

**The climate change-urban planning nexus in a mountain environment: The case of the Eastern Free State Region of South Africa.**

by

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*A Dissertation presented in partial fulfilment of the requirements for the degree of  
Master of Arts in the Department of Geography, Faculty of the Humanities at the  
University of the Free State.*

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## **Dedication**

I would like to dedicate this MA to my parents (Mhlaseli Radebe and Thenjiwe Ntombifuthi Radebe), and my siblings.

## Abstract

Thabo Mofutsanyana District is a rugged and mountainous area located in the eastern part of the Free State Province, South Africa. The area owes its ruggedness to the Drakensberg and Maloti Mountains. Mountain areas have been reported to be more sensitive and vulnerable to climate change, making it necessary to assess climate change in such areas and the surrounding urban areas. This study aimed to identify the negative impacts of climate change in the Thabo Mofutsanyana District and assess how urban planners responded to these impacts. This study used mixed-research methods, including climate data collected from the Koninklijk Nederlands Meteorologisch Instituut (KNMI) Climate Earth Explorer analysed using Microsoft Excel. It used social data from formal interviews with local urban planners and survey questionnaires distributed to urban residents. The social data was analysed using Statistical Package for Social Sciences (SPSS) and Microsoft Excel. Lastly, the study used spatial data from Google Earth Explorer, and PlanetScope analysed using ArcGIS (ArcMap 10.7.1). The results revealed a statistically significant increase in monthly mean temperature (from 1990 to 2020) experienced in Thabo Mofutsanyana District towns, while the decrease in annual total precipitation (from 1990 to 2020) was not statistically significant. This implies that the increase in temperature results from climate change, while the decrease in precipitation is only climate variability. The results further revealed that the urban planners' strategies implemented to alleviate the impact of climate change were ineffective due to the magnitude of the effects of climate change, especially flooding during heavy rains and extreme temperatures. Furthermore, it was discovered that the exclusion of climate change during urban planning led to a decline in the protection of Green and Blue Urban Ecological Infrastructure (UEI). The increasing Grey UEI is not sustainable as the blocking of drainage systems and the limited porosity of roads do not reduce the effects of climate change, such as flooding. If not effectively maintained, the Green and Blue UEI will continue to decrease in Thabo Mofutsanyana District, affecting the area's sustainability. The study concluded that sustainable urban planning could mitigate the effects of climate change in cities and small towns, and help communities adapt to these effects effectively. Incorporating climate change during urban planning is necessary.

**Keywords:** Urban planning, climate change, urban ecological infrastructure, sustainable urban development

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Finally, I would like to thank my parents, my siblings and my friends (Zandile Mncube, Nkadimo Motlohi and Sinenhlanhla Mabaso) for the endless support, love and motivation I needed throughout the study.

## Declaration

I, Ntombizodumo Shezi hereby declare that this dissertation submitted to the University of the Free State for the Master of Arts Degree in the Department of Geography is my original work and has not been presented before for any degree or examination in any other University.

A handwritten signature in black ink, appearing to read 'N. Shezi', written over a horizontal line.

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(Signature of Candidate)

**21 February 2023**

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(Date)

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## List of Acronyms

BRT	Bus Rapid Transit
CBD	Central Business District
Covid-19	Corona Virus Disease - 2019
DEAT	Department of Environmental Affairs and Tourism
EIA	Environmental Impact Assessment
GHG	Greenhouse Gas
IDP	Integrated Development Plan
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
KNMI	Koninklijk Nederlands Meteorologisch Instituut
NCCRP	National Climate Change Response Plan
NDP	National Development Plan
RDI	Reclamation Drought Index
SAWS	South African Weather Services
SDG	Sustainable Development Goal
SPSS	Statistical Package for Social Sciences
SUP	Sustainable Urban Planning
UEI	Urban Ecological Infrastructure
UGI	Urban Green Infrastructure
UHI	Urban Heat Island
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change

## Definition of Key Terms

**Urban planning** is one of a number of designations for forms of spatial planning that encompass ways in which land, land use, spatial morphologies, resource distribution, and economic and social interactions may be planned and managed.

**Climate change** refers to a statistically significant variation in the climate's mean state or variability, lasting for an extended period (approximately decades or longer).

**Urban ecological infrastructure** is defined as the organic integration of blue (water-based), green (vegetated), and grey (non-living spaces), combined with “exits” (outflows, treatment, or recycling) and “arteries” (corridors) at an ecosystem scale.

**Sustainable urban development** refers to a city’s use of resources and space in a way that meets the needs of its residents in the present without negatively impacting residents' needs in the future.

**Urban areas** are places of high populations and high density, characterised by their built-up infrastructure.

**Mountain** is a steep landform that is elevated above the surrounding surface.

# **CHAPTER ONE:**

## **ORIENTATION OF THE STUDY**

This first chapter of the study gives a background discussion on urban planning, and climate change as an environmental issue. It identifies and discusses the research problem and presents the aim and objectives of the study. It further presents the research questions, study rationale, and significance of the study. The last section presents the overall organization of the study.

### **1.1. Introduction and Background**

“Urban planning is one of a number of designations for forms of spatial planning that encompass ways in which land, land use, spatial morphologies, resource distribution, and economic and social interactions may be planned and managed” (Huxley and Inch, 2022). Fainstein (2022; 1), defines urban planning as the “design and regulation of the uses of space that focus on the physical form, economic functions, and social impacts of the urban environment and on the location of different activities within it. Because urban planning draws upon engineering, architectural, and social and political concerns, it is variously a technical profession, an endeavour involving political will and public participation, and an academic discipline.”

Climate change refers to a statistically significant variation in the climate's mean state or variability, lasting for an extended period (approximately decades or longer). This change may result from persistent anthropogenic changes in the atmosphere's composition or land use (World Meteorological Organization, 2019). This definition differs from that used in the (United Nations Framework Convention on Climate Change, 1992), where climate change refers “to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.”

Climate change includes significant changes in precipitation, temperature, wind patterns, and sea levels (Abbass, 2022). For instance, globally, the earth has been experiencing high temperatures. This has been accompanied by a rise in global sea levels and changes in rainfall patterns. Currently, Northern Europe is experiencing high rainfall, while the Sahel and Southern Africa are experiencing low rainfall. In recent years, there has been a frequent occurrence of extreme

weather events globally. These events include veld fires, floods, and dust storms (Senevirate *et al*, 2012). Additionally, the prolonged and intense droughts, especially in the tropics and sub-tropics, also show rapid climate change (Senevirate *et al*, 2012).

Climate change has been a major global issue over the past few decades. Living in the 21<sup>st</sup> century involves experiencing the impacts of climate change, working towards adapting to patterns of this change, and coming up with solutions to curb the effects caused by this global issue. As expected, climate change significantly impacts urban areas, including those in the Thabo Mofutsanyana District. The Thabo Mofutsanyana District is one of the five districts of the Free State Province of South Africa. It comprises of 6 local municipalities: Setsoso, Dihlabeng, Nketoana, Maluti-a-Phofung, Phumelela, and Mantsopa.

With climate change affecting urban areas and the people living and working there, it is important to understand its patterns and trends and determine how the local urban planners respond to this phenomenon. This will provide the basis for drawing up effective recommendations that can be implemented to solve problems arising from climate change in urban areas in the district.

Unlike rural areas, most urban environments have non-porous, hard surfaces that do not allow water to infiltrate through them (Yang and Zhang, 2011). This issue then leads to flooding, especially after heavy rainfalls (Yang and Zhang, 2011). The high number of vehicles on urban roads and the high number of buildings and roads made of concrete emit excessive Greenhouse gases (GHG) into the atmosphere and trap heat, leading to increased temperature and the development of urban heat islands (UHIs) (Lan and Zhan, 2017). Furthermore, the congested buildings in urban areas block air passage, thus preventing the dissipation of heat (Lan and Zhan, 2017). Consequently, as the climate changes, urban environments experience more challenges than rural areas. Undoubtedly, environmental changes caused by climate change create a critical need for understanding how local urban planners mitigate the impacts of climate change or the strategies they adopt to adapt to the changing environmental conditions.

Furthermore, climate change leads to constraints in water supplies and the availability of other vital natural resources. For example, many people are exposed to water stress due to reduced rainfall caused by climate change (World Meteorological Organization, 2022). To illustrate, Phuthaditjhaba, one of the towns in Thabo Mofutsanyane District, is experiencing water scarcity that has persisted for more than ten years (Tshangana, 2020). According to UN-Habitat (2011), in at least 14 countries in Africa, half of the urban population is already experiencing water shortage and sanitation problems. So, the issue of climate change worsens the challenge of access to clean and safe water. Given these points, Sustainable Urban Planning (SUP) and Urban Ecological Infrastructure (UEI) were chosen as the conceptual frameworks to guide this study.

## 1.2. Problem Statement

Mountain ecosystems are extremely sensitive to the effects of climate change compared to other terrestrial habitats. They are currently being affected at a rapid rate as the climate continues to change over years. Mountain ecosystems around the world have the risk of becoming hazardous to the surrounding communities, while their fast evolution simultaneously brings further risks to the environment of the surrounding areas (University of the Witwatersrand, 2022). Thabo Mofutsanyana District being one of the local areas in South Africa surrounded by mountains is reported to be in a higher risk of climate change effects. These climate change effects include extreme temperatures, storm surges, high or low rainfall intensity, UHIs, and increased flooding, which are likely to worsen soon all over the world (UN-Habitat, 2011).

Due to climate change, there has been a loss of high-priority biomes, including grasslands and wetlands, and a decrease in the quantity and quality of drinking water due to drought in Thabo Mofutsanyana District (Zengele, 2014). Urban dwellers' do not have adequate access to clean air, safe and healthy water, and urban environmental infrastructures such as open spaces and greenways. Experiencing unbearable harsh weather conditions is one of the other significant effects of climate change that has been undermining sustainable urban development in the district (Zengele, 2014). Without any mitigation and adaptation, the changing climate will likely decrease people's living standards, future prosperity, and environmental quality (World Meteorological World, 2022).

There is an exclusion of climate change during urban planning in Thabo Mofutsanyana District, and this failure to accommodate climate change in urban planning hinders the towns' ability to achieve Sustainable Development Goals (SDGs). The SDGs are 17 interlinked global goals designed to be a "blueprint for achieving a better and more sustainable future for all" (United Nations, 2017). These goals were established in 2015 by the United Nations General Assembly and are expected to be achieved by 2030 (United Nations, 2015). However, only two of these SDGs directly apply to climate change in urban environments.

Namely, Goal 11: Sustainable cities and communities, whose purpose is "to make cities and human settlements safe, resilient, inclusive and sustainable"; and Goal 13: Climate action, which requires society "to take urgent action to reduce climate change and its impacts by regulating emissions and promoting developments in renewable energy" (United Nations, 2017). The United Nations has recommended that every country, city, or region worldwide achieve SDGs (Caballero, 2016). Good health and well-being, affordable and clean energy, sustainable cities and

communities, and climate action are the key sustainable development goals that cannot be achieved if climate change is not accommodated in urban planning. Without a sound and effective climate change strategy and proper urban planning, urban areas in Thabo Mofutsanyana District may find it challenging to meet these goals.

It is therefore, necessary to seek a detailed understanding of the extent of climate change, how urban planners are reacting to the continuous issue of climate change, and identify effective strategies that can be implemented to mitigate and adapt to climate change in Thabo Mofutsanyana District

### **1.3. Purpose of the Study**

This study aims to identify the impacts of climate change in the Thabo Mofutsanyana District and assess how urban planners respond to the effects of climate change in the district.

### **1.4. Study Objectives**

The four main objectives of the study are as follows:

- I. To assess the precipitation and temperature trends in Thabo Mofutsanyana District from 1990 to 2020.
- II. To identify and evaluate the strategies that urban planners in the Thabo Mofutsanyana District have adopted from 2011 to 2021.
- III. To assess the change in Urban Ecological Infrastructure in the Thabo Mofutsanyana District from 2011 to 2021.

### **1.5. Research Questions**

The results of this research were intended to answer the following questions:

- I. What are the precipitation and temperature trends of Thabo Mofutsanyana District over the past 31 years?
- II. What strategies have urban planners in Thabo Mofutsanyana District adopted to mitigate climate change? To what extent do these strategies contribute to sustainable urban development in the district?
- III. How has the Urban Ecological Infrastructure in Thabo Mofutsanyana District changed?

## **1.6. Assumption**

Sustainable urban planning has the potential to mitigate the impacts of climate change in the Thabo Mofutsanyana District towns.

## **1.7. Study Rationale**

Most research conducted on urban planning and climate change focuses on adaptation rather than mitigation, although urban climate change adaptation is a relatively new topic (Carter and Kazmierczak, 2015). Previous research mainly focused on how urban areas could adapt to the extreme effects of climate change. Therefore, this study focuses on assessing rainfall and temperature trends to determine the extent of climate change's impact on urban environments. It focuses on strategies that urban planners have adopted to mitigate the effects of climate change and evaluates the effectiveness of these strategies.

Furthermore, most previous urban climate research studies have focused mainly on major cities such as Tokyo, Johannesburg, and Stockholm (UN-Habitat, 2011). Unlike previous research studies, this study identified urban planning-climate change response strategies in small towns. In South Africa, most research of this nature has been conducted at the district level and has given little attention to individual urban areas. Urban areas in Thabo Mofutsanyana District are still developing, which makes it essential to investigate how their development is influenced by climate change. Furthermore, Hunt and Watkiss (2011), states that most literature on climate change in urban areas focuses more on coastal cities than inland cities and towns, which creates a gap in the knowledge available about inland cities and towns regarding climate change. The Thabo Mofutsanyana District occupies an inland location, and the impact of climate change on its towns has not yet been studied. Therefore, there is a lack of literature on the effects of climate change in urban areas and adaptation and mitigation strategies for addressing climate change in these areas. The current study aimed to fill this gap.

The current study assessed how urban planners in the Thabo Mofutsanyana District respond to climate change impacts in the district. The study also evaluated climate change mitigation strategies adopted by urban planners to determine if these strategies can promote sustainability in urban environments. Also, the study addressed the necessity to determine how climate change can be incorporated into development plans for urban areas characterized by fragile environments.

## 1.8. Significance of the Study

The world we live in keeps on changing. From time to time, new developments and interventions need to be applied. The physical built environment is changing and becoming more urban and modern. As the built-up environment changes, it is essential to ensure that the change is sustainable and capable of preserving the natural environment, allowing future generations access to a safe and healthy environment.

The importance of this study also includes determining the extent to which national strategies on climate change are being implemented at the local level. It also provides new knowledge about solutions that local urban planners and environmental managers can adopt to make urban environments in the Thabo Mofutsanyana District healthier and safer and reduce the effects of climate change on urban communities in the district.

Furthermore, the study generated knowledge about the urban planners' responses to climate change and provides essential information about what has been done by other urban planners and environmental managers to mitigate the effects of climate change. The study further helped determine the current extent of climate change impacts in the Thabo Mofutsanyane District, allowing other researchers to develop appropriate solutions.

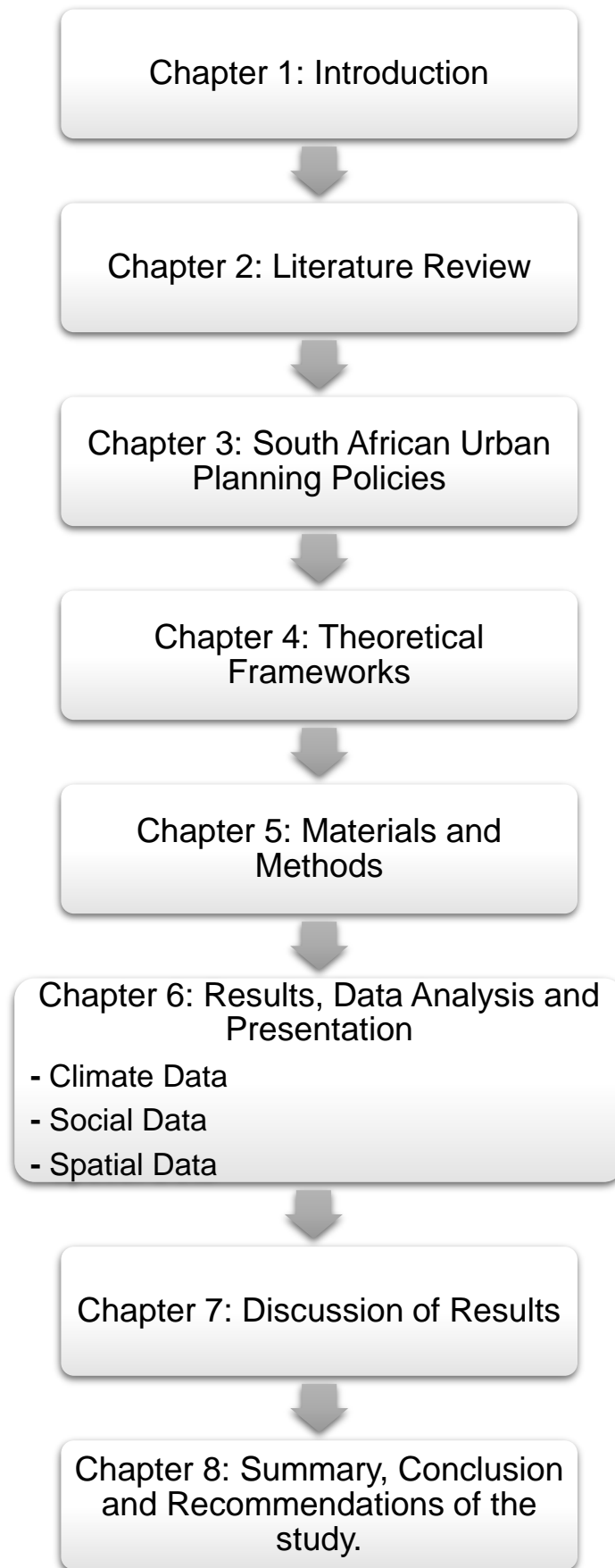
In addition, the current research study helped the researcher to gain insights into climate change and urban planning processes in local urban areas. It also assisted in sharpening the researcher's research skills in developing procedures that should be undertaken to produce valid and reliable research results.

## 1.9. Design and Layout of the Study

The structure of the study is presented in Figure 1.1. The study consists of six chapters, as illustrated below:

**Chapter 1** This introductory chapter provides a background of the study, presents the problem statement, and introduces the research aim and objectives. This chapter also presents the research questions, assumption, study rationale, importance of the study, and lastly, the layout of the study. **Chapter 2** covers the literature review. **Chapter 3** discusses the urban planning policies that have been established in South Africa and their relation to climate change. **Chapter 4**

discusses the theoretical frameworks employed in previous studies and those considered for this study. **Chapter 5** consists of a description of the research methodology, study area, and ethical considerations that were made in this study. This chapter also outlines the limitations of the study. **Chapter 6** presents the collected data and the analysis of the data. **Chapter 7** discusses the research results, while **Chapter 8** contains the summary, conclusion, and recommendations of the research study.



**Figure 1.1: Structure of the study**

## **1.10. Chapter Summary**

This chapter introduced the research aim and objectives. It stated the problems experienced in Thabo Mofutsanyana District regarding climate change impacts and urban planning. The chapter also presented the research questions, hypotheses, study rationale, importance of the study, and lastly, the layout of the study. The next chapter will introduce the literature review, covering studies that have been conducted on the relationship between urban planning and climate change in urban areas.

# CHAPTER TWO: LITERATURE REVIEW

## 2.1. Introduction

This chapter aimed to address knowledge gaps in the existing literature on the relationship between urban planning and climate change on global and local scales. It addressed the effects of climate change on urban areas and the inclusion of climate change mitigation and adaptation in urban planning as a development process.

As climate change affects urban systems worldwide, adaptation is the key response to climate change that can help communities who reside and work in urban areas cope with the negative impacts of climate change. Urban planning can become a significant factor in developing and implementing effective adaptive responses in urban systems. The universality of urban planning and its tools make it advantageous in tackling the impacts of climate change in urban areas. Planning, development management, design standards, and stakeholder engagement are all tools used by urban planning regimes worldwide (Shalaby and Aboelnaga, 2017).

## 2.2 Mountain Environments and their Vulnerability to Climate Change

The current study focuses on urban areas around the Maloti-Drakensberg Mountains. Cities and towns in mountain environments are vulnerable to climate change. Mountains are “large landforms or groups of landforms that are elevated in relation to surrounding areas and which are characterized by processes and ecosystems that reflect corresponding altitudes” (Bevington, Brideau, and Geertsema, 2017: 1). Mountain cities are located “in mountain areas, hills and rugged plateaus, which have different urban morphologies and ecological environments than plain and plateau cities” (Wang and Xhiang, 2018: 2).

Mountains play a huge role as “water towers” to the low-lying areas surrounding them. They store and provide fresh and clean water for these areas (Kohler *et al*, 2014). Much of the supply of surface water is sourced from mountains, making it important to assess how climate change affect these regions (Rangwala and Miller, 2012). Climate change poses a major threat in many mountainous areas in terms of water security (Rangecroft *et al.*, 2016). As reported by Torres *et al.* (2021), in mountain environments there is an increased pressure on water due to both high or low rainfall, leading to droughts on the surrounding towns (Torres *et al.*, 2021). Furthermore, the growing population in mountain environments exacerbate the effect of climate change, which is

water scarcity. This issue has caused the demand for water to be greater than the water available from source catchments (Kinouchi *et al*, 2019). Bolivian Andes is one of the cities that have been experiencing water scarcity as a result of climate change (Rangecroft *et al.*, 2016). Global warming and changes in precipitation have a major impact on the mountains, as well as the surrounding areas, as these lead to a reduction in reservoir storage, frequent occurrence of wildfires, drought, and changes in aquatic life caused by extreme temperatures (Rangwala and Miller, 2012). Palomo (2017), identifies the impacts of climate change as not only on food and water availability but also on spiritual and cultural identity, aesthetic and recreation. The author further identifies climate change effects as being a threat to people living in mountain regions and the surrounding areas.

Mountain environments have been reported to be fragile due to deforestation, overgrazing, cultivation of marginal soils, and the process of urbanization that is rapidly increasing. These processes then lead to degradation of water resources, biodiversity decline, and frequent occurrence of natural hazards, increasing the risk on population living in the surrounding areas (Körner, 2013). The increasing population in mountain environments exacerbate the issue of deforestation which increases the risk of floods (Torres *et al.*, 2021).

Mountain environments have been reported to be very sensitive to climate change (Fort, 2015). Climate models predict that tropical mountainous areas will be more affected by global warming than lowland areas (Buytaert and De Bièvre, 2012). This is because global warming has caused snow and ice to melt causing the mountains to be darker. As the mountain land surfaces get darker this then leads to a dramatic change in their heat balance, meaning that the mountains are getting warmer faster compared to the surrounding areas. Therefore, the extent of climate change effects is higher on mountains than they are in other areas. This is a serious issue, for both the mountains and the areas surrounding them (Knight, 2022). Mountainous areas are warming faster than the lowland areas (Rangecroft *et al.*, 2016). According to Buytaert and De Bièvre (2012), “a higher air moisture content results in a lower rate of change of temperature with altitude (lapse rate), which may exacerbate warming at higher elevations”.

Communities living in mountain environments are isolated and less economically developed. There is poor distribution of infrastructure or resources which causes mountain environments to be more vulnerable to threats posed by climate change (Torres *et al.*, 2021). Flash floods in mountain areas are a major results of climate change. Managing the risks of flash floods in mountain environments is challenging since there is a lack of proper data, literature on mountain climate and proper infrastructure that can effectively handle large floods. Moreover, as the

frequency of severe droughts and floods increases, communities, infrastructure and water systems in mountainous cities are severely affected (Othman, 2023).

In addition, most studies have shown that there is a lack of literature on the climate of mountain environments or ecosystems on the global south (Palomo, 2017), emphasizing the need to assess the extent of climate change effects to strengthen strategies that can be put in place to adapt to this changing climate in mountain areas.

### **2.3. Impacts of Climate Change on Urban Areas and Urban Planning**

The sea levels and global mean temperatures will continue to rise above average (Wilby, 2011). Given these factors, the anticipated effects of climate change for cities include increasing air and water pollution frequency, shorter cold winters; increased storm surge risks; and urban flooding (Wilby, 2011). Da Silva et al. (2012) states that there are two types of climate change impacts, the direct and indirect effects. The immediate effects of climate change include typhoons, storms, stresses, and heatwaves, while the indirect effects include general temperature increases, changes in rainfall patterns, and a rise in sea levels. The indirect impacts build gradually over time. In addition, many researchers have emphasized the link between vulnerability, urban poverty, and climate change and how low and middle-income countries are at high risk of being affected by the climate change effects (da Silva *et al.*, 2012).

In quantitative terms, urban systems produce 75% of all GHG emissions generated in the world. That is why proper urban planning is considered a key element in mitigating or reducing climate change (Fallmann, 2020). Transportation also contributes to climate change, as vehicles produce hydrocarbons, carbon monoxide, nitrogen oxide, and other pollutants (Alam and Khan, 2022) which act as GHG's (Shalaby and Aboelnaga, 2017).

The low-income countries found in the global south are already facing shortages of clean and safe water for drinking and are also facing problems related to poor sanitation (Boretti and Rosa, 2019). In these countries, some low-income urban communities are located in high-risk areas, such as floodplains and flood-prone coastal areas, making them more prone to the negative impacts of climate change (Wilby, 2011). Hunt and Watkiss (2011), states that the vulnerability of a settlement to climate change is mainly caused by four factors, which are location; economy (dependent on weather-related sectors at most risk); size (large settlements at greater risks); and adaptive capacity (resources). Poor urban communities are more vulnerable since they have limited adaptive capabilities or resources (Bele, Sonwa, and Tiani, 2014). Moreover, the rapid urbanization in Asian and African countries occurs while municipalities lack the institutional and

financial resources to ensure the resident's well-being, socially and economically. People living in slums (overcrowded settlements, poor-quality shelter, inadequate access to water and sanitation, and lack of tenure) may be more vulnerable to climate change effects (da Silva *et al.*, 2012).

It is important to note that the effects of climate change vary according to location (Shalaby and Aboelnaga, 2017). Moreover, the urban population is increasing in developing countries. Climate change effects are increased by the concentration of people and commercial activity in small spaces (Shalaby and Aboelnaga, 2017). As stated above, population densities play a role in increasing the effects of climate change (Hanberry, 2022). With the high presence of human activities such as the burning of fossil fuels and the dumping of toxic chemical waste, harm is caused to the atmosphere (Manisalidis, 2020). Other human activities include the use of gas kitchen stoves that release nitrogen dioxide, and the use of spray products (air fresheners, cleaners, and deodorants), air conditioners, and refrigerators. These activities then result in increased temperatures in urban areas (Shalaby and Aboelnaga, 2017). Human activities that take place in urban spaces will continue to alter the atmospheric composition (Wilby, 2011).

UHIs have been recognized to be up to 5 to 6 °C warmer than the surrounding areas. UHIs occur when a metropolitan area is significantly warmer than the surrounding rural areas due to human activities in urban areas. Kabisch *et al.* (2017) state that UHI are one of the major effects of climate change in urban areas. They also worsen the change in climate, so the problem feeds on itself. UHIs result from the increasing dark surfaces such as asphalt and roofing material with low albedo and high admittance and the release of heat generated from motor vehicles and air conditioners (Phelan *et al.*, 2015). The decreasing vegetation surfaces and open, porous surfaces such as gravel or soil contribute to reduced shading and increased evapotranspiration, causing UHIs in urban areas (Han, 2023). All of this then causes certain areas to experience the UHIs in some locations within the city. The effects are higher for regions with more built-up land and less in the green spaces of the leafy urban areas (Kabisch *et al.*, 2017). However, it is important to understand that the magnitude of UHIs results from the physical characteristics of the urban area and its urban morphology, waste heat release, urban extent, and lastly, regional climate factors (McCarthy *et al.*, 2010). As stated by (Sera *et al.*, 2019), urban features worsen the impacts and vulnerability of urban spaces. Urban areas have lower wind speeds due to high, concentrated buildings, which yield more energy for surface warming (Wilby, 2011).

Climate change should be the biggest concern when it comes to urban planning. Proper urban planning helps to reduce the negative impacts of climate and ensures that more sustainable cities and towns are built. Adapting to climate change in urban areas should be done through improved

infrastructural design. For example, urban planners should opt for porous surfacing instead of having hard surfaces in urban areas. Green roofs should be adopted in every city or town. The benefits include aesthetically pleasing cities, urban cooling, reduction of urban heat islands, and decreased absorption of solar radiation (Li and Yeung, 2014). According to Fallman and Emeis (2020), urban planning plays a major role in responding to the global issue of climate change. As Oloke et al. (2021) mentioned, in developing countries, there is a lack of pedestrian sidewalk and proper drainage systems; the available one is poorly maintained or managed. This lack of pedestrian infrastructure forces residents to use the roads, especially during rainstorms, which exposes them to vehicular accidents.

Hunt and Watkiss (2011) also state that most literature on climate change in urban areas focuses more on coastal cities than inland cities and towns, which creates a gap in the knowledge available about inland cities and towns regarding climate change. McCarthy *et al.* (2010) note that climatologists have gone to great lengths to reduce the possible influence of urban development on historical climate records. Advances that have been made in the past few years have produced many different numerical models designed to simulate processes regulating moisture and heat and momentum exchanges within the urban canopy.

Effective models designed to solve climate change include the Global Climate Model designed by Olesen *et al.* (2010), which quantifies the potential impact of implementing white roofs as a climate change mitigation strategy. The waste heat released from urban environments leads to urban micro-climates, making it essential to implement climate change solutions like white roofs (Olesen *et al.*, 2010). Academic and professional practitioners' circles and policymakers are responsible for cities' role in contributing to climate change mitigation, which involves reducing GHG emissions and introducing energy-efficient systems (da Silva *et al.*, 2012).

## **2.4. Urban Mitigation Strategies to Climate Change**

Without a doubt, climate change leads to increased occurrence of catastrophic events, both in frequency and intensity. This increase accelerates degradation mechanisms and increases cultural heritage losses (Gandini *et al.*, 2016). Regarding urban adaptation and mitigation, Gandini *et al.* (2016) state that strategies to mitigate climate change have been discovered as insufficient. Therefore, more effort is still required to ensure that they are adequately effective. Climate change adaptation has shifted from managing the direct manifestation of climate change hazards to risk-based approaches. Furthermore, integrated urban development has become more important in

many countries due to adopting the Leipzig Charter on Sustainable European cities in 2007 (Gandini *et al.*, 2016).

The “Leipzig Charter on Sustainable European Cities” is a document that European stakeholders signed in Leipzig in 2007 to promote an ‘integrated urban development’ policy (European Commission, 2007). It ensures that the ministers responsible for urban development in any European city are committed to initiating a political debate in their provinces regarding incorporating the principles and strategies of the charter into national, provincial, and local development policies (European Commission, 2007). There are two fundamental principles of the Leipzig Charter. These principles cover various aspects of urban policy (European Commission, 2007). The first principle involves ensuring that European cities adequately use integrated urban development policy approaches by creating and providing high-quality public spaces, modernizing infrastructure networks, improving energy efficiency, and implementing proactive innovation and educational policies. The second principle involves ensuring that special attention is given to deprived neighbourhoods in the entire city through pursuing strategies for upgrading the physical environment, strengthening the local economy and local labour market policy, proactive education and training policies for children and young people, and promotion of efficient and affordable urban transport (European Commission, 2007).

Furthermore, the Leipzig Charter encourages the general public to participate in policy-making (European Commission, 2007). Regarding physical and social cohesion, the Leipzig Charter makes ‘deprived neighbourhoods’ within cities the centre of attention. Moreover, the Leipzig Charter promotes establishing a balanced regional organization based on a European multi-centric urban structure (European Commission, 2007).

Also, to successfully mitigate the effects of climate change, treating all the dimensions of sustainable development in the same manner and at the same time can play a huge role. These dimensions include economic prosperity, social balance, and a healthy environment (Gandini *et al.*, 2016). The priority of effective management should be balancing conservation and sustainability in the changing environmental context. Gandini, Garmendia, and Mateos (2016). further state that decisions made on climate change should not be static but should be made under an iterative process, learning from and taking advantage of the new scientific information.

Gustavsson and Elander (2012) states that governments at all levels (cities, municipalities, and nations) had made climate change mitigation an urgent matter that must be successfully and adequately addressed. Many countries worldwide have committed to decreasing the emission of GHG’s, as the 2011 UN-Habitat Global Report on Human Settlements: Cities and Climate Change states (UN-Habitat, 2011). In Sweden, even small towns are expected to engage in climate

change mitigation. These towns have been given full financial support and legal resources to implement climate mitigation policies and strategies. They also have many well-trained environmental professionals who can push the concept of sustainable development forward.

Furthermore, the Green Party in these towns holds a balance of power, which assists in providing sustainability issues with majority support (Gustavsson and Elander, 2012). Gustavsson and Elander (2012) state that climate change mitigation gives towns a positive image, considered as smart growth. This growth is also good for the economy as it attracts tourists and visitors for learning. In developed countries, cities and towns have the needed resources to address the challenges caused by climate change (Rosenzweig *et al.*, 2010). The urban climate actions such as reducing GHG emissions, and implementing green roof projects on urban buildings place a considerable demand on the community of scientific researchers to provide valuable and timely data and knowledge. To effectively mitigate climate change effects, an integrated approach is required to consider the energy use, urban development, health of human beings, environments, and the ecosystem (Mi *et al.*, 2018).

Since vehicles on the road contribute to the excessive emissions of GHG's, changing from cars that use fossil fuels such as petrol and diesel to electric vehicles can play a huge role in reducing GHG emissions in the transport sector (Mi *et al.*, 2018). Most of the cities around the world have taken many actions to mitigate climate change. These actions involve ensuring that the polluter pays carbon or energy consumption tax. The participant is given a limit on the number of emission permits they can buy or sell in the marketplace (Mi *et al.*, 2018). Without a doubt, cities and towns are all expected to address climate change by improving energy efficiency, promoting low-carbon life, creating carbon trading markets, and reducing the use of fossil energy (Mi *et al.*, 2018).

As determined by Owusu and Asumadu-Sarkodie (2016), using renewable energy technologies is key in mitigating the emission of GHG's and reducing global warming since they provide an incomparable alternative to conventional energy sources. Renewable energy sources are considered clean energy sources, and optimum use of these sources produces less secondary waste and decreases environmental impacts. Moreover, renewable resources are sustainable, based on the present and future economic and social needs (Asumadu-Sarkodie, 2016).

## **2.5. Urban Adaptation to Climate Change**

Increases in heat waves and heavy precipitation events are some of the results of climate change facing urban environments in the 21<sup>st</sup> century. Climate change is creating a significant risk to all societies and ecosystems. Carter and Kazmierczak (2015) states that since 1990, the global

emissions of GHG's have increased by 45% and 30% since 2000. Furthermore, GHG's such as carbon dioxide, methane, nitrous oxide, and ozone are naturally present in the atmosphere. Additional quantities of these gases are being emitted into the atmosphere through human activities such as the burning of fossil fuels, burning of wood, use of gas kitchen stoves, use of spray products, use of air conditioners and refrigerators, and dumping toxic chemical waste (Karl and Trenberth, 2013).

Climate change is expected to have far-reaching effects on developing countries' sustainable development, including their ability to attain the United Nations Millennium Development Goals by 2015 (UN, 2017). UNFCCC (2007a) states that developing countries are most vulnerable to climate change impacts because they have fewer resources to adapt: socially, technologically, and financially. Globally, the vulnerability to climate change has been determined by three indicators, which are as follows: the level of exposure of the areas to extreme events, the regions' ability to adapt to climate change, and the degree of sensitivity of the population. Furthermore, the increase in the use of non-renewable resources increases vulnerability (Pinto, 2014).

Stone *et al.* (2012) observed that most of the available literature on climate change focuses on the global scale rather than the national or regional scale. Climate change agreements such as Intergovernmental Panel on Climate Change (IPCC) released temperature change projection reports on the planet without considering the pace of warming at sub-continental to local scales. Stone *et al.* (2012) emphasize the importance of identifying effective climate management strategies at regional and local scales. They also emphasize the importance of considering how these strategies differ from the approaches incorporated at a global scale under international climate agreements such as the Kyoto Protocol, and the United Nations Framework Convention on Climate Change (UNFCCC).

However, climate change can be significantly managed and reduced with proper planning and management (Pinto, 2014). There are three reasons why cities occupy a central position in the plan of adaptation. The first reason is that urbanization is an ongoing process, such that it sets to define and shape the 21<sup>st</sup> century. Secondly, the design of cities creates unique micro-climates that affect climate variables such as temperature and wind (Carter and Kazmierczak, 2015).

The complex topography and the occurrence of a mass of buildings, replacing pervious vegetated surfaces with impervious built surfaces, and the emission of heat from anthropogenic activities in cities have led to extreme consequences. The third reason is that high population density, increased reliance on interconnected and networked infrastructure, and a significant concentration of materials, such as artificial impervious surfaces (building and roads) and non-porous paving materials, contribute to increased temperatures and excessive emission of GHG's

in urban areas. Social, economic, and political processes such as inadequate or insufficient urban planning by local governments have exacerbated the impacts of climate change in urban areas (Carter and Kazmierczak, 2015).

Carter and Kazmierczak (2015) claimed that spatial planning is the key policy lever and task for urban adaptation. For instance, cities in different parts of the world have decided on the location and design of new buildings. However, Carter and Kazmierczak (2015) ask whether urban planning decisions should be based on what is already known about the harsh current climate and its impacts on urban areas, or whether it is time to overlook this historical information and focus more on climate change projections for the future.

Erikson *et al.* (2021), state that adaptation to climate change involves actions that reduce a community's vulnerability and improve resilience capacity to cope with future climate change. The Urban Green Infrastructure (UGI) stems from planning, in which the focus is on green space integration and associated ecosystem services within urban planning at multiple scales. However, the increasing competition for urban space makes it difficult to allocate and implement green or blue spaces for a single purpose only. All the aspects of sustainability (environmental, economic, and social) need to be considered (Kabisch *et al.*, 2017).

Managing current weather-related risks has become an essential activity. This is shown by the increasing number of urban heat warning systems and implemented measures to control excessive temperatures in Central Business Districts (CBDs) and improve urban planning processes and building designs (Wilby, 2011). Matthews (2015) states that adapting to climate change is emerging as one of the most significant challenges urban planners face in the 21<sup>st</sup> century. The adaptation process involves improving emergency services in planning systems and developing coastal retreat strategies. However, this adaptation has been a slow process since some potential solutions are politically unacceptable. These solutions may be expensive, constrain future development options, affect private property rights, and significantly change existing planning systems (Matthews, 2015).

As noted by Matthews (2015), hard surfaces cover 67% of the land area in cities, while green spaces cover as low as 16% in some cities. The efficacy of green spaces as a climate change adaptation measure is shaped by four classes of interrelated factors: the built environment's biophysical character, institutional frameworks, governance structures, planning systems, and the perceptions and values of urban residents. Without a doubt, climate change adaptation is necessary to reduce the risks of climate change such as floods, dust storms, heat stress, and drought since these risks can lead to property damage, social disruption, and significant loss of life. Lack of knowledge about the necessary adaptation methods leads to ineffective and limited

adaptation to climate change. The available literature on climate change assumes that governance of climate change adaptation needs a new policy domain. This policy domain would indicate that resources for climate change adaptation are available (Uittenbroek et al., 2012).

Uittenbroek et al. (2012) determined that five types of barriers can influence how adaptation to climate change is mainstreamed. These barriers include physical and ecological limits, technological, financial, informational, and cognitive (lack of knowledge, uncertainty, complexity) and social and cultural barriers (opposing views from different regions) (Uittenbroek *et al.*, 2012). Yet, national policies on sustainable development are considered rare. This then leads to limited and ineffective climate change adaptation and mitigation methods. A community that is adaptive and resilient to climate change effects is considered a more productive and progressive community (Pinto, 2014). This refers to a community that has implemented nature-based solutions and building improvements such as planting trees along the streets and installing green roofs to cool down the heat.

From the perspective of Goh (2020), the emphasis on the need for urban climate change adaptation is increased by the climate-related disasters, the inclusion of the loss and damaged plan, and the inadequate action on mitigation. However, urbanization, globalization, and geopolitics are often neglected when it comes to the contexts to be considered when looking at the effects of climate change. As global urban development continues, the climate change threats heighten. Furthermore, as the researchers continue to study how cities and towns respond to the changing climate and geopolitical conditions, it is also important to define other new conceptual categories for the relationships, the interface, and risk and expertise formation (Goh, 2020).

The extent of the effect of future climate change depends on many variables, such as the pace of GHG emissions and the response of ecosystems to the changing climate (Carter and Kazmierczak, 2015). The Cancun Adaptation Framework, adopted in 2010 under the United Nations Framework Convention on Climate Change (UNFCCC), recommends that climate change adaptation be uniformly implemented to reduce GHG's in cities or towns. Nature-based solutions to climate change can promote and simplify implementation actions in urban landscapes by taking into account the services provided by nature. These solutions include establishing green features in urban areas such as parks and street trees that can reduce high temperatures in towns and cities, control airflow and water movement, or establish natural habitats in floodplains that may buffer impacts of flood events. Architectural solutions for buildings, such as green roofs and wall installations, may reduce temperature and save energy (Kabisch *et al.*, 2017).

The UNFCCC (2015), states that temperature increases should be kept well below 2 degrees Celsius to avoid significant future climate-driven catastrophes. Systematic planning and capacity-

building plans are needed to decrease disaster risks and raise the resilience of communities in these countries to cope with extreme events such as droughts, dust storms, and tornadoes. Furthermore, employing green infrastructure should be viewed as a necessity, not an amenity. It is essential to protect and restore our natural life-support system (Matthews, 2015). Integrating climate change adaptation into other policy domains can lead to improved innovation opportunities and efficiency of policy-making (Uittenbroek *et al.*, 2012). Pinto (2014) sees the need to create and implement mitigation and adaptation methods to increase urban resilience.

However, several cities have effectively adapted to climate change. Examples of these cities include Stockholm, Heidelberg, Malmo, and Vaxjo (Kenworthy, 2020). They have reduced their carbon dioxide emissions by more than 20% in less than ten years. These cities are mainly dependent on renewable energy. Their sustainable policies mainly focused on eco-building, climate strategies, urban planning, and sustainability mobility.

