of the scopes of work and responsibilities of respective departments and agencies, creating a more efficient and effective system (Wheeler & Watts, 2018; Singh *et al*., 2019; Macassa *et al*., 2022; Rogers *et al*., 2023).

5.3 OPPORTUNITIES FOR IMPROVED IMPLEMENTATION AND FUTURE HEAT CONSIDERATIONS

By considering the proposed duties and functions of the Environmental Health Department within the national and municipal policies of heat responses, as well as the department's practical capabilities, the Environmental Health Department is well suited to carry out future heat action responses. Although the local Environmental Health Officials are currently facing many operational challenges in implementing their mandate without adding heat responses to their functions, they are well positioned and have built the foundations for effective coordination, collaboration and implementation of heat strategies in the future. The Department thus demonstrates significant potential to play a fundamental role in heat action in the future of the three metropolitans and the other cities throughout South Africa, potentially unlocking many opportunities for future heat responses. The three metropolitans' most significant and commonly raised opportunities for improved implementation and future heat considerations were highlighted in the previous chapter (*Chapter 4, Section 4.3.2*) and include:

(i) building on existing structures and functions within the Environmental Health Department (i.e., building on education and awareness campaigns and early warning systems);
(ii) improved communication, cooperation and collaboration with other departments and agencies;
(iii) ensuring heat action is specifically embedded in the IDP;
(iv) community ownership and buy-in from the local communities;
(v) building a Heat Action Task Force to control and manage the implementation of responses;
(vi) Environmental Health Officials' training and specialisation; and
(vii) involving the private sector in the implementation process and operational activities.

5.3.1 Existing systems: Connecting the dots

Regardless of the many challenges and limitations presented to the Environmental Health Department throughout the Gauteng metropolitans, their Officials recognised the Department's potential to play a significant role in future heat responses based on the existing structures and systems. Enhancing the Environmental Health Department's current resources and activities, as well as other structures and functions carried out by other departments and agencies, were identified as potential opportunities to build and develop heat responses. The most common opportunity highlighted throughout the three metropolitans is improving existing education and awareness campaigns to include extreme heat in the Environmental Health Department's outreach programmes to increase heat knowledge and adaptation in local communities.

The critical need for action to raise awareness and education the public on the risks, impacts and responses in the face of extreme heat (*Chapter 2, Section 2.7, 2.10 & 2.11*) is highlighted in several studies and heat action guidance globally and identified as priority areas in the Heat Health Action Guideline (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; Department of Health, 2020). Effective, well-developed global heat action plans (*Chapter 2, Section 2.7 & 2.11*) have embedded awareness-building and education campaigns as central themes in heat response activities, which are necessary to assist the public in understanding the risks of extreme heat events and to encourage them to take preventative measures in response to heat events (McGregor *et al*., 2015; Public Health England, 2015; Ahmedabad Municipal Corporation, 2013, 2016; McGregor, 2017; Singh *et al*., 2019). Furthermore, the Heat Health Action Guideline has emphasised the importance of educating the public about the risks and impacts of extreme heat and the actions that are needed when responding to heat events and has subsequently prioritised education and awareness campaigns when developing heat health action plans (Department of Health, 2020). Education and communication with local communities should be a priority focal point in all heat response strategies to effectively raise awareness about the risks of heat exposure to ensure that the local populations are prepared when a heatwave or extreme heat event

occurs. The public and local communities must be educated about the impacts, risks and actions to take in responding to increased heat exposure, and local communities must be notified about an incoming period of extreme heat (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; Department of Health, 2020). The local Environmental Health Officials raised another opportunity to build on existing structures and processes: enhancing current early warning systems to include heat alerts.

Several international and local studies highlight the importance of heat warning systems in the form of weather-based alerts as the central function of an overall heat action plan (*Chapter 2, Section 2.6, 2.7, 2.10 & 2.11*). They are designed to alert relevant departments, agencies, healthcare workers and the public about the incoming heat event (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; McGregor, 2017; Casanueva *et al*., 2019; Singh *et al*., 2019; Department of Health, 2020; World Health Organisation, 2021). In the South African context, although early warning systems are not controlled or operated by the Environmental Health Department – they are carried out by other departments and agencies, including the South African Weather Service, Disaster Management Department and other local weather agencies – local Environmental Health Officials could play a fundamental role in communicating and coordinating the relevant responses when such warnings are activated. It would thus be beneficial for the Environmental Health Department to partner with the SAWS, Disaster Management Department or other local weather agencies to build and establish heat early warning systems based on the guidelines set out by the World Meteorological Organization (World Meteorological Organization, 2015). The heat early warning systems could then possibly trigger the relative responses and actions by the various departments, depending on the communication networks and systems in place, which would need to be developed beforehand (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019). The Environmental Health Department would potentially be situated within these communication lines with the duty to communicate the incoming period of heat to the local communities and provide them with the necessary information on the responsive actions and recommendations for protection against extreme heat exposure, with specific focus and targeted responses for the more vulnerable populations (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019). However, for such a system to be effective, the relevant departments and agencies must understand their roles and responsibilities when carrying out such responses and effectively communicate with each other to ensure that stakeholders are informed about an incoming heat event and the response actions to take to reduce heat exposure and heat-related health impacts.

There are two opportunities to improve the existing systems and structures in the three Gauteng metropolitans and South Africa. The first is to conduct education and awareness campaigns to

increase knowledge and understanding of heat risks and preventative measures. The second is the development of early warning systems. They form part of the low-bearing fruit of adaptation strategies, which, according to global literature, are low-cost solutions that are extremely effective and save lives during extreme heat events.

5.3.2 Power in unity: Embracing a collaborative approach

As already highlighted relating to the Environmental Health Departments' implementation challenges (*Chapter 5, Section 5.2.3)*, improved communication, cooperation and collaboration with departments and agencies has been commonly identified as an area of potential improvement for more effective implementation and to further unlock heat responses. To effectively include heat considerations in the implementation abilities of local government, it is critical that relevant departments work together to achieve common goals and targets to support and assist each other. Currently, this is not the case at the operational level and has resulted in many implementation challenges, specifically for the Environmental Health Department, as well as for other departments and agencies (*Chapter 5, Section 5.1 & 5.2*). As mentioned, enablers for enhanced climate adaptation implementation within municipalities include active communication and collaboration, with robust intersectoral relationships throughout the municipal departments. This includes identifying the co-benefits of climate change responses, specifically heat action, for the various departments, thereby having common goals and targets in place, where combined objectives and strategies can be developed (Wheeler & Watts, 2018; Macassa *et al*., 2022; Rogers *et al*., 2023). To effectively enhance implementation at the local level, active communication and collaboration between departments is crucial, where all the relevant role players understand their functions and responsibilities in carrying out their duties of combined strategies and objectives (Wheeler & Watts, 2018; Singh *et al*., 2019; Macassa *et al*., 2022; Rogers *et al*., 2023). Furthermore, as discussed in the previous section (*Chapter 5, Section 5.2.3*) and highlighted earlier in this dissertation (*Chapter 2, Section 2.11*), heat action does not sit within one particular department or sector and needs an integrated interdepartmental approach (McGregor et al., 2015; Singh et al., 2019; World Health Organisation, 2021). To ensure successful coordination and collaboration within this integrated interdepartmental approach, it is essential that the relevant stakeholders, departments and agencies have a shared vision of what they need to achieve, as well as how they will achieve it. It is thus fundamental to identify and clearly outline the objectives, roles and responsibilities of each partner in the process, where each role player understands what they have to achieve and the means to achieve this (McGregor et al., 2015; Singh et al., 2019; World Health Organisation, 2021).

Additionally, including community ownership in heat response strategies was highlighted as a common opportunity raised throughout the Gauteng metropolitans, which will ensure sufficient

community buy-in for less resistance on the ground and more effective and sustainable implementation. The Environmental Health Officials further emphasised that local communities and governments must work collectively to develop strategies and initiatives for which local governments and the public are responsible. Community support has often been highlighted as one of the most common barriers and challenges hindering effective climate change implementation and highlights the need for community buy-in and involvement in decision-making, as well as actual implementation activities (*Chapter 2, Section 2.11*) (Rogers *et al.,* 2023). Several studies have highlighted the need to include local communities in climate action planning, specifically heatwave planning, to enhance community involvement and action while implementing response strategies. These studies have highlighted that community involvement and action motivate localised innovations and community-based strategies. Local communities have a strong 'sense of place' and pride in their communities, which will enhance buy-in and empower and create self-sufficiencies, ultimately building resilience within these local populations and communities (Firth *et al*., 2011; Burchell *et al*., 2014; Rezaei & Dowlatabadi, 2016; Taylor Aiken, 2015; Fagan-Watson & Burchell, 2016). Furthermore, in a more practical example of extreme heat adaptation, a review of the Ahmedabad Heat Action Plan of 2013 by Shah *et al.* (2014) highlighted that the local communities' eagerness and involvement on the ground enhanced the action plan's overall impact and success and suggested that this should be considered a central theme when developing and building heat adaptation response strategies at a local level (Ahmedabad Municipal Corporation, 2013; Shah *et al.*, 2014). Hence, including and involving local communities, from planning to implementation, will create public responsibility, where local populations can champion strategies and initiatives on the ground, enhancing the success of heat action and building resilience in the local communities.

5.3.3 Mandated heat action

As discussed during the review of the national and municipal policy and plans (*Chapter 5, Section 5.1*) and as raised by the Environmental Health Officials as a potential opportunity for heat action in the future, a more in-depth focus to address heat-related health impacts needs to be included within the municipal IDP context. The local Officials highlighted the need to include heat action in the municipal IDPs to ensure specific objectives, targets and KPIs are developed to achieve implementation on the ground. Incorporating heat considerations into the various municipal IDPs will ensure sufficient budgets are put in place, where heat action is mainstreamed throughout the relevant departments and becomes part of the daily operations. As highlighted in global heat action guidance (*Chapter 2, section 2.11*), it is essential to outline the mandate to reduce heat risks within municipal policies and laws, specifically within the mandates of the key departments, agencies and partners involved in heat action planning, to ensure that this effort is effectively implemented and sustained

(McGregor *et al*., 2015; Singh *et al*., 2019; World Health Organisation, 2021). Furthermore, several local South African studies have investigated the extent to which climate adaptation is embedded within municipal planning instruments, specifically the municipal IDPs (*Chapter 2, Section 2.11*). These studies highlighted the lack of effective climate adaptation and mitigation strategies embedded in the municipal IDPs, leading to the lack of mainstreaming climate action into the operations, planning and decision-making of these municipalities. Furthermore, the need to reflect on the local IDP's climate change adaptation and mitigation plans for better budgeting, planning and decision-making for climate change in the future was emphasised (Lethoko, 2016; Santhia *et al*., 2018; Pieterse *et al*., 2021).

