WATER AVAILABILITY, INFRASTRUCTURE MANAGEMENT AND WATER GOVERNANCE IN THE GOEDVERWACHT HISTORICAL SETTLEMENT IN THE WESTERN CAPE, SOUTH AFRICA

by

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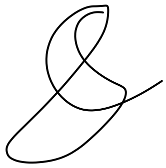
DECLARATION

I, Aphiwe Manyiki, declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed  **Date** 27-02-2026

ABSTRACT

Smallholder farmers in Africa, particularly in South Africa, face significant challenges in transitioning to commercial farming. As a developing nation, South Africa's agricultural sector struggles with limited support for smallholder farmers, hindering their growth and development. Climate change exacerbates these challenges, particularly through the increased scarcity of water resources. This scarcity leads to heightened competition among smallholder farmers for access to water during critical rainfall periods. This study investigates (i) the agricultural water availability to smallholder farmers in the Goedverwacht historical settlement in the Western Cape Province of South Africa, (ii) assess the impacts of drought and climatic change on smallholder farming in the area, (iii) investigate the condition and the performance of the agricultural water infrastructure used by smallholder farmers, (iv) and assess the water governance policies in Goedverwacht and how they affect water availability to smallholder farmers.

Data was collected from 17 smallholder farmers in the Goedverwacht, as well as five key informants from the Western Cape Department of Agriculture. A survey questionnaire was administered to gather quantitative data, while water measurements were taken using a Global Water Flow Probe, accompanied by a visual assessment of the water infrastructure's condition. Qualitative data regarding farmers' perceptions was analysed using Atlas.ti software (Version 23.4.0) to provide deeper insights into the challenges they face, Microsoft Excel software (365) was used to analyse the rainfall and temperature trend over a period of 20 years. Water measurements indicated that there is an adequate supply of water for

smallholder farmers operating in Goedverwacht. The perceptions of the farmers also reflect that they do not experience complete water shortages during dry periods. However, the farmers pointed out that social issues pose greater challenges. These include instances of residents blocking water flow during the summer months to create swimming pools, which in turn restricts the farmers' ability to irrigate their crops. Additionally, farmers experience a loss of water pressure due to simultaneous irrigation by multiple farmers. Key informants operating in the area confirmed that Goedverwacht is one of the few locations where water remains consistently available for farmers, as the water source is supplied by a spring.

The infrastructure for water delivery is generally in good condition, with no visible signs of deterioration. However, there was inconsistency in the perceptions of both farmers and key informants regarding the state of the infrastructure. While some farmers suggested that the infrastructure is in poor condition, the majority were unaware of its age, despite expressing concern over its reliability. No records of the irrigation system's design were available due to the local context of ambiguous land tenure contracts. Climate change data reveals a slight decrease in rainfall and an increase in temperature over the past 20 years. Qualitative analysis corroborates these findings, with both smallholder farmers and key informants noting a rise in temperatures and a reduction in rainfall. Many farmers indicated that the impact of climate change has become more apparent in recent years. In terms of governance, the study found that there is no clear structure for farmer participation in decision-making processes. Farmers mentioned that the church, which is the custodian of the land in the area, was expected to play a central role in overseeing these processes. However, they expressed frustration that the church neglects the needs and concerns of smallholder farmers. The issue of water rights, which contributed to water shortages during the 2015–2018 drought, as highlighted in a Water Research Commission (WRC) study, requires intervention from the Western Cape government and other relevant institutions regarding land tenure. However, while the WRC report identified challenges such as poor infrastructure, this study’s findings indicate that the infrastructure is in good condition. Instead, social issues were the primary cause of water shortages during the 2015–2018 drought period. These findings of the study imply that policy interventions should prioritise strengthening local water governance, clarifying land and water rights, and regulating non-agricultural water use, rather than focusing solely on infrastructure investment, to enhance equitable and sustainable water access for smallholder farmers.

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GLOSSARY

Abbreviations and acronyms	Explanation
AGNES	African Group of Negotiators Expert Support
ARC	Agricultural Research Council
CCT	City of Cape Town
CMA	Catchment Management Agent
CMS	Catchment Management Strategy
CPUT	Cape Peninsula University of Technology
DoA	Department of Agriculture
DALRRD	Department of Agriculture, Land Reform, and Rural Development (DALRRD)
DWAF	Department of Water Affairs and Forestry
DWS	Department of Water and Sanitation
DWA	Department of Water Affairs
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Product
Ha	Hectares
HDI	Historically disadvantaged individual
IPCC	Intergovernmental Panel on Climate Change
km	Kilometres
L	Litres
LHWP	Lesotho Highlands Water Project
m	Metres
m/s^2	Metres per second squared
m^3/s	Cubic metres per second
NGO	Non-governmental organisation
NWA	National Water Act
NWRS	National Water Resource Strategy
OECD	Organisation for Economic Cooperation and Development
POPI	Protection of Personal Information
PVC	Polyvinyl chloride
SADC	Southern African Development Community
SANS	South African National Standard
SAWS	South African Weather Services
StatsSA	Statistics South Africa
UNDESA	United Nations Department of Economic and Social Affairs
UNECA	United Nations Economic Commission for Africa

Abbreviations and acronyms	Explanation
UNFCCC	United Nations Framework Convention on Climate Change
UNDRR	United Nations Office for Disaster Risk Reduction
WCWSS	Western Cape Water Supply System
WHO	World Health Organisation
WMA	Water Management Areas
WMI	Water Management Institutions
WMO	World Meteorological Organisation
WRC	Water Research Commission
WRM	Water Resource Management
WRPM	Water Resources Planning Model
WRYM	Water Resources Yield Model
WSI	Water Services Institutions
WUA	Water Users Association
WWDR	World Water Development Report
WWF-SA	Worldwide Fund for Natu - South Africa

CHAPTER ONE

INTRODUCTION

1 Introduction

This chapter provides an overview of the study, establishing the context and framework for the research. It begins by detailing the background of the study, which presents the relevant context and identifies the key issues that inform the research problem. The problem statement is then articulated, clearly defining the central research question that the study seeks to address. Following this, the chapter outlines the aim and specific objectives of the study, providing a roadmap for the research process and the intended outcomes. The motivation for the study is also discussed, offering a rationale for why the research is timely, significant, and relevant. Additionally, the chapter highlights the significance of the study, emphasizing its potential contributions to the field and broader implications for theory, practice, or policy. Finally, the limitations of the study are acknowledged, identifying any constraints or challenges that may impact the research process or the generalizability of the findings.

1.1 Motivation for the study

The recent drought that occurred between 2015 to 2018 impacted most parts of South Africa. In the Western Cape Province, the drought caused water shortages in places such as the Goedverwacht historical settlement in the West Coast District Municipality, located in the Western Cape Province (Ncube, 2020). According to the Water Research Commission (WRC), a study titled "Smallholder farmer drought coping and adaptation strategies in Limpopo and Western Cape" (Ncube, 2020), conflicts arose between smallholder farmers regarding water usage in areas such as the Goedverwacht. Most farmers and community members raised concerns about inequitable water distribution, particularly favouring upstream farmers, as well as reduced water pressure, which resulted in insufficient water reaching smallholder farmers located downstream. Another complex issue raised by smallholder farmers in Goedverwacht was the ambiguity of lease contracts, which made them hesitant to make long-term investment decisions regarding the water infrastructure.

The institutional arrangements and governance in the Goedverwacht are complex and unique (Ncube, 2020). The Moravian Church owns land in Goedverwacht, and smallholder farmers are made to only pay taxes and rates for a lease of almost ten years. The water rights are held by the church, not the Municipality, as is normally the case in many parts of the country. According to the study conducted by non-governmental organisations (NGOs) in the community (EMG, 2016), the local Municipality intervened and offered their support at a point when the landowner (Moravian Church) could not maintain the water infrastructure properly by supplying chemicals for water treatment, and supplying water using water tankers during the summertime when reservoirs run dry. According to Law and Pereira (2018), the West Coast District Municipality also offered support to conduct monthly water quality tests to ensure water in the area complied with the drinking South African National Standards.

Other challenges identified were the broken pipes that distribute water and poor management policies due to a lack of land contracts (Ncube, 2020, Fanadzo et al., 2021). The underlying cause of the water shortages during the drought periods in Goedverwacht may be more than what smallholder farmers claimed in the WRC study. The problems could have been due to the community's population growth, which affects the water demand allocated to the community, an increase in agricultural activities since the area has potential for cultivation, and the poor maintenance of the water distribution system infrastructure, which might cause leaks and water loss throughout the system. It could also be due to the arrangements of water management policies responsible for water allocations, hence the need for a study to investigate all the challenges that were not necessarily covered in the scope of the WRC research. Once these aspects are addressed, it is anticipated that the findings will contribute to understanding the real issues responsible for water shortages during the dry seasons in the Goedverwacht historical settlement.

1.2 Problem statement

Drought is a global problem affecting human beings and the environment, particularly water resources (Vicente-Serrano et al., 2019). In many instances, drought causes water shortages and if emergency measures to mitigate the problem are not in place, it can lead to food shortages and loss of lives (Unfried et al., 2022). Drought is no stranger to the African continent and in the case of South Africa, having diverse climatic conditions, drought has been experienced throughout the country (Baudoin et al., 2017a). Amongst the reported cases over the years, one of the drought events which caught the South African government unprepared was the 2015-2018 drought in the Western Cape Province which significantly impacted various sectors throughout the province, particularly the agriculture sectors, which primarily depends on water either for crop or livestock production (Theron et al., 2021). The commercial farmer within the agriculture sector experiences the consequences of drought even though in most instances they have resources at their disposal, while emerging farmers, particularly the smallholder farmers, do not have resources to assist them in coping or adapting to these extreme weather events.

In the Western Cape Province, smallholder farmers vulnerable to the 2015-2018 drought included farmers in communities such as the Goedverwacht. As highlighted in the WRC report entitled “Smallholder farmer drought coping and adaptation strategies in Limpopo and Western Cape” (Ncube, 2020), one of the key challenges faced by smallholder farmers in the Goedverwacht historical settlement during the drought was the lack of water rights. This resulted in poor management of water resources, with upstream smallholder farmers accessing more water than stipulated on their schedules according to the findings from the WRC report.

The poor state of infrastructure in distributing water to smallholder farmers was also highlighted as a major challenge. This can be attributed to the historical neglect of water infrastructure in many rural areas, which has resulted in a lack of maintenance and repair. This, in turn, has led to leaks, inefficiencies, and unreliable water supply to smallholder farmers in Goedverwacht(Pili & Ncube, 2022). These challenges highlight the need for improved water governance and infrastructure management in rural areas. Smallholder farmers are often the most vulnerable to the impacts of water scarcity and climate change, yet they are often excluded from water governance processes and lack access to reliable water infrastructure (Zenda, 2024). To address these challenges, there is a need for more participatory and inclusive water governance processes that involve smallholder farmers in decision-making and planning. This will assist in considering the needs and perspectives of smallholder farmers in water management and infrastructure planning.

1.3 The objectives of the research

The main aim of this study was to investigate the causes that led to agricultural water shortage during the 2015- 2018 drought season in the Goedverwacht historical settlement in the West Coast Municipality of the Western Cape Province. To achieve this, the specific objectives of this study were to:

- Assess the agricultural water availability to smallholder farmers in Goedverwacht.
- Assess the impacts of drought and climatic change on smallholder farming in the area.
- Investigate the condition and the performance of the agricultural water infrastructure used by smallholder farmers.
- Assess the water governance policies in Goedverwacht and how they affect the availability of water for smallholder farmers.

1.4 Research question

To achieve the study's aim and objectives, the central question guiding this research is:

What were the principal causes of agricultural water shortage during the 2015–2018 drought season for smallholder farmers in the Goedverwacht historical settlement?

This main question is addressed through the following specific sub-research questions:

- What was the state of agricultural water availability, including sources and reliability, for smallholder farmers in Goedverwacht during and preceding the drought period?
- How did the 2015-2018 drought and underlying climatic trends affect local water resources and the viability of smallholder farming in the area?
- What was the condition and performance of existing agricultural water infrastructure, and in what ways did it influence the severity of the water shortage?
- How did water governance policies, institutional arrangements, and local management practices shape the availability and allocation of water for smallholder agriculture in Goedverwacht?

1.5 Significance of the study

This study provides empirically grounded insights into how water governance arrangements and infrastructure conditions influence water availability for smallholder farmers in historical settlements such as Goedverwacht. By documenting the condition, capacity, and functioning of the spring-fed canal system, alongside farmer and institutional perspectives, the study identifies specific governance and infrastructure constraints that limit reliable access to agricultural water. These findings form the evidence base for targeted recommendations aimed at improving water allocation, infrastructure maintenance, and institutional coordination.

As part of a broader Water Research Commission (WRC) project, the study contributes context-specific evidence to ongoing policy and planning processes concerned with sustainable water management in historically marginalised rural settlements in the Western Cape. The results are directly relevant to key stakeholders, including provincial agricultural departments, water management authorities, traditional or institutional landholders, and local water user groups, by highlighting practical interventions that can enhance system performance and equity under conditions of increasing climatic stress.

More broadly, the study contributes to the literature on smallholder water security by demonstrating how climate variability, infrastructure performance, and governance structures interact to shape agricultural water outcomes in resource-constrained settings. By linking observed water shortages to identifiable institutional and physical factors, the research supports the development of realistic, evidence-based strategies to improve agricultural productivity, resilience, and long-term water security. The findings also provide a foundation for future research and innovation focused on locally appropriate governance reforms and low-cost infrastructure improvements in similar historical settlements.

1.6 Delineation of the study

The scope of this study was limited to Goedverwacht, a historical town located in the West Coast District Municipality of the Western Cape Province in South Africa. The study focused on smallholder farmers and local institutions operating in Goedverwacht. This targeted approach enabled the researcher to obtain in-depth insights into the water-related challenges faced by smallholder farmers in the town and assess the effectiveness of local water governance systems in addressing these challenges. The study's restricted focus on a specific geographical area and target population ensured the accuracy and relevance of the study's findings and recommendations, contributing to the development of tailored interventions for addressing water challenges in similar historical settlements.

1.7 Limitations of the study

Several constraints were encountered during the process of data collection. One major challenge was securing approval from the Department of Agriculture in the Western Cape Province. Prior to conducting any study involving people and the environment, it is necessary to obtain permission from relevant governing institutions in the specified area to comply with the Protection of Personal Information (POPI) Act. According to the Western Cape Government, the purpose of the POPI Act is due to the rising incidents of theft and improper utilization of individuals' personal data have highlighted the necessity to establish regulations aimed at safeguarding both personal information and the fundamental right to privacy.

The POPI Act has been introduced to establish baseline standards pertaining to the acquisition and 'processing' of any personal data owned by others. According to the Act, 'processing' encompasses activities such as gathering, receiving, documenting, arranging, retrieving, as well as utilizing, distributing, or exchanging any of said information. The most significant hurdle emerged in the form of equipment unavailability, specifically the absence of the equipment intended for measuring water flow to accurately assess the water supplied to the smallholder farmers in Goedverwacht. Moreover, the use of a small vehicle during interviews with the smallholder farmers posed limitations. This choice hindered the possibility of conducting on-site visits for visual assessments of water infrastructure and sources. The small vehicle proved inadequate for navigating through certain parts of Goedverwacht due to the rugged and uneven terrain features.

Summary

This study investigates the agricultural water shortages faced by smallholder farmers in Goedverwacht, Western Cape, during the 2015-2018 drought, as outlined in the WRC report. It examines the complex interplay of factors contributing to water scarcity, including inadequate water infrastructure, poor maintenance, ambiguous lease contracts, and unique governance structures where the Moravian Church, rather than the Municipality, holds water rights. The research aims to assess water availability, the impacts of drought and climate change, the condition of water infrastructure, and the effectiveness of local water governance policies. By focusing on Goedverwacht, the study seeks to provide insights into improving water management and infrastructure to ensure equitable access and enhance resilience for smallholder farmers. Despite its significance, the study faced limitations, such as challenges in securing approvals under the POPI Act, equipment unavailability for measuring water flow, and logistical constraints due to inadequate vehicles for on-site assessments. The findings are expected to inform sustainable water management practices and contribute to policy development for historical settlements facing similar challenges.

1.8 Thesis structure

This study is structured across five distinct chapters. Chapter one serves as the introduction to the research, outlining the rationale and significance of the study, alongside the contextual background. It delineates the central research problem, establishes the boundaries and scope of the investigation, and sets forth the specific research objectives guiding the study. Chapter two provides an extensive review of the relevant literature, with a primary focus on water availability in relation to smallholder farmers. The chapter critically examines the impact of climate change on agricultural productivity, particularly in the African context, with a focus on South Africa. This literature review juxtaposes meteorological data with the lived experiences of smallholder farmers, as documented by various scholars. Additionally, the chapter investigates the adaptation strategies employed by smallholder farmers across the African continent, with a specific emphasis on those in South Africa, during periods of water scarcity and low rainfall. An assessment of the water governance framework is also conducted, with a focus on identifying the governmental and institutional bodies primarily responsible for supporting smallholder farmers in the context of water resource management.

Chapter three presents a detailed account of the study area, offering background information on the geographical, socio-economic, and environmental characteristics of the region under investigation. This chapter also outlines the research design and methodology employed in the study, justifying the choice of methods and techniques for data collection and analysis. Chapter four presents the empirical findings of the research. The results are organized around several key themes, including water measurements, an assessment of water infrastructure, the impact of climate change on smallholder farmers and their agricultural activities, and the relationship between water governance policies and the perceptions of smallholder farmers and key informants. The analysis of these findings is conducted through a comparative lens, highlighting discrepancies or alignments between policy and practice. Chapter five synthesizes the conclusions drawn from the study and offers a set of recommendations. Based on the empirical data and analysis, the chapter presents actionable recommendations for policy development, governance reforms, and practical interventions aimed at improving water resource management for smallholder farmers in South Africa and other similar semi-arid regions.

CHAPTER TWO
LITERATURE REVIEW

2 Introduction

This chapter presents a review of the existing literature regarding water availability in South Africa, specifically focusing on water allocated for agricultural production, particularly in the Western Cape Province. The study aims to examine the water allocated to smallholder farmers in relation to the total water allocated to the agriculture sector, the state and type of irrigation infrastructure predominantly used by smallholder farmers to enhance our understanding of government efforts in supporting smallholder farmers' development. It also explores the perspectives of smallholder farmers on climate change compared to meteorological evidence of climate change across the African continents, giving particular attention to the South African context. Moreover, it examines the different adaptation strategies that smallholder farmers are likely to employ.

Due to the heightened significance of the Western Cape region, the literature pertaining to smallholder farmers in this area is given particular attention. Additionally, an assessment is conducted to evaluate water management institutional setup, and governance systems that have proven successful among smallholder farmers in Africa, South Africa, and the Western Cape Province. Furthermore, the governance system implemented by smallholder farmers is scrutinized to gain insights into practices that can ensure the sustainable management of water resources on their farms.

2.1 Global water resources

Water is a fundamental and essential resource for humanity, abundantly present across our planet. Water resources are essential for maintaining biodiversity and delivering social and economic benefits to people (Grizzetti et al., 2016; Lu et al., 2019). However, despite its widespread presence, only a relatively small fraction of freshwater is readily accessible and usable. The estimated amount of water on earth and in the atmosphere is approximately 13,000 billion m^3 (Baisch, 2009). This total volume of water is, however, not readily available to be used by humans, whether for agricultural, industrial, recreational, household or environmental activities. About 97% of the water on earth is salty (mostly sea water) and it is not usable as it is expensive to treat as compared with surface water(Ding, 2024). Approximately 3% of the earth's water is freshwater, with more than 2% of it being frozen in glaciers and polar ice caps. This means the freshwater available for human beings and the ecosystem is 1%. Approximately 30% of this available water for humans and ecosystems is groundwater, which on its own is not easily accessible, only 0.3% of freshwater is easily accessible above the ground in lakes and rivers. This small portion (0.3%) of freshwater totals about 835 000 km³, with most of it (630 000 km³) stored in groundwater, while the remaining 205 000 km³ is distributed across lakes, rivers, wetlands, and soils (Abbott et al., 2019). Freshwater supports a range of human activities from irrigation to industrial processes including the generation of hydroelectricity and the cooling of thermoelectric power plants (Bates et al., 2008; Schewe et al., 2014). Globally, about 70% of freshwater is used for irrigation, 22% is used for industry and 8% is used for domestic needs (Georgeson et al., 2016a). These activities require an adequate supply of freshwater, which can be sourced from rivers, lakes, groundwater reserves, and, in some cases, desalinated seawater (Schewe et al., 2014). Hoekstra & Mekonnen (2012) also indicated that agriculture accounts for around 92% of total freshwater use, while irrigation is responsible for approximately 70% of all freshwater withdrawals globally. Global water demand for all uses, currently around 4 600 km³ per year, is projected to rise by 20 to 30% by 2050, reaching between 5 500 and 6 000 km³ per year (WWAP/UN-Water, 2018). Additionally, water demand for agriculture is expected to grow by 60% by 2050 (WWAP/UN-Water, 2018)

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The combined effects of water supply and demand will likely widen the gap between water availability and demand, further intensifying existing water management challenges (Lu et al., 2019). To ensure water is always available for different uses, infrastructure such as dams are developed to store water. Reservoirs are commonly used to store water during periods of excess availability and continuously supply water to cities to avoid water shortages during dry periods (Di Baldassarre et al., 2018). Accessible water resources that support both humans and the environment are vulnerable to various factors that can lead to shortages. These factors include climate change and drought, pollution, and population growth.

2.2 Global factors affecting the availability of water resources

2.2.1 Climate change

There are various factors affecting the availability of water resources globally. Amongst these factors, the most popular factors are climate changes such as prolonged high temperatures, and extreme low rainfall, while the rapid increase of population, and poor service delivery by the governments are also important. Over the past decades, the combined effects of climate change and human activities have made freshwater availability a major global concern (Hoekstra et al., 2012; Famiglietti, 2014; Konapala et al., 2020). Increased rainfall can lead to higher water flow, a greater risk of flooding, and reduced groundwater recharge (Sen, 2021). Meanwhile, rising temperatures contribute to increased evapotranspiration, raising the demand for irrigation water, which is already a significant consumer of freshwater (Wang et al., 2016).

Rising temperatures are considered evidence of environmental change and have begun to significantly impact water resources, with increasingly severe consequences expected over time (Lu et al., 2019; Srivastav et al., 2021). Precipitation is essential for sustaining life on Earth, with the global average precipitation estimated at approximately 860 mm [Statistics South Africa (StatsSA), 2010]. Climate change remains one of the most critical challenges faced by both human populations and natural ecosystems [Intergovernmental Panel on Climate Change (IPCC) 2007, 2013]. Current global climate projections indicate that rising temperatures are driving more frequent extreme weather events, including heavy rainfall, floods, storms, and prolonged droughts (IPCC 2012, 2019; Nicholson, 2017). An imbalance of water, either excessive or insufficient, heightens the risks of flooding and drought as precipitation patterns become more variable in a warming climate (Stocker et al., 2013; Hoegh-Guldberg et al., 2018). According to the World Health Organisation (WHO, 2019), the impacts of climate change are often experienced through water-related challenges, highlighting the urgent need for climate adaptation measures to ensure water security and build resilient communities and ecosystems.

It is now widely recognized that Earth's climate is changing at an unprecedented rate in recent history (IPCC, 2021). Based on global temperature trends recorded in 2007 by the United Nations Framework Convention on Climate Change (UNFCCC, 2007), the average global temperature has risen by approximately 0.74°C since pre-industrial times. Observations by the World Meteorological Organisation (WMO) in 2020 indicated that, due to continued increases in atmospheric carbon emissions, global temperatures in 2019 were about 1.1°C higher than pre-industrial levels. According to the prediction by IPCC's AR5 report (IPCC, 2014), atmospheric temperatures could rise globally by 4°C by 2100, which in turn will significantly affect global water supply. All these predictions about climate change have something in common: the increasing trend of temperature levels that might have a negative impact on humans and the environment. This temperature increases ranked 2021 as one of the fifth to seventh warmest years on record, even in the presence of prevailing La Niña conditions (WMO, 2022). In climate change and hydrology studies, rainfall and temperature parameters are accepted as the major factors underlying unexpected adverse effects on nature, agriculture, and society.

The changes in temperature or rainfall normally results in naturally hazardous extreme events across the world. These events caused damages that cost huge money to fix and directly affected people, causing deaths and loss of shelter. According to WMO (2021), a total of 432 large and medium-scale natural hazard extreme events were recorded worldwide. These events resulted in nearly 10 000 deaths, caused over US$ 250 billion in damages, and directly impacted more than 100 million people globally. In 2019, the World Bank (2019) reported that "over US$3 trillion has been lost to natural disasters caused by natural hazards, with total damages increasing by more than 600% from $23 billion a year in the 1980s to US$150 billion a year in the last decade". These extreme events included drought and floods. Since 2008, an average of 22.5 million people were displaced annually, due to climate- or weather-related disasters such as droughts and floods (Bower et al., 2015).

2.2.2 Population growth

The world population is growing at a faster rate, from 0.8 billion in 1950, the population grew to 4.4 billion in 2020, and is expected to reach 10 billion by 2050 [United Nations (UN), 2018; World Water Development Report (WWDR), 2018]. The increase in population will have a significant impact on human beings, as many parts of the world already face challenges such as water scarcity caused by the imbalance between water availability and demand, where water demand exceeds availability. Over the past 100 years, global water demand has risen by 600% (Wada et al., 2016). Global water demand will grow significantly over the next two decades in all three sectors, industry, domestic, and agriculture (WWDR, 2018). Even though the agricultural water will always remain the largest component, the domestic and industrial water demand will grow faster than the agricultural water (WWDR, 2018). Rapid population growth has led to increased water consumption, significantly intensifying the frequency of global droughts by 27% (Wada et al., 2013).

Water scarcity is a complex issue of human deprivation, defined by a lack of access to affordable and safe water to meet societal needs or by a situation where these needs are fulfilled at the expense of the environment. Although water scarcity is a global challenge, its effects are most severe for the poorest and most vulnerable populations. Currently, nearly half of the world's population (3.6 billion people; 47%) experiences water scarcity for at least one month each year (Mekonnen & Hoekstra, 2012; WWDR, 2018). This scarcity has significant consequences for food production, which is directly dependent on water resources. The increasing global demand for food is placing immense pressure on the Earth's land and water systems. Rising food demands due to rapid population growth could lead to severe food insecurity, posing a challenge to the United Nations' 2030 Zero Hunger Agenda, which aims to achieve sustainable development [Food and Agriculture Organisation (FAO), 2017; Fujimori et al., 2019].

2.3 Water resources in Africa

Water scarcity can be categorized into two primary types: physical and economic. Physical water scarcity arises when water resources are extensively utilized for various purposes, leading to a situation where these resources no longer adequately fulfil the needs of the population (UNICEF, 2023). In this scenario, there is an actual deficiency of water availability in physical terms. Conversely, economic water scarcity is associated with issues such as inadequate governance, deficient infrastructure, and limited investments in water-related systems (FAO, 2007). This form of water scarcity can persist even in regions or countries where water resources and infrastructure are theoretically sufficient.

Africa is home to some of the world's largest freshwater systems, including the Nile, the longest river on Earth, and the Congo River, which has the second largest basin globally in terms of drainage area and discharge into the ocean (Dai et al., 2009; Laraque et al., 2020). Additionally, three of the ten largest freshwater lakes by area and volume, Lake Victoria, Lake Tanganyika, and Lake Malawi, are also located on the continent (Hernegger et al., 2021). However, these water resources are unevenly distributed across Africa, leaving some arid regions in water scarcity. In addition to these major water bodies, smaller systems such as streams, reservoirs, ponds, and tanks are also essential parts of Africa's landscapes (Gardelle et al., 2010). These smaller water sources play a crucial role in providing water, food, and other natural resources for agriculture, particularly for the largely rural populations in regions like sub-Saharan Africa. It is however very surprising that the hydrology of the African river basins remains one of the least studied worldwide and has not attracted as much attention among the scientific and international communities (Alsdorf et al., 2016) as the Amazon River basin (Fassoni-Andrade et al., 2021) or the Indian sub-continent with the Ganges-Brahmaputra (Papa et al., 2015). At the beginning of the 21st century, Africa's water resources were described as "increasingly threatened" due to transboundary issues, climate change, water scarcity, desertification, pollution, and environmental degradation [United Nations Economic Commission for Africa (UNECA), 2003].

Water challenges in urban and rural areas are very likely to increase through competing dem ands, rapid population growth and a lack of infrastructure
(IPCC, 2001). At the same time, Africa is the continent with the lowest conversion factor of pr ecipitation to runoff (15%) and faces challenging high evaporation rates (IPCC, 2001; UNEC A, 2003). In many regions of Africa, access to clean water is already limited. When considering the expected population growth based on statistical projections, it becomes evident that both the demand for food and, subsequently, the need for water will increase. According to a report

by Oluwasanya (2022), overall, water security levels in Africa remain low. No country, let alone an entire subregion, has yet reached a "model" or even "effective" stage of water security. Except for Egypt, all countries have water security scores below 70. Among the 54 African nations, only 13 have attained a modest level of water security in recent years, while more than a third fall below the lowest threshold of 45. Among the most water-secure countries in Africa at present are Egypt, Botswana, Gabon, Mauritius, and Tunisia. However, it is important to note that their absolute levels of water security remain modest. These scores were obtained from a composite index calculated from 10 indicators across five dimensions (drinking water/sanitation, water availability, productivity, quality/ecosystems, and governance/resilience). Each indicator is scored out of **10** (based on normalized data from sources like WHO, FAO, World Bank, etc.), then summed to give the total national score out of 100. Higher scores mean better water security; the score is classified into stages: Emerging (0–45), Slight (45–60), Modest (60–75), Effective (75–90), or Model (90–100).

On the other end of the spectrum, Somalia, Chad, and Niger appear to be the least water-secure countries in Africa (Oluwasanya, 2022). There has been little progress in the national water security of most African states over the past decades. In Africa, small-scale agriculture heavily relies on rainfall, as it is primarily rain-fed rather than irrigated (Barrios et al., 2008; FAO, 2016). As a result, traditional farming systems are highly affected by droughts and floods, particularly during the early stages of planting and germination. Over the past two decades, the availability, long-term security, and sustainability of local water resources have become increasingly important. Climate change has further impacted their resilience, reliability, and quality, making water management a critical issue (Adhikari et al., 2015; Nicol et al., 2015).

2.4 Factors affecting water resources in Africa

2.4.1 Climate change and its impact on water resources

Climate fluctuations in Africa are influenced by the continent's complex topography and marine conditions (Jury, 2018). African countries are becoming increasingly susceptible to the risks of climate change and other water-related disasters. The rising climate variability results in more frequent and severe hydroclimatic extremes like floods and droughts. A warming climate intensifies precipitation variability, thereby raising the likelihood of floods and droughts (Stocker et al., 2013; Hoegh-Guldberg et al., 2018). These events pose a significant threat to both lives and livelihoods, leading to substantial economic losses (WMO, 2022).