Stone *et al.* (2012) consider the following as the leading climate change mitigation strategies that can be implemented to reduce the effects of climate change. Firstly, the emission of GHG's should be reduced globally. The global GHG effect is insensitive to regional changes in GHG emissions. Secondly, there should be a reversal of land cover change activities that serve to reduce surface albedo or produce a shift in the surface energy balance from latent to sensible turbulent fluxes. Thirdly, there should be a decrease in activities that minimize vegetation cover or replace the forested land cover with the built environment (Stone *et al.*, 2012).

## **2.6. Urban Planners' Actions towards Climate Change**

It is crucial to increase the dependence on public transport and non-motorized transport to reduce GHG emissions. In short, no further subdivisions in any urban area should be permitted. Furthermore, rejecting large car parks in urban areas and encouraging people to use public transport routes will reduce the need for private vehicles and encourage walking and cycling for short trips around the area and public transport for long trips (Nel, 2011). In addition, spatial planning can enable integrated public transport systems in the urban areas and play a role towards carbon sequestration by ensuring that natural areas are maintained and remain unspoiled and that indigenous vegetation in these areas is retained (Nel, 2011).

To fully understand climate change trends, it is essential to look closely into the number of expanding cities, geographic location, size, and position in their functional hierarchy (Heinrichs *et al.*, 2013). They are authorized to change transportation, green space and land use, and zoning

and energy policy. In addition to these measures, some smaller cities also play a role in ambitious environmental master plans. (O'Neill, 2020). Planning tools are becoming more available for solving the impact of climate change in urban areas. These tools include appropriate urban planning and building design, incorporating climate change in urban plans, and climate-sensitive planning. They also include avoidance of places at high risk of climate change consequences through stringent development control, allocation of green spaces, and incorporation of allowances for climate change (Wilby, 2011).

Bulkeley (2010) has distinguished two phases of urban responses to climate change. The first phase involves concrete local policy plans to mitigate the excessive consumption of natural resources. Local governments primarily launched these plans in the global north. After the first phase, the second phase, which is more political, occurred in the early 2000s. This phase also embraces a much broader array of climate change effects that are not solely connected to the sustainability discourse but also sensitive to vulnerability and risk concerns (Heinrichs *et al.*, 2013). O'Neill (2020) said that urban planning must be driven by human health, well-being, and technology to combat climate risks. This includes having open space, clean air, and connection with other people in the city.

Undoubtedly, urban planners are considered responsible and capable of adapting to the impacts of climate change, including extreme weather events. However, the role they should play, and actions they must take, and their responsibilities as local authorities are often unclear (Wamsler *et al.*, 2013). Urban planners and architects have shown a desire to develop planned settlements and construct more water and energy-efficient houses while simultaneously enhancing environmental and human health (Wilby, 2011).

Cities are viewed as potentially powerful agents of positive change (O'Neill, 2020). These measures will help to develop resilient cities. A resilient city is an urban system that adapts to climate change and plans and manages a strategy that is efficient in the long term to ensure social stability through effective public governance and the creation of healthy and safe conditions characterized by low carbon concentrations (Pinto, 2014). Creating adaptation plans is more complex than building cities from scratch (greener, healthier built environment) (O'Neill, 2020). However, only 18% of cities worldwide have climate adaptation plans. Transitioning to greener cities is not solely viewed as a process that leads to a better, cleaner, and safer environment but also improves the well-being of urban dwellers, including their mental and physical health. This transition means that greener cities are vital for the health of people who reside and work in urban areas (O'Neill, 2020).

Wamsler *et al.* (2013) claimed that urban planners face difficulties as they work towards finding ways to incorporate climate change adaptation strategies in their work. This challenge is due to the fact that climate change adaptation is a relatively new field of study, so there is a scarcity of knowledge and competence related to this field. However, insights from urban planners suggest that socio-political factors may cause significant barriers to the provision of green infrastructures (Matthews, 2015). Extensive research has demonstrated the effectiveness of the strategies that cities can employ to reduce GHG emissions from the sector of transportation. However, less work has been done in determining whether cities are effectively planning to implement the strategies suggested by the literature (Simons, 2020).

Copenhagen in Denmark is effectively harnessing variable wind power to become the first carbon-neutral city by 2025 (O'Neill, 2020). Urban planners and developers have been encouraged to include green space in planning and make good use of shading and green roofs to help reduce the urban heat islands. Implementing green spaces is considered to be an effective solution to climate change. Still, planners should ensure that vegetation does not dry soils in the local area or cause clay shrinkage (Wilby, 2011). Most cities in the global north consider extensive infrastructure procedures as strategic protection against the effects of climate change. On the other hand, cities in the global south have applied episodic and less strategic and integrative responses, which results from limited economic resources and because ecological security is not highly considered an important concept in politics (Heinrichs *et al.*, 2013). The municipality should address climate change by providing the urban community with proper public transport, renewable energy, and waste management programs. Urban community members should be informed about scientific climate change information (Heinrichs *et al.*, 2013).

## **2.7. Chapter Summary**

In this chapter, it has been shown that there is a lack of literature on how urban planners can successfully address climate change in small towns. Most climate change adaptation and mitigation strategies in conferences and agreements can only be effectively implemented globally rather than locally. This then leaves more room for future research that will include effective climate change adaptation and mitigation strategies that can be effectively implemented locally. The next chapter focuses on the urban planning policies that have been enacted and promulgated in South Africa and their relation to climate change.

## CHAPTER THREE:

# URBAN PLANNING POLICIES IN SOUTH AFRICA AND THEIR RELATION TO CLIMATE CHANGE

### 3.1 Introduction

This chapter reviews the urban planning and climate change policies that have been established in South Africa. These policies include the Spatial Planning and Land Use Management Act 16 of 2013, Constitution of South Africa, National Environmental Management Act 107 of 1998, National Development Plan 2030, and Climate Change Bill (B9-2022). This chapter further explains the relationship of these urban planning policies to climate change since this study aimed to assess the urban planning response to climate change. Reviewing the above-mentioned urban planning policies is important as the South African urban planners are guided by these statutes and policies when planning, hence some of their “failures” or incompetency may stem from urban planning policies that fail to incorporate climate change in urban planning practice.

### 3.2 Spatial Planning and Land Use Management Act 16 of 2013

The Spatial Planning and Land Use Management Act (SPLUMA) 16 of 2013 intends

*” to provide a framework for spatial planning and land use management in the Republic;*

- to specify the relationship between the spatial planning and the land use management system and other kinds of planning;*
- to provide for the inclusive, developmental, equitable and efficient spatial planning at the different spheres of government;*
- to provide a framework for the monitoring, coordination and review of the spatial planning and land use management system;*
- to provide a framework for policies, principles, norms and standards for spatial development planning and land use management;*
- to address past spatial and regulatory imbalances;*
- to promote greater consistency and uniformity in the application procedures and decision-making by authorities responsible for land use decisions and development applications;*
- to provide for the establishment, functions and operations of Municipal Planning Tribunals;*
- to provide for the facilitation and enforcement of land use and development measures; and*
- to provide for matters connected therewith” (South African Government, 2013).*

The act is a national legislation for all spatial planning in South Africa. It was established in 2013 and implemented in the country from 2015. In essence, SPLUMA supports the National Development Plan's aim of using spatial change to address South Africa's significant socio-economic problems (Mponwana and Mphethi, 2017).

### **3.2.1 SPLUMA on Climate Change**

The SPLUMA act provides guidelines for provinces and municipalities on the strategies or measures that must be undertaken during the development and implementation of spatial and land use plans. This is essential as spatial and land use plans may pose negative impacts on the environment. One of these impacts include the emission of green-house gases. However, according to (DEA, 2014), this document does not provide explicit climate change mitigation measures that can be implemented at a provincial or municipal level. This then makes it challenging for South Africa to efficiently mitigate the effects of climate change (Mokgotho and Mokoetele, 2021). The document only provides general guidelines about environmental considerations (DEA, 2014).

The SPLUMA Act and other spatial plans such as (MSDF) and (IUDF), encourage the use of renewable energy sources, the protection of the environment, and the employment of energy mic as a way to mitigate climate change (Mokgotho and Mokoetele, 2021). These spatial plans coupled with the National Development Plan (NDP) 2030 promote the reduction of green-house gas emissions (Mokgotho and Mokoetele, 2020), which can be done through sustainable transportation, enabling the reduced use of private cars, and increased use of walking, cycling and public vehicles (Jehling and Banon, 2020).

### **3.3 NATIONAL DEVELOPMENT PLAN (2030)**

South Africa has developed a National Development Plan (NDP) that is designed to ensure that the country sustains its environment for the benefit of both the present and future generations. There are objectives in this plan that are supposed to be achieved by the year 2030. The National Planning Commission (2011), states that the accumulation of wealth in the country increases the impact of development on the natural environment. Africa contributes less to GHG concentrations but faces the worst consequences. Like other third-world regions, Africa has less capacity to cope with the impacts of climate change (National Planning Commission, 2011).

The National Planning Commission (2012) states that South Africa must use its solar resources. Regional hydropower opportunities, skills, technology, and institutional capacity must be improved to support the competitive renewable energy sector. The excessive use of non-renewable energy leads to climate change and global warming. Hence, to solve and mitigate this problem, sustainable urban development must be implemented. The National Development Plan 2030 aims to achieve environmental sustainability and develop a climate change resilient community and a low-carbon economy. This plan includes having affordable and safe energy, clean water, proper sanitation, and a less socio-economically vulnerable society (National Planning Commission, 2012).

Molewa (2011), states that South Africa's response to climate change has two objectives. The first one is to ensure that the impacts of climate change are effectively managed through sustainable interventions that build and sustain the country's economic, environmental and social resilience. The second objective involves making a fair contribution to the global effort to curb the concentration of GHG's in the atmosphere. This process should be done at a level that prevents dangerous human-caused interference with the climate system within a timeframe that allows social, environmental, and economic development to proceed sustainably. South Africa's response to climate change is guided by principles set out in the National Environmental Management Act, the Constitution, the Millennium Declaration, the Bill of Rights, and the United Nations Framework Convention on Climate Change (Department of Environmental Affairs, 2011).

More than 60% of South Africa's population lives in urban areas, covering only 1.5% of the country's surface area (Department of Environmental Affairs and Tourism, 2004). Urbanization is consistently growing rapidly. Urban areas consume more resources and significantly affect the urban areas themselves and the surrounding areas. The climate change challenges faced by urban settlements in South Africa include flash flooding caused by urban-induced soil erosion, storm-water drainage systems, lack of access to clean water, and consumption of large amounts of energy (Department of Environmental Affairs and Tourism, 2004). South African cities are spread out, and this leads to increased transport emissions, as people travel within the city for work and other daily activities.

The longer the distance travelled from one city to another, the higher the emission of GHG's. Based on the International Energy Agency (IEA) and IPCC, it is estimated that the transport sector contributes a significant share of worldwide energy consumption and emission of GHG's (Toledo and Rovero, 2018). A typical private motor vehicle produces approximately 4.6 metric tons of carbon dioxide per year. As reported by the South African GHG inventory (DEA, 2013), transportation contributed a total of 8.4% of South Africa's direct GHG emissions. A private motor

vehicle is thought to produce more than 50% of these emissions. In urban areas, it is assumed that each person makes two trips per day, from home to work/school and vice versa. Furthermore, it is determined that these trips are less than 10km and are most likely to be in areas not serviced by Bus Rapid Transit (BRT) systems and trains. Also, more trips made in urban areas include traveling to the shops, health care centres, and recreational areas (WWF, 2016).

The resolutions adopted by the Department of Environmental Affairs and Tourism (DEAT) require the government to reduce the emissions of GHG's from land-use change and housing developments and to promote mitigation actions in Integrated Development Plans (IDPs) (South Africa. Department of Environmental Affairs and Tourism, 2009). South African companies are also encouraged to take advantage of the mechanism established by the Kyoto Protocol, the clean development mechanism, which aims to improve clean development in developing countries (Clifford, 2013). The Kyoto Protocol is an international treaty extended from the 1992 United Nations Framework Convention on Climate Change (UNFCCC). This treaty states that nations or parties agree to reduce the emission of GHG's, based on the scientific finding that global warming, which is caused by human-made carbon dioxide emissions, is occurring. It was adopted in Japan, Kyoto on the 11<sup>th</sup> of December 1997, and 192 countries have signed and ratified the Kyoto Protocol treaty (UNFCCC, 2007a).

The main strategies of climate change mitigation are the adoption of renewable energy sources and energy efficiency, carbon capture and storage, and reduction of transport emissions (South Africa. Department of Environmental Affairs and Tourism, 2009). Nel (2011) determined that spatial planning can contribute to low-carbon emissions by creating an efficient urban lay-out that enables sustainable transport through carbon sequestration and the use of more sustainable energy. The low densities of population in the majority of South African cities cannot support effective public transport systems. Furthermore, the newer areas of high densities, often located in the fringes of urban areas, create a major dependence on private transport and, for the underprivileged, mini-bus taxis (Nel, 2011).

In South Africa, 61% percent of the population lives in urban areas. The green infrastructure supports both social and ecological activities and processes. It includes street trees, parks, private and public gardens, different types of urban agricultural spaces such as food and community-based gardens, and riparian zones (Schaffler and Swilling, 2013). Furthermore, green spaces and features can be found in all cities, whether to a greater or lesser extent. The Green infrastructure approach is an approach that sees natural and ecological assets as equivalent to water or power networks. It ensures that the green infrastructure is given more and sufficient

attention, including water or power infrastructure. They are all considered a priority (Schaffler and Swilling, 2013).

### **3.4 National Environmental Management Act (NEMA), 1998**

The National Environmental Management Act, 1998 (also known as Act No. 107 of 1998) is the legislation that allows South Africa to implement Section 24 of its Constitution. The NEMA aims to advance cooperative governance, guarantee the protection of human rights, and acknowledge the importance of economic development. The Environmental Conservation Act is replaced by NEMA, which was created to be more effective in dealing with enforcement, administration, and governance (Republic of South Africa, 1998).

The main features and objectives of the law NEMA are as follows:

NEMA aims to integrate environmental issues into the decision-making processes of various industries and government agencies. The Act establishes the standards and procedures for conducting environmental impact assessments for certain activities and developments that may have a significant impact on the environment. To reduce and control the impact on the environment, NEMA promotes the preparation and implementation of environmental management plans. The objective of the law is to support the establishment and management of protected areas and the protection of biodiversity. The National Environmental Management Law (NEMA) aims to prevent and control pollution and waste management methods. The law promotes public participation in environmental decision-making. NEMA has measures to enforce environmental standards and penalizing noncompliance (Republic of South Africa, 1998).

#### **3.4.1. NEMA Act On Climate Change**

The NEMA Act in South Africa is a comprehensive law that establishes a framework for the country's management of natural resources and the environment. Although it is not only concerned with climate change, it seeks to promote sustainable development and environmental protection, which is indirectly linked to solving climate-related problems. Since climate change is a global issue, several countries have enacted climate-related legislation or incorporated climate change issues in their environmental policies. In general, these laws aim to reduce greenhouse gas emissions, promote the use of renewable energy, preserve natural ecosystems, and encourage adaptation measures to address the impacts of climate change (Republic of South Africa, 1998).

The NEMA definition refers to the "physical, chemical, aesthetic and cultural environment" of people, including urban areas and the social challenges that come with them (Du Plessis, 2021). Scholars welcome the tacit inclusion of cities in ecosystems. According to Kidd (2011), for the right stated in Section 24 to truly serve man as a human right, it must concern the environment of all individuals, not just the natural environment. Furthermore, Pieterse (2014), believes that the wording of Section 24(a) allows cities and urban areas to be included in the environmental concept.

Using this definition of the environment, which includes the natural dimensions of urban space (such as parks, community gardens, wetlands, rivers, etc.) (Tan *et al*, 2020), the constitutional right to a defined environment determines that the government take action to create environmentally sustainable cities. When local governments use nature-based solutions in cities to create sustainable urban development (Du Plessis, 2015), improve public health, and/or ensure adaptation to climate change, they meet both responsibilities (Hattingh, 2022).

The importance of local governments in the development and implementation of nature-based solutions cannot be overstated, as they are responsible for planning urban areas and have a great influence on their communities due to their connections with major cities and rural areas, as well as their function as service centres (Frantzeskaki, 2019). It is therefore advisable to be more explicit about the role of local authorities in ensuring ecosystem protection and achieving social, economic and environmental benefits for communities, and to provide for less conventional solutions as described in the nature-based solutions (Hattingh, 2022). This would provide certainty about how various urban planning stakeholders can incorporate nature-based solutions into urban regions and perhaps influence cities to do the same, which could then have a cascading effect on nearby urban and rural areas (Reffeira *et al.*, 2020).

### **3.5 Climate Change Bill (B9-2022)**

The Department of Forestry, Fisheries, and Environment ("DFFE") formally submitted the Climate Change Bill [B9- 2022] (the "Bill") in Parliament on February 18, 2022 (Parliament of the Republic of South Africa, 2022).

The South African Climate Change Bill intends:

“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” ( ). The bill identifies climate change as a significant threat and points out the necessity to develop an effective, progressive, and incremental response (Parliament of the Republic of South Africa, 2022).

The bill seeks to (i) enable a coordinated and integrated response to climate change, (ii) ensure effective management of the impacts of climate change, (iii) contribute fairly to global efforts to stabilise greenhouse gas “concentrations, (iv) ensure a just transition to a low-carbon economy and society, (v) give effect to South Africa’s international climate change pledges and commitments, and (vi) protect and preserve the planet for the benefit of present and future generations of humankind (Parliament of the Republic of South Africa, 2022).

### **3.5.1 Climate Change Bill (B9-2022) at a National Level**

One of the most important aspects of the bill is the Minister’s commitment to establish a national GHG emissions pathway (i.e., a pathway that allows for incremental reductions in GHG emissions over time). The national GHG emissions pathway must establish a national GHG emissions reduction target that is consistent with South Africa’s international commitments (Engelbrecht, Wright, and Vogel, 2022).

The bill makes no reference to the time frame in which the Minister must establish the national greenhouse gas emissions target path. However, the bill indicates that the interim target path in Schedule 3 of the bill applies until the Minister of State publishes the national target path for greenhouse gas emissions. The bill requires the Minister must publish a list of greenhouse gases that cause or are likely to cause or exacerbate climate change and a list of activities that emit one or more of the listed gases. The greenhouse gas emission thresholds must be expressed in carbon dioxide equivalents so that the Minister can determine the entities that will be allocated a carbon budget (Jeffrey, 2023).

A carbon budget refers to the amount of greenhouse gas emissions a company is allowed to emit for at least three consecutive five-year periods. The Minister must review carbon budgets at the end of the five-year commitment period or at the request of an entity subject to a carbon budget. If an entity has been allocated a carbon budget, it must prepare a GHG mitigation plan that outlines the GHG mitigation actions the entity will implement to comply with the allocated carbon budget. Failure to prepare and submit a GHG mitigation plan to the Minister constitutes an offence under the bill. Interestingly, the bill does not provide for any other criminal offences. This is discussed in more detail in item 10 below (Jeffery, 2023).

The bill does not impose deadlines for the Minister must publish listed greenhouse gases and activities. There is also no prescribed time frame for allocating carbon budgets. Given that this is one of the most important means of facilitating equitable transition, it is surprising that the bill does not impose deadlines. Clear time frames need to be set in the climate change bill (Snyman, 2021).

### **3.5.2. Climate Change Bill (B9-2022) at a Provincial and Municipal Level**

The bill imposes other obligations on provincial governments and municipalities. It requires an MEC and a mayor of a metropolitan or district municipality (as applicable) to conduct a climate change needs and response assessment for that province or municipality. The climate change needs and response assessment must analyse the nature and characteristics of the province or municipality, as well as the particular and unique climate change needs and risks that arise from that nature and characteristics, and identify considerations and options for responding to climate change. This must be done within one year of the publication of the NASP (Parliament of the Republic of South Africa, 2022).

Once the climate change needs and response assessment is conducted, the MEC and the mayor of the city or county government have two years to develop and implement a climate change response plan. Since the Minister has two years to publish the NASP after the law takes effect, this could mean that provincial and municipal climate change response implementation plans are not developed and implemented until five years after the law takes effect. Climate change needs and response assessments and implementation plans for responding to climate change must be reviewed every five years and adjusted to reflect any climate-related changes (Parliament of the Republic of South Africa, 2022).

## **3.6. Chapter Summary**

In this chapter, urban planning and climate change policies established in South Africa have been reviewed on how they guide urban planners during urban planning processes. These policies have been reviewed in terms of how they relate to climate, specifically how they guide urban planners in working towards mitigating the effects of climate change at a national and local level. It has been shown that South African policies urban policies do not specify the climate change mitigation and adaptation measures in an explicit manner. Solutions on environmental concerns are identified and explained in a general manner, making it complex for urban planners to implement them in local urban areas. The urban planning and climate change policies do not

respond to the urgency of the climate change issue and its effects on the country. The next chapter focuses on the theoretical approaches or conceptual frameworks employed in climate change studies in urban areas, including the Sustainable Urban Planning (SUP) and Urban Ecological Infrastructure (UEI) frameworks.

## **CHAPTER FOUR:**

### **THEORETICAL APPROACHES OR CONCEPTUAL FRAMEWORKS EMPLOYED IN CLIMATE CHANGE STUDIES IN URBAN AREAS**

#### **4.1. Background to Theoretical and Conceptual Frameworks on Climate Change Adaptation**

It is believed by Cobbinah *et al.* (2019) that urban planning is usually blamed for its inability to effectively exert a positive influence on managing the impacts of climate change in Urban Africa. Yet, there is little knowledge about the perspectives of planning agencies on climate change-to-urban planning dilemma and corresponding policy responses. Cobbinah *et al.* (2019) further explore the views of agency and policy responses to harness urban planning as a critical tool that can be utilized to manage the impacts of climate change in the urban areas of developing countries. Climate change adaptation strategies in urban environments are characterized by three key elements, namely (1) mitigation and adaptation, (2) resilience, and (3) disaster prediction and prevention, all of which are discussed below.

- **Mitigation and Adaptation**

Urban planning responses to climate change involve two approaches: mitigation and adaptation (Cobbinah *et al.*, 2019). While mitigation refers to reducing GHG emissions, adaptation involves adjusting to a new climate-change induced situation (Ratinen, 2021). Mitigation involves minimising the severity of climate change impacts by preventing or reducing the GHG emissions into the atmosphere. The examples of mitigation include reducing the sources of GHG by using renewable energy sources, afforestation and increasing the size of forests (Lawler, 2013). It is basically, humans taking action to reduce the sources of GHG emissions. Adaptation involves foreseeing the negative effects of climate change and preventing or minimizing the damage they can cause to the natural environment, human beings and animals (Lawler, 2013). The examples of adaptation include large-scale infrastructure changes such as building defences to protect against the rise of sea levels.

The net benefits of these approaches have reported to differ in different scales. To illustrate, the net benefits of adaptation at a local scale are high compared to the net benefits of mitigation which are low. At a global scale, the net benefits of adaptation are low, whereas the net benefits of

mitigation are high. Adaptation has a great impact on climate change at a local – regional scale, and have higher urgency than mitigation (Zhao, 2018).

For this reason, it is then understandable that many consider incorporating climate change impacts into urban planning as it is necessary to ensure that each country achieves the Sustainable Development Goals (Cobinnah *et al.*, 2019), specifically, goal 11 aiming to “Make cities inclusive, safe, resilient and sustainable.” Similarly, goal 13 considers taking “urgent action to combat climate change and its impacts” (UN General Assembly, 2015). Sustainable Development Goals also involve providing adequate equipment and operational funds to support waste management activities, ensure effective planning and management of urban growth and sprawl, and promote climate change adaptation and mitigation strategies (Cobbinah *et al.*, 2019).

Eriksen *et al.* (2011) state that sustainable adaptation recognizes that successful responses involve integrating local knowledge with other sources of knowledge about climate change. There are four principles that can guide adaptation responses in a manner that fully supports sustainability. Firstly, sustainable adaptation should recognize the vulnerability context. Secondly, it should acknowledge that different values and interests affect the outcome of adaptation. Thirdly, sustainable adaptation should integrate local knowledge into adaptation responses; and lastly, it should consider potential criticisms or views between local and global processes (Eriksen *et al.*, 2011).

Spatial plans developed to mitigate the effects of climate change have potentiality. However, these plans face difficulty during implementation due to the challenges such as political will, human resources, constraints on the budget, and administrative capacity (Oliveira and Hersperger, 2019). Reckien *et al.* (2012) argued that many sustainable cities prioritize climate change mitigation over adaptation because of its ability to effectively reduce harmful emissions and improve energy security and economic savings. Also, the strategies mentioned on the white paper should be monitored and measured against the national GHG emissions trajectory to keep climate change to a maximum of 2 Degrees Celsius above pre-industrial levels. Other plans such as IDPs only state the climate change mitigation, without the municipality providing clear strategies on how these plans will be fully implemented. Therefore, spatial plans should not only be indicated in rhetoric but should also be implemented to improve the citizens' standard of living to create better cities (DEA, 2012).

Also, as a way to mitigate the effects of climate change the South African government promulgated the Disaster Management Act, 2002 (Act No. 57 of 2002) on 15 January 2002 as an act that provides:

*“i) an integrated and co-ordinated disaster risk management policy that focuses on preventing or reducing the risk of disasters, mitigating the severity of disasters, preparedness, rapid and effective response to disasters, and post-disaster recovery*

*ii) the establishment of national, provincial, and municipal disaster management centres*

*iii) disaster risk management volunteers*

*iv) matters relating to these issues”.* (Department of Cooperative Governance, 2002).

- **Resilience**

In contrast, resilience plans seek to enhance communities. They address certain weaknesses of climate change adaptation (Meerow and Woodfuff, 2020). The resilience theory simply refers to the system’s ability to return to stability (Mokgotho and Mokoelé, 2020). With regards to this theory, urban planners are required to identify the stochastic processes and disturbances that a particular landscape or city is likely to face. Also, they should determine the frequency and intensity of events and how the city can build the adaptive capacity to respond to the disturbance while remaining in a functional state of resilience (Mokgotho and Mokoelé, 2020). Given these points, the resilience theory provides urban planners with an ideology within which climate change adaptation and mitigation plans should be undertaken (Mokgotho and Mokoelé, 2020).

Tyler and Moench (2012) state that urban planners and professionals need a framework that provides guidance for what climate resilience means in practice and how it can be strengthened to build urban climate change resilience. Vulnerability to climate change occurs due to a lack of resilience (Tyler and Moench, 2012). Resilience to climate change increases through proper and well-structured urban planning. It is more focused on the enabling and service provision role of core infrastructure and ecosystems instead of focusing on future climate projections and defining uncertainties and risks of climate. This framework intends to guide practice, which can also help identify patterns of vulnerability that cut across social and political or power divides (Tyler and Moench, 2012).

From Eriksen *et al.* (2011), the environmental concern was low in South Africa before 1994, the year of democratic transition. The environmental situations improved when the programs started to focus more on vulnerability and climate protection, such as conveying a vulnerability assessment as an opportunity to engage different municipal stakeholders in climate change discussions (Eriksen *et al.*, 2011). The second phase focused on key municipal sectors such as

urban infrastructure, human health, and disaster risk reduction, including vulnerable groups in the science-policy interface, and enhancement of understanding of the implications of climate change in the local context (Eriksen *et al.*, 2011).

According to Van Niekerk *et al.* (2020), monitoring and profiling the extent of vulnerability of towns to climate change-related risks has been reported to be significant in addressing the human settlements' resilience. This is emphasized as an international and national priority in the Sustainable Development Goal, the National Climate Change Response Policy of 2011, and the South African Disaster Management Amendment Act, Act No. 16 of 2015. The promotion of sustainability has also been emphasized in the Sendai Framework for Disaster Risk Management 2015 – 2030, which focuses on understanding disaster risk, strengthening disaster risk governance to manage disaster risk, investing in disaster reduction for resilience, and enhancing disaster preparedness for effective response, and “Building Back Better” rehabilitation and reconstruction (Third UN World Conference on Disaster Risk Reduction, 2015).

- **Predict and Prevent**

There is a significant need for countries to invest in infrastructure to ensure that adapting to near or future climate change impacts becomes possible (Tyler and Moench, 2012). Predicting future climate has been said to be crucial when incorporating climate change in urban planning as it allows environmental managers and urban planners to identify avenues for prevention. As mentioned above, the logic of the approach is straightforward in principle or paper, but challenges arise when put into practice (Tyler and Moench, 2012).

The “predict and prevent” approach has been implemented in many countries, especially Asian cities. However, it has been discovered that this approach cannot deal with surprise. This is where the resilience approach is introduced, as it can address the weaknesses of the “predict and prevent” approach. Although it is a new and unfamiliar concept to local practitioners and planners, the resilience approach can help prepare for climate change impacts even under high uncertainty (Tyler and Moench, 2012).

However, two conceptual frameworks were recently developed to apply climate change adaptation strategies in urban environments. The Sustainable Urban Planning (SUP) Framework and Urban Ecological Infrastructure (UEI) Framework are discussed below. They both revolve around the need to promote (1) mitigation and adaptation, (2) resilience, and (3) disaster prediction and prevention of the impacts of climate change in urban environments.

## 4.2. Sustainable Urban Planning Framework

Sustainable Urban Planning aims to control urban sprawl or urban sprawl, especially in developing countries (Silva, 2021). Objective of land use planning for sustainability to limit the negative impact of urban developments through organized land use planning activities (Kalfas, 2023). No country should implement sustainability planning in isolation, as the sustainability global-scale processes are complex when applied on a local-scale (Moallemi *et al*, 2020).

Sustainable urban planning is affected by the proportion of built-up area (height-to-width ratio of buildings and streets vs. green spaces per unit area; weather conditions (e.g., wind and humidity); and socio-economic activities. All these factors determine an urban heat island (UHI) (Maimaitiyiming *et al.*, 2014). However, urban planners and environmentalists have been utilizing green space as a key tool that works against climate change. Trees and plants can cool the environment, making green space a simple and effective way to mitigate urban heat island effects. Green spaces decrease surface and air temperature through evapotranspiration due to lower thermal inertia than impervious surfaces and bare soils.

Furthermore, as Maimaitiyiming *et al.* (2014) states, continuous green spaces have more substantial cool island effects than several small pieces of green space, even if the total area of the small pieces equals the area of the constant green space. Therefore, urban planners should optimize the configuration of green space patches in selected areas by increasing the size of existing green space patches instead of building new smaller patches. The issue with this climate change mitigation strategy and process is that green spaces usually compete with other socio-economic interests that also require space. The increase of green space cover is highly restricted by water availability (Maimaitiyiming *et al.*, 2014).

In the past decades, spatial planning has been used to regulate, control and condition the design of urban centres. However, recently, urban planning laws have changed on a global scale. These laws have integrated planning systems from various sectors such as energy, waste disposal, and transportation to address societal issues, including climate change mitigation and adaptation (Mokgotho and Mokoele, 2020). Urban renewal programs, urban planning, and spatial planning policies were initiated to address the ongoing urban problems and control GHG emissions (Mokgotho and Mokoele, 2020).

Many African cities such as Accra, Lagos, Abidjan, and Johannesburg are experiencing many challenges such as traffic congestion and pollution, which can be traced back to the planning systems that existed during the colonial eras (Mokgotho and Mokoele, 2020). Spatial plans should be implemented in a manner that aims to control the dynamics of the population and manage

urbanization to ensure the sustainability of urban areas (Mokgotho and Mokoeele, 2020). Environmental sustainability involves reducing electricity or non-renewable energy consumption, reducing traffic congestion, and using solar energy. In addition, regional spatial planners should ensure that open and green spaces are strictly protected in local development practice, which assists in controlling carbon dioxide (Mokgotho and Mokoeele, 2020).

Oliveira and Hersperger (2019) state that designing buildings that are energy-efficient and promoting integrated transport planning can help reduce the emission of GHG's. Furthermore, saving energy through the conducive location of new commercial and residential developments and producing energy through renewable resources can help mitigate the effects of climate change. The burning of fossil fuels and high energy consumption (common in local municipalities of South Africa) should be avoided (Oliveira and Hersperger, 2019).

As specified by Meerow and Woodruff (2020), urban planners and planning scholars have a significant role in addressing the effects of climate change and helping communities prepare for these impacts. The first step involves creating robust climate change plans. Some cities now develop adaptation (ability to cope with a variety of shocks and stresses such as natural hazards and extreme weather conditions) plans before mitigation plans, where mitigation refers to "the process of adjustment to actual or expected climate and its effects" (IPCC, 2014b). It focuses on mitigating GHG emissions (Meerow and Woodruff, 2020).

There are seven fundamental principles of solid climate change planning derived from the broader plan-quality literature and applied to evaluate climate and resilience plans (Meerow and Woodruff, 2020). After doing research for ten years on the US cities, Meerow and Woodruff (2020) discovered that cities must first attain data on current climate conditions, future projections, and modelled impacts to combat climate change. The seven fundamental principles of climate change planning include setting attainable goals; providing a strong fact base; outlining diverse strategies; engaging the public to foster justice in all planning processes; coordinating efforts to address climate change across actions, sectors, and plans; managing climate change uncertainty; and improving methods for implementation and monitoring (Meerow and Woodruff, 2020).

The following are examples of cities in the world where the Sustainable Urban Planning Framework has been employed.

- **Mexico City**

It might not be the primary metropolis that you can think of when you consider clean air (it was once one of the most polluted cities in the world). However, Mexico City took the Air Quality award for Pro Aire IV in 2013. This program has dramatically reduced carbon dioxide emissions and air

pollutants over the past twenty years through everything from automobile emissions reductions to containment of conurbation. This change shows that a strong plan can effectively enhance air quality (Mexico City Climate Close Up, 2014).

- **Bogota**

This metropolis took the Urban Transportation award for its ultra-green bus and taxi fleets. Bogota's Bus Rapid Transit system, released in 2000, shuttles over 70% of the metropolis's 7.1-million-character population. Future goals include replacing the metropolis' diesel fleet with hybrid and electric-powered buses, electrifying the whole taxi fleet, and including a brand-new metro line (Vergel-Tovar, 2018).

- **Munich**

Munich obtained the Green Energy award for their programs to electrify the city using renewable energy sources by 2025. The city had already implemented 37% usage of green energy (renewable energy) in 2015. The wind projects that have been implemented will cause 80% of the city to function on green energy (Frangoul, 2015) fully.

- **San Francisco**

San Francisco took the Waste Management award for an exceptionally effective zero waste program, seeing 80% of trash diverted from landfills. The city's goal was to achieve zero waste in the entire city by 2020 (Silva, 2016).

### **4.3. Urban Ecological Infrastructure (UEI) Framework**

“Urban Ecological Infrastructure comprises all part of a city that support ecological structures and functions, as well as the ecosystem services provided by UEI that directly affect human outcomes and wellbeing” (Childers *et al*, 2019). Many urban climate change experiments started in 2005 after the Kyoto Protocol was ratified to respond to the changing climate. Only 5 percent of them had been created before 2005. These experiments focused on urban infrastructure despite the difficulties inherent in managing and maintaining infrastructures at the local level. The

built environment and transport experiments are common in cities in the global south, where there is a rapid growth of population in peri-urban areas (Broto, 2013). This rapid population growth has led to rising demands for housing and transport. Furthermore, the absence of carbon sequestration experiments emphasizes that cities lack land resources to implement large carbon appropriation programs successfully. It also highlights that they lack urban greening programs developed with the independence of concerns with climate change mitigation (Broto, 2013).

From the perspective of Whitehead (2013), the implications of critical urban theory for climate change studies are yet to be accomplished. The critical urban theory is understood as a set of approaches to urban areas recognizing the provisional form of urban politics and policy.

Infrastructure is the set of essential facilities and structures that help support the sustainable functionality of households and firms. These infrastructures support a country, city, or locality. The infrastructure consists of public and private physical structures such as railways, roads, tunnels, bridges, water supply, sewers, and electric grids (O'Sullivan and Sheffrin, 2003). They provide the facilities needed to link the economy and the human functions it serves (Li et al., 2017). Urban ecological infrastructure is defined as the organic integration of blue (water-based), green (vegetated), and grey (non-living spaces), combined with "exits" (outflows, treatment, or recycling) and "arteries" (corridors) at an ecosystem scale (Li et al., 2017).

The urban ecological infrastructure (UEI) framework considers the biotic and abiotic interconnections within an ecosystem. It emphasizes the connections that exist among species and the conservation of wildlife. Most importantly, UEI provides the basis for establishing sustainable urban development and appropriate quality of life for urban citizens (Li et al., 2017). Childers et al. (2019) argue that the concept of Urban Ecological Infrastructure, which came from a 2013 forum held in Beijing and several subsequent 2017 publications, is a more inclusive alternative.

- **Green infrastructure (open spaces and parks)**

The green infrastructure includes forests, green roofs, farmlands, urban parks, and other natural or artificial green spaces found in urban areas. This infrastructure provides essential ecosystem services, such as improving the quality of air, managing the microclimate, enhancing the urban landscape, and maintaining biodiversity (Li et al., 2017). Stockholm, in Sweden, was named the first European Green Capital in 2010. One of the main reasons for that designation is that Stockholm's administrative system prioritizes sustainability, including city budget planning. Eco-taxis, which have priority placement at the front of taxi ranks, are used for transporting people

around the city. In addition, there are over 700 kilometres of bike lanes and a community bicycle rental program, not to mention that the city's Stockholm Waterfront Congress Centre is made of recycled materials and has solar panels on its roof. Apart from overarching sustainability measures that affect the entire city, Stockholm has an official "eco-district" in Hammarby Sjöstad, whose objective is to halve the environmental impact of a typical town. Residents use renewable energy for gas and electricity, and they live in houses made of raw materials that provide excellent insulation in winter (Brears, 2018).

Li et al. (2017) suggests that increasing green space could reduce surface run-off by 4.9 percent while tree cover could reduce run-off by 5.7 percent, and utilizing green roofs could reduce run-off by 11.8 – 4.1 percent. To further explain the importance of green infrastructure in urban areas, urban trees are known for cooling the area and providing several ecosystem services, such as soil retention and development. Green and white-painted roofs are not considered green UEI. Only the roofs that include soil and plants are considered green UEI, as they are designed and managed for storm water and heat abatement (Childers *et al.*, 2019). Singapore is now known as one of Asia's greenest cities, but it hasn't always done so well in terms of sustainability. Singapore's green infrastructure includes a driverless metro and even incorporates sustainability into its meeting venues by assisting clients in determining how to make their gatherings as environmentally friendly as possible (Brears, 2018).

- **Blue infrastructure (water-related areas, including rivers and wetlands)**

The blue infrastructure includes ponds, streams, wetlands, lakes, and wetlands with flowing and fluctuating water. It is an essential part of urban ecological infrastructure. It plays an important role in the urban environment, particularly in water purification, groundwater replenishment, flood control, and protection from storms. This urban infrastructure protects urban wetlands, water resources, and aquatic biodiversity while also providing a habitat for the ecological restoration of urban marine ecosystems (Li et al., 2017). To raise awareness of the issues of storm water quality and surface run-off, Melbourne has developed the Water Smart City Model, an educational activity model for all, appropriate for all ages. It can be used in events and festivals hosted by the community. Food dye, representing pollutants, is placed on the city model, and rainfall is simulated, carrying the pollutants over the impervious surfaces and into the 'bay.' Different features such as rain gardens, swales, rainwater tanks, and rooftop gardens are then added. Pollution is also added to the model and rain simulated. The volume of surface run-off is then significantly decreased due to the retention capabilities of the new features, which then reduces

the risks of flooding. Also, pollutants carried by water are captured in the features so that the water flowing into the “bay” is made cleaner (Brears, 2018).

However, blocked connections between lakes and rivers in urban areas will reduce wetlands' function and biodiversity, resulting in conflicts between urban environmental protection and socio-economic development (Wu, 2016). Singapore's water supplies were once so scarce that the city-state had to import water from Malaysia. It did, however, make numerous changes, including making two-thirds of the city's surfaces, roofs, and sidewalks capable of capturing rainwater and depositing it to 18 reservoirs. The city also has plans for purifying used water and recycling it using advanced methods (Brears, 2018).

- **Grey infrastructure (non-living spaces)**

Grey infrastructure includes roads and highways, artificial drainage systems, electrical grids, and utilities. The presence of a porous surface allows the water, nutrients, and air to pass through the soil and the atmosphere, thereby enhancing the functions of the urban soil such as storing, filtering, and regulating the adverse impacts caused by impervious urban soils. However, the impervious grey infrastructure in urban areas blocks the exchange of water, air, and nutrients between the soils and the atmosphere, thus affecting urban ecosystem services and urban environments significantly (Li et al., 2017). Incorporating urban grey land into the UEI helps reconstruct the urban “skin” (surface) ecological functions. Pervious pavements and vertical plantings are commonly used strategies to mitigate the adverse effects of impermeable surfaces and have been discovered to be an effective tool for reducing the chances of flooding in the area, controlling pollutants, and improving soil functioning (Li et al., 2017).

One way Rotterdam is responding to flooding in the city is by focusing on more storm water runoff storage. Rainfall prevention is a top priority for the city in the coming years. This dedication is embodied in a full-scale water square at Benthemplein in the city centre, an ambitious project that avoids the technocratic route by dealing with water in a playful, creative, and highly visible manner. The tiered, multi-coloured square can collect 1.7 million litres of water from nearby roofs and paved surfaces before slowly releasing it into the groundwater and nearby canal. When the weather is suitable, this one-of-a-kind sunken square serves as a playground for locals and students from a nearby school. Shallow stainless steel-lined channels appear in the ground like an abstracted silver spider web. Each narrow strip begins at a different point in the square and follows a different path, some producing mini-waterfalls and others disappearing quickly into the

concrete. When it rains heavily, the sunken areas become deep pools, giving the square a completely different purpose or function (Keeton, 2014).

Schaffler and Swilling (2013) states that green spaces need to be perceived as green infrastructures the same way as other built infrastructures, ensuring that they are developed and designed to function as a whole instead of acting as a set of separate and unrelated parts. Furthermore, nature in cities should be managed in an integrated manner, the same way grey infrastructure (storm water systems, treatment facilities, sewer systems, or storage basins) has been. Schaffler and Swilling (2013) further state that green infrastructure benefits include air purification, sewage treatment, rainwater drainage, food provisioning, and social and recreational uses. Failure to understand the mutual benefits of green space planning towards ecological and social systems has negatively affected cities (Schaffler and Swilling, 2013).