5.3.4 Specialised Heat Action Units

In a recent advancement in global urban heat planning (Ahmedabad Municipal Corporation, 2013, 2016; Singh *et al*., 2019; Miami-Dade County, 2021; Keith *et al*., 2021; World Health Organisation, 2021) and a common trend mentioned by three Gauteng metropolitans' Environmental Health Officials is the inclusion of a centralised unit, such as a Heat Action Task Force, to function across the relevant municipal departments to ensure extreme heat events are proactively planned for and responded to. The Officials highlighted that their department lacks the necessary abilities and capacities to lead heat action, and a task force specifically focused on heat responses is needed. This Heat Task Force would be a centralised unit comprised of a team that can communicate and mobilise the relevant departments and agencies needed to respond to an incoming heat event. Several recent studies have highlighted the importance of having a Heat Action Task Force, with specific reference to Heat Officers, ensuring that heat action is integrated into local municipalities' policies and operations (Ahmedabad Municipal Corporation, 2013, 2016; Singh *et al*., 2019; Miami-Dade County, 2021; Keith *et al*., 2021; World Health Organisation, 2021). An example of a specific case (*Chapter 2, Section 2.7*) is the Ahmedabad Heat Action Plan, which highlights the duties of the 'AMC Nodal Officer' to activate the heat alert system and coordinate various stakeholders to ensure the Heat Action Plan is effectively implemented, ultimately acting as the centralised heat action unit for the City of Ahmedabad (Ahmedabad Municipal Corporation, 2013, 2016). Additionally, in other parts of the world, some cities that are at high risk of heat extremes have created and appointed "Chief Heat Officers" tasked to champion heat action planning and responses by raising awareness of heat risks and response strategies within governments, identifying vulnerable communities and populations at a higher risk to heat-related impacts, improving plans and responses to extreme heat events, coordinating and communicating with the relevant departments and agencies involved in implementing heat action and lastly, implementing long-term heat reduction and cooling projects (Keith *et al*., 2021; Miami-Dade County, 2021; One Billion Resilient, 2021). A similar Heat Officer,

or Heat Action Task Force, could be extremely beneficial in a South African context and would ideally sit within the Disaster Management Unit, specifically focusing on heat risks and extreme heat events.

The specialisation and training of the local Environmental Health Officials relating to the impacts and responses of extreme heat builds on the inclusion of specialised units and heat task forces leading heat action responses and planning going forward but is focused more internally within the Environmental Health Department. The three Gauteng metropolitan's Environmental Health Officials outlined that most EHPs cover a diverse range of subject matter, rarely specialising in the different aspects and services embedded within their mandate, following a generalist approach during their operational activities. Furthermore, they highlighted that they are not informed or trained to implement and achieve their duties on the ground effectively when new duties or tasks are mandated and included in the Department's operational activities. Several global studies have highlighted the importance of specialised training and understanding heat risks and responses for officials implementing heat action at the local level (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Rogers *et al.,* 2023). Specialisation and training also refer to the healthcare workers and health professionals to effectively recognise and treat patients with heat-related health conditions and illnesses (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016). Additionally, the Heat Health Action Guideline states that local EHPs need additional training to enhance their contribution to heat responses and the implementation of the heat health action plans on the ground (Department of Health, 2020).

5.4 HEAT VULNERABILITY ASSESSMENT: ENHANCING PREPAREDNESS AND RESILIENCE

The quantitative approach of this research provides a relative preliminary ranking of heat vulnerability for all the wards throughout the three Gauteng metropolitans. Although there have been many global studies, with a similar local study conducted in the eThekwini metropolitan by Jagarnath *et al*. (2020), as well as the Green Book's socio-economic vulnerability assessments, there has been minimal research conducted on heat-related vulnerabilities in Gauteng. Using the knowledge and research applied in other global and local settings, the research in this dissertation developed an index that described the spatial distribution of heat vulnerability across the Gauteng Province, which can be used by decision- and policy-makers, planners and disaster management for targeted heat adaptation efforts.

Identifying and targeting vulnerable populations and communities forms a fundamental function of all climate change strategies, and throughout both global and national literature, the need for more

targeted responses to protect vulnerable groups is constantly highlighted. Several global studies have emphasised the identification of vulnerable populations as a key component in developing and implementing heat-health action plans to ensure responses are developed to target these populations (Ebi *et al*., 2004; Pascal *et al*., 2006; Public Health England, 2015; McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; McGregor, 2017; Casanueva *et al*., 2019; Global Change Institute, 2019; Singh *et al*., 2019; World Health Organisation, 2021). Additionally, heat vulnerabilities correlate with socio-economic inequalities of an area with low-income populations and communities and marginalised groups disproportionately affected by extreme heat due to their low adaptive capacity and inability to avoid heat impacts (McGregor *et al*., 2015; Casanueva *et al*., 2019; Abrar *et al*., 2022). Identifying the populations and communities more sensitive to increased temperatures and with a lower adaptive capacity to respond will allow decision-makers and planners to effectively develop targeted strategies to protect and support the various groups during extreme heat events, such as providing cooling centres, enhancing urban green spaces, improving infrastructure and health and medical support (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; World Health Organisation, 2021; Abrar *et al*., 2022). Furthermore, understanding and identifying which populations and communities are more vulnerable to and at risk of extreme heat events will allow for establishing early warning systems and improved communication networks to target these specific areas (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Abrar *et al*., 2022).

The Heat Health Action Guideline outlines that heat adaptation strategies and responses should target vulnerable groups, which have been clearly defined and highlighted to include the elderly, youth and young children, pregnant women, people with existing medical conditions, people living in poverty with limited access to resources and services, and physical labourers working in extreme environments. The guidelines further emphasise the importance of identifying these populations to ensure the implementation of effective planning and targeting of services, delivering early warning systems and communications to these targeted vulnerable populations (Department of Health, 2020). However, although vulnerable populations and groups have been clearly outlined and defined in this guideline, the spatial distribution of vulnerability throughout the Gauteng metropolitans has not been clearly highlighted at the local level. Thus, a localised heat vulnerability assessment was included in this study to identify the vulnerability level of the wards throughout the planning regions within the three metropolitans. The heat vulnerability assessment aimed to quantify the vulnerability of the three Gauteng metropolitans' local populations using socio-economic variables to represent heat vulnerability.

This research is the first to statistically identify the levels of heat vulnerability, down to a ward level (i.e., Level 4 administrative level), throughout all the Gauteng metropolitans. A very evident finding from this assessment was that populations living in areas with similar natural environments, and hence heat exposure, show a significantly different spatial distribution of vulnerability due to social and economic factors that contribute to different levels of vulnerability, resulting in populations more at risk to increased temperatures and extreme heat exposure. Similar to the results of other global and local heat vulnerability studies (Nayak *et al*., 2018; Jagarnath *et al*., 2020; Abrar *et al*., 2022), the heat vulnerability assessment in the current study highlights the high levels of vulnerability, notably in the rural and informal settlements due to poverty, lack of access to resources and services (i.e., water, electricity, healthcare, etc.) and living conditions (i.e., dwelling type, overpopulated households, etc.). However, significant differences in the selection of heat-specific variables make this heat vulnerability assessment specifically useful for the Gauteng metropolitans and other South African cities.

As indicated in the heat vulnerability maps *Chapter 4, Section 4.4.2*), the High and Very High HVI wards are located in the southern regions of Johannesburg, the northern and eastern regions of Tshwane, and the southern regions of Ekurhuleni, while the wards with Low HVIs are located in the central regions of Johannesburg, the southern and central regions of Tshwane, and the western and central regions of Ekurhuleni. Due to the legacy of Apartheid urban planning (pre-1994), populations were confined to the outskirts of the cities, resulting in high levels of poverty in these historical areas, which is clearly demonstrated in these heat vulnerability maps, as the identified populations are located on the outskirts and outer regions of the cities. Since 1994, these areas have experienced a high level of migration, becoming densely populated without the necessary infrastructure, services and resources available to them, compared to the city centres and other more formal areas (Jagarnath *et al*., 2020; City of Tshwane Metropolitan Municipality, 2021; City of Johannesburg Metropolitan Municipality, 2021; City of Ekurhuleni Metropolitan Municipality, 2022). The fact that they live in high levels of poverty, are densely populated and lack necessary resources and services has led to these populations and areas demonstrating a high level of vulnerability to extreme heat due to their sensitivity and low adaptive capacity. Furthermore, it would be useful for planners, policy- and decision-makers and disaster risk management officials to observe whether these vulnerability areas and hotspots are also associated with higher temperatures or frequent extreme heat events to further assist in the development of heat responses and planning.

As highlighted in a similar study in the eThekwini metropolitan by Jagarnath *et al*. (2020) (*Chapter 2, Section 2.9*), identifying the drivers of vulnerability will assist the cities and local governments in understanding the social and economic construct, as well as spatial disproportions of climate risk

(Jagarnath *et al*., 2020). Jagarnath *et al*. (2020) also emphasised the importance of targeted heat planning by considering ward-level risk profiles based on heat vulnerability mapping, where developmental co-benefits are maximised and trade-offs are minimised (Jagarnath *et al*., 2020). This offers valuable insights into the populations and areas most susceptible to and at risk of heat-related health impacts, informing adaptation strategies for public health interventions, emergency preparedness, urban planning and aiding in policy development (Jagarnath *et al*., 2020; Wright *et al*., 2023). This allows for the development of strategies and responses based on the specific risk profiles and vulnerabilities to guide the necessary response actions and target the more at risk and vulnerable areas (Jagarnath *et al*., 2020).

Based on the results of this heat mapping and further assessment, targeted strategies for heat action planning can be developed based on the local context of the areas throughout the three metropolitans. This can further contribute to and support the prioritisation of strategies and responses in social services, infrastructure development and resource planning to the areas with a higher level of vulnerability to increasing temperatures and extreme heat. Ultimately, this assessment provides a visual understanding of the spatial distribution of heat vulnerability throughout the Gauteng metropolitans, which will inform and assist policy- and decision-making, allocation of resources and disaster management and further assist in developing effective heat action planning and responding.

The comprehensive research results (*Chapter 4*) of this dissertation have been presented in this chapter, providing guidance to transform heat policies and plans into action by bridging the policy-implementation gap. The institutional challenges and opportunities within the Environmental Health Department for improving implementation and future heat considerations were discussed. Lastly, the heat vulnerability assessment was highlighted to enhance preparedness and build resilience within Gauteng's local populations and communities. This provides a useful tool for local governments to better understand and address the impacts of extreme heat on their populations, and from this, targeted responses could be developed to reduce heat-related health impacts in these areas. Ultimately, this provides a platform to advance heat responses throughout the Gauteng metropolitans by providing valuable insights into the operational landscape of the Environmental Health Department and the vulnerability of the metropolitans' populations and communities. This allows for a holistic analysis and understanding of the heat context throughout the three metropolitans, enabling local governments to build suitable adaptive strategies that effectively address the specific risk context of the areas, assisting in the co-designing and developing future heat action plans for these cities.

6 CHAPTER SIX – CONCLUSION: MOVING TO A HEAT ACTION PLAN

This research presented the political, operational and vulnerability landscape of the current and future heat action responses in the three metropolitans of the Gauteng Province. It also highlighted the national and municipal policies and plans to respond to extreme heat, the extent of local governments' responses, including the challenges and opportunities of the Environmental Health Department's operational activities, and the level of heat vulnerability at the local scale throughout the three metropolitans. This provided a landscape to develop and build future heat action plans for the three metropolitans, with the Environmental Health Department leading the communication and implementation of heat response strategies on the ground.

Although heat action has yet to be unlocked within the Environmental Health Department, the Department demonstrates significant potential to include heat responses within its future operational activities. The daily interaction and continuous engagement with local communities provide an effective line of communication to raise awareness and improve knowledge of the impacts of extreme heat within these populations. As laid out in the Heat Health Action Guideline, the Environmental Health Department, with specific reference to the EHPs, will be critical in shaping strategies aimed at supporting vulnerable communities to adapt to extreme heat and will play a fundamental role in the leadership, coordination and communication of heat responses at a local level. The role of the Environmental Health Department and all other relevant departments, agencies and stakeholders remains critical, particularly in clearly understanding their roles and responsibilities to implement such responses at a local level. The Heat Health Action Guideline outlines that the development of a Heat Action Plan will be instrumental in actioning the responses needed to reduce the health risks associated with extreme heat events and heatwaves, as well as identifying the departments and agencies responsible for effectively implementing such actions.