In January 2021, Tropical Cyclone Eloise brought heavy rainfall to Mozambique, Madagascar, and South Africa (WMO, 2022). The resulting floods impacted over 467 000 people and tragically resulted in the loss of up to 12 lives. On the other hand, Ethiopia, Kenya, and Somalia have experienced a series of consecutive years with below-average rainfall, leading to a regional drought (WMO, 2022). This prolonged dry spell has resulted in up to 18 million people facing food insecurity, with over seven million children suffering from acute malnutrition. Since the 1960s, Africa has faced over 382 drought events, impacting millions of people, especially in the Sahel and Southern Africa regions (Shiferaw et al., 2014).

2.4.2 Population growth

Most of the population growth is expected in developing countries, first in Africa, and then in Asia, where scarcity of clean water is already a major issue. In Africa and Asia, it is anticipated that the population will increase by 1.3 billion and 0.75 billion respectively by 2050 [United Nations Department of Economic and Social Affairs (UNDESA), 2017]. Africa is the second-largest continent in the world, both in size and population with an approximate area of 30 million km^2. The population in Africa is estimated to be approximately 1.3 billion (Worldbank, 2023) and Africa is considered the fastest-growing population in the world. The continent's population currently makes up approximately 17% of the global total population. By that year, Africa's share of the global population is projected to increase to 26%, with expectations to reach nearly 40% by 2100 (UN DESA, 2017). Africa’s annual growth rate currently exceeds 2.4% and in the next 20 years is projected to remain above 2% (Oluwasanya et al., 2022).

The expected population growth in most African countries is predicted to significantly reduce water availability. Simultaneously, economic development is anticipated to increase water consumption, exacerbating the challenge of addressing the gap in water supply (Baggio et al., 2021). In 2020, more than half of the 771 million people worldwide who still lacked access to basic drinking water services lived in Africa (Oluwasanya et al., 2022). According to Joint Monitoring Program (2021), of the two-thirds of people still lacking basic sanitation services in rural areas around the world, nearly half live in the African region. Agriculture remains the backbone of economic growth for most countries in Africa (African Group of Negotiators Expert Support (AGNES), 2020). Besides the impacts of climate change, population growth is also expected to increase natural resource scarcity and food insecurity in Africa (Godfray et al., 2010; Khan et al., 2014; Seto et al., 2012). In rapidly growing African economies, increasing demands for freshwater supply to sustain population growth and the needs of the agriculture and industrial sectors now pose significant threats to water resources (Haddeland et al. 2014; Mehran et al. 2017).

2.5 Water Resources in South Africa

2.5.1 Surface water resources

Water is an exceedingly scarce yet immensely vital resource in Africa, and South Africa specifically finds itself in the category of countries grappling with limited rainfall. It is worth noting that South Africa is ranked as the 30th driest nation worldwide (Hedden & Cilliers, 2014). The quantity of water available within the country to cater to human needs and maintain the water ecosystem exhibits significant variations across diverse locations, seasons, and even from one year to the next. South Africa, on average, receives a yearly rainfall of less than 500 mm, a stark contrast to other African countries and the global average of approximately 850 mm (Mahlalela et al., 2020). The low annual rainfall, averaging about 460 mm, is compounded by a high potential evapotranspiration of over 1800 mm per year (Du Preez et al., 2019). In terms of surface runoff, the country witnesses an approximate annual volume of 49 million cubic meters (Stevens & Van Koppen, 2015). This runoff is distributed across South Africa's 19 water management areas (Department of Water and Sanitation (DWS), 2022).

South Africa shares a total of four river basins (Limpopo, Inkomati, Orange, and Maputo) with six neighbouring African countries, namely Zimbabwe, Namibia, Mozambique, Botswana, Swaziland, and Lesotho. These countries have established bilateral cooperation agreements (DWA, 2014). The primary rivers that supply water for various purposes including agriculture, industries, and domestic use in South Africa encompass Umzimvubu, Pongola, Vaal, Orange, Limpopo, and Tugela (Book SA Irrigation history, 2024). It is estimated that more than 60% of the country's river flow originates from just 20% of its land area (IWRM, 2009).

South Africa is geographically divided into nine provinces, each experiencing varying amounts of rainfall during different periods of the year. To counterbalance the uneven distribution of water resources and effectively manage the challenges of floods and droughts, the country has established numerous dams. Collectively, these dams can store roughly two-thirds of the nation's mean annual rainfall (DWS, 2016). Among the approximately 5102 registered dams, a substantial majority (3 832) are classified as small dams, measuring less than 12 metres in height (DWS, 2015) as depicted in Table 2.1. Dams with a safety risk, meaning dams of more than 5 m and if the storage capacity exceeds 50 000m^3 according to section 120 of the National Water Act (NWA) must be registered by the dam owners (DWA, 2013b). These smaller dams play a pivotal role in bolstering local water security and enhancing resilience to climate fluctuations.

Table 2.1: Distribution of registered dams according to size (DWS, 2015)

Size class	Number	%
Small (less than 12 m) Medium (12 m to 30 m) Large (30 m and higher)	3 832 1 093 177	75.1 21.4 3.5
Total	5 102	100

Approximately 9 500 km^3 per year of the total water demand, which amounts to 12 871 km^3 per year, is withdrawn from surface water resources. The remaining portion is sourced from groundwater, the recycling of return flows, and the capture of water through afforestation (Stevens & Van Koppens, 2015). The collective storage capacity of larger dams amounts to approximately 31 000 million m^3. Notably, the country's reliance on surface water resources extends across sectors like agriculture, mining, and various socio-economic activities in both urban and rural environments.

South Africa's reliance on surface water remains substantial, and even in areas where additional water resources are potentially available, such as in the uThukela, Mzimvubu, and Pongola basins, these resources tend to be located quite distant from existing centres of demand. This underscores the significance of South Africa's commitment to enhancing integrated water resource management, a key aspect of ensuring ongoing water security. A pivotal part of this strategy involves optimizing the utilization of dam storage and efficient transfer systems, effectively managing the combination of water resources, and exploring a spectrum of options to harmonize water availability with demand.

A notable illustration of this approach can be seen in the remedial efforts undertaken at Clanwilliam dam in the Western Cape Province. This initiative involves raising the dam's height by 13 metres, a measure that contributes to bolstering water capacity. Another critical aspect is the transfer of water from Lesotho, which plays a substantial role in fortifying South Africa's water sector. Notably, this initiative, contributes immensely (60%) to the national economy and significantly supports the Gauteng region, which faces a scarcity of natural water resources. According to the DWS (2018), it is projected that the Clanwilliam dam will yield an additional 70 million m^3 of water upon completion by 2027.

On the other hand, the Lesotho Highlands Water Project (LHWP), a significant initiative, presently contributes approximately 780 million m^3 of water annually to the Gauteng Province. Upon completion of its second phase, which is anticipated by 2027, this contribution is slated to increase substantially to 1 260 million m^3 per year. This far-reaching project plays a pivotal role in supplying water to a vast population of 26 million individuals residing in the Gauteng region, including parts of Northwest, Free State, Mpumalanga, and Northern Cape Provinces closer to Gauteng province. The LHWP effectively ensures a consistent supply of water for a variety of purposes, including domestic consumption, irrigation, industries, and mining (Chand, 2021).

Over 77% of South Africa's water resources come from surface water sources, while groundwater contributes 14% and recycled return flows make up 7% (Africa et al., 2009). The allocation of usable water resources across various sectors is depicted in Figure 2.1 (DWS, 2018). Agriculture claims the largest share at 58%, followed by industrial and municipal use at 30%, mining at 6%, afforestation at 3%, power generation at 2%, and international obligations at 1% (Joshua Rasifudi et al., 2022). As depicted in Table 2.2, if water resources are managed prudently, the agricultural sector's water usage is projected to decline from the current estimate of 58% to 53% by the year 2040 given that there will be improvement in water governance and exploring additional water resources in South Africa.

Looking at the allocation of water resources by province, the Western Cape leads in utilizing water for agricultural purposes at 47.4%, followed by KwaZulu-Natal at 23%, Limpopo at 19.2%, Mpumalanga at 5.7%, Eastern Cape at 1.7%, Gauteng at 0.8%, Free State at 0.7%, Northwest at 0.5%, and Northern Cape at 0.4% (DWS, 2018). In South Africa, should the current trajectory of demand persist, it is anticipated that there will be a water supply deficit of approximately 2.7 to 3.8 million m^3 annually by the year 2030 (WWF-SA, 2016). This projected shortfall is largely attributed to factors like population growth and economic development, as articulated by WWF-SA (2016) and NW & SMP (2018b).

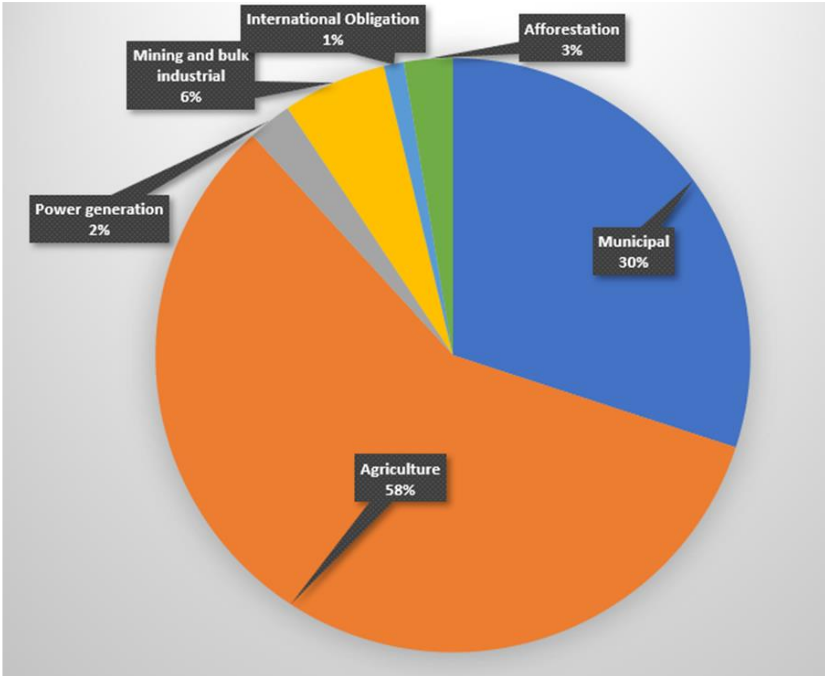

Figure 2.1: Water usage per economic sector (DWS, 2018)

Table 2.2: Water user per sector projections (Joshua Rasifudi et al., 2022)

User sector*	Water requirements (million m^3/ annum)				
	2015	**2020**	**2025**	**2030**	**2040**
Municipal (industries, commerce, urban and rural domestic)	4 447	4 900	5 400	5 800	6 600
Agriculture (irrigation and livestock watering)	9 000	9 500	9 600	9 700	9 800
Strategic/ Power generation	362	390	410	430	450
Mining and bulk industrial	876	921	968	1017	1124
International obligation	178	178	178	178	178
Afforestation	**15 294**	**16 321**	**16 989**	**17 559**	**18 586**

2.5.2 Groundwater resources in South Africa

Groundwater plays a pivotal role in South Africa's water supply framework, acting as a crucial supplement to surface water resources. It plays an indispensable role in catering to the demands of the nation's burgeoning economy, its agricultural sector, as well as its urban and rural populations. In rural regions and numerous towns across the country, groundwater serves as a dependable source of safe drinking water. Additionally, groundwater is a lifeline for irrigation purposes, sustaining vast expanses of valuable arable land throughout South Africa. Furthermore, it supports substantial numbers of livestock and wildlife, contributing significantly to various ecosystems (DWA, 2013). However, the availability of groundwater is influenced by a range of climatic factors, encompassing aspects such as rainfall patterns, drought occurrences, and flood events. These elements can exert a substantial impact on the availability of groundwater resources. Additionally, the issue of over-abstraction, wherein groundwater is withdrawn at a rate exceeding its natural replenishment, can further influence groundwater availability, potentially leading to depletion.

Around 11% of South Africa's populace relies on groundwater as their primary water source. The nation's Utilizable Groundwater Exploitation Potential is assessed at approximately 10 343 million m^3 annually (7 500 million m^3 in drought years) (WRC,2013). This estimation accounts for factors like extraction constraints, transportability, and maximum allowable drawdown. Notably, about 1 900 million m^3, equivalent to 9% of the country's provided water, are sourced from recorded groundwater abstractions. The extent of potentially accessible groundwater across South Africa displays notable variance, with estimates ranging from a maximum of 47 727 million m^3 per year to a minimum of 7 536 million m^3 per year (Woodford et al., 2006). For general water resource planning under normal rainfall conditions, it is advisable to consider an average groundwater exploration potential of roughly 19 073 million m^3. However, during periods of drought, this value decreases to approximately 16 253 million m^3. Groundwater serves diverse purposes, with the primary applications being agriculture (66%), domestic water supply (13%), mining (15%), as well as industry and aquaculture (6%) (DWAF, 2010; Middleton and Bailey, 2009). Given the country's propensity for drought, groundwater is particularly beneficial in many areas. However, the availability of groundwater varies from location to location across South Africa, and some regions of the country have no groundwater at all (Figure 2.2). Groundwater exploitation is an option for smaller towns and agriculture as well as for larger cities such as Cape Town and Nelson Mandela Bay Municipality (DWA 2010c). However, it's imperative to implement licensing requirements for both commercial and smaller areas to ensure the responsible utilization of groundwater and prevent its overuse.

The excessive withdrawal of groundwater, known as over-abstraction, can trigger a range of negative consequences, including the formation of sinkholes. In the South African context, the replenishment of groundwater resources can also be facilitated through artificial recharge. This process entails channelling surplus surface water underground to be stored within aquifers for subsequent extraction and usage (Bouwer, 2002). An illustrative example of this practice can be found in Atlantis, situated in the Western Cape Province. Areas with notably high groundwater recharge rates are referred to as high ground recharge area. In these regions, groundwater recharge occurs at a rate at least three times greater than that of primary catchments (Nel et al., 2011). These recharge areas hold immense importance in sustaining river flows, particularly during periods of dryness. Underground water storage offers notable advantages over surface storage, as it is less vulnerable to losses from evaporation and pollution.

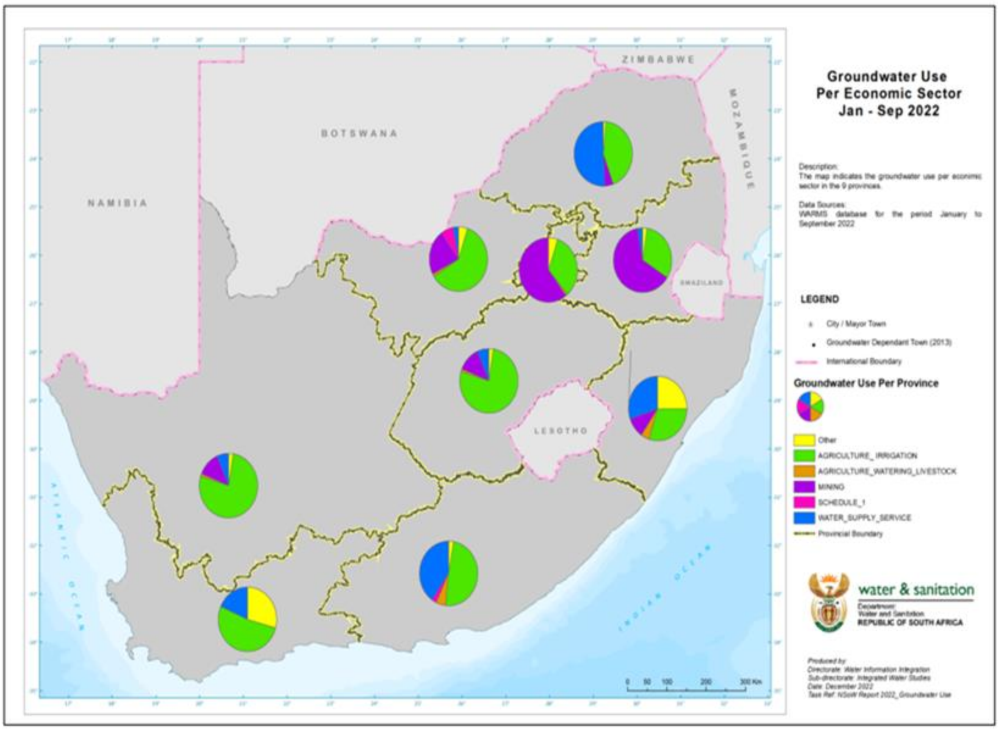

Figure 2.2: Groundwater usage per economic sector (DWS, 2022)

2.6 Summary

In conclusion, South Africa's water resources, characterized by limited rainfall and high evaporation rates, underscore the pressing need for effective management strategies. The country's dependence on surface water, supplemented by crucial groundwater resources, highlights the importance of optimizing water storage and distribution systems to address regional imbalances and support diverse economic activities. Strategic initiatives such as the Clanwilliam dam expansion and the Lesotho Highlands Water Project exemplify efforts to enhance water availability, but ongoing challenges related to population growth and climate variability necessitate continued innovation and investment.

Furthermore, the disparity between water supply and demand, exacerbated by factors such as drought and over-abstraction, underscores the critical need for integrated and multi-level water governance from national policy frameworks to local implementation, and including the vital role of local institutions like Water User Associations (WUAs), coupled with sustainable resource management. By implementing sustainable practices, improving infrastructure, and investing in both traditional and innovative water solutions, South Africa can better navigate its water scarcity issues and build resilience against future challenges. Addressing these issues proactively will be essential for securing water resources for agriculture, industry, and domestic use, ensuring long-term water security for the nation.

2.7 Water availability in the Western Cape Province

The Western Cape Province of South Africa is one of the nine provinces of the country with an area of 129 462 m^2, located on the southern tip of the African continent between the Atlantic and Indian oceans. The Western Cape is bordered by the Eastern Cape and Northern Cape Provinces, regions that are climatic and topographic diverse (Western Cape municipalities, 2017). It lies in the Mediterranean climate region, which receives winter rainfall (May to October) compared to other parts of the country, which receive summer rainfall (Blersch & Du Plessis, 2017). In the Western Cape Province, approximately 50% of the overall system storage is designated for winter flows, strategically aimed at fulfilling the demand during the summer season (Western Cape Government, 2018a). The remaining 50% is dedicated to the crucial purpose of maintaining long-term drought storage (Shand & Sparks, 2004).

The Western Cape Province boasts abundant agricultural resources, and a significant portion of its agricultural activities relies heavily on irrigation water. Within this region, a diverse array of crops is cultivated, including grains, fruits, vegetables and wine grapes (Partridge et al., 2020). To sustain these endeavours, the primary water source utilized for agricultural needs in the Western Cape Province is surface water, procured from rivers, streams, and reservoirs. The availability of surface water exhibits notable variability and remains susceptible to the impact of frequent drought occurrences. In response to this challenge, recent years have witnessed a growing emphasis on exploring alternative water sources. In this regard, there has been a heightened focus on harnessing groundwater and desalination resources, aimed at providing supplementary water supplies to augment the Western Cape's agricultural pursuits. Throughout history, South Africa's water demands have been met predominantly by the more economically feasible surface and groundwater resources. This context has led to the conclusion that the utilization of seawater desalination as a viable water source has not been seriously entertained.

2.7.1 Surface water resources

Surface water in the Western Cape Province is supplied through the Western Cape Water Supply Scheme (WCWSS) with a reliable annual yield of 556 million m^3 (Ahjum et al., 2015). This system caters to multiple entities, including the City of Cape Town Municipality, West Coast District Municipality (which supplies water to local municipalities like Swartland, Saldanha Bay, and Bergrivier), Stellenbosch, Drakenstein, Witzenberg local municipalities, and several agricultural users. These stakeholders collectively derive their water from the intricate and interconnected Western Cape Water Supply System, a network encompassing dams, pipelines, and distribution networks (Basson et al., 2018). The main dams of the WCWSS are operated as an integral system to reduce the probability of spillage, hence increasing the overall system yield (DWA, 2007) (Table 2.3). The WCWSS encompasses the oversight and management of a variety of critical components, including dams, pump stations, tunnels, and pipelines. These elements collectively serve the purpose of supplying water to the region. It's noteworthy that the scheme plays a pivotal role in supporting a region that contributes around 14% to the country's Gross Domestic Product (GDP) and a significant 84% to the provincial GDP (City of Cape Town (CCT), 2019). The water systems facilitated by this scheme serve diverse areas including the West Coast, Overberg, Cape Winelands, and the City of Cape Town Municipality, catering to both domestic and agricultural needs. In the Western Cape Province, the primary water resource comes from surface water sources, comprising rivers and dams. According to the planning documents for the WCWSS, the cumulative water consumption from the system was reported as 503 million m^3 per annum in the year 2013 (DWA, 2013a). The total integrated system yields a 98% assurance of supply of 596 million m^3 per annum (DWA, 2011).

In contrast to the broader water resource usage trends observed across South Africa, where the agricultural sector consumes over 58% of the available water, the Western Cape Province showcases a distinct distribution of water consumption among the domestic, agricultural, and industrial sectors (CCT, 2018). Particularly noteworthy is the fact that within the Western Cape, substantial water users are distributed across these sectors. Within the Western Cape Province, the City of Cape Town stands as a significant hub, encompassing more than 60% of the province's total population. Consequently, it constitutes a major consumer of domestic water, constituting a significant proportion of the province's overall water demand (CCT, 2019). In the context of agriculture, the total water allocation for this sector from 2010 to 2017 amounted to approximately 162 million m^3 annually.

The aggregate system reserves water for the province reaches approximately 590 million m^3 per year. Within this allocation, two-thirds is designated for urban use, encompassing commercial, residential, and industrial purposes (DWS, 2019b). On average, agricultural allocations receive approximately 35% of available water, while the remainder (approximately 65%) is allocated for urban and industrial uses (Rawlins, 2019). To effectively address demands, yield, and planning considerations within the WCWSS, the implementation of the Water Resources Yield Model (WRYM) and Water Resources Planning Model (WRPM) has been established. These models are employed to simulate the inflows and demands placed on the system, enabling the projection of storage trajectories for the upcoming year (DWA, 2007). According to Shand & Sparks (2004), these models (WRYM and WRPM) are run annually in November to determine whether the dams are adequately full to meet the projected summer demands at the required assurance of supply, or whether water restrictions should be implemented.

The primary water supply infrastructure serving the Western Cape Province centres around six main dams. These dams play a crucial role in providing water for irrigation (City of Cape Town, 2024). Complementing these main dams are various smaller dams and weirs, each contributing to the province's water supply. Notable among these are the Kogelberg and Rockview dams, owned by the DWS. These reservoirs play a role in supplying water to the upper Steenbras dam as well as Eskom's Palmiet Pumped Storage Scheme. Additional smaller dams and weirs further contribute to the water supply network, such as the Kleinplaas dam situated in the Jonkershoek tributary of the Eerste River.

The Kleinplaas dam functions as a conveyance route for the Riviersondend dam. Collectively, the main dams mentioned above boast an estimated capacity of around 898.3 million m^3 annually. Among these reservoirs, Theewaterskloof is the largest, followed by Voëlvlei, Berg River, Wemmershoek, Steenbras Lower, and Steenbras Upper, respectively. The Western Cape Sustainable Water Management Plan (2017) has identified several alternative water sources to complement the existing supply. These options encompass rainwater and stormwater harvesting, the reuse of process water and greywater, the direct potable reuse of treated effluent, and the utilization of both groundwater and desalination. The successful adoption and execution of these diverse sources hold the potential to alleviate the strain on water resources across various sectors within the Western Cape Province.

Table 2.3: Western Cape dam storages and their allocation (DWS, 2015)

System	**Allocation (million m^3/annum)**	Share
Riviersonderend (Theewaterskloof dam)	62.7	31%
Zondkerend IB	36.1	
Vyeboom IB	13.2	
Individual irrigators	12.4	
Wynland WUA	26.2	14%
Stellenbosch IB	11.9	
Helderberg IB	11.6	
Lower Eerste River IB	2.1	
Industrial use	0.7	
Banhoek Tunnel	1.8	1%
Upper Berg Irrigation Boards	**54.4**	**29%**
Sub-District 1	14.3	
Sub-District 2	21.5	
Sub-District 2	0.6	
Sub-District 3	18.0	
Upper Berg River Pumped Schemes	**21.1**	**11%**
Suid-Agter Paarl	3.5	
Simondium Pipeline	1.0	
Simonsberg	0.5	
Perdeberg	6.6	
Noord–Agter Paarl	3.6	
Noord–Agter Paarl	1.3	
Groenberg Ward 1 – Pipeline	1.1	
Groenberg Ward 2 – Pipeline	0.6	
Riebeek West Ward 1	1.5	
Riebeek West Ward 2	0.7	
	0.8	
Lower Berg Irrigation Boards	**21.3**	**11%**
Lower Berg Irrigation Boards	11.0	
Other licences	10.3	
WCWSS Total allocation	186.4	100%

2.7.2 Groundwater resources

Groundwater resources are also available in the Western Cape Province; however, the abstraction data are not readily available for many parts of the province (GreenCape, 2021). The Western Cape Department of Agriculture is responsible for managing and regulating agricultural water resources in the province. The department works closely with farmers and other stakeholders to promote sustainable water use practices and to develop strategies for coping with water scarcity. Some of the key challenges facing agricultural water resources in the Western Cape Province include the impact of climate change on water availability, the increasing demand for water from urban areas, and the need to balance competing demands for water between different sectors. Despite these challenges, the agricultural sector in the Western Cape Province continues to play a vital role in the economy of the region and the food security of South Africa. Groundwater resources make a significant contribution, particularly in areas where surface water is abundant.

2.8 Alternative water resources in the Western Cape Province

South Africa hosts merely six modest desalination facilities in operation across the country. Remarkably, half of these plants were established as emergency measures in response to the acute drought experienced in the Southern Cape during 2009 and 2010 (Blersch & Du Plessis, 2017). Seawater desalination is currently being investigated at a feasibility level in Saldanha Bay, Cape Town, Port Elizabeth and Durban, and is mentioned in all the national water planning documents (Department of Water Affairs and Forestry (DWAF), 2008; DWA 2010, 2013b).

2.9 Summary

In conclusion, the Western Cape Province faces significant challenges in water availability due to its Mediterranean climate and reliance on surface water resources. While the WCWSS effectively manages surface water through its intricate network of dams and pipelines, the region's water supply remains vulnerable to variability and frequent droughts. Agriculture, a key sector of the province’s economy, is particularly reliant on irrigation, with a considerable portion of water allocated to domestic and industrial uses. The province's growing urban population, especially in Cape Town, adds pressure on water resources, demanding more effective management to balance the competing needs of different sectors in the Western Cape Province.

To address these challenges, there has been an increasing focus on alternative water sources such as groundwater, desalination, and water reuse. Groundwater plays an essential role in supplementing surface water, particularly in regions where surface water is less abundant.

The exploration of desalination and other innovative methods, such as rainwater harvesting and treated effluent reuse, presents opportunities for enhancing the resilience of the Western Cape's water supply system. However, the successful implementation of these strategies will require careful planning, investment, and a sustainable approach to managing water resources, ensuring the long-term security of the province's water supply amidst growing climate and population pressures.

2.10 Water resources allocated to smallholder farmers in South Africa

Despite widespread literature indicating that agriculture accounts for more than 60% of water resource utilization in South Africa, a comprehensive study specifically outlining the allocated percentage to smallholder farmers from the overall water consumption within the sector remains elusive. This lack of clarity could potentially stem from the gradual process of government-led land reallocation, particularly concerning smallholder farmers in South Africa (Rawlins, 2019). Most land is still held by commercial farmers, as highlighted by various scholars. For instance, a study conducted by Mpandeli & Maponya (2014) emphasized that smallholder farmers in Limpopo face challenges primarily centred around land ownership. Likewise, Fanadzo & Ncube (2018) identified land tenure insecurity has been singled out as a major institutional challenge leading to poor performance of irrigation schemes. These studies advocate for the urgent development of land tenure policies that facilitate expanded access to arable land. The issue of inadequate land ownership among smallholder farmers was similarly verified within the Northwest Province, as highlighted by ACHA (2014). The lack of land ownership presents a substantial challenge confronting smallholder farmers in the region.

Smallholder farmers commonly depend on a diverse range of water sources across the country. These sources encompass methods such as extracting water from rivers through pipelines, utilizing vehicles like bakkies and tractors to retrieve water from rivers with tanks or other suitable containers, employing buckets to draw water either from rivers or municipal taps and using manpower or wheelbarrows for transportation, accessing water from springs, fountains, and dams.

In the Genadendal region within the Overberg District Municipality of the Western Cape Province, Mugejo et al. (2022) reported that smallholder farmers heavily relied on surface water sources like rivers and irrigation dams to sustain their farming activities during the mentioned drought period. This suggests that these farmers depended on these sources to mitigate the impact of water scarcity on their agricultural practices. However, the authors did not clearly elucidate the mechanisms by which governments contribute to water allocation, both during dry periods and in terms of the specified quantities designated for smallholder farmers within the study area. On the other hand, a study conducted by Pili et al. (2022) focused on the Overberg and the West Coast districts. In the Overberg district, it was observed that many smallholder farmers utilized water from boreholes, dams, and taps for their farming needs, with only a small percentage using rivers and wells. In contrast, smallholder farmers in the West Coast district predominantly used dam water and tap water, while a minority relied on rivers, boreholes, and wells. Pili et al. (2022) also failed to address government interventions aimed at expediting water allocations to the smallholder farming sector. Consequently, it is evident that the issue of slow progress in land redistribution is linked to the allocation of water resources to smallholder farmers. The water resources in South Africa are also affected by various, factors including climatic change which manifests through drought, floods, and other factors such as population growth.

2.11 Factors affecting water availability for smallholder farmers in South Africa

2.11.1 Climate change

An assessment by the FAO (2007) revealed that approximately 11% of Africa's arable land in rural areas is projected to be lost due to changing climate conditions. This loss of arable land could result in food insecurity and an increase in malnutrition across the continent. According to Aliber and Hart (2009), the impact of climate variability on agricultural productivity is expected to become more pronounced as there are changes in the timing, frequency, and severity of rainfall events. Indeed, climate change-induced increasing water scarcity and insufficient irrigation are expected to lead to severe declines in agricultural productivity of up to 50% in South Africa, as well as other countries in the Southern African Development Community (SADC) region (Davis-Reddy & Vincent, 2017). Concerns about the negative effects of climatic variability on crop production are raised by these anticipated changes. This is applicable to most African countries, including South Africa. Their agricultural production relies heavily on rainfall as a primary water source for crops, as pointed out by Barrios et al. (2008). The availability of agricultural water is affected by the imbalance between evapotranspiration and rainfall due to the projected changes in temperature and rainfall in South Africa, according to global climate models (GCM) (Kiker, 2000). In line with this, Easterling (2007) stated that agriculture is highly influenced by climate conditions. Even a modest increase of 1°C in temperature has the potential to alter the distribution of rainfall, potentially rendering crops more vulnerable to either drought-induced stress or excessive flooding in certain regions. As a result, in areas experiencing increased aridity, the need for agricultural water is anticipated to grow.