In South Africa, ecological issues are considered low-priority compared to economic and social issues (Schaffler and Swilling, 2013). Conservation is perceived as a luxury limited to protected areas only (Schaffler and Swilling, 2013). However, certain tree species and shrubs can immobilize certain pollutants and act as pollutant sinks (Schaffler and Swilling, 2013). Trees and other vegetated areas are ecological assets that can control the flow of water and storm water run-off by reducing the run-off over impervious surfaces. Green infrastructure also plays a significant role by providing air-filtering of airborne pollutants (Schaffler and Swilling, 2013). The following are examples of cities where the UEI Framework has been employed

#### **4.4. Conceptual Frameworks Applicable to this Study**

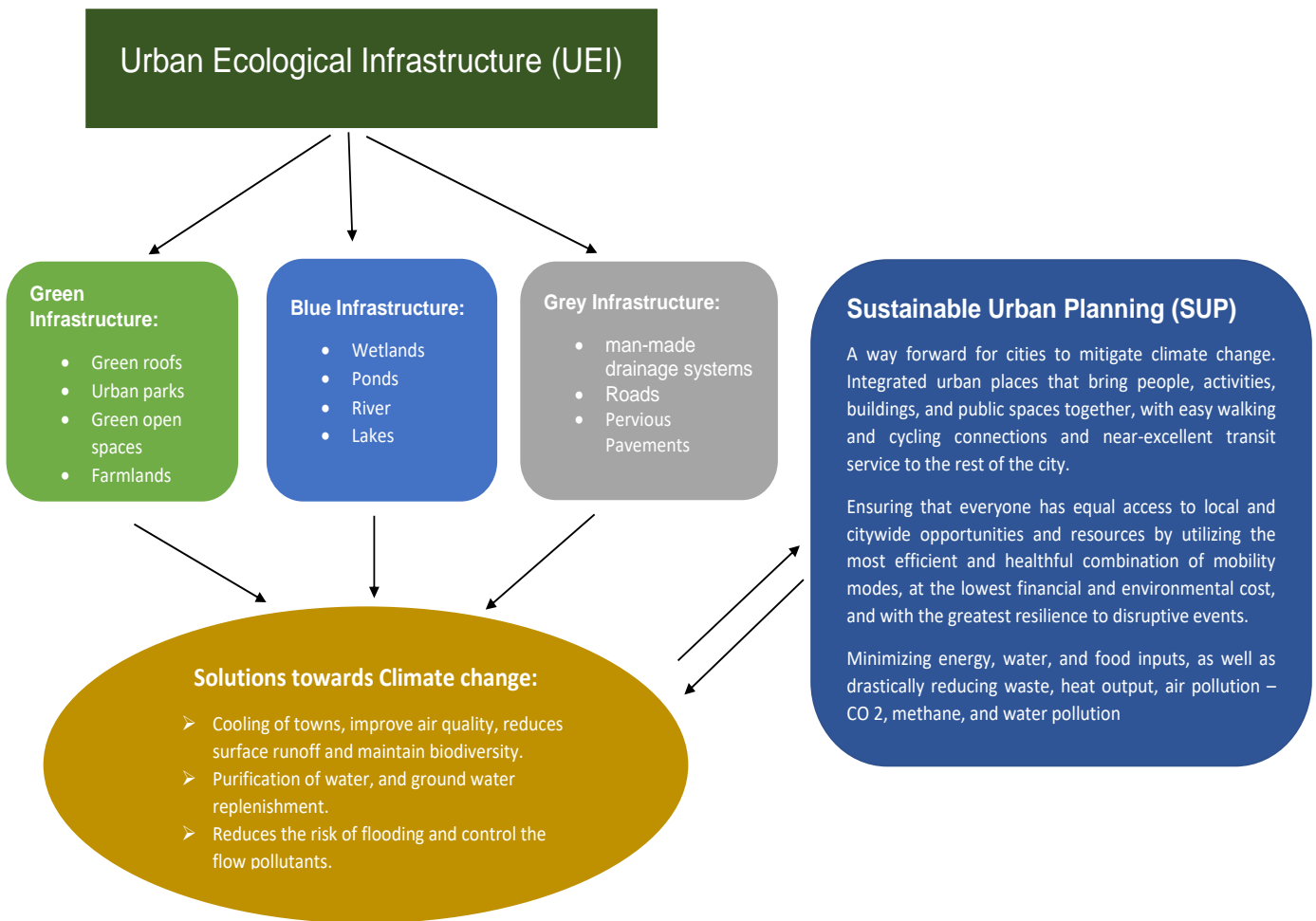
The Sustainable Urban Planning (SUP) and Urban Ecological Infrastructure (UEI) frameworks can be used to assess the impact of recent housing plans on overall city sustainability. As a result, this will lay the groundwork for environmental net gain assessments that have the potential to fundamentally alter how we construct buildings in the future (Brown and Mijic, 2019). Accordingly, these two frameworks were jointly applied in this study.

The Urban Ecological Infrastructure framework was used as the main conceptual framework in this study by identifying three infrastructures incorporated in each sampled town in Thabo Mofutsanyana District. For example, the urban planners' response to climate change was assessed by determining whether green infrastructure has been incorporated in town planning. This process includes whether green roofs, urban parks, farmlands, or other artificial green infrastructure have been adopted in each town to cool the towns, reduce surface run-off, improve

air quality and maintain biodiversity. The advantage of integrating green infrastructure in urban areas is that it is less costly (Hsu and Chao, 2020), making it a good urban infrastructure to introduce, even in developing countries such as South Africa.

Also, the UEI framework was used in this study by evaluating the blue infrastructure in each sampled town. This process involved assessing whether wetlands, rivers, ponds, and lakes are sustainably maintained to ensure that the risk of flooding is controlled or reduced and to ensure that as each town progresses towards urbanization, biodiversity is not disturbed or destroyed. Similarly, the assessment of grey infrastructure helped guide this study. As mentioned earlier, grey infrastructure includes roof water retention systems, permeable pavements, and porous artificial drainage systems, which reduce the risk of flooding, controls pollutants that flow with the water, and improves soil function in the area. Altogether, the Urban Ecological Infrastructure framework allowed the researcher to assess whether urban infrastructure is being effectively used or maintained by urban planners to mitigate climate change's negative effects and help adapt to these effects.

The SUP was used as a subsidiary framework of the study. This study used this framework by determining the urban planners' response or strategies towards mitigating climate change in each sampled town. This process helped assess whether urban planners understood the sustainability status of the towns they plan for and determine their capacity to define and outline sustainable visions or formulate effective action plans.



**Figure 4.1 Interactions Between the Principles Involved in Urban Ecological Infrastructure and Sustainable Urban Planning.**

In brief, introducing sustainable urban infrastructures such as green roofs, open green spaces and parks, permeable pavements and roads, man-made drainage systems, and maintaining rivers and wetlands helps mitigate climate change in urban areas. Effectively implementing sustainable infrastructure in urban areas enhances the sustainability of cities and towns, ensuring that the needs of the present are met without compromising the ability of future generations to meet their own needs. For the urban infrastructure to be considered sustainable, the infrastructure needs to be environmentally friendly in every way, including economic, financial, social, and institutional ways.

Once these conditions are met, urban infrastructure will mitigate the negative effects of climate change, such as extreme temperatures, heavy rainfalls, drought, and flooding. As a result, this will improve the residents' living standards and ensure that the environment is stable and suitable.

Altogether, this means that incorporating sustainable infrastructure in urban areas mitigates and reduces the effects of climate change and leads to a sustainable and safe environment.

## **4.5 Chapter Summary**

In this chapter, theoretical frameworks implemented in urban-climate studies were reviewed. These theoretical frameworks guided the current study, and showed how different cities and towns around the world have implemented the solutions and strategies provided in these theoretical frameworks as a way to encourage sustainable urban development, mitigate the effects of climate change and adapt to climate change effects. The next chapter, describes the study area and focuses on the materials and methods that were used to conduct this study.

## **CHAPTER FIVE: MATERIALS AND METHODS**

### **5.1. Introduction**

This chapter consists of a description of the research methodology that was used to collect the required data. It further describes how the data were analysed and presents the research results derived from the analysis. It also briefly describes the study area, Thabo Mofutsanyana District, situated in the eastern part of the Free State Province. This chapter also briefly highlights the research ethics and considerations that were followed while conducting the study. Furthermore, the chapter outlines the limitations of the study, all the difficulties and challenges that the researcher faced while conducting the study. Overall, this chapter describes the data collection tools, and the procedures followed to ensure the study results were valid and reliable.

### **5.2. Research Methodology**

According to the nature of this research study, a mixed-methods research approach was used, involving both quantitative and qualitative methods. The quantitative research method allowed the researcher to gain information through mathematical, statistical, or computational techniques such as experiments and surveys. It is displayed and presented to the reader in a numerical form, e.g., percentages and statistics. The qualitative research method allowed the researcher to gain information by understanding the respondents' underlying reasons, motivations, and opinions. This research method is conducted through interviews and questionnaires (Creswell, 2012). Applying both qualitative and quantitative approaches to a research study increases the likelihood of yielding greater insight into a research topic, while at the same time providing a higher level of validity and accuracy than applying a single approach (Gogo and Musonda, 2022).

### **5.3. Research design**

A mixed-methods research approach was used in this study, which involved collecting, analysing, and integrating qualitative and quantitative data. A sequential exploratory research design was utilized in this study. A research design refers to procedures and methods used to collect and analyse the measures of the variables specified in the research problem (Creswell, 2014). It is simply an arrangement of collections or conditions related to how a research study is conducted.

A sequential exploratory research design was adopted. Exploratory sequential method explores concepts before validating them, thus increasing the versatility in discovering new ideas that the qualitative approach offers (Gogo and Musonda, 2022). An exploratory sequential approach has been described as a method that provides relatively more robust validity (Gogo and Musonda, 2022). The advantage of this approach is that the quantitative data (climate data and changes in urban ecological infrastructure data) and their subsequent analysis provide a general understanding of the research problem. The qualitative data and its analysis, refine and explain these statistical results by further examining the urban planners' and urban residents' views.

This research design embraced an initial phase of collecting qualitative data from the urban planners, and urban residents to gain insights into the extent of climate change in the Thabo Mofutsanyana District, and to identify the actions taken by urban planners to address climate change impacts. This phase was then followed by a phase of quantitative data collection to determine whether the collected qualitative data corresponded with the actual conditions in the environment and determine the extent to which the urban planners' strategies contributed to sustainable urban development in the district. The second phase of quantitative data collection was collected using satellite imagery from Google Earth Pro and PlanetScope. In this type of research design, priority is given to the qualitative aspect of the research, and the results are combined during the data analysis stage of the study (Berman, 2017). The first phase of data collection assisted the second phase of data collection by providing unique and original insights about the extent of climate change, the urban planners' response to climate change, and the conditions of urban infrastructure in Thabo Mofutsanyana District. The first phase provided information about the district that is not available from other sources which helped during the second phase of data collection, which involved assessing the extent of climate change and the change in Urban Ecological Infrastructure in the district. The qualitative data collected in the first phase was compared with quantitative data collected in the second phase to come up with valid and reliable conclusions that are supported by the information from urban planners and urban residents, climate data from KNMI Climate Explorer and, conditions of Urban Ecological Infrastructure on the actual ground.

#### **5.4. Study Area**

Thabo Mofutsanyana District is one of the five districts of the Free State Province, located in the central region of South Africa. The district was named after a stalwart of the communist party, Edwin Thabo Mofutsanyana. It comprises 6 local municipalities, namely Setsoto, Dihlabeng,

Nketoana, Maluti-a-Phofung, Phumelela, and Mantsopa. Witsieshoek, currently known as Phuthaditjhaba, is the seat of Thabo Mofutsanyana District (Government Communication & Information System, 2010). Thabo Mofutsanyana District has an area of 33 269 km<sup>2</sup> and the main economic sectors in this district are agriculture and tourism. The Thabo Mofutsanyana District is located between 26°58'45''S 26°47'32''E, 26°58'08''S 29°53'22''E, and between 29°39'21''S 26°46'35''E and 29°36'12''S 30°00'38''E. Two National Roads (N3 and N5) pass through the district. The well-known Golden Gate Highlands National Park is found in the area on the hills of the Drakensberg Mountains (Government Communication & Information System, 2010).

A town is a human settlement with shops and amenities, residential districts, and a local government. Towns are generally larger than a village and smaller than a city (Orvell, 2012). Thabo Mofutsanyana District includes 22 towns which are as follows: Bethlehem, Ficksburg, Phuthaditjhaba, Ladybrand, Vrede, Warden, Fouriesburg, Marquard, Clocolan, Paul Roux, Reitz Tweespruit, Lindley, Hobhouse, Petrus Steyn, Senekal, Fouriesburg, Valsriver, Bohlokong, Clarens, Harrismith and Memel (Government Communication & Information System, 2010). Thabo Mofutsanyana District is a rugged and mountainous area located in the eastern part of the Free State Province. The area owes its ruggedness to the Drakensberg and Maluti Mountains, which are found in the area.

The mountains are shown in Figure 5.1.



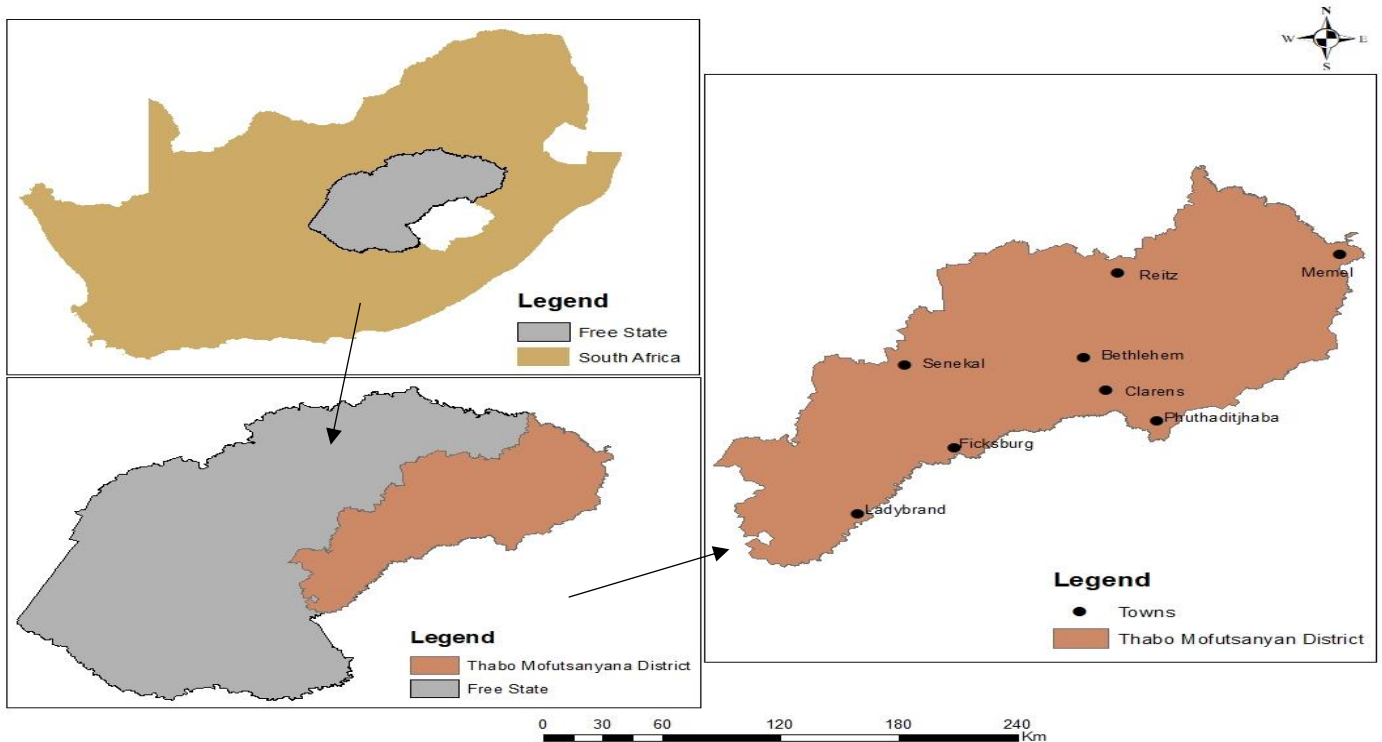
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**Figure 5.1: Drakensberg and Maluti Mountains**

These highlands make the district a popular tourist attraction. For this reason, assessing climate change in the area and identifying how the local urban planners are responding to this ongoing global issue appears to be necessary. Furthermore, the assessment of impacts of climate change should be considered essential because mountain areas have been reported to be more sensitive and vulnerable to climate change. According to Kohler (2014), mountains are home to approximately 800 million people worldwide. They provide vital ecosystem services for the entire globe, including freshwater for half the human population. However, they are sensitive to the impacts of climate change, putting a significant risk on several goods and services provided by mountain areas.

They are fragile in that they can be damaged by various factors such as overgrazing by livestock, progression of urbanization, cultivation of marginal soils, and change in temperature and precipitation patterns at all scales. All this may lead to a rapid decrease in biodiversity and water resources, soil degradation and an increase in extreme weather events, thus putting near populations at risk (Fort, 2015). The seasonal runoff impacts the entire geosystem, including soils, rocks, river discharges, and vegetation. Due to climate change, water will become scarce, and the consequences will also reach areas far from mountain regions. Due to climate change, exposure to natural or economic hazards is likely to increase in mountain areas because poverty levels are higher than in lowland areas, and food insufficiency is more widespread. However, assessing the impacts of climate change is challenging because of the diversity and complexity of mountain systems (Fort, 2015).

The study area is presented in the map showing the sampled towns in Thabo Mofutsanyana District located in the Free State Province of South Africa in Figure 5.2:



**Figure .2: Map showing sampled towns of Thabo Mofutsanyana District within the Free State Province**

The co-ordinates of the eight sampled towns are as follows; Ladybrand, 29°11'26"S 27°27'23"E; Senekal, 28°19'10"S 27°37'46"E; Ficksburg, 28°52'02"S 27°52'36"E; Bethlehem, 28.14'43"°S 28°18'51"E; Clarens, 28°30'37"S 28°24'55"E; Reitz, 27°47'51"S 28°25'49"E; Phuthaditjhaba, 28°34'00"S 28°49'05"E, and Memel, 27°39'41"S 29°32'49"E

## 5.5. Study Population

According to Municipalities of South Africa (2012), the total population of Thabo Mofutsanyana District is 736,238. Its ethnic composition comprises 93.8% Black African; 0.8% Coloured; 0.4% Indian/Asian, and 4.8% White.

**Table 5.1 Demographic characteristics of each sampled town:**

Name of Sampled Town	Local municipality	Population	Ethnic composition (5)					Main Economic Sectors	Unemployment rate (%)	Youth unemployment rate (%)
			Blacks	Coloureds	Indians/Asians	Whites	Other			
Ladybrand	Mantsopa	4 218	37.2%	13.1%	4.7%	37.3%	3.7%	Tourism, commercial farming, and the private and public sector.	29.2%	38.2%
Senekal	Setsotso	3 466	53.3%	1.4%	1.7%	42.8%	0.8%	Manufacturing, wholesale and retail trade.	38.7%	48.1%
Ficksburg		5 400	37.2%	7.0%	12%	42.3%	1.5%			
Bethlehem	Dihlabeng	28 591	32.7%	8.7%	2.1%	56%	0.5%	Services, trade, finance, agriculture, and manufacturing	28.7%	38.9%
Clarens		751	34.09%	4.13%	3.2%	58.32%	0.27%	Tourism, Accommodation		

								(Hotels and Lodges).		
Reitz	Nketoana	20 183	90%	1.3%	0.2%	9.1%	0.4%	Farming, agriculture (maize cultivation), and manufacturing.	30.4%	41.6%
Phuthaditjhaba	Maluti-A-Phofung	54 661	98.98%	0.51%	0.51%	0.23%	0.16	Small-scale business, wholesale and retail trade.	41.8%	53.0%
Memel	Phumelela	7 142	94.6%	0.2%	0.3%	4.8%	0.1%	Tourism, subsistence farming, agriculture.	25.3%	34.6%
Total		124 412	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Adapted from – Municipalities of South Africa, 2011.

## 5.6. Study Sampling

The current population of Thabo Mofutsanyana District is unknown since the last population census was carried out in 2011. To determine the sample size of unknown population size or a very large population, the following equation is used (Smith, 2013):

$$\text{Necessary Sample Size} = (Z\text{-score})^2 * \text{StdDev} * (1 - \text{StdDev}) / (\text{margin of error})^2$$

$$\text{Margin of error} = 5\%$$

$$\text{Confidence level} = 95\%$$

**Standard deviation (StdDev)** = 0.5 (Before the survey is administered, the safe decision is to use 0.5 as this is the most forgiving number, ensuring that the sample will be large enough).

**Z-Score** = 1.96 (The confidence level corresponds to a Z-score).

Z-scores for commonly used confidence levels are as follows:

- 90% = 1.645
- 95% = 1.96
- 99% = 2.326

$$\begin{aligned} \text{Sample size} &= ((Z\text{-score})^2 * \text{StdDev} * (1 - \text{StdDev})) / (\text{margin of error})^2 \\ &= ((1.96)^2 * 0.5 * 0.5) / (0.05)^2 \\ &= (3.8416 * 0.25) / 0.0025 \\ &= 0.9604 / 0.0025 \\ &= 384.16 \end{aligned}$$

Therefore, **384** respondents were selected.

No. of urban residents that did not participate in the study: 134

No. of urban residents at the beginning of the study: 384

No. of urban residents who participated in the study: 250

Therefore, **attrition rate = 0.42%**.

Three hundred and eighty-four respondents were randomly sampled from each of the eight randomly selected towns. Only those who were at home during the survey and who have lived for more than 10 years in Thabo Mofutsanyana District were included in the study. Computer-generated random numbers were used in the sampling. Using a random number table ensured that all towns in the Thabo Mofutsanyana District had an equal and independent chance of being selected for the sample group.

Thabo Mofutsanyana District has 22 towns, which may be too many to include in the study. As a result, probability sampling was used to identify a sample that would be studied. A study sample refers to a small group of people who participate in the study or research. This smaller group engages in a given study to represent the entire population. In probability sampling, each member of the population has an equal chance of being selected to participate in the study (Showkat, 2017).

The type of probability sampling that was used in the study was simple random sampling. The advantage of applying random sampling in a study of this nature is that it removes bias from the selection procedure, resulting in a representative sample (Gravetter and Fornazo, 2011). Since there are 22 towns in Thabo Mofutsanyana District, the easiest way to take a random sample of these towns was to list the towns in alphabetical order in each local municipality. Then, a unique number was assigned to each town and the towns were randomly selected proportional to the number of towns in that municipality. This sampling type ensured a balanced representation of the municipalities in the Thabo Mofutsanyane District.

**Table 5.2 Total population size and sample size of each sampled town.**

<b>Municipalities</b>	<b>Towns</b>	<b>Assigned Unique Numbers</b>	<b>Names of Selected Towns</b>	<b>Population</b>	<b>Sample size</b>
Mantsopa	Tweespruit	19	Ladybrand	4 218	13
	Hobhouse	08			
	Ladybrand	10			
Setsotso	Marquard	12	Senekal	3 466	11

	Clocolan	04	Ficksburg	5 400	17
	Senekal	18			
	Ficksburg	05			
Dihlabeng	Paul Roux	14	Bethlehem	28 591	88
	Valsriver	20			
	Fouriesburg	06			
	Bethlehem	01	Clarens	751	2
	Bohlokong	02			
	Clarens	03			
Nketoana	Lindley	11	Reitz	20 183	62
	Petrus Steyn	15			
	Reitz	17			
Maluti-A-Phofun	Kestell	09	Phuthaditjhaba	54 661	169
	Phuthaditjhaba	16			
	Harrismith	07			
Phumelela	Warden	22	Memel	7 142	22
	Vrede	21			
	Memel	13			
<b>Total</b>	22		8	124 412	384

Therefore, eight towns were investigated in this research study. They are as follows: Ladybrand, Senekal, Ficksburg, Bethlehem, Clarens, Reitz, Phuthaditjhaba and Memel. These account for 32% of the towns in the district.

Furthermore, probability sampling was applied in each town to select urban residents who participated in the study. A random sampling technique was used to select these participants. The population of Thabo Mofutsanyana District was defined, ensuring that the researcher had access to every individual member of the population, so that data can be collected from those who are selected for the sample, a sample size was then calculated using a confidence level of 95%, margin error of 0.05, a standard deviation of 0.05, and a Z-score of 1.96. The participants were then randomly selected in each sampled town, using the lottery method (randomly distributing survey questionnaires to any individual older than 18 years who has been residing in the sampled towns for more than 10 years).

Finally, urban planners were selected from each municipality. Each municipality in Thabo Mofutsanyana District has one urban planner, meaning that the whole district has six urban planners as it consists of six municipalities. All six urban planners participated in the study.

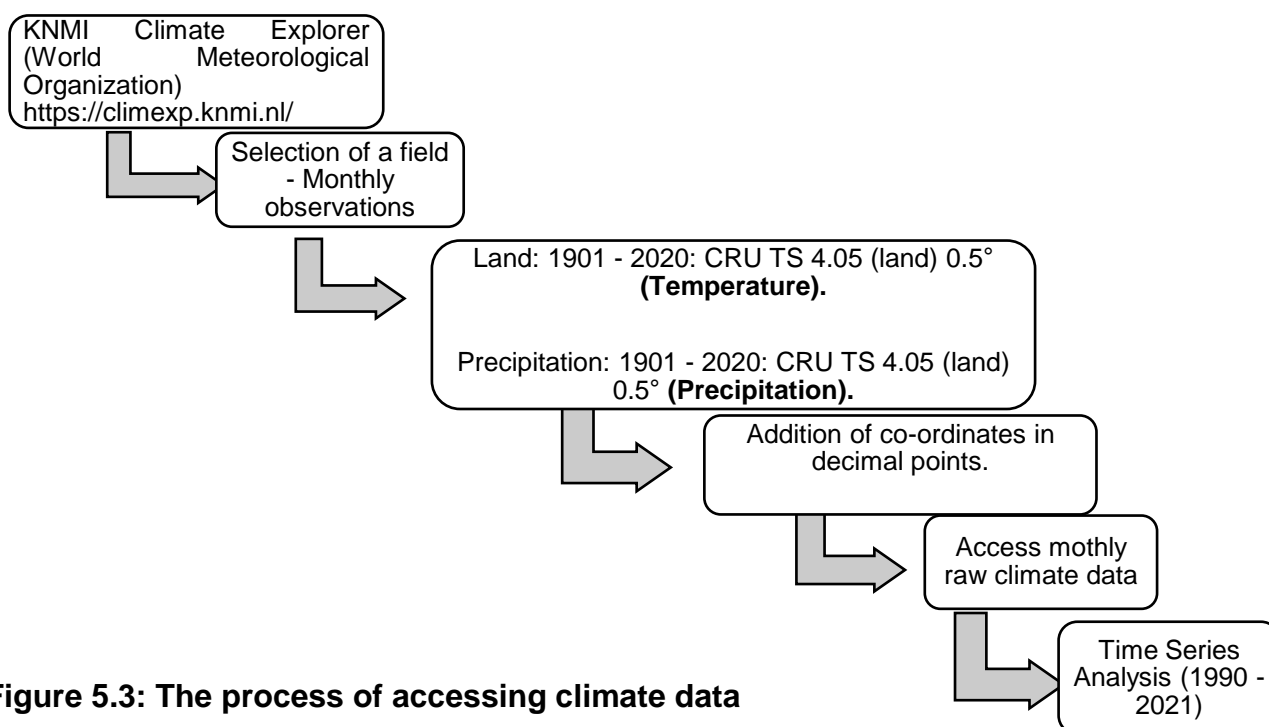
## 5.7. Data Collection

Data collection is a process that involves gathering and measuring specific information on variables of interest in a conventional manner. It enables the researcher to answer research questions, stated research hypotheses, and evaluate the outcomes (Vuong *et al.*, 2018).

### 5.7.1. Data collection methods

**Objective 1: To assess the precipitation and temperature trends in Thabo Mofutsanyana District from 1990 to 2020.**

The temperature and precipitation data were collected from the KNMI Climate Explorer, a tool used to investigate climate. In this study, Koninklijk Nederlands Meteorologisch Instituut (KNMI) Climate Explorer was used as a data collection tool to assess the temperature and precipitation trends in Thabo Mofutsanyana District over the past 31 years, from 1990 to 2020. The data were collected for each sampled town using CRU TS 4.05 – 0.5° resolution. To access the climate data, the following steps in Figure 5.3 were taken:



**Figure 5.3: The process of accessing climate data**

The monthly mean temperature was divided by 12 (months) to get the yearly mean. However, the nature of this study focuses on the monthly mean temperature, which is the average of each month in a given year.

## **Objective 2: To identify and evaluate the strategies that urban planners in the Thabo Mofutsanyana District have adopted 2011 to 2021**

Data were collected through the use of survey questionnaires from the urban residents (citizens). The advantage of using survey questionnaires is that they are cheap and allow the researcher to obtain more information quickly. They usually have standardized answers, making it simple to compile data (Saris and Gallhofer, 2014). Survey questionnaires were used to collect data from the urban residents because the sample size was large (384 residents). The survey questionnaire is presented in Appendix A of this report.

The urban residents were asked questions to gain more information about how they perceived the effects and extent of climate change. These questions were asked to find out from the urban residents if the plans drawn by urban authorities were effective. Most importantly, urban residents were asked questions to find out if they knew what was meant by climate change and whether they were aware of it and see if they had any known responsibilities as urban residents towards mitigating the effects of climate change.

Furthermore, more information was collected from all the urban planners in Thabo Mofutsanyana District through formal interviews. The interview questions are listed in Appendix B of this report. Urban planners were asked about the strategies that they had adopted towards sustainable urban planning. Also, the effectiveness of their approach, the techniques they had implemented to warn people in case of extreme weather events (dust storms, hailstorms, floods and tornadoes), and the challenges they experienced as they worked towards sustainable urban development planning. Moreover, the urban planners were asked about their objectives to mitigate climate change and when did they expected those objectives to be achieved. In addition, to get a complete picture of the proposed study, the participants (urban residents and urban planners) were asked similar questions and the results were compared.

These questions enabled the researcher to get a complete picture of the impacts of climate change that affect towns in Thabo Mofutsanyane District and how urban planners respond to

these impacts. Furthermore, obtaining information from urban residents and urban planners helped the researcher gain more insights into how urban planners' response to climate change contributed to sustainable urban development in the district. Most importantly, gaining this kind of information allowed the researcher to propose relevant and effective solutions that could be implemented to address and mitigate the effects of climate change on urban areas in the district.

**Objective 3: To assess the change in Urban Ecological Infrastructure in the Thabo Mofutsanyana District from 2011 to 2021**

The details of the data collection tools or sources used to obtain the third objective are presented in Table 3.3.

**Table 5.3. Particulars of the data sources and types**

Satellite Imagery					
Platform	Resolution (pixel)	Date	Path/Row	Format	Source
Maxar Technologies	1 m to 1 cm	01 November 2011 – 31 January 2012	169/79 169/80 170/79 170/80	Electronic	Google Earth Pro
PlanetScope	3.7 m	01 November 2016 – 31 January 2017		Electronic	Planet
PlanetScope	3.7 m	01 November 2021 – 31 January 2022		Electronic	Planet

Satellite imagery from Google Earth Pro and Planet was used to determine the conditions of the environment in sampled towns in the Thabo Mofutsanyana District. Google Earth Pro and Planet satellite imagery were used for this study because of their extremely high-resolution, ranging from 1 m to 1 cm, and 3.7 m per pixel resolution, respectively (Farr *et al*, 2007; Jin *et al*, 2021). Satellite images for year 2011 were obtained from Google Earth Pro while satellite images for year 2016 and 2021 were obtained from Planet. This is because PlanetScope operated by Planet became

active from 2016. Google Earth Pro and Planet scope enable the user to define the geographic extent, time, and imagery type.

The data from Google Earth Pro and Planet were used to identify the Green (parks, trees, green space, green roofs), Blue (lakes, wetlands, ponds and rivers) and Grey (Roads, drainage systems, settlements, and water-treatment plants) Urban Ecological Infrastructure (UEI), which helped determine whether the urban planners' response to climate change corresponded with the actual conditions in the environment. In brief, the Maxar Technologies and PlanetScope satellite imagery obtained from Google Earth Pro and Planet helped assess urban planners' actions (urban planning) to mitigate the effects of climate change in each town.

Furthermore, since the National Climate Change Response Plan (NCCRP) of South Africa was launched in 2011, the adaptation and mitigation methods identified and assessed in sampled towns in the Thabo Mofutsanyane District were those that were implemented after 2011. An interval of 5 years was used to assess the urban infrastructure in Thabo Mofutsanyana District, meaning that from each sampled town, 2011, 2016 and 2021 satellite images were assessed and analysed.

The adaptation and mitigation methods mentioned in the National Climate Change Response Plan (NCCRP) of South Africa include green buildings and housing and greenways or open spaces, trees, maintained water bodies such as rivers, lakes and ponds, dams and functioning drainage systems. Identifying and assessing these methods helped prove whether urban planners were working towards mitigating the effects of climate change in the area. Moreover, this also helped determine whether urban planners were following the national policies for climate change mitigation and adaptation.

The features mentioned above were identified through the use of Landsat imagery available on Google Earth Pro and Planet Scope. This process was done through supervised classification, whereby the image processing software was guided to specify the land cover classes of interest. Supervised classification can be much more accurate and yields cleaner images (Hasmadi and Pakhriazad, 2009). The data were more valid or reliable to reflect the actual urban planners' response to climate change. The software that was used during this process is ArcGIS (ArcMap 10.7.1). ArcGIS consists of contextual tools for mapping and spatial reasoning, which allow the user to handle and analyse geographic data (Teixeira, 2018). Also, other features stated by urban planners and personnel from the Department of Environmental Management, as climate change mitigation or adaptation measures during interviews, were included in the study and assessed through Landsat imagery and ArcGIS.

### 5.7.2. Data collection tools

In this study, the following data collection tools were used:

- I. Interviews – this data collection tool can be done formally (structured), semi-formally, or informally, and it can be conducted in person or over the cell phone or telephone. It is qualitative (Sutton and Austin, 2015). One-on-one formal interviews were conducted with the urban planners and environmental managers in Thabo Mofutsanyana District.
- II. Survey questionnaires – this data collection tool consists of questions to gather data from respondents (Dolnicar, 2013). Survey questionnaires were distributed to urban residents to gain more information about the effectiveness of urban planners' strategies or actions towards climate change.
- III. Documents and records involve examining the existing data in a database form, such as reports, meeting minutes, and newsletters. This data collection tool is an inexpensive form of collecting data, but it may be incomplete (Sutton and Austin, 2015). Document analysis was used by gathering climate data from the KNMI Climate Explorer (World Meteorological Organization) accessible through <https://climexp.knmi.nl/> to assess the temperature and precipitation trends in Thabo Mofutsanyana District over a period of 31 years.
- IV. Google Earth Pro and Planet – this data collection tool allows the researcher to obtain geospatial datasets. These geospatial datasets include Landsat satellite imagery, aerial photos, sentinel satellite data, and land cover data. (Sasscer, 2010). In this particular research, Google Earth Pro and Planet were used to obtain information showing whether urban planners' response to climate change corresponded with the actual conditions in the environment.

### 5.8. Data Analysis and Presentation

The data on temperature and precipitation trends were collected from the KNMI Climate Explorer and analysed through Excel and presented in graphs (line graphs and bar graphs). The temperature and precipitation data were from 1990 to 2020. The satellite imagery (Maxar Technologies and PlanetScope) collected from Google Earth Pro and Planet were analysed using ArcGIS (ArcMap 10.7.1), specifically using Supervised Classification using the algorithm of maximum likelihood, where green, blue and grey UEI were set as the standard of classification. The satellite imagery that was used was from the summer months (November, December, January) in the 8 sampled towns which are namely Senekal, Bethlehem, Phuthaditjhaba,

Ficksburg, Reitz, Memel, Ladybrand, and Clarens. The data were presented in the form of maps. Lastly, data collected through interviews and survey questionnaires were analysed through thematic analysis and use of Statistical Package for Social Sciences (SPSS), respectively. The data were then presented in descriptive words, bar graphs, pie charts, and numbers (percentages).

## **5.9. Reliability and Validity**

To ensure the validity of this study, an appropriate time scale was selected (February 2020 – December 2021), and the proper methodology was used, including data collection tools, types of research and designs, and study sampling methods.

Also, the appropriate research respondents were chosen to provide the relevant information. Again, the participants were not pressured to alter their way of responding to the questions. This was done to ensure that the extent to which the same finding and results can be obtained using the same data collection tools is great (Dudovskiy, 2016). Also, relevant questions were used to address the research aim and objectives. To further improve the reliability and validity of the study, four primary research ethics were considered—namely, informed consent, beneficence, respect for anonymity and confidentiality, and justice.

## **5.10. Research Ethics and Considerations**

Ethical considerations are the standards or norms for conduct that distinguish between right and wrong (Resnik, 2020). They help in determining the difference between acceptable and unacceptable behaviours when conducting and compiling research. Research ethics search for reasons for refraining from an act and acting, for deciding to approve or disapprove conduct, for trusting and believing or denying something about behaviour, whether virtuous or vicious (Resnik, 2020).

This study was conducted under the following ethical considerations:

- I. Informed consent – In this study, the participants were informed about how the research unfolds (asking questions and voice recording) and its risks towards the participant and society. They were informed that the research is solely for academic purposes. The participants who were included in the study were those who voluntarily agreed to participate in the research.

- II. Beneficence - the study did not harm anyone who participated, including the participants, the local authorities, and the society as a whole.
- III. Respect for anonymity and confidentiality – In this study, the participant's identity known by the researcher was protected from being discovered by other people. Any time the participant asked to be anonymous, their request was granted throughout the whole research. The responses they provided were handled confidentially and were not shared with any third parties.
- IV. Justice – there was a fair selection of participants in the study. Hence, there use of probability sampling, simple random sampling. The respondents were treated fairly, no monetary benefits were provided to any of the respondents, and no respondents experienced harsh treatments.

### **5.11. Chapter Summary**

The methods used in this study helped improve the study's quality by identifying the appropriate data collection tools of the study, research methods and designs, study population, study sampling, and sample size. The research methods also improved the quality and reliability of the study by using the four primary ethical considerations. The following chapter focuses on the research results, data analysis, and presentation.

## **CHAPTER SIX: DATA PRESENTATION AND ANALYSIS**

### **6.1. Introduction**

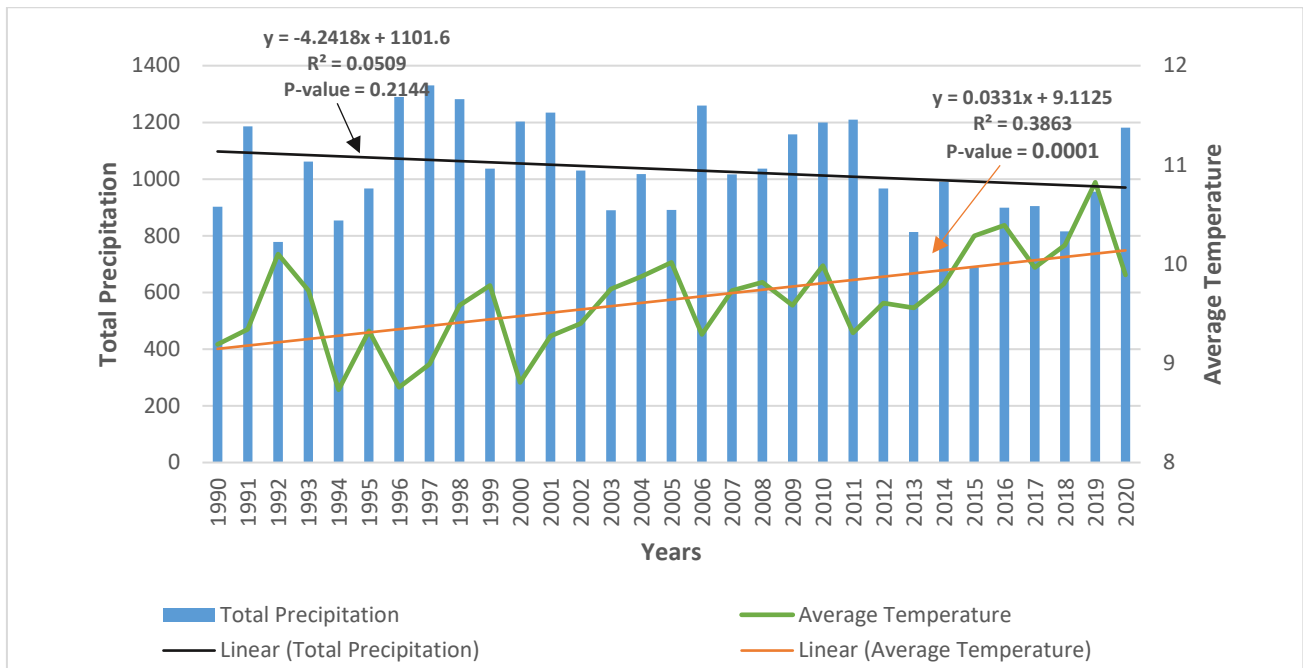
This chapter presents the results of the study, and it presents the results on the monthly mean temperature and annual total precipitation trends from 1990 to 2012, the urban residents and urban planners' perceptions of the extent and effect of climate change, and urban planning responses to climate change in Thabo Mofutsanyana District. The chapter also presents the changes in the Urban Ecological Infrastructure (UEI) in Thabo Mofutsanyana District due to urban planning.

The results are reported following the research objectives, namely to: 1) assess the rainfall and temperature trends in Thabo Mofutsanyana District over the past 29 years, 2) identify actions taken by urban planners toward climate change, and 3) evaluate such actions to determine the extent to which these strategies contribute to sustainable urban development in the district. Also, the results are presented in graphical, tabular and narrative form.

### **6.2. Temperature and precipitation trends from 1990 to 2020 in Thabo Mofutsanyana District**

This research study was conducted in Thabo Mofutsanyana District to determine if the climate of the eight sampled towns had changed from 1990 to 2020. The results obtained from the data analysis on monthly mean temperatures and precipitation show a temporal variation of monthly mean temperature and precipitation in the eight towns included in the study, namely, Ladybrand, Senekal, Clarens, Bethlehem Phuthaditjhaba Reitz, Memel, and Ficksburg.