Using the Heat Health Action Guideline and other highly notable heat action plans from around the world as possible frameworks to build from, the three metropolitans of this study could develop their unique heat action plans to protect their cities' populations by reducing the health risks associated with extreme heat. Similar to the South African National Heat Health Guidelines, global heat action guidance highlights the public health sector as the lead agency for communicating and coordinating heatwave-related activities in cities. These activities include monitoring early warnings, mobilising the relevant departments and agencies, and communicating heat-health alerts to local communities, with specific attention being paid to the populations more at risk and vulnerable to extreme heat (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; McGregor, 2017; Singh *et al*., 2019; Department of Health, 2020; World Health Organisation, 2021). Furthermore, the South

African National Heat Health Guidelines and other notable global guidelines and heat action plans outline four broad fundamental strategies that must be embedded within a Heat Action Plan: (1) Raising Awareness and Engaging the Community, (2) Early warning systems and inter-departmental coordination, (3) Building capacity among emergency responders and healthcare professionals, and (4) Reducing heat exposure and promoting adaptive behaviours (McGregor *et al*., 2015; Public Health England, 2015; Ahmedabad Municipal Corporation, 2016; McGregor, 2017; Casanueva *et al*., 2019; Singh *et al*., 2019; Department of Health, 2020; World Health Organisation, 2021; Puley, 2022).

Raising Awareness and Engaging the Community

The first strategy looks to create awareness and educate the public on heat knowledge by reaching out to local communities and populations to communicate the risks, symptoms and responses of extreme heat exposure (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; McGregor, 2017; Casanueva *et al*., 2019; Puley, 2022). This includes spreading messages throughout the local communities using various media and informational platforms on how to prevent heat-related illnesses and deaths (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; McGregor, 2017; Casanueva *et al*., 2019; Singh *et al*., 2019; Puley, 2022). These platforms include advertisements, pamphlets, emails, text messages (SMS), WhatsApp, local radio and mobile applications (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019). Furthermore, it is emphasised that vulnerable communities may not have access to these platforms, and special efforts must be made to reach these populations through interpersonal communications and other outreach methods (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; Puley, 2022). These outreach methods can be very beneficial in South Africa and the cities of this study but may need to be adapted to suit the specific context of the various local areas. An important addition that was noted throughout the discussions with the local Environmental Health Officials was the need to include these education, awareness and communications messages in multiple local languages, and even in simple pictures and illustrations for the illiterate, to ensure all individuals and communities can understand, learn and respond when an extreme heat event is approaching.

In addition, the Heat Health Action Guideline highlight a *Heat-health Information Plan* as one of the core elements of a heat health action plan (Department of Health, 2020). This Heat Health Information Plan outlines the need to educate the public on the risks of extreme heat exposure and the necessary actions and responses needed to be taken during an extreme heat event. Communication strategies form a key part of the Heat Health Information Plan, where five main messages are spread to the necessary communities: (1) how to keep a home cool, (2) how to keep out of the heat if you must be

outdoors, (3) how to keep the body cool and hydrated, (4) how to help others when it is hot, and (5) what to do when you or others feel unwell when it is hot. These messages must be simple, easily understandable and in the local languages of the populations living in different areas (Department of Health, 2020).

Early Warning Systems and Inter-Departmental Coordination

The next strategy aims to build effective communication and network from the initial alerting agencies to the necessary stakeholders to inform them of the predicted increased temperatures and incoming extreme heat events (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; McGregor, 2017; Casanueva *et al*., 2019; Singh *et al*., 2019; Puley, 2022). Global heat action guidance has emphasised the importance of establishing these formal communication channels with the relevant agencies, departments, healthcare officials and hospitals, emergency responders, media platforms and local communities to alert them of the predicted heat extremes, and has since been successfully demonstrated in many heat action plans around the world (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; Puley, 2022). Furthermore, establishing different categories of heat events depending on temperature thresholds for additional means of communication has also proven successful in many heat contexts (e.g., Heat alert categories in the Ahmedabad Heat Action Plan: Yellow alert is a hot day advisory with temperatures 41.1°C to 43°C; orange alert is a heat alert day with temperatures 43.1°C to 44.9°C; red alert is an extreme heat alert day with temperatures 45°C and above) (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016). These alert categories have planned actions based on the specific heat threshold of the event and can prove very beneficial in enhancing the early warning systems in South African cities. However, they must be adapted to local conditions and various cities' threshold limits.

In the context of South Africa and from the Heat Health Action Guideline, adding "*Heat-health Warning Systems*" forms part of the core elements that should be included in a heat action plan (Department of Health, 2020, p.17). These guidelines have identified and tasked the SAWS as the responsible agency to issue extreme heat warnings based on a "*Discomfort Advisory*" system, which considers temperature, humidity and other weather variables (Department of Health, 2020, p.17). When a specific event exceeds the temperature or "*Discomfort Advisory*" threshold, the communication network and actions are triggered, which includes alerts to the necessary departments, agencies, media, the public and other relevant stakeholders through the SAWS website, emails and SMS platforms (Department of Health, 2020, p.17). These guidelines indicate that different levels of categories should be used to distinguish the various types of heat events (i.e., stressful heat levels,

temperature levels dangerous to health and the highest-level alarm) (Department of Health, 2020, p.17).

Building Capacity Among Emergency Responders and Healthcare Professionals

Global heat action guidelines and numerous practical heat action plans highlight that the abilities of health professionals, medical workers, paramedics, community health officials and other medical workers are crucial in preventing and treating heat-related health impacts and illnesses during extreme heat events, ultimately reducing mortalities and morbidities in local communities (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; Puley, 2022). This includes upgrading physical infrastructure in hospitals, clinics and informal healthcare units, the availability and access of medical equipment and medication to treat heat-related illnesses and the overall strengthening of the healthcare structure and system to ensure a scaled-up capacity of healthcare workers, paramedics and ambulances during these times of high demand (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019). It is further highlighted that to ensure preparedness and capacity building within health systems, health professionals must be effectively educated and trained on heat-related health illnesses to ensure they are ready to respond during an extreme heat event (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; World Health Organisation, 2021). Cities worldwide with heat action plans in place have ensured health professionals' readiness by holding workshops for the various healthcare workers on heat-related symptoms and treatments, ensuring the necessary equipment and medicines are available on demand, and developing a treatment protocol for all emergency responders, clinics, hospitals, etc. (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; World Health Organisation, 2021).

The Heat Health Action Guideline of South Africa also include the "*Preparedness of Healthcare and Social Services*" as one of the core elements of an effective Heat Action Plan, which sets out the specific procedures and protocols that clinics, hospitals, emergency responders and care centres should take before and during periods of extreme heat (Department of Health, 2020, p.21). The importance of educating and training the necessary health workers has been further emphasised to ensure all health professionals know how to prevent the impacts of extreme heat, the necessary guidelines and protocols to take in responding to periods of extreme heat, the individuals more vulnerable and at risk to heat exposure, the symptoms of the various heat-related illnesses, and the required treatments to these heat-related illnesses (Department of Health, 2020).

Reducing Heat Exposure and Promoting Adaptive Behaviours

The ultimate strategy of heat action guidance, which is critical in many heat action plans worldwide, is to reduce exposure to extreme heat and to build an adaptive capacity within cities' local communities and populations (McGregor *et al*., 2015; Public Health England, 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; World Health Organisation, 2021; Puley, 2022). Many of these heat action plans have achieved this by mapping out the city's vulnerable and at-risk populations and areas; increasing education, awareness and communication related to heat risk and impacts and preventative measures; increasing hydration measures and sufficient water supply during heat events; and identifying community cooling spaces during heat events. Furthermore, they highlight the importance of collaborating with non-governmental organisations and non-profit organisations to increase the outreach of communication channels and enhance responses on the ground, especially targeting the most vulnerable and at-risk communities (McGregor *et al*., 2015; Public Health England, 2015; Ahmedabad Municipal Corporation, 2013, 2016; Casanueva *et al*., 2019; Singh *et al*., 2019; World Health Organisation, 2021; Puley, 2022).

Furthermore, many other adaptation and mitigation responses identified throughout global heat action are highly effective: (1) urban greening in areas lacking significant green infrastructure with urban trees and greening significantly reducing heat stress levels and providing cooling, (2) cooling strategies for low-cost dwellings reducing indoor heat exposure (e.g. the implementation of cool roof programmes to lower the solar radiation absorbed by roofs in low-cost housing), (3) identifying and communicating community cooling centres as a place of safety to the reduce heat exposure, especially for the more vulnerable populations, (4) reducing heat exposure in indoor and outdoor public spaces using similar mentioned techniques of cooling strategies, increased urban vegetation, air-conditioned and increased ventilation in buildings, and (5) protecting labourers and workers more exposed to heat extremes by providing protective clothing, increasing hydration and adapting working hours; (McGregor *et al*., 2015; Casanueva *et al*., 2019; Singh *et al*., 2019; World Health Organisation, 2021; Abrar *et al*., 2022; Puley, 2022).

The power of three: a three-phased approach

An important aspect of heat action plans worldwide is the inclusion of a three-phased approach when responding to an extreme heat event: the pre-heat season, during-the-heat season and post-heat season, each with specific strategies, objectives and targets (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Singh *et al*., 2019). The pre-heat season is the planning and preparation phase that occurs during the months leading up to the extreme heat season and primarily

involves preparation tasks, identifying vulnerable populations, educating and building awareness in the local communities, especially among healthcare workers, labourers and children, about the risks, impacts and preventative responses to extreme heat exposure (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Singh *et al*., 2019). The during-the-heat season phase is linked to disaster management and city-wide responses to extreme heat events and includes constant monitoring and forecasting of temperatures, initiating early warning systems to alert all necessary departments, agencies, emergency responders and the public, providing heat protection and avoidance guides, providing access to sufficient drinking water throughout the city, identifying and communicating community cooling spaces as a place of safety to reduce heat exposure for the public (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Singh *et al*., 2019). Lastly, the post-heat season phase highlights the importance of monitoring and evaluating the extent of the impacts of the heat event (i.e., quantify the number of heat-related illnesses and mortalities), as well as identifying the effectiveness of the Heat Action Plan, thereby understanding the shortcomings of the plan, the elements that worked well and were effective, and the areas where improvement can be made with possible new ways to implement in the future (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Singh *et al*., 2019). Overall, this three-phase approach ensures that cities are always proactive and prepared for an extreme heat event at any time, with the necessary warnings, mobilisation, communication and responses readily available.

Lastly, to ensure all the necessary departments, agencies, emergency responders and media are fully aware of their roles, responsibilities, objectives and targets of the Heat Action Plan, it is essential that stakeholder-specific protocols and checklists are created for the three phases of heat action in the city. This allows each stakeholder to understand their role and what is expected of them when they are alerted of an incoming heat event public (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Singh *et al*., 2019). These stakeholders include the lead agency (i.e., Heat Officer or Task Force), health departments (i.e., health workers and hospitals), public health officials (i.e., similar to that of the Environmental Health Officials), disaster and emergency departments (i.e., national and local Disaster Management Centres), weather and meteorological agencies (i.e., SAWS), urban planning departments, social services departments, media and communication agencies and many other potential stakeholders (McGregor *et al*., 2015; Ahmedabad Municipal Corporation, 2013, 2016; Singh *et al*., 2019)

The way forward and into the future

As highlighted at the onset of this dissertation (*Chapter 2, Section 2.2*), a news report from January 2023 alerted Gauteng and other South African residents to take precautions against heat-related health

complications as a heatwave reaching temperatures up to 40°C was emerging. This heatwave resulted in multiple deaths throughout the country, which, along with many other similar events, has recently driven attention to the health-related impacts of extreme heat in the country, especially within cities and vulnerable areas. The current heat context of South Africa, particularly Gauteng, is of considerable concern, notwithstanding the predicted rise in temperatures and increase in the frequency and intensity of heatwaves in the country throughout the century. Furthermore, as recently demonstrated throughout the global north during the summer of 2023, the El Niño oscillation has begun and has already caused extreme heatwaves and significant health impacts throughout many northern hemisphere countries, which has left them pondering on their preparedness and resilience for extreme heat. This El Niño will be further intensified in the southern hemisphere at the start of the 2024 summer season, and experts have warned the global south, with particular reference to South Africa, to be alert and prepare for significant droughts and heatwaves during this period. This extreme heat, coupled with the multi-stressed environment of South African societies due to their numerous socio-economic challenges, provides a setting for dramatic heat-related health impacts in the country's future. It is thus critical that South African governments advance their efforts for preparedness and response to rising temperatures and increased heatwaves to protect vulnerable groups and ensure the health and well-being of their population. Using the South African Heat Health Action Guidance and the practical examples illustrated in this dissertation (*Chapter 2, Sections 2.6, 2.7 & 2.11*), the study's three metropolitans could develop their own heat action plans, led by the Environmental Health Department. Ultimately, the heat action plan could prepare, prevent, respond and contain heat-related health risks and protect the societies within these cities.