The changing rainfall patterns in South Africa are linked to the predominant influence of the La Niña and El Niño Southern Oscillations (ENSO). During ENSO, rainfall tends to decrease, accompanied by a rise in temperatures. Conversely, the La Niña phase has the opposite effect, leading to increased rainfall (MacKellar et al., 2014). ENSO is typically associated with extreme weather conditions resulting from the complex interplay between the atmosphere and the ocean. This interaction leads to cyclic variations in sea surface temperatures (SST), ultimately influencing the wet or dry conditions experienced within a specific ENSO cycle (Lester, 2019).

2.11.2 Drought

The four common types of droughts are described as (i) meteorological drought (precipitation deficiency), (ii) agricultural drought (soil water deficiency), (iii) hydrological drought (reduced streamflow and inflows from reservoirs), and (iv) socio-economic drought (social, economic, and environmental impacts) (Tallaksen & Van Lanen, 2004). Droughts are considered among the most costly natural disasters on a global scale, resulting in considerable financial outlays for ecosystems, agriculture, and human societies. The ramifications are noteworthy. Predictions indicate that climate change will amplify both the frequency and severity of drought occurrences across extensive regions of the world, particularly in semi-arid regions that are already experiencing pronounced water scarcity challenges. In South Africa, major drought events have been recorded during 1973-1974, 1983-1984, 1991-1992, 1994-1995, 2014-2016, and 2017-2018 with devastating socio-economic and environmental impacts (Baudoin et al., 2017b). Improving our understanding of how droughts operate within the framework of climate change stands as a crucial domain within climate research, particularly given the recent catastrophic droughts witnessed in the Western Cape Province of South Africa.

Droughts have long-lasting effects on various industries, including agriculture, tourism, energy generation, and public water supply, with the latter frequently being the most severely impacted (Dilley et al., 2005; UNDRR, 2019). Drought in South Africa is a big challenge that puts the agricultural sector under pressure. South Africa is recognized as a drought-prone country (1996; Jordaan et al., Baudoin et al., 2017; Gibberd et al., 2017a) that has experienced several severe drought events, as occurred in the early 1980s and 1990s, the period 2014-2016 (Baudoin et al., 2017), and the recent ongoing drought since 2018 (Mahlalela et al., 2020). The Nelson Mandela Bay Metropolitan Municipality in the Eastern Cape is currently experiencing an intense drought which is affecting local farmers and the entire water supply system in the surrounding areas.

2.11.3 Population

South Africa has an estimated population of 60 million people (StatsSA, 2019). The average South African population growth rate is 1.8% per annum. Due to the country's growing population, water supply plans must take this into consideration. An estimated 13 million people lack access to clean water, yet the water used by both the agriculture and mining industries accounts for over half of the country's water. However, the balance of this water used by these industries contributes to boosting the economy and food production. Generally, the average water consumption in South Africa is 237 litres/person/day, which is higher than the world average of about 173 litres per capita per day (Ngobeni & Breitenbach, 2021). This suggests that to meet the existing conditions of each decade (an approximately 8 million increases in population), approximately 1 900 million m^3 of additional water would be required for each decade to balance the demand.

Population growth is high in urban areas because of people moving from rural areas to urban areas in search of better opportunities. South Africa's urban areas expand by 2.7% annually to accommodate the increasing population numbers in these areas (Department of Human Settlements, 2004). Informal settlements receive minimal attention, and some do not have access to water resources. Most of the agricultural activities in South Africa are located near urban areas implying that when the migration rate increases, the water demand also increases, adding pressure to agricultural water resources.

2.12 Climate change and smallholder farmers

2.12.1 Climate change and smallholder farmers in Africa

The worldwide impact of climate change is diverse and widespread. Regrettably, developing countries, such as those in Africa, contribute the least to global warming but are among the most affected by climate change (Tadesse, 2010). The World Bank (2008) reports various signs of climate change, including heatwaves, floods, and droughts. Similarly, Hallie and Dilley et al. (2005) emphasized that Africa is already grappling with recurring food shortages and water scarcity, which are triggered or intensified by climate fluctuations and extreme events like droughts, heavy rainfall, and floods. These events negatively affect agricultural productivity and, consequently, the food security of rural households. While the African continent experiences diverse climatic conditions ranging from extreme aridity in the North and South to high humidity in the Central and Western regions the impact of the climate is felt in various ways. Importantly, these climatic conditions are highly changeable, and their characteristics and consequences are unpredictable (Nicholson, 2017; Helbling et al., 2021).

The impacts of climate change vary across regions, with the drier Western areas expected to face the most severe consequences. Africa is confronting a range of climate change effects, including rising temperatures and reduced rainfall. These changes are likely to decrease the productivity and yields of smallholder agriculture, posing a significant threat to food security, particularly among rural households (Lal, 2013). This food security challenge is amplified in Africa, a continent known for its heightened vulnerability to climate change. This vulnerability arises from a combination of factors, such as naturally high levels of climate variability, heavy dependence on rainfed agriculture, and limited economic and institutional capacity to effectively manage and adapt to climate shifts (Challinor et al., 2007; Muller et al., 2010; Roudier et al., 2011). According to Niang et al. (2014), Africa is one of the global regions most susceptible to the impacts of climate change.

As stated by the World Bank (2015a), approximately 96% of crop yields in Africa rely on rainfall. Agriculture plays a substantial role in mitigating unemployment in the region, employing around 65% of Africa's workforce (World Bank, 2013). Research indicates a projected increase in the frequency of extreme weather events in the future, encompassing phenomena like droughts, storms, varying precipitation patterns, and temperature fluctuations. Unfortunately, Africa is deemed more susceptible to the detrimental outcomes of these events (Bwalya, 2013; Sousa, 2018).

The potential consequences for food insecurity in developing African countries could be dire. Should climate change continue to escalate, these impacts might exacerbate, potentially leading to global price surges for essential cereals and staple crops in the years ahead. Ngcamu and Chari (2020) highlighted that the effects of drought extend beyond agriculture, impacting interconnected sectors and causing spikes in food prices. Drought's ramifications even extend to employment, as farmers lose their alternative income sources (Sutcliffe et al., 2016). These extreme events are unpredictable and occur at various times across the African continent.

In Zimbabwe, the effects of climate change are evident through an increase in the frequency and intensity of floods, droughts, and extreme temperatures, as reported in the study by Mushore et al. (2021). A study conducted in Ethiopia revealed that maize smallholder farmers perceive climate change through a rise in hot and warm days and nights, alongside decreasing rainfall volumes (Bedeke et al., 2018). In another study that explored climate change events and their impacts on farmers in the Yatta region of Kenya, drought (70%), crop diseases (79.1%), and floods (33.3%) were identified as the most prevalent climate-related events (Kalele et al., 2021). These events significantly affected aspects of livelihoods such as food shortages, heightened food prices, and reduced water availability.

Similarly, in Madagascar, smallholder farmers widely expressed their perception that climatic conditions have undergone changes in the past decade (Harvey et al., 2014). Farmers noted higher temperatures, reduced rainfall, increased variability in rainfall patterns, greater seasonal fluctuations, and more intense cyclones as common observations. These perceived shifts in climate were deemed significant by the farmers in the study. The perception of smallholder farmers on climate change, as documented by various scholars in Africa, coincides with different trend analyses that have been documented regarding the evidence of climate change in Africa.

Both local and global researchers have acknowledged Africa as the hottest region on the planet. Although Africa has faced criticism for a lack of accessible data that would enable global researchers to make precise determinations about evidence of climate change, numerous studies have utilized historical rainfall and temperature data from the region. The emphasis on recording such data has notably grown due to the heightened concerns of ordinary individuals about this global phenomenon. In Ethiopia, the perception of climate change (increased hot and warm days and nights as well as decreased precipitation volumes) among smallholder farmers was found to align with the results obtained from trend analysis using historical data spanning from 1985 to 2015 (Bedeke et al., 2018).

In a study conducted by Ilori and Ajayi (2020), future trends and change detection in temperature and rainfall were examined across three agro-climatic zones in West Africa. Historical data spanning from 1961 to 2000 was used alongside projections for the years 2020 to 2099. The study unveiled that change points emerged in both rainfall and temperature series during the 1970s and 1980s. Furthermore, a noteworthy upward trend was identified in temperature across all climatic zones. The study's future projections indicate that the mean temperature is set to increase by a range of 0.5 to 1.30 °C and 0.19 to 1.67 °C under RCP4.5 and RCP8.5 respectively. This suggests that climate change is anticipated to intensify in West Africa in the upcoming years.

Agriculture plays a pivotal role within the South African economy, serving as a significant source of employment, particularly in rural areas. In South Africa, the food security of rural households is closely intertwined with the sustainability of the country's agriculture sector, which provides food, income, and employment opportunities for more than 70% of the population (Cammarano et al., 2020). However, the repercussions of climate change and erratic weather patterns have led to adverse impacts on agricultural production, particularly affecting smallholder farmers in rural areas who heavily depend on nature for their livelihoods.

South Africa has observed evident shifts in climate over recent decades, marked by rising temperatures and changes in precipitation patterns (Benhin, 2008; Joubert, 2011; Ziervogel et al., 2014).

The agricultural landscape in South Africa is characterized by a dualistic structure, comprising highly advanced commercial farming with substantial capital investments, and smallholder or subsistence farming, primarily practiced by rural households in former homeland regions. The commercial farming sector encompasses approximately 30 000 large-scale farmers operating across all nine provinces. In contrast, the smallholder sector consists of over 2 million farmers, predominantly concentrated in provinces like KwaZulu-Natal, Eastern Cape, and Limpopo (Wolfgang et al., 2016; Mpandeli & Maponya, 2014). The FAO (2016a) underlines that extreme weather events have already caused substantial harm to agricultural crop production in smallholder farms, impacting 226 583 such farms in South Africa, many of which are currently facing drought conditions.

A substantial portion of South Africa's population is aware of climate change and its implications for their livelihoods. However, only 33% of the population demonstrates climate literacy, indicating a comprehensive understanding of the causes, effects, and adaptation strategies related to climate change (Richard Kwame et al., 2022). Additionally, the authors determined that socio-economic and demographic factors significantly shape the population's literacy and engagement concerning climate change. Educated individuals with higher incomes, access to information, and urban residences tend to possess greater awareness of climate change dynamics compared to their rural, less affluent counterparts.

Tomlison and Rhiney (2018) underscore that smallholder farmers confront an array of challenges resulting from climate change, encompassing drought, escalating temperatures, degradation of grazing lands, heightened prevalence of parasites and diseases, and diminished productivity. These factors engender complex and unpredictable alterations that impact farming practices and agricultural yield. Smallholder farmers bear the brunt of climate variability and face heightened vulnerability if effective adaptation strategies are not implemented. In accordance with the study by Thamanga and Morojele (2014), smallholder farmers, particularly those residing in rural or communal areas, encounter heightened susceptibility to climate change effects. Their vulnerable status arises from their marginalized geographical location, limited technological advancements, restricted access to climate information, and inadequate availability of essential farming resources. Consequently, their vulnerability escalates, ultimately leading to heightened food insecurity.

Ubisi et al. (2017), investigated the perceived impacts of climate change on crop production and household livelihoods among smallholder farmers in the Mopani and Vhembe districts of South Africa's Limpopo Province, highlighted that these farmers have directly encountered extreme weather events such as droughts and reduced rainfall. These events have exerted a negative influence on crop production, leading to numerous instances of crop failure due to prolonged drought periods. The study's findings also revealed that while farmers do employ specific coping mechanisms, their dependence on rainfed agriculture renders them susceptible to ongoing poverty and food insecurity.

Gandure et al. (2013) conducted a study focusing on smallholder farmers' perceptions of climate change adaptation and water stress in Gladstone village near Thaba Ncu in South Africa's Free State Province. Regardless of age or gender, all smallholder farmers concurred that the climate is undergoing change, and there exists a discernible connection between farmers' perceptions and observed data on long-term changes in climate. These farmers noted consistent occurrences of unexpected heavy rainfall, occasionally delayed rainy seasons, and notably warmer summers, a clear indication of climate change. However, they provided limited information regarding their views on the causes of climate change. Yet, they emphasized the changing seasons and deforestation as key contributors. Rainfall variability, combined with extreme temperature, was identified as having pronounced impacts on livelihoods, reflecting the perception of climate change's significant effects on the community (Gandure et al., 2013).

As indicated by Oduniyi (2013), a study involving 241 participants unveiled that a noteworthy portion of smallholder farmers in the Mpumalanga Province of South Africa, observed a rise in temperature. Specifically, 98.8% of the respondents noted an increase in temperature. A small fraction, 0.8%, did not perceive any alterations in temperature, and an even smaller group, 0.4%, reported a temperature decrease. In the Eastern Free State, smallholder farmers linked climate change to a reduction in crop yields, escalated food prices, food scarcity or insecurity, and complete crop loss. A minority of farmers identified the demise of livestock and loss of assets as major impacts of climate change (Myeni & Moeletsi, 2020). Additionally, the study highlighted that most smallholder farmers (72%) associated climate change with triggering droughts, whereas only 2% believed it led to an increase in disease incidence. A study by Samuel et al. (2018) in the Ngaka Modiri Molema District Municipality revealed that, although most respondents were aware of climate change, their understanding of the concept was incomplete.

Factors such as farm size, education level, ownership, and information sources were identified as determinants of climate change awareness. A study by Mdiya et al. (2023) focused on the influence of extension services on the adoption of climate change coping strategies among smallholder farmers in the Eastern Cape Province. The study suggested that climate change was primarily recognized through shifts in rainfall patterns. Around 80% of the respondents emphasized deforestation as a contributing factor. The authors proposed that access to extension services played a role in encouraging the extensive application of climate change coping strategies, resulting in a 10% reduction in livestock numbers. In a study conducted by Dippenaar et al. (2022) in Overberg, Western Cape, a comparison between meteorological data and farmers' perceptions about climate change revealed that smallholder farmers perceived and directly experienced climate conditions such as drought and flooding. Similarly, according to a study by Fanadzo et al. (2021), a significant majority of smallholder farmers in both the Overberg and West Coast districts perceived drought as a contributor to water scarcity and shortages. These farmers expressed observations of rising temperatures and decreasing rainfall (increased dryness) over the years.

In Genadendal, also located within the Overberg district of Western Cape, smallholder farmers relying on river water faced significant challenges during the 2015-2018 drought period according to Mugejo et al. (2022). The authors further alluded that this drought led to severe water shortages impacting both crop production and livestock. In contrast, smallholder farmers who relied on dams for irrigation were less affected. Zwane's study (2019) assessed the impact of climate change on primary agriculture and food security in the Western Cape Province. The study highlighted that numerous dams experienced low water levels during the 2016-2017 period, which subsequently reduced crop yields. This decline in yields was attributed to the limited rainfall experienced within the Western Cape Province during that time.

Researchers in South Africa have undertaken a range of studies to examine historical patterns of climate change by analysing rainfall and temperature data across the country. These investigations have utilized various analytical methods with the common aim of extracting evidence that illuminates rainfall and temperature trends over specific timeframes. These trends provide valuable insights into the technical aspects of the global challenge of climate change, employing real-time data to draw conclusions about observed patterns. While these research projects have differed in their parameters and durations, their overarching goal has remained consistent: to detect discernible trends.

McBride et al. (2022) conducted a study focusing on extreme daily rainfall characteristics in South Africa from 1921 to 2020. Using data from 70 manual weather stations across the country, the study indicated that while the number of rain days remained relatively stable, the likelihood of experiencing significant and extreme daily rainfall events has generally increased across most regions in South Africa. This trend raised concerns due to the potential consequences such rainfall events might have on flooding, erosion, agriculture, and infrastructure. In a similar vein, Kruger and Nxumalo (2017) examined historical rainfall trends in South Africa spanning from 1921 to 2015. Their study revealed a notable increase in rainfall in Western South Africa, extending toward the Southern Interior. Conversely, the Northeastern region experienced a decline in rainfall. Multiple rainfall stations from various districts were used for this analysis.

The study by Botai et al. (2016) aimed to explore the historical evolution of drought in the Free State and Northwest Provinces of South Africa from 1985 to 2015. Their findings indicated that drought severity and frequency were more pronounced in the Free State Province, while drought intensity was higher in the Northwest Province during the study period. The authors noted variations in moderate drought occurrences over different time periods in both provinces. In another study covering the Free State Province, Gandure et al. (2013) analysed rainfall data spanning the period 1960 to 2009. Their findings revealed inter-annual variability, with above-average annual rainfall observed in approximately half the years (study period). They also noted an average increase of 1-2 °C in minimum temperatures during June and July over 47 years.

Nel's study (2009) on trends in the KwaZulu Natal Drakensberg region highlighted shifts in seasonality between 1955 and 2000. It identified increased summer rainfall and decreased autumn and winter rains. Long-term and short-term analyses showcased distinct trends in seasonal rainfall patterns. The study by Nyoni et al. (2021) delved into air temperature and relative humidity trends in South Africa's Limpopo Province. Examining the period from 1950 to 2016, the study indicated a steady rise in temperatures over time. This increase in temperature led to heightened heatwave frequency, intensity, and amplitude, with subsequent implications for sectors like agriculture. The study's findings suggested that rising heat indices could adversely affect sectors such as agriculture, particularly in smallholder farming systems with limited adaptive capacities. Coupled with concerns about rainfall scarcity and drought, these factors collectively pose a risk of future food insecurity in South Africa.

Kruger and Shongwe (2004) conducted an analysis of climate data collected from 26 weather stations located across the country as depicted in Figure 2.3. Their findings revealed that 23 weather stations reported an increase in the average annual maximum temperature, with 13 of them experiencing significant increases. Similarly, average annual minimum temperatures exhibited an upward trend, with 18 of the weather stations showing significant increases. Overall, their analysis indicated that the country's average yearly temperatures had risen by 0.13°C per decade between 1960 and 2003. This temperature increase varied across the seasons, with the following changes observed: a 0.21°C increase in autumn, a 0.13°C increase in winter, a 0.08°C increase in spring, and a 0.12°C increase in summer. Additionally, there was a noticeable rise in the number of warmer days, accompanied by a decrease in the number of cooler days.

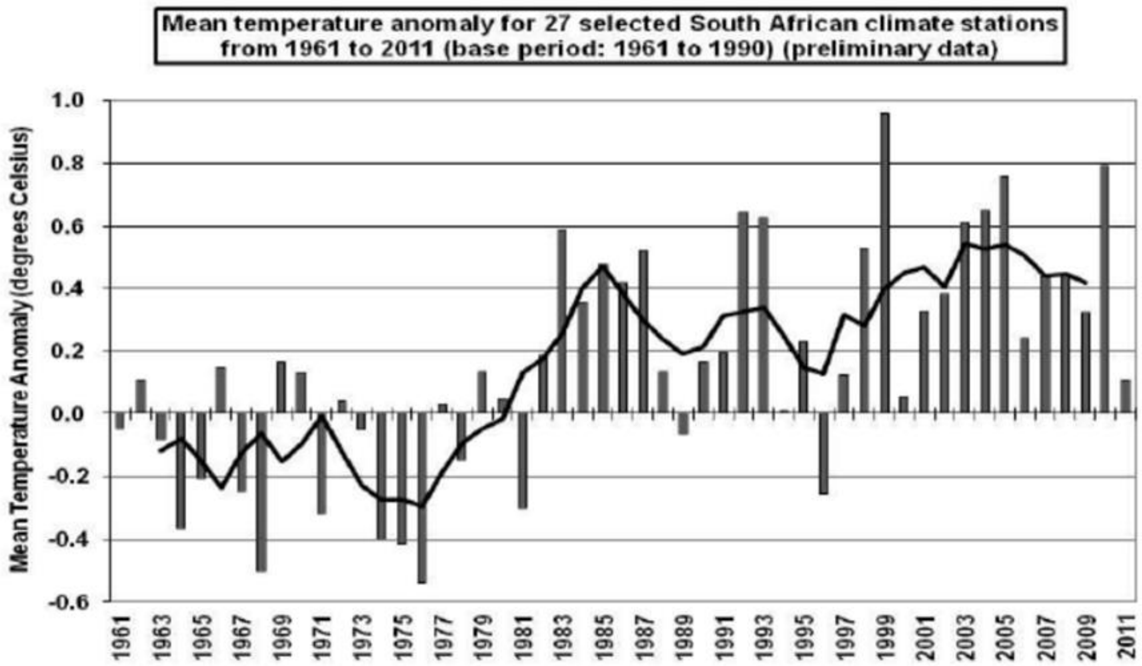

Figure 2.3: Annual mean temperature anomalies (1961-1990) of 27 weather stations in South Africa (Kruger et al, 2012)

2.13 Adaptation strategies in smallholder farming systems

2.13.1 Adaptation strategies in smallholder farming systems in Africa

The impacts of climate change within Southern Africa exhibit variation, with the drier Western regions expected to bear the brunt of these effects. While investing in irrigation technologies remains a vital strategy for adapting to these agricultural changes, the diminishing availability of water resources demands the adoption of more efficient irrigation systems. This step is crucial in responsibly utilizing limited water supplies and generating sufficient agricultural yield to meet the growing food demand (Nhemachena et al., 2020). Adaptation is particularly important in agriculture, given the climate sensitivity of the sector (Smit & Skinner 2002; Haden et al., 2012; Niang et al., 2014).

In Zambia, a study by Simatele et al (2012) suggested that local governments should embrace pro-poor urban planning policies to decrease the vulnerability of impoverished households and bolster the resilience of the urban poor. This approach involves close collaboration with local communities, NGOs, and community-based organisations (Simatele et al., 2012). Similarly, in a study focussing on the impact of climatic conditions on food security and water in South Africa, Enwereji (2021) supported the need for such approaches. A range of conservation and agroecological practices, including agroforestry, contouring, terracing, mulching, and no-till methods, are progressively being adopted by African smallholder farmers (Pereira, 2017). These practices contribute to more sustainable and resilient agricultural systems in the face of climate change. Efforts to disseminate environmental information and enhance awareness should have the goal of elevating public consciousness and comprehension within the community of interest, while also emphasizing the shared ecosystem forged by the environment (Tadesse, 2010).Gafar and Ijaiya (2023) pointed out that effective governance and robust institutions, particularly those tasked with environmental management, must prioritize accountability, transparency, and adherence to the rule of law in overseeing both the environment and its underlying resources.

Furthermore, the scope of climate change information dissemination should extend beyond the mere arrangement of conferences, workshops, and seminars, as has been recently observed. It should encompass the utilization of traditional and indigenous channels for conveying information. This could involve town criers in rural areas and traditional communication networks in urban settlements, as well as leveraging local radio and television stations to ensure effective communication reaches diverse segments of the population. In a study conducted by Bekede et al. (2018), which focused on maize-dependent smallholder farmers in Ethiopia, it was revealed that the adaptation strategies of these farmers were significantly influenced by their perception of climate change, along with socio-economic factors such as education level and experience. The study underscored that these smallholder farmers employed modest yet adaptable strategies to address climate change, including altering cropping schedules, utilizing improved crop varieties, establishing farm ponds, practicing agroforestry, diversifying income through off-farm activities, and engaging in seasonal migration.

Another study carried out by Mushore et al. (2021) focused on Zimbabwean smallholder farmers and highlighted their diverse approaches to combat the impacts of climate change.

These strategies encompassed initiatives for afforestation, wildfire prevention, and the preservation of wetland areas. The authors also identified several obstacles hampering the farmers' capacity to adapt to climate change. These challenges encompassed the lack of accessible markets for selling agricultural products, insufficient institutional support, poverty, unpredictable climate patterns, and heightened uncertainty regarding seasonal behaviour. According to Kalele et al. (2021), smallholder farmers in Kenya adopted strategies such as water conservation and water harvesting during drought periods to survive.

A study by Harvey et al. (2014) uncovered that only a portion of farmers reported implementing changes in their farming practices to address potential vulnerabilities to droughts, floods, and long-term shifts in climatic conditions in Madagascar. Common adaptation strategies identified included cultivating new crops or varieties, improving water management, adopting practices to enhance agricultural sustainability, and implementing measures for better water resource management. Nonetheless, smallholder farmers expressed that these strategies were not particularly effective in mitigating the impacts of droughts and floods.

2.13.2 Adaptation strategies in smallholder farmer systems in South Africa

South Africa has formulated commendable policies and strategies to address climate change mitigation (Mthembu & Nhamo, 2021). However, certain interventions have proven ineffective due to their voluntary nature, lack of concrete implementation actions, and inconsistencies within the broader policy framework. Ubisi et al. (2017) conducted a study in South Africa's Limpopo Province and found inadequate institutions to implement the established policies and strategies. The authors advocated for enhancing the relationship between smallholder farmers and extension officers to bolster climate change adaptation. Different adaptation strategies were observed between male and female smallholder farmers, with females altering planting dates and males diversifying crop varieties and employing mixed cropping in the study area.

Factors such as household gender composition, age, tropical livestock unit, and access to climatic information enhance the likelihood of smallholder farmers adopting climate change adaptation measures in South Africa (Ogundeji, 2022). Governments and NGOs support indigenous adaptation options for smallholder farmers, particularly those in female-headed households. In the Eastern Cape Province, smallholder farmers adopted strategies like mulching and water reuse to sustain limited water resources, while also recommending the establishment of farmer associations for knowledge sharing (Novienyo et al., 2023).

Sugarcane smallholder farmers in the KwaZulu Natal Province of South Africa lacked climate change awareness due to language barriers and insufficient training (Ncoyini et al., 2022).

The author indicated that the best strategy is to employ multilingual extension services to be able to reach farmers. Richard Kwame's study (2022) on climate change threats to water and food security in South Africa emphasized the lack of coherency in policies across different departments and institutions. The author recommended a coordinated approach and increased research investment. Adaptation strategies used by smallholder farmers included minimum or low tillage, plant-tolerant seeds, and adjusted planting dates in the study that sought to establish the nexus between climate change adaptation strategy and smallholder farmers' food security status in South Africa (Samuel & Sylvia, 2019). In the Free State Province, farmers adopted rainwater harvesting, altered planting dates, and diversified crops (Gandure et al., 2013).
Echoing these findings, Myeni & Moeletsi (2020) reported similar preferences for rainwater harvesting and changing crop varieties among Eastern Free State farmers. Coping strategies for water challenges in Limpopo involved water-saving technologies and storage facilities (Nephawe et al., 2021). In the Eastern Cape Province, retraining extension officers were recommended to improve climate change adaptation knowledge transfer to livestock smallholder farmers (Mdiya et al., 2023). The authors also stressed the importance of awareness and access to climate-related extension services to mitigate the impact on smallholder farmers. During the drought period from 2015 to 2018, smallholder farmers in the West Coast region of the Western Cape Province, relied on borehole water and sold their livestock for survival (Pili & Ncube, 2022). In contrast, farmers in the Overberg district adopted coping strategies such as purchasing fodder and transporting water from rivers and dams to the farms.

Zwane (2019) emphasized that human activities contribute to climate change, underscoring the importance of raising awareness about climate change and its impacts. This awareness can enable the adoption of climate-smart farming techniques and practices. Zwane's study (2019) proposed adaptation strategies for both crop and livestock farmers. These strategies focused on minimizing environmental impact while enhancing productivity. They encompassed employing organic matter to prevent burning and reduce gas emissions, using livestock manure as nutrient-rich mulch for crops, and selecting adaptable seed varieties. Efficiently managing livestock manure for mulching was recommended to reduce water loss through evaporation. Overall, these strategies aimed to foster sustainable farming practices and enhance resilience to climate change.

The study by Zwane (2019) recommended various mitigation measures, including livestock breeding, precise farming strategies, environmental conservation, effective manure management, and the promotion of climate research and drought-resistant crops. The study also highlighted the role of educating extension officers in facilitating climate change adaptation. In the Overberg region, smallholder farmers implemented climate change adaptation strategies like adjusting planting dates, increasing irrigation, practicing mulching, selling livestock, and enhancing fungicide use (Dippenaar et al., 2022). Both in the Overberg and West Coast districts, Fanadzo et al. (2021) suggested improved coping and adaptation strategies tailored specifically to drought conditions. These strategies emphasized asset ownership and support from both private and public organisations.

Table 2.3: Summary Table of Adaptation Strategies

Actor	**Province/Region (Country)**	**Key Adaptation Strategies Cited**
Farmers	**Multiple (Southern Africa)**	Changing cropping schedules/dates; Using improved/drought-tolerant crop varieties; Crop diversification & mixed cropping; Water harvesting & farm ponds; Agroforestry; Mulching; Minimum/low tillage; Soil conservation (contouring, terracing); Selling livestock; Off-farm income diversification; Seasonal migration.
	Limpopo (SA)	Changing planting dates (female), crop diversification & mixed cropping (male).
	Eastern Cape (SA)	Mulching, Reusing water; Formation of farmer associations for knowledge sharing.
	KwaZulu-Natal (SA)	*(Awareness was low due to language barriers)*.
	Free State (SA)	Rainwater harvesting, changing planting dates; Crop diversification.
	Western Cape - West Coast (SA)	Using borehole water; Selling livestock.
	Western Cape - Overberg (SA)	Purchasing fodder; Transporting water; Adjusting planting dates; Increasing irrigation; Mulching; Selling livestock; Increasing fungicide use.
	Zimbabwe	Afforestation/reforestation; Wildfire prevention; Wetland preservation.
	Kenya	Water conservation and harvesting.
	Ethiopia	Changing cropping schedules; Improved varieties; Farm ponds; Agroforestry; Off-farm activities; Seasonal migration.
	Madagascar	Cultivating new crops/varieties; Improving water management; Adopting sustainable agricultural practices.
Government	**General (Multiple)**	Develop pro-poor urban planning policies; Strengthen governance (accountability, transparency, rule of law) in environmental management; Invest in irrigation technology & efficient systems; Coordinate policy across departments; Increase research investment; Support indigenous adaptation options.
	Zambia (Urban)	Collaborate with communities, NGOs, CBOs for pro-poor planning.
	South Africa (National)	Formulate climate policies & strategies *(but implementation is inconsistent)*.

	South Africa (Provincial)	Retrain extension officers; Employ multilingual extension services; Disseminate information via traditional channels (town criers, local radio/TV).
Private/ NGOs & CBOs	**General (Multiple)**	Provide institutional support; Facilitate access to markets; Offer training and awareness programs; Collaborate with governments on community projects; Provide asset support during droughts.

2.14 Water governance systems in South Africa

The Organisation for Economic Cooperation and Development (OECD) define water governance as encompassing a broad range of political, institutional, and administrative regulations, along with both formal and informal practices and procedures (Table 2.4). These mechanisms play a significant role in the formulation and implementation of decisions regarding water management. Additionally, they provide a platform for stakeholders to voice their interests and ensure that their concerns are duly considered. Furthermore, water governance establishes accountability among decision-makers for their responsibilities in the management of water resources (OECD, 2015). Water governance, as discussed by Gallaher and Heikkila (2014), entails collective decisions and choices related to the utilization and oversight of water resources. These decisions are implemented through established institutions and encompass the establishment of regulations and governing bodies for water resource management. Such institutions in South Africa include the DWS, Catchment Management Areas (CMA), Water User Associations (WUA), Water Services Institutions (WSI), Ward Councillors, and NGOs. It is crucial for all water users in the country to understand the hierarchical structure through which water resources are managed and the policies to be adhered to.