The results on how the monthly mean temperature and annual total precipitation for Phuthaditjhaba varied from 1990 to 2020 are presented in Figure 6.1:



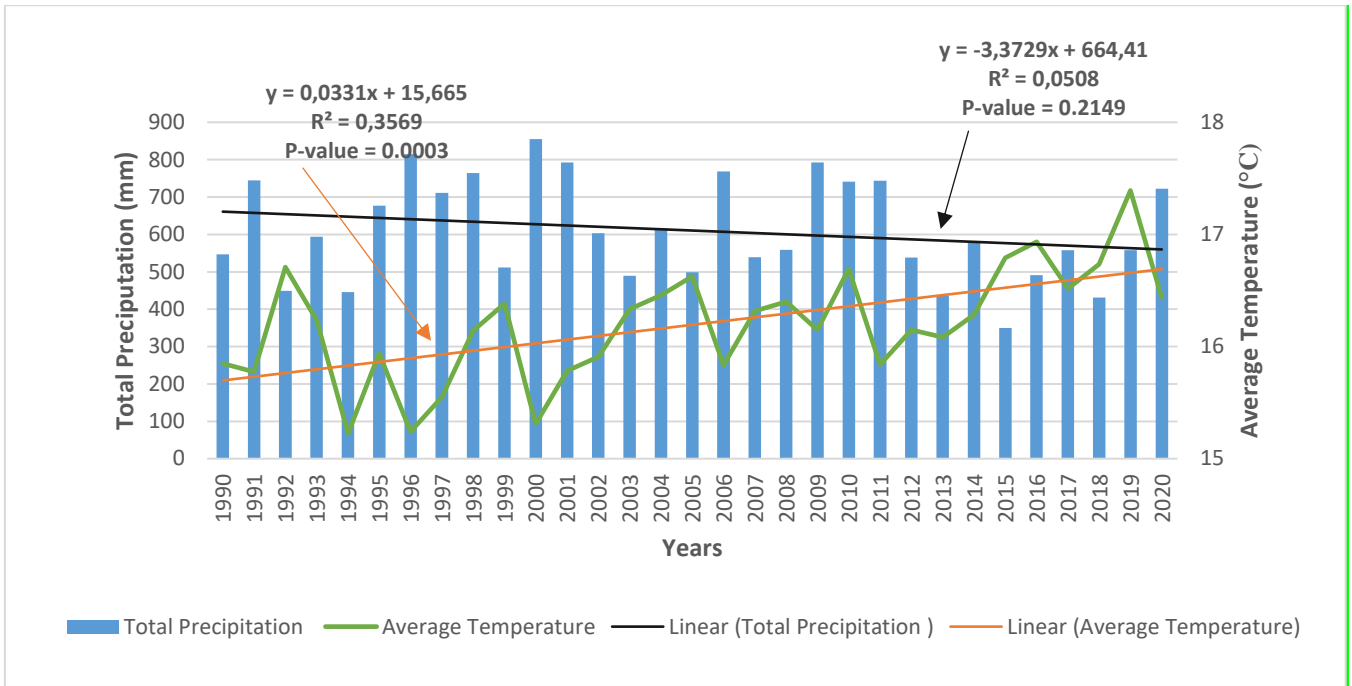
**Figure 6.1 The monthly mean temperature and precipitation trends for Phuthaditjhaba from 1990 to 2020**

As shown in Figure 6.1, between 1990 and 2020, the monthly mean temperature and annual total precipitation have been increasing and decreasing over the years. The monthly mean temperature experienced in Phuthaditjhaba ranged between 8°C and 11°C, while the annual total precipitation received in this town ranged between 650mm and 1350mm.

The graphs in Figure 6.1 depict that the trend in monthly mean temperature increased in Phuthaditjhaba between 1990 and 2020, while the annual total precipitation decreased. The change in monthly mean temperature is statistically significant as the p-value is 0.0001, while the change in annual total precipitation is statistically insignificant with a p-value of 0.2144. Moreover, the monthly mean temperature peaked in 2019, as the temperature of 10,38°C was recorded, while the lowest monthly mean temperature was recorded in 1994 when 8.73°C was recorded.

Furthermore, the annual total precipitation peaked in 1997 when a depth of 1329.90mm was recorded, while the lowest annual total precipitation of 689.40mm was recorded in 2015. The years 1992, 1994, 2003, 2005, 2013, and 2015 were characterized by the lowest total precipitation, while the years 1996, 1997, 1998, and 2006 were characterized by the highest total precipitation.

The monthly mean temperature and annual total precipitation trends for Senekal are presented in Figure 6.2:



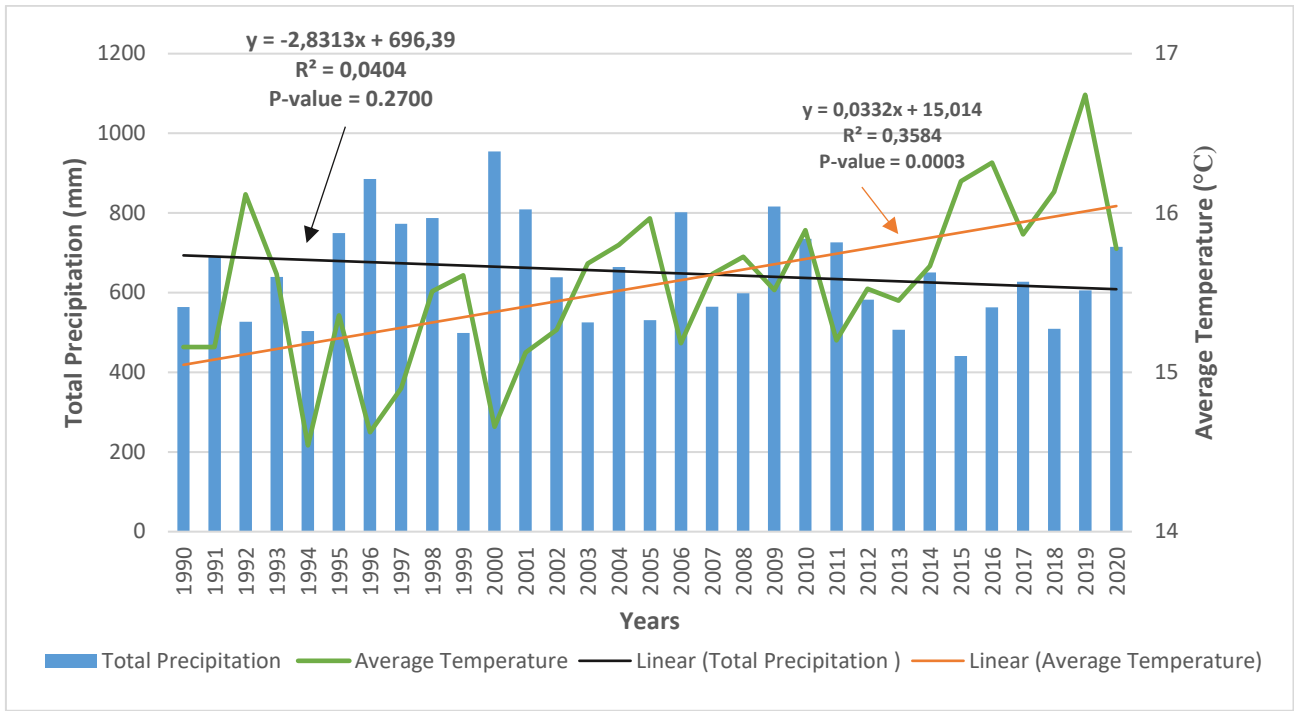
**Figure 6.2 The monthly mean temperature and precipitation trends for Senekal from 1990 to 2020**

As illustrated in Figure 6.2, the monthly mean temperature experienced in Senekal from 1990 to 2020 slightly increased, while the annual total precipitation received in this town decreased. The change in monthly mean temperature in Senekal is statistically significant since the p-value is 0.0003. In contrast, the change in annual total precipitation in this town is not statistically significant, as the p-value of the change in annual total precipitation is 0.2149.

Although the monthly mean temperature increased between 1990 and 2020, as shown in Figure 6.2, this increase was not drastic or rapid, with the monthly mean temperature changing between 15°C and 18°C in these 31 years. The highest monthly mean temperature in Senekal was recorded in 2019 at 17.39°C, and the lowest was recorded in 1994 with a temperature of 15.22°C.

Despite the rise and fall in the annual total precipitation recorded between 1990 and 2020, there has been a significant decrease in the precipitation between the years 1991 and 1992, 1998 and 1999, 2001 and 2003, 2006 and 2007, 2011 and 2013, and 2014 and 2015. As shown in Figure 6.2, the annual total precipitation reached its highest peak in 2000 with a total of 855,20 mm, but reached its lowest level in 2016 when only 349,80 mm was received.

Figure 6.3 illustrates the monthly mean temperature and annual total precipitation trends for Reitz which are characterized by an increase in monthly mean temperature and a decrease in annual total precipitation:

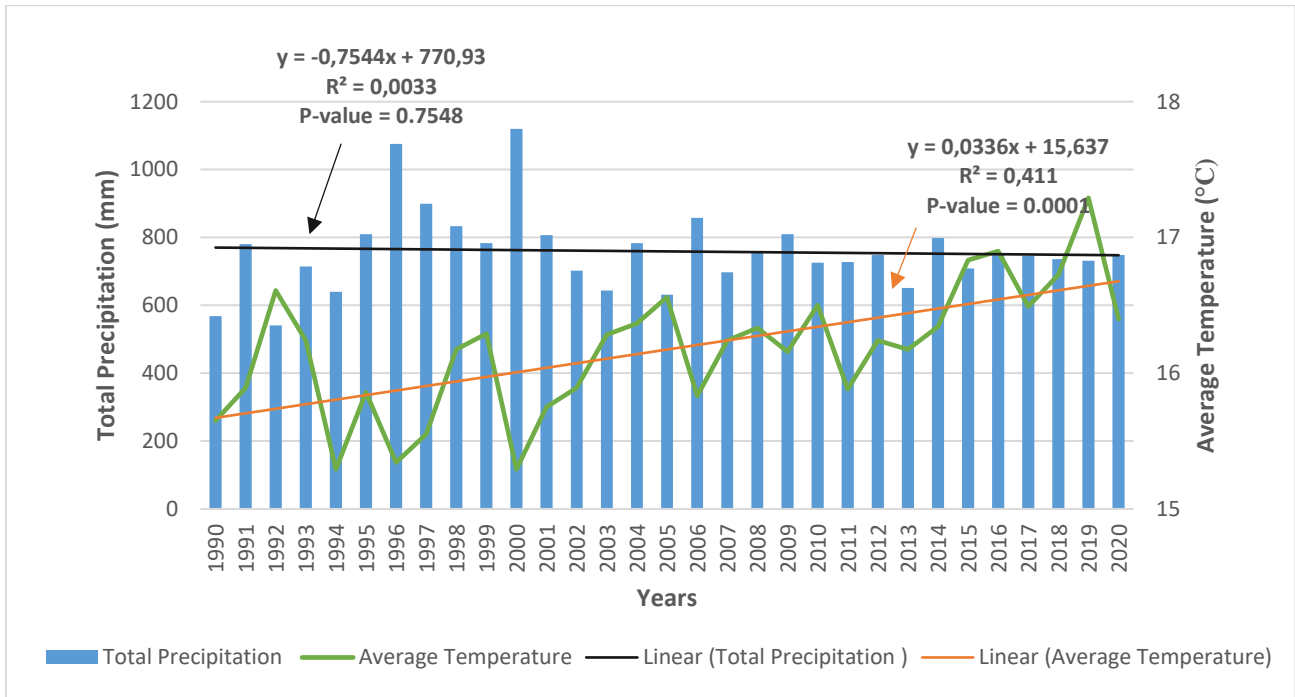


**Figure 6.3 Monthly mean temperature and annual total precipitation trends for Reitz from 1990 to 2020**

Figure 6.3 shows that in Reitz the trend in the monthly mean temperature increased between 1990 and 2020, while the annual total precipitation decreased during the same period. Reitz's change in monthly mean temperature is statistically significant as the p-value is 0.0003. Although there is a change in annual total precipitation received in Reitz, which has decreased from 1990 to 2020, this change is not statistically significant as the p-value is 0.2700.

In Reitz, the highest monthly mean temperature was experienced in 2019, when a temperature of 16.74°C was recorded, and the lowest was recorded in 1994 with a temperature of 14.54°C. Regarding the annual total precipitation in Reitz, the highest precipitation was received in 2000 when it reached a depth of 954.80mm, while the lowest was recorded in 2015 with a depth of 440.90mm. As shown in Figure 6.3, there was a decrease in annual total precipitation between 2009 and 2013. This marks a decrease in precipitation that occurred during these five years.

The monthly mean temperature and annual total precipitation trends in Memel for the 1990 - 2020 period are presented in Figure 6.4:

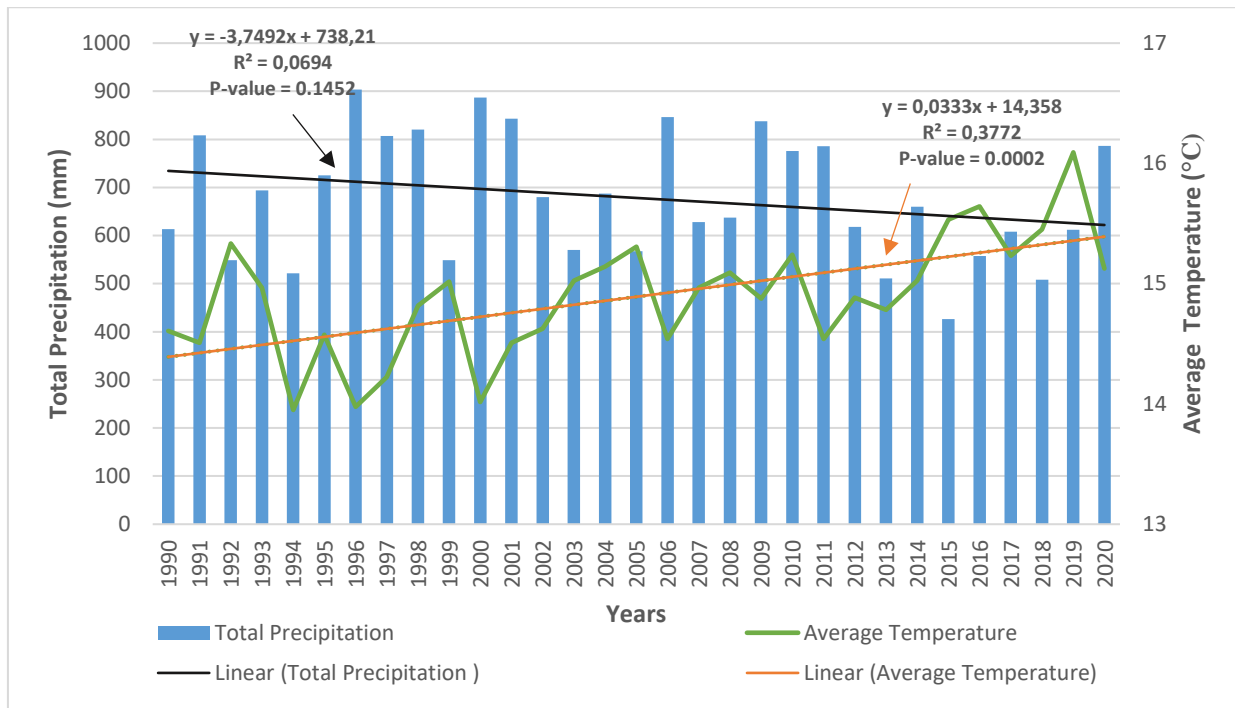


**Figure 6.4 Trends in monthly mean temperature and annual total precipitation in Memel for the 1990 to 2020**

As illustrated in Figure 6.4, during the 1990-2020 period the monthly mean temperature in Memel increased significantly, with a p-value of 0.0001. In contrast, the annual total precipitation in Memel slightly decreased during the same period. Although the annual total precipitation decreased during these 31 years, the change is not statistically significant as the p-value is 0,7548.

The monthly mean temperature in Memel reached its highest peak in 2019 with a temperature of 17,29 °C, and the lowest was recorded in 1994 when the value of 15,29 °C was recorded. Furthermore, as illustrated in Figure 6.4, between 2000 and 2005, a significant temperature increase occurred over five consecutive years, with no decrease in the monthly mean temperature. Regarding the precipitation, in 2000 an annual total precipitation of 1119,60mm was recorded in Memel as the highest precipitation received between 1990 and 2020, while the lowest was received in 1992 when the value of 540,80mm was recorded. There was a major increase in annual total precipitation between 1999 and 2000 in Memel. An increase of more than 330mm.

As depicted in Figure 6.5, monthly mean temperature and annual total precipitation trends for Bethlehem have been characterized by fluctuations.

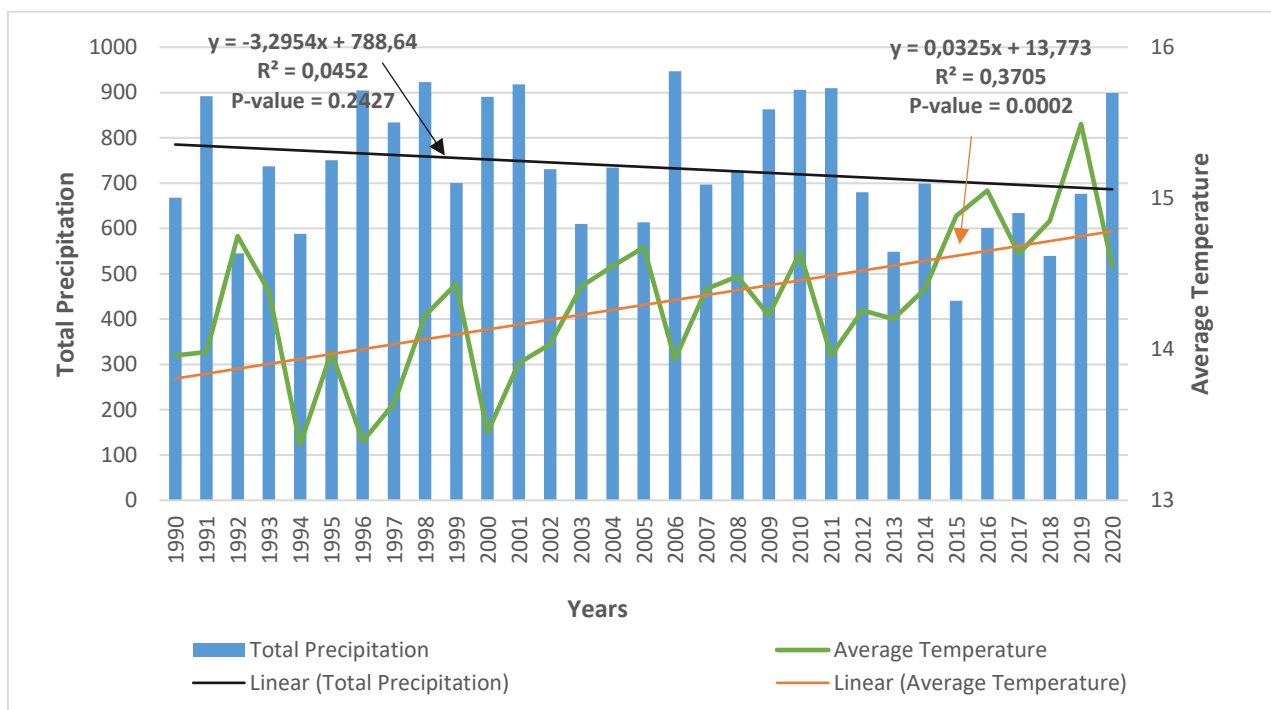


**Figure 6.5 Trends in monthly mean temperature and annual total precipitation in Bethlehem between 1990 and 2020**

As seen in Figure 6.5, the monthly mean temperature in Bethlehem drastically increased from 1990 to 2020, and the change is statistically significant as the p-value is 0.0002. In contrast, the annual total precipitation in Bethlehem decreased from 1990 to 2020. However, this change in precipitation is statistically insignificant since the p-value is 0.0689.

Figure 6.5 above shows a significant increase in the monthly mean temperature from 1990 to 2020, as shown by the trend-line. The highest monthly mean temperature was recorded in 2019, with a temperature of 16.09°C, while the lowest was recorded in 1994, when the highest monthly mean temperature of 13.95°C was recorded. In Bethlehem, the annual total precipitation reached its peak in 1996 when 903.60mm was received. The years 1998, 2000, 2001, 2006, and 2009 were also characterized by relatively high annual total precipitation compared to the other years, with precipitation of 820.20mm, 886.80mm, 843.30mm, 846.10mm, and 837.40mm recorded in these years, respectively. As illustrated in Figure 6.5, the lowest annual total precipitation was recorded in 2015, when 426.60mm was recorded.

Figure 6.6 illustrates the monthly mean temperature and annual total precipitation recorded in Clarens.

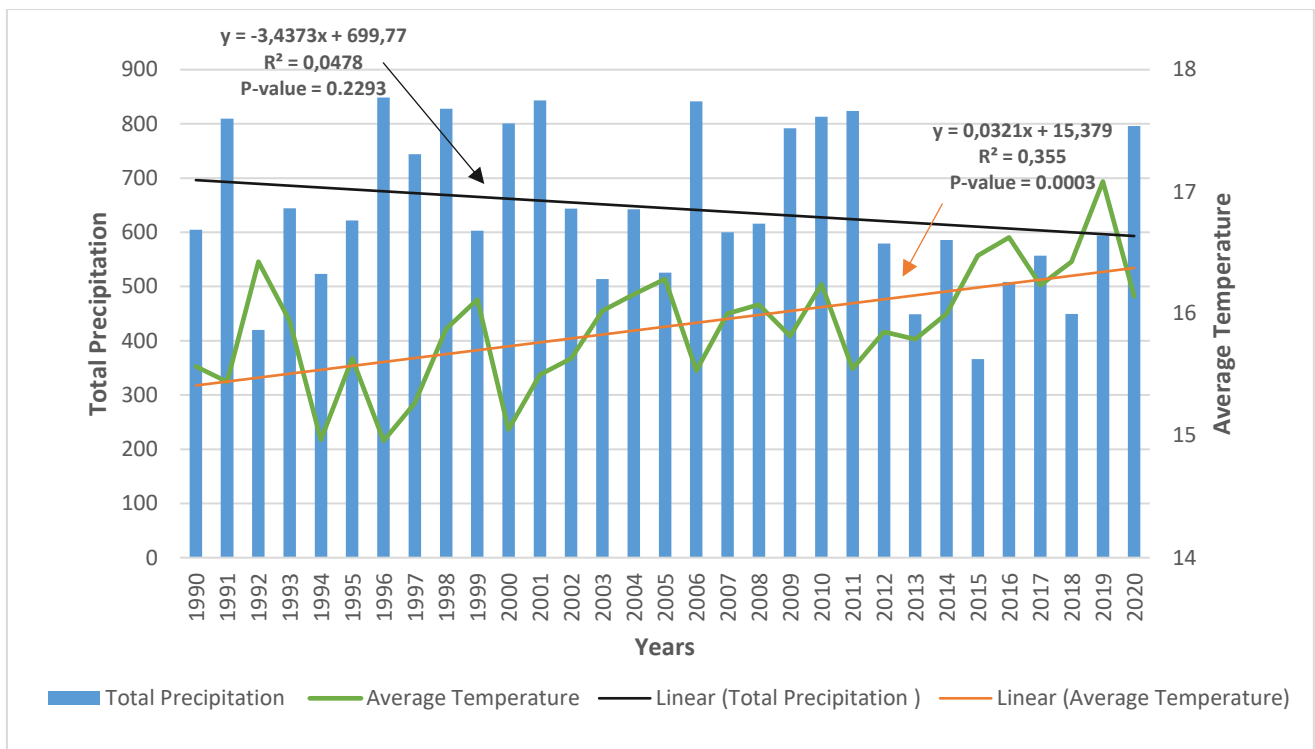


**Figure 6.6 Monthly mean temperature and annual total precipitation trends in Clarens for the 1990 – 2020 period**

As depicted in Figure 6.6, the monthly mean temperature experienced in Clarens increased between 1990 and 2020. According to the analysis, this change in monthly mean temperature is statistically significant as the p-value is 0.0002. However, the change in annual total precipitation received in Clarens is not statistically significant as the p-value is 0.2427, even though the annual total precipitation increased between 1990 and 2020.

Clarens experienced the highest monthly mean temperature in 2019, when 15.49 °C was recorded, while the lowest was recorded in 1994 when monthly mean temperature dropped to 13.37°C. Between 2000 and 2005, as well as between 2011 and 2016, there was a significant increase in temperature without even a slight decrease in each of these five consecutive years. Clarens received the highest annual total precipitation in 2006 when a depth of 947.40mm was recorded. The lowest annual total precipitation was recorded in 2015, when only 440.60mm was recorded. As illustrated in Figure 6.6, 1992,1994, 2013, 2015, and 2018 were characterized by relatively low annual total precipitation

According to Figure 6.7, between 1990 and 2020 monthly mean temperature in Ficksburg increased while annual total precipitation decreased.

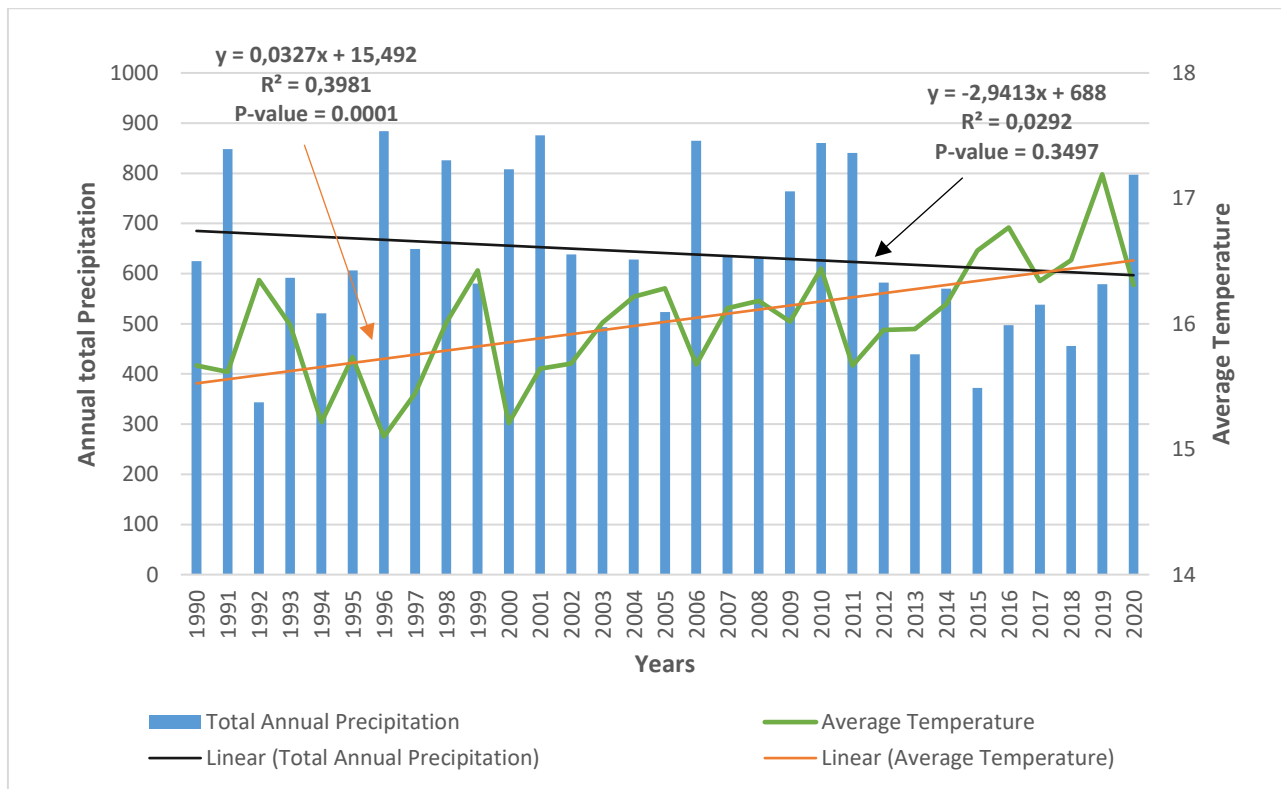


**Figure 6.7 Monthly mean temperature and annual total precipitation trends in Ficksburg between 1990 and 2020**

The increase in monthly mean temperature is statistically significant since the p-value is 0.0003. On the other hand, the decrease in annual total precipitation received in Ficksburg is not statistically significant as the p-value is 0.2293.

In Ficksburg, the highest monthly mean temperature was recorded in 2019 when a monthly mean temperature was 17.08°C, while the lowest was recorded in 1996 when 14.96°C was recorded. From 1992 to 1994, as well as during 1999, 2000, 2005 and 2006, there was a drop in the monthly mean temperature. Figure 6.7 also illustrates the changes in annual total precipitation received in Ficksburg. The annual total precipitation peaked in 1996 when a total of 848.40mm was recorded. The lowest amount (366.30mm) was recorded in 2015. Although the trend line shows a decrease in the annual total precipitation, it is seen that there were fluctuations in precipitation between 1990 to 2020, as well as between 1994 and 1996, and 1999 and 2000. Similarly, there was a marked increase in precipitation during the 2005 - 2006, 2015 - 2017, and 2019 - 2020 periods. Conversely, the years 1991, 1992, 1998, 1999, 2001, 2002, 2003, 2006, 2007, 2011, 2012, 2013, 2014, and 2015 were marked by a decrease in annual total precipitation.

Between 1990 and 2020 in Ladybrand, the trend for monthly mean temperature was characterized by an increase, while the trend for annual total precipitation reflected a decrease, as shown in Figure 6.8.



**Figure 6.8 Monthly mean temperature and annual total precipitation in Ladybrand between 1990 and 2020**

As shown in Figure 6.8, the monthly mean temperature in Ladybrand increased between 1990 and 2020. The change in monthly mean temperature is statistically significant since the p-value is 0.0001. To the contrary, there was a decrease in annual total precipitation in this town, though this decrease is not statistically significant, as the p-value is 0.3497.

The graph illustrates that Ladybrand had an upward trend in the monthly mean temperature and a downward trend in the annual total precipitation. However, both the monthly mean temperature and annual total precipitation were fluctuating. The monthly mean temperature reached its peak in 2019 when 19.19°C was recorded, whereas the lowest was recorded in 1996, when a monthly mean temperature of 15.10°C was recorded.

Ladybrand recorded the lowest monthly mean precipitation in 1992, when 343.20mm was received. The annual total precipitation reached its peak in 1996 when precipitation of 883.80mm was recorded. The years 1991, 1996, 2001, 2006, 2010, and 2011 recorded relatively high annual total precipitation compared to other years, especially 1992, 2003, 2013, and 2015.

## 6.3 Urban Residents' Perceptions of Climate Change in Thabo Mofutsanyana District

The perceptions of the Thabo Mofutsanyana District's residents were analyzed from the data derived from the survey questionnaires distributed to the residents. These results are presented in five sub-sections, including the demography of the urban residents, Urban residents' perceptions of climate change, Urban residents' perceptions of urban planning response to climate change, urban residents' climate change awareness, and urban residents' perceptions of UEI in Thabo Mofutsanyana District. Understanding the resident's perceptions on climate change in the district assisted in explaining the views of residents on how the climate has changed over the years, the effects of climate change in the district and how these effects have affected them, and most importantly, their views on the urban planners' response to climate change. In this study, urban planning is identified as the critical process in mitigating or reducing the effects of climate change in the district. Therefore, evaluating the actions taken by urban planners towards climate change assisted in determining the effectiveness and the extent of the urban planners' response to climate change.

### 6.3.1 Demographic information (Urban Residents)

Results on demographic information of urban residents are presented in Table 4.1:

Table 6.1 Demographic Information

	Options	Frequency	Percentage of total respondents
<b>Gender</b>	Male	123	49
	Female	127	51
	<b>Total</b>	<b>250</b>	<b>100</b>
<b>Age</b>	18 – 24	106	42
	25 – 34	64	26
	35 – 44	50	20
	45 – 54	22	9
	55 – 64	7	2
	65 +	1	1
	<b>Total</b>	<b>250</b>	<b>100</b>
<b>Ethnicity</b>	Black	233	93
	White	16	6
	Coloured	1	1

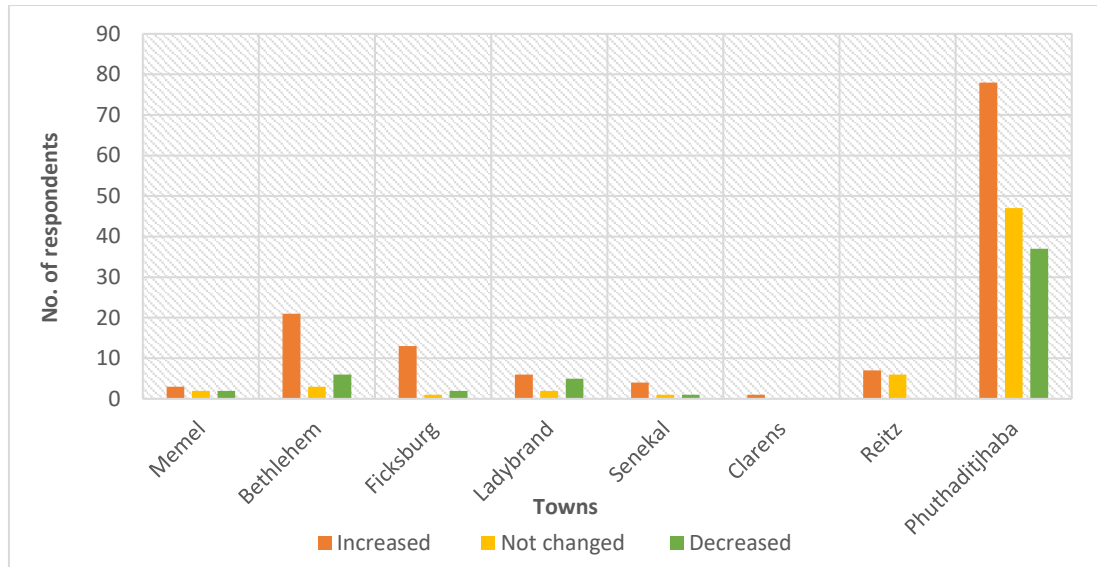
	<b>Total</b>	<b>250</b>	<b>100</b>
<b>Level of education</b>	No school completed	62	25
	Matric higher certificate	51	20
	Diploma	34	14
	Bachelor's degree	61	24
	Honour's Degree	29	12
	Master's degree	12	4
	Doctorate	1	1
	<b>Total</b>	<b>250</b>	<b>100</b>
<b>Town</b>	Senekal	7	3
	Reitz	13	5
	Bethlehem	30	12
	Clarens	2	1
	Phuthaditjhaba	162	65
	Ficksburg	16	6
	Memel	7	3
	Ladybrand	13	5
	<b>Total</b>	<b>250</b>	<b>100</b>

Among the urban residents who participated in the study, 49% were male. Forty-two percent of the participants who participated in the study were aged between 18 and 24. The ages of 26% of the participants ranged between 25 and 34. Twenty percent of the participants were between the ages of 35 and 44, 9% were between 45 and 54, while 2% of the participants were aged between 55 and 64, and only 1% of the respondents were aged 65 and above. Regarding the ethnicity of urban residents who participated in the study, 93% of the participants were Black, 6% were White, and the remaining 1% were Coloured.

The analyses further revealed that 25% of the residents who participated in the study did not complete Matric. Twenty percent hold a Matric higher certificate, meaning they completed their secondary education. Fifty-five percent of the participants had a diploma, 24% had a bachelor's degree, 12% had an honor's degree, 4% had a Master's degree, and only 1% had a doctorate. Out of the 250 residents who participated in the study, 3% were from Senekal, 5% from Reitz, 12% from Bethlehem, 1% from Clarens, 6% from Ficksburg, 3% from Memel, 5% from Ladybrand, and the majority of participants were from Phuthaditjhaba constituting 65% of the respondents.

### 6.3.2 Urban residents' perceptions of climate change in Thabo Mofutsanyana District.

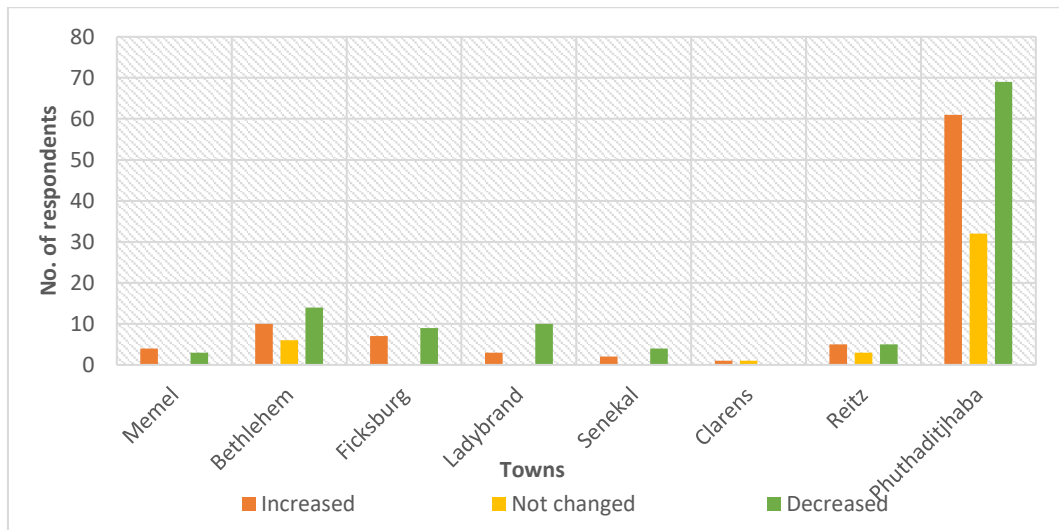
This section of the study addresses the participants' perceptions of climate change and how it affects them and the urban planners' response to climate change in each town in the Thabo Mofutsanyana District. The respondents' views on temperature trends in sampled towns in the district are summarized in Figure 6.9.



**Figure 6.9 Respondents who noted the change in the level of temperature**

As depicted in Figure 6.9, in all towns, most respondents stated that there had been an increase in temperature, with Memel having a 43% of respondents noting an increase in temperature, compared to 70% in Bethlehem, 81% in Ficksburg, 46% in Ladybrand, 67% in Senekal, 50% in Clarens, 54% in Rietz, and 48% in Phuthaditjhaba. In Bethlehem, Ficksburg, and Ladybrand, a significant number of respondents stated that there had been a decrease in environmental temperature, as illustrated in Figure 6.9

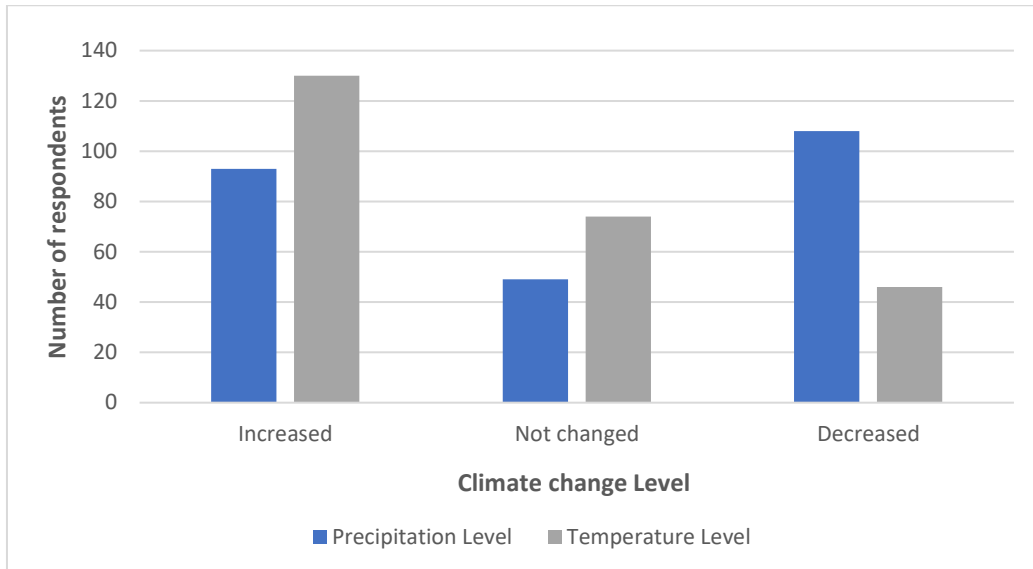
The graph in Figure 6.10 highlights the respondents' views on precipitation trends in towns of the Thabo Mofutsanyana District.



**Figure 6.10 Respondents who noted the change in the level of precipitation**

In most towns, the majority of the respondents noted a decrease in the levels of precipitation in their environment. The exception was Memel and Reitz, where the majority noted an increase, and Clarens, where none of the respondents reported the precipitation as not changed. Forty-seven percent of respondents from Bethlehem noted a decrease in precipitation received, compared to 56% from Ficksburg, 77% from Ladybrand, 67% from Senekal, and 43% from Phuthaditjhaba. In Memel, 57% of respondents noted an increase in precipitation, while in Clarens, 50 % of the respondents reported an increase in precipitation received. In Reitz, 38% of the respondents noted an increase in precipitation, and 38% stated that there had been a decrease in precipitation.

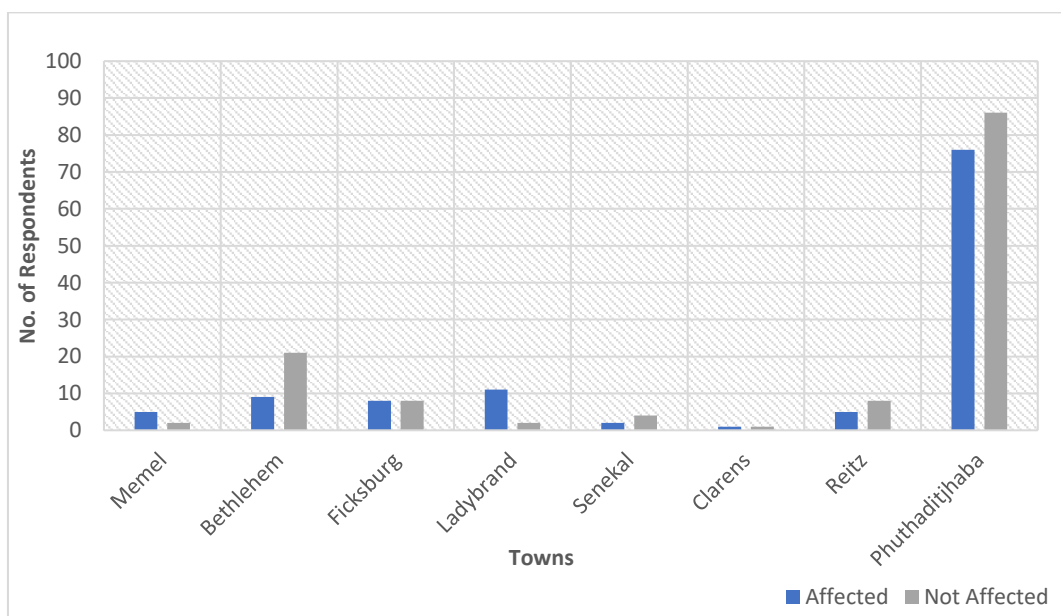
Figure 6.11 shows respondents' views on temperature and precipitation trends in the Thabo Mofutsanyana District.