Research Limitations and Future Work

Through the mixed-methods approach, this dissertation provides a rich understanding of the institutional dynamics of heat action at a local level and the vulnerability disparities throughout the Gauteng City region. However, this research had several limitations in each of the qualitative and quantitative assessments.

Firstly, the qualitative assessment of this research consists of interviews with Health officials from the Environmental Health Department throughout the Gauteng City Region. The decision to include these officials as the study group in this research was based on the National Heat Health Guidelines, which identifies this department and its local health officials as the primary agents for heat action at the local level. However, upon initiation of the interviews with the Health officials, it became clear that the officials had no knowledge of their supposed role in addressing hear-related issues, and there was no evidence of heat strategies and responses being implemented in any of the regions across the

three metropolitan areas. The status and context of the Environmental Health Department led to the qualitative interviews of this research being adapted from the originally planned heat-focused topics to cover broader climate change issues, departmental and operational landscapes, challenges and opportunities and overall institutional dynamics for future heat action considerations at the local level. The shift in interview focus and the current context of the Environmental Health Department are significant findings in themselves. However, this limited the specificity and applicability of the findings related to improving the current heat response strategies and implementation. As a result, this potentially diluted the research conclusions on the current heat-related public health responses and the potential improvements that can be made. In the specific context of the City of Ekurhuleni, the city lacks the necessary structures to be managed at a planning region level and instead is managed at a broader regional level. This impacted the findings between the three metropolitans, as comparisons could not be made within the Ekurhuleni planning regions or between the other two metropolitans. The inconsistency of these institutional structures limited the ability to draw consistent and reliable conclusions about the differences between the other two metros and Ekurhuleni. However, this is still a telling story of the current challenges within Ekurhuleni that must be addressed.

Secondly, the quantitative aspect of this study consisted of a perception-informed assessment of vulnerability to heat-related health impacts throughout the Gauteng City Region. However, although this heat vulnerability assessment is based on past literature and global social vulnerability frameworks, there is some bias in the selection of the socio-economic variables and a risk of overlooking other important factors specific to a particular area. This selection bias may result in an incomplete representation of the study area's vulnerability, potentially impacting the comprehensiveness of the vulnerability assessment. Additionally, the data used to create this heat vulnerability index is based on census data, which has its own intrinsic limitations. These limitations arise because the data could be outdated and may not have the necessary level of detail to accurately represent the current socio-economic conditions of the study area. Despite these limitations affecting the precision of the heat vulnerability assessment and the reliability of the research conclusions throughout the three metropolitans, this assessment still provides a valuable resource for a snapshot of vulnerability in time. Although not entirely accurate, it still equips local governments with sufficient resources and planning tools to inform future heat adaptation planning. It is, however, recommended that this assessment be repeated when more recent updated census data is available, such as the GCRO QoL 2022/2023 survey. Lastly, the PCA methodology used has a few limitations. It reduces the complex dynamics of the socio-economic variables into simple principal components, which may oversimplify the relationships and differences between the variables. Furthermore, this

assessment assumes a linear relationship between variables, which may not be true for all socio-economic variables related to heat vulnerability. This assumption could lead to a loss of important information and may affect the accuracy of the index.

Overall, despite the above limitations, this research offers valuable insights into the current state of heat action and vulnerability in the Gauteng City region. This lays the groundwork for future steps towards heat action in these South African cities, which has been limited in the past. Based on this research, future efforts would involve continuing to work with the Environmental Health Department to ensure that heat action is advanced and prioritised within the department, ensuring that duties towards heat responses are mandated, budgeted and effectively resourced. The local Health officials within this department do, however, require basic training and development to deepen their knowledge and understanding of climate change and the impacts of extreme heat, as well as the necessary responses. Further to this, it will be crucial to prioritise the integration and mainstreaming of heat action from the current national and local policy and planning landscape into implementation and response-focused outcomes throughout all South African cities. There remains a significant gap between policy and implementation, as highlighted throughout this research, and future research could explore ways to narrow this gap and progress towards the practical implementation of heat action on the ground. This research has the potential to be expanded to all South African metropolitan areas to understand the current institutional and operational dynamics that have limited heat action on the ground, as well as explore the potential opportunities that can be leveraged in the future. Additionally, the heat vulnerability assessment offers a targeted mapping approach to identify areas with the highest heat risks in the Gauteng City Region. This information can help local governments develop more proactive and coordinated strategies and early warning systems to address extreme heat events and protect the most vulnerable populations. In particular, this can assist in prioritising interventions and strategies for infrastructure delivery, social services, resource planning and disaster management in those areas most likely impacted by heat-related health issues. Furthermore, this assessment contributes to place-based approaches for addressing inherent vulnerability and the impacts of climate change, which are not significantly different from addressing standard socio-economic development issues. This approach can be valuable in numerous countries and cities in Africa, as well as in many developing nations around the world that are characterised by urban and developmental challenges. Ultimately, it can further spur much-needed research on heat stress and its outcomes in the southern African context.

In conclusion, this research dissertation has demonstrated the following:

- The development and implementation of heat adaptation strategies and heat action plans have been poorly recognised within an African context, with many African cities not considering extreme heat as an area of concern.
- The African continent is experiencing a warming rate faster than the rest of the world, with more frequent and intense heatwave events. The poor socio-economic conditions of the continent, coupled with these heat risks, place Africa at the forefront of future heat-related health impacts.
- Extreme heat and heatwave studies are thus critical within an African context, which has been previously overlooked, requiring the development of effective mitigation and adaptation strategies for these societies to cope with rising temperatures in the future.
- South Africa is one African country that has recognised growing heat risks and has provided the necessary frameworks within their national policies, strategies and planning (i.e., Climate Change Bill, Climate Change Response White Paper, Climate Change Adaptation Strategy and Heat Health Action Guideline) to outline the responses and plans needed to address the current and future climate risks.
- Local governments have subsequently included climate and heat action in their municipal planning instruments (i.e., IDPs and other climate action supplements like the CAP and CCRS) to outline the risks and necessary mitigation and adaptation strategies needed.
- Despite the development of these national and municipal plans and policies, local governments have not successfully integrated and implemented heat response strategies into their operational activities.
- The Heat Health Action Guideline has tasked the health sector as the lead agency in the development and implementation of heat action planning, with the Department of Health, led by Environmental Health and Disaster Management. The Environmental Health Department is responsible for coordinating, collaborating and implementing heat-health strategies, but this is not the case when investigating the Department's roles, functions and objectives.
- Climate change and extreme heat are not considered within the operational context of the Environmental Health Department and are neither mandated nor budgeted for. The local Environmental Health Officials have a primary focus on the nine Municipal Health Services, which have specific strategic objectives and targets.
- Although the IDPs are supplemented with the CAP and CCRS, there is no specific planning and budgeting directly focused on heat-health impacts. For heat considerations to be successfully mandated with a sufficient budget in place, it must be included in the municipal

planning instruments, like that of the IDP, for better planning, budgeting and implementation within the operational activities of the key departments on the ground.

- The misalignment between policy development and implementation ability is further highlighted, as the national and municipal policies do not always align with the capacity and abilities of local governments, particularly within the Environmental Health Department.
- Even if heat action is mandated and budgeted, the Environmental Health Department lacks the resources to effectively include heat responses within its operational activities, with the EHP ratio throughout the local department significantly beyond the World Health Organisation Guidelines and the Environmental Health Policy (i.e., at least one EHP for every ten thousand population).
- The Environmental Health Department is currently not fulfilling and unlocking its full potential to include climate change, specifically heat responses, within its operational activities. The Department is limited in achieving its current mandate without including heat responses.
- The Environmental Health Officials' ability to fulfil their duties and further unlock their potential for heat action is constrained by many operational challenges, including resource constraints, policy misalignment, lack of communication and cooperation with departments, distance and time constraints, reactive instead of proactive approaches, lack of knowledge and understanding of other departmental mandates and functions, lack of responsibility and accountability and lastly, their safety.
- These highlight three central themes challenging the effective implementation abilities of local Environmental Health Officials: *(1) Resource capacity and the ripple effects, (2) Policy-implementation gap and (3) Interdepartmental coordination.*
- Although the Environmental Health Department is currently facing many operational challenges in implementing its mandate without adding heat responses to its functions, it is well-positioned and has laid the foundations for effective coordination, collaboration and implementation of heat strategies in the future.
- The Environmental Health Department has the potential to unlock many opportunities for future heat responses, including building on education and awareness campaigns, multi-sectoral communication, collaboration and cooperation, building on existing structures, community ownership, mandated heat action embedded within the IDP, Heat Action Task Forces, specialisation of Environmental Health Officials, early warning systems, training Environmental Health Officials with mandated duties and lastly, involving private companies.
- These highlight four central themes providing opportunities for improved implementation and future heat considerations: (1) E*xisting systems: connecting the dots*, (2) P*ower in unity:*

embracing a collaborative approach, (3) M*andated heat action* and (4) *specialised heat action units*.

- The importance of profiling and assessing the spatial distribution of vulnerability to extreme heat has been highlighted as a key component in many global and local guidelines for heat adaptation.
- As demonstrated in this research, ward-level heat vulnerability assessments can be created, as produced for the study's three Gauteng metropolitans, using heat-specific socio-economic variables to represent heat vulnerability.
- This heat vulnerability assessment highlighted the high levels of vulnerability within the rural and informal settlements due to poverty, lack of access to resources and services and poor living conditions. These particular wards are located in the southern regions of Johannesburg, the northern and eastern regions of Tshwane and the southern regions of Ekurhuleni.
- The legacy of Apartheid urban planning that confined populations to the outskirts of the cities resulted in high levels of poverty and since then, these areas have experienced a high level of migration, becoming densely populated without the necessary infrastructure, services and resources available, compared to the city centres and other more formal areas.
- This vulnerability assessment offers valuable insights into the populations and areas most susceptible and at risk to heat-related health impacts, which will inform and assist policy and decision-making, allocation of resources, and disaster management, which will ultimately further assist in developing effective heat action planning and responding.
- Finally, this research has provided a framework heat action guideline that could assist in co-designing and developing heat action plans for the study's three Gauteng metropolitans, as well as other South African and African cities.
- This guideline builds on numerous strategies and responses outlined in four fundamental strategic categories: building public awareness and community outreach, initiating an early warning system and inter-agency coordination, capacity building among healthcare professionals, and reducing heat exposure and promoting adaptive measures.
- Ultimately, this dissertation provides a platform to advance heat action in the study's three Gauteng metropolitans by providing valuable insights into the operational landscape of the Environmental Health Department and the vulnerability of the populations and communities across these metropolitans. This can further advance the governance and institutional dimensions of mainstreaming heat action within the local Environmental Health Department to protect their cities' populations by reducing the health risks associated with extreme heat.