The formulation of these institutions was driven by the recognition of water scarcity in the South African economy. As highlighted by Backeberg (2005), the economy transitioned from a growth phase to a stage where water allocation and management gained significance. While South Africa possesses water resources for various sectors, the governance aspects of water access become particularly important during dry seasons when water shortages occur. Therefore, comprehending past responses to water resource management by different institutions is crucial in devising effective governance strategies for policymakers. To assess the effectiveness of these responses in aiding farmers during water scarcity periods, it's essential to understand the responsibilities of each governmental department within the three-tier structure of the South African government: national, provincial, and local levels.

Table 2.4: Role of public organisations and departments in the management and implementation of policies and legislation*(Stevens & Van Koppen, 2015)*

Public organisation and department	Main function
National:	
Department of agriculture, forestry and fisheries (DAFF)	Infrastructure on small scale irrigation schemes and aquaculture
Department of Water Affairs (DWA)	Legislation, administration, bulk water supply, regulation and pricing, water strategies
Department of Environmental Affairs (DEA)	Environmental impact assessment (biodiversity) and protection of wetlands, lakes, mountain catchment areas, mineral and petroleum resource development, and estuaries like Lake St Lucia
Council of Geoscience	Groundwater studies and research
Research organisations such as: Water Research Commission (WRC) Council for Science and Industrial Research (CSIR) Agricultural Research Council (ARC)	Research on various aspects regarding water use and water management.
Department of Rural Development and Land reform	Agrarian reform
Department of Mineral Affairs	Mining and pollution (AMD)
Department of Tourism	Protection of conservation areas (SANPARKS: all the declared conservation parks; Ecological Reserve and pollution)
Department of Energy	Power generation, use of coal, integrated resource planning
Department of Trade and Industry	Industrial Policy Action Plan: job creation, agro processing
b. Provincial:	
Provincial Departments of Agriculture (9)	Implementation of agriculture policy at provincial level (Landcare and Farmer Support Programme)
CMAs	Management and administration of water at catchment level (9)
Water boards (15)	Supplying water to municipalities
Water Service Providers	The main objective is implementation of the Water Services Act (Act 108 of 1997) which incorporates providing for the right of access to basic water supply
Water Service Authorities	Any Municipality responsible for ensuring access to water services in the Act. It may perform the functions of a WSP

2.15 Governing institutional setup of the water sector in South Africa

2.15.1 National institutions

Department of Water and Sanitation

The DWS is the principal governmental body responsible for shaping and executing policies related to bulk water supply in South Africa (DWS, 2022). Their role encompasses the management of dams, maintenance of infrastructure, and the distribution of water to various sectors on both national and local levels. Additionally, they oversee water rights and licensing, ensuring that water resources, including surface water (such as rivers, dams, and lakes) and groundwater, are allocated fairly and utilized for the public benefit while upholding environmental considerations. The DWS plays a pivotal role in formulating regulations and policy frameworks for each sector, with the aim of safeguarding, utilizing, developing, conserving, managing, and controlling water resources effectively. In fulfilling this responsibility, they are accountable for crafting the National Water Resource Strategy (NWRS) and implementing nationwide monitoring and information systems. Furthermore, the DWS defines national guidelines, benchmarks, and pricing objectives.

The NWRS serves as the overarching framework for water conservation and protection in South Africa (NWRS, 2023). It provides the direction and principles for the management and preservation of the country's water resources. The initial NWRS was established in 2003, followed by a revised version in 2013. The third revision is currently under public review, as the NWRS undergoes updates every five years to ensure its continued relevance and alignment with its intended purposes. Within the DWS, there exists a Water Trading Entity consisting of two distinct components, established to manage the recovery of costs associated with services provided by the department to water users. These components are water resource management and infrastructure management. The water resource management component focuses on matters related to water quality, conservation efforts, and the equitable allocation of water resources through the CMAs. This aspect encompasses activities that ensure the sustainable utilization of water resources while maintaining their quality.

Conversely, the infrastructure management component concentrates on the operation, maintenance, and advancement of water-related infrastructure. This involves overseeing the various physical systems that facilitate the storage, treatment, distribution, and conveyance of water to end-users. Furthermore, the DWS is entrusted with establishing CMAs and WUAs. The purpose of these entities is to encourage the active involvement of local communities in the management of water resources. The department's role encompasses ensuring that CMAs adhere to national policies and align with the principles outlined in the NWRS. In instances where functional CMAs are absent within specific WMAs, the DWS assumes the responsibilities of a CMA within that WMA.

According to section 64 of the NWA, the DWS is empowered to acquire property when it serves a public purpose or is in the public interest, specifically for the purposes outlined within the NWA. This underscores the department's authority to take measures that contribute to the effective management and utilization of water resources for the benefit of the public and the environment. In the interviews by Weidl (2022) with the DWS representatives, they highlighted that the centralized top-down governance structure by DWS causes ambiguities and inefficiencies in the execution of policies and separation of work amongst the different governance levels.

National Water Act

The water policy in South Africa has undergone a transformation to address the historical racial and gender discrimination inequalities in water and land access that were entrenched during the apartheid era prior to 1994. In 1998, the country introduced the NWA under Act 36 of 1998, as part of a comprehensive effort to decentralize and integrate water management. This move led to the establishment of new local and regional institutions aimed at achieving equitable representation, meticulous recording and permitting of water usage, and the eventual cultivation of a water rights market (Denby, 2013).

The governance of water resources in South Africa is guided by the constitution and pertinent legislation related to water. These legislative measures include the NWA Act (Act 36 of 1998) and the Water Service Act (WSA; Act 108 of 1997). These laws play a fundamental role in shaping the operations of various institutions responsible for managing water resources. Notably, the NWA acknowledges water rights in connection with essential human needs and environmental imperatives for water availability. In contrast, the WSA oversees domestic water supply services and entrusts the responsibilities for these services to Water Authorities (WSAs), which encompass entities like Category A and C municipalities.

2.15.2 Provincial institutions

Catchment Management Area

As defined by the NWA, a Water Management Area (WMA) is a designated region established as a unit for water management. Within each WMA, there are subdivisions known as catchments. A catchment refers to an area where rainfall flows into a common point through surface runoff into watercourses. The NWA initially envisioned that each WMA would have a corresponding Catchment Management Agency (CMA). However, this has not been fully realized, with only two (out of an envisaged total of nine) operational CMAs established since the enactment of the NWA in 1998. These functioning CMAs are Breed-Gouritz and Inkomati-Usuthu CMAs located in Mpumalanga province. The delay in establishing both CMAs and large-scale WUAs can largely be attributed to the persistent challenges of achieving meaningful participation from Historically Disadvantaged Individuals (HDIs) (Karar, 2003). The remaining seven proto-CMAs are currently at different stages of development towards becoming fully operational CMAs.

In instances where a CMA is not in place within a WMA, the responsibility for water resources management falls under the jurisdiction of the Regional Office of the Department of Water and Sanitation. This arrangement continues until a CMA is established and functioning effectively. The primary purpose of a CMA is to decentralize water resource management to regional or catchment levels. They are entrusted with the planning, execution, and supervision of water resource initiatives. They play a pivotal role in orchestrating and harmonizing the water-associated endeavours of diverse water management entities and users within specific WMAs. As summarized in Figure 2.4, the specific mandate that CMAs should fulfil within their specified WMAs includes developing a CMS as a framework for the management of water resources within the WMA. This strategy must be in alignment with the NWRS, which serves as the national framework for the management of water resources in South Africa. The CMAs' responsibilities include ensuring sustainable water use, promoting cooperative governance, coordinating the WMIs within the WMA, and promoting community participation in WRM.

To enable the effective functioning of institutions like the NWA, there are established entities for water management at various levels of government, ranging from National to local levels. Notable among these institutions are CMAs, WUAs, and the Water Tribunal, all of which play roles in overseeing water resource management at the regional level and ensuring active community participation within the framework of the South African National Water Resource Strategy (SANWRS). Originally, nineteen WMAs were established in South Africa, although these were later merged into nine WMAs in 2016 depicted in Figure 2.5, as approved and gazetted by the then Minister of the Department of Water and Sanitation, Nomvula Mokonyane. Recently, there has been a proposal to further consolidate WMAs, particularly merging the Western Cape and Limpopo Provinces, resulting in a total of six approved WMAs as indicated in Figure 2.6. Such consolidation offers benefits including improved management of integrated systems, distribution of technical expertise, and faster establishment of CMAs. Larger, consolidated CMAs would also facilitate better cooperation and coordination at regional, provincial, and international levels. Each CMA has its own Catchment Management Committees and Land Catchment Management Forums, which play a significant role in promoting community participation within their respective water management areas. The Department of Agriculture (DoA) and the Department of Rural Development and Land Reform (DRDLR) are present within WMAs of South Africa to provide support to farmers concerning water use license applications (Ncube, 2018).

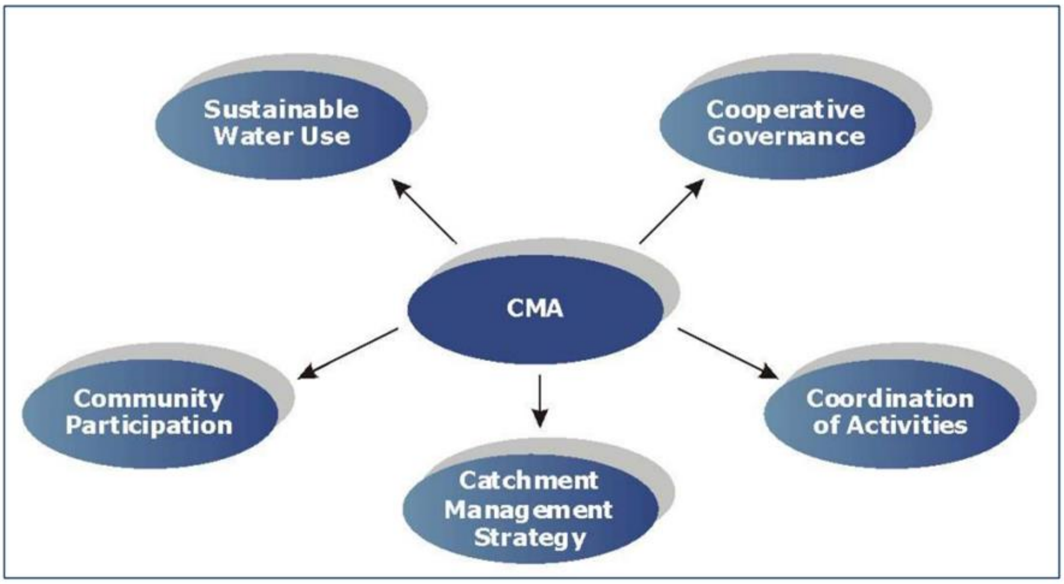

Figure 2.4: Roles and purpose of CMAs (Mazibuko & Pegram, 2006)

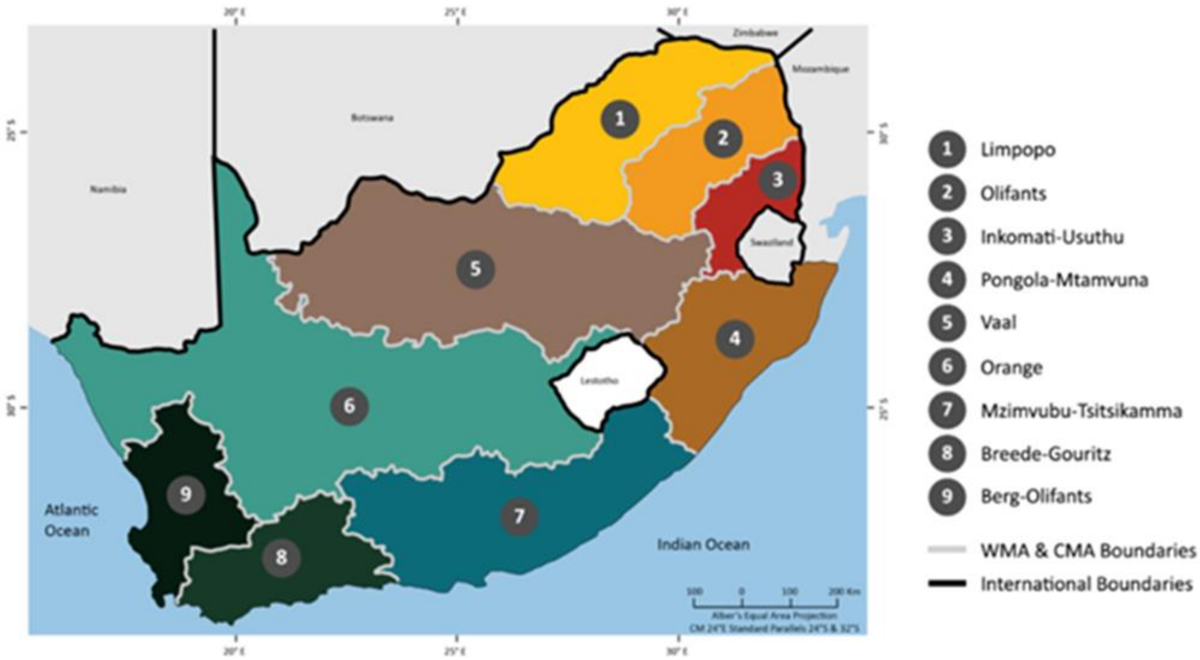

Figure 2.5: Water Management Areas in South Africa (DWS, 2016)

Figure 2.6: Current Water Management Areas within South Africa (DWS, 2022)

Water User Associations

Water Management Areas (WMAs) are established by the DWS as local-level water management institutions. These entities serve as the necessary organisational framework for individual water users to collaborate and combine their efforts, thereby enabling more efficient execution of water-related activities. According to Muchara (2014), the engagement of water users encountered challenges due to farmers' limited grasp of water policies that underpin the formalization of local water management systems. These policies encompass the registration of water user associations and the requirement for farmers to contribute to the sustainability of these associations.

The efficacy and significance of water user associations as formal local water governance bodies, along with their connections to informal management structures like local irrigation committees and traditional leadership, are currently weak (Muchara, 2014). Enhancing coherent institutional linkages at the local level necessitates farmer training. The deficiency of robust regulatory measures characterized by inadequate rule enforcement mechanisms, absence of secured property rights (especially for land), and inadequate water security adversely affect irrigation water management among smallholder farmers.

Irrigation boards were initially established during the apartheid era to financially support disadvantaged white farmers (Kemerink et al., 2013). Over time, they transformed WUAs to extend access to water resources to historically marginalized individuals, particularly smallholder farmers. Despite this well-intentioned initiative, progress has been sluggish. Research indicates that only 99 irrigation boards have successfully transitioned into WUAs, leaving around 100 irrigation boards still awaiting the transformation process (NWRS, 2013)]. This delay has been attributed to factors such as slow access to land, insufficient capacity and skills, and challenges related to service allocation.

2.15.3 Local government

Municipal institutions

South Africa is comprised of three distinct categories of municipalities. The first category, Category A, encompasses metropolitan municipalities that are shown in Table 2.5, which are situated in the country's eight major cities. The second category, Category B, encompasses 205 local municipalities, encompassing areas outside the jurisdiction of metropolitan municipalities. Lastly, Category C comprises 44 District Municipalities, which consist of multiple municipalities within their administrative boundaries (du Plessis, 2013). In accordance with the WSA, municipalities hold the responsibility for managing water within their designated areas. This encompasses a range of tasks, including ensuring the availability of water, equitable distribution, allocation oversight, regulatory compliance enforcement, and preservation of water resources. Functioning as water service authorities, municipalities are obligated to provide and facilitate access to clean drinking water and sanitation services within their designated regions (du Plessis, 2013).

Crucially, municipalities are charged with ensuring universal access to fundamental water supply and sanitation services, guaranteeing these rights for all citizens (Algotsson and Murumbo, 2009). Operating at the local level, municipalities work directly with community members, fostering stakeholder engagement and participation in service delivery in collaboration with the government (Haigh, 2010). In situations where feasible, municipalities may outsource their responsibilities to capable service providers who can ensure the delivery of high-quality services, encompassing the management of water distribution and sanitation services, including the operation and maintenance of wastewater treatment facilities (Mazibuko and Pegram, 2006). As emphasized by Du Plessis (2013), municipalities bear an institutional duty to manage water resources effectively. This involves implementing measures to prevent water wastage, such as the implementation of water conservation practices and demand management plans.

Table 2.5: The eight South African metropolitan municipalities and their locations

Metropolitan	Province	Town
Buffalo City	Eastern Cape	East London
City of Cape Town	Western Cape	Cape Town
Ekurhuleni	Gauteng	East Rand/ Germiston
City of eThekwini	KwaZulu-Natal	Durban
City of Johannesburg	Gauteng	Johannesburg
Mangaung	Free State	Bloemfontein
Nelson Mandela Bay	Eastern Cape	Gqeberha
City of Tshwane	Gauteng	Pretoria

2.16 Water governance in the South African smallholder irrigation sector

Defining smallholder farmers is a widely debated topic across South Africa. There is no officially accepted definition to be adopted when defining smallholder farmers, various scholars and government institutions have chosen a particular definition depending on their context. To have a specific definition of smallholder farmers that can be adopted in South Africa, it is vital to have evidence of literature classifying different farming groups that operate across different parts of the country. The advantages of having a classification of smallholder farmers would ease government interventions, especially during disaster events such as drought (Carelson et al., 2021). Characterising and classifying the smallholder farmers based on the livelihoods approach promises a more effective service delivery tool because it recognizes their entitlements, endowment, and capabilities.

As adopted by Carelson et al. (2021), the only classification is introduced by the WC DoA. The South African DoA (2015) defines smallholder farmers as individuals who engage in farming for both household consumption and market purposes. While their farming endeavours contribute to the family's income, they typically do not serve as the primary income source. Additionally, these farming operations are often supplemented by various non-farm activities that provide income to support the family. Consequently, for the scope of this study, this definition is being employed among the various definitions available.

The total area of irrigated land in South Africa is estimated to be approximately 1 354127 ha (Figure 2.7). The province with the highest amount of irrigated land is the Western Cape

Province, with 286 004 ha, followed by the Northern Cape Province with 188 903 ha as depicted in Table 2.6 (DAFF, 2010). Within this context, Van Averbeke and Khosa (2011) reported that approximately 7.7% of the irrigated land in the country, which accounts for around 10 000 ha, is utilized by smallholder farmers, particularly the former Bantustans. The authors noted that roughly half of this smallholder-utilized irrigated land consists of small home gardens, while the other half is located within smallholder irrigation schemes, totalling 317.

Table 2.6: Area irrigated in various provinces of South Africa (DAFF, 2010)

Province	Area irrigated (ha)
Western Cape	286 004
Northern Cape	188 903
Free State	137 887
Eastern Cape	188 901
KwaZulu Natal	131 032
Mpumalanga	129 308
Limpopo	161 127
Northwest	101 593
Gauteng	29 372
Total	**1 354 127**

According to Denison and Manona (2007), these irrigation schemes have around 33 000 plot holders, each cultivating an average of 1.5 ha of land. However, the authors highlighted that a significant portion of these schemes over one-third, and half of those in the Limpopo Province were inactive in 2007. Movik et al (2016) indicated that most smallholder irrigation schemes serving poor rural communities in South Africa, specifically 98.8% of them, only have access to 5% of the available water resources for their agricultural production. Interestingly, even though the agriculture sector consumes more than 60% of South Africa's available water resources according to the DWS, the allocation of 5% of water resources to smallholder farmers, as highlighted by Movik et al (2016), is not clearly detailed.

According to Muchara et al (2014), agricultural water provided to most smallholder irrigation schemes in South Africa is supplied as a complimentary resource, subsidized entirely by the government. This notion is also supported by Schreiner (2015), who reveals that South Africa allocates a subsidy of more than US$30 million annually to the irrigation sector. To obtain a balance between economic efficiency and the social equity aspect of irrigation water supply, the “Drafting Strategy for Water Use Charges” was formulated under the NWA. This policy aimed to establish guidelines for subsidized water pricing rates, and operations and maintenance fees for irrigation schemes benefiting economically disadvantaged communities (DWS, 2015). The policy outlines that farmers within such communities are exempt from charges during the initial 5-year period, and subsequently, water charges are incrementally introduced over the following 5 years at a rate of 20% per annum. Backeberg (2006) highlighted that this approach has led to the perception that water is a cost-free commodity and has resulted in scenarios where smallholder irrigation schemes depend on the government to cover operation and maintenance expenses.

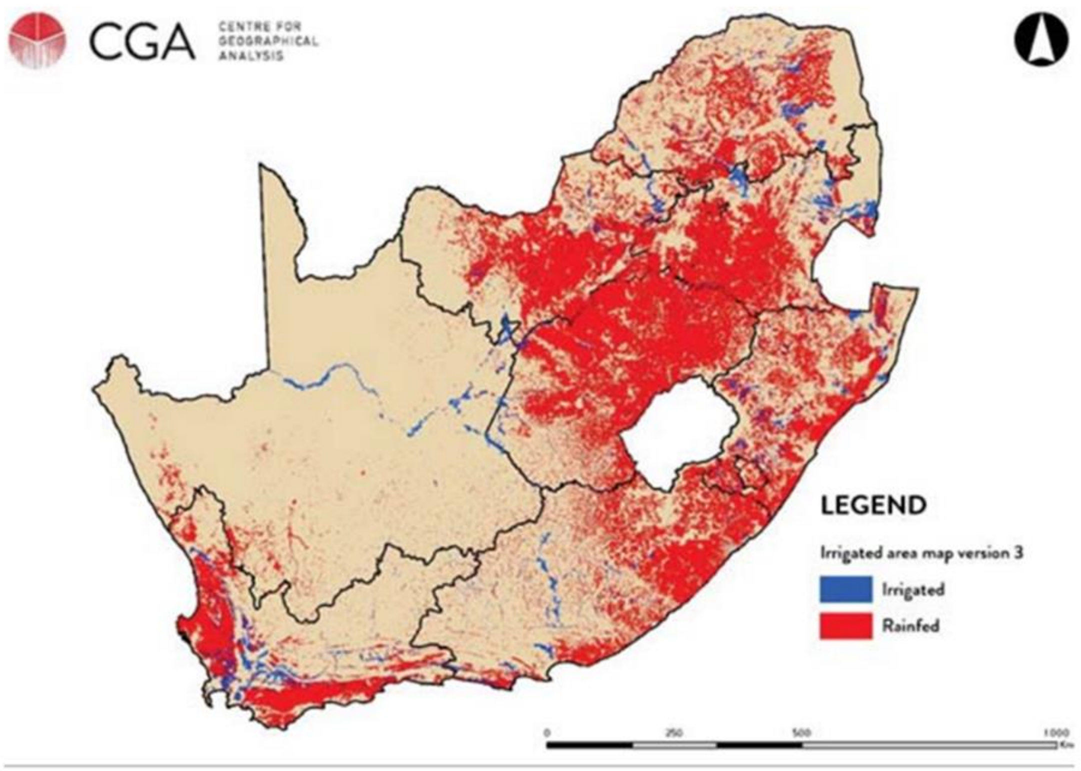

Figure 2.7: Map showing irrigated and rainfed areas in South Africa (WRC, 2022)

2.17 Water governance challenges in the South African smallholder irrigation sector

Water management remains a significant challenge for smallholder farmers, with issues like poor performance often stemming from inadequate water management structures, lack of technical knowledge, and inappropriate land tenure arrangements (Bembridge, 2000). Scholars such as Tshuma and Monde (2012), along with Muchara (2014), also point out that ineffective institutional establishments and management within smallholder irrigation schemes (SISs) in South Africa contribute to the dysfunctionality of these schemes. For successful operation, effective water rights, water governance, and institutional arrangements are essential to control and regulate water use (Dlangalala & Mudhara, 2020).

The history of water access in South Africa is intertwined with apartheid-era land setups, creating a connection between land ownership and water access. Despite efforts to separate land and water rights, little progress has been made since the end of apartheid in 1994 (Van Koppen et al., 2009). Kemerink et al. (2013) further argued that the establishment of Water User Associations (WUAs) has been dominated by commercial farmers, indicating a lack of true inclusion and representation for historically disadvantaged individuals. This lack of integration and collaboration between agricultural activities and government levels also hinders the growth of the smallholder farming sub-sector (Nyawo et al., 2021).

Numerous studies in South Africa have focused on water management in smallholder irrigation schemes, especially in provinces like KwaZulu-Natal, Eastern Cape, and Limpopo. These studies often involve various inter-sectoral institutions such as government, WUAs, Irrigation Management Committees (IMCs), and traditional authorities to formulate and implement policies for these schemes. The water governance structure in South Africa is comprehensive and involves multiple levels, principles, mandates, and shared responsibilities among different stakeholders (WRC, 2018). Dirwai et al. (2019) identified factors affecting water sufficiency, including governance-related elements, and recommended informed governance strategies to enhance scheme performance.

In community-managed schemes, varying levels of water access and understanding of water-use security pose challenges (Muchara, 2014). The issue of water scarcity is often linked to drought and climate change, exacerbating existing challenges in water availability. The land tenure system also plays a role, with traditional authorities granting permission-to-occupy rights to farmers, both within and outside of irrigation schemes (Chipfupa & Wale, 2019). Water management is often facilitated through cooperatives or third-party institutions managing irrigation schemes on behalf of farmers. In conclusion, water management in South Africa's smallholder farming sector is complex, involving various factors such as historical land setups, institutional arrangements, and climate challenges. Effective water governance and collaboration among stakeholders are vital to address these challenges and ensure the sustainability of smallholder farming.

2.18 Summary

The literature review examines water availability in South Africa, with a focus on the agricultural sector, particularly smallholder farmers in the Western Cape Province. It highlights the critical role of water in agriculture, which consumes over 60% of South Africa's water resources, yet only 5% is allocated to smallholder farmers, who face challenges due to limited land ownership and insecure tenure. The review explores the reliance of smallholder farmers on diverse water sources like rivers, boreholes, and dams, and their vulnerability to climate change impacts such as droughts and erratic rainfall, which threaten crop yields and food security. It assesses adaptation strategies employed by smallholder farmers, including water conservation, crop diversification, and agroforestry, alongside governance systems like the Department of Water and Sanitation (DWS), Catchment Management Agencies (CMAs), and Water User Associations (WUAs), which aim to manage water equitably but face inefficiencies and historical inequities.

Globally, freshwater is scarce, with only 3% of the earth's water being freshwater, and agriculture accounts for 70% of its use. In South Africa, surface water dominates, contributing 77% of resources, supplemented by groundwater and recycled flows, but the country faces water scarcity due to low rainfall (460 mm annually) and high evapotranspiration. Climate change exacerbates these challenges through rising temperatures, variable precipitation, and frequent droughts, while population growth increases water demand, and projected to rise 20-30% by 2050. In the Western Cape Province, the Water Supply System (WCWSS) manages surface water through dams, but frequent droughts necessitate alternative sources like groundwater and desalination. Governance challenges, including slow land reform and weak institutional setups, hinder equitable water access for smallholder farmers, underscoring the need for improved policies, infrastructure, and climate adaptation strategies to ensure sustainable water management.

CHAPTER 3
METHODOLOGY

3 Introduction

This chapter provides a detailed overview of the study area of the research topic and introduces the approach used to conduct the study. It goes into depth about the specifics of the research methodology. Furthermore, it discusses the chosen research design or strategy for gathering data and the data analysis method.

3.1 Study area

This study was carried out in the small town of Goedverwacht, located in the West Coast district of the Western Cape Province of South Africa (Figure 3.1). The Western Cape Province of South Africa stands as one of the country's nine provinces, encompassing an area of 129462 km^2. Situated on the southern tip of the African continent, the province is flanked by the Atlantic and Indian oceans. Its neighbours include the Eastern Cape and Northern Cape Provinces. The province is one of the five regions on earth that are classified as Mediterranean-type ecosystems, namely, Central Chile, Mediterranean Basin, Southwest Australia, California, and the Cape region of South Africa (Cowling et al., 1996). Mediterranean-type ecosystems regularly experience a winter-rainfall and summer drought precipitation cycle (Blumler 2005; Rebelo et al. 2006).

The Western Cape Province is categorised into three different climatic regions (Van Niekerk and Joubert, 2011; Western Cape municipalities, 2017). These climatic regions include the Mediterranean, South Coast and Karoo regions as depicted in Figure 3.2. The Mediterranean climatic region in the Western Cape is characterized by mild, wet winters and warm, dry summers. The Mediterranean climate is ideal for the cultivation of certain crops such as grapes, olives, and citrus fruits, and has also led to the development of a thriving wine industry in the region. The South Coast climatic region in the Western Cape is characterized by mild, wet winters and cool, dry summers. The summer months (December-February) are cooler and drier than other parts of the Western Cape, with temperatures rarely exceeding 25°C. The Karoo climatic region in the Western Cape Province is characterized by hot summers and cold winters, with low rainfall throughout the year. During the summer months (December-February), this region experiences hot and dry conditions, with temperatures often exceeding 30°C.

Administratively, the province is divided into one metropolitan Municipality, five district municipalities, and 24 local municipalities (Western Cape municipalities, 2018). It significantly contributes around 24% to South Africa's Gross Domestic Product (GDP), with 4% originating from the agricultural sector. Distinguished by its agricultural richness, the Western Cape boasts an array of crops ranging from fruits and vegetables to grains and wine grapes. However, most of the agriculture in this region relies heavily on irrigation water. Typically, the primary water source for agricultural activities within the Western Cape Province is surface water, procured from rivers, streams, and dams. Nonetheless, the availability of surface water is characterized by significant variability and susceptibility to frequent drought episodes. In recent times, there has been a notable shift towards recognizing groundwater resources as an increasingly viable alternative water source for the Western Cape Province.

Goedverwacht is in the Mediterranean climate zone of the Western Cape Province climatic regions. Goedverwacht is located at -32.5153 degrees latitude and 18.4146 degrees longitude. Even though Goedverwacht does not lie under the municipal-owned land, it is within the borders of the Bergrivier local Municipality and covers an area of 3.8 km^2 along the river with an average elevation of 130 m. Goedverwacht is privately owned by the Moravian Church of South Africa and is held in trust by the Minister of Land Affairs for the benefit of the residents under the Rural Areas Act (Act No. 9 of 1987) (Pinfold, 2018). According to the Census (2022), Goedverwacht had 1979 inhabitants with approximately 650 houses that increased from 200 people that were initially accommodated in the area. The number of inhabitants increases to 3000 on weekends and holidays when those who work outside of Goedverwacht return (EMG, 2016. The primary languages spoken are Afrikaans and English, with a diverse population of Coloured, and White residents.