**Figure 6.11 Respondents who noted the change in the level of precipitation and temperature**

Overall, 37.2% of residents of the Thabo Mofutsanyana District stated that the precipitation received in their area had increased, while 19.6% residents reported that the level of precipitation received in the district had not changed. In contrast, 43.2% of the residents stated that the precipitation received in the district had decreased. Regarding temperature, 52% of residents noted that the environmental temperature within the district had increased, while 29.6% indicated that environmental temperature had not changed, and only 18.4% of residents pointed out that the temperature had decreased.

Figure 6.12 is an illustration of urban residents' views on whether they have been affected by the levels of temperature in each town or not.



### Figure 6.12 Respondents who noted that they had been affected by the change in temperature levels

As seen in Figure 6.12, most of the respondents from Memel and Ladybrand stated that they had been affected by temperature changes. In Memel, 71% of the respondents stated that they had been affected by the changes in temperature, compared to 85% in Ladybrand. In Bethlehem, Senekal, Reitz, and Phuthaditjhaba, most respondents indicated that they were not affected by the change in temperature. Seventy percent of the respondents from Bethlehem said that they were not affected by temperature change, compared to 67% from Senekal, 62% from Reitz, and 53% from Phuthaditjhaba. In Ficksburg and Clarens, 50% of the respondents from each town stated that they had been affected by the change in environmental temperature.

The overall results on the urban residents' perceptions on whether the change in the climate of Thabo Mofutsanyana District has affected them or not are presented in Figure 6.13.

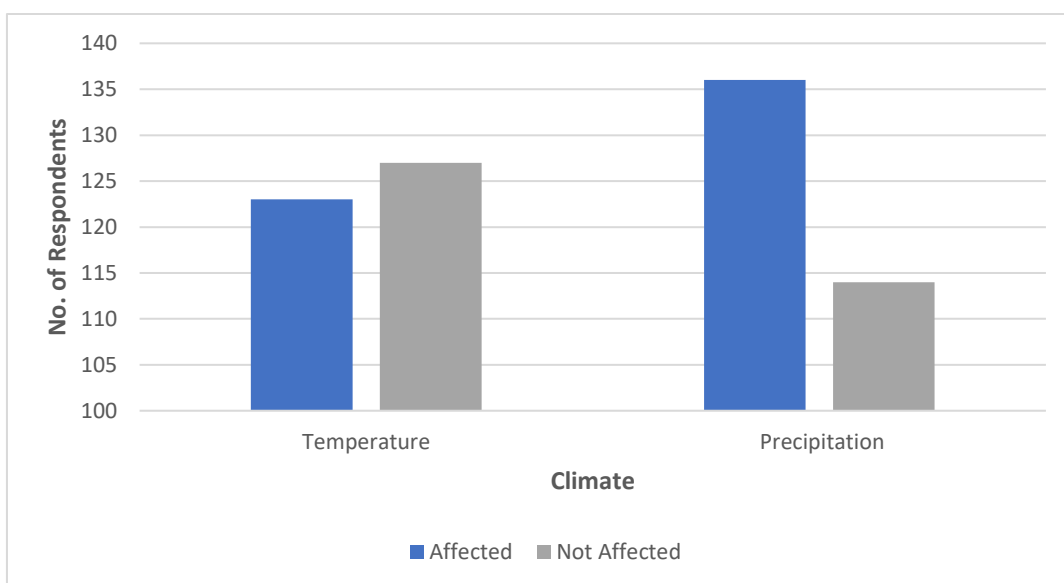


Figure 6.13 Respondents who noted that they had been affected by the change in precipitation and temperature levels

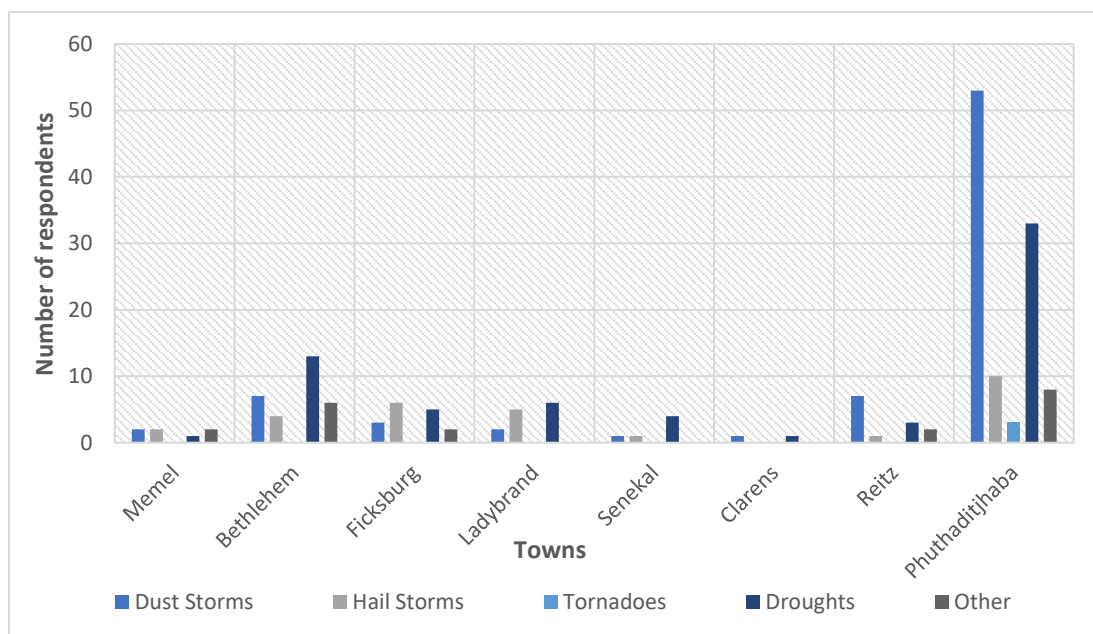
One hundred and twenty-three out of 250 residents of the Thabo Mofutsanyana District stated that they had been affected by the temperature changes. This accounts for 49% of all the respondents. In comparison, 127 residents said they were not affected by the temperature changes, accounting for 51 % of the respondents. One hundred and thirty-six residents stated

they had been affected by the amount of precipitation received in the district, which equals 66% of the respondents. In contrast, 44% of the respondents said they were not affected.

The residents stated that climate change had affected them in various ways, including floods and infrastructural damages caused by heavy rains. The residents also indicated they were facing water shortages, drought, crop failure, soil erosion, high water bills, and increased food prices (inflation) due to low rainfall levels (see Figure 6.14). According respondent number 172, less rainfall leads to a shortage of clean and safe water, causing a rise in water bills. Respondent number 118, further stated that the decrease in rainfall causes food prices to increase as there is less food to meet the demand. Forty-nine percent of the urban residents reported that they had been affected by the extreme temperatures (cold/hot weather). These extreme temperatures have led to drought, mainly caused by hot weather. The residents reported that they find it challenging to adapt to the extremely low temperatures due to frequent load shedding (i.e., cuts in electricity supply), which has become an issue in the district. Urban resident number 203 stated that:

*“Phuthaditjhaba experiences more load-shedding during winter. We fail to cope as there is no electricity to keep us warm, help us cook and bath, or perform our daily tasks”.*

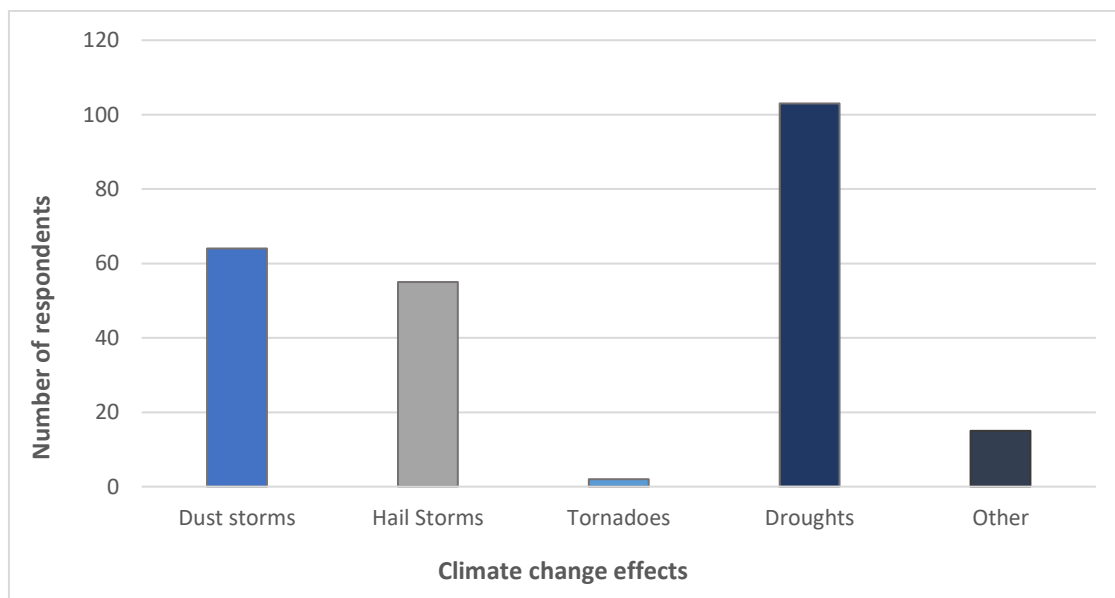
Figure 6.14 indicates the effects of climate change experienced in the sampled towns of Thabo Mofutsanyana District.



**Figure 6.14 Effects of climate change experienced in the sampled towns of Thabo Mofutsanyana District**

As shown in Figure 6.14, most of the respondents from Bethlehem, Ladybrand, and Senekal noted drought as one of the most frequently experienced effects of climate change. Forty-three percent of the respondents from Bethlehem, 46% from Ladybrand, and 67% from Senekal stated that drought had seriously affected them. Due to drought, they did not have access to clean and fresh water from the taps. Fifty-four percent of respondents from Reitz and 33% from Phuthaditjhaba noted dust storms as a significant impact of climate change. Thirty-eight percent of the respondents from Ficksburg stated that hail storms had been a significant effect of climate change in the town. According to the respondents who participated in the study, dust storms, hail storms, and droughts have affected both Memel and Clarens.

The effects of climate change experienced in the Thabo Mofutsanyana District are presented in Figure 6.15:



**Figure 6.15 Effects of climate change experienced in Thabo Mofutsanyana District**

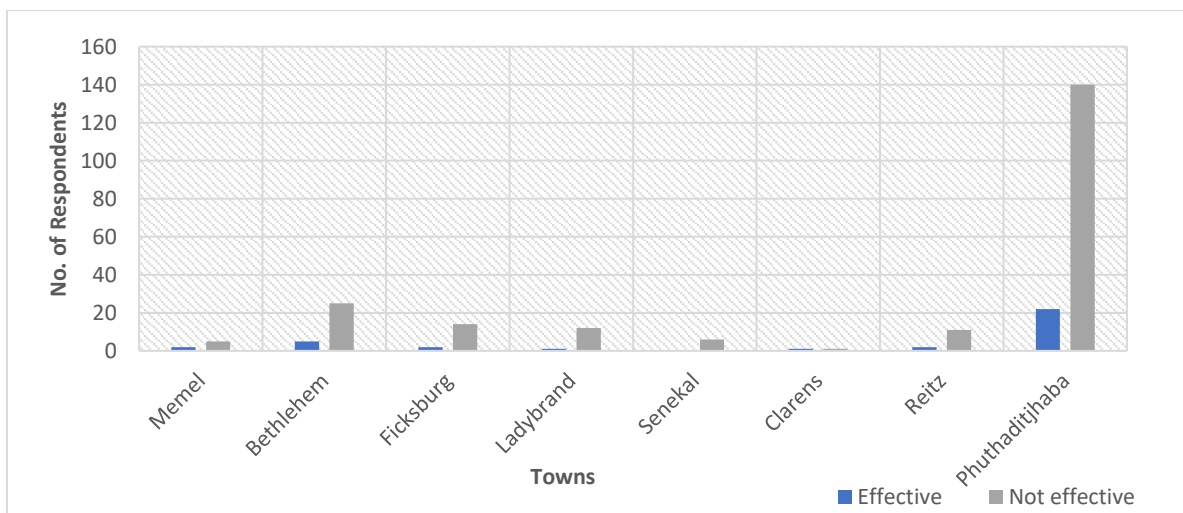
It can therefore be concluded that Thabo Mofutsanyana District has experienced several environmental challenges due to climate change. Sixty-four (25,6%) of the 250 respondents from the district stated that they experienced dust storms, while 55 residents (22%) said they had experienced hailstorms. In comparison, only 2 (0,8%) residents stated that they had experienced tornadoes in the district. One hundred and three (41,2%) of the residents noted that the area where they lived had experienced drought. Fifteen residents (6%) indicated that there had been

other effects of climate change in the district besides dust storms, hailstorms, tornadoes, and drought. These "other" effects include strong winds, heavy rainfalls, and soil erosion.

The perceptions on climate change provided by the urban residents in this study varied from one place to another regardless of their differences in gender, educational background, ethnic group, or place differences (towns in the district).

### 6.3.3 Urban residents' perceptions of urban planning response to climate change in the Thabo Mofutsanyana District

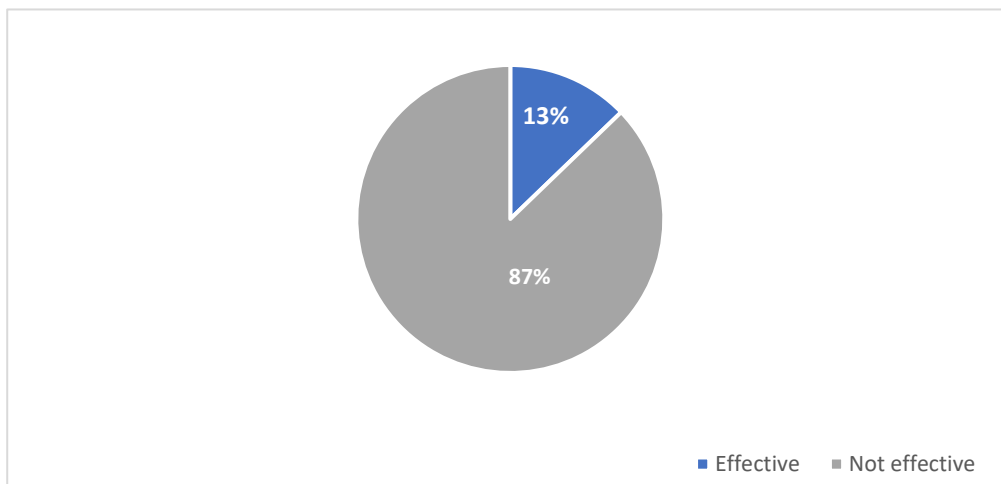
Figure 6.16 illustrates how the urban residents perceived the response of urban planning to the effects of climate change in the sampled towns of Thabo Mofutsanyana District.



**Figure 6.16 Respondents' perceptions on the effectiveness of urban planners' strategies towards mitigating the effects of climate change**

As reflected in Figure 6.16, most urban residents perceived the urban planners' strategies for mitigating the effects of climate change as ineffective. These strategies mentioned by urban planners include planting more trees, implementing the flood-line plan, and building drainage systems by the road. Only a few of the residents regarded the strategies as effective. Seventy-one percent of respondents from Memel stated that urban planners were not effectively working against the effects of climate change, compared to 83% from Bethlehem, 88% from Ficksburg, 92% from Ladybrand, 100% from Senekal, 85% from Reitz, and 86% of respondents from Phuthaditjhaba stated that the strategies of urban planners were not effective. However, in Clarens, 50% of the respondents said that urban planners effectively addressed climate change.

As shown in Figure 6.17, the study's results revealed that most residents in Thabo Mofutsanyana District perceived urban planners' response toward mitigating the effects of climate change in the district as ineffective.



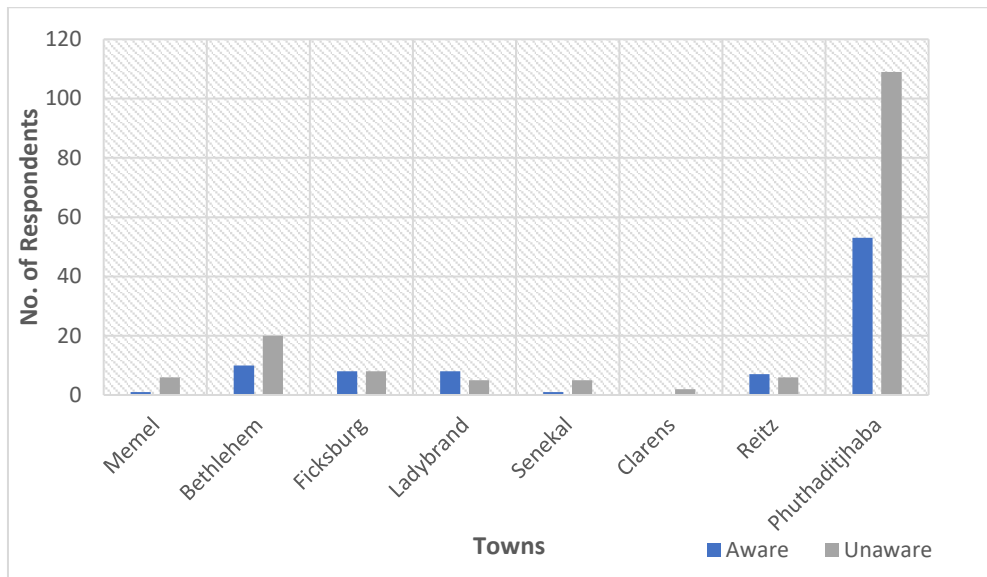
**Figure 6.17 Respondents who indicated that urban planners are effectively working towards mitigating the effects of climate in Thabo Mofutsanyana District**

Two hundred and eighteen residents stated that urban planners in Thabo Mofutsanyana District are not effectively working towards mitigating the effects of climate. This accounts for 87 percent of the residents. Only the remaining 13 percent indicated that urban planners effectively reduce the negative impacts of climate change in the district. Most residents stated that urban planners had not put any effort into adaptation to climate change and reported that urban planning projects did not focus on climate change adaptation.

When asked about the residents' responsibilities towards mitigating and adapting to climate change, one hundred and fifty-eight residents stated that they were unaware of their responsibilities towards mitigating and adapting to climate change. This accounts for 63 percent of the respondents, as shown in Figure 6.17. The remaining 37 percent indicated that they were knowledgeable and knew of their responsibilities towards mitigating and adapting to climate change in the district.

### 6.3.4 Urban residents' climate change awareness

Figure 6.18 illustrates the urban residents' level of awareness and knowledge about their responsibilities toward mitigating the effects of climate change in each sampled town of Thabo Mofutsanyana District.



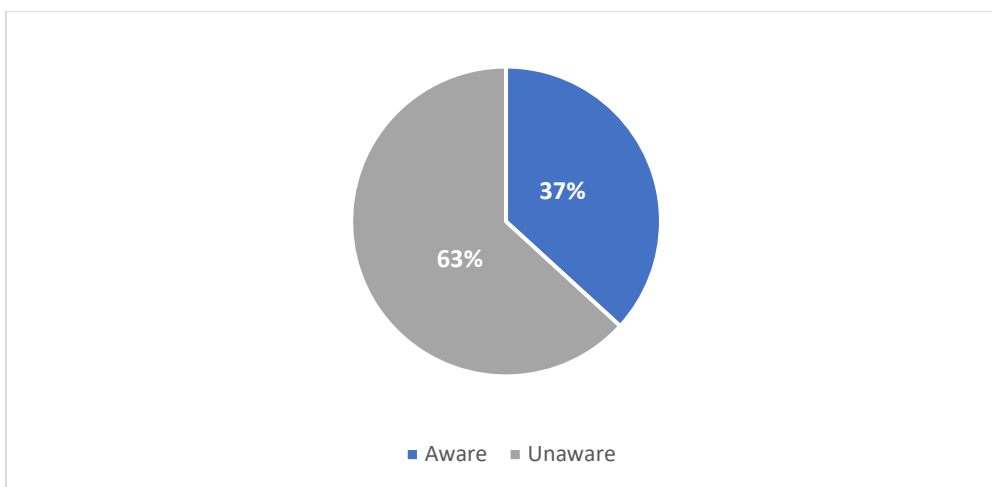
**Figure 6.18 Respondents who noted their awareness of strategies for mitigating the effects of climate change in each town.**

As depicted by Figure 6.18, most respondents from Memel, Bethlehem, Senekal, Clarens, and Phuthaditjhaba were unaware of their responsibilities as urban residents regarding the issue of climate change. Eighty-six percent of urban respondents from Memel, 67% from Bethlehem, 83% from Senekal, 100% from Clarens, and 67% of respondents from Phuthaditjhaba stated that they were not aware of the responsibilities they have towards mitigating and adapting to climate change. In contrast, most of the respondents from Ladybrand and Reitz noted that they were aware of their responsibilities towards climate change, with 62% of respondents from Ladybrand and 54% of respondents from Reitz indicating that they were aware of these responsibilities.

In Ficksburg, 50% of the respondents noted being aware of their responsibilities as urban residents towards mitigating and adapting to climate change. According to the results, the 50% of the respondents who are aware of the responsibilities, stated reducing households' carbon footprint by living an eco-friendly lifestyle and using Chlorofluorocarbon free and ozone-friendly products as ways in which they can mitigate the effects of climate change. They further noted the planting of trees, roof planting, conserving natural resources and the environment, using electricity wisely, and practicing the 3Rs, which include, waste reduction, resource reuse and resource recycling as ways adapt to the effects of climate change. The urban residents also noted using green energy as one of their climate change adaptation responsibilities. Learning more and teaching others about climate change was also mentioned by the respondents as an effective way of adapting to climate change. Urban resident number 85 stated:

*"For an individual familiar with environmental rights and legislation, it is much easier to know my role towards mitigating climate change. Basically, I should limit the rate of pollution I personally add into the atmosphere and cooperate with the National Environment Management: Air Quality Act (NEM: AQA; no 39 Of 2004), National Environmental Management: Waste Act (NEM: WA; no 59 of 2008) and National Water Act. The word "limit" is used based on the fact that some pollution and waste production are impossible to avoid. Environmental awareness programmes are also essential for developing knowledge that can benefit the illiterate and other people."*

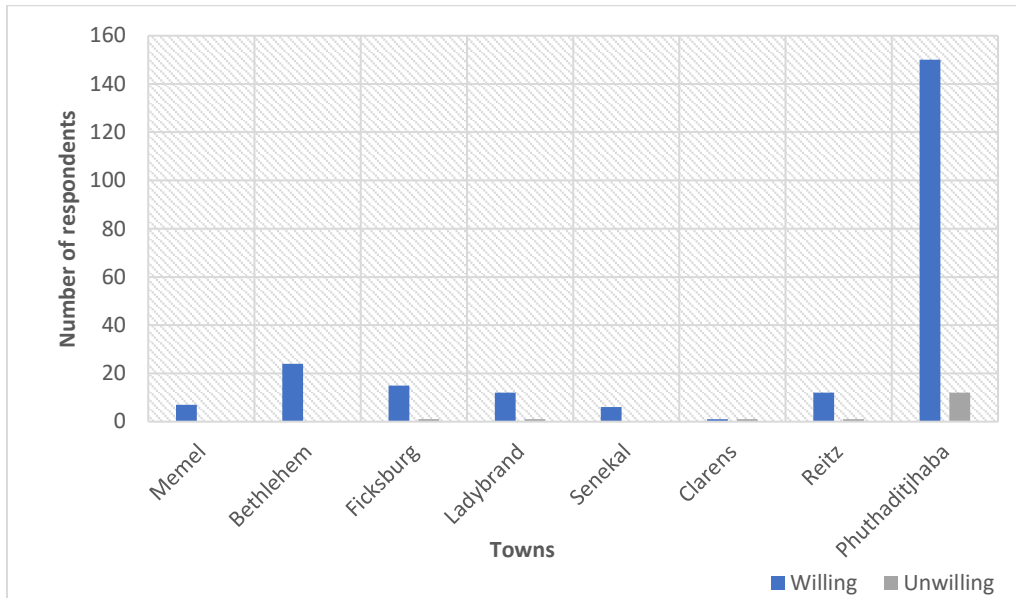
Figure 4.19 illustrates the urban residents' awareness and knowledge of their responsibilities toward mitigating the effects of climate change in the Thabo Mofutsanyana District.



**Figure 6.19 Indications by residents of their awareness of their responsibilities towards mitigating and adapting to climate change**

Thirty-seven percent of the residents who knew their responsibilities towards mitigating and adapting to the effects of climate change mentioned conserving water, conserving nature, managing waste/ not littering, using Ozone friendly products (aerosol sprays and air-conditioners), planting trees, using green energy (e.g., solar power), and practicing the 3 Rs, which are reducing, reusing and recycling, as effective ways they have been implementing against the issue of climate change.

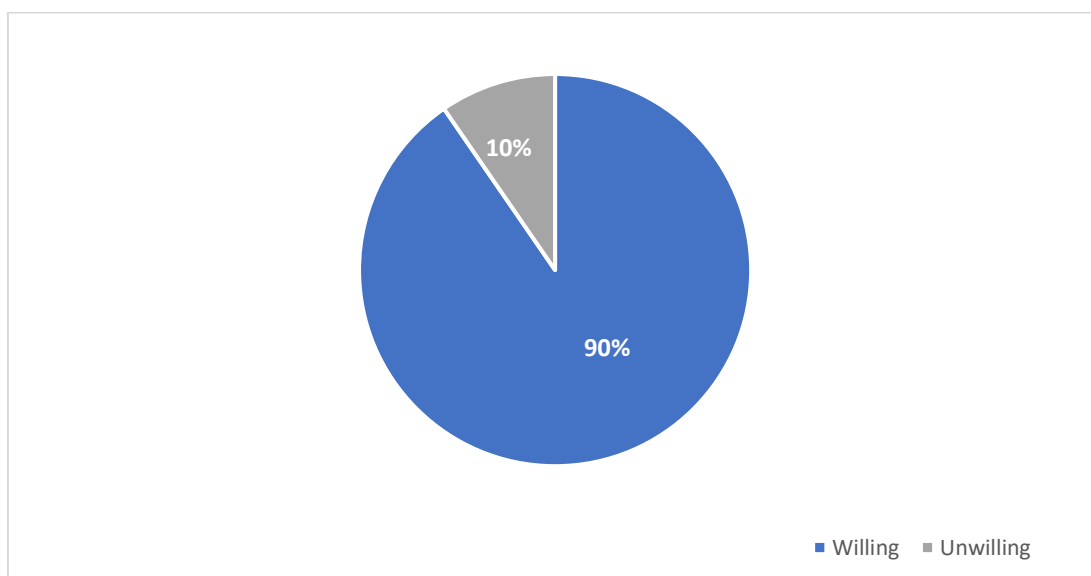
The willingness of the urban residents to learn more about climate change in each of the eight sampled towns in the Thabo Mofutsanyana District is illustrated in Figure 6.20.



**Figure 6.20 Urban residents who indicated their willingness to learn more about climate change in towns located in Thabo Mofutsanyana District**

As seen in Figure 6.20, the majority of the respondents from each town were willing to learn more about the issue of climate change. One hundred percent of the respondents from Memel, 80% from Bethlehem, 94% from Ficksburg, 92% from Ladybrand, 100% from Senekal, 50% from Clarens, 92% from Rietz, and 93% of respondents from Phuthaditjhaba stated that they were willing to receive more information about the causes, effects of, as well as the mitigation and adaptation strategies which address climate change.

Figure 6.21 indicates the Thabo Mofutsanyana District urban residents' willingness to learn more about the issue of climate change.

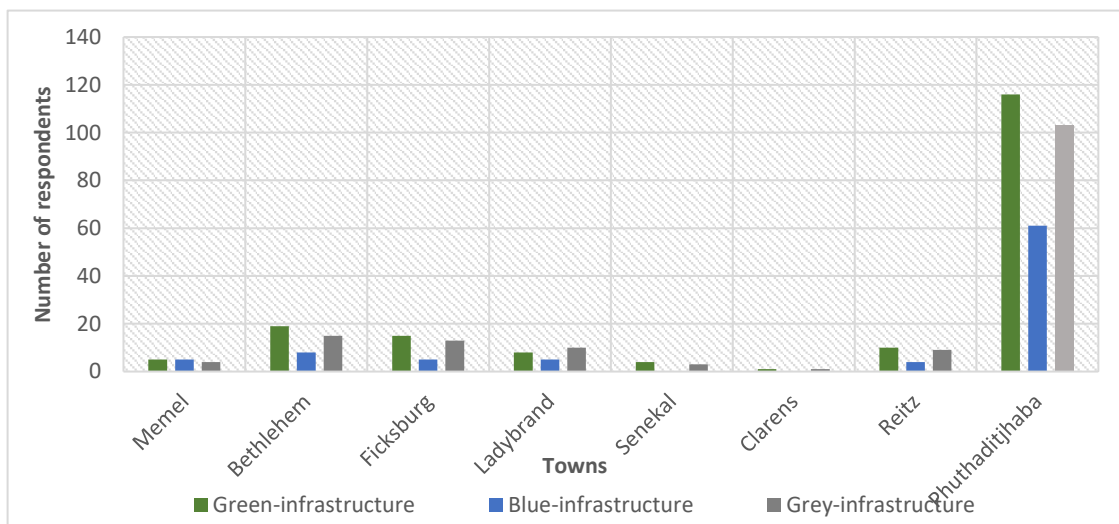


**Figure 6.21 Urban residents who noted their willingness to learn more about climate change in towns located in Thabo Mofutsanyana District**

As can be seen from Figure 6.21, 90% of the respondents from the Thabo Mofutsanyana District stated that they were willing to learn more about the climate change causes, the strategies for mitigating the effects of climate change, as well as how they could adapt to the continuously changing climate change.

**6.3.5 Urban residents' perceptions of UEI in Thabo Mofutsanyana District**

Figure 6.22 illustrates the urban residents' perceptions of UEI in the Thabo Mofutsanyana District. The graph indicates the number of respondents who referred to certain forms of UEI that need to be maintained and implemented in each town to cope with climate change.

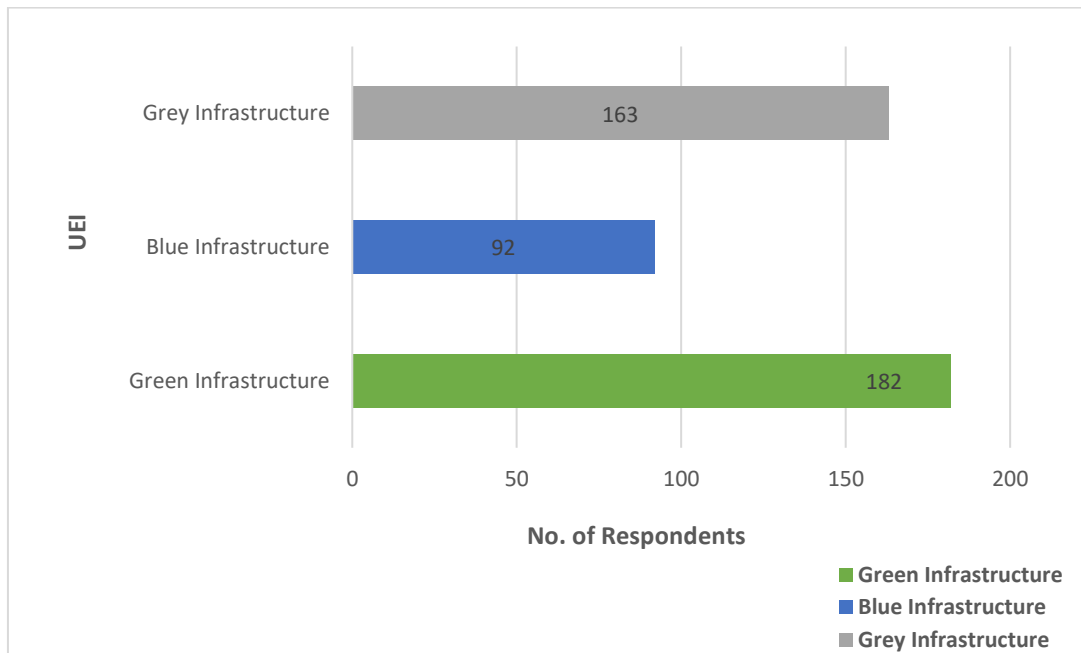


**Figure 6.22 UEI requirements in the towns of Thabo Mofutsanyana District**

As illustrated in Figure 6.22, in Bethlehem, Ficksburg, Senekal, Reitz, and Phuthaditjhaba, the respondents referred to green infrastructures such as parks, trees, grasslands, shrubs, and open spaces needed to be more implemented and maintained in each town. Sixty-three percent of the respondents from Bethlehem, 94% from Ficksburg, 67% from Senekal, 77% from Reitz, and 72% from Phuthaditjhaba, stated that the green infrastructure needs to be introduced or maintained. In Memel, most respondents noted that the blue and green infrastructure needs more maintenance within the town. Thirty-six percent of the respondents called for green infrastructure, and 36% for blue infrastructure as the UEI needed in Memel. The blue infrastructure refers to lakes, wetlands, and rivers. In contrast to the rest of the towns,

the majority of the respondents, 77% from Ladybrand, noted that grey infrastructure, which refers to dams, roads, pipes, or water treatment facilities, needs more maintenance in the town.

The perceptions of urban residents regarding the adequacy of UEI requirements and maintenance in the Thabo Mofutsanyana District are presented in Figure 4.23.



**Figure 6.23 UEI requirements in Thabo Mofutsanyana District**

When the urban residents were asked about their perceptions of infrastructural needs or maintenance in the Thabo Mofutsanyana District, 163 out of 250 (65%) residents noted the grey infrastructure (roads, pipes, or water treatment plants) needed to be upgraded in the district. Respondent number 180 stated:

*"During heavy rainfalls, there are floods in the area because there are no proper drainage systems along the pavements."*

Regarding the district's blue infrastructure (lakes, wetlands, and rivers), 92 out of 250 (37%) residents who participated in the study noted that the blue infrastructure also needs upgrading. One hundred and eighty-two (72.8%) residents pointed out that the green infrastructure in the district needs better maintenance, with most residents stating that there are few trees in the area.

## **6.4. Urban planners' perceptions of climate change in Thabo Mofutsanyana District**

The results reported below highlight the urban planners' views on how they perceived the issue of climate change and their responses in each sampled town of Thabo Mofutsanyana District. The interviewed urban planners from the eight sampled towns have been employed as government officials in the Thabo Mofutsanyana District for 2 to 10 years.

### **6.4.1 Effect of climate change in Thabo Mofutsanyana District towns**

According to the urban planners, the Thabo Mofutsanyana District towns have been affected by climate change. Major effects of climate change mentioned by urban planners include extreme weather events (Heavy rainfalls and extremely hot and cold weather). Extreme coldness leads to a huge issue of electricity in towns, especially in Phuthaditjhaba, where the load shedding lasts more hours than usually scheduled. This is because, during extremely cold weather, the urban community uses electricity excessively. As mentioned by the urban planner from Bethlehem, the town also experiences frequent wildfires due to climate change. Also, the heavy rains affect the state of roads in the area, leading to the formation of potholes on the roads, flooding, and overflowing of bridges. An urban planner from Memel also stated that climate change had created dongas in the area and inundated wetlands due to heavy rains.

Road eroded by heavy rainfalls in Phuthaditjhaba is shown in Plate 1:



**A)**



**B)**

**Plate 1 (A-B): Road in Phuthaditjhaba eroded by heavy rainfalls**

Images **A)** and **B)** in Plate 1 show the road that has been eroded by one of the effects of climate change, continuous heavy rainfalls in Phuthaditjhaba.

Plate 2 shows a wetland in Bethlehem.



#### **Plate 2: Wetland in Bethlehem accumulated by water**

Plate 2 is a visual representation of a wetland in Bethlehem, with blue infrastructure still maintained in the town. Another vast effect of climate change that has been experienced in Thabo Mofutsanyana District towns is drought. Drought has been a frequent phenomenon in the sampled towns of Thabo Mofutsanyana District, especially during dry seasons, including autumn and winter. During drought, people have limited access to clean and safe water. In case of natural hazards caused by climate change, such as floods, storms, and droughts, the urban communities are informed about expected hazards by the disaster management team through media, which includes newspapers, Television, Radio, and social media, as stated by one of the urban planners from Thabo Mofutsanyana District.

#### **6.4.2 Strategies implemented by urban planners towards climate change**

Urban planners from Thabo Mofutsanyana District stated that they had been working towards mitigating the effects of climate change in the district. However, in each town, the urban planners were working individually when implementing strategies to combat climate change. There were only a few cases where they worked collaboratively with urban planners from other towns in developing and implementing mitigation and adaptation strategies to climate change. In such cases, once strategies have been developed or planned, external stakeholders perform an

environmental auditing process after a certain period of time to check whether these strategies were successfully implemented.

Regarding climate adaptation strategies, urban planners from Phuthaditjhaba, Ficksburg, Memel, Clarens, Ladybrand, Senekal, Reitz, and Bethlehem, stated that the flood-line plan had been implemented to ensure that the community is not vulnerable to flooding. According to the urban planners, the flood-line program instructs the community to build 5km away from the rivers and dams. Furthermore, building a mall in one of the towns reduced some socio-economic challenges in the Thabo Mofutsanyana District. For instance, the urban planner from Maluti-A-Phofung stated that the construction of the new mall in Phuthaditjhaba had helped reduce the number of people who travel from Phuthaditjhaba to other towns in the district for work and shopping purposes, which in turn reduces the number of pollutants emitted from vehicles.

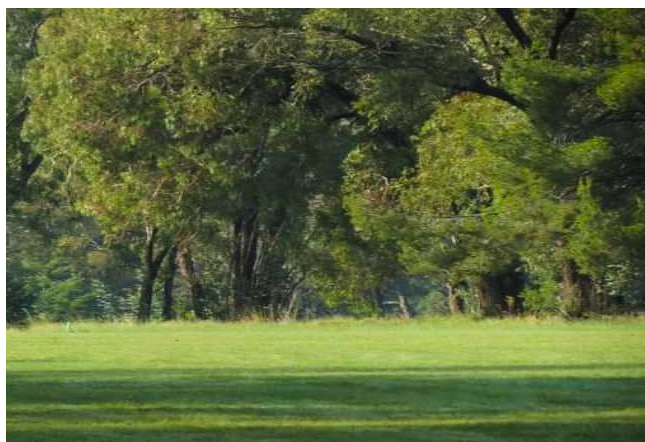
However, the information provided by urban planners emphasized that climate change is not adequately included during urban planning. The focus is more on the built-up environment of the physical facilities of the town. According to urban planners, the effective urban planning response to climate change that had been implemented in each sampled town of the Thabo Mofutsanyana District included the Environmental Impact Assessment (EIA). No plan had been implemented explicitly toward climate change in the towns. Only EIAs were conducted before constructing a project in each town.

In response to climate change adaptation strategies, urban planner from Ficksburg stated that most municipalities in Thabo Mofutsanyana District did not have a disaster management team. However, there are disaster management plans in place, which were reported to have had a minimum impact on the community. These disaster management plans make provision for disasters that occur within the budget of the municipality, ensuring improved assistance during and after a disaster, raising awareness of the dangers of each disaster, and ensuring the capability of municipalities to cope with disasters. The urban planners from Thabo Mofutsanyana District further reported the non-existence of programs that inform urban communities about natural hazards such as floods and wildfires. Also, urban planners stated that as much as they were responsible for planning and constructing every physical facility in the towns, they were usually not accountable for its maintenance. For example, one of the urban planners stated that the Parks and Recreation Department maintains parks and open spaces. According to Bethlehem's urban planner, 10% of the town is reserved for parks during urban planning.

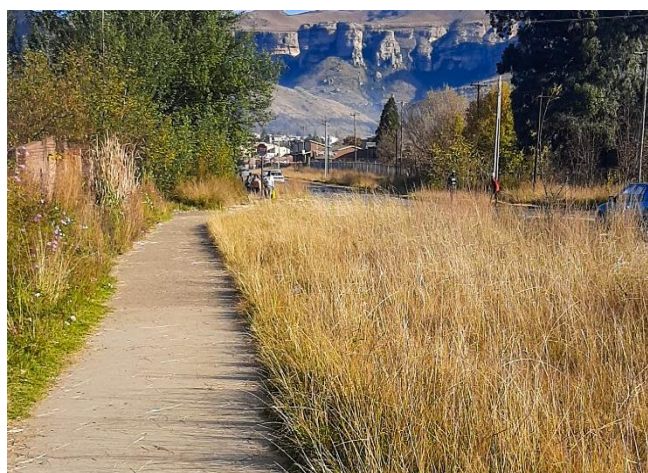
Plate 3 shows the green infrastructure that has been implemented and maintained in Thabo Mofutsanyana District Towns.



**A)**



**B)**



**C)**



**D)**

**Plate 3 (A-D): Urban Green Infrastructure in Thabo Mofutsanyana District Towns**

**A)** an open space found in Memel; **B)** recreational parks in Ficksburg; **C)** an open space in Phuthaditjhaba; and **D)** trees that have been planted and maintained in Clarens.

As much as the green UEI has been reported to play a huge role in mitigating the effects of climate change, the green UEI found in Thabo Mofutsanyana District has been developed for recreational and aesthetic purposes and spatial design, rather than for climate change adaptation. As stated by most of the interviewed urban planners, less attention is paid to incorporating climate change during urban planning. The focus is more on the spatiality of the area than adapting to climate change.

Furthermore, an urban planner from Ficksburg stated that although the trees are planted in the towns of Thabo Mofutsanyana District, the issue is that the urban residents or community cut and use the trees for firewood. Even though, there are projects to ensure that people who invade parks are relocated to maintain the green infrastructure in the area. Generally, the urban planners emphasized that the Parks and Recreation Department is responsible for maintaining parks in the district, not the Urban Planning Department.