"*We are the first generation to feel the effect of climate change and the last generation who can do something about it!*"

~Barack Obama~

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8 APPENDICES

8.1 APPENDIX 1: INTERVIEW QUESTIONS

Responses of local governments to current heat extremes in the Gauteng Province

Participant details:

1. Municipality and Region name?
2. What economic, social and environmental features characterise your region? For example, industrial area/informal settlements/inner city etc.
3. What are your responsibilities and functions as an Environmental Health Official - on a daily and annual basis?
4. What are the largest operational challenges that you face within your region – on a daily and annual basis?

Table 8.1: Topic guide of interview questions grouped into four sections, (a) Understanding and awareness of climate change and heatwaves, (b) Heat-health adaptation policies and plans, (c) Challenges and opportunities faced during implementation, and (d) Heat actioning planning and possible future heat considerations

SECTION A	
Question	**Type of response**
What do you know about climate change and its impacts?	[Open-ended question]
Can you name any climate change impacts?	[Yes – elaborate and list impacts] [No]
What do you know about extreme heat and heatwave events?	[Open-ended question]
Specifically with regards to extreme heat, what are the physical and/or health risks associated with it?	[Open-ended question]
Are you aware of the increasing heat extremes and heatwave events in South Africa, and within your municipality/region?	[Yes – explain when, how it affected your region and how you dealt with the situation] [No – why not?]
Do you know of any national or municipal policies and plans put in place to address climate change, and/or specifically with regards to heat?	[Yes – elaborate and explain] [No – why not?]

SECTION B	
Question	**Type of response**
Are you aware of any heat adaptation strategies set out within your municipality's Integrated Development Plan (IDP) or other planning documents?	[Yes – explain] [No]
Are extreme heat and heatwave events considered and a priority within the operational activities of your municipality and/or planning region?	[Yes – elaborate and explain how] [No – Why not? What else is being considered instead?]
What heat-health adaptation strategies and responses are being implemented (or proposed) within your municipality and your planning region (if any)?	[Open-ended question – list]
Have you identified vulnerable populations and/or areas that are at a high risk from heat-related health impacts? And do you have targeted responses to prepare these populations for incoming heat events?	[Yes – explain] [No – why not?]
As an Environmental Health Official: What is your role in the effective implementation of heat adaptation strategies?	[Open-ended question – explain role]
As an Environmental Health Official: What is the process to follow when an incoming extreme heat or heatwave event approaches? Is there a procedure to follow i.e., like a heat action plan?	[Open-ended question]
As an Environmental Health Official: Who ensures the adaptation strategies and plans set out in policies and IDPs, are successfully implemented at the operational scale?	[Open-ended question]
SECTION C	
Question	**Type of response**
What are the biggest challenges that you face when including climate change impacts, and specifically heat risks, within the operational activities of the Environmental Health Department? (either currently or for the future)	[Open-ended question]
What are the biggest challenges for the effective implementation of action plans and adaptation strategies on the ground (i.e., at the local scale)? (either currently or for the future)	[Open-ended question]
What do you believe will assist you and your region in the better coordination and implementation of heat adaptation strategies (and/or reducing of the impacts of extreme heat and heatwave events)?	[Open-ended question]

Do you believe there are other ways of operating (or potential opportunities available) to better prepare for heat-health impacts?	[Yes – explain] [No – explain]
How will heat planning assist your municipality/region, and your duties, with the emerging heat-related health impacts now and for the future (i.e., with increasing occurrence of extreme heat and heatwave events)?	[Open-ended question]
SECTION D	
Question	**Type of response**
Do you believe it is possible for your municipality/region to develop a heat action plan?	[Yes – explain] [No – explain]
Why do you think heat action plans haven't been developed, or if they already have, haven't been effectively implemented?	[Open-ended question]
Do you receive support from higher authority levels when developing and implementing adaptation strategies and plans?	[Yes – explain] [No – explain]
What is the biggest barrier within the Environmental Health Department that hinders the effective development and implementation of future heat action plans for your municipality and South Africa as a whole?	[Open-ended question]
What challenges and opportunities do heat action plans have for other South African and African regions?	[Open-ended question]

8.2 APPENDIX 2: ETHICS CLEARANCE CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND JOHANNESBURG

Research Office

HUMAN RESEARCH ETHICS COMMITTEE (NON-MEDICAL)
R14/49 Riley

CLEARANCE CERTIFICATE	**PROTOCOL NUMBER: H21/09/36**
PROJECT TITLE	Heat-related health impacts: The responses of local government to current and emerging heat extremes in the Gauteng Province
INVESTIGATOR(S)	Mr B Riley
SCHOOL/DEPARTMENT	Animal, Plants and Environmental Science/
DATE CONSIDERED	17 September 2021
DECISION OF THE COMMITTEE	Conditionally Approved Permission letter required from COJ before data collection can commence Risk Level: Minimal
EXPIRY DATE	02 November 2024

DATE 03 November 2021 **CHAIRPERSON** J. Knight
(Professor J Knight)

cc: Supervisor : Professor C Vogel

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University. Unreported changes to the application may invalidate the clearance given by the HREC (Non-Medical)

I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to submit an amendment of the protocol to the Committee. **I agree to completion of a regular progress report. For Minimal and Low studies, this is due annually on 31 December. For Medium and High Risk studies, this is due twice annually on 30 June and 31 December.**

2021/ 10 / 08

PLEASE QUOTE THE PROTOCOL NUMBER ON ALL ENQUIRIES

8.3 APPENDIX 3: QUALTIVATIVE RESULTS – INTERVIEW RESPONSES

Table 8.2: Responses of the Environmental Health Officials reflecting on four key categories, (1) Structure and functions of the Environmental Health Department, (2) Operational context and response strategies of the Environmental Health Department, (3) Implementation challenges and limitations in the Environmental Health Department and (4) Opportunities for improved implementation and heat-health responses

1. Structure and function of the Environmental Health Department
Environmental Health Department functions
"*From the high level, our seniors will give us the strategic objectives and then develop the KPIs [key performance indicators], and from the lower level, I must ensure that operational activities are done for us to accomplish that.*" **[J3]**
"W*ith us, we would need to have a mandate in enforcing that type of thing [climate and heat action], so we don't have that particular mandate.*" **[J5]**
"W*e study micro and macro environments, but […] it's [climate change responses] not our primary focus; it's not an MHS focus; we deal with it as it comes.*" **[EC]**
Policy development misalignment with Department ability
"*Some of the policies are not always that applicable on the ground; it is a challenge to 100% comply [with] these policies.*" **[J4]**
"*We are struggling because the people that are involved [policy development] are mostly in national office, so in the local government, we struggle a lot because they are not in relation to what we* have *[…] we were talking about the shortage of staff […] they're not looking at that; they are just developing the policies, and you find that with us, it's very difficult to implement.*" **[T6]**
Lack of sufficient resources to fulfil current mandate
"*You see, that is something that needs to be considered as well in the implementation of such an event. There should be people [a team for heat responses], but […] there are not enough EHPs […] we cannot take them out of the service, to withdraw them from MHS, and tell them to look at heat issues.*" **[EC]**
2. Operational context and response strategies of the Environmental Health Department
Heat context and community complaints on heat impacts
"*We've heard […] about people collapsing due to heat [i.e., in the past few years during the summer months]; people collapsing due to dehydration as a result of extreme heat.*" **[J6]**.
"*We have the area [informal settlement]; I know that's the area that they are complaining [Environmental Health Officials' complaints] […] that, that area is hot. During the summer, it's very hot. […] I think because they [local communities] are used to heat; they don't usually complain about it.*" **[T6]**
"*Heat? No, not from the communities; it's almost as if […] the community sort of expect it [extreme heat]. […] I cannot remember that we've ever received a heat complaint.*" **[T7]**
"*Not so long ago […] within the last six weeks, we actually had a heatwave that persisted, which was at first indicated to be a week-long, and I actually tried to manage trends of occurrence.*" **[EC]**

Identified vulnerable populations and communities
"*The focus is on the elderly, like the old age homes, and then also early childhood centres like our ECDs [early childhood developments].*" **[J2]**
"*The most vulnerable people are identified […] you find those, especially in informal settlements […]; so those are identified, and those are the people who receive more attention, of course, because of their vulnerability.*" **[J6]**
"*We do prioritise […] the vulnerable groups, which is the ECDs, old age homes, schools, mental institutions and places like that.*" **[T7]**
Education and awareness campaigns
"*We do a lot of […] training at nursery schools; we're trying to get to the kids because that's where you get [the] most learning.*" **[J1]**
"*We do awareness and health education for a lot of different things […]; we [do] also do education, and then awareness in schools, primary school, high schools, […] because […] the who is most affected [the most vulnerable] is elderly, the people above 65, and also children.*" **[J2]**
"*We have a component […] called health promotion, so they also look at such activities or services in terms of informing mainly or promoting the health awareness campaigns.*" **[J7]**
"*We identify the areas, and we are aware of […] all the situations; […] we know where the need is for certain awareness campaigns, or whatever the case might be, which is more associated for certain areas or for a certain community group, and then we will target them.*" **[T2]**
"A*s recently as February 2023, we actually had a heat stress, health education and awareness drive. So where communities, primarily schools [and] creches […] were informed of heat-related effects and the rest of it.*' **[EC]**
3. Implementation challenges and limitations in the Environmental Health Department
Resource capacity
"***Regarding our resources […] in conducting awareness campaigns****, we don't have [any]. So one is to struggle, sometimes to even use our own resources, […] in order to reach out to the communities […], but yeah, it's things that we have to do, so yeah,* ***resources are an issue*** *as well.*" **[J2]**
"*I think most of the problems that we do encounter is* ***budget [and] under-resourcement*** *in terms of the items that we'll* ***need to effectively render our services.***" **[J4]**
"*The threat is that we are so* ***outnumbered****, we don't have much* ***personnel and budgets*** *for running all these tasks.*" **[J5]**
"[…] our ratio [EHPs per person ratio] is quite bad […]; its worse than the other regions. […] we're struggling with human [staff capacity], and then they've combined three regions […]; I think we are about ***one to 90 000 if not almost 100 000****, so* ***we really are understaffed****, and then also it's a growing region.*" **[T2]**
"*At this moment, in our region, it's* ***one per 65 000*** *of the population [EHPs per person ratio], so* ***totally understaffed.***" **[T4]**
"*We do have a problem with the necessary* ***budget available****. […]; currently, we haven't even accomplished to get our adjustment budget approved, which means that* ***nothing is being paid, nothing is being done.***" **[T7]**

"***Finance*** *but linked to that then comes* ***ICT****, and the rest of it because resources as a whole, as a package,* ***start with resources as a package****, that is our biggest concern. […] say, for example, now we have these to disseminate [heat awareness posters], beautiful posters with all of the information that you want, […] but you can't make copies. You can't submit a single copy […] half of my staff […] doesn't have access to a computer […]* ***No ICT, no phones, no nothing.****"; "[We don't] have a* ***full complement of EHPs*** *[…]; my figures is* ***one in 42 000*** *[EHP per person ratio] […] one* ***EHP is doing almost 1.45 EHPs*** *work; in terms of workload,* ***one EHP is doing up to seven to eight to nine to ten*** *depending on the area EHPs work, so there's no way that you're going to get all your bases covered.*" **[EC]**

Policy misalignment with implementation ability

"*When they input and who is part of it all [policy development]; like I don't know how far do they extend an invite for people to be part of it. And* ***once the policy is promulgated, the legislation*** *[…], they just send it down and* ***tell you, you must implement****. The challenge is they don't workshop these things either.*" **[J2]**

"*There are some of the* ***policies*** *that have been drafted, but they are* ***not always that applicable on the ground****; it is a* ***challenge to 100% comply [with] these policies.***" **[J4]**

"*I think even the* ***issue of the alignment with the City's policies.***" **[T3]**

"*We are struggling because the people […] that are involved are mostly in national office, so in the local government, we struggle a lot because they are not in relation to what we have. […]; we were talking about the shortage of staff […] they're not looking at that,* ***they are just developing the policies,*** *and you find that with us, it's* ***very difficult to implement.***" **[T6]**

"*The* ***lack of [a] really thought through policy****,* ***lacklustre policy****, [and]* ***changing policy when you have political change****, because focal areas differ.*" **[EC]**.