Figure 3.1: Locality map showing Goedverwacht, Western Cape, South Africa (Google Maps)

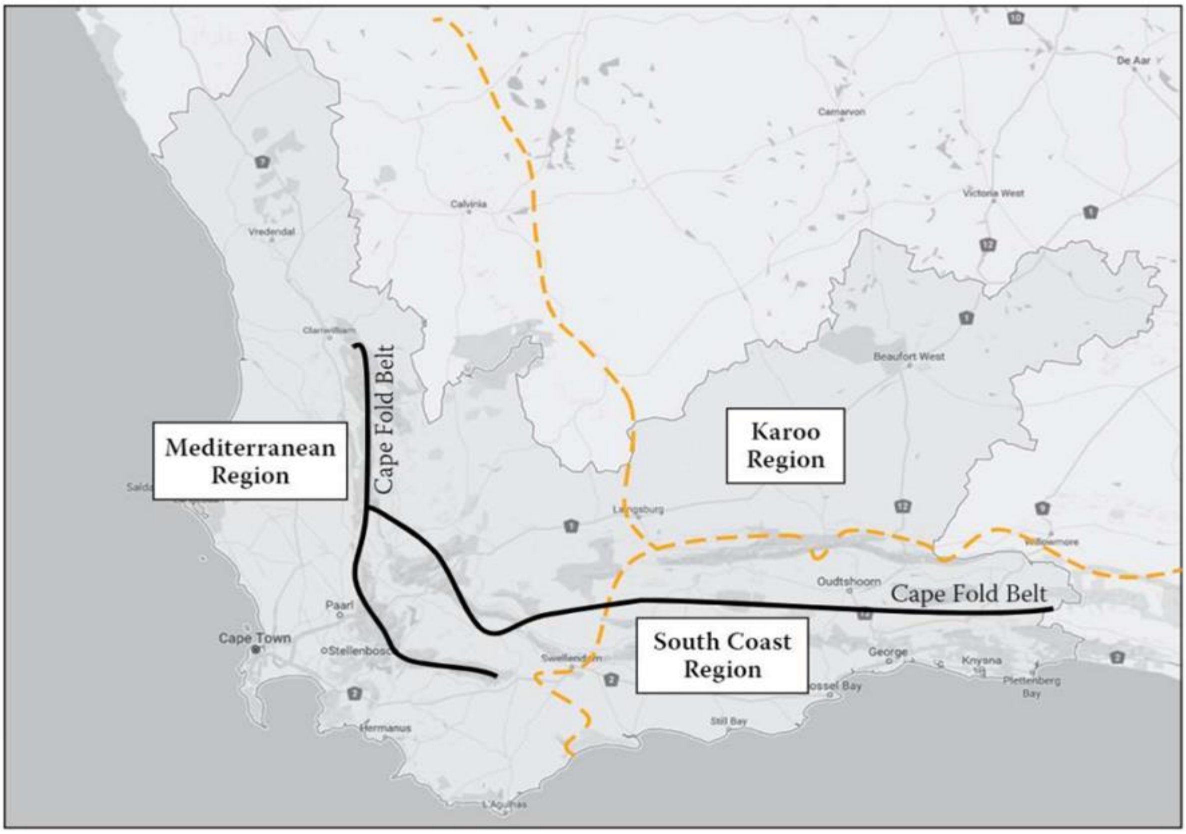

Figure 3.2: Topographical map of the Western Cape Province (boundary indicated by the grey highlighted area) which illustrates the Cape Fold Belt (indicated by the black

solid line) and the resulting climate zones, Mediterranean, South Coast and Karoo (indicated by the orange dotted line) (Du Plessis & Schloms, 2017)

3.2 Research methodology

Research methodology is traditionally divided into two main categories: qualitative and quantitative methods (Nyame-Asiamah, 2009). Research methodology focuses on solving research problems scientifically and systematically (Trochim, 2010). According to Walliman (2011), a research methodology outlines the steps involved in conducting an analysis, specifying factors such as the timing (when), sources of data (from whom), and contextual conditions for data collection. This methodology establishes a blueprint for generating empirical evidence that will be employed to address the research questions. The survey questionnaire used in this study comprises both open-ended and closed-ended questions. Open-ended questions are structured, while closed-ended questions constitute an unstructured questionnaire.

Given that most of the questions in this survey are open-ended, the questionnaire falls under the category of a structured survey questionnaire. In a structured questionnaire, the research instrument consists of a set of standardized questions aimed at gathering responses from participants (Battacherjee, 2012). This study employed a mixed-methods approach, combining both qualitative and quantitative methods. This approach, often referred to as a mixed-methods approach, involves researchers drawing knowledge and forming claims based on pragmatic considerations (Cresswell, 2003).

3.3 Data collection techniques

3.3.1 Key informant interviews

The key informant interview took place on 14 April 2023 at the West Coast District Office of the Western Cape DoA in Moorreesburg. The scheduled meeting time was originally 09:00 but was rescheduled to 11h00 due to unforeseen circumstances (load shedding). The interview involved six agricultural officials from the Western Cape government who work with smallholder farmers in the West Coast District Municipality. These officials included the West Coast Agriculture District Manager, Agricultural advisors, Agricultural economists, and intern. Two of the Agricultural advisors specifically covered the area of interest, Goedverwacht on the West Coast.

Before the presentation, consent was obtained for recording and capturing photographs to ensure compliance with the POPI Act. A register was administered during the interview to document the number of participants present. Following the WRC research project presentation, one-on-one interviews were conducted using structured questionnaires. Prior to each interview, the contents of the form were explained to the participants, and they were asked to sign it to protect their identity. The duration of each interview ranged from 30 to 45 minutes based on the number of questions and the interview structure. The questionnaire consisted of both open-ended and closed-ended questions. The information collected from the participants focused on agricultural water resources, agricultural infrastructure, climate changes, and governance systems in the West Coast District Municipality. A purposive sampling method was employed to identify these participants.

3.3.2 Structured survey questionnaires

The second set of data was collected from smallholder farmers in the study area of Goedverwacht in May 2023. One of the Agricultural Advisors responsible for smallholder farmers in Goedverwacht provided contact details of some farmers. On the first day, the advisor introduced the researcher to some smallholder farmers in the study area. This is necessary to develop rapport with participants so that they are more open and forthcoming when working with someone they know (Rogers, 2003). Using a snowballing technique, an additional number of farmers were identified through existing connections. A snowball sampling method is utilized because it allows the researcher to identify respondents by asking previous participants and locals whom to interview (Babbie, 2012).

A total of 17 smallholder farmers were interviewed, with each interview lasting between 20 to 45 minutes.A snowball sampling technique was employed to identify and recruit additional participants. According to the smallholder farmers, the final sample of 17 farmers represented the full population actively engaged in agricultural activities during the study period. The participants predominantly spoke Afrikaans, which is one of the most spoken languages in the Western Cape Province, and all the participants were identified as being of coloured ethnicity. However, some participants had a basic understanding and speaking proficiency in English. A translator fluent in Afrikaans was present to assist during the interviews. Since this study forms part of the Water Research Project, two other researchers were assisting during the interviews with smallholder farmers. The WRC study includes the Overberg and West Coast District Municipalities of the Western Cape Province, and all three researchers were working collectively in collecting data from these two districts.

Prior to each interview, the consent process was explained to the participants, and they signed the consent form, granting permission for the recording to be used throughout the interview. A tape recording of an interview allows for precise and authentic recording throughout the communication process (Witzel, 2000). Thus, the interviewer can focus on the discussion and observe nonverbal expressions. The consent form assured participants that their identity would be protected and that they were allowed to decline to answer certain questions they were uncomfortable with. The participants were interviewed in a setting that was appropriate and comfortable for them.

3.3.3 Flow rate measurements

Water flow velocities were measured using Global Water Flow Probe equipment (FP211) as depicted by Figure 3.3. It was chosen for its accuracy in measuring water velocity, especially in irrigation canals, which are prevalent in the selected study area. The primary objective was to measure the amount of water delivered to smallholder farmers through the irrigation system (Figure 3.4). To obtain more accurate velocity readings, the channel was divided into, sections. Measurements were conducted in April 2024, during a season of low rainfall in the Western Cape region of South Africa. Two research assistants carried out the measurements as part of the main WRC project. During the water flow measurement process, the probe was submerged in water, ensuring the propeller was correctly oriented with the water flow, and gently moved three times across the channel section. To reduce errors, the probe was set to take average readings by averaging several measurements, rather than repeating the process multiple times at each point.

Figure 3.3: A Global water flow probe (YSI, Yellow Springs (OH), United States)

Figure 3.4: Area under irrigation (Google Earth)

3.3.4 Meteorological data

The historical rainfall and temperature data contain daily and monthly rainfall data, and the minimum and maximum daily temperatures were obtained from the South African Weather Services (SAWS), which measures and hosts climatological variables in South Africa. The data was provided in Excel (.csv) format by the SAWS. Before SAWS could provide the researcher with the required data, the researcher had to complete a disclosure form accompanied by proof of registration, since the data was to be used for educational purposes, and return it to SAWS. This process of requesting the data took approximately two months from February to April 2023. The SAWS consultant who provided the rainfall and temperature data for the targeted stations indicated that the Piketberg station is only a rainfall station and does not include the temperature measurements, whereas the Porterville carted for both the rainfall and temperature measurements.

In the study area of Goedverwacht, the closest rainfall station is Piketberg (lat -32.9061, long 18.7544), located within a 10 km radius, and Porterville station (lat -33.0122, long 18.9947) is approximately 35 km away. Therefore, the rainfall data used in this study was from the Piketberg rainfall station and the temperature data was from the Porterville station. The data of interest for this study covered a 20-year period, specifically from 2003 to 2022. A preliminary quality check was conducted on the historic rainfall data to ensure that the required duration had sufficient data available and that it met the criteria.

3.3.5 Condition of the irrigation water infrastructure

To access information regarding the infrastructure used for supplying water to smallholder farmers for irrigation in the study area, a map was requested from an article by Nicolas Pinfold (2018). The article focused on communicative mapping to promote legal land tenure in Goedverwacht. The reason for requesting such information from the researcher was that Goedverwacht lacks cadastral records due to the land still being owned by the Moravian Church of South Africa. People started developing the area without proper authorization from the landowners. The map obtained from Pinfold's article was a coordinated map and would greatly assist in accurately depicting the layout of the pipe infrastructure and water sources identified during the transect walk. The map was received in AutoCAD format, enabling the layout to be plotted at a larger scale for precise referencing purposes during the mapping of the infrastructural layout.

A visual assessment of the irrigation infrastructure was conducted in Goedverwacht in September 2023. The assessment took place from the water source (river) to the agricultural land for smallholder farmers. Photographs and measurements were taken at the offtake, canal, and sedimentation tank located at the head section of the irrigation infrastructure supplying water to the farmers. At the head section of the irrigation system, there was an offtake to pipe transition, pipe to canal transition, canal to sedimentation storage tank connection, and a storage sedimentation tank-to-supply pipeline connection. In the middle section, there was a water supply pipeline with a scour valve, while the tail section comprised the main valve and a distribution pipeline serving various farms. Photographs were taken only at the head and tail sections. In the middle section, photographs were taken exclusively at the scour valve due to the underground burial of the water supply pipeline and the supply connection at the tail section of the infrastructure.

3.3.6 Literature review

A desktop study was undertaken to assess the status of water resources in South Africa, with a specific focus on the Western Cape region. The study aimed to delve into the perspectives of smallholder farmers regarding climate change, as shaped by their direct experiences. Additionally, it aimed to examine the existing meteorological research pertaining to climate change, as well as the coping mechanisms that smallholder farmers employ during periods of drought in Africa, particularly within South Africa and the Western Cape Province. The methodology primarily encompassed a thorough review of available literature. By scrutinizing reports, governmental publications, both published and unpublished theses, online articles, conference papers, and published scholarly articles, a holistic understanding of the subject matter was garnered.

One key element of the study involved capturing the perceptions of smallholder farmers. Their insights into climate change were analysed through the lens of their own encounters and observations. This qualitative approach illuminated the nuanced ways in which climate change manifests in their agricultural practices and lives. In conjunction with the experimental aspect, the study incorporated an analysis of meteorological studies. These investigations, conducted by experts in the field, provided empirical evidence of climate change trends. By comparing these findings with the firsthand accounts of smallholder farmers, a comprehensive picture emerged, highlighting areas of alignment or divergence.

Furthermore, the study delved into the strategies adopted by smallholder farmers to navigate the challenges posed by dry seasons, which are prevalent in the African context, especially in South Africa and the Western Cape Province. These coping mechanisms, often grounded in local knowledge and practices, shed light on the resilience and adaptability of these farmers in the face of climate-related adversity. The institutional framework for water governance in

South Africa was also a pivotal aspect of the study. By scrutinizing existing structures and systems, an understanding of the mechanisms in place for managing water resources at a broader level was obtained. Moreover, the governance systems predominantly employed at the smallholder production level were examined. This sheds light on the interplay between institutional frameworks and grassroots practices, underscoring the complex dynamics that shape water management in the context of smallholder agriculture.

3.4 Data analysis

3.4.1 Flow measurement

The velocity area method was employed after obtaining water velocity measurements to determine the flow rate. The velocity area method is recommended for temporary flow measurements, such as research studies, and in the absence of hydraulic structures (Yoder, 1999). This method involves multiplying the measured velocity of flowing water at various points across the channel by the cross-sectional area of the channel. The continuity equation, as depicted in Equation 1, was used to carry out the inflow calculations into the irrigation system.

$Q = V \times A$ ……………………………………………………………*Equation 1*

Where:

Q = flow velocity (m^3/s)

V = velocity (m/s)

A = cross-sectional area (m^2)

Total channel width (W) = 0.5 m

Depending on the type of channel, there are various equations used to calculate the cross-sectional area of the channel. For this study, an equation for a rectangular channel was used, as shown in Equation 2.

$A = W \times D$……………………………………………………………………*Equation 2*

Where:

W = top width of the channel (m)

D = flow depth (m)

3.4.2 Trend analysis

The study conducted a trend analysis to assess changes in rainfall time series in the Goedverwacht area, utilizing data from the Piketberg and Potterville weather stations. The analysis employed a simple linear regression model, expressed as Y=mx+c, where Y represents rainfall, x denotes time in years, m is the slope coefficient, and c is the intercept.

The slope's sign indicates the trend direction: positive for increasing and negative for decreasing. Microsoft Excel was used to perform the trend analysis for both rainfall and temperature data from the two weather stations. This approach aligns with common practices for understanding historical trends and making predictions, as noted in Berger (2010), and is consistent with other studies analysing rainfall trends.

3.4.3 Smallholder farmers and key informants' perceptions

The analysis of the perception of key informants and smallholder farmers was conducted using Atlas.ti software. This software facilitated the generation of quotes, cross-tabulation, and networks, contributing to the maintenance of the information's validity and reliability. The steps involved in utilizing Atlas.ti included transcribing the questionnaire, generating pseudonym-based codes organized by themes, assigning these codes, and creating tables and networks for analysis.

3.4.4 Infrastructure condition assessment

The most widely used method for analysing the condition of infrastructure is typically a visual assessment, which involves inspecting the physical parameters of the infrastructure through direct observation. This method allows for the identification of visible signs of deterioration, wear, or damage, such as cracks, corrosion, or structural deformities. Visual assessments are often the first step in evaluating infrastructure, as they are relatively simple, cost-effective, and can provide immediate insights into the overall state of the system. Photographs of the infrastructural components were taken to analyse the state of the irrigation infrastructure.

3.5 Ethical consideration

This study was conducted under a framework of rigorous ethical principles designed to protect the rights, dignity, and welfare of all participants. The research protocol received formal approval from the CPUT Ethics Review Committee before commencement and was further authorized by the Government of the Western Cape as part of the broader Water Research Commission (WRC) project. To ensure compliance with the Protection of Personal Information Act (POPIA) of 2013, all participants provided signed informed consent, explicitly guaranteeing that their personal details would not be disclosed to any third party and would be used solely for the stated academic and WRC-linked research purposes. Data was captured using audio recorders and manual notes during fieldwork, with all materials, including digital recordings, scanned consent forms, and digitised notes, securely transferred to the university's designated research server immediately upon returning from the field. This centralised, password-protected repository, accessible only via encrypted university credentials, ensured robust data security and confidentiality from the point of collection.

The study implemented stringent measures to protect participant anonymity and minimise any potential harm, particularly given the close-knit community of Goedverwacht and the sensitive nature of discussing water governance and resource conflicts. All smallholder farmer participants are referred to using non-identifiable codes (e.g., SGoeWD) in all research outputs, with any personally identifiable or locational details removed from the data. Key informants are acknowledged only by their organisational role unless explicit prior agreement was obtained. The research was guided by the principles of beneficence and non-maleficence, with interview protocols designed to explore systemic challenges rather than attribute individual blame. As a reciprocal benefit, a summary of the aggregated findings will be shared with the Goedverwacht community and relevant government stakeholders, ensuring the knowledge contributes to future dialogue and supports equitable water governance.

3.6 Summary

The research methodology employed a comprehensive approach to gather both qualitative and quantitative data, ensuring a thorough analysis of the irrigation systems. Data collection involved key informant interviews, smallholder farmer surveys, and flow measurements, providing diverse insights into the current state of irrigation practices. Meteorological data was also considered to understand environmental factors, while the condition of the irrigation infrastructure was assessed to gauge its efficiency. A thorough literature review further contextualized the findings. For data analysis, the Velocity Area method, trend analysis using graphs and Atlas.ti software were utilized to process and interpret the collected data, enabling a robust evaluation of irrigation system performance and the factors influencing its effectiveness. This multi-faceted methodology ensures a well-rounded understanding of the study area, laying the groundwork for informed recommendations and interventions.

CHAPTER FOUR
RESULTS AND DISCUSSION

4 Introduction

This chapter presents the results and discussions of water availability, impact of drought and climate change, condition and performance of the agricultural infrastructure and water governance police in Goedverwacht. It also presents their effect on water availability for smallholder farmers, it further discusses the implications of the results. These results included the quantitative and qualitative analysis of the study where perspectives of the farmers are also taken into consideration. The results were also compared to the previous studies conducted about the themes discussed in this chapter.

4.1 The availability of agricultural water for utilization by smallholder farmers

The availability of agricultural water is a critical factor for smallholder farmers, as it directly influences crop production and overall farm productivity. This section explores the challenges and perceptions surrounding water access and management in smallholder farming in Goedverwacht. It begins by measuring water availability for smallholder farmers, followed by an exploration of their perceptions regarding water sources, rights, use payments, and experiences with water shortages. Key informants, such as extension officers from the Western Cape Department of Agriculture, provided valuable insights into the broader context of water availability, including issues related to water rights, allocation, and payments, offering a more comprehensive view of the factors affecting smallholder farmers' access to water.

4.1.1 Measurement of water availability

The velocity-area method (Herschy, 2008) was used to assess the quantity of water supplied to smallholder farmers through a weir in Goedverwacht. Measurements conducted during the dry summer season, characterized by minimal rainfall in both the study area and the broader Western Cape region revealed an average discharge (Q) of approximately 0.03 m^3/s, which is equivalent to 2.59 megalitres per day (ML/day) (Table 4.1). Interviews with smallholder farmers indicated access to over 50 ha of agricultural land, of which less than 10 ha are actively cultivated. The primary crops grown in the study area include cabbage, carrots, onions, and potatoes, which have water requirements ranging from 3.5 to 7 megalitres per hectare (ML/ha) over a 120-day growing season (Allen et al., 1998). This translates to a maximum daily water demand of approximately 59 000 L/day per hectare. Therefore, the irrigation water demand for 10 ha is 590 000 L/day.

The measured water supply of 2.59 ML/day exceeds the maximum estimated daily demand of 590 000 L for 10 ha, indicating a surplus of approximately 2 000 000 litres per day. This surplus suggests that the current water availability is sufficient to meet the irrigation needs of the smallholder farmers in Goedverwacht and could potentially support the expansion of cultivated land. The surplus of 2 ML/day can support roughly 30 - 34 additional hectares? If the actively cultivated land in Goedverwacht were to increase from 10 to 40 ha, the maximum daily water demand would also increase accordingly.

Considering the corresponding maximum daily water requirement per ha remains approximately 59000 litres. For 40 ha, this translates to a total daily water demand of 2.36 ML. With a measured water supply of 2.59 ML/day (2 590 000 litres), the available water would still exceed the maximum estimated daily demand by approximately 230 000 L. This indicates that, even with the expansion of cultivated land to 40 ha, the current water availability is sufficient to meet the irrigation needs of smallholder farmers. Therefore, the measured water supply in the study area appears sufficient to meet the needs of the smallholder farmers.

Table 4.1: Canal velocity area method results

Position no.	**Width (m)**	**Actual flow depth (m)**	**Velocity (1) (m/s)**	**Velocity (2) (m/s)**	**Velocity (3) (m/s)**	**Average velocity (m/s)**	**Flow(m^3/s)**
1	0.5	0.11	0.2	0.4	0.9	0.50	0.03
2	0.5	0.11	0.1	0.4	0.6	0.37	0.02
3	0.5	0.11	0.1	0.3	0.3	0.23	0.01
Average discharge							0.03

4.1.2 Smallholder farmer’ perceptions on water availability

Water sources

Understanding the sources of water that smallholder farmers depend on is crucial, as agricultural production is fundamentally reliant on water. Identifying and analysing these water sources allows for a better assessment of their availability, sustainability, and impact on agricultural practices. Given that smallholder farmers often operate under constraints such as limited access to water and variability in water supply, this understanding is essential for developing strategies to enhance water management and improve agricultural productivity. The smallholder farmers in the study area primarily rely on river water, fountains, springs, and rain harvesting for their water supply as reported by smallholder farmers. Some smallholder farmers elaborated that the water originates from mountain springs, which then form streams that eventually contribute to the main river, providing water for their irrigation needs through the irrigation scheme system. **SGoeWD2** shared**:**

"Our river comes from the mountain; it's like a fountain that flows into a river stream."

Interestingly, no farmers indicated the use of boreholes or dams as water sources or alternative water sources for their agricultural activities in Goedverwacht. One smallholder farmer mentioned using tap water for their irrigation activities. This farmer operates in a garden setting and does not share the open land with other farmers. Figure 4.1 depicts the network diagram generated from Atlas.ti software illustrating the smallholder farmers' responses when queried about their water sources for irrigation activities. The source of water was further verified during the transect walk, a visual inspection of the irrigation infrastructure, confirming that water for both drinking and agricultural purposes in the area originates from the mountain springs and flows to the river.

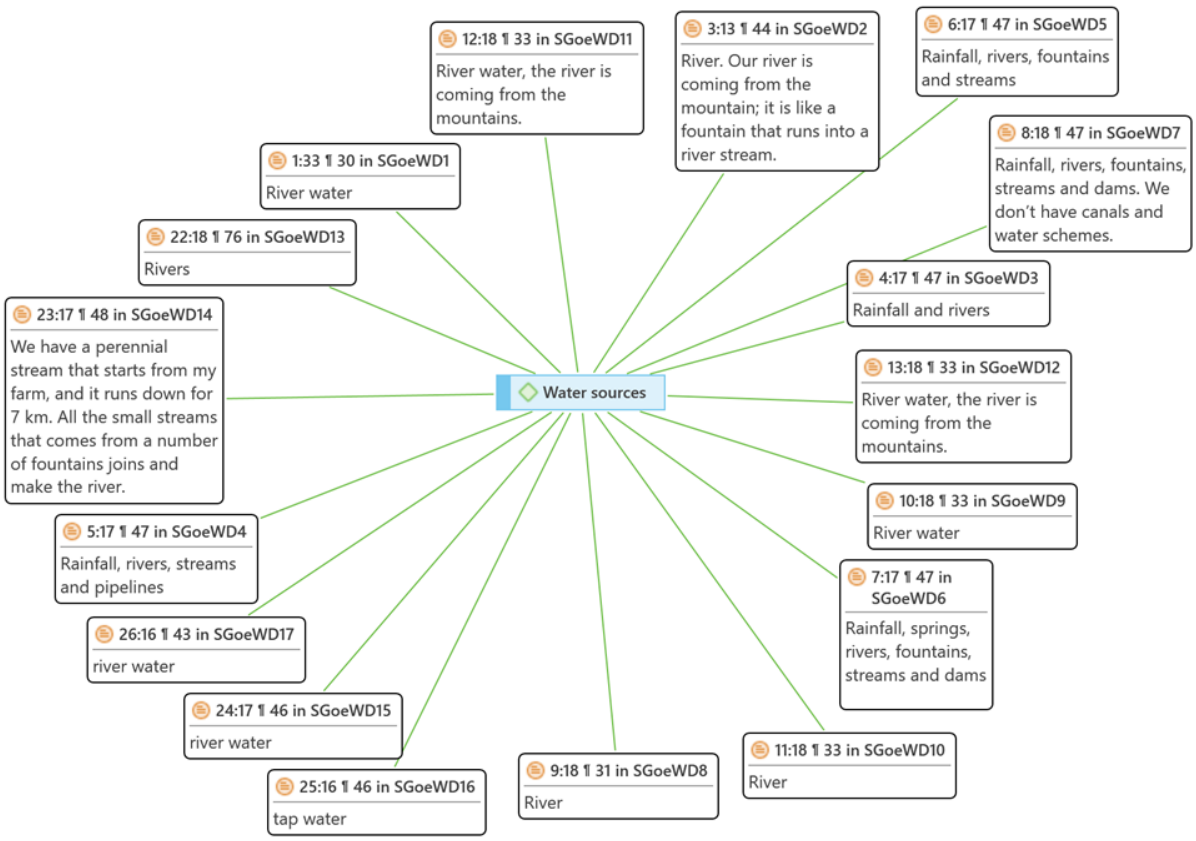

Figure 4.1: Water sources in Goedverwacht

Water rights possession

Most smallholder farmers in the study area do not possess water usage rights for the water drawn from the river. Only one farmer (SGoeWD16) claimed to have water usage rights. SGoeWD16 operates at household garden level and engages in farming part-time and the water that he uses for irrigation is the domestic water supply. Other farmers who lack water usage rights explained that the Moravian church holds these rights. Those who lease land from the church gain water rights by paying the church for access to the land for agricultural activities. Farmer SGoeWD14 provided a detailed explanation, stating: "Squatters cannot own permits. What we have done over the past years was to inform the Department of Water Affairs that we are using the water even though according to the books we are not the rightful owner of the land". Another farmer (farmer SGoeWD8) mentioned: "No water license. However, as a group of farmers, we have a right to use water in this area. We obtained these rights when we requested water for 500 ha, and the government indicated that they only issue such licenses to a group of farmers, not individuals. We then formed a farmers' union called “Goedverwacht Boere Vereniging organisation” that applied for and obtained the right to use water."

These remarks from the smallholder farmers proves that there is a link between land and the right to use water. As highlighted by smallholder farmers and other scholars, the land issue appears to be a constraint affecting agricultural activities in the area. According to Makeleni et al. (2018), the Moravian church owns land in Goedverwacht, and access is granted through traditional means or by applying through the overseer's council. Dissatisfaction among farmers regarding the land issue is evident, with varying opinions on whether the area should be converted into a village or a small town. Some farmers, especially the Rastafari, argued that their birthright gives them the inherent right to use natural water resources, proposing a shift to a village model like other South African villages where the authority powers are shared between government and the community leaders such as chiefs. Conversely, other farmers support the idea of transforming the area into a small town.

The complexity of the land issue is further emphasized by disagreements among farmers, highlighting the need for a legal system to register individual land rights. Pinfold (2018) suggested creating an interim cadastral map using general boundaries to address the land issue in Goedverwacht. This approach aligns with the Western Cape Land Use Planning Act (Act No. 3 of 2014) (LUPA), which requires communal land within a Municipality to be incorporated into an existing municipal zoning scheme (Western Cape, South Africa, 2014: 18).

Water usage payment

Most smallholder farmers indicated that they do not pay for the use of water for irrigation activities. This is not surprising because the payment for water usage is closely linked to water usage rights. Farmers who did not lease from the church are not expected to pay for water, as opposed to those who formally leased from the church. To gain a comprehensive understanding of the water use rights and payment issue, it is crucial to consider the land ownership status in the area. Table 4.2 illustrates the land ownership status reported by farmers in the area. Most farmers indicated that they are renting or hiring land, while others mentioned borrowing or inheriting land. However, even farmers who mentioned inheriting the land clarified that they do not own the land as it was inherited by their forefathers through the same means of permission to occupy the land.

A minority of farmers mentioned that they do pay fees for irrigation water. These farmers primarily indicated that they pay these water fees to the church, which issues them contracts to operate for nine years and 11 months. Among the farmers paying fees for irrigation water, some mentioned paying R840 per year. Other farmers reported paying varying amounts such as R300, R600, and R1 800 for lease, which includes water payments. The discrepancies in the amounts paid by farmers may be attributed to the size of the farm they occupy.

Table 4.2: Land ownership in Goedverwacht

Farmer code	Land ownership
SGoeWD1	Unsure
SGoeWD 2	Inherited
SGoeWD 3	Renting
SGoeWD 4	Renting
SGoeWD 5	Renting
SGoeWD 6	Renting
SGoeWD 7	Renting
SGoeWD 8	Hired
SGoeWD 9	Renting
SGoeWD 10	Hired
SGoeWD 11	Inherited
SGoeWD 12	Borrowed
SGoeWD 13	Borrowed
SGoeWD 14	Hired
SGoeWD 15	Bought
SGoeWD 16	Bought
SGoeWD 17	Bought

Water shortages experienced

Regarding water shortages experienced during the study period (2003-2022), the outcomes varied. Some farmers reported never running out of water for their agricultural activities, consistently having sufficient water resources. However, a group of farmers mentioned that during the summer, when temperatures are high, residents sometimes block water from entering the canal to create swimming pools because they lack access to pools or the beach in the area and that affect the water used for irrigation. Goedverwacht is located far away from the ocean for the people to swim during the summer when temperatures are very high. It is also important to note that the temperatures in the study area gets too over 40ºC during the summer season and people will always look for water to bath in. This blockage of water by residents could also be managed if the farmers and the residents could have a proper engagement with each other and try to have schedules for irrigation and swimming. For example, most swimming happens during the day, not in the early hours of the day or late evening, which are the proper irrigation times. Some farmers noted that during summer, they encounter low water pressure on the farms due to other farmers located upstream using excessive water.

Farmer SGoeWD 15: "I experienced low pressure when every farmer is irrigating, and this only happens during summer when there is low rainfall in the area". These farmers do not coordinate irrigation schedules, leading to water shortages during the summertime. Those farmers indicated that the upstream farmers take more water resulting in a shortage of water. The shortage could also be attributed low pressure due to the design and the position of the distribution pipeline. This issue might be attributed to the fact that the system might have been designed during the time when there were abundant water resources, and the engineer underestimated the issue of climate change that might impact the water resources in future. The farmers mentioned that the water resources are sufficient during the rainy season.

These findings address the issues raised in the WRC study (Ncube, 2020), which had not clearly identified the causes of conflict during the 2015-2018 drought in the Western Cape. The results of the current study indicate that the conflict among farmers particularly complaints about unfair water distribution by upstream farmers and reduced water pressure leading to inadequate water supply for smallholder farmers downstream, was not necessarily the main reason for the water shortages experienced during the drought. Pili and Ncube (2022) pointed out similar challenges in the West Coast district where farmers did not get water because of low pressure in the pipeline. Similarly, Mpandeli and Maponya (2014) also identified similar problem in Limpopo Province, where some farmers indicated that periods of water shortage are also caused by the low water pressure system installed by the Department of Water and Sanitation.

4.1.3 Key informants' perceptions of water availability

Water source

In the effort to understand the water sources used by smallholder farmers across the West Coast district, the officers reported that the smallholder farmers access water from a variety of sources, including river water, streams, dams, municipal water, boreholes, well points, and fountains (Figure 4.2). Extension officer KMorWD5 was responsible for smallholder farmers (Mixed farming) in the Goedverwacht area, which is the focus of this study. The information provided by the extension officer regarding the water sources used by smallholder farmers aligns with the responses of the smallholder farmers themselves. It was confirmed that these farmers primarily rely on river water sourced from fountains and springs in the study area.