Trees maintained in Ficksburg are shown in Plate 4:



**Plate 4: Trees in Ficksburg**

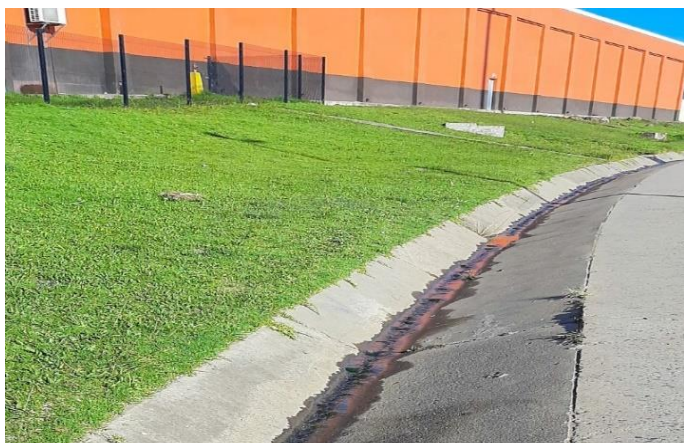
In some towns such as Phuthaditjhaba, Memel, Reitz, and Memel, urban planners have been trying to relocate people who reside in informal settlements to reduce the effects of climate change in the district. People who live in informal settlements do not have access to essential resources such as electricity, which makes them rely on fossil fuels or wood for energy to meet their daily household needs such as cooking, lighting, and heating. This then contribute to the effects of climate change. Another way urban planners have been working towards mitigating the effects of climate change in the Thabo Mofutsanyana District includes the advisory services they render to urban residents, for instance, by planting trees in their yards. If the urban residents are found cutting down a tree, they are subjected to a fine of R500 to R50 000, depending on level of the act.

#### **6.4.3 Implementations of Sustainable UEI**

The grey infrastructure found in towns worsens the effect of climate change. To illustrate, the urban planner from Ficksburg stated that the tarred roads constructed in the towns of Thabo Mofutsanyana District cause flooding as they are non-porous. There are poor drainage systems

in the streets, which leads to excessive run-off in these towns. According to the urban planners, the storm-water channels that redirect water to the desired area (catchment tanks, sewerage systems) are old and blocked. They are no longer in proper working condition and are expensive to maintain. The urban planner from Memel further reported that drainage systems require more funding than any other infrastructure in urban areas. However, V-shaped drains on the side of the roads have been implemented as a temporary strategy to reduce flooding. These drains transport water from the town to the rivers, dams, and sewers.

Plate 5 shows drainage systems that urban planners have implemented in the towns of Thabo Mofutsanyana District.



**A)**

**B)**

**Plate 5 (A-B): Drainage systems in Thabo Mofutsanyana District:**

**A)**, V-shaped drains have been implemented in Phuthaditjhaba to reduce the town's floods; **B)** shows storm water drains implemented in Reitz to minimize surface runoff and flooding in the area.

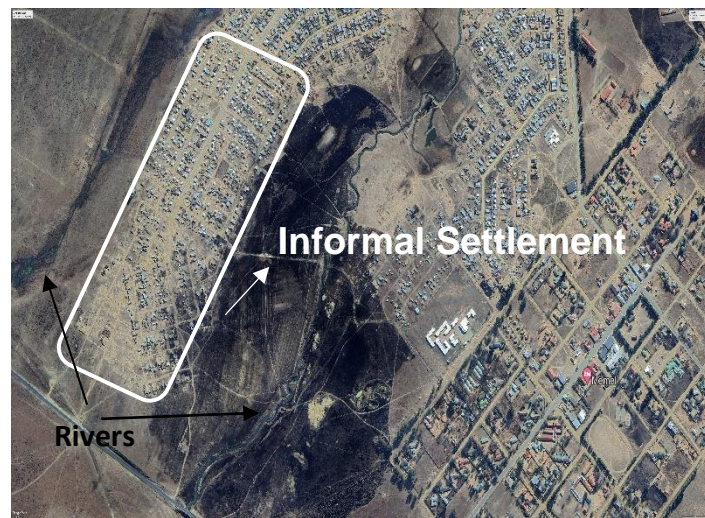
According to the urban planner from Bethlehem, small homes have been developed using solar energy. This is to improve sustainable energy use and reduce air pollution. Also, during the construction of the Dihlabeng Mall, an EIA was conducted to ensure that the environmentally sensitive areas and indigenous birds found in the area were preserved. Also, the wetlands next to the mall were preserved.

#### **6.4.4 Challenges of incorporating climate change into Urban Planning**

Although the urban planners have reported incorporating climate change in urban planning as a complex and challenging task, they still believe that more studies should be done concerning the inclusion of climate change in urban planning. According to the urban planners, more climate

change specialists are needed to provide climate change reports to the urban planners. Also, regarding the challenges of incorporating climate change into Urban Planning, the urban planner for Bethlehem and Clarens stated that implementing the flood-line plan has been challenging. Even after conducting the public consultation, the urban residents build informal settlements less than 5 km from rivers, even though they would have been advised to build 5km away from any blue infrastructure, including rivers, dams, lakes, and wetlands.

Informal settlements located less than 5km away from the river in Memel are shown in Plate 6: A and B.



A)

B) © Google Earth Pro image

**Plate 6 (A-B): Informal settlements located near a river in Memel**

The urban planners stated that some climate change strategies incorporated in urban planning are challenging to implement on the actual ground due to politics. Urban planner from Ficksburg stated:

*“Political challenges arise because we work with the land, and land is very scarce and a sensitive topic when it comes to politics. Moreover, some of the climate change mitigation and adaptation that have been put on paper are not feasible to implement due to funding challenges” – Urban planner 4.*

For example, an urban planner from Bethlehem stated that one of the Environmental Management Framework Plans could not be implemented in time. Its implementation was delayed because funds had not been allocated to implement it.

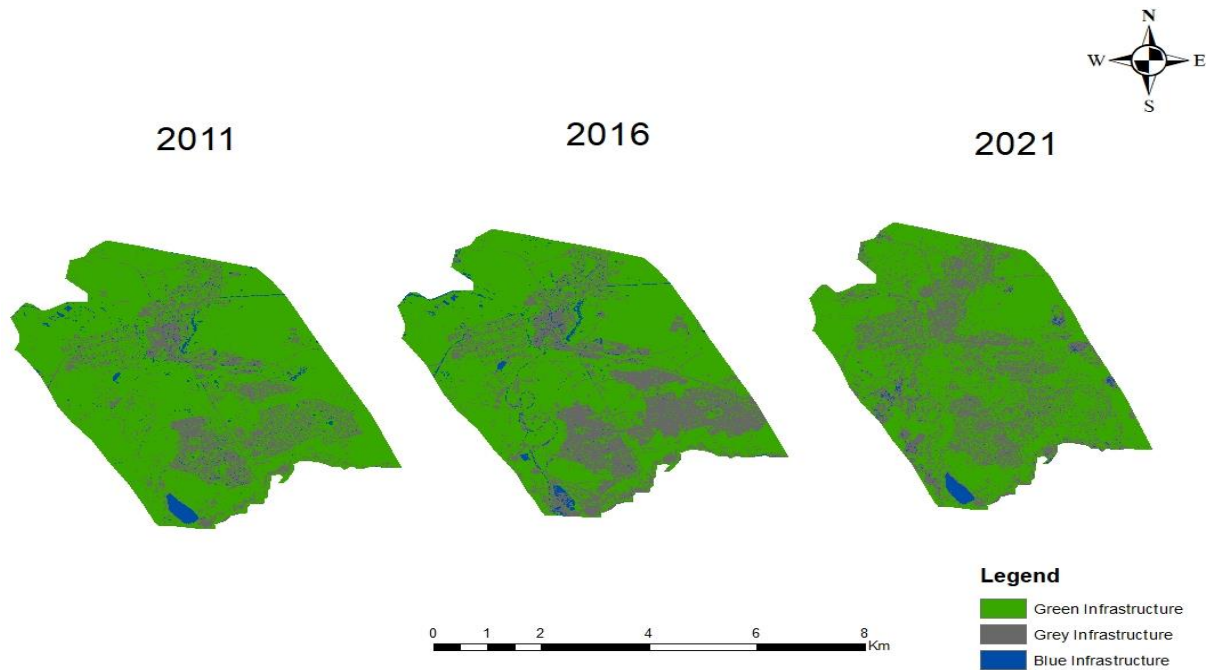
Another challenge the urban planners faced was the scale of climate change strategies. To illustrate this issue, the urban planners stated that although there is a link to the national - provincial - local plan for climate change adaptation, the national climate change adaptation plan cannot be fully applied locally. As a result, urban planners stated that they only choose what is applicable in the local space from the national plan and use it. In addition, the urban planners said that more studies needed to be conducted by researchers locally so that the climate change and urban planning plans may reflect what is happening in a particular area.

## **6.5 Change in Urban Ecological Infrastructure in Thabo Mofutsanyana District from 2011 to 2021**

The results presented in this section address the third objective of the study, i.e., to assess the change in Urban Ecological Infrastructure in Thabo Mofutsanyana District from 2011 to 2021. These results are presented in the form of maps, tables, and graphs, showing how the change of each town's Urban Ecological Infrastructure (UEI) has varied through an interval of five years between 2011 and 2021.

According to the Urban Ecological Infrastructure framework, three types of infrastructure can be identified on the urban landscape. These are the Green, Blue, and Grey UEI. In this study, these three forms of infrastructure were identified and evaluated using ArcGIS. The Green UEI includes open spaces, trees, and parks, while the Blue UEI includes rivers, dams, wetlands, lakes, and ponds, and Grey UEI relates to roads, buildings, and artificial drainage systems.

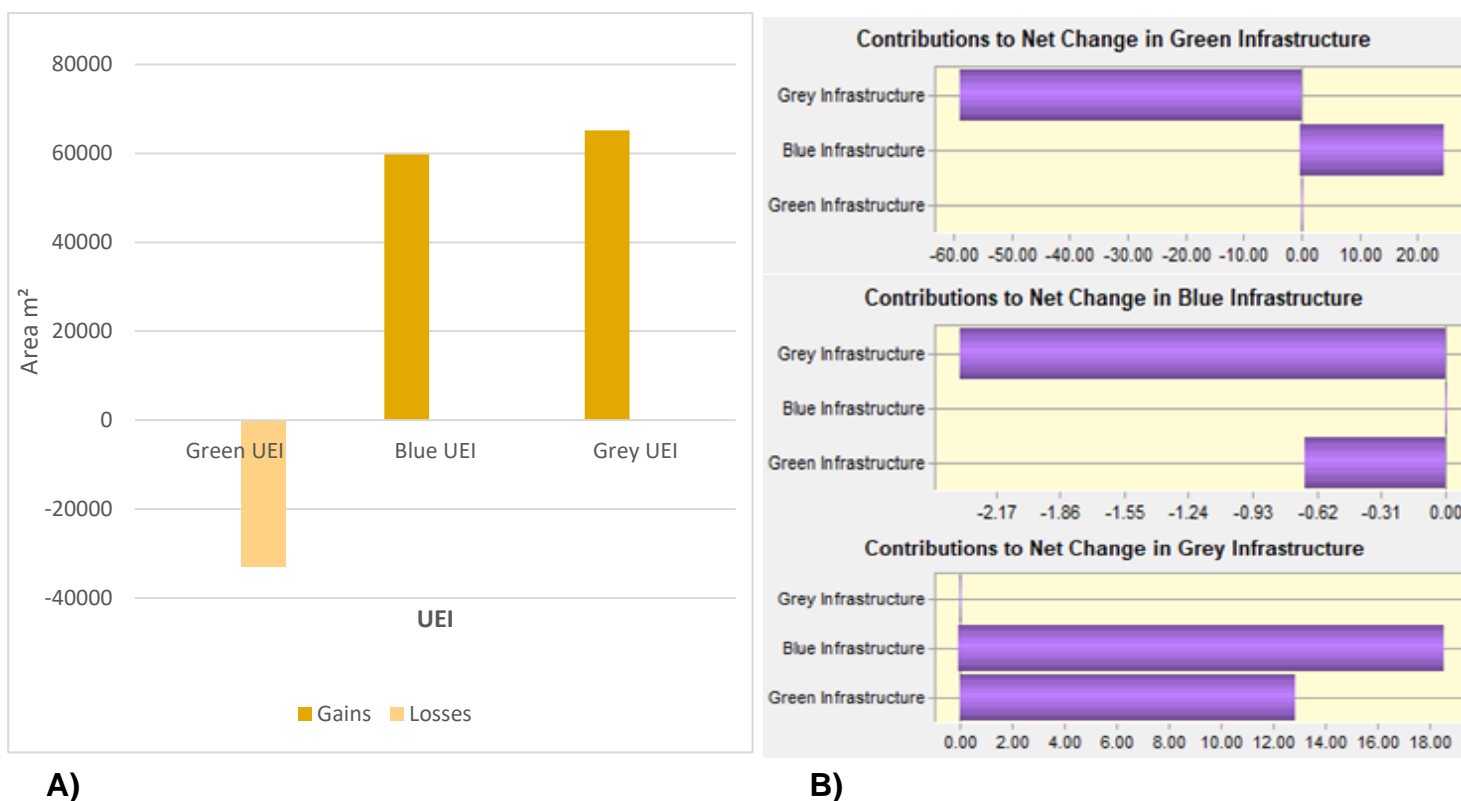
Figure 6.24. illustrates the variability of three Urban Ecological Infrastructures (green, blue, and grey) in Senekal between 2011 and 2021.



**Figure 6.24 Urban Ecological Infrastructure in Senekal from 2011 to 2021**

As shown in Appendix D, the accuracy assessments for the Senekal UEI classification ranged differently for each year. The calculated overall accuracy for 2011 was 90%, for 2016 it was 93%, while for 2021 it was 90%. The user accuracy for 2011 ranged from 86% to 100%, and for 2016 it ranged from 67% to 100%, while the 2021 user accuracy ranged from 88% to 100%. The producer accuracy for 2011 ranged from 85% to 100%, for 2016 it ranged from 92% to 100%, while for 2021 it ranged from 88% to 100%.

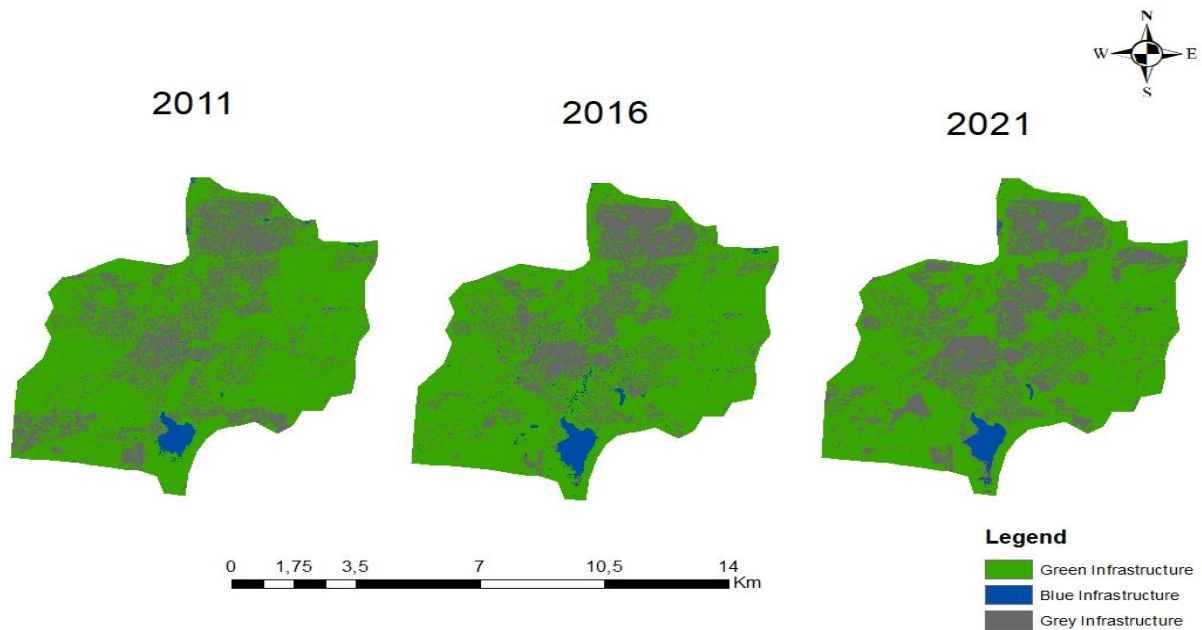
Figure 6.25 is an illustration of the Gains and Losses in the UEI of Senekal between 2011 and 2021, and contributions to net change in each UEI (Green, Blue, and Grey).



**Figure 6.25 (A-B): Gains and Losses in the Senekal UEI between 2011 and 2021, and contributions to net change in each UEI.**

As shown in Figure 6.25 (A), during the period between 2011 and 2021, the area covered by Green UEI decreased by 32917.22 m<sup>2</sup>, while the Blue and Grey UEI increased by 59793.34 m<sup>2</sup> and 65198.28 m<sup>2</sup>, respectively. As presented in Figure 6.25 (B), the green UEI lost 58.82% to the Grey UEI and gained 24.75% from the Blue UEI. The Blue UEI, on the other hand, lost 2.34% to the Grey UEI and lost 0.68% to the Green UEI, while the Grey UEI gained 18.56% and 12.81% from the Blue and Green UEI, respectively.

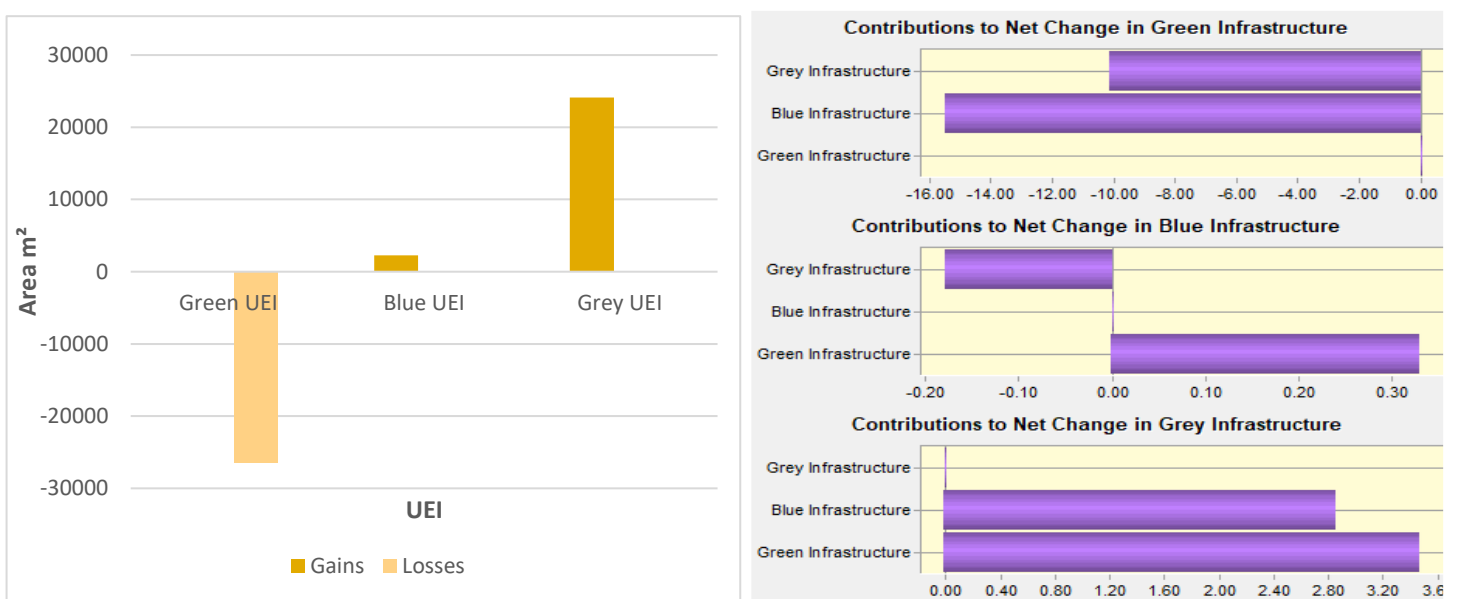
The maps in Figure 6.26 below show the location and change of three UEIs in Bethlehem between 2011 and 2021.



**Figure 6.26. Urban Ecological Infrastructure in Bethlehem from 2011 to 2021**

The overall accuracy for the Bethlehem maps ranged from 97%, 87%, and 97% for 2011, 2016, and 2021, respectively. The user accuracy for Bethlehem maps varied for each year, with the year 2011 having user accuracies between 86% to 100%, 2016 user accuracies ranging from 75% to 94%, while in 2021, it ranged from 75% to 100%. The producer accuracy for 2011 ranged between 86% to 100%, for 2016 it ranged from 75% to 100%, while for 2021, it ranged from 93% to 100%.

The gains and losses in UEI of Bethlehem between 2011 and 2021, and the contributions to net change in each UEI (Green, Blue, and Grey) are illustrated in Figure 6.27.



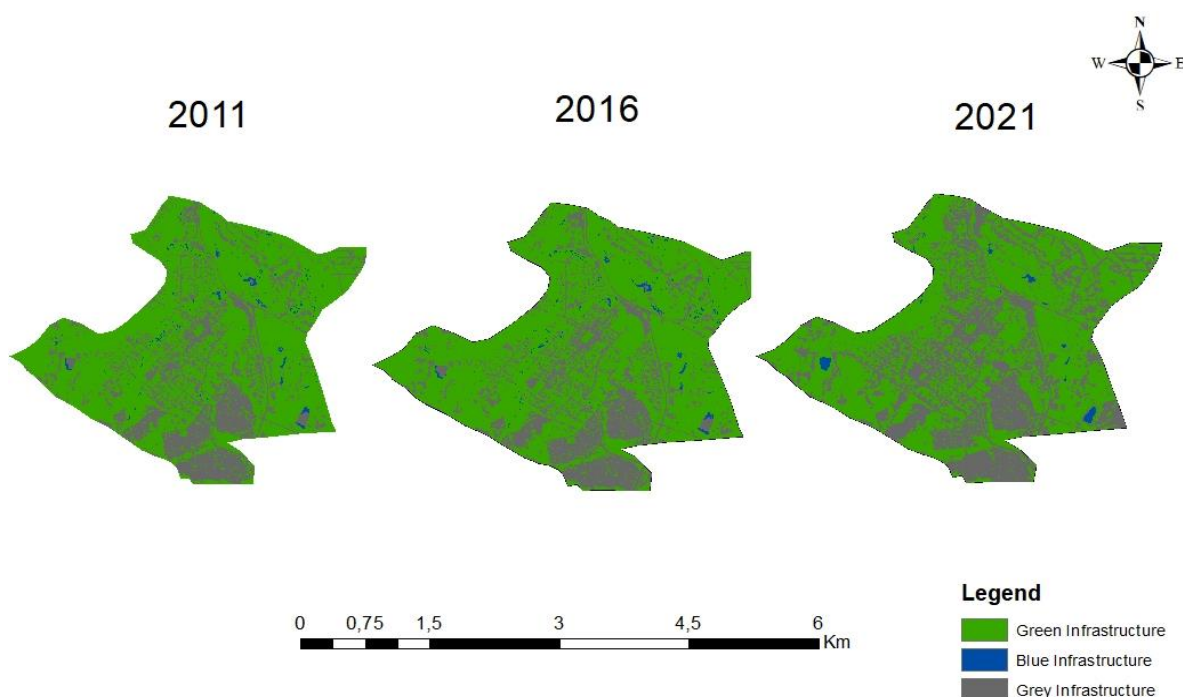
A)

B)

**Figure 6.27 (A-B): Gains and Losses in UEI of Bethlehem between 2011 to 2021, and contributions to the net change in each UEI.**

As shown in the graph in Figure 6.27 (A), the green UEI has decreased by 26405.67 m<sup>2</sup> between 2011 and 2021 in Bethlehem. The Blue and Grey UEI increased by 2 276.97 m<sup>2</sup> and 24128.7 m<sup>2</sup>, respectively. Furthermore, as seen in Figure 6.27 (B), the Green UEI lost 10.11% to the Grey UEI and 15.46% to the Blue UEI. The Blue UEI lost 0.18% to the grey UEI and gained 0.33% Green UEI. The Grey UEI gained 2.86% and 3.48% from the Blue and Green UEI, respectively.

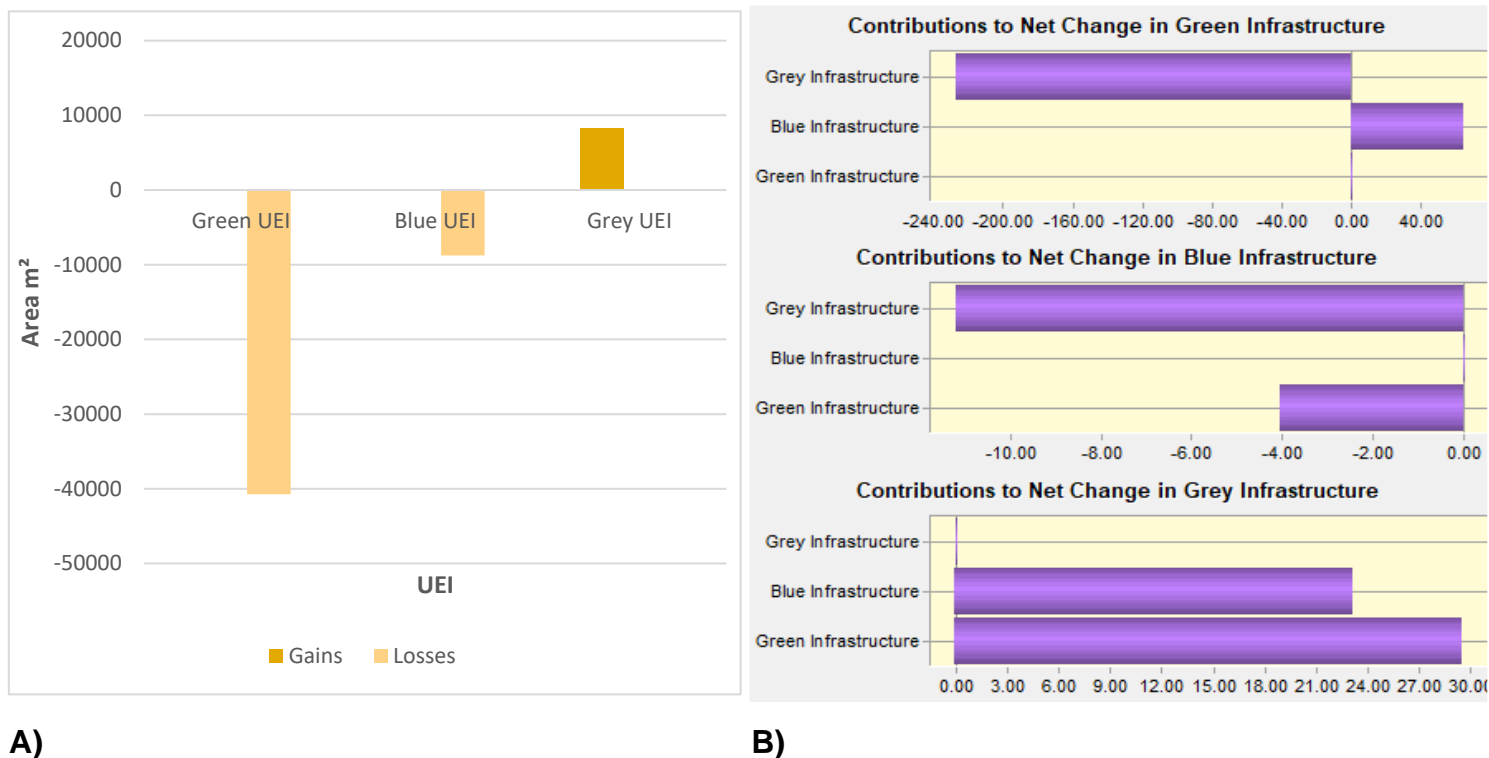
The following maps indicated in Figure 6.28 present the location and change in the extent of the UEI in Clarens from 2011 to 2021.



**Figure 6.28 Urban Ecological Infrastructure in Clarens from 2011 to 2021**

. The overall user accuracy for 2011, 2016, and 2021 for the Clarens' maps was 80%, 93%, and 90%, respectively. The user accuracy calculated for Clarens' maps varied for each year, with the 2011 user accuracy ranging from 71% to 90%, in 2016 from 75% to 100%, and in 2021, it ranged from 60% to 100%. The producer accuracy that was calculated for the year 2011 ranged between 75% and 100. For 2016, it ranged between 89% to 100, and for 2021 it ranged between 82% to 100%.

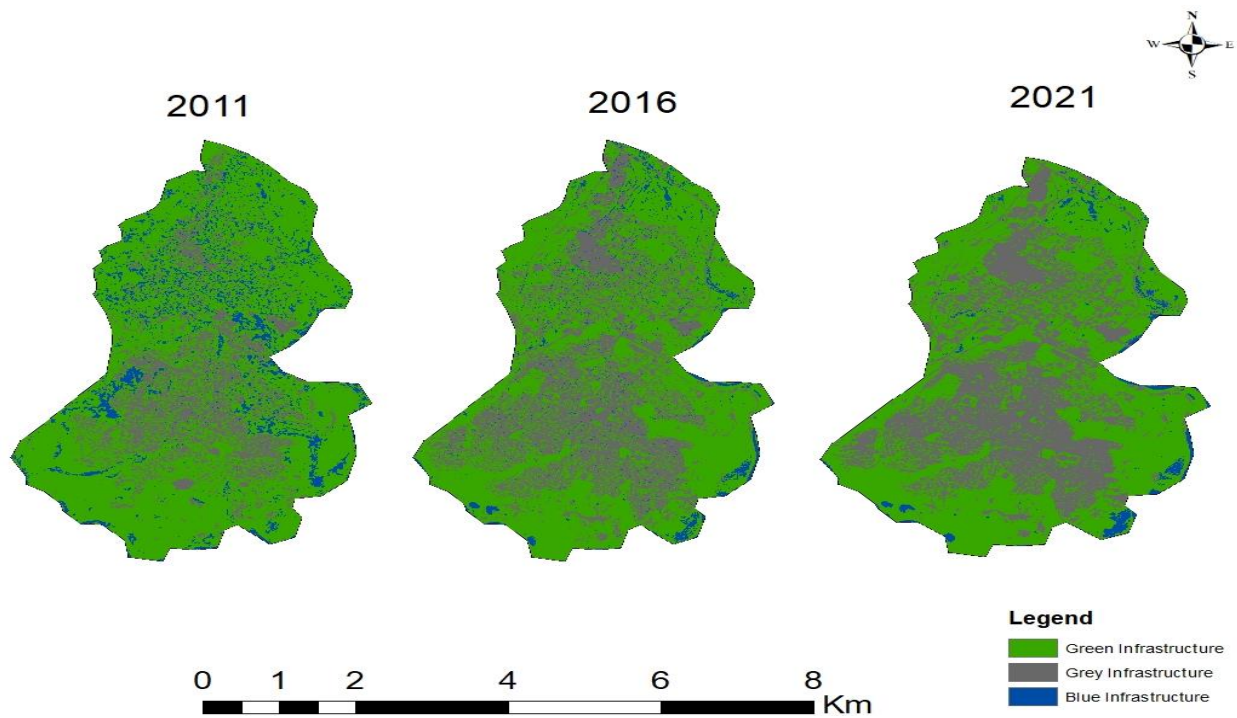
Figure 6.29 shows the gains and losses in the UEI of Clarens between 2011 and 2021, and the contributions to net change in each UEI (Green, Blue, and Grey).



**Figure 6.29 (A-B): Gains and Losses in UEI of Clarens between 2011 to 2021, and contributions to net change in each UEI.**

As seen in Figure 6.29 (A), in Clarens, there was a loss of 40724.81 m<sup>2</sup> in the Green UEI and a loss of 8771.19 m<sup>2</sup> in the Blue UEI. The Grey UEI on the other hand gained 8 272.22 m<sup>2</sup> in area. Moreover, as reflected by the graphs in Figure 6.29 (B), the Green UEI lost 226.56% to the Grey UEI and gained 63.97% from the Blue UEI. The Blue UEI lost 11.20% and 4.03% to the Green and Grey UEI, respectively. The Grey UEI gained 29.61% from the Green UEI and 23.33% from the Blue UEI.

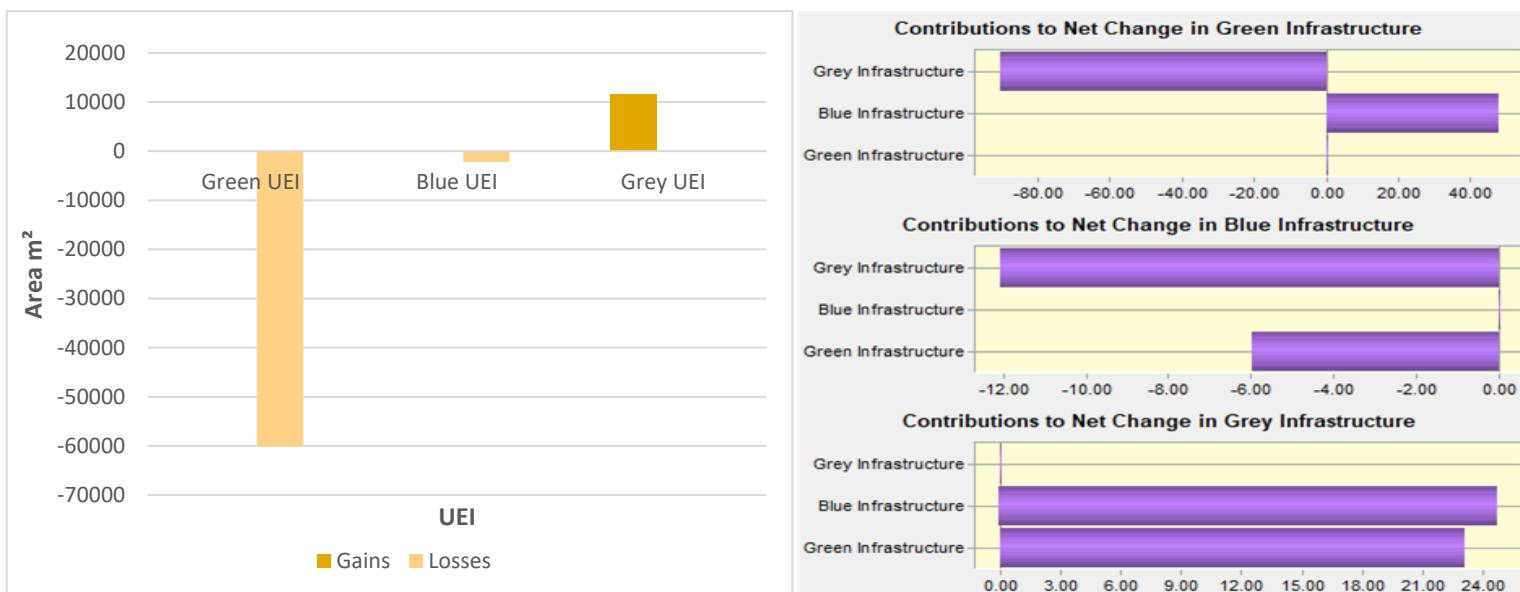
Figure 6.30 shows the location and change in the extent of UEI in Ficksburg from 2011 to 2021



**Figure 6.30. Urban Ecological Infrastructure in Ficksburg from 2011 to 2021**

The accuracy assessment calculated for Ficksburg maps presented in Figure 6.30 differed for each year. The overall accuracy calculated for 2011 was 80%, for 2016 it was 93%, while for 2021, it was 100%. The user accuracy for 2011 ranged from 75% to 82%. For 2016 ranging from 67% to 100%, while the user accuracy for 2021 ranged from 75% to 100%. The producer accuracy ranged between 69% to 100% in 2011. In 2016 it ranged between 77% to 100%, while in 2021, it ranged between 79% to 100%.

The following graphs in Figure 6.31 represent the gains and losses in the UEI of Ficksburg between 2011 and 2021, and the contributions to net change in each UEI (Green, Blue, and Grey).



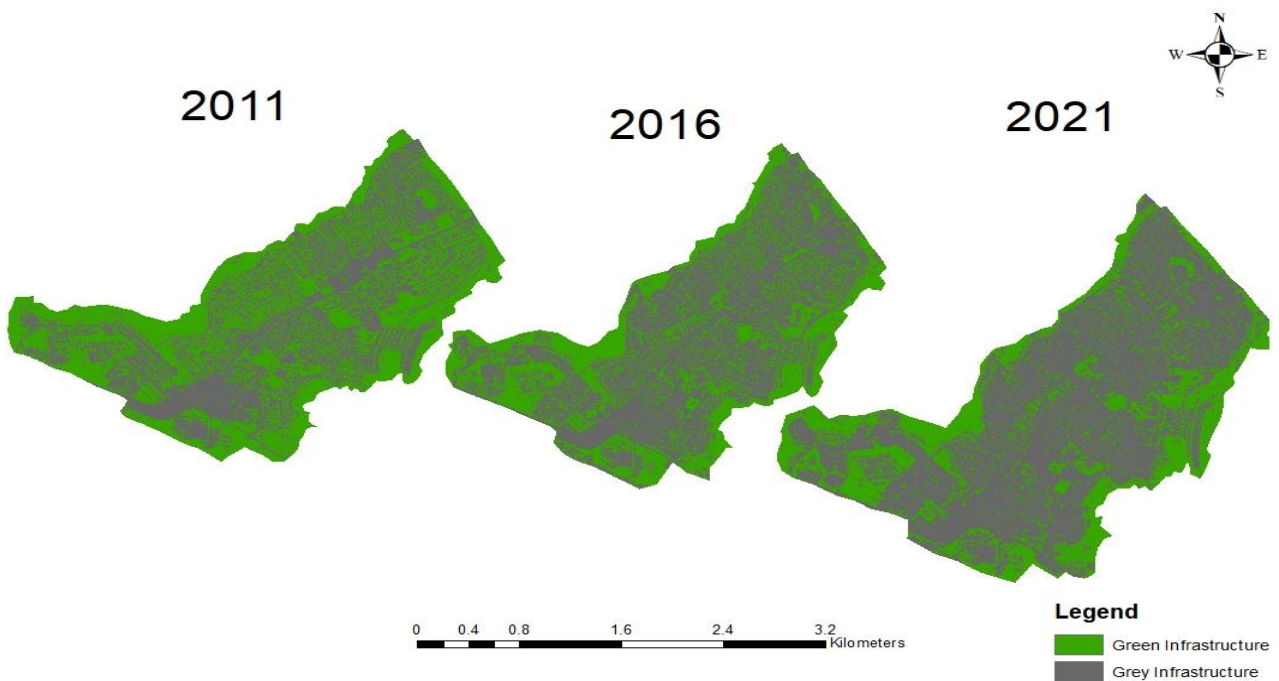
A)

B)

**Figure 6.31 (A-B): Gains and Losses in UEI of Ficksburg between 2011 and 2021, and contributions to net change in each UEI.**

Figure 6.31 (A) indicates that Green and Blue UEI in Ficksburg lost 60110.2 m<sup>2</sup> and 2189.94 m<sup>2</sup>, respectively. The Grey UEI gained 11521.68 m<sup>2</sup> in area. The “Contributions to Net Change” graphs in Figure 6.31 (B) show that the Green UEI lost 90.22% of change to the Grey UEI and gained 47.75% from the Blue UEI. The Blue UEI lost 12.06% to the Grey UEI and lost 5.95% to the Green UEI. On the other hand, the Grey UEI gained 24.81% and 23.13% from the Blue and Green UEI, respectively.

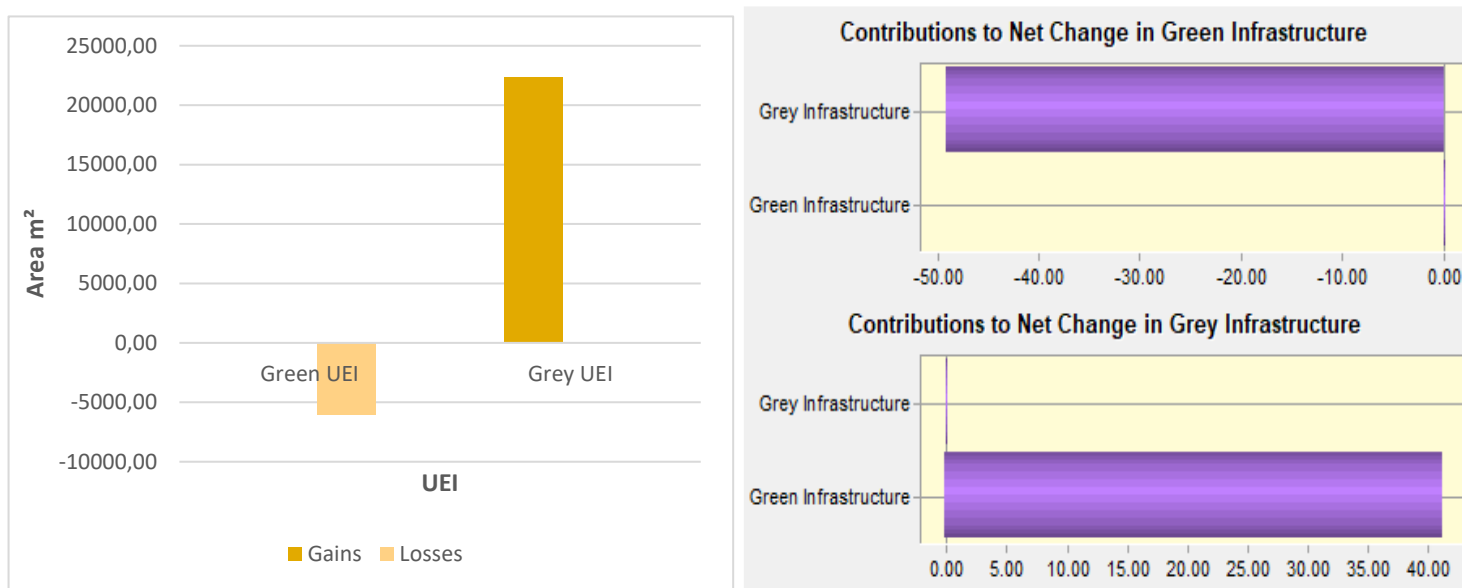
The location and change in the extent of UEI in Phuthaditjhaba from 2011 to 2021 are illustrated in Figure 6.32 below.



**Figure 6.32 Urban Ecological Infrastructure in Phuthaditjhaba from 2011 to 2021**

The accuracy calculations that were done for the Phuthaditjhaba maps shown in Figure 6.32 above ranged differently for each year or each map. The user accuracy for 2011 ranged between 94% to 100%. For 2016 it ranged between 88% and 93%, while for 2021, 89% to 100%. The overall accuracy for the Phuthaditjhaba maps was 97% for 2011, 90% for 2016, and 97% for 2021. The producer accuracy for 2011 ranged between 93% to 100%. For 2016 it ranged between 87% to 93%, and for 2021, the producer accuracy ranged between 89% to 100%.