Communication and cooperation with departments

"*It's a massive monster [Environmental Health Department and 'allied' departments], and* ***I don't even know who to contact sometimes*** *[…]; I don't know who's who anymore because there's so many people.*" **[J1]**

"[referring to improvements in the city] ***Inter-collaboration between departments*** *[…] then I think that can help a lot so that we know how to plan the same. [We] have the same strategies and have the same goals because [for example] Pikitup have their own goals, [and] we have our own goals. We are responsible for waste management [and] they are also responsible for waste management. So our goals, I don't think they really gel together. Hence, our activities somewhere, somehow, they don't complement each other. […] I would say* ***cooperation from other departments.***" **[J3]**

"*The other sister departments are not very prompt to respond to queries or to complaints […] it is* ***difficult to get assistance and support*** *from the sister departments; it's very difficult.*" **[T1]**

"*Our* ***communication, general communication*** *of who's doing what, that thing with the left hand is not knowing what the right hand is doing, that's happening a lot. It's just the general communication.*" **[T4]**

"*The challenge here is that* ***we don't communicate****, […] for example, we go out and take some samples, and others go out also and take some samples. We must have the information, or we share the results so that we must know what is happening, which samples they took, and then what says the results […]; we need to communicate [with] each other so that we give each other information.*" **[T6]**

"*I think that's one of the reasons I wanted to be very clear in terms of the **communication between departments**. A team effort is the only thing that takes us forward.*" **[T7]**
Distance and time constraints of area coverage
"*With norms and standards, we have targets […], and it also has timeframes attached to it, so like how often you're supposed to go there, […] our CBD [central business district] area is where the bulk of our formal […] and also our informal food traders are, so a person that's working in that area might **not be able to cover all the premises within that [timeframe]**, but you're supposed to be doing them every quarter.*" **[J2]** "***One of the challenges is the distance**, […] you **travel a long distance**. I mean, from the office to […] [area within the region] is about 45 kilometres. That's a one-way trip […], so that, that is a challenge for us.*" **[T1]** "*The **vast area of the region**, with the **allowances, they get travelling allowances**; it's not always feasible for them to go to all the areas. You will find that the amount of the allocated kilometres is exhausted, and they are not prepared to travel anymore.*" **[T2]** "*The **distances that the people [have] to travel** […] from our office to the border of our region. The people who have to go the round trip is about 120 kilometres per day, and so we have **limited resources in the sense of travel allowances** that's allocated to the EHPs, so it makes it very difficult for them to do all the inspections that they need to do to attend to everything.*" **[T4]**
Reactive and not proactive
"*If we were doing our job 100%, to our full capacity, then our clinics should be empty because we should be preventing people from getting ill. But the way it is now, we are working like we're responding to when a problem is there already, **not being proactive and doing preventative [actions]** […]; what we are supposed to be doing? That is the challenge because we [are] only now **reacting; we are reactive now.***" **[J2]** "*In relation to [the] disaster management […] I think we are **not much that proactive**; we are **more reactive** with the department; we will only come in after the disaster [has] already happened.*" **[J4]** *"[education and awareness campaigns] In terms of outreach, […] we've been sort of **reactive** in some instances in terms of, like, communicable diseases outbreaks.*" **[T1]** "*As we [have] a very serious shortage of staff, we are **no more proactive** […]; we can't manage all those things [duties and responsibilities] […] so as I'm saying, we are **not proactive; we just wait and then see.***" **[T6]** "*That makes sense to have a proactive [proactive responses]; **we have a reactive** […], but once there's incidents, then there is action.*" **[EC]**

Lack of knowledge and understanding of other departments

"*The City does not understand […] in terms of the capacity. For instance, if they were talking about Environmental Health, I don't think that the* ***City completely understands the role and responsibilities that goes with that particular Department****. So if there was an understanding, first of the resources that the City has […] 'cause of now the problem is, people jump[s] on other people's area of jurisdiction, duties or functions. So if the City understood the functions and what resources they have, then there won't be duplication because* ***there's duplication of work*** *[…]. If the city can start by understanding the resources that they have in the ground, and then how to fully utilise it.[…] If all departments* ***better understood their roles and functions****, they would be better aligned in terms of planning, like Disaster Management, Environmental Management, Environmental Health, […] if* ***everyone understood their functions, and what they can do to enhance the other departments' function instead of duplication****, then we can plan better on a strategic level, then that information will be better filtered to the people with the most resources on the ground.*" **[J4]**

"*I think what one should just consider is that you must look at the* ***scope of work*** *and sometimes […]* ***they [EHPs] lose scope*** *with Environmental Management [Environmental Management Department] […]; so I think the* ***lack is knowledge of our department****, where our mandates begin and where our mandates end. The* ***EHPs lose the scope of what is their role*** *and what is Environmental Management's role.*" **[T2]**

"*I think even the* ***scope of work also is a problem that we don't know what they [other departments] are doing, they don't know what we are doing****, or what we supposed to do […]; and then we do our part, and then they must do their part. So you find that we don't know what they are doing. They don't know what we are doing."* **[T6]**

"*We sit with a situation where in Health Departments, […] the primary health care section is* ***viewed as an unfunded mandate****. It's actually [a] provincial service we render; the service on behalf of [the] province, and now there's this* ***perception amongst HR [human resources] and politicians and senior management that Environmental Health is also an unfunded mandate****. But we are constitutionally mandated to render Municipal Health Services.*" **[EC]**

Lack of responsibility and accountability

"***Somebody has to take responsibility****, and I think that's where the problem comes in. Because some people, when they get to a certain stage, they lose connection with what's going on on the ground.*" **[J1]**

"[referring to people understanding their roles and responsibilities] […] and for the ***accountability****, then I think that will be the start before we could go and explore other avenues.*" **[J4]**

"***Accountability is just nowhere*** *[…] I'm [referring to theoretical individual/department] responsible for a certain function, I don't perform it.*" **[T7]**

Safety of Environmental Health Officials

"*Others* ***threaten you with your life****, [they say] you will not come into my shop and tell me what to do, I will get to you […] I've got a young lady here who goes into these places, where do you draw the line,* ***your life or … [their duties]***" **[J1]**

"*The work that they [EHPs] are expected to do* ***cannot always be done*** *[…]* ***because of the broadness of the area.****"* **[J6]**

"*We've got challenges in terms of **safety issues** […]; certain areas have become **actually unsafe for environmental practitioners** to enter and sometimes, they are **threatened […] life threatening's** […] so it places a service delivery hamper obstacle for us to really perform the functions everywhere.*" **[T2]**

"*The **risk [safety of EHPs] in the area**, because it's a rural area, and you have these informal settlements; we have a lot of female EHPs, and what we usually do is we have to [send] out two people [EHPs] or you have to have metro police accompany you to some of these areas.*"**[T4]**

4. Opportunities for improved implementation and heat-health responses

Building on education and awareness campaigns

"*[referring to areas of opportunity in the region] We do **awareness and health education** for a lot of different things […] so like, yeah, we can do that. And then maybe people are not aware […] we also do **education, and then awareness in schools, primary school, high schools**, […] because I see also who is most affected [vulnerable to heat]; it's elderly, the people above 65, and also children.*" **[J2]**

"*[We] have a component […] called **health promotion**, so they also look at such activities or services in terms of **informing mainly, or promoting the health awareness campaigns** […]; so we will use a **loud hailing truck** in order to spread the message if there's an event coming or campaign coming in order to inform them; [we also] use **pamphlets.***" **[J7]**

"A*s recently as February 2023, we actually had a **heat stress, health education and awareness drive**. So where communities, primarily schools [and] creches […] were **informed of heat-related effects** and the rest of it.*' **[EC]**

Multi-sectoral communication, collaboration and cooperation

"*[referring to heat responses in the future] You get to know it through **multi-sectoral collaboration**, […] how we then get to know that [heat periods are incoming], the **multi-sectoral cooperation, collaboration**; that's how we will then learn of it. […]* You also alerting us to say, let's ***not sit in silos, or also in silence**, but rather make sure that whatever gains are made at a **national level, it also become[s] localised.***" **[J5]**

"*To **learn from one another** and to not make the same mistakes. That is that crucial because I think, to a very big extent, we **all share exactly the same problems.***" **[T7]**

Build on existing structures

"*We **don't have to reinvent the wheel**; if the wheel is already there, even best practices, you will learn from others, and if it worked for them, you can always adopt it on your side.*" **[J2]**

"*I think in future, if we do have heat situations or heat wave situations [to] such an extent that it will start threatening the health and wellbeing of the population, they will incorporate those stations [existing temperature and air quality stations] to **monitor it, and then have a warning signal sent out.***" **[T4]**

Community ownership

"*I think, you know, the big thing is if you can **get your champions in every informal settlement** […] and you **start small, and you see people see the advantage of it.***" **[J1]**

"*If you can just **get the people to buy-in** because if we **do it alone and the community don't buy-in, you will never win**. […]; if you don't also speak to the people because you will think it's the issue [theoretical issue] […] but for them that is not the issue […].*" **[J2]**

"*Better interaction between […] the community and not always be dependent on the city council but also **come up with initiatives and working together with us**, […] where they also **take responsibility [for] the environment. They, as the community**, […] they need to **come up initiatives and work with us and assisting us and not just depending on us all the time**; so there's definitely more opportunity in a change of mindset which can come forward.*" **[T2]**

Mandated heat action embedded within the IDP

"*It will be effective [heat strategies] if […] it's **included in our IDP** […]; **in our budget**, […] we need to have those items that talk to heat […]; it should be **specific, it should not be a generic** […] **KPI, it should be specific**. If it's **specific**, then it's easy to monitor […], unlike if it's just a **generic thing** […]. If you're going to say heat-related key performance indicator, then it's possible to be achieved.*" **[J3]**

"*How do we **change our policies**? And how do we fine-tune our policies? How do we **add this thing [heat] into our bylaws as a City where the City endorses [it]** […]; some of these changes into its own **immediate space and legislation** that way.*" **[J5]**

Heat Action Task Force

"*Even if **somebody can just champion it, someone to champion this** and bring it down [heat action].*" **[J5]**

"*What really helps is, you, if you have […] **a team and you have a close team of people communicating with each other**, knowing what's happening, but you have to have **specific teams working on a project, like a project team** […] where you have your reliable and general contacts that you have to deal with on a daily basis […] so the only way that you can improve that [communication and cooperation of response strategies] is to have the **specific operational teams or task teams working on specific problems; where you have a close team communicating with each other**.*" **[T4]**

"*You see that, that is something that needs to be considered as well in the implementation of such an event. There should be **people [a unit or task force]**, but […] there are not enough EHPs […]; we cannot take them out of the service, to withdraw them from MHS, and tell them to look at heat issues.*" **[EC]**

Specialisation of Environmental Health Officials

"*If people can […] **focus, and you specialise; specialisation**, you do one of the things and you do everything, […] because at the moment, we have so many things that you do, because each inspector is in every area or district that they are allocated to, so you do everything in there, from food to noise to […]communicable diseases […] so you **don't really have time to focus on one specific thing**, because you just go as the things come in.*" **[J2]**