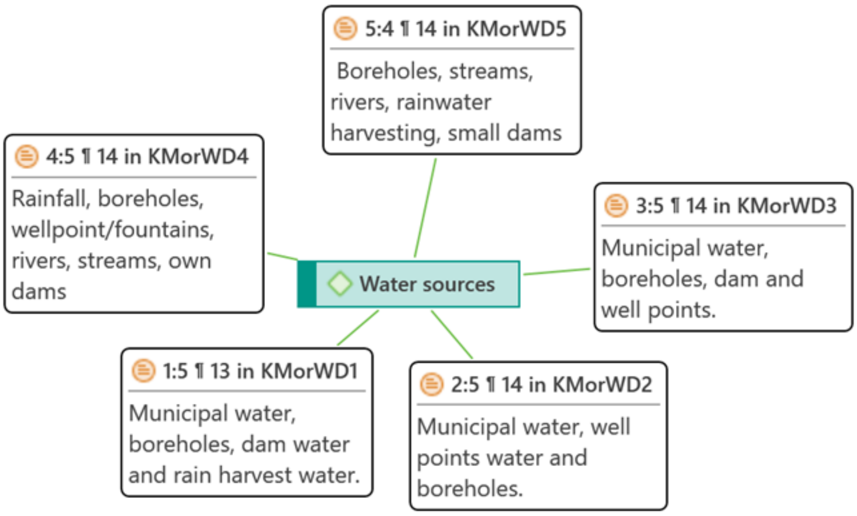

Figure 4.2: Water sources used by smallholder farmers according to the extension officers

The use of river water by smallholder farmers in South Africa was also addressed (Mkuna & Wale, 2023). The findings by Averbeke et al. (2011) align with both the key informants and smallholder farmers in Goedverwacht. This suggests that smallholder farmers have access to water resources, and river water is less vulnerable than water stored in dams during drought conditions. This water was sourced through direct pumping, diversion using weirs, or storage in dams. Additionally, water was supplied through gravity to 164 97,2 ha (34.6%) of the land

(Van Averbeke et al., 2011). While the case of Goedverwacht differs slightly from what is typically categorized as the formal irrigation scheme, it shares similar characteristics with such schemes. Therefore, it might be considered an informal irrigation scheme. Farmers in Goedverwacht also access water from the river, diverting it through weirs and utilizing gravity, which aligns with the findings presented by Van Averbeke et al. (2011).

Water rights

The extension officers mentioned that they are currently in the process of obtaining water rights for smallholder farmers in the West Coast district. However, they emphasized that this process is challenging and time-consuming. Some also noted that only smallholder farmers who acquired their land through the Department of Agriculture, Land Reform, and Rural Development (DALRRD) have the necessary water rights and licenses which unfortunately is not the case in Goedverwacht. The Goedverwacht water rights possession is linked to the access to land which is the larger challenge. Additionally, as highlighted by extension officer KMorWD5: "Some farmers have registered boreholes, and those who use river water also possess water use rights. Boreholes are mainly utilized for livestock farming".

Based on the information provided by the key informants, it is evident that the government of the Western Cape under the South African government is putting effort in terms of application for the smallholder farmer to have access to water licences, however, the process seems to be slow due to government processes. The water licence application process is slow for smallholder farmers primarily due to a cumbersome and technically complex bureaucratic system, which is poorly matched to their limited financial and technical capacity (Mukuyu et al., 2020). This is compounded by significant institutional backlogs and under-resourcing within the governing authorities, creating a lengthy queue for all applications. Consequently, the very system designed for inclusion creates a structural barrier that disproportionately delays smallholder access. The information obtained from farmers and extension officers does not correspond. Farmers claim that they have no water rights due to prevailing conditions and yet the extension officers emphasised that those who use water from the river have the rights to use water. This situation in the study area may be attributed to the challenges related to land access which appear to impede development efforts in the region. According to Pili et al. (2022), similar land constraints have been identified as a significant barrier to the advancement of smallholder farmers in Goedverwacht. These findings suggest that the land access is a critical factor affecting the ability of smallholder farmers to improve their agricultural practices and overall development.

Water allocation

To comprehensively assess the government's support for the smallholder farming industry, it is essential, for this study, to examine water allocation to the agricultural sector. Agriculture consumes more than 60% of the total water resources in South Africa, making it crucial for the government to have a detailed breakdown of water allocation among various agricultural segments. Obtaining this information required engaging with government officials responsible for agricultural institutions. Results suggest that the extension officers expressed uncertainty regarding the exact water allocation for smallholder farmers in the West Coast district. Most officers stated that there are no imposed limits on water usage, which could potentially lead to overexploitation and water wastage, consequently contributing to water shortages. However, one officer mentioned that farmers with water rights are allocated a specific volume of water. When farmers are wasting water resources, that might contribute to water shortage.

Extension officer KMorWD3: "There is no specific amount of water allocated to smallholder farmers". This was also reported by Mpandeli and Maponya (2014) in Limpopo, where only 30% of the farmers had access to water due to misuse and mismanaging of water resulting in shortage, especially during drought. It is evident that the smallholder farmers in the West Coast district are not included in water allocation to assist them in developing as farmers. Compared to commercial farmers, smallholder farmers are still left out in decision making regarding water resources.

Water payments

In South Africa, the water payment system for agricultural use reveals significant disparities between commercial and smallholder farmers, compounded by challenges during drought and water scarcity, as well as gaps in governance and transparency. Commercial farmers are required to pay for water usage, with government subsidies supporting affordability for agricultural activities, as outlined in the NWA, which regulates water as a national resource. The 2024 Revised Raw Water Pricing Strategy further promotes efficient water management, providing allowances for "resource-poor" farmers, though these exemptions are being phased out over five to ten years. Smallholder farmers, however, often face financial and infrastructural barriers to covering water costs, particularly during droughts, which can severely limit agricultural productivity (Pricing Strategy for Raw Water Use Charges, 2024). Studies, such as those by Mpandeli and Maponya (2014), highlight how water scarcity exacerbates these challenges, with smallholder farmers in regions like Limpopo struggling due to low water pressure and inadequate infrastructure.

Extension officers play a critical role in bridging this gap by informing farmers about subsidies and assistance programs, such as debt relief or extended payment periods for resource-poor farmers, as noted by the DWS. However, the results indicates that farmers using municipal water face consumption-based charges without subsidies, increasing their financial burden. In contrast, smallholder farmers relying on boreholes incur no fees, which may lead to unregulated overuse and negative regional water resource impacts, as boreholes are a primary water source in drought-prone areas like the Northern Cape. Additional insights were provided by extension officer KMorWD5 who works with farmers from the area of interest, who stated: “Those farmers using water from the rivers pay, but I have no idea how much they pay because I am new to this area; I was previously working in another province” The statement from extension officer KMorWD5, expressing uncertainty about water payment rates due to being new to the area, underscores a lack of transparency and local knowledge dissemination, reflecting broader water governance issues. This aligns with Dlangalala and Mudhara (2020), who noted that poor institutional arrangements and inadequate information sharing hinder smallholder farmers’ efficiency in water management. The officer’s unfamiliarity suggests gaps in training and communication, as highlighted by Van Averbeke et al. (2011), who emphasized the need for collaborative arrangements in smallholder irrigation schemes to ensure equitable water distribution. These findings point to the necessity for clearer, more inclusive water governance systems to ensure all farmers are informed about usage and costs, particularly during water-scarce periods, to enhance compliance and sustainability.

4.1.4 Summary

The results of water availability in Goedverwacht, conducted using the velocity-area method, revealed an average discharge rate of 0.03 m^3/s, equivalent to 2.59 ML/day. This volumetric measurement significantly exceeds the estimated irrigation requirements for the currently cultivated 10 ha as indicated by the smallholder farmers. Even with a hypothetical expansion to 40 ha and more, the water supply would remain adequate. These findings suggest that the physical availability of water in Goedverwacht is sufficient to support not only existing agricultural practices but also a moderate increase in cultivated area. However, despite this technical adequacy, challenges related to infrastructural design, uncoordinated water usage, and seasonal interferences such as the use of irrigation canals for recreational purposes during summer undermine the reliability of water access for all farmers as indicated by the results. The presence of low-pressure conditions for downstream users during peak irrigation periods further illustrates the need for improved system management and equitable distribution mechanisms.

The perceptions of smallholder farmers and key informants provide critical insights into the socio-political dimensions influencing water access and utilisation. Smallholder farmers rely on natural sources such as rivers and mountain springs yet lack formal water use rights due to the complex land tenure system dominated by the Moravian Church. This situation reinforces the link between land access and water rights, with only those leasing land through formal agreements having conditional access to water for irrigation from the church. Key informants, corroborate these constraints, noting that the formal allocation of water rights remains limited and administratively burdensome. The lack of transparency regarding water payment obligations and the inconsistent institutional support further exacerbates the vulnerability of smallholder farmers. Although the provincial government is reportedly working toward formalising water access for resource-poor farmers in the West Coast district, the process is protracted and lacks effective communication and implementation at the local level.

4.2 The impact of drought and climate change on smallholder farmers

Smallholder farmers, who rely on subsistence and rain-fed agriculture, are increasingly vulnerable to the impacts of climate change, especially droughts, shifting rainfall patterns, and rising temperatures. These changes significantly affect their crop yields, water availability, and overall food security. By examining the perceptions of smallholder farmers and key informants, such as agricultural extension officers, this chapter seeks to understand how these stakeholders interpret and respond to evolving climatic conditions. The research explores their experiences with drought, the changing nature of rainfall and temperature trends, and the coping strategies employed to mitigate these challenges, aiming to inform more effective, context-specific adaptation strategies that align with local knowledge and realities. The perceptions of smallholder farmers and key informants are compared with the results of trend analysis on the status of climate change. This comparison seeks to assess the alignment between local observations of climate variability, such as changes in rainfall patterns, temperature fluctuations, and drought occurrences, and the scientific data derived from trend analysis.

4.2.1 Temperature and rainfall trends

This section focuses on analysing annual rainfall and temperature for a period of 20 years (2002-2022) at the Piketberg and Porterville weather stations, which are chosen to represent the study area (Goedverwacht) due to the unavailability of a rainfall and temperature station in the study area. Temperature and rainfall are very significant players of climate change and therefore, it is essential to carry out an analysis when trying to understand the climate change in a particular region as they enable adequate planning and avert or manage the effects that will impact on the economy of the country (Bolan et al., 2024). Both rainfall and temperature contribute to the state of water resources.

Climate change has direct impact on the hydrological cycle, hence affecting agriculture and other important production sectors in the industry relying heavily on freshwater and thus affecting the country's economy. The results are compared to available literature on similar studies conducted in the Western Cape Province. The results are further compared to the perspectives of smallholder farmer and key informants on drought and climate change in the study area.

Rainfall trends for the Piketberg weather station

The Piketberg station, being a rainfall station, exclusively recorded rainfall data and did not include temperature measurements when received from SAWS. The highest mean annual rainfall (49.9 mm) for the study duration (2002-2022), was recorded in 2013 (Figure 4.3). The average rainfall data reveals the inconsistency of rainfall patterns in this area. Heavy rainfall is often followed by drought events, and conversely, droughts may be succeeded by periods of excessive rainfall. The lowest mean annual rainfall was recorded in 2005, 2015 and 2017 with just below 25 mm rainfall recorded, with 2017 being the worst year with the lowest rainfall recorded. To ascertain the trend in the rainfall data over the past two decades, an equation was generated using Microsoft Excel software.

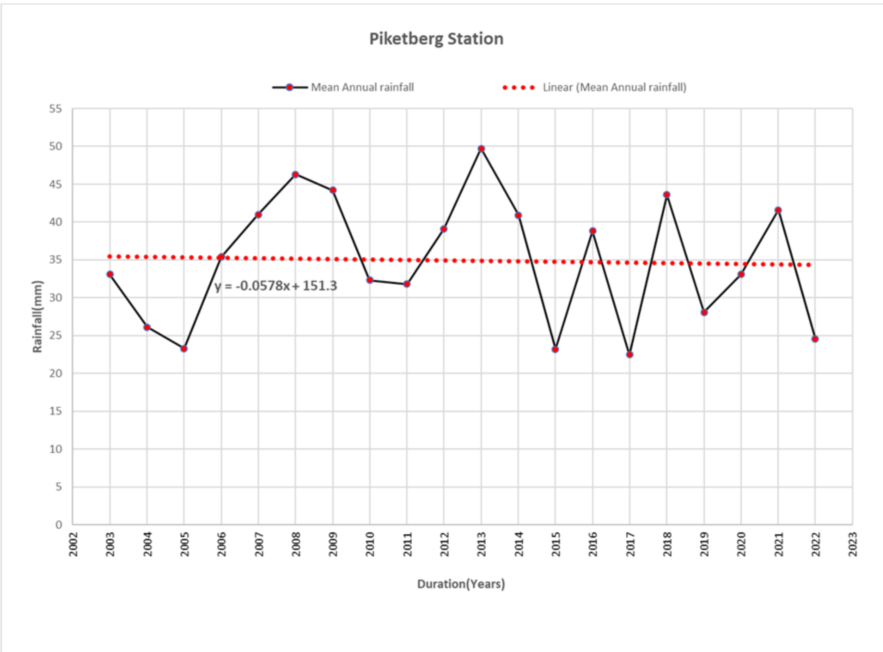

Figure 4.3: Mean annual rainfall trend for Piketberg rainfall station from 2002-2022

Source: Data obtained from the South African Weather Service (SAWS), 2023.

The resulting graph displayed a negative slope, signifying a decreasing trend in rainfall over the past 20 years at the Piketberg station. Considering the station's proximity of within 5 km to Goedverwacht, the findings are expected to be highly consistent between the two locations. Rainfall is a key factor in the hydrologic cycle and any change in the pattern directly impacts on the water resources of a given area (Chabalala et al., 2023). A decline in rainfall patterns and low mean annual rainfall is typically associated with the phenomenon of drought, which is a period characterized by water shortages. In the Western Cape Province. Drought has been experienced in this region in the past.

The drought in the Western Cape led to severe water shortage for domestic and commercial use, which disrupted the livelihood and security of its citizens and visitors (Nhamo & Agyepong, 2019). A study by Botai et al. (2017) assessed drought conditions in the Western Cape from 1985 to 2016. Their findings align with these results, suggesting that the 2015–2016 drought was a manifestation of past dry periods. The authors further highlighted that the trend analysis depicted notable spatial-temporal dependence wherein the Southern and Western regions experienced more severe drought compared to the Eastern and Northern regions of the Western Cape Province.

Trends exhibited up to approximately 8% variability over the past decade. The meteorological analysis of the event indicates that below average total rainfall in the region was caused by a strong rainfall anomaly in the shoulder seasons (March-May and August-October), while the core of the rainy winter season (June and July) was characterised by near-normal rainfall (Wolski et al, 2018). Climate change projections show some degree of reduced rainfall for the mid-century (2040–2060) (Western Cape Government, 2018a). Archer et al (2019) suggested that the drought, which began in 2015 with below-average rainfall, had evolved into a socio-economic drought after three consecutive periods of low precipitation.

It can be difficult to associate the rainfall trend over a certain period with the water deficit as the trends are normally computed from a variation of rainfall for a certain period. However, the prolonged low rainfall is highly associated with the water shortages. Evidence of low rainfall's impact on water resources can be drawn from the 2015-2018 situation in the Western Cape Province. Water availability was affected as most areas had below-normal rainfall, with a few exceptions (Government of Western Cape, 2017). The impact of lower rainfall had negative effects on the agricultural sector, resulting in a decrease in agricultural activities, loss of livestock, shortage of water, low yields and a shortage of seeds for subsequent cultivation (Mpandeli, Nesamvuni & Maponya, 2015).

The findings of decreasing trends of rainfall also align with those of, Burls et al. (2019) and Odoulami et al. (2021) who identified longer-term drought trends linked to the combined influence of a long-term (1910-2017) decrease of rainfall day frequency associated with a more recent (1979-2017) deficit in rainfall intensity. Several studies on climate change, particularly focusing on rainfall trends in the Western Cape Province, have suggested a fluctuation between decreasing and increasing patterns. As an example, du Plessis & Scholms (2017) conducted an analysis of seasonal changes in rainfall patterns within South Africa's Western Cape region, using parametric methods. Their research uncovered variations in rainfall patterns, highlighting cyclic patterns involving both dry and wet periods across different seasons. However, it must be noted that their trend analysis period differs from the current study's trend analysis period.

Rainfall trends for the Porterville weather station

The highest mean annual rainfall for the Porterville station was recorded in 2007, utilizing data encompassing 20 years (2002-2022) of rainfall records (Figure 4.4). The lowest mean annual rainfall was recorded in 2004, 2015 and 2017, and was below 25 mm. Notably, this station demonstrated a positive trend, indicating an upward trajectory in rainfall over the past two decades. However, both rainfall stations reported their lowest recorded rainfall in the same years, i.e. 2015 and 2017. This outcome is not surprising, given that this period marked a phase during which a significant portion of the Western Cape Province encountered reduced rainfall. Subsequently, this drought condition prompted the declaration of drought emergency in the province. Winter rain, occurring from June-August, is of great importance to the Western Cape Province, and the 2015-2018 drought had severe implications for the agricultural sector (Archer et al., 2019). Both stations recorded similar rainfall in the year 2004 and 2005, which was also the lowest level below 25 mm. The Pikertbeg station recorded a rainfall of 23.3 mm in 2005 and Porterville recorded 22.1mm in 2004. Porterville station also recorded the lowest rainfall 22.4mm in 2003. These stations displayed similar data, with slight variation.

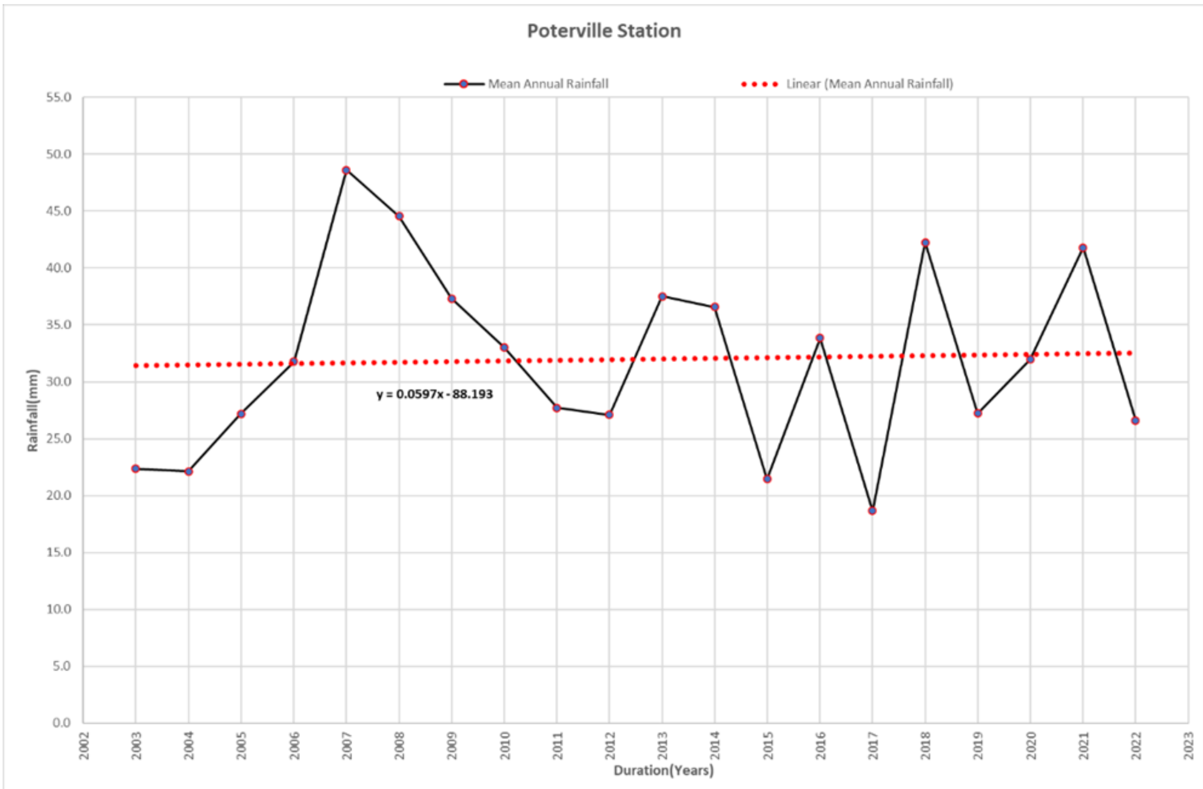

Figure 4.4: Mean annual rainfall trend for Porterville rainfall station from 2002-2022

Source: Data obtained from the South African Weather Service (SAWS), 2023.

Lakhraj-Govender and Grab (2019) investigated annual and winter rainfall trends at seven weather stations and river flow at five stations in the Western Cape Province (Table 4.3). Two distinct periods were analysed: 1987-2017 and 1960-2017. The findings from this study indicate that over a 30-year period (1987-2017), annual rainfall in the region exhibited a decreasing trend. Additionally, statistically significant decreasing winter trends were identified at four of the seven stations during the 30-year period. Furthermore, the magnitude of the winter river flow decreased at Bree@Ceres and Berg@Franschoek and was more pronounced during the 30-year period (1987-2017) compared to the longer period of 1960-2017.

Table 4.3: List of weather stations located in the Western Cape Province from which data were sourced. Source: (Lakhraj-Govender & Grab, 2019)

Station Name	Latitude	Longitude	Altitude (masl)	Station Type
Vogel Villij@Voeliv	-33.34	19.04	683	Rainfall
Zachariashoek@ Wemmershoek	-33.70	19.01	1735	Rainfall
Cape Columbine	-32.48	18.29	62	Rainfall
Cape Point	-34.20	18.28	228	Rainfall
SA Astronomical Observatory	-33.56	18.28	15	Rainfall
Langewens	-33.27	18.25	179	Rainfall
Cape Agulhas	-34.49	20.01	11	Rainfall
Bree@Ceres	-33.38	19.30	269	River flow
Berg@Franschock	-33.89	19.08	315	River flow
Wit River@Drosterkloof	-33.97	19.15	838	River flow
Little Berg@Nieuwkloof	-33.36	19.08	1021	River flow
Palmiet@van Aries Kraal	-34.20	18.98	315	River flow

The observations by Lakhraj-Govender and Grab (2019) align with the results from the Piketberg station, where a decreasing trend in rainfall was observed. However, it is important to note that the findings differ from those at the Porterville station, which exhibited an increasing rainfall trend during the study period. It should be acknowledged that conducting a fair comparison necessitates the use of data over the same duration. Remarkably, when the Porterville station was analysed for the same 30-year period, it displayed similar characteristics of decreasing rainfall trends (Figure 4.5). Many other parts of the Western Cape experienced similar rainfall levels (Dippenaar, 2022). Vyeboom-Villiersdorp saw the most sustained rainfall deficit, with below-average totals in all four years from 2015 to 2018. In Ceres, rainfall was below the long-term average in 2016 and 2017, with 2017 receiving less than half the typical amount. Groenland's rainfall varied across the period: 2016 and 2018 were wetter than average, while 2015 and 2017 were drier.

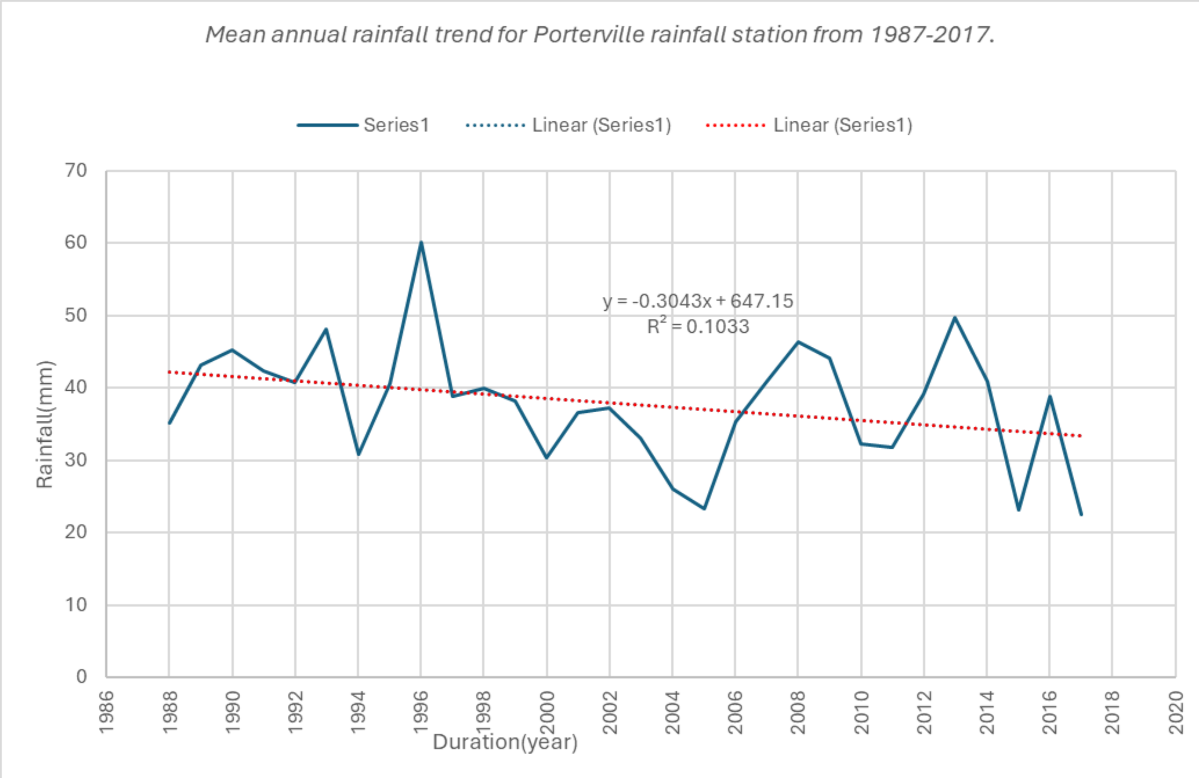

Figure 4.5: Mean annual rainfall trend for the Porterville rainfall station from 1987-2017
Source: Data obtained from the South African Weather Service (SAWS), 2023.

Temperature trends for the Porterville weather station

The highest mean annual maximum temperature for the Porterville weather station was recorded in the year 2017, based on temperature data of 20 years (2002-2022) (Figure 4.6). The 2015-2018 drought period as declared in the Western Cape Province, corresponds with the data recorded from the year 2015, 2016 and 2017. The temperature trends over the study period (20 years) showed a positive value on the equation, which indicates the increasing trend of mean annual maximum temperature over the period of 20 years. These findings aligned with the corresponding lowest rainfall data in 2015 and 2017 from both the Porterville and Piketberg weather stations. Remarkably, both stations documented their lowest mean annual rainfall in the year 2017. This convergence of data substantiates the occurrence of a drought phenomenon that was officially acknowledged in the Western Cape Province during the period spanning from 2015 to 2018, a declaration made by authorities based on a sustained period of significantly low precipitation combined with its severe impacts on regional water reserves, agriculture, and supply systems.

According to reports from the WMO (2017) and the Climate System Analysis Group (2017), three out of the four hottest years since 1977 occurred during this drought, including 2015, 2016, and 2017. Furthermore, 2017 stood out as the warmest year on record that was not influenced by an El Niño event. The warming trend aligns with the trends identified by Theron et al. (2021) in their trend analysis, aimed at determining whether drought observations are part of the long-term trends in the Western Cape Province. Their findings, based on data from six stations across the region, as depicted in Table 4.4, reveal that from 1988-2018, the Western Cape consistently experienced prolonged drought conditions characterized by high spatial-temporal variability. Furthermore, the authors noted that this drought was most severe during the 30-year study period at five of the six stations. There has been a noticeable increase in temperatures across South Africa in the past 40 years. During the summer months of 2011-2012, temperatures higher than 26ºC were observed in the Northern Cape, Northwest, Limpopo and northern parts of KwaZulu-Natal Provinces (SAWS, 2014). Climate change projections show some degree of increased temperature in the range of 1.5 to 3 °C for the mid-century (2040–2060) (Western Cape Government, 2018a).

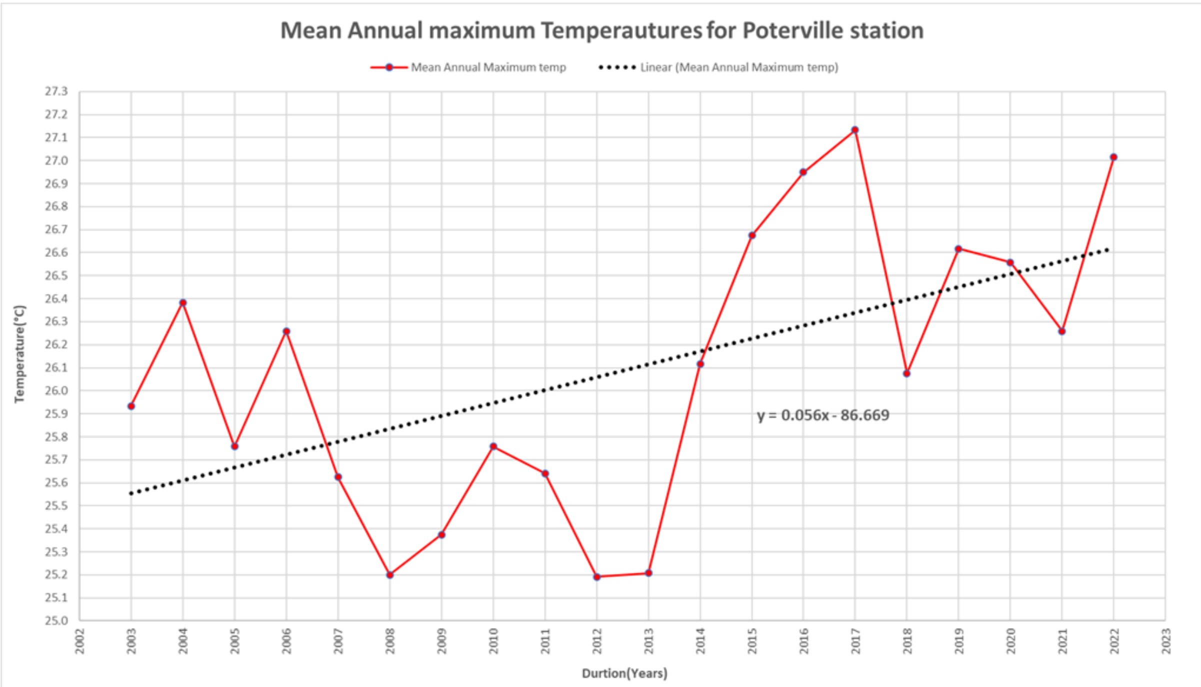

Figure 4.6: Mean annual maximum temperature for Porterville rainfall station from 2002-2022.

Source: Data obtained from the South African Weather Service (SAWS), 2023.