The gains and losses in UEI of Phuthaditjhaba between 2011 and 2021, and contributions of the net change in each infrastructure (Green, Blue, and Grey) are presented in Figure 4.33.



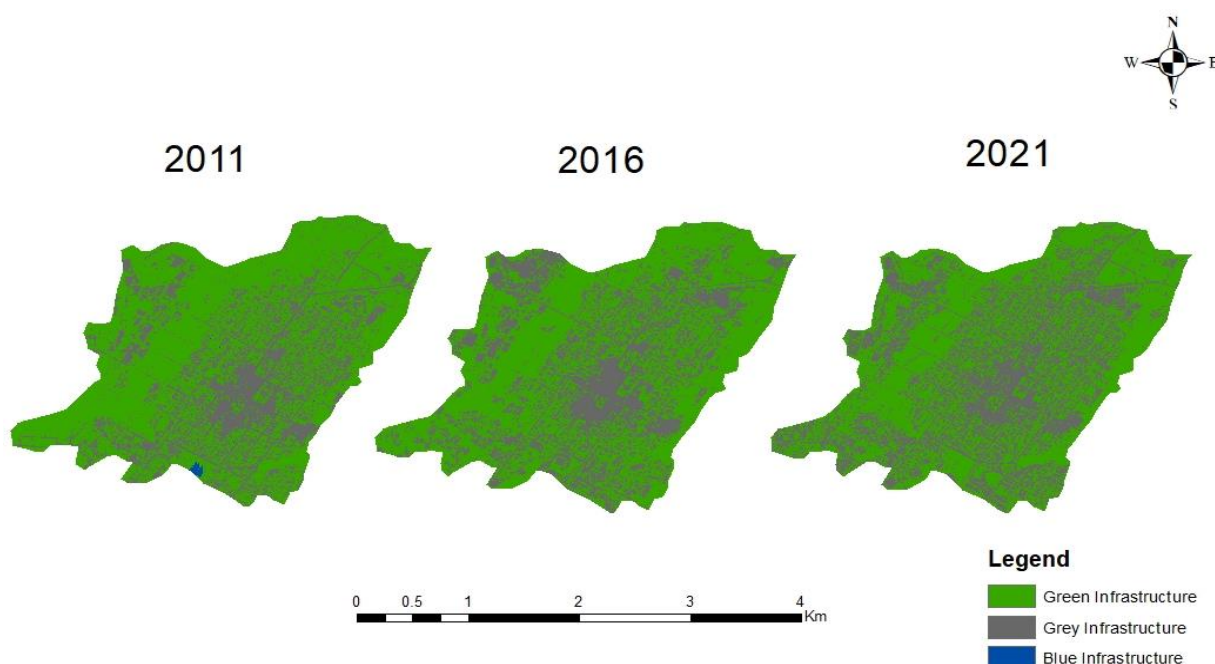
A)

B)

**Figure 6.33 (A-B): Gains and Losses in UEI of Phuthaditjhaba between 2011 and 2021, and contributions to net change in each UEI.**

Figure 6.33 (A) shows a loss of 5981.15 m<sup>2</sup> in the area of the Green UEI in Phuthaditjhaba and a gain of 22295.28 m<sup>2</sup>. As depicted by the graphs in Figure 6.33 (B), the Green UEI lost 49.09% to the Grey UEI, while the Grey UEI gained 41.28% from the Green UEI.

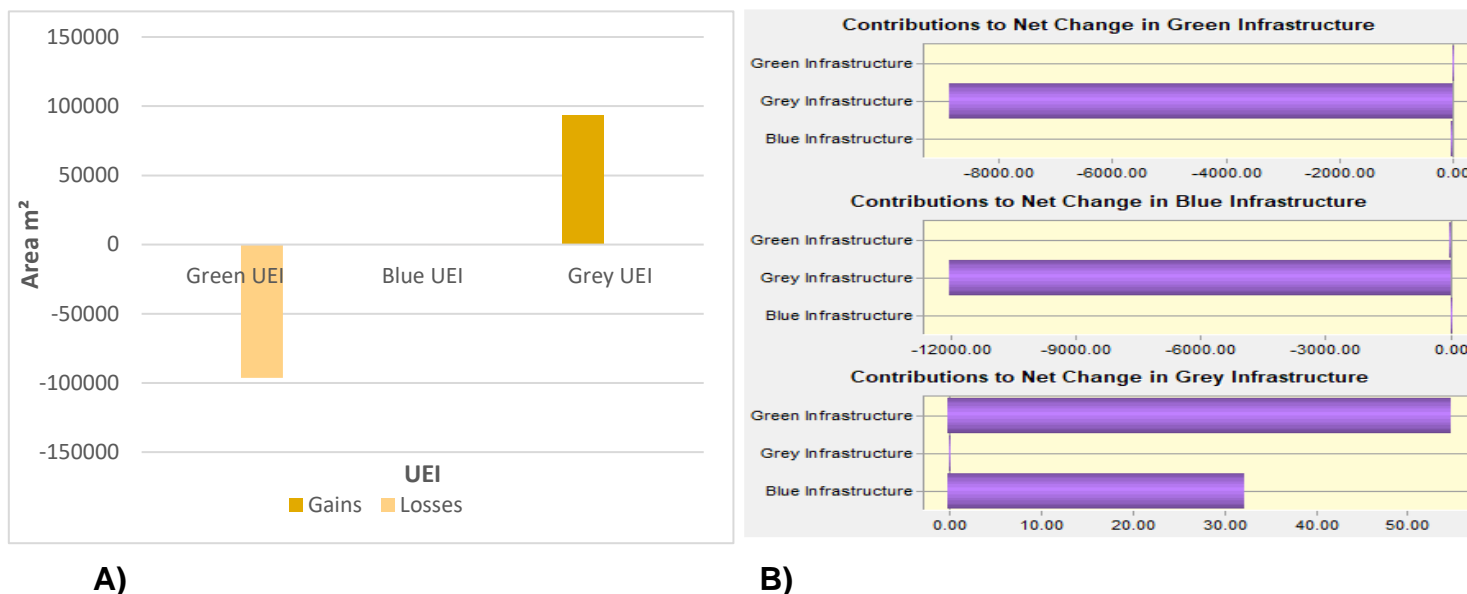
The location and change in the extent of Urban Ecological UEI from 2011 to 2021 in Ladybrand are presented in the maps in Figure 6.34.



### Figure 6.34 Urban Ecological Infrastructure in Ladybrand from 2011 to 2021

The accuracies calculated for Ladybrand maps shown in Figure 6.34 differed according to years. The overall accuracy was 90%, 83%, and 93% for 2011, 2016, and 2021, respectively. The user accuracy calculated for 2011 ranged between 79% and 100%. In 2016 it ranged between 73% to 89%, and in 2021 it ranged between 93% to 94%. The producer accuracy for 2011 ranged between 81% to 100%. For 2016, it ranged between 80% to 85%, and for 2021, it ranged between 93% to 94%.

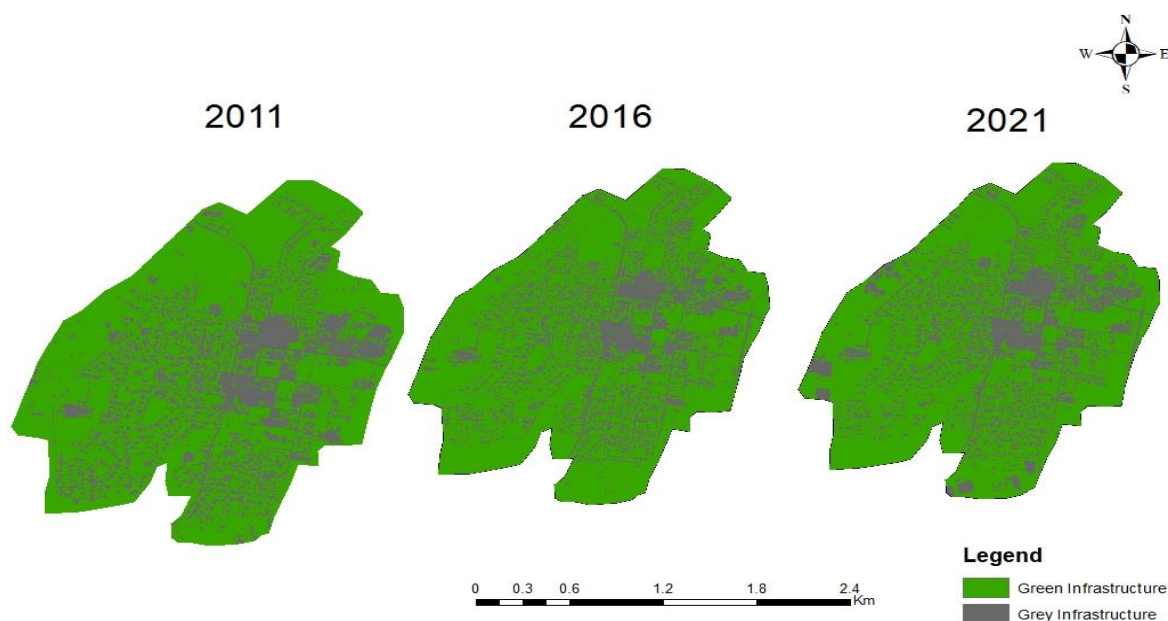
Figure 6.35 is an illustration of the gains and losses in the UEI of Ladybrand between 2011 and 2022, and the contributions to the net change in each UEI (Green, Blue, and Grey).



**Figure 6.35 (A-B): Gains and Losses in UEI of Ladybrand between 2011 and 2021 and contributions to net change in each UEI.**

In Ladybrand, Green and Blue UEI had a loss of 96362.45 m<sup>2</sup> and 39.26 m<sup>2</sup> in area, respectively. While in the Grey UEI, there was a gain of 93122.37 m<sup>2</sup>. Furthermore, Figure 4.35 (B) depicts that the Green UEI lost 8869.24% to the Grey UEI and lost 19.60% to the Blue UEI. As can be seen from the graph representing the “contributions to net change in Blue UEI,” the Blue UEI lost 12020.73% to the Grey UEI and gained 45.12% from the Green UEI. The Grey UEI gained 32.31% from the Blue UEI and 54.88% from the Green UEI.

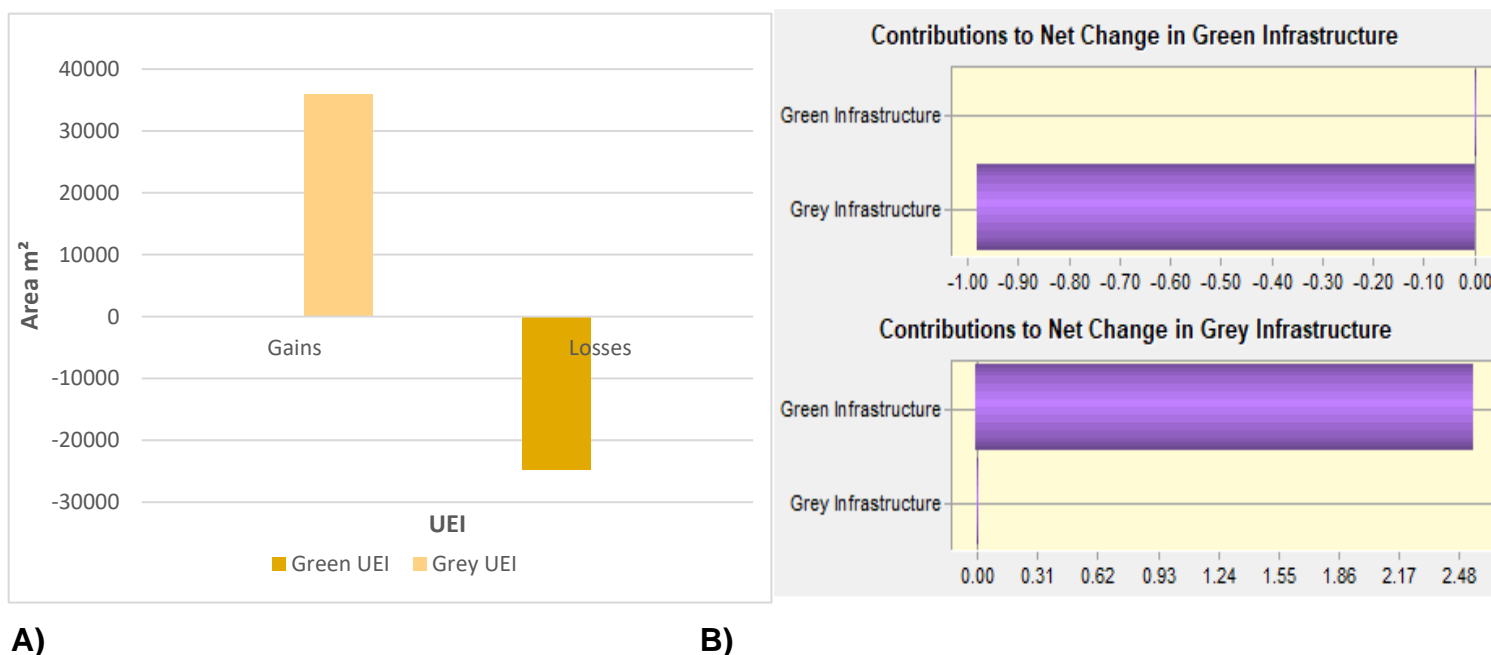
Figure 6.36 shows the location and change in the extent of UEI in Reitz from 2011 to 2021



**Figure 6.36 Urban Ecological Infrastructure in Reitz from 2011 to 2021**

The accuracy assessment calculated for Reitz maps varied with years, with the 2011 user accuracy ranging between 95% and 100%. The overall accuracy calculated for 2011, 2016, and 2021 was 97%, 97%, and 90%, respectively. The 2016 user accuracy ranges between 91% to 100%, and the user accuracy for 2021 ranges between 82% to 100%. The producer accuracy for 2011 ranged between 92% to 100%. For 2016 it ranged between 95% to 100%, and for 2021 it ranged between 81% to 100%.

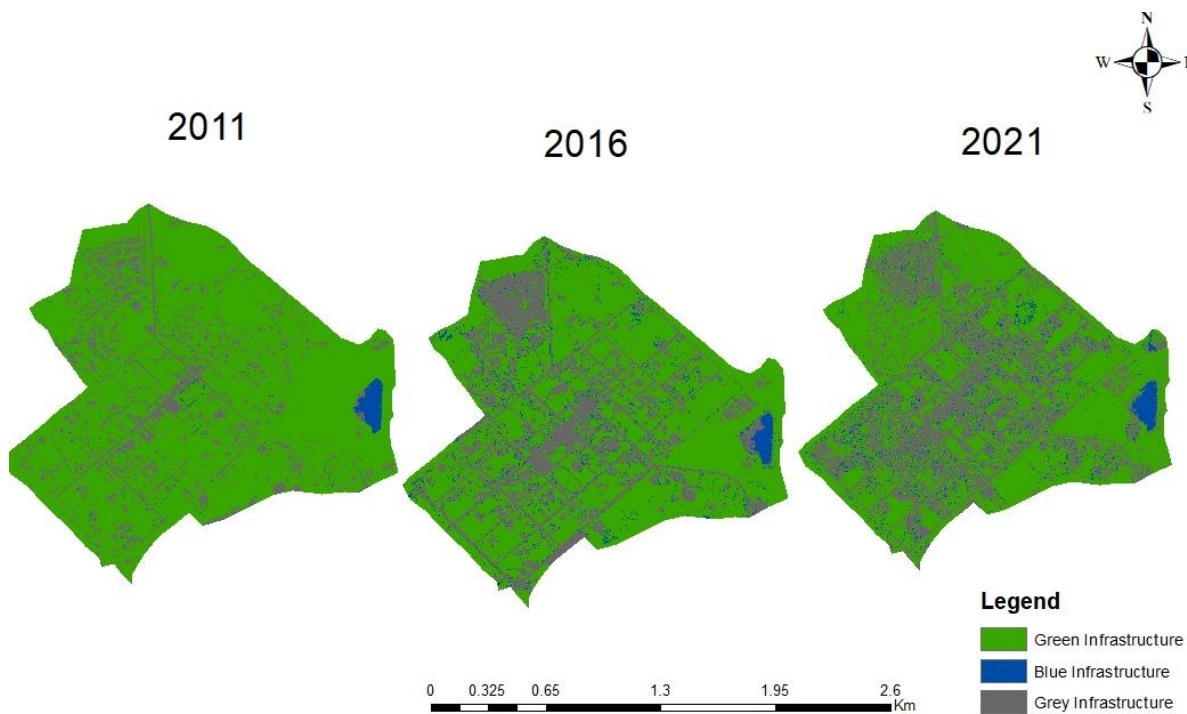
There have been gains and losses in the UEI (Green and Grey) of Reitz from 2011 to 2021, as shown in Figure 6.37.



**Figure 6.37 (A-B): Gains and Losses in UEI of Reitz between 2011 and 2021, and contributions to net change in each UEI (Green, Blue, and Grey).**

According to Figure 6.37 (A), in Reitz, there was a loss of 24675.27 m<sup>2</sup> in the Green UEI and a gain of 35934.96 m<sup>2</sup> in the Grey UEI. As illustrated in Figure 4.37 (B), the Green UEI lost 0.98% to the Grey UEI, while the Grey UEI gained 2.56% from the Green UEI.

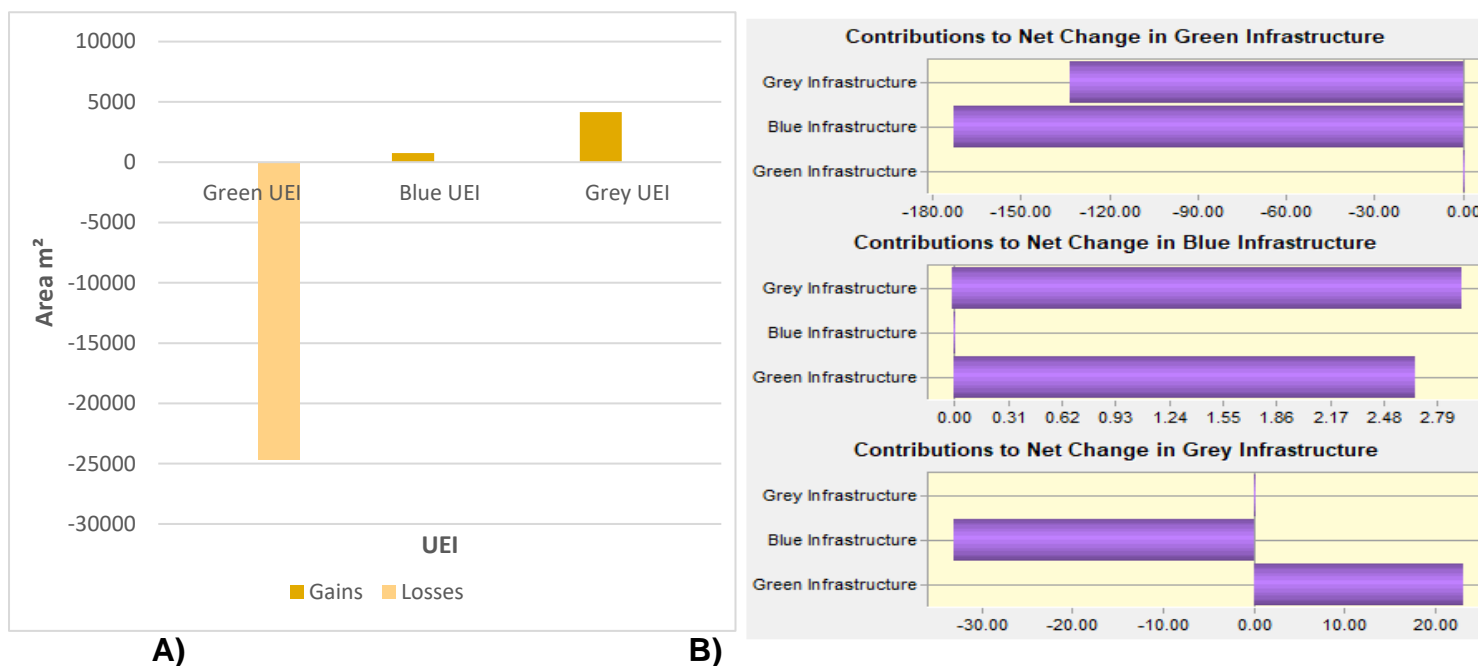
Changes in the location and extent of UEI in Memel are illustrated in Figure 6.38.



**Figure 6.38 Urban Ecological Infrastructure in Memel from 2011 to 2021**

According to the accuracy assessment calculations done for Memel maps, the accuracies vary for each map or each year. The overall accuracy for 2011 was 90%, for 2016 it was 87%, and for 2021 it was 87% as well. For 2011, the user accuracy ranged between 70% to 100%; for 2016, it ranged between 70% to 100%, while for 2021, it ranged between 75% to 100%. The producer accuracy for 2011 ranged between 83% to 100%. For 2016, between 75% and 100%, and for 2021, it ranged between 75% to 100%.

Figure 6.39 indicates the gains and losses in the UEI in Memel between 2011 and 2021, and contributions to net change in each UEI (Green, Blue, and Grey).



**Figure 6.39 (A-B): Gains and Losses in UEI of Memel between 2011 and 2021, and contributions to net change in each UEI.**

In Memel, there is a gain of 140 m<sup>2</sup> in the Green UEI and a loss of 670 m<sup>2</sup>. Blue UEI gained 70 m<sup>2</sup> and lost 10 m<sup>2</sup>. There is a gain of 620 m<sup>2</sup> and a loss of 150 m<sup>2</sup> in the Grey UEI, as seen in Figure 6.39 (A). Figure 6.39 (B) illustrates that the Green UEI lost 133.29% to the Grey UEI and lost 172.56% to the Blue UEI. The Blue UEI gained 2.94% from the Grey UEI and 2.66% from the Green UEI. On the other hand, the Grey UEI gained 23.06% from the Green UEI and lost 32.06% to the Blue UEI.

**Table 6.2:** Changes in areas covered by different UEI in the Thabo Mofutsanyana District between 2011 and 2021

Town	Type of UEI	Amount of land covered by different UEI in different years (m <sup>2</sup> )			Comment
		2011	2016	2021	
<b>Senekal</b>	Green	83793.97	59337.74	50876.75	A significant decrease in Green UEI was accompanied by an increase in Blue and Grey UEI. During this period, Green UEI decreased by 39,28%, while Blue and Grey UEI increased by 2400% and 426,16%, respectively.
	Blue	2491.39	2376.44	62284.73	
	Grey	15299.05	28339.00	80497.33	
<b>Bethlehem</b>	Green	105872.00	227494.71	210287.90	There was an increase in the Green and Blue UEI from 2011 to 2016, followed by a decrease from 2016 to 2021. During this period, Green and Blue UEI increased by 114.88% and 7.56%, respectively, following which. these two types of infrastructure decreased by 421.33% and 24.96%, respectively. There was an increase of 69.35% in the Grey UEI between 2011 and 2021.
	Blue	781.91	4076.31	3058.88	
	Grey	34792.61	40697.06	58921.31	
<b>Clarens</b>	Green	81013.18	47036.29	40288.37	A major decrease in the Green and Blue UEI and an increase in the Green UIE took place during this period. Between 2011 and 2021, the Green and
	Blue	8843.86	231.2	72.67	
	Grey	8958.78	10324.73	17231	

					Blue UEI increased by 50.27% and 99.18%, respectively. On the other hand, the Grey UEI increased by 92.34%.
<b>Ficksburg</b>	Green	106706.94	51516.75	46596.74	A significant decrease in the Green UEI took place during the 2011 – 2021 period. There was a decrease in the Blue UEI from 2011 to 2016 and an increase from 2016 to 2021, accompanied by an increase in the Grey UEI. During these years, the Green UEI decreased by 56.33%, and the Blue UEI decreased by 41.93% and then increased by 17.03%. The Grey Infrastructure increased by 73.63%.
	Blue	6833.62	3967.98	4643.68	
	Grey	15649.86	17845.35	27171.54	
<b>Phuthaditjhaba</b>	Green	29269.31	25605.58	23288.16	A decrease in the Green UEI was accompanied by a major increase in the Grey UEI during the 2011 and 2021 period. During this period, the Green UEI decreased by 20.43% while the Grey UEI increased by 93.27%.
	Grey	23904.84	37684.46	46200.12	
<b>Ladybrand</b>	Green	268700.15	246643.13	172337.70	A decrease in Green and Blue UEI was accompanied by a significant increase in Grey UEI. The Green and Blue UEI decreased by 35.86%
	Blue	39.258			
	Grey	48164.61	66273.62	141286.99	

					and 100%, respectively, while the Grey UEI increased by 193.34%
<b>Reitz</b>	Green	294938.42	305039	270263	A minor increase of 3.42 % occurred in Green UEI from 2011 to 2016. This was followed by a decrease of 11.40% from 2016 to 2021. A significant increase of 223,16% in Grey UEI from 2011 to 2021.
	Grey	26948.94	30655.19	628333.9	
<b>Memel</b>	Green	480021.51	31444.119	23336.85	A significant decrease in Green UEI was accompanied by an increase in Blue and Grey UEI. During this period, the Green UEI decreased by 95.14%, while the Blue and Grey UEI increased by 105.01% and 50.08%, respectively.

## 6.6 Chapter Summary

The trend-lines of the analysed climate data show that the average temperature has increased from 1990 to 2020 in Thabo Mofutsanyana District and that the annual precipitation has decreased from 1990 to 2020. However, the results show that the increase in temperature is statistically significant while the decrease in annual precipitation is not. The decrease in precipitation is a key aspect of climate change.

Furthermore, the results show that urban residents and urban planners noted an increase in temperatures compared to previous years while they noted a decrease in the levels of precipitation. The results further prove that urban residents have not implemented effective strategies towards climate change through urban planning. Hence, the major decrease in green and blue UEI.

The grey UEI gained from the Green and Blue UEI. The green and blue UEI increased and decreased during this period in an interval of five years. Above all, the results show that the green and blue UEI have decreased from 2011 to 2021, while the Grey UEI has increased. This means that, as the result of ineffective efforts made by urban planners, the green and blue UEI decreased over the years (2011 to 2021) instead of increasing or being stable, while the grey UEI increased. The next chapter presents the discussion of results.

## **CHAPTER SEVEN: DISCUSSION OF RESULTS**

### **7.1 Introduction**

This chapter discusses the results of the research study that were presented in Chapter 4, including the urban residents' and urban planners' perceptions about climate change, as well as urban planners' responses to climate change in the Thabo Mofutsanyana District. It highlights the possible reasons behind the results obtained from the analysis of the climate data obtained from KNMI Climate Explorer, the survey conducted on urban residents who participated in the research study, and the interviews with urban planners in the Thabo Mofutsanyana District. It further discusses the changes in Urban Ecological Infrastructure in Thabo Mofutsanyana and how this research has reinforced what is known about urban planning and climate change in the district.

### **7.2 Monthly mean temperature and annual total precipitation trends from 1990 to 2021 in Thabo Mofutsanyana District.**

The monthly mean temperature in the sampled Thabo Mofutsanyana District towns increased between 1990 to 2020, while the annual total precipitation decreased. With regards to the average surface temperature of the earth, 1989 to 2019 was the warmest 30-year period in more than 800 years. According to the p-values calculated from the trends shown in the graphs in the previous chapter, the monthly mean temperature is statistically significant in the sampled towns of Thabo Mofutsanyana District. The p-values for monthly mean temperature are less than 0.05, meaning that the temperature change between 1990 and 2020 can be considered as climate change. Previous studies have indicated that the 2010 - 2019 decade was the warmest decade since 1850 (National Academy of Sciences, 2020). On a global scale, the average surface temperature has increased by 0.6 °C over the past 100 years (Shikwambana *et al.*, 2021). Unless sound climate action is taken, by 2100, temperatures may increase by more than 4°C over the interior of southern Africa (Chersich and Wright, 2019).

In contrast, the p-values calculated from the precipitation trend lines, presented in the graphs, indicate that the change in annual total precipitation is not statistically significant. The p-values are greater than 0.05, meaning that the change in precipitation received in the Thabo Mofutsanyana District cannot be considered a key aspect of climate change. The decrease in precipitation in towns within the Thabo Mofutsanyana District proves that the area is characterized

by high climate variability and not necessarily climate change (National Academy of Sciences, 2020). The precipitation trends show that the precipitation has decreased between the year 1990 to 2020. These trends are similar to those experienced in South Africa as a whole. South Africa has been reported to be a semi-arid country, characterized by a highly variable climate with limited water resources. The observed trends are associated with extreme weather conditions caused by climate change and climate variability. The average rainfall in South Africa is 450mm a year, which is 410mm less than the world's annual average rainfall (Botai *et al.*, 2018).

### **7.3 Urban Residents' Perceptions of Climate Change in Thabo Mofutsanyana District**

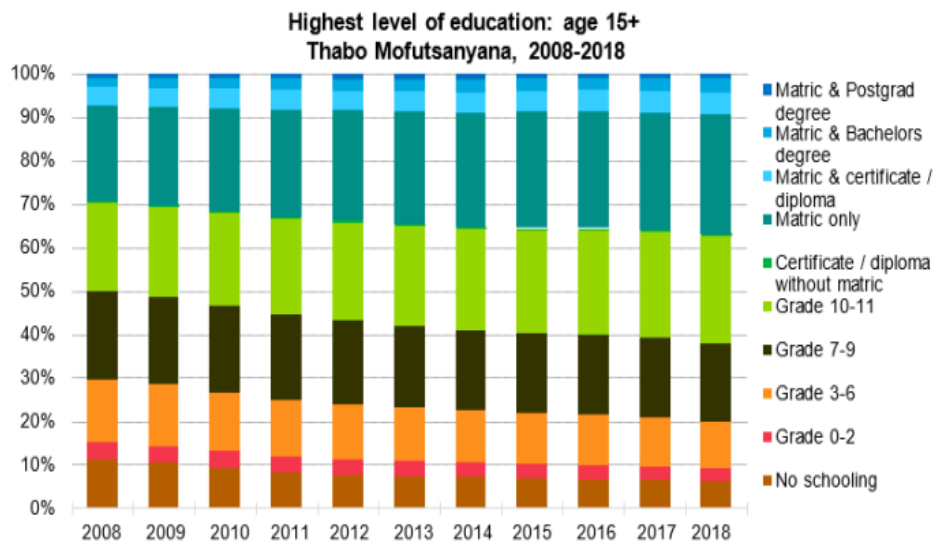
Fiarras-Gomalez (2021) states that people's perceptions about climate change are influenced and shaped by the individuals' characteristics, the level of knowledge or received information, the cultural and geographic context, beliefs, and concerns about how the climate is changing. The results that were obtained from this study do not fully support this statement. This is because the perceptions on climate change provided by the urban residents of Thabo Mofutsanyana District who participated in this study did not reflect the differences in gender, educational background, ethnic group, or location (different towns in the district). However, their responses concerning climate change were based on experience.

#### **7.3.1 Demographic Information (Urban residents)**

The results presented in Chapter 4 show that most urban residents who participated in the study were between the ages of 18 and 24. This high proportion of young people in the study results from the high number of urban residents aged 18 to 24 willing to participate. The ethnic makeup of Thabo Mofutsanyana District is 98% Black, 4.8% White, 0.8% Coloured, and 0.4% Indian/Asian, hence the high number of black respondents who participated in the study.

Twenty-five percent of the respondents who participated in the study did not complete Matric (Grade 12), followed by those who only obtained their Matric Higher Certificate and did not further their studies. According to the Cooperative Governance and Traditional Affairs (n.d.), the number of people who only obtained Matric Higher Certificate as their highest qualifications increased in Thabo Mofutsanyana District, from 93 800 to 124 000. As reported by Simpson *et al.* (2021), level of education, gender, age, urban or rural residence, social status, and employment in the agricultural sector all play a role in people's climate change literacy. Figure 7.1. further illustrates

the high number of people who did not complete Matric, which is then followed by a high number of people with Matric only in the Thabo Mofutsanyana District:



Highest Level of Education: age 15+, 2018 Source: IHS Markit Regional eXplorer version 1803

**Figure 7.1: The highest level of education obtained by Thabo Mofutsanyana District residents from 2008 to 2018 (Cooperative Governance and Traditional Affairs, n.d.).**

In addition, the high number of respondents who participated in the study were from Phuthaditjhaba. Among the eight sampled towns in Thabo Mofutsanyana District, the town with the highest population is Phuthaditjhaba, with 44% of the population.

As noted in Chapter 4, 63% of the respondents who participated in the study stated that they were not aware of the responsibility they had towards mitigating the effects of climate change in Thabo Mofutsanyana District towns. In addition, others stated that they did not have any knowledge about the causes of these effects and how they could be mitigated. According to Simpson *et al.* (2021), climate change literacy in Africa lies at only 37%. However, only 51% of the climate literate people are confident that their actions to combat climate change can be effective.

### 7.3.2 Urban residents' perceptions of climate change in Thabo Mofutsanyana District.

Perceptions provided by the urban residents on climate change did not reflect the differences in gender, educational background, ethnic group, or location (towns in the district). This was because their responses concerning climate change were based on experience. However, many researchers have reported demographic dimensions impacting climate change perceptions.

According to Haq and Ahmed (2016), young people below 30 years have more knowledge about climate change or environmental issues because of their level of education, and exposure to such knowledge through social media, while older people over 60 years are more concerned about the causes and impacts of climate change due to their experiences. Lee *et al.* (2020) further explain that young people rely on information provided by adults and formal environmental textbooks, while adults rely on the experienced change in the climate. Nonetheless, knowledge from reading and word-of-mouth leads to similar perceptions with actual experience.

Also, since the socioeconomically disadvantaged groups are more vulnerable to climate change effects, their perceptions of climate change have been reported to be different from those who are socio-economically advantaged. Pearson *et al.* (2017), states that economic status plays a major role in the perceptions of climate change. Also, since the majority of Whites live in areas that are less prone to the effects of climate change, their perceptions of climate change are different from those of other races who are more vulnerable to the effects of climate change (Pearson *et al.*, 2017), which means race or ethnicity also plays a role in shaping the perceptions that people have on climate change.

Furthermore, several studies have shown that gender influences climate change perceptions. Haq and Ahmed (2016) reported that men have more accurate knowledge about climate change than women. Based on previous studies that have been conducted, women have shown to express less trust in science to solve problems than men do. Also, women have been reported to hold stronger attitudes toward environmental issues than males. In many countries, women are also more involved in environmental engagements than men (Haq and Ahmed, 2016).

The urban residents in Thabo Mofutsanyana District have perceived the change in climate as a phenomenon that negatively affects them. The respondents have viewed climate change as a threat to their well-being and livelihood. It is most important to understand that the perceptions of climate change are mainly shaped by experience. Based on the results presented in the previous chapter, urban residents have been negatively affected by climate change. This is because they have experienced extreme temperature, a decrease in precipitation, and all the other effects that result from these conditions. Urban residents have been prone to water scarcity, flood risk, drought, and unstable provision of resources such as electricity and safe and clean water due to decreased precipitation (Shikwambana, 2021). The decrease in precipitation has caused water scarcity in South Africa, resulting in an increased demand for water as the population keeps on increasing (Mahlalela, 2020).

As noted by 52% of the respondents in the previous chapter (Chapter 4), in the Thabo Mofutsanyana District, the temperature has increased while precipitation has decreased. Urban residents' perception of the increased temperatures is influenced by the high temperatures they have experienced in the past years. Although most urban residents have perceived temperature as increased over the years and 43.2% of the respondents noted precipitation as decreased, some stated otherwise. Fierras-Gonzalez (2021), states that perception is subjective; for this reason, different people in the same town, municipality, district, province, or country may formulate different perceptions of climate change even though they experience the same weather conditions. Hence, the different perceptions the urban residents had even though they live in the same town and have other similar characteristics, such as level of education, gender, age and race.

### **7.3.3 Urban residents' perceptions of urban infrastructure in Thabo Mofutsanyana District**

The green infrastructure has been reported as an urban infrastructure that needs to be developed and maintained the most. Green space and infrastructure in cities and towns have been considered a crucial aspect of urban planning or policy strategy because they promote climate resilience, urban sustainability, and liveability. Venter et al. (2020) have observed that South African cities or towns have an uneven pattern of green infrastructure, which is affected by the historical apartheid era. There is unevenness in the availability of green infrastructure in high-income areas (dominated by Whites) in relation to low-income areas (dominated by Blacks). Towns dominated by Whites have 12% higher tree cover than those dominated by other races, and the spatial inequalities are visible when comparing public and private green space. Also, sustainable and well-maintained grey and blue infrastructure is found in suburbs of the high-income class (Venter *et al.*, 2020).

### **7.4 Urban planners' perceptions of climate change in Thabo Mofutsanyana District**

The urban planners investigated in this research study have worked for the government for 2 to 10 years. Each urban planner is responsible for each municipality and all the towns in that municipality. Since Thabo Mofutsanyana District has six towns, six urban planners work under the whole district. According to the results presented in the previous chapter, the urban planners' perceptions of climate change are shaped or formulated by the climate they have been

experiencing as human beings and the challenges they have been facing as government officials in the urban planning and environmental management department.

#### **7.4.1 Effect of climate change in Thabo Mofutsanyana District towns**

As mentioned by urban planners, the extreme temperatures have led to a major load shedding issue in the Thabo Mofutsanyana District. During winter, the eastern part of the Free State Province experiences extreme cold weather, leading to increased consumption of electricity as the use of heaters and air-conditioners increases. This leads to load-shedding because the electricity demand exceeds the existing supply in the district, and wildfires occur due to climate change, especially in Bethlehem. Wildfires occur naturally due to lightning or human-related activities. However, the prevailing dry weather conditions usually promote the outbreak of fire. Also, extremely high temperatures, low to no rainfall, and wind can leave trees, fallen leaves, tree branches, and shrubs dried out and ready to fuel a fire. Since Thabo Mofutsanyana District is a mountainous region, wildfires are likely to be severe, as the flame burns uphill faster than they burn downhill (Tedim and Leone, 2020).

In addition, due to the occasional heavy rains associated with climate change, infrastructure in towns of the Thabo Mofutsanyana District is often affected by floods, resulting in the creation of potholes on the roads, washing away of bridges, and inundation of wetlands. Floods cause massive damage to the infrastructure and buildings, leading to a high loss in finances during repairing and maintaining the damaged infrastructure and facilities. As a result, this hinders the region's economy (Van Niekerk et al, 2020).

#### **7.4.2 Strategies implemented by urban planners toward climate change**

Urban planners have implemented the 5 km flood-line plan to ensure that urban residents are not affected by floods. According to Van Niekerk *et al.* (2020), monitoring and profiling the extent of vulnerability of towns to climate change-related risks has been reported to be significant in addressing the human settlements' resilience. This is emphasized as an international and national priority in the Sustainable Development Goal, the National Climate Change Response Policy of 2011, and the South African Disaster Management Amendment Act, Act No. 16 of 2015. The promotion of sustainability has also been emphasized in the Sendai Framework for Disaster Risk Management 2015 – 2030, which focuses on understanding disaster risk, strengthening disaster risk governance to manage disaster risk, investing in disaster reduction for resilience, and

enhancing disaster preparedness for effective response, and “Building Back Better” rehabilitation and reconstruction (Third UN World Conference on Disaster Risk Reduction, 2015).

Although disaster management plans are implemented in Thabo Mofutsanyana District towns, the results presented in the previous chapter (Chapter 4) show a shortage of Disaster Management teams in the district. South Africa’s Department of Cooperative Governance is responsible for disaster management. However, its role is not reflected in the Thabo Mofutsanyana District, especially at the local level. Other than the disaster management plans put in place by the Thabo Mofutsanyana District, as mentioned in the previous chapter, the South African government promulgated the Disaster Management Act, 2002 (Act No. 57 of 2002) on 15 January 2002 as an act that provides:

*“i) an integrated and co-ordinated disaster risk management policy that focuses on preventing or reducing the risk of disasters, mitigating the severity of disasters, preparedness, rapid and effective response to disasters, and post-disaster recovery*

*ii) the establishment of national, provincial, and municipal disaster management centres*

*iii) disaster risk management volunteers*

*iv) matters relating to these issues”.* (Department of Cooperative Governance, 2002).

Also, one of the challenges facing the Thabo Mofutsanyana District is the non-existence of programs that inform urban communities about natural hazards such as floods and wildfires. However, weather forecasts are communicated daily through national television and radio. Also, the South African Weather Services (SAWS) has introduced an Impact-Based Severe Weather Warning System developed to warn the general public about possible impacts that might result from a hazardous event (South African Weather Service, n.d). This means that the public is not only informed about the meteorological thresholds but also informed about what the weather will do.

In addition, South African municipalities have been dependent on volunteers after an occurrence of a disaster. Residents who volunteer their knowledge, time, resources, and skills have been considered as a great resource for emergency and disaster management (Whittaker *et al.*, 2015). However, disaster risk management programs that depend on volunteers are unlikely to be effective. This is due to the lack of prior training, relevant skills, or experience, especially from volunteers not previously affiliated with a recognized volunteer agency. The volunteers provide assistance already provided by the government or other activities, which leads to duplicated

efforts. These volunteers might involve themselves in situations where they get harmed or harm others or provide insufficient efforts to the disaster. Although volunteerism during and after a disaster should be expected and planned for, it cannot be relied upon (Whittaker *et al.*, 2015).

Urban residents or communities sometimes destroy the green infrastructure by cutting down trees, though urban planners and other government officials levy fines. According to the National Forest Act [No. 30 of 1998], any person guilty of cutting down trees from protected areas may be sentenced to imprisonment or a fine of R500 to R50 000, depending on the severity of the offense (Department of Environmental Affairs, 1998).

Relocating people who reside in informal settlements has been proposed by urban planners to reduce the effects of climate change on residents. Due to the lack of resource provision (electricity), residents in informal settlements are forced to burn fossil fuels to perform their daily activities. For example, residents in informal settlements cut down trees for wood to cook food and keep themselves warm, increasing the effects of climate change by increasing pollutants in the air (Satterthwaite *et al.*, 2018). Also, informal settlements are at high risk of flooding and landslides, infectious and parasitic diseases, natural hazards, accidental wildfires, and pollution. Therefore, living conditions in informal settlements increase the risk of climate change impacts such as extreme temperatures, intense precipitation events and floods, storms, and water scarcity (Satterthwaite, 2018).