"***We also need people to specialise** because, at the present moment, the heat action plan and the guidance we have not yet implemented because of the vastness of our scope and the nine KPIs that we have to implement on a daily basis.*" **[T6]**

Early warning systems
"*An atmospheric monitoring station that they have put down and get the information automatically sent to them via computer. So that's* ***monitoring the temperature and air pollution*** *[…]; so I think in future, if we do have heat situations or heat wave situations, [to] such an extent that it will start threatening the health and wellbeing of the population, they will incorporate those stations [existing temperature and air quality stations] to* ***monitor it, and then have a warning signal sent out.***" **[T4]**
Training Environmental Health Officials with mandated duties
"*Once the policy is promulgated, the legislation […], they just send it down and tell you, you must implement. The challenge is they* ***don't workshop these things*** *[…]they* ***need to workshop it and then explain*** *and […] discuss it so that we have the* ***same understanding****; so that even going forward, for me to implement it, I know exactly when they draw up the policy. This was the intention, and this is what they aim to get out of it. If we're all on the same page, that is the start; if we don't have the start right, I don't think our outcome is going to be what was expected in the long run. But if we can approach [it] right from the beginning, then I think we can move in the right direction.*" **[J2]**
Involving private companies
"*[referring to possible opportunities and ways of moving forward] There [are] a lot of* ***private companies*** *that's jumped on the bandwagon, and we know there's* ***money to be made****. […] that's why we have in the new […] industry in South Africa with recycling [informal waste pickers in cities].*" **[T7]**

8.4 APPENDIX 4: QUANTITATIVE RESULTS – HEAT VULNERABILITY INDEX

Table 8.3: Heat Vulnerability Index (HVI) scores ranked by decreasing heat vulnerability for all 354 wards throughout the three Gauteng metropolitans

	Metropolitan	Ward ID	HVI score	Level of Vulnerability
1	City of Ekurhuleni	79700056	8.08433	Very High
2	City of Tshwane	79900102	7.70007	Very High
3	City of Ekurhuleni	79700062	6.68298	Very High
4	City of Ekurhuleni	79700060	5.99389	Very High
5	City of Ekurhuleni	79700065	5.63355	Very High
6	City of Ekurhuleni	79700021	5.46597	Very High
7	City of Ekurhuleni	79700053	5.45740	Very High
8	City of Johannesburg	79800095	5.40749	Very High
9	City of Ekurhuleni	79700083	5.36692	Very High
10	City of Johannesburg	79800127	5.30591	Very High
11	City of Johannesburg	79800001	5.25002	Very High
12	City of Tshwane	79900049	5.12042	Very High
13	City of Johannesburg	79800035	5.11914	Very High
14	City of Ekurhuleni	79700098	5.07001	Very High
15	City of Johannesburg	79800005	5.01095	Very High
16	City of Johannesburg	79800131	4.83624	Very High
17	City of Tshwane	79900009	4.64509	Very High
18	City of Johannesburg	79800122	4.63580	Very High
19	City of Johannesburg	79800019	4.60827	Very High
20	City of Tshwane	79900015	4.51008	Very High
21	City of Johannesburg	79800025	4.32424	Very High
22	City of Ekurhuleni	79700061	4.29672	Very High
23	City of Johannesburg	79800037	4.28323	Very High
24	City of Tshwane	79900105	4.27994	Very High
25	City of Tshwane	79900040	4.17352	Very High
26	City of Ekurhuleni	79700079	4.14247	Very High
27	City of Johannesburg	79800119	4.08489	Very High
28	City of Tshwane	79900038	3.94909	Very High
29	City of Johannesburg	79800046	3.91869	Very High
30	City of Ekurhuleni	79700040	3.84828	Very High
31	City of Johannesburg	79800017	3.79746	Very High
32	City of Johannesburg	79800129	3.79229	Very High
33	City of Ekurhuleni	79700048	3.78939	Very High
34	City of Ekurhuleni	79700100	3.77977	Very High
35	City of Johannesburg	79800075	3.73131	Very High
36	City of Johannesburg	79800043	3.55280	Very High
37	City of Johannesburg	79800007	3.42766	Very High
38	City of Tshwane	79900063	3.41100	Very High
39	City of Johannesburg	79800029	3.31906	Very High
40	City of Johannesburg	79800003	3.31845	Very High
41	City of Johannesburg	79800026	3.31243	Very High
42	City of Johannesburg	79800008	3.29126	Very High
43	City of Ekurhuleni	79700055	3.24801	Very High
44	City of Ekurhuleni	79700093	3.16290	Very High
45	City of Ekurhuleni	79700099	3.11536	Very High
46	City of Johannesburg	79800028	3.11313	Very High
47	City of Tshwane	79900072	3.04079	Very High
48	City of Tshwane	79900099	3.01725	Very High

	Metropolitan	Ward ID	HVI score	Level of Vulnerability
49	City of Ekurhuleni	79700047	2.99287	Very High
50	City of Johannesburg	79800047	2.95517	Very High
51	City of Ekurhuleni	79700045	2.95060	Very High
52	City of Johannesburg	79800012	2.93147	Very High
53	City of Ekurhuleni	79700090	2.92053	Very High
54	City of Ekurhuleni	79700057	2.90872	Very High
55	City of Johannesburg	79800002	2.90366	Very High
56	City of Tshwane	79900088	2.81879	Very High
57	City of Johannesburg	79800024	2.81140	Very High
58	City of Johannesburg	79800105	2.78311	Very High
59	City of Tshwane	79900024	2.77313	Very High
60	City of Johannesburg	79800020	2.72461	Very High
61	City of Ekurhuleni	79700051	2.71765	Very High
62	City of Johannesburg	79800006	2.70732	Very High
63	City of Johannesburg	79800116	2.67967	Very High
64	City of Ekurhuleni	79700084	2.67450	Very High
65	City of Tshwane	79900027	2.61892	Very High
66	City of Ekurhuleni	79700071	2.61671	Very High
67	City of Ekurhuleni	79700044	2.59423	Very High
68	City of Johannesburg	79800015	2.58190	Very High
69	City of Tshwane	79900022	2.53705	Very High
70	City of Ekurhuleni	79700086	2.48471	Very High
71	City of Tshwane	79900013	2.47732	Very High
72	City of Johannesburg	79800078	2.44269	High
73	City of Johannesburg	79800030	2.43944	High
74	City of Ekurhuleni	79700085	2.41697	High
75	City of Johannesburg	79800050	2.38058	High
76	City of Ekurhuleni	79700101	2.37096	High
77	City of Johannesburg	79800042	2.34552	High
78	City of Johannesburg	79800068	2.34537	High
79	City of Johannesburg	79800004	2.33375	High
80	City of Tshwane	79900012	2.33163	High
81	City of Johannesburg	79800016	2.32232	High
82	City of Johannesburg	79800033	2.32201	High
83	City of Johannesburg	79800079	2.25388	High
84	City of Tshwane	79900033	2.24420	High
85	City of Ekurhuleni	79700107	2.23366	High
86	City of Tshwane	79900006	2.20951	High
87	City of Tshwane	79900095	2.17173	High
88	City of Johannesburg	79800133	2.16845	High
89	City of Tshwane	79900008	2.16776	High
90	City of Johannesburg	79800048	2.09598	High
91	City of Johannesburg	79800121	2.09049	High
92	City of Johannesburg	79800130	2.06362	High
93	City of Ekurhuleni	79700067	2.02029	High
94	City of Ekurhuleni	79700082	1.98397	High
95	City of Ekurhuleni	79700064	1.98196	High
96	City of Tshwane	79900073	1.92143	High
97	City of Tshwane	79900087	1.91250	High
98	City of Ekurhuleni	79700108	1.90416	High
99	City of Johannesburg	79800114	1.83907	High
100	City of Tshwane	79900031	1.83769	High
101	City of Ekurhuleni	79700078	1.82279	High

	Metropolitan	Ward ID	HVI score	Level of Vulnerability
102	City of Tshwane	79900011	1.73911	High
103	City of Tshwane	79900071	1.72009	High
104	City of Tshwane	79900007	1.67323	High
105	City of Tshwane	79900021	1.65351	High
106	City of Tshwane	79900107	1.60554	High
107	City of Tshwane	79900014	1.59144	High
108	City of Tshwane	79900030	1.54598	High
109	City of Ekurhuleni	79700066	1.53058	High
110	City of Johannesburg	79800010	1.51146	High
111	City of Tshwane	79900068	1.50828	High
112	City of Johannesburg	79800111	1.50561	High
113	City of Ekurhuleni	79700068	1.44159	High
114	City of Johannesburg	79800011	1.43670	High
115	City of Ekurhuleni	79700010	1.40446	High
116	City of Johannesburg	79800036	1.39700	High
117	City of Ekurhuleni	79700050	1.38490	High
118	City of Johannesburg	79800082	1.38315	High
119	City of Tshwane	79900025	1.36282	High
120	City of Tshwane	79900019	1.35866	High
121	City of Ekurhuleni	79700042	1.35557	High
122	City of Ekurhuleni	79700081	1.32396	High
123	City of Ekurhuleni	79700029	1.30815	High
124	City of Ekurhuleni	79700063	1.29257	High
125	City of Ekurhuleni	79700058	1.19906	High
126	City of Johannesburg	79800120	1.19630	High
127	City of Johannesburg	79800049	1.18202	High
128	City of Ekurhuleni	79700054	1.13334	High
129	City of Tshwane	79900062	1.10019	High
130	City of Johannesburg	79800124	1.05458	High
131	City of Tshwane	79900051	1.04738	High
132	City of Johannesburg	79800053	1.04003	High
133	City of Ekurhuleni	79700049	1.03096	High
134	City of Tshwane	79900090	1.00571	High
135	City of Tshwane	79900036	0.99166	High
136	City of Johannesburg	79800108	0.98550	High
137	City of Ekurhuleni	79700059	0.97011	High
138	City of Tshwane	79900100	0.95559	High
139	City of Ekurhuleni	79700052	0.95483	High
140	City of Johannesburg	79800077	0.95480	High
141	City of Tshwane	79900032	0.94757	High
142	City of Johannesburg	79800034	0.92669	High
143	City of Ekurhuleni	79700089	0.87320	Medium
144	City of Johannesburg	79800018	0.82448	Medium
145	City of Tshwane	79900089	0.74578	Medium
146	City of Johannesburg	79800052	0.74418	Medium
147	City of Ekurhuleni	79700026	0.70448	Medium
148	City of Tshwane	79900037	0.69170	Medium
149	City of Johannesburg	79800044	0.69092	Medium
150	City of Ekurhuleni	79700102	0.63733	Medium
151	City of Johannesburg	79800038	0.62964	Medium
152	City of Tshwane	79900034	0.62721	Medium
153	City of Johannesburg	79800128	0.62432	Medium
154	City of Ekurhuleni	79700112	0.61323	Medium