Table 4.4: Geographic positions, elevations, and data availability (numbers in brackets indicate month of the year). Source:(SJE ce, Author& Theron, n.d.)

Station	Latitude (S)	Longitude (E)	Elevation (masl)	Data Availability
		Swartland		
Langgewens	-33.28	18.70	177	1967- 2018
Hopefield	-33.10	18.42	71	1997- 2018
Piketberg	-32.78	18.89	171	1988-2007 (7) & 2007 (9)-2018
		Rûens		
Tygerhoek	-34.13	19.9	331	1964-2018
Protem	-34.47	19.90	283	1924-2009 (2) & 2009 (3)-2018
Caledon	-34.22	19.36	191	1920-2004 & 2006-2018

Influence of observed climate trends on spring and canal flows in Goedverwacht

The observed trends in rainfall variability and increasing temperature have important implications for both spring discharge and canal flows supplying irrigation water in Goedverwacht. Springs in the region are primarily sustained by shallow groundwater systems that are recharged during the winter rainfall season. Consequently, declining or increasingly erratic rainfall, particularly during the shoulder and winter months, is expected to reduce groundwater recharge, leading to lower and less reliable spring flows during the dry season.
The decreasing rainfall trend observed at the Piketberg station, together with the occurrence of prolonged dry periods such as the 2015 - 2018 drought, suggests a reduction in effective recharge over time. Even where annual rainfall totals may appear near normal in some years, changes in rainfall timing and intensity, such as reduced rainfall during critical recharge periods, can significantly limit infiltration and subsurface storage. This is consistent with findings by Wolski et al. (2018), who showed that the Western Cape drought was driven largely by rainfall deficits outside the core winter months, thereby weakening catchment and groundwater recovery despite near-normal winter rainfall.

Rising temperatures further exacerbate these impacts by increasing evapotranspiration losses from soils, vegetation, and open water bodies. Higher evaporative demand reduces the proportion of rainfall that contributes to groundwater recharge and baseflow, while simultaneously increasing irrigation water requirements. As a result, springs feeding the irrigation canals are likely to experience reduced discharge volumes and shorter flow durations, particularly during late summer and drought years. The concurrence of the highest recorded temperatures and lowest rainfall in 2015–2017 strongly supports this interpretation. Canal flows in Goedverwacht are directly dependent on spring discharge and are therefore highly sensitive to climate-driven reductions in baseflow. During extended dry periods, reduced spring yields translate into lower canal flows, limiting the reliability of water supply for irrigation. This qualitative linkage is supported by farmer and key informant perceptions, which indicate that water shortages during drought periods are not solely the result of infrastructure condition, but also of diminished water availability at the source. Reduced flows also increase vulnerability to conveyance losses, such as seepage and evaporation, further constraining water delivery to downstream users.

Overall, the combined effect of declining or variable rainfall and rising temperatures is likely to intensify pressure on spring-fed irrigation systems in the study area. These climate-driven hydrological changes help explain observed reductions in canal flows during drought periods and reinforce the need to interpret infrastructure performance and water governance outcomes within the broader context of climate variability and change. While this study does not model spring discharge directly, the observed climate trends provide a strong qualitative basis for understanding the hydrological stresses experienced in Goedverwacht.

4.2.2 Smallholder farmers' perceptions of drought and climate change

Climate change description

Understanding climate change is essential for farmers, whether they are producing for home consumption or selling their produce, as it helps them mitigate the risks associated with changing weather patterns. When smallholder farmers were asked about their understanding of climate change, various responses were obtained. The most common understanding of climate change among the farmers was related to changing seasonal rainfall and temperatures. For the context of this study, climate change is defined as a significant and prolonged alteration in average weather conditions, such as high temperatures, increased precipitation, or extended periods of dryness, over several decades or longer (Trenberth, 2011). Therefore, farmers who expressed their understanding of climate change as the weather patterns displayed a basic understanding of climate change that aligns with the study's adopted definition. A few smallholder farmers provided more detailed descriptions of climate change.

For example, one participant (Farmer SGoeWD11), explained climate change as:

“It is the pollution that is generated all over the world and breaks the layer that protects us from the ultraviolet from the sun, once that ultraviolet goes through the layer then we experience climate change in certain parts of the world. When those signs of climate change show even you as a farmer you must learn to adapt by planting certain cultivars that can survive in certain climatic conditions".

Another farmer rather mentioned that he gauges climate change by monitoring river levels. If the water level in the river remains stable, they do not consider climate change to be a significant issue. However, if the river levels decrease, they interpret it as a sign of climate change. Another farmer (SGoeWD17) described climate change as follows: “There are two key aspects to consider regarding climate change. First, we can observe changes in weather patterns in this area. We no longer receive the amount of rain we used to. Rainfall used to occur in winter, but the current levels of rainfall are significantly lower than what we were accustomed to. Second, maintenance plays a crucial role. Although this is not directly related to climate change, proper maintenance of water areas is essential. Invasive plants and trees that consume excessive amounts of water need to be managed. This, in turn, can help address the decline in water levels. Additionally, we have noticed that summers are possibly not hotter than they used to be when I was a child. While it was indeed hot back then, the changes in groundwater levels may have some connection to boreholes or other factors. We have observed a decrease in natural springs, many of which have completely dried up”.

Farmer SGoeWD17, even though he did not give a straight definition of climate change, displayed an understanding of the climate change concept. On the other hand, a few farmers stated that they were uncertain about what climate change is, and some believed they were not affected by these changes and did not see the need to learn more about it. One of the reasons farmers struggle with understanding the climate change concept normally relates to their education. Most farmers in Goedverwacht have basic education, thus when they are properly educated about this phenomenon, they would easily understand the concept.

Drought description

On the issue of drought, which significantly affected most parts of the Western Cape Province between 2015 and 2018, most smallholder farmers described drought as a period characterized by very low rainfall, leading to water shortages. According to Rind et al. (1990) and Wang et al. (2019), drought is a prolonged period of anomalous dry weather interrupting the hydrological balance driven due to enhanced potential evapotranspiration. Naumann et al. (2021), defined drought as a period of abnormal soil moisture deficit caused by a shortage of precipitation, increased temperature, and excess evapotranspiration, resulting in adverse impacts on agricultural production and ecosystem functioning. The IPCC (2021) defines drought as “a period of abnormally dry weather long enough to cause serious hydrological imbalances”. For this study, drought is defined as a period when an area or region experiences below-normal precipitation, resulting in a decrease in water availability which aligns with the definitions by these authors. Therefore, smallholder farmers who associated drought with low rainfall were in line with the adopted definition of drought for this study. Farmer SGoeWD14 described the drought as follows: “I have not experienced a drought, but my understanding of it is that it entails the absence of rainfall for an extended period, often lasting for at least a full calendar year. I also have a community in the Northern Cape that I support, and they are involved in rooibos farming. They are currently grappling with a drought, and in their case, my understanding is that it means they are receiving significantly reduced rainfall. Essentially, drought is characterized by the presence of very limited rainfall.”

Few farmers provided a description of their understanding of drought that aligned with the adopted definition of the study. However, some farmers had different interpretations of drought, viewing it as a period of water resource shortage rather than emphasizing the lack of rainfall. For example, farmer SGoeWD11 described drought as: "It is when there is water scarcity or less water than usual, and you basically cannot use the amount of water that you normally use for your farming activities, so you must limit water usage".

Even though some farmers' descriptions of drought were not significantly precise, they displayed a minimal understanding of this phenomenon. Their responses included statements such as: "when there is a lot of alien invasion in the river that takes up water, it is a problem” (Farmer SGoeWD15).

Farmer SGoeWD3: "What I know about drought is that the moment animals suffer, we know there are signs of drought and there is a lot of money that is spent to keep the livestock going during such periods. There is nothing that can be done about it; people do not want to listen when being told about climate change which causes drought".

Farmer SGoeWD2: "Overpopulation has significantly increased, and the removal of forestry is one of the major factors contributing to the current drought situation".

Other farmers mentioned that they were not significantly affected by drought because they consistently had access to sufficient water resources, while some indicated they were uncertain about how to describe drought”.

Climate change causes

Awareness of climate change drivers is crucial for farmers to adopt sustainable farming practices. By understanding the factors contributing to climate change, farmers can adjust their activities to minimize their environmental impact, thereby promoting more sustainable agricultural systems. Most farmers perceived that the primary drivers of climate change are associated with industrial pollution, vehicles using fuel for operation, and human activities in general. Farmer SGoeWD11: “Pollution is one of the main things that causes this climate change problem. The pollution is mainly derived from industries and cars amongst other pollutants”.

Some farmers mentioned that extremely high temperatures contribute to climate change, emphasizing that stable temperature levels could prevent it. Among the responses, one farmer believed climate change is a natural phenomenon created by God, beyond human influence. Other smallholder farmers were unsure about the causes of climate change, with some indicating they were not educated enough to understand it, and others could not provide a response. Other farmers mentioned causes such as floods, which are not related to the cause of climate change based on the concept of this study.

This information highlights how pollution from industry and transport drives climate change. This aligns with the broader context of environmental degradation and its direct impact on agriculture, especially for smallholder farmers. The release of pollutants, such as greenhouse gases from industrial activities and vehicles, contributes to rising global temperatures, altering weather patterns and disrupting local ecosystems. For smallholder farmers, these changes can result in more frequent and severe droughts, floods, or unpredictable rainfall, affecting crop yields and water availability. Understanding the connection between pollution, climate change, and agricultural outcomes is crucial for developing strategies to mitigate these impacts and improve the resilience of water infrastructure, which smallholder farmers heavily rely on.

Causes of drought

Smallholder farmers believed that drought is primarily caused by climate change, while others pointed to water shortages as the root cause of drought. Some farmers could not respond what caused the drought. There was a farmer who provided a detailed explanation of the causes of drought, for instance, farmer SGoeWD11 explained: "There is a certain thing called El Nino. What I understand is that El Nino goes along with dryness, and now we are in that zone where drought is likely to be experienced. So, as I understand it, in South Africa, there is going to be more drought because we fall under the El Nino zone." While most of them could not respond to questions about their understanding of drought causes, this lack of awareness suggests that extension officers need to provide more education on the fundamentals of climate change and drought in the area. Although smallholder farmers reported that they were not significantly affected by droughts, it remains essential for them to understand the causes of drought. Awareness of these causes can help them develop strategies to mitigate potential impacts on their agricultural practices in the future.

Supporting this, research confirms that El Niño, as noted by the SAWS (2023) and Baudoin et al. (2017), drives drought in South Africa by reducing rainfall, aligning with the farmer's explanation. The IPCC (2022) and DWS (2020) validate farmers' views on climate change and water shortages as drought causes, noting increased drought frequency and water scarcity issues. Maponya and Mpandeli (2012) and Thinda et al. (2020) highlighted the knowledge gap among South African smallholder farmers and supported the need for enhanced extension services, as emphasized by DALRRD (2021). Mthembu and Zwane (2022) and the FAO (2019) underscore that understanding drought causes enables farmers to adopt resilient practices, such as drought-resistant crops, to mitigate future agricultural impacts.

Dissemination of information

Early warnings of climate change impacts on water resources are crucial to help farmers implement measures to cope during such periods, as timely information enables smallholder farmers in South Africa to adopt adaptive strategies like water conservation or crop diversification (Ziervogel et al., 2014). Without access to this information, farmers risk being unprepared for the challenges posed by these changes, a concern echoed in the Limpopo Province where limited access to reliable climate information leaves farmers vulnerable to erratic rainfall and droughts (Maponya & Mpandeli, 2013). Most farmers received information about climate change from television, followed by the radio, social media, and some farmers mentioned that they receive information from the internet, family, and friends. Studies in the Eastern Cape Province confirmed that mass media and informal networks are primary information sources for smallholder farmers (Gandure et al., 2013).

Some farmers indicated that they get climate change information through newspapers and few mentioned extension officers, highlighting the limited role of extension services in rural areas, as noted in research from the Northwest Province where extension officers often lack the capacity to educate farmers effectively about climate change (Mugi-Ngenga et al., 2016). These results show that farmers do not receive necessary assistance from extension officers to educate them about climate change and its impact on their agricultural activities, underscoring the need for more active engagement given the low awareness in rural South

African communities (Mandleni & Anim, 2011). Considering the level of education among the farmers, extension officers must be active in raising awareness about climate change in the area, in rural communities of developing countries such as South Africa climate change awareness remains low due to limited educational outreach (Mandleni & Anim, 2011). This was also highlighted by one of the farmers (SGoeWD2): “Only through TV; nobody comes to educate people. I am so happy to see people coming here with such interventions. Most of the people coming to this place go to the church first and then they turn around and go back from there. The church does not distribute information to the farmers in this area; they are the mafias”, a sentiment reflecting broader frustrations documented by the Agricultural Research Council (ARC) about the neglect of rural farmers by formal institutions (ARC, 2018).

Temperature and rainfall

To achieve a thorough understanding of the analysed meteorological data, it is essential to consider the perspectives of local farmers regarding variations in temperature and rainfall within the study area. This approach will facilitate an evaluation of whether incorporating farmers' experiences into policy formulation is warranted, rather than relying solely on climatic data. Given that farmers are particularly vulnerable to fluctuations in temperature and rainfall patterns, their first-hand experiences provide valuable insights that could enhance the relevance and efficacy of climate-related policies.

When farmers were asked about their perception on temperature and rainfall trends in Goedverwacht for the past 20 years (2002-2022), farmers indicated that they have experienced an increase in temperature levels in the past 20 years in the area and decreased rainfall. Very few farmers mentioned an increase in rainfall, and no farmers mentioned a decrease in temperature levels. According to the Intergovernmental Panel on Climate Change, more intense and longer droughts have been observed over wider areas during the twentieth century dominantly linked to higher temperatures and decreased precipitation (IPCC, 2007), which coincides with farmers' experiences in Goedverwacht. The response from the smallholder farmers aligns with the various scholars that have mentioned the increased temperature and decreased rainfall in the Western Cape Province in recent years, evidence can be drawn from the recent 2015-2018 drought event that took place in this province.

Measurement of rainfall and temperature

The quote from SGoeWD3, "We do not have measuring devices, we do not see a need to have it," sheds light on a key issue that many smallholders farmers face: a lack of access to tools and knowledge that could help them make informed decisions about their farming practices. While farming in many regions heavily depends on rainfall, the availability of surface or groundwater can reduce this dependence. Despite this, when farmers were asked whether they measure critical variables such as temperature and rainfall, most indicated they do not. This highlights a gap in both the physical infrastructure needed for data collection and the awareness of how such data could support better planning and predictions for future farming activities.

Farmers' reluctance to measure temperature and rainfall, even in areas where water resources are available, suggests a reliance on traditional farming methods and perhaps a belief that external factors like climate change or drought will not affect them consistently. The statement, "We do not see a need to have it," indicates a lack of perceived urgency, possibly because of past experiences where water availability has been stable. However, this mindset may be counterproductive, especially as climate variability increases, and periods of drought become more common. While they may not feel the immediate need for measurement tools, this lack of foresight becomes evident when unexpected droughts occur, and they are unprepared to adapt. Thus, the absence of monitoring devices reflects not only a lack of resources but also a gap in understanding how climate trends and data could help farmers mitigate risks and improve water management strategies in the face of changing environmental conditions.

Extreme weather events and impacts

Most farmers indicated that they experienced several extreme weather events in the Goedverwacht area during the study period from 2003 to 2022, with drought being the most common, followed by forest fires as the next most frequently encountered event, while floods were also frequently mentioned. Heat waves and storms were the least experienced. The occurrence of these events varied across years, with some years marked by dry conditions leading to droughts and forest fires, while others saw heavy rainfall resulting in floods; notably, farmers highlighted a significant drought in 2015, though subsequent years experienced less severe drought conditions, and in 2021, floods occurred towards the end of the year, alongside unusual instances of multiple fires within a short period.

Overall, Goedverwacht has been susceptible to droughts, floods, forest fires, and heatwaves, necessitating ongoing monitoring and mitigation efforts. These patterns align with broader trends of extreme weather events, such as drought, reported across the Western Cape Province (SAWS Annual State of the Climate of South Africa report, 2015); the Western Cape Department of Agriculture’s Western Cape Agricultural Sector Report 2021/2022, which validates the 2021 floods, a South African Journal of Science study by Kraaij et al. (2020) noting frequent wildfires from 2000-2020, a Council for Scientific and Industrial Research

(CSIR) report (2021) on climate variability in the Western Cape, and a Western Cape Government Disaster Risk Assessment (2020) highlighting rural vulnerability to these events.

The effects of extreme events

Extreme weather events had various effects on the water resources that farmers depend on for their agricultural activities, including livestock and crops. The farmers noted that they lost livestock due to droughts and fires, which drastically reduced the availability of grazing grass for their livestock. Some farmers explained that their crop yields were significantly reduced during drought periods due to uncertainty around planting in conditions of low rainfall and high temperatures. Infrastructure was also affected; pipe infrastructure was destroyed during a fire in the study area. Also, road access infrastructure was destroyed by flood, as exemplified by farmer SGoedWD, who stated: "The floods did not affect the crops, but they damaged the roads, and the water was contaminated. There was a guy from another farm who fixed the issue".

Some farmers could not respond to this question, primarily those who were not affected by the extreme weather events, as reported by most farmers in the area. Others, who do not primarily benefit from irrigation systems and rely mainly on rainfall, also mentioned road infrastructure disruption due to flooding, which complicated access to their farms. These findings coincided with Archer et al. (2019) who indicated that the Swartland agricultural region in the Western Cape is the most productive agricultural region in the province, and the recent drought resulted in crop losses and associated economic impacts.

The effects on livestock were also experienced by smallholder farmers in Mfekayi, Mtubatuba in the KwaZulu Natal Province who indicated that farmers also suffered livestock deaths and crop failure as major impacts of drought during the 2014-2016 drought (Bukhosini and Moyo 2023). Similarly, Orimoloye (2022) indicated that between 2015-2018, extreme drought impacted the crops, affecting most of the Free State Province. The author further revealed that maize production reached its lowest recorded levels in the years 2014 and 2015 due to the extreme drought experienced. Other parts of the country (Northern Cape) also highlighted that they experienced drought, subsequently affecting production (Table 4.5) (Matlou et al., 2021).

Table 4.5: The agricultural drought, experience and perceptions of smallholder livestock farmers (Matlou et al., 2021)

Variable	Category	Frequency (n)	Percentage (%)
Experienced Drought	Yes	207	100.0
	No	0	0.0
Duration of Most Recent Drought	Entire Year	112	54.1
	Four to Six Months	56	27.1
	One Month	39	18.9
Perceived Trend in Drought Occurrence/Intensity	More Frequent/Intense	145	70.1
	No Difference	37	17.9
	Less Frequent/Intense	25	12.1
Reported Agricultural & Livestock Impacts	Poor Animal Health	82	39.6
	Loss of Livestock	56	27.1
	Decline in Livestock Prices	27	13.0
	Sold Livestock at Lower Price	21	10.1
	Combined Loss & Poor Health	21	10.1

Coping measures

To mitigate the effects of extreme events such as droughts, floods, forest fires, heatwaves, and storms, farmers implemented various coping measures. Some farmers mentioned that they chose to plant drought resistant crops to ensure survival during dry seasons. This aligns with Ogundeji (2022), who highlighted the adoption of drought-tolerant crop varieties, to enhance resilience against water scarcity. Others, who had access to tanks, used them to store water, enabling them to manage water shortages effectively. This practice is consistent with findings that emphasize water harvesting and storage as critical copying strategies among smallholder farmers in water-stressed regions (Pili & Ncube, 2022). Farmers whose infrastructure (access roads) was damaged by floods repaired it to regain access to their farms and resume farming operations. Additionally, to protect their farms against fires, a farmer mentioned using pipes to create a water-based firebreak around the farm’s perimeter, reflecting localized innovations in fire management.

Those involved in livestock moved their livestock to other farms where the grass was not affected too much, and the water resources were available. This strategy corresponds with research on pastoral mobility as a traditional coping mechanism, where farmers relocate livestock to areas with better grazing and water availability during droughts (Bukhosini & Moyo, 2023). Most farmers could not respond regarding their coping mechanisms. This appears to be related to the fact that most farmers mentioned their involvement in crop production, and they mostly rely on irrigation, while those engaged in mixed farming with livestock were fewer. This observation is supported by studies indicating that crop-focused farmers in South Africa often depend heavily on irrigation infrastructure, limiting their adaptive flexibility compared to mixed farmers (Pili & Ncube, 2022). The drought coping strategies adopted, such as purchasing expensive supplements, practising crop variation, and applying indigenous knowledge like livestock movement, align with documented practices by Bukhosini and Moyo (2023).

Farmers with livestock kept them separate, situated on their land far from their crop fields. During droughts, they use vehicles and tanks to transport water to the livestock. This practice is well trusted as a coping measure, where water transport is a common adaptation to sustain livestock during dry periods (Pili & Ncube, 2022). Some mentioned selling a portion of their livestock to survive during drought periods, a strategy corroborated by studies noting livestock sales as a financial coping mechanism to offset losses during climate-induced crises (Ogundeji, 2022). A farmer, operating gardens, mentioned using a pool to extinguish fires due to the absence of nearby fire hydrants, highlighting challenges in rural farm fire management. A farmer identified as SGoeWD2, operating gardens, mentioned: "Since I have a farm at my house, I have a pool that I can use to extinguish the fire. There is no fire hydrant on the road that can be used by the fire brigade to connect and extinguish the fire. That is why it is difficult to overcome fire in this area. The last time a big fire happened, we received help from the Municipality, which sent three helicopters."

Support from institutions

When farmers were asked whether they received any assistance during extreme weather events such as drought, approximately half of the respondents indicated that they received support from the government to mitigate the effects of extreme weather events. This is interesting considering the Goedverwacht situation regarding land tenue and the position of government in relation to the service delivery to the area. The other half mentioned that they did not receive any government support. This lack of support might be attributed to the fact that some farmers do not farm legally as they lack proper land rights. It seems that institutions that could provide significant assistance to these farmers are not fully engaged, though the DoA appears to extend a helping hand where necessary, even given the challenging land situation in Goedverwacht.

For those who indicated that they received assistance, the support included tablets for livestock, livestock feed, storage tanks, pipes, planting seeds, and insecticides for potatoes, beans, plants, and pumps. Mutero (2016) supported this by highlighting that even though farmers might have basic tools to work with, they require funding to acquire irrigation, water storage facilities, transport and tractors. Smallholder farmers who did not receive assistance had comments such as farmer SGoeWD11: "We do not get any support from the government, I do not know the government, I only hear about them on television". This farmer belonged to the group classified as "Rastas", those who believe they do not need certain agreements to operate in the area and that they are the rightful leaders of this community. This indicated a division amongst the farmers as they had varying opinions about the challenges they face in the study area.

Coping challenges

The most prevalent challenges that farmers faced in coping with the effects of extreme weather events, as reported by the smallholder farmers, included a lack of funds to purchase livestock feed. Farmer SGoeWD14: "The lack of funds is the challenge to coping during drought". The lack of funding during the drought period has been widely experienced by the smallholder farmers as they do not have necessary resources reserved for such an event. Some farmers also highlighted the challenge of obtaining sufficient water. Those farmers that had challenges in fetching water and taking it to their farms were those involved in livestock farming, their farms are far away from the river.

Most of the smallholder farmers did not have transport for water, hence they could not cope during the drought period. It is worth noting that most farmers were unable to respond to this question. Their lack of response to coping challenges corresponds with their earlier responses regarding the coping strategies they employed during extreme weather events, where most farmers could not respond. Also, those farmers who could not respond were more likely to be engaged in crop production only and the crop production farmers highlighted that they are not affected when there is water shortage.

Adaptation strategies

Farmers in Goedverwacht employ various adaptation strategies during drought periods. These included, using JoJo tanks as water storage, installing pipes for irrigation, and using spray pipes for fire extinguishing. Additional measures involve planting crops earlier, building cattle houses, removing alien plants from rivers, and creating firebreaks by clearing grass around the farm perimeter. Farmers express a need for assistance in obtaining more water storage tanks to enhance water storage capabilities, despite the region generally having water available. These farmers emphasized the importance of adapting to climate change by choosing crop varieties suited to specific climatic conditions. Individual adaptive behaviour is strongly influenced by the perception of climate change, the appraisal of associated risks (Hyland et al., 2015), and the perception of one's own capacity to adapt (Woods et al., 2017).

4.2.3 Key informants' perceptions on drought and climate change

Extreme weather events

South Africa is susceptible to a range of extreme weather events, including droughts, floods, and heatwaves. These events have significant implications for various sectors, with agriculture being particularly vulnerable (Zhang et al., 2025). Given the critical role of agriculture in the country's economy and food security, it is imperative to conduct studies that explore human perceptions of these extreme weather events. Understanding which events are perceived as most impactful by individuals can provide valuable insights for developing targeted adaptation and mitigation strategies. Such studies are essential for enhancing resilience and informing policy decisions aimed at mitigating the adverse effects of climate variability on the agricultural sector. The key informants' (agricultural extension officer) responses regarding climate-related disaster experiences in the West Coast district for the period of 2002-2022 included drought, floods, fires, and strong winds. Key informant KMorWD05 stated: "Mostly drought, and occasionally veld fires (wildfires) and strong winds can be a concern. No frost, no floods, and no heavy rainfall. Veld fires have particularly affected grazing land". Key informant KMorWD05, who worked around interest, had responses that aligned with the smallholder farmers' accounts concerning drought, floods, and fires experienced from 2002-2022.

The responses from key informants were consistent with existing studies conducted in the region, which highlighted that extreme weather events such as drought significantly contribute to water shortages. Smallholder farmers corroborate these findings by acknowledging the prevalence of drought in the area. However, they also point out that their water resources are less severely impacted due to their reliance on spring water in Goedverwacht. This suggests that while drought is a notable concern, the availability of spring water provides a crucial buffer against the worst effects of water scarcity for these farmers in Goedverwacht.

Dissemination of information

It is crucial for farmers to be informed about climatic changes that may impact the agricultural sector. A lack of awareness regarding climate change can exacerbate challenges, particularly when farmers do not have access to necessary resources. Without adequate knowledge and resources, farmers may struggle to adapt to changing conditions, potentially compromising

their productivity and sustainability. Therefore, increasing awareness and providing relevant information are essential steps in supporting farmers to effectively manage and mitigate the impacts of climate variability. The extension officers primarily mentioned the use of social media as the most preferred method for disseminating information to smallholder farmers. Word of mouth was also highlighted by most officials, often through awareness programs, farmers' day events, and onsite training sessions.
Alongside these methods of conveying information to the farmers, they also noted the use of cell phones, even though they acknowledged that some farmers do not own cell phones. Interestingly the smallholder farmers shared different views with regards to sharing of information, they highlighted that even though they had various ways of getting information, it does not primary come from the extension officers. It is worth noting that this too could relate to the issue of land tenure, where the government cannot perform to their full ability due to the constraints they have in the area.

Effects of extreme weather events

Most of the key informants pointed out that climate-related disasters had the most significant impact on water resources for smallholder farmers in the West Coast region. The primary aspect of water resources that was affected was a shortage of water. This scarcity of water resources, resulting from extreme weather events, led to reduced crop yields and lower crop quality. In some cases, farmers were compelled to abandon their farming operations, as reported by the key informants. Key informant KMorWD05 provided comments which also included the area of interest, Goedverwacht: "Drought has caused the water table to drop, making it difficult to drill boreholes. Additionally, the low water levels in dams have resulted in insufficient water for irrigation".

Other effects of these extreme weather conditions that were highlighted included job losses, decreased income for farmers involved in selling their produce, and the loss of topsoil on farms due to strong winds in the region. It is important to note that the extension officers cover multiple areas, and the results are based on the areas they are covering within the West Coast District Municipality. The extension officer who was responsible for the area of interest had little knowledge about the effects of the extreme weather events specific to the area because he is new in the West Coast District Municipality. However, his experiences aligned with smallholder farmers' experiences on the effects of extreme weather events where they mentioned the decrease of the water table which results in loss of pressure to some farms. The other impacts as highlighted by the key informants included smallholder farmers abandoning or downscaling their production, less crop yields, loss of income, selling of livestock, existing boreholes that ran out of water, all contributing to the increased poverty, while other farmers farm for home consumption.

Coping strategies

Extension officers indicated that they provide smallholder farmers with farming inputs such as seeds, pesticides (medicines), fuel, and JoJo tanks for water storage to cope with extreme weather events. Some officers also advised farmers to adjust their irrigation schedules, recommending watering at sunrise and sunset. This method is preferred because it is believed to save water, reducing the chances of evaporation compared to daytime irrigation. Other officers suggested various farming techniques, including crop rotation, mulching, and the adoption of modern farming methods. Key informant KMorWD05's response, in particular: "As for dams, there was not much support; there was nothing we could do to assist farmers using water from dams. In terms of grazing land, the government helped by drilling additional boreholes." Interestingly, key informant KMorWD05's response as an extension officer covering the study area did not align with the information provided by the smallholder farmers. None of the farmers mentioned the use of boreholes as a coping strategy, even those who were engaged in livestock farming.

Coping challenges

Extension officers indicated that some of the coping challenges are related to the level of funding received from the government. Another challenge includes smallholder farmers that are not cooperative in terms of irrigation schedules that are introduced during the emergency periods, e.g. where water shortages are experienced. The results also suggested that farmers are not willing to move from their traditional farming practise to the modern farming, including the use of cultivars that are drought resistance. Extension officers should not only aim to convincme farmers during the time they experience extreme weather events to change farming practices but also conduct regular workshops and demonstrate modern practises to win them over.

Adaptation strategies

The results of the study indicated that extension officers recognize a significant need for farmers to adopt water-saving strategies as part of their adaptation strategy to changing environmental conditions. In addition to the focus on water conservation, extension officers identified several other strategies that could help farmers cope with these challenges. These strategies include crop rotation, which helps maintain soil fertility and reduces dependency on water-intensive crops. The use of modern farming techniques was also emphasized, particularly those that incorporate efficient irrigation systems, improved seed varieties, and technological advancements to optimize resource use.

Borehole usage was mentioned as an alternative water source, allowing farmers to reduce reliance on surface water. Additionally, irrigation schedules were suggested to ensure water is used more efficiently, preventing wastage. In some cases, extension officers recommended reduced agricultural production to manage water scarcity by scaling down crop cultivation or diversifying into less water-demanding crops. Finally, the use of greywater, or recycled water from household activities, was proposed as an innovative solution to supplement water supply in agricultural practices. These strategies collectively aim to help farmers adapt to water scarcity and ensure long-term agricultural sustainability.

4.2.4 Summary

The analysis of climatic data from the Piketberg and Porterville stations over the period from 2003 to 2022 reveals a concerning trend of decreasing rainfall and increasing annual temperatures, with the 2015–2018 drought period marking a peak in these adverse conditions. The decreasing rainfall trend at Piketberg, and increasing temperature trend at Porterville, particularly pronounced in 2017, when both stations recorded their lowest rainfall and Porterville its highest temperature, substantiates the severe drought officially declared in the Western Cape Province. These trends align with broader regional and global climatic patterns, indicating a shift towards warmer and drier conditions that threaten water resources and agricultural sustainability (WMO, 2017; Chabalala et al., 2023). The convergence of these climatic trends with the perspectives of smallholder farmers and key informants provides a comprehensive understanding of the challenges faced in the region.