The green infrastructure developed in Thabo Mofutsanyana District is for recreational, aesthetic purposes, and spatial design rather than for climate change mitigation and adaptation. Pataki *et al.* (2021) state that urban trees in streets, yards, parks, and open spaces have been included in urban design and landscape architecture plans for centuries. Besides, trees have been reported to have many environmental benefits in urban areas. These benefits include atmospheric cooling, pollution absorption, storm water mitigation, energy use reduction, and habitat provision. To ensure that the urban residents play a role in mitigating the effects of climate change, urban planners have introduced a plan to advise the urban residents to plant trees in their yards. A considerable amount of literature indicates that trees benefit municipalities and the residents, and this finding has encouraged local, national, and global initiatives that promote urban tree planting (Pataki *et al.*, 2021).

### **7.4.3 Implementations of Sustainable Urban Infrastructure**

In the previous chapter, it was noted that reliance on poor urban infrastructure had worsened the effect of climate change in the Thabo Mofutsanyana District. According to Fallman and Emeis (2020), urban planning plays a major role in responding to the global issue of climate change. As Oloke et al. (2021) mentioned, in developing countries, there is a lack of pedestrian sidewalk and proper drainage systems; the available one is poorly maintained or managed. This lack of pedestrian infrastructure forces residents to use the roads, especially during rainstorms, which exposes them to vehicular accidents. As explained by Noah *et al.* (n.d.), the lack of a holistic approach to network planning, ineffective and poor integration of transportation and land-use planning, and inadequate planning of public transport are the main factors within the planning and design frameworks that lead to high risk and exposure of pedestrians to vehicular accidents.

The local towns lack roads in proper conditions, which are difficult to access, especially during rainy seasons. Pipe-borne water practically does not exist, and many households do not have access to safe, clean, and treated water. The poor infrastructure in developing countries aggravates due to climate change, and as these conditions worsen, they exacerbate the effects of climate change (Oloke *et al.*, 2021). It is more of a cycle. For instance, as heavy rainfalls persist in a particular area, objects are transported to the drainage system during runoff which then blocks the drains. As gray infrastructure is not maintained and in proper conditions, this increases the risk of flooding and impacts urban communities.

Environmental Impact Assessments (EIA) have been conducted during projects such as building malls in Thabo Mofutsanyana District. EIAs have only been effectively implemented before every project to mitigate the effects of climate change. This has been done to determine the likelihood of environmental impacts due to a proposed development or project. This process helps in determining whether the proposed project should proceed or not as a way of protecting the environment.

### **7.4.4 Challenges of incorporating climate change into urban planning**

One of the major challenges urban planners in the Thabo Mofutsanyana District face is that some residents build informal settlements close to the rivers, despite the 5 km flood-line prohibition rule applied by urban planners. For example, in Phuthaditjhaba, there are many places where the flood-line prohibition rule has been ignored. However, in some instances, the implementation of the flood-line rule has been effective, as indicated by the absence of settlements in areas that

have been inundated by floods, thus reducing the impact of flooding in the study area (African Environmental Development, 2022). In South Africa, apartheid may have ended 28 years ago. However, its effects continue to persist even in the current period. This is visible in the country's high number of informal settlements, caused by a lack of affordable housing for the middle and low-income class, predominately Blacks (SERI, 2018). This has caused informal settlements to be uncontrollable, as shown by some houses built in high-risk areas near rivers and dams, which are susceptible to flooding.

As depicted in the previous chapter, climate change has not been adequately included in urban planning. This is partly because South Africa's response to climate change has been hindered by policy uncertainty and corruption, mainly in the energy and transport sectors (Chersich, 2018). As a result of a growing population and other local factors, incorporating climate change plans has been challenging since there has been an increase in levels of disaster risks. Finances are often diverted to disaster response (Van Niekerk *et al.*, 2020).

Another challenge that urban planners and environmental managers face is the scarcity of information or literature on the vulnerability of municipalities to climate change impacts in urban areas. Climate change mitigation, resilience adaptation plans, and information about the effects of climate change need to be relevant to the local scale and time frame so that the urban planners can take effective action against climate change (Measham *et al.*, 2011). The local governments in the district largely operate from a policy framework imposed by provincial and national policies, making it challenging to implement effective action plans on a local scale (Measham *et al.*, 2011). This is because the national framework, policy, or plan may not be applicable or relevant for the local municipalities or towns due to the difference in scale, environment, and spatiality. Also, municipalities are mostly limited by low financial capacity.

## **7.5 Change in Urban Ecological Infrastructure in Thabo Mofutsanyana District from 2011 to 2021**

### **Blue UEI**

The results that were obtained from KNMI Climate Earth Explorer show that Senekal and Ficksburg towns experienced less precipitation which indicates a season of drought during the years 2011 and 2015. Abubakar *et al* (2020), states that the years 2011 and 2015 were characterized by drought due to low-rainfall events in the spring to the summer season (October – December). This explains the low levels of Blue UEI during this period, as shown in Figure 4.25

and Figure 4.30. Abubakar et al. (2020) further states that the 3-month Reclamation Drought Index (RDI) showed that Senekal had the most frequent droughts. In 2021, there was an increase in the Blue UEI as the towns were emerging from a season of drought. Also, both these towns are located in the same municipality, Setsoto Municipality of the Thabo Mofutsanyana District; This explains the similar characteristics in the decrease and increase of the Blue UEI over the period of 2011 to 2021.

The results presented in Chapter 4 further show an increase in Blue UEI from 2011 to 2016 and a decrease from 2016 to 2021 in Bethlehem and Memel. This is because these towns were emerging from a season of drought from 2011 to 2016, and then after 2016, due to low precipitation, the town experienced another drought. Furthermore, Clarens' Blue UEI has decreased over the past ten years, from 2011 to 2021. This decrease in Blue UEI can be explained by the Climate Data obtained from the KNMI Climate Earth Explorer. This town's precipitation has been relatively low from 2015 to 2021 compared to other years since 1990. According to local authorities investigated in this study, the town is usually dry until the summer rains arrive. Throughout the year, the days are usually associated with sunny and bright weather, and due to the lack of cloud cover, there is less precipitation of any form.

The significant decrease in the Blue UEI found in Ladybrand results from low precipitation received. The precipitation levels recorded from 2011 to 2019 are relatively low compared to other years since 1990. After 2011, precipitation levels decreased drastically. According to Local Authorities from Ladybrand, the lack of proper planning and effort from the urban planners and environmental managers toward implementing and maintaining Blue UEI has resulted in the decrease of this UEI in Ladybrand over the years. In Reitz and Phuthaditjhaba, no Blue UEI was determined between 2011 and 2021. However, this UEI is available in the surrounding areas. Also, it can be noted that the Blue UEI has been decreasing to the Grey UEI. The decrease in the Blue UEI results from the extraction of freshwater from the environment due to urbanization (Okello *et al.*, 2015).

## **Green UEI**

As indicated in the previous chapter (Chapter 4), there is a decrease in the Green UEI as the Grey UEI increases. As the urban planners in Thabo Mofutsanyana District stated, their plans mainly focus on the spatiality of the town rather than the climate. There is less focus on environmental issues in urban planning. However, most of the urban planners that were

interviewed stated that they needed to effectively work towards implementing and maintaining the Green UEI to respond to the ongoing and global issue of climate change.

Although, according to the National Climate Change Response White Paper that was released in 2011, each province, district, and municipality in South Africa should work towards mitigating and adapting to climate change. The strategies include Green City Concept, which provides clean water, protects green space and offers an enhanced public experience. However, the results show that in Thabo Mofutsanyana District, such strategies have not been effectively implemented as the Green UEI continues to decrease drastically.

The decrease in the Green UEI of Thabo Mofutsanyana District illustrated in Chapter 4 was reported by the urban residents who participated in the study. They stated that the Local Authorities were not effectively working towards implementing the Green UEI as a strategy to combat Climate Change. Parks were either poorly developed or poorly maintained. According to Venter and Masterson (2020), inequality is still a significant problem that results in the low Green UEI found in local towns dominated by Blacks and low-income class, while towns dominated by Whites and high-income class have high and healthy Green UEI.

The green UEI have been reported to be playing a major role in mitigating climate change. This involves cool air temperatures and reduced flooding (Almaaitah *et al*, 2021), however, as a result of social inequalities, low-income neighborhoods have the least green space compared to high-income neighborhoods (Astell-Burt *et al*, 2014). This makes adapting to climate change a challenge for low-income neighborhoods found in local towns.

## **Grey UEI**

The graphs that show how each UEI has been increasing or decreasing in relation to the other UEI (The contributions to net change) in Chapter 4 illustrate how the Grey UEI has been gaining from the Green and Blue UEI. Urban development is affecting the Green UEI as the world is progressing towards urbanization. Greyer UEI, such as buildings/housing, roads, drainage systems, pipes, and water treatment, are being built. During the construction of such UEI, the existing green UEI is affected. The increase in the number and size of cities /towns leads to the loss of ecosystems as the semi-natural, and natural ecosystems in urban areas are transformed into impervious surfaces (artificial/ built-up areas). This loss of Green UEI to Grey UEI occurs through soil degradation, deforestation, and habitat loss (Klimanova *et al.*, 2018). This means that the increase in Grey UEI negatively affects the Green UEI.

According to the results obtained from this study, the Grey UEI found in Thabo Mofutsanyana District does not contribute towards combating the effects of Climate Change. For instance, the urban residents who participated in the study stated that the drainage systems along the roads are usually blocked due to poor maintenance, making them non-functional as they are designed to reduce surface water runoff that leads to flooding. The State of the Cities Report (2011), states that the progress in Built Environment is measured in physical terms, (the number of newly built houses), and not whether these houses are located in appropriate areas/appropriate form or whether the provision of these houses is in response to people's needs and sustainable in the future.

## **7.6 Conclusion**

This chapter presented the discussion of results. It highlighted and explained the changes in climate, the urban residents' and urban planners' perceptions on urban planning response to climate change, and discussed the changes in UEI in Thabo Mofutsanyana District. Based on the results obtained in this research study, it is clearly evident that the increased average temperature indicates the global issue of climate change. Hence, the urban residents and urban planners are affected by this increased temperature. The decrease in annual precipitation proves climate variability, as the p-values were statistically insignificant for all towns under investigation.

Furthermore, according to results it is evident that the urban planners are not adequately and effectively working towards incorporating climate change in urban planning to mitigate and adapt to the effects of climate change. This inability of urban planners has exacerbated the effects of climate change in Thabo Mofutsanyana District. This is because urban planning focuses mainly on the built-up (Grey UEI) and ignores the environmental and sustainability part of development, which explains the rapid increase in grey UEI, and decrease in green UEI and blue UEI.

Overall, not incorporating climate change during urban planning leads to increased impact of climate change in Thabo Mofutsanyana District, as the results show how urban residents, in the majority, affected by climate change due to urban planners' lack of effective focus on the environmental issue of climate change. The following chapter summarizes the research study by providing information on how each objective was achieved, concludes the study, and draws up recommendations for future research studies.

# CHAPTER EIGHT: SUMMARY, CONCLUSION, AND RECOMMENDATIONS OF THE STUDY

## 8.1 Introduction

Climate change has been an ongoing issue that has been affecting the whole world (Rocha *et al*, 2022). However, it has been reported to have major impact on mountain environments as they are fragile due to the cutting down of trees, overgrazing by livestock, cultivation of marginal soils, and the process of urbanization that is rapidly increasing. These processes then lead to degradation of water resources, biodiversity decline, extreme temperatures and frequent occurrence of natural hazards, increasing the risk on population living in the surrounding areas (Körner, 2013). Due to their influence on the definition of spatial planning, structure and function, urban planners can play an important role in adaptation to climate change. However, so far urban planning has a limited role in adaptation to climate change (Hurlimann and March, 2012). Functions of local government, such as the production of infrastructure and services, maintenance of infrastructure and integrated development planning, can facilitate or oppose adaptation. Actions to combat climate change are often neglected due to immediate development dilemmas, such as service delivery lagging behind and many local plans being short-term perspectives that conflict with long term consequences of climate change (Pieterse, du Toit, and van Niekerk, 2020).

With this background, this research study has shown that climate change is not prioritized in urban planning. Therefore, development strategies implemented by urban planners are not effective in mitigating the adverse effects of climate change. The main aim of this research study was to identify the negative impacts of climate change in the Thabo Mofutsanyana District and assess how urban planners respond to the effects of climate change in the district. This was done with a focus on towns located in the district. The specific objectives of the study were:

- I. To assess the precipitation and temperature trends in Thabo Mofutsanyana District from 1990 to 2020.
- II. To identify actions taken by urban planners towards climate change.
- III. To evaluate the strategies that urban planners in the Thabo Mofutsanyana District adopted from 2011 to 2021 and determine the extent to which these strategies contributed to sustainable urban development in the district.

- IV. To draw up recommendations that could be considered during urban planning to solve and mitigate the effects of climate change in the district.

This chapter presents the summary and conclusions, as well as the recommendations of the study. Suggestions for future research are also presented. The chapter further highlights the limitations of the study, including the difficulties or challenges that the researcher encountered while conducting the study.

## **8.2 Conclusions from the research results and their implications**

### **Objective 1:**

The study's first objective was to assess the annual total precipitation and monthly mean temperature trends in the Thabo Mofutsanyana district over 31 years from 1990 to 2020. After assessing the climate data in Thabo Mofutsanyana District towns, it was established that although there are variations in precipitation and temperature in Thabo Mofutsanyana District between 1990 and 2020, there was an increase in the temperature and a decrease in precipitation through time. These changes can be attributed to climate change and variability. However, the change in monthly mean temperature is statistically significant, while the change in annual total precipitation is not. The Thabo Mofutsanyana District is characterized by high-temperature levels and low precipitation levels compared to previous years.

### **Objective 2:**

The second objective of the study was to identify the actions urban planners took to mitigate the effects of climate change in Thabo Mofutsanyana District and to propose strategies to adapt to these effects. It was established that urban planners were implementing a limited number of strategies to mitigate the effects of climate change. These strategies include the 5 km flood-line rule, relocation of communities and informal settlements located near rivers or dams, disaster risk management programs, enforcing legal steps towards individuals who cut down trees, advising urban residents to plant trees in their yards, and conducting Environmental Impact Assessments (EIA) during construction projects.

It was determined that these actions taken by urban planners were ineffective due to the magnitude of the effects of climate change, especially extreme temperatures and flooding during heavy rains.

### **Objective 3:**

This objective was achieved by assessing the change in Urban Ecological Infrastructure in Thabo Mofutsanyana District towns. After the assessment, it was determined that there was a drastic change in the green, blue, and grey UEI from 2011 to 2021 in each town investigated in the study.

The exclusion of climate change during urban planning has led to a decline in the protection of Green and Blue UEI. As the urban planners mainly focus on the built-up (grey UEI), the area covered by Green and Blue UEI has decreased, making the area more susceptible to climate change. The Green UEI is lost as a result of increasing Grey UEI, which is promoting soil degradation, deforestation, and habit loss. On the other hand, the loss in Blue UEI results from the extraction of freshwater from the environment due to urbanization. The Grey UEI found in Thabo Mofutsanyana District is not sustainable. The blocking of drainage systems and the limited porosity of roads do not reduce the effects of climate change, such as flooding. If not effectively maintained, the Green and Blue UEI will continue to decrease in Thabo Mofutsanyana District, affecting the area's sustainability.

Overall, in this study, it was established that there are changes in UEI that occurred from 2011 to 2021. The decrease in the area covered by Green and Blue UEI and an unsustainable increase in Grey UEI result from ineffective urban planning and inadequate efforts towards climate change preparedness. The study reveals that the towns of Thabo Mofutsanyana District have been affected by climate change effects (extreme temperatures and low precipitation) due to poor urban planning which has led to a major decrease in green and blue urban ecological infrastructure. It can therefore be concluded from the results that unsustainable urban planning worsens the impact of climate change in Thabo Mofutsanyana District.

### **8.3 Recommendations**

Based on the results and conclusion of the research study, the following recommendations should be considered in urban planning strategies:

- I. Tree-planting should be undertaken, and the Green UEI (parks, greenways, open spaces) already available in Thabo Mofutsanyana District should be maintained and protected to regulate temperature extremes and increase the area's capacity to adapt to climate change.

- II. The Grey UEI (roads, drainage systems) in Thabo Mofutsanyana District should be maintained and made sustainable to reduce the risk of floods. The road drainage systems should be functional in order to reduce flood risk.
- III. The Blue UEI (dams, rivers, wetlands, ponds) must be maintained to reduce water scarcity resulting from droughts.
- IV. Environmental education and awareness on the causes and effects of climate change should be provided to urban residents to enhance the implementation of adaptation plans and avoid the exacerbation of climate change effects.
- V. There should be greater focus on implementing adaptation plans as they are local in scale. The impacts of adapting to climate change have been reported to manifest quickly compared to mitigation measures which are global in scale.
- VI. The towns in Thabo Mofutsanyana District can reduce the impacts of high temperatures by installing light-coloured roofs and asphalt.
- VII. Energy efficient urban planning should be prioritized in order to mitigate the emissions of GHG.

Recommendations in areas of future research:

- I. More studies on the vulnerability of local towns to climate change impacts in urban areas should be conducted. Future studies should assess the extent to which local towns are affected by climate change.
- II. Studies conducted under climate change mitigation and resilience adaptation plans must be relevant to the local scale and time frame so that urban planners can take effective action against climate change. A local town policy framework should be developed in each town.
- III. Overall, a more comprehensive investigation of the link between climate change and urban planning should be conducted. This will provide information for developing specific spatial plans incorporating climate change.

#### **8.4. Limitations of the study**

The limitations of this study include the language barrier. Most research participants were Sesotho-speaking people since the Sotho people dominate the Thabo Mofutsanyana District. As the researcher was a Zulu-speaking person, the language barrier was a challenge, especially when the research participants could not understand the universal language of communication,

English. A translator was requested to distribute survey questionnaires to urban residents, which could negatively influence the results through exaggerated and altered translations.

Also, Corona Virus Disease – 2019 (Covid-19) has been one of the most challenging issues during the data collection process. The researcher had to ensure that all the Covid-19 safety measures were applied before interacting with each respondent. These measures included wearing a mask at all times, washing hands regularly, and keeping a safe distance from the respondent. The research process was plodding due to the Covid-19 protocols and being expected to work from home.

The study only included urban planners as the stakeholders that respond to climate change. This creates a knowledge gap, as other stake holders such environmental managers, environmentalists and environmental consultants also contribute to urban planning and working towards the issue of climate change.

Some of the investigated urban planners contributed to the slow progress as it took very long to schedule interviews with them as they were busy, and some of the interviews had to be postponed. To avoid delays and enhance research progress, 250 urban residents were investigated instead of 380. However, the validity of the study was not affected as the participants that were investigated in the study were selected through simple random sampling in each town included in the study.

Lastly, some respondents were hesitant to respond as they believed their responses would be used against them, even after the confidentiality measures applied in the study were explained to them.

## **8.5 Chapter Summary**

Incorporating climate change during urban planning is necessary because sustainable urban planning can mitigate the effects of climate change in cities and towns and help communities adapt to these effects effectively. To conclude, this chapter provided an overview of the research aim and its objectives. It highlighted the key results for each objective of the study and the implications of these results. It also provided practical recommendations that could be considered to minimize the effects of climate change in local towns and strategies that should be implemented to adapt to the effects of climate change. Furthermore, recommendations on research studies that can be further conducted in the future were also presented in this chapter.

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## Appendices

**Appendix A – The survey questionnaire that was used to collect social data from the urban residents. It consists of two sections:**

**Section A** (Personal details), this section sought to obtain basic information about the urban residents in Thabo Mofutsanyana District. It includes gender, age, level of education, and race of the respondents.

**Section B** (Information about climate change and urban planning), this section sought to obtain knowledge that urban residents have about the extent of climate change, and urban planning response to climate change in Thabo Mofutsanyana District.

### **Urban Planning Response to Climate Change in Thabo Mofutsanyane District Survey Questionnaire**

**Geography Department**

**University of the Free State**

This questionnaire is supposed to be completed by urban residents in Thabo Mofutsanyane District. The purpose of the questionnaire is to collect information about how urban residents in the district perceive the extent and effects of climate change in the area. Before you complete the survey questionnaire you should understand that your participation in this survey is completely voluntary, and you are not required to provide your name or details about your identity. The information you will provide will be treated confidentially. When completing the questionnaire, indicate your responses by ticking the appropriate boxes or by filling in the blank spaces provided.

#### **General Information:**

<b>QUESTIONNAIRE NO</b>	
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Name of interviewer: .....

Name of town: .....

Date of interview: .....

Time of interview: .....

## Section A: Personal details

(Tick or fill in the appropriate box where applicable)

1. Gender:

Male	
Female	

2. Age:

18 - 24	
25 - 34	
35 - 44	
45 - 54	
55 - 64	
65 +	

3. Race:

Black	
White	
Indian	
Coloured	
Other	

4. Please indicate your highest level of education/ qualification:

Have not received any formal education at all	
Primary School	
High School	
Higher Certificate	
Diploma	
Bachelor's degree	
Master's degree	
Professional degree	
Doctorate degree	

**Section B: Questions related to climate change and urban planning response**

5. According to your opinion, how has the amount of precipitation received in this area changed?

Increased	
Not changed	
Decreased	

6. Are you affected by the amount of precipitation that is received in this area?

Yes	
No	

If yes, briefly explain how it affects you?

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7. According to your own opinion, how have the temperatures of this area changed?

Increased	
Not changed	
Decreased	

8. Are you affected by the temperatures experienced in this town?

Yes	
No	

If yes, briefly explain how it affects you?

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- 
- 
- 
9. Apart from changes in rainfall and temperature, which other effects of climate change have affected this area?

Dust storms	
Hail storms	
tornadoes	
Drought	
Other (Please specify)	

10. According to your own opinion, are the urban planners and officials from the Department of Environmental Management effectively working towards mitigating the effects of climate change in this area?

Yes	
No	

Kindly explain your answer in brief,

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11. According to your own opinion, are the strategies implemented by urban planners contributing to sustainable urban development in the area?

Yes	
No	

Briefly explain your answer?

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12. Do you know any responsibilities you have as a citizen regarding the mitigation or adaptation to climate change in the area?

Yes	
No	

If yes, please list them in the space provided below:

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13. Have you received any education, training or public awareness information on climate change related issues?

Yes	
No	

14. Are you willing to receive more information about the causes and impacts of climate change in the area, and its solutions?

Yes	
No	

If yes, what kind of information would you need?

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15. In the space provided below, please make recommendations about what should be included in strategies for addressing climate change in the area?

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16. According to your own observation, which urban infrastructure do you think needs to be more implemented in this town? Choose any relevant answer.

Green-infrastructure (parks, trees, grasslands and open spaces)	
Blue-infrastructure (lakes, wetlands, and rivers)	
Grey-infrastructure (dams, roads, pipes or water treatment plants)	

THANK YOU!!!

## Appendix B – Questions used in interviews

Formal interviews were conducted to obtain information about the effects of climate change and their extent in Thabo Mofutsanyana District, and the strategies implemented by urban planners to mitigate the effects of climate change and the effectiveness of these strategies towards mitigation and adaptation of climate change. The key informants included urban planners from each municipality in the district.

1. How long have you been employed as a Government Official?
2. According to your own observation, is this town affected by climate change?

Yes	
No	

If your answer is “yes”, briefly explain how the town is affected by climate change.

3. What are the effects of climate change in this town, kindly list them?
4. As an urban planner, how do you view the idea of incorporating climate change strategies in urban plans?
5. What objectives do you aim to achieve towards mitigating the effects of climate change in this town?
6. When do you expect these objectives to be achieved?
7. Kindly state the strategies that you have adopted in response to climate change in this town, since 2011?
8. According to your perspective, are these strategies effective?

Yes	
No	

If yes, briefly explain how? and if no, briefly explain why they are not effective?

9. Are there any programmes in place to warn urban residents in case of extreme weather events, such as dust storms, tornadoes or hail storms?

Yes	
No	

If yes, kindly describe the programmes, and if no, briefly explain why there are no such programmes?

10. According to your own opinion, what is sustainable urban development planning?

11. What challenges do you face in implementing sustainable urban development planning?

12. Developing countries are perceived as most vulnerable to climate change impacts because of limited resources to adapt socially, technologically and financially. How are you financing the budget for climate change adaptation strategies in this town?

13. From your own perspective, do you view urban residents as being adequately educated or informed about the issue of climate change?

Yes	
No	

Please answer the following questions in brief ...

14. What are the responsibilities of urban residents towards mitigating and adapting to the effects of climate change?

15. What role do you play as an urban planner to ensure effective sustainable urban development planning in this town?

## Appendix C – Consent Form

### RESEARCH STUDY INFORMATION LEAFLET AND CONSENT FORM

#### DATE

February 2020 – December 2022

#### TITLE OF THE RESEARCH PROJECT

The climate change-urban planning nexus in a mountain environment: The case of the Eastern Free State Region of South Africa.

#### PRINCIPLE INVESTIGATOR / RESEARCHER(S) NAME(S) AND CONTACT NUMBER(S):

Ntombizodumo Shezi                      2015318260                      0658434287

#### FACULTY AND DEPARTMENT:

Faculty of the Humanities  
Department of Geography

#### STUDY LEADER(S) NAME AND CONTACT NUMBER:

Professor Geoffrey Mukwada  
Contact number: 058 718 5476

#### WHAT IS THE AIM / PURPOSE OF THE STUDY?

The aim of the proposed research project is to identify the negative impacts of climate change in Thabo Mofutsanyana District and assess how urban planners are responding to the impacts in the district.

#### WHO IS DOING THE RESEARCH?

This research study is conducted by Ntombizodumo Shezi, under the department of Geography at the University of the Free State (QwaQwa Campus).

This is a Master's Degree study which aims to identify the negative impacts of climate change in Thabo Mofutsanyana District and assess how urban planners are responding to the impacts in the district. Furthermore, to evaluate the strategies that urban planners have adopted and determine the extent to which they contribute to sustainable urban development in the district.

### **HAS THE STUDY RECEIVED ETHICAL APPROVAL?**

This study is yet to receive approval from the Research Ethics Committee of UFS.

**Approval number:** UFS-HSD2020/1235/3010

### **WHY ARE YOU INVITED TO TAKE PART IN THIS RESEARCH PROJECT?**

The information related to the study will be obtained from 384 participants, who are community members of the 8 sampled towns (Ladybrand; Senekal; Ficksburg; Bethlehem; Clarens; Reitz; Phuthaditjhaba and Warden) in Thabo Mofutsanyana District. More information will be collected from local urban planners and personnel from the department of manager environment and waste management.

In this study, community members of the 8 sampled towns in Thabo Mofutsanyana District; the local urban planners; and personnel from the department of manager environment and waste management environment, are the best fit, because they have more relevant and applicable information that will address the objectives and aim of the study.

### **WHAT IS THE NATURE OF PARTICIPATION IN THIS STUDY?**

The data will be collected through the use of survey questionnaires from the urban residents (citizens) and through formal interviews from local urban planners and personnel from the department of manager environment and waste management. The participation will require the urban residents to fill in the survey questionnaire which will take approximately 10 – 15 minutes, and conducting formal interviews with the local authorities will involve one visit of approximately 45 minutes in length.

The urban residents will be asked questions to gain more information about how they perceive the effects and extent of climate change. These questions will be asked to find out from the urban residents if the plans that are drawn by urban authorities are working or not. Most importantly, urban residents will be asked questions to find out whether they are affected by the effects of climate change in anyway, whether they know of any responsibilities that they should apply in order to mitigate climate change or adapt to its impact, and whether they receive any kind of education, training or public awareness information on climate change related issues.

The urban planners will be asked about the strategies that they have adopted towards sustainable urban planning, the effectiveness of their strategies, the techniques that they have implemented to warn people in case of harsh weather events (dust storms, hail storms and tornadoes), and about the challenges they experience as they work towards sustainable urban development planning. Moreover, the urban planners will be asked about the objectives that have set to mitigate the effects of the changing climate and when do they expect those objectives to be achieved. In addition, in order to get a full picture of the proposed study, the participants (urban residents and urban planners), will be asked similar questions so that the results can be compared.

The responses you provide will be used solely for research purposes. Furthermore, I would like to interview you on record, so that I can get more information as possible and be able to get back to the provided responses without exaggerating or altering the information.

### **CAN THE PARTICIPANT WITHDRAW FROM THE STUDY?**

As a respondent or an interviewee, you are not required to provide your name and any information you provide will be treated confidentially. The responses you provide will be used solely for research purposes. Your participation in this study is fully voluntary, and your refusal to participate or withdrawal of consent will not affect your relationship with the University of the Free State or the Department of Geography.

### **WHAT ARE THE POTENTIAL BENEFITS OF TAKING PART IN THIS STUDY?**

The potential benefits of taking part in this study include understanding more about the climate change experienced in the area, and being environmentally aware of the local authorities' actions towards the environment and their response to climate change. The benefits also include gaining more information about the climatic and environmental conditions of Thabo Mofutsanyana District. Furthermore, more research studies can be conducted from the gaps that may have been revealed on the current study, which will further help the community by improving effective climate change solutions in the district.

### **WILL WHAT I SAY BE KEPT CONFIDENTIAL?**

The information you will provide will be treated confidentially. Your name is not required and no one will be able to connect you to the answers you provide. Your responses will be given a fictitious code number and you will only be referred to in this way in the data, or any publications. The researcher and research supervisor are the only people who will have access to the data, and they will treat it with confidentiality. The responses you provide in this research may be reviewed by people who are responsible for making sure that the research is done in a proper manner, including the research supervisor, and members of the Research Ethics Committee. Other than that, records that identify you will be available only to people

working on the study, unless permission is granted by you for other people to see the records. Your anonymous data may be used for other purposes such as research report, conference presentations and journal articles. Your privacy will be totally protected in any publication of the information. A report of the study may be submitted for publication, but individual participants will not be identifiable in such a report.

### **HOW WILL THE INFORMATION BE STORED AND ULTIMATELY DESTROYED?**

Hard copies of your answers will be stored by the researcher for a period of five years in a locked cupboard at the researcher's place for future research or academic purposes; the electronic information will be stored on a password protected personal computer. Future use of the stored data will be subject to further Research Ethics Review and approval if applicable. The hard copy information will be destroyed by trashing the hard copies in the bin and disposing it into the landfill sites. The electronic information will be destroyed by completely deleting it from the researcher's computer.

### **WILL I RECEIVE PAYMENT OR ANY INCENTIVES FOR PARTICIPATING IN THIS STUDY?**

Participating in this research study does not come with any reward or payment, financial or otherwise. Any costs incurred by the participant should be explained and justified. The participant will not be subjected to any kind of discomfort or inconvenience. There are no side effects or risks of harm associated with participating on this research. The person's participation in the research will not be identified by others. If injury or harm occurs during the conduction of the study, which is highly unlikely to occur, the participant will be given sufficient and needed attention to assist with the incident. If needed, the relevant authorities will be contacted immediately to also assist.

### **HOW WILL THE PARTICIPANT BE INFORMED OF THE RESULTS / RESULTS OF THE STUDY?**

If you would like to be informed of the final research results or require any further information or want to contact the researcher about any aspect of this study , please contact Ntombizodumo Shezi on 065 843 4287 or email [2015318260@ufs4life.ac.za](mailto:2015318260@ufs4life.ac.za). The results are accessible for five years. Should you have concerns about the way in which the research has been conducted, you may contact Professor Geoffrey Mukwada on 058 718 5476 or email [mukwadaG@ufs.ac.za](mailto:mukwadaG@ufs.ac.za).

**Thank you for taking time to read this information sheet and for participating in this study.**

## CONSENT TO PARTICIPATE IN THIS STUDY

I, \_\_\_\_\_ (participant name), confirm that the person asking my consent to take part in this research has told me about the nature, procedure, potential benefits and anticipated inconvenience of participation.

I have read (or had explained to me) and understood the study as explained in the information sheet. I have had sufficient opportunity to ask questions and am prepared to participate in the study. I understand that my participation is voluntary and that I am free to withdraw at any time without penalty (if applicable). I am aware that the results of this study will be anonymously processed into a research report, journal publications and/or conference proceedings.

I agree to the recording of the formal interview.

I have received a signed copy of the informed consent agreement.

Full Name of Researcher:

\_\_\_\_\_

Signature of Researcher: \_\_\_\_\_

Date: \_\_\_\_\_

## Appendix D – Accuracy Assessment Tables

An overall accuracy of 80% and above calculated from classified images is accepted to identify whether an image can be used for the study (Tilahun and Teferrie, 2015). Also, previous studies that undertook a supervised classification using the algorithm of maximum likelihood established that the accepted level of overall accuracy for an image is 80%.

The Results of the accuracy assessment that was undertaken for Senekal classified images are shown in **Table 1**.

True Pixels (Actual) - Senekal						
	<b>2011</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>	
Classified	Green Infrastructure	11		1	12	92%
	Blue Infrastructure		4		4	100% (User accuracy)
	Grey Infrastructure	2		12	14	86%
	<b>Total (Producer)</b>	13	4	13	30	
		85%	100%	92%		
		Producer Accuracy				
	Total correct	27				
	Total pixels	30				
	Overall Accuracy	90%				
	<b>2016</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>	
Classified	Green Infrastructure	11	0	0	11	100%
	Blue Infrastructure	1	4	1	6	67% (User accuracy)
	Grey Infrastructure	0	0	13	13	100%
	<b>Total (Producer)</b>	12	4	14	30	
		92%	100%	93%		
		Producer Accuracy				
	Total correct	28				
	Total pixels	30				
	Overall Accuracy	93%				

	<b>2021</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>	
Classified	Green Infrastructure	14	0	1	15	93%
	Blue Infrastructure	0	4	0	4	100% (User accuracy)
	Grey Infrastructure	2	0	9	11	88%
	<b>Total (Producer)</b>	16	4	10	30	
		88%	100%	90%		
		Producer Accuracy				
	Total correct	27				
	Total pixels	30				
	Overall Accuracy	90%				

The Results of the accuracy assessment that was undertaken for Bethlehem classified images are shown in **Table 2.**

True Pixels (Actual)							
	<b>2011</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>		
Classified	Green Infrastructure	16			16	100%	(User Accuracy)
	Blue Infrastructure		6	1	7	86%	
	Grey Infrastructure	1		6	7	86%	
	<b>Total (Producer)</b>	16	6	7	30		
		100%	100%	86%			
		Producer Accuracy					
	Total correct	29					
	Total pixels	30					
	Overall Accuracy	97%					
	<b>2016</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>		
	Green Infrastructure	16		1	17	94%	

Classified	Blue Infrastructure		4	1	5	(User Accuracy) 80%		
	Grey Infrastructure	2		6	8			
	<b>Total (Producer)</b>	18	4	8	30			
		89%	100%	75%				
		Producer Accuracy						
	Total correct	26						
	Total pixels	30						
	Overall Accuracy	87%						
	<b>2021</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	13			13	(User Accuracy) 100% 75% 100%		
	Blue Infrastructure		3	1	4			
	Grey Infrastructure			13	13			
	<b>Total (Producer)</b>	13	3	14	30			
		100%	100%	93%				
		Producer Accuracy						
	Total correct	29						
	Total pixels	30						
	Overall Accuracy	97%						

The results of the accuracy assessment that was undertaken for Clarens classified images are shown in **Table 3**.

		True Pixels (Actual)						
	<b>2011</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	10		3	13	(User Accuracy) 77% 71% 90%		
	Blue Infrastructure	2	5		7			
	Grey Infrastructure	1		9	10			

	<b>Total (Producer)</b>	13	5	12	30			
		77%	100%	75%				
		Producer Accuracy						
	Total correct	24						
	Total pixels	30						
	Overall Accuracy	80%						
	<b>2016</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	16			16	100%	(User Accuracy)	
	Blue Infrastructure		3	1	4	75%		
	Grey Infrastructure	1		8	10	80%		
	<b>Total (Producer)</b>	17	3	9	30			
		94%	100%	89%				
		Producer Accuracy						
	Total correct	28						
	Total pixels	80						
	Overall Accuracy	93%						
	<b>2021</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	15			15	100%	(User Accuracy)	
	Blue Infrastructure		3	2	5	60%		
	Grey Infrastructure	1		9	10	90%		
	<b>Total (Producer)</b>	16	3	11	30			
		94%	100%	82%				
		Producer Accuracy						
	Total correct	27						
	Total pixels	30						

Overall Accuracy	90%							
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The results of the accuracy assessment that was undertaken for Ficksburg classified images are shown in **Table 4.**

		True Pixels (Actual)						
	<b>2011</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	9		2	11	82%	(User Accuracy)	
	Blue Infrastructure	2	6		8			
	Grey Infrastructure	2		9	11			
	<b>Total (Producer)</b>	13	6	11	30			
		69%	100%	82%				
		Producer Accuracy						
	Total correct	24						
	Total pixels	30						
	Overall Accuracy	80%						
	<b>2016</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	10			10	100%	(User Accuracy)	
	Blue Infrastructure	2	4		6			
	Grey Infrastructure	1		14	15			
	<b>Total (Producer)</b>	13	4	14	30			
		77%	100%	100%				
		Producer Accuracy						
	Total correct	28						
	Total pixels	30						
	Overall Accuracy	93%						
	<b>2021</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			

Classified	Green Infrastructure	11			11	100% 75% (User Accuracy) 88%		
	Blue Infrastructure	1	3		4			
	Grey Infrastructure	2		15	17			
	<b>Total (Producer)</b>	14	3	15	30			
		79%	100%	100%				
		Producer Accuracy						
	Total correct	29						
	Total pixels	30						
	Overall Accuracy	100%						

The results of the accuracy assessment that was undertaken for Phuthaditjhaba classified images are shown in **Table 5**.

		True Pixel (Actual)						
		Green Infrastructure	Grey Infrastructure	Total (User)				
Classified	2011 Green Infrastructure	15	1	16	94% (User Accuracy) 100%			
	Grey Infrastructure		14	14				
	<b>Total (Producer)</b>	15	15	30				
		100%	93%					
		Producer Accuracy						
	Total correct	29						
	Total pixels	30						
	Overall Accuracy	97%						
		Green Infrastructure	Grey Infrastructure	Total (User)				
Classified	2016 Green Infrastructure	14	2	16	88% (User Accuracy) 93%			
	Grey Infrastructure	1	13	14				
	<b>Total (Producer)</b>	15	15	30				

		93%	87%			
		Producer Accuracy				
	Total correct	27				
	Total pixels	30				
	Overall Accuracy	90%				
	<b>2021</b>	Green Infrastructure	Grey Infrastructure	<b>Total (User)</b>		
Classified	Green Infrastructure	11	2	13	85% (User Accuracy)	
	Grey Infrastructure		17	17	100%	
	<b>Total (Producer)</b>	11	19	30		
		100%	89%			
		Producer Accuracy				
	Total correct	29				
	Total pixels	30				
	Overall Accuracy	97%				

The results of the accuracy assessment that was undertaken for Ladybrand classified images are shown in **Table 6**.

True Pixels (Actual)						
		Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>	
Classified	<b>2011</b>					
	Green Infrastructure	13			13	100%
	Blue Infrastructure		3		3	100%
	Grey Infrastructure	3		11	14	79%
	<b>Total (Producer)</b>	16	3	11	30	
		81%	100%	100%		
		Producer Accuracy				
	Total correct	27				
	Total pixels	30				
	Overall Accuracy	90%				
	<b>2016</b>	Green Infrastructure		Grey Infrastructure	<b>Total (User)</b>	
Classified	Green Infrastructure	17		2	19	89%
	Grey Infrastructure	3		8	11	73%
	<b>Total (Producer)</b>	20		10	30	
		85%		80%		
		Producer Accuracy				
	Total correct	25				
	Total pixels	30				
	Overall Accuracy	83%				
	<b>2021</b>	Green Infrastructure		Grey Infrastructure	<b>Total (User)</b>	

Classified	Green Infrastructure	15		1	16	94%  (User Accuracy)		
	Blue Infrastructure							
	Grey Infrastructure	1		13	14			
	<b>Total (Producer)</b>	16		14	30			
		94%	93%					
		Producer Accuracy						
	Total correct	28						
	Total pixels	30						
	Overall Accuracy	93%						

The results of the accuracy assessment that was undertaken for Reitz classified images are shown in **Table 7**

		True Pixel (Actual)					
	2011	Green Infrastructure	Grey Infrastructure	Total (User)			
Classified	Green Infrastructure	18	1	19	95% User Accuracy		
	Grey Infrastructure		11	11			
	<b>Total (Producer)</b>	18	12	30			
		100%	92%				
		Producer Accuracy					
	Total correct	29					
	Total pixels	30					
	Overall Accuracy	97%					
		True Pixel (Actual)					
	2016	Green Infrastructure	Grey Infrastructure	Total (User)			
Classified	Green Infrastructure	10	1	11	91% User Accuracy		
	Grey Infrastructure		19	19			

	<b>Total (Producer)</b>	10	20	30			
		100%	95%				
		Producer Accuracy					
	Total correct	29					
	Total pixels	30					
	Overall Accuracy	97%					
	<b>2021</b>	Green Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	14	3	17	82%	User Accuracy	
	Grey Infrastructure		13	13	100%		
	<b>Total (Producer)</b>	14	16	30			
		100%	81%				
		Producer Accuracy					
	Total correct	27					
	Total pixels	30					
	Overall Accuracy	90%					

The results of the accuracy assessment that was undertaken for Memel classified images are shown in **Table 8**

		True Pixels (Actual) - Memel						
	<b>2011</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	10			10	100%	User Accuracy	
	Blue Infrastructure	2	7	1	10	70%		
	Grey Infrastructure			10	10	100%		
	<b>Total (Producer)</b>	12	7	11	30			
		83%	100%	91%				

		Producer Accuracy						
		Total correct	27					
		Total pixels	30					
		Overall Accuracy	90%					
	<b>2016</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	9		1	10	90%	User Accuracy	
	Blue Infrastructure	3	7		10	70%		
	Grey Infrastructure			10	10	100%		
	<b>Total (Producer)</b>	10	7	11	30			
		75%	100%	91%				
		Producer Accuracy						
		Total correct	26					
		Total pixels	30					
		Overall Accuracy	87%					
	<b>2021</b>	Green Infrastructure	Blue Infrastructure	Grey Infrastructure	<b>Total (User)</b>			
Classified	Green Infrastructure	12			12	100%	User Accuracy	
	Blue Infrastructure	1	6		7	86%		
	Grey Infrastructure	3		8	11	73%		
	<b>Total (Producer)</b>	16	6	8	30			
		75%	100%	100%				
		Producer Accuracy						
		Total correct	26					
		Total pixels	30					
		Overall Accuracy	87%					