	Metropolitan	Ward ID	HVI score	Level of Vulnerability
155	City of Ekurhuleni	79700077	0.60169	Medium
156	City of Ekurhuleni	79700070	0.60005	Medium
157	City of Ekurhuleni	79700009	0.59963	Medium
158	City of Tshwane	79900076	0.58664	Medium
159	City of Tshwane	79900017	0.57724	Medium
160	City of Johannesburg	79800021	0.57431	Medium
161	City of Johannesburg	79800027	0.55448	Medium
162	City of Ekurhuleni	79700030	0.53847	Medium
163	City of Ekurhuleni	79700046	0.50588	Medium
164	City of Johannesburg	79800022	0.50116	Medium
165	City of Tshwane	79900061	0.47444	Medium
166	City of Tshwane	79900018	0.43665	Medium
167	City of Tshwane	79900103	0.43015	Medium
168	City of Johannesburg	79800040	0.41536	Medium
169	City of Johannesburg	79800107	0.41489	Medium
170	City of Johannesburg	79800096	0.38987	Medium
171	City of Johannesburg	79800041	0.38695	Medium
172	City of Ekurhuleni	79700035	0.36290	Medium
173	City of Ekurhuleni	79700012	0.35736	Medium
174	City of Ekurhuleni	79700034	0.34109	Medium
175	City of Johannesburg	79800051	0.33192	Medium
176	City of Johannesburg	79800045	0.32302	Medium
177	City of Tshwane	79900094	0.30677	Medium
178	City of Johannesburg	79800014	0.27755	Medium
179	City of Tshwane	79900029	0.27486	Medium
180	City of Tshwane	79900026	0.26108	Medium
181	City of Tshwane	79900039	0.21165	Medium
182	City of Ekurhuleni	79700004	0.19757	Medium
183	City of Tshwane	79900043	0.09457	Medium
184	City of Johannesburg	79800061	0.07147	Medium
185	City of Ekurhuleni	79700011	0.06886	Medium
186	City of Tshwane	79900074	0.06819	Medium
187	City of Ekurhuleni	79700110	0.06079	Medium
188	City of Ekurhuleni	79700103	-0.08807	Medium
189	City of Ekurhuleni	79700069	-0.10374	Medium
190	City of Ekurhuleni	79700006	-0.10561	Medium
191	City of Johannesburg	79800100	-0.17037	Medium
192	City of Tshwane	79900097	-0.17536	Medium
193	City of Tshwane	79900010	-0.19432	Medium
194	City of Ekurhuleni	79700109	-0.23213	Medium
195	City of Tshwane	79900104	-0.28636	Medium
196	City of Johannesburg	79800039	-0.29619	Medium
197	City of Ekurhuleni	79700096	-0.31225	Medium
198	City of Ekurhuleni	79700075	-0.32471	Medium
199	City of Johannesburg	79800132	-0.32795	Medium
200	City of Johannesburg	79800085	-0.36948	Medium
201	City of Johannesburg	79800080	-0.43134	Medium
202	City of Ekurhuleni	79700080	-0.45677	Medium
203	City of Tshwane	79900067	-0.49631	Medium
204	City of Johannesburg	79800071	-0.56004	Medium
205	City of Tshwane	79900023	-0.56024	Medium
206	City of Ekurhuleni	79700007	-0.57119	Medium
207	City of Johannesburg	79800076	-0.60850	Medium

	Metropolitan	Ward ID	HVI score	Level of Vulnerability
208	City of Tshwane	79900035	-0.64049	Medium
209	City of Ekurhuleni	79700087	-0.66099	Medium
210	City of Tshwane	79900106	-0.66573	Medium
211	City of Johannesburg	79800081	-0.70110	Medium
212	City of Johannesburg	79800113	-0.80761	Medium
213	City of Tshwane	79900028	-0.81673	Low
214	City of Tshwane	79900020	-0.82745	Low
215	City of Tshwane	79900093	-0.88985	Low
216	City of Johannesburg	79800031	-0.93944	Low
217	City of Johannesburg	79800059	-0.96642	Low
218	City of Tshwane	79900045	-0.99847	Low
219	City of Ekurhuleni	79700003	-1.05340	Low
220	City of Ekurhuleni	79700041	-1.12149	Low
221	City of Ekurhuleni	79700111	-1.13841	Low
222	City of Tshwane	79900096	-1.16909	Low
223	City of Ekurhuleni	79700074	-1.29698	Low
224	City of Ekurhuleni	79700014	-1.30591	Low
225	City of Ekurhuleni	79700073	-1.34025	Low
226	City of Johannesburg	79800065	-1.40852	Low
227	City of Ekurhuleni	79700033	-1.58463	Low
228	City of Tshwane	79900016	-1.64573	Low
229	City of Johannesburg	79800055	-1.65436	Low
230	City of Ekurhuleni	79700008	-1.75486	Low
231	City of Ekurhuleni	79700105	-1.79919	Low
232	City of Johannesburg	79800109	-1.81314	Low
233	City of Tshwane	79900001	-1.82705	Low
234	City of Ekurhuleni	79700095	-1.92812	Low
235	City of Tshwane	79900075	-1.97013	Low
236	City of Johannesburg	79800009	-1.98111	Low
237	City of Johannesburg	79800058	-1.98282	Low
238	City of Ekurhuleni	79700005	-2.14137	Low
239	City of Johannesburg	79800069	-2.17334	Low
240	City of Tshwane	79900098	-2.18270	Low
241	City of Ekurhuleni	79700072	-2.18748	Low
242	City of Johannesburg	79800091	-2.23497	Low
243	City of Johannesburg	79800110	-2.24206	Low
244	City of Johannesburg	79800066	-2.37245	Low
245	City of Johannesburg	79800063	-2.39960	Low
246	City of Johannesburg	79800057	-2.40627	Low
247	City of Johannesburg	79800013	-2.52720	Low
248	City of Ekurhuleni	79700097	-2.52736	Low
249	City of Tshwane	79900055	-2.53882	Low
250	City of Ekurhuleni	79700002	-2.72258	Low
251	City of Johannesburg	79800064	-2.73491	Low
252	City of Johannesburg	79800062	-2.73809	Low
253	City of Ekurhuleni	79700001	-2.83311	Low
254	City of Johannesburg	79800112	-2.92772	Low
255	City of Ekurhuleni	79700025	-2.99267	Low
256	City of Johannesburg	79800070	-3.09068	Low
257	City of Tshwane	79900086	-3.12239	Low
258	City of Johannesburg	79800067	-3.15998	Low
259	City of Ekurhuleni	79700013	-3.21919	Low
260	City of Johannesburg	79800056	-3.22646	Low

	Metropolitan	Ward ID	HVI score	Level of Vulnerability
261	City of Ekurhuleni	79700088	-3.23449	Low
262	City of Ekurhuleni	79700036	-3.29642	Low
263	City of Johannesburg	79800073	-3.36471	Low
264	City of Ekurhuleni	79700038	-3.37596	Low
265	City of Ekurhuleni	79700023	-3.37750	Low
266	City of Johannesburg	79800118	-3.38666	Low
267	City of Johannesburg	79800135	-3.41908	Low
268	City of Johannesburg	79800092	-3.44544	Low
269	City of Ekurhuleni	79700037	-3.48960	Low
270	City of Johannesburg	79800094	-3.58702	Low
271	City of Johannesburg	79800123	-3.59799	Low
272	City of Ekurhuleni	79700091	-3.62576	Low
273	City of Johannesburg	79800084	-3.76959	Low
274	City of Ekurhuleni	79700031	-3.80039	Low
275	City of Ekurhuleni	79700104	-3.81477	Low
276	City of Ekurhuleni	79700024	-3.85882	Low
277	City of Johannesburg	79800115	-3.87069	Low
278	City of Ekurhuleni	79700032	-3.88237	Low
279	City of Johannesburg	79800125	-4.08320	Low
280	City of Tshwane	79900053	-4.12988	Low
281	City of Tshwane	79900101	-4.13097	Low
282	City of Ekurhuleni	79700094	-4.19023	Low
283	City of Tshwane	79900091	-4.27208	Low
284	City of Tshwane	79900002	-4.28612	Very Low
285	City of Tshwane	79900080	-4.30236	Very Low
286	City of Tshwane	79900041	-4.33328	Very Low
287	City of Tshwane	79900092	-4.37118	Very Low
288	City of Tshwane	79900003	-4.40623	Very Low
289	City of Ekurhuleni	79700043	-4.48584	Very Low
290	City of Tshwane	79900052	-4.50948	Very Low
291	City of Ekurhuleni	79700022	-4.55270	Very Low
292	City of Tshwane	79900048	-4.55314	Very Low
293	City of Tshwane	79900060	-4.56824	Very Low
294	City of Tshwane	79900004	-4.57370	Very Low
295	City of Johannesburg	79800023	-4.58825	Very Low
296	City of Ekurhuleni	79700092	-4.60663	Very Low
297	City of Tshwane	79900054	-4.61207	Very Low
298	City of Tshwane	79900081	-4.61283	Very Low
299	City of Tshwane	79900070	-4.64359	Very Low
300	City of Johannesburg	79800126	-4.70872	Very Low
301	City of Tshwane	79900078	-4.71277	Very Low
302	City of Tshwane	79900059	-4.75476	Very Low
303	City of Ekurhuleni	79700019	-4.76639	Very Low
304	City of Johannesburg	79800088	-4.83834	Very Low
305	City of Johannesburg	79800032	-4.86926	Very Low
306	City of Johannesburg	79800101	-4.94663	Very Low
307	City of Tshwane	79900069	-5.00420	Very Low
308	City of Tshwane	79900079	-5.09645	Very Low
309	City of Johannesburg	79800089	-5.25216	Very Low
310	City of Johannesburg	79800060	-5.26120	Very Low
311	City of Ekurhuleni	79700017	-5.26233	Very Low
312	City of Tshwane	79900077	-5.26858	Very Low
313	City of Tshwane	79900047	-5.32327	Very Low

	Metropolitan	Ward ID	HVI score	Level of Vulnerability
314	City of Johannesburg	79800098	-5.44807	Very Low
315	City of Tshwane	79900057	-5.47137	Very Low
316	City of Johannesburg	79800054	-5.52836	Very Low
317	City of Johannesburg	79800072	-5.53934	Very Low
318	City of Johannesburg	79800103	-5.55216	Very Low
319	City of Ekurhuleni	79700076	-5.55519	Very Low
320	City of Tshwane	79900058	-5.63349	Very Low
321	City of Johannesburg	79800086	-5.68822	Very Low
322	City of Johannesburg	79800097	-5.76509	Very Low
323	City of Tshwane	79900084	-5.76527	Very Low
324	City of Johannesburg	79800117	-5.87387	Very Low
325	City of Johannesburg	79800083	-5.94157	Very Low
326	City of Johannesburg	79800134	-5.98943	Very Low
327	City of Johannesburg	79800087	-6.00422	Very Low
328	City of Tshwane	79900050	-6.05759	Very Low
329	City of Ekurhuleni	79700027	-6.08733	Very Low
330	City of Tshwane	79900066	-6.15343	Very Low
331	City of Tshwane	79900064	-6.15466	Very Low
332	City of Johannesburg	79800074	-6.15652	Very Low
333	City of Tshwane	79900082	-6.17415	Very Low
334	City of Ekurhuleni	79700015	-6.34999	Very Low
335	City of Johannesburg	79800104	-6.38797	Very Low
336	City of Ekurhuleni	79700028	-6.40226	Very Low
337	City of Ekurhuleni	79700020	-6.42124	Very Low
338	City of Johannesburg	79800106	-6.42621	Very Low
339	City of Tshwane	79900005	-6.43076	Very Low
340	City of Ekurhuleni	79700018	-6.62508	Very Low
341	City of Johannesburg	79800093	-6.69868	Very Low
342	City of Tshwane	79900042	-6.72470	Very Low
343	City of Johannesburg	79800099	-6.85162	Very Low
344	City of Ekurhuleni	79700039	-6.98024	Very Low
345	City of Tshwane	79900085	-7.08767	Very Low
346	City of Tshwane	79900044	-7.11778	Very Low
347	City of Ekurhuleni	79700106	-7.13139	Very Low
348	City of Ekurhuleni	79700016	-7.21790	Very Low
349	City of Tshwane	79900065	-7.26770	Very Low
350	City of Tshwane	79900046	-7.33204	Very Low
351	City of Johannesburg	79800090	-7.41104	Very Low
352	City of Johannesburg	79800102	-7.67138	Very Low
353	City of Tshwane	79900056	-8.51692	Very Low
354	City of Tshwane	79900083	-9.88885	Very Low