Smallholder farmers in the study area have reported increasing difficulties in maintaining agricultural productivity due to erratic rainfall patterns and prolonged dry spells. Their lived experiences corroborate the quantitative data, as they describe shorter growing seasons, reduced crop yields, and increased reliance on limited water resources during the 2015–2018 drought. Farmers have noted the unpredictability of rainfall, with heavy downpours followed by extended droughts, mirroring the variability observed in the Piketberg rainfall data. Additionally, the rising temperatures reported by farmers align with the Porterville temperature trend, as heat stress has impacted both crop and livestock health, further straining livelihoods. These perspectives highlight the direct socioeconomic impacts of climatic trends, emphasizing the vulnerability of smallholder farmers to climate change and the urgent need for adaptive strategies such as drought-resistant crops and improved irrigation systems.

Key informants provide a broader contextual understanding that complements both the climatic data and farmer perspectives. They confirm the long-term decline in rainfall and rise in temperatures, attributing these trends to anthropogenic climate change and regional climatic variability. The key informants emphasized the 2015–2018 drought as a critical event that exposed systemic weaknesses in water infrastructure and agricultural planning in the West Coast region. They also highlighted the spatial consistency of these trends across the Western Cape, as evidenced by the similar findings at Piketberg and Porterville, and stressed the need for policy interventions such as enhanced water storage, climate-smart agriculture, and community-based adaptation programs. However, some key informants noteed a gap between policy formulation and implementation, particularly in supporting smallholder farmers, which aligns with farmers' reports of limited access to resources and technical support during drought periods.

In comparing these perspectives, a clear synergy emerges: the quantitative climatic trends of declining rainfall and rising temperatures are directly experienced by smallholder farmers and acknowledged by key informants as part of a broader climatic shift. While the data provides empirical evidence of drought and warming, farmers' perspectives ground these trends in tangible impacts on livelihoods, and key informants offer a systemic view of the challenges and potential solutions. However, discrepancies exist in the perceived adequacy of adaptation measures, with farmers often feeling underserved compared to the optimistic outlook of some key informants regarding policy interventions. This suggests a need for better integration of local knowledge and scientific data into policy frameworks to ensure that adaptation measures are both effective and equitable. Collectively, these findings underscore the urgent need for collaborative, multi-stakeholder approaches to mitigate the impacts of climate change and build resilience in the Western Cape's agricultural sector.

4.3 Condition and performance of the agricultural infrastructure used by smallholder farmers.

Smallholder farmers play a crucial role in global food production, with access to reliable water infrastructure being essential for their agricultural activities. The condition of water infrastructure, such as irrigation systems, and water storage facilities, directly impacts crop yields and overall food security. However, the perception of smallholder farmers regarding the state of these systems is often shaped by factors like reliability and accessibility. Visual assessments, which involve evaluating the physical condition of water infrastructure, and condition assessments, which focus on more technical evaluations, both provide important insights into infrastructure performance. Understanding the farmers' perceptions alongside these assessments helps identify gaps between subjective views and objective realities, offering valuable information for improving water infrastructure and supporting the sustainability of smallholder farming.

4.3.1 Condition assessment

Platkloofrivier weir

The smallholder farmers in Goedverwacht received their water for agricultural use through a weir constructed in the Platkloofrivier (Figure 4.7). The weir is used to divert water from the river to the farmers downstream. Based on the visual inspection, the weir was designed and constructed to ensure even distribution of water flowing downstream and diverting water to the smallholder farmer's irrigation systems through openings on the same level. There was a visible configuration for a sluice gate at the entrance of the canal used for water diversion, however, no sluice gate was attached. The opening for river water that flowed downstream, did not have a sluice gate configuration. There were visible sandbags nearby, which, according to the farmers, were used during the summer season when the river flow decreased, to increase the flow to the canal. The weir structure showed no major cracks, with slight exposed aggregates mostly at the corners of the structure.

Figure 4.7: The weir in the Platkloofrivier which is used to obtain irrigation water

The cross-sectional area of 715 mm and 690 mm was measured for the offtake structure that conveys water from the weir to the concrete pipe. The offtake is constructed using reinforced concrete and concrete blocks, running for a length of 1.7 m. It transitions into a 525 mm nominal diameter concrete pipe, which is 2.5 m long and has a cut at an angle on the female joint side. The condition of the offtake structure appeared to be fine, with minor aggregate exposed, especially on the apron slab.

Concrete pipe

The concrete pipe is partially buried underground, and there is no visible encasement to prevent pipe movement caused by soil pressure, water pressure, and soil erosion (Figure 4.8). However, the concrete pipe appears to be in good condition, with no fractures or visible reinforcing materials. The measured inside diameter of the pipe was 525 mm.

Figure 4.8: Concrete pipe

Main Canal

The concrete pipe transitions into the rectangular main lined concrete canal (Figures 4.8 and 4.9). The concrete rectangular canal measures 300 mm in width, 443 mm in depth, and extends over a length of 3 m. Since the water was clear during the site visit, the condition of the canal was visible, revealing minor defects but an overall structurally sound condition. The canal follows a curved path, following the natural ground level slope, all the way to the rectangular sedimentation tank.

Figure 4.9: Canal conditions

Sedimentation storage tank

The sedimentation water storage tank (Figure 4.10) is connected via a 300 mm x 447 mm concrete canal. The tank has a rectangular shape with a length of 3300 mm, a width of 1400 mm, and a depth of 700 mm. Inside the storage tank, there are ten 100 mm diameter uPVC pipes cast at the base of the tank vertically, each cut to an equal length of 780 mm. These pipes are cast into the base of the tank with equal spacing of 40 mm between them, and they are filled with concrete as measured. The 100 mm diameter pipes serve as screens to remove large objects that enter the storage tank and slowing water velocity inside the tank.

The storage tank has two main 200 mm PVC water pipes connected at the invert level. One pipe gravitates to the farmers, while the other is used for washout to the river stream during the cleaning of sediments inside the storage tanks. When the main pipe is in use, the pipe used for cleaning is closed using a sandbag as a flushing sluice, and no water flows into that pipe. The storage tank has an overflow section, which is 1000 mm wide and 50 mm deep, located at the top level on the side facing the river. The storage tank is equipped with a bar screen at the outlet section, where the pipe inlet is located for water transportation to the farmers. The bar screen consists of 30 steel bars, each measuring 12 mm in diameter, and they are spaced at equal intervals of 40 mm. The screen serves the purpose of deliberately capturing small objects that may manage to pass through, and it requires regular cleaning as it might clog if not taken care off.

Figure 4.10: Sedimentation tank

Infrastructure Condition and Hydraulic Performance Assessment

The assessment of irrigation infrastructure condition in this study adopted established condition-scoring methodologies previously applied in similar contexts. The condition scoring method developed by Mutema et al. (2023) was used as a reference framework, as it has been successfully applied to assess irrigation infrastructure at Agri-Parks, covering components such as pump tanks, booster pumps, filter units, and in-field infrastructure. In addition, Tiwara's assessment approach, which evaluated gates, canals, pipes, pumps, and control structures using an infrastructure condition scoring technique proposed by Le Gauffre et al. (2007), was reviewed. That approach was further strengthened through a multi-criteria assessment framework adapted from Davis et al. (2013).

Table 4.6: Infrastructure condition assessment rating *(Le Gauffre et al,2007).*

	Description	Condition rating
Excellent	Components may still be new or may have been recently maintained	1
Good	Hydraulic structure exhibits superficial wear and tear, minor defects observed	0.8
Fair	significant portion requires maintenance. Infrastructure has suffered abuse or disrepair	0.6
Bad	Significant portions have deteriorated badly. Maintenance needed. The infrastructure and some components have exceeded service life	0.4
Very bad	Critically damaged component(s). Immediate repair needed	0.2

While the infrastructure condition rating system proposed by Le Gauffre et al. (2007) provides discrete condition scores, it does not incorporate score ranges, which may limit flexibility where exact condition classification is uncertain. For this reason, the present study adopted a range-based infrastructure condition rating system (Table 4.6), which allows for more nuanced classification of infrastructure condition and aligns more closely with practical asset management approaches. This system enables the translation of qualitative observations into quantitative scores and links condition ratings directly to maintenance and rehabilitation actions.

Table 4.7: Infrastructure condition rating (Mutema et al., 2023)

Scale	**Linguistic Scale**	**Criteria**	**Action Needed**
9-10	Excellent	Newly/recently installed	No action required
8-9	Very good	Like new with no signs of corrosion or deterioration	Reassess in 15 years.
6-8	Good	Coatings, linings still intact remaining wall thickness 75% or more of original.	Reassess in 10 years. Schedule for cathodic

			protection within next 5-10 years.
4-6	Moderate	Some damage to coatings and or linings noted. Remaining wall thickness 75% or more of original.	Reassess in 3-5 years for lining and rehabilitation within or replacement within next 5-10 years
3-4	Poor	Significant signs of internal/external corrosion. Collapse inevitable. No lining or coatings. Leaking. Remaining wall thickness 50%-75% of original.	Schedule for rehabilitation or replacement within next 3-5 years.
<3	Critical	Severe internal or external corrosion. Collapse evident. Large cracks/ holes. Remaining wall thickness less than 50% of original. Breakage rate>3.	Immediate repair or replacement required

Infrastructure condition scores were used as simple performance indicators, where higher scores represent satisfactory operational performance, low failure risk, and minimal maintenance requirements. Components with ratings above 7 were classified as being in good to very good condition, indicating that they are structurally sound, well-maintained, and capable of fulfilling their intended function without immediate intervention. These thresholds are consistent with commonly applied infrastructure management norms, where assets scoring within this range are considered serviceable and compliant with acceptable operational standards.

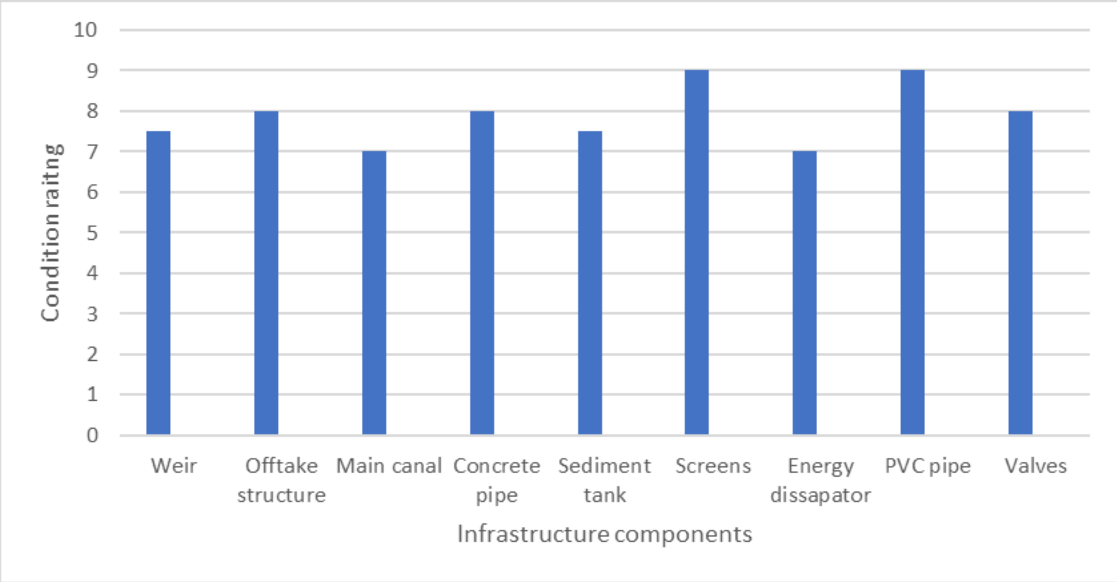

Figure 4.11: Study infrastructure condition rating

The results of the condition assessment (Figure 4.11 indicate that all evaluated components, including the weir, offtake structure, main canal, concrete pipe, sediment tank, bar screen, energy dissipator, PVC pipe, and valves, achieved condition ratings above 7. This suggests that the infrastructure is generally in good condition, with no significant structural defects, leakage, or deterioration observed. Such results are indicative of sound construction quality and effective maintenance practices. Although no detailed hydraulic modelling was undertaken, the good condition ratings of the conveyance and control structures provide a strong indication of satisfactory hydraulic performance under current operating conditions. The absence of visible sediment accumulation, structural deformation, leakage, or flow obstructions suggests that the system can convey design flows with limited hydraulic losses. Consequently, infrastructure condition is unlikely to be a limiting factor to water delivery efficiency at present.

Despite the favourable conditions and inferred hydraulic performance, infrastructure components will inevitably experience wear and degradation over time. In line with the adopted rating system and basic asset management norms, a reassessment is recommended within the next 10 years to detect gradual deterioration and emerging risks. Furthermore, the planned implementation of cathodic protection within the next 5–10 years represents a proactive maintenance strategy aimed at preventing corrosion and extending infrastructure service life. Together, these measures support the long-term sustainability, reliability, and hydraulic functionality of the irrigation system.

4.3.2 Perception of smallholder farmers on the condition of the water infrastructure

Type of infrastructure used for water

All the smallholder farmers have indicated that they use pipe infrastructure to transport irrigation water to their farmlands. A few farmers have mentioned the use of lined canals to convey water to their farms. As confirmed during the transect walk, both the farmers who mentioned pipes and canals are correct because the water in Goedverwacht diverts from the stream to a small canal, and from there, it connects to the pipes that transport water to the farmers. This confirms that smallholder farmers in the study area have the necessary infrastructure for water transportation from the source.

Pumping means

The smallholder farmers have indicated that water is transported to their farms from the source using gravity. However, there is one farmer, SGoeWD7, who mentioned the use of a pump: "The pipes are connected to the river, and we use pumps. Water also flows by gravity to certain sections of the farms. We use an electric pump, but the electricity is always off. The electricity is always off because the church did not pay the money that was supposed to be paid to Eskom. The water flows by gravity and it passes through the filter".

Water storage facility

Most smallholder farmers indicated that they do not have storage facilities such as tanks or dams at their farms to store water. Instead, they mostly use a sprinkler system that connects directly to the water main. Some farmers explained that they do not have storage facilities because they always have enough water resources in the area, and they do not see the need to store water. Having water storage facilities as secondary sources in case of problems with the main supply system would be beneficial. On the other hand, some farmers have mentioned that they do have storage facilities, with the majority mentioning tanks as their preferred storage method. One farmer, SGoeWD12, who operates from a garden, alluded to the following: "Yes. I got my tanks because I am asking now for tanks to catch rainwater from my roof, without a contract with the church, you get nothing". This farmer was the only farmer who used their garden to perform agricultural activities, he highlighted that if you are a farmer and you do not have a contract with the church, it is not easy for you to receive services that are for other farmers.

Water storage adequacy

Most farmers indicated that they do not have enough storage facilities to store water for their farming activities. The farmers highlighted that if they could have more storage such as tanks, they would store enough water to survive during the summer when it is dry and there is less rainfall. In commercial farming, water storage facilities such as dams are more prevalent as they are convenient ways of storing water for later use. Since the smallholder farmers might not have the necessary financial resources to dig dams to use as their storage, government institutions must step in assist these farmers. The government efforts have been seen in some other parts of the country, even though the progress has been labelled by some research to be very slow (Koppen et al., 2009). However, in the case of Goedverwacht, it is quite evident that government efforts are not seen by smallholder farmers in the area.

Age of the infrastructure

The responses from smallholder farmers regarding the age and condition of their water transportation infrastructure reveal notable variability and uncertainty. Most farmers reported that the infrastructure, which includes pipes, weirs, and canals, is more than 20 years old. However, these farmers were unable to provide an exact number of years, which suggests a lack of detailed record-keeping or awareness about the precise history of the infrastructure. This could be attributed to the informal nature of farming in many rural areas, where farmers may not prioritize documenting such specifics unless it directly affects their day-to-day operations. Additionally, many farmers may have inherited or taken over farming practices from previous generations without being fully aware of the infrastructure's age or maintenance history.

On the other hand, some farmers estimated the infrastructure to be around 15 years old, with others reporting it to be as recent as less than one year to approximately 15 years old. This broad range of responses further underscores the uncertainty in the farmers' understanding of the infrastructure's age. Such variability in responses could also reflect differences in the locations of the farms, as infrastructure development might have occurred at different times or with varying levels of investment in different regions. For example, farmers in areas with more recent development might report newer infrastructure compared to those in more established farming regions.

One particular response, from a farmer (SGoeWD5) who indicated that the infrastructure is approximately four years old and that they have only three years of farming experience, highlights another layer of uncertainty. This farmer's limited experience in farming could contribute to a lack of awareness about the history of the infrastructure, further complicating their perception of its age. Moreover, the relatively short time frame of both the infrastructure's existence and the farmer’s personal experience might suggest that these systems are newly implemented or were recently rehabilitated. It is possible that newer infrastructure is being introduced in some areas to address water management issues or adapt to climate-related changes, such as altered rainfall patterns and increased water scarcity.

These varying responses indicate that smallholder farmers have different levels of engagement with and knowledge of the infrastructure they rely on. It may also reflect the differing degrees of access to resources and information. Farmers with more experience or access to agricultural extension services might have a better understanding of their infrastructure's age and condition, while those with limited exposure to such services may be less informed. This uncertainty and lack of clarity could have implications for the management and maintenance of water infrastructure, as farmers might not recognize the importance of timely repairs or updates, which could ultimately affect their productivity and adaptation to climate change.

Maintenance schedule

The farmers mostly indicated that they fix the infrastructure by themselves, however those that lease officially from the church, indicated that the church is responsible for maintaining the infrastructure. They are, however, not satisfied with the church’s maintenance programs, claiming that the church personnel use the money for other reason and end up neglecting the maintenance of the irrigation infrastructure. Others pay people to perform maintenance duties for as they do not have the necessary skills for such conduct. The farmers that manage their own maintenance seem to have a proper plan that contributes to avoiding water wastage caused by leaking infrastructure. If all maintenance programs would be passed to farmers who work the land, and even to those who lease from the church, it would be a viable option. When farmers perform their own maintenance programs, they have more advantages of not waiting for a skilled person to come attend to their problem, they immediately fix it.

Water measuring devices

The absence of water measuring devices is a significant challenge for smallholder farmers in Goedverwacht, a privately owned area in the West Coast district of South Africa. Research findings indicate that most farmers lack installed meters at their connections to the irrigation system, making it difficult to accurately quantify water usage on their farms. This gap in water measurement infrastructure aligns with broader challenges in South African smallholder agriculture, where unmonitored water use can lead to inefficiencies and overexploitation of resources, particularly in water-scarce regions (Van der Merwe & Cloete, 2021).

In the absence of formal metering devices, farmers in Goedverwacht have adopted alternative strategies to minimize water wastage and promote equitable resource use. One farmer, identified as SGoeWD14, explained: “There are no measuring devices. The key thing to remember is that you should avoid using an excessive amount of water that could potentially impact other farmers. Our approach typically involves initially using a larger pipe of 40 mm at the branch and then reducing it to 25 mm for your specific farm”.

This approach, which involves adjusting pipe diameters to regulate water flow, reflects a practical, community-driven effort to manage water use and mitigate the risk of overuse affecting downstream farmers. Such adaptive strategies, while resourceful, are less precise than formal metering systems and may not fully address the need for accurate water allocation and conservation (Machethe & Fanadzo, 2022). The reliance on pipe size adjustments also suggests a lack of access to advanced water management technologies, which could enhance efficiency and sustainability in irrigation practices (Botha & Van Niekerk, 2020).
The absence of measuring devices in Goedverwacht, particularly for farmers not connected to municipal water systems, underscores disparities in water management infrastructure. Farmers connected to municipal systems benefit from installed water meters, which promote accountability and efficient use, while those reliant on non-municipal sources face challenges in monitoring consumption (Ziervogel et al., 2019). This situation is compounded by the private land tenure status of Goedverwacht, which may limit access to governmwent or municipal support for installing metering infrastructure (Cousins & Chikazunga, 2021).

Addressing these challenges requires targeted interventions to equip smallholder farmers with affordable and accessible water measurement technologies, such as low-cost flow meters, alongside training to enhance their understanding of water management practices. Improved access to metering devices could support equitable water distribution, reduce wastage, and enhance resilience to climate-induced water scarcity. Additionally, collaboration between government agencies, private landowners, and the farming community is essential to develop systematic water management strategies that address the unique constraints of Goedverwacht’s land tenure arrangements.

Observed leakages

Smallholder farmers in Goedverwacht, have reported challenges with irrigation system maintenance, particularly concerning observed leakages. According to some farmers, pipe bursts in the irrigation system pose significant issues due to the absence of nearby shut-off valves. One farmer, identified as SGoeDW12, articulated: "There are observed leaks. When there is a pipe burst, we must cut off the water supply to where the canal is located because that is where the valves are placed on the irrigation system and wait for the place to dry up before we can fix it. This is another challenge; I feel like the irrigation system is not designed properly because there are no visible valves on the system. If there were valves along my farm, I would be able to address the issue more efficiently".

This observation suggests that the design and placement of valves in the irrigation system may be inadequate for timely maintenance, leading to delays in addressing pipe bursts and potential water losses. The need to shut off water at distant canal locations and wait for the affected area to dry before repairs can be conducted indicates a structural limitation in the system's accessibility and functionality (Van der Merwe & Cloete, 2021). However, other farmers reported no significant water leaks, suggesting variability in the condition of the irrigation infrastructure or differences in farmers' experiences and perceptions.

The claims regarding inadequate valve placement could be partly attributed to farmers limited technical knowledge of the irrigation system's design and operation, as suggested by the variability in reported issues (Machethe & Fanadzo, 2022). This highlights a potential need for capacity-building initiatives to enhance farmers' understanding of irrigation infrastructure and its maintenance requirements. The use of modern materials like polyvinyl chloride (PVC) pipes in Goedverwacht's irrigation systems, while structurally sound, does not eliminate the need for accessible maintenance features such as strategically placed valves to minimize water loss during repairs.

The reported leakages and maintenance challenges underscore broader issues in South African smallholder agriculture, where aging and poorly maintained irrigation systems contribute to substantial water losses (Smith & Van der Merwe, 2021). In Goedverwacht, the private land tenure status may further complicate access to government or municipal support for infrastructure upgrades, leaving farmers to address maintenance issues independently. Addressing these challenges requires targeted interventions, including the installation of additional shut-off valves, improved system design documentation, and training programs to empower farmers with the skills needed for effective infrastructure management. Such measures could enhance the efficiency and sustainability of irrigation systems, thereby reduce water losses and support smallholder farmers in the region.

Maintenance

Many irrigation systems in South Africa, established decades ago, are now in poor condition due to aging infrastructure and inadequate maintenance, resulting in significant water losses (Van der Merwe & Cloete, 2021). In the study area of Goedverwacht, these challenges are evident among smallholder farmers. Proper maintenance of irrigation infrastructure is essential for minimizing water losses and ensuring efficient resource use, particularly in the context of increasing water scarcity driven by climate change (Ziervogel et al., 2019).

In Goedverwacht, smallholder farmers report maintenance issues reactively, attending to problems as they arise rather than following a preventative maintenance schedule. Farmers noted that the responsibility for infrastructure maintenance was originally intended to be managed by the church, identified as the landowner in this privately owned area. This arrangement introduces complexities in maintenance coordination, as the church's role in infrastructure maintenance appears limited or unclear. Notably, female farmers highlighted their active involvement in performing repairs themselves, while a few farmers employ individuals to handle maintenance tasks. This reflects a diverse and often ad-hoc approach to infrastructure management within the farming community, underscoring the absence of systematic maintenance strategies.

4.3.3 Perception of key informants on the condition of the infrastructure

It is crucial that the perspectives of key informants are taken into consideration when trying to assess the state of the agricultural infrastructure, as in most cases, they are the most informed about the state of the infrastructure. In most cases, they have access to the information about the infrastructure, such as the design records, age, and the condition of the infrastructure.

Type of infrastructure used for water

The predominant infrastructure for water management among smallholder farmers in the West Coast district, as reported by a key informant from the Western Cape DoA, consists primarily of piped water systems. This finding reflects the infrastructure across the West Coast district, rather than specifically focusing on the study area of Goedverwacht. In addition to piped systems, some informants noted the use of drums and tractors for transporting water from sources to farms. This practice of water transportation corroborates findings by Pili et al. (2022), who identified it as an adaptation strategy employed by farmers in the West Coast district to address water access challenges.

The continued reliance on drums and tractors for water transport, as highlighted by the key informant, reveals a notable gap in the development of modern irrigation infrastructure for smallholder farming in the region. Such methods suggest that some farmers lack access to efficient water delivery systems, which could constrain agricultural productivity and resilience to environmental stressors. This observation is consistent with studies by Du Plessis et al. (2019), who noted that inadequate infrastructure remains a barrier to sustainable smallholder farming in water-scarce regions of South Africa. However, in the specific study area of Goedverwacht, fully installed piping systems are reported to be available, particularly for smallholder farmers engaged in crop production. These systems indicate a higher level of infrastructural development compared to the traditional methods observed in other parts of the district.

The disparity between the widespread use of piped systems and the persistence of rudimentary water transport methods underscores uneven infrastructure development across the West Coast district. This finding aligns with research by Van Averbeke et al. (2017), which emphasizes the need for targeted interventions to improve irrigation access for smallholder farmers to enhance food security and economic viability. Addressing these gaps requires further investment in modern irrigation technologies and extension services to ensure equitable access to resources for all smallholder farmers in the region.

Age of the infrastructure

Key informants from the Western Cape Department of Agriculture indicated that irrigation infrastructure across the West Coast district primarily comprises piped water systems, estimated to be 10-20 years old. However, specific records for the study area of Goedverwacht were unavailable, and informants were uncertain about the age of its infrastructure. This uncertainty was mirrored by smallholder farmers in Goedverwacht, who similarly lacked clarity on the infrastructure's age. The absence of detailed records for Goedverwacht may be attributed to its status as private land, which obscures the extent of the Department's involvement in the implementation of its irrigation systems.

Despite the lack of precise documentation, a condition assessment revealed that the irrigation infrastructure in Goedverwacht is structurally sound, utilizing modern materials such as PVC pipes instead of outdated and hazardous materials like asbestos. The use of PVC, known for its durability and resistance to corrosion, indicates a relatively modern and reliable irrigation system, enhancing water delivery efficiency for smallholder farmers (Jones & Roux, 2020). This finding contrasts with the broader district's reliance on aging infrastructure and suggests that Goedverwacht's systems may have been upgraded or installed more recently than the district average.

The absence of comprehensive design records, however, remains a significant challenge. Design records are critical for documenting system specifications, maintenance schedules, and material details, which are essential for long-term infrastructure management (Smith & Van der Merwe, 2021). Without such records, maintenance and future upgrades may be hindered, potentially compromising the sustainability of even structurally sound systems. This issue aligns with broader challenges in South African smallholder agriculture, where inadequate documentation and uneven infrastructure development limit progress (Machethe & Fanadzo, 2022).

The contrast between Goedverwacht's modern, structurally sound irrigation infrastructure and the broader West Coast district's aging systems, combined with uncertainties about infrastructure age and implementation, highlights disparities in infrastructure management. Addressing these challenges requires improved record-keeping, continued investment in modern materials, and enhanced collaboration between private landowners and agricultural authorities to ensure sustainable and equitable irrigation systems for smallholder farmers.

Water storage facility

Key informants from the Western Cape DoA identified portable water storage tanks, such as JoJo tanks, as the preferred water storage solution for smallholder farmers in the West Coast district. They reported that interventions have been implemented to provide these tanks to farmers, aiming to enhance water security in the region. However, informants emphasized that the quantity of tanks distributed remains insufficient to meet the farmers' needs. They highlighted the critical role of water storage in ensuring a reliable water supply, particularly in the context of climate change, which increases the frequency and severity of droughts and water scarcity.

In the study area of Goedverwacht, smallholder farmers confirmed receiving water storage tanks during drought periods, indicating that government support has extended to this privately owned land despite its unique administrative challenges. This support underscores the government's recognition of the importance of water storage for smallholder agriculture, especially in water-stressed regions (Machethe & Fanadzo, 2022). However, the limited availability of tanks suggests a gap in the scale of interventions, which may hinder farmers' ability to fully adapt to climate-induced water challenges.

The reliance on portable tanks like JoJo tanks reflects a practical and scalable solution for smallholder farmers, given their ease of installation and adaptability to varying farm sizes (Botha & Van Niekerk, 2020). Nonetheless, the insufficiency of these storage facilities points to broader challenges in resource allocation and infrastructure support for smallholder agriculture in South Africa. Addressing this gap requires increased investment in water storage infrastructure, coupled with strategic planning to ensure equitable distribution and adequate capacity to meet farmers' needs in the face of climate variability.

Water measuring devices

Effective water management is critical for sustainable resource use across domestic, industrial, and agricultural sectors, with measuring devices playing a pivotal role in regulating water consumption (Van der Merwe & Cloete, 2021). Key informants from the Western Cape Department of Agriculture reported that smallholder farmers connected to municipal water infrastructure in the West Coast district benefit from water meters installed by the Municipality to monitor water usage. These meters enable precise tracking of consumption, promoting accountability and efficient water management practices.

In contrast, smallholder farmers not connected to municipal infrastructure lack installed water meters, relying instead on unregulated water sources. This finding aligns with reports from smallholder farmers in the study area, who confirmed the absence of water measurement devices for non-municipal water supplies. The lack of metering among these farmers may lead to overexploitation of water resources, potentially exacerbating water scarcity in the region, particularly in the context of climate change and increasing drought frequency (Ziervogel et al., 2019). Unmonitored water use can also hinder the implementation of equitable water allocation strategies, as noted by Machethe and Fanadzo (2022), who emphasized the importance of water measurement for sustainable agricultural water management. The disparity in access to water metering infrastructure highlights a significant gap in water resource management for smallholder farmers. Farmers connected to municipal systems benefit from structured monitoring, which supports conservation efforts, while those reliant on alternative sources face challenges in quantifying and managing their water use.

Maintenance

Key informants reported that programs are in place to support smallholder farmers in maintaining their irrigation infrastructure in the West Coast district. These programs aid with minor maintenance tasks, but informants emphasized that farmers are primarily responsible for the maintenance of their irrigation systems. This aligns with findings from smallholder farmers in the study area of Goedverwacht, who indicated that they independently manage the maintenance of their irrigation infrastructure, with no reported support from the local Municipality. The absence of municipal involvement may reflect the unique land tenure arrangements in Goedverwacht, a privately owned area, which could complicate access to government or municipal support systems.

The reliance on farmers for infrastructure maintenance, particularly in the absence of consistent external support, poses challenges for ensuring the long-term functionality of irrigation systems. Regular maintenance is critical for sustaining water delivery efficiency and preventing system degradation, especially for infrastructures utilizing modern materials, which, while durable, require periodic maintenance. The limited scope of government programs, which focus on small-scale maintenance, may not adequately address more significant repair needs, potentially placing a financial and technical burden on smallholder farmers.

It remains unclear whether the lack of robust maintenance support in Goedverwacht stems from slow implementation of government programs or is a consequence of the area's private land tenure status, which may limit eligibility for certain forms of assistance. This ambiguity underscores broader challenges in South African smallholder agriculture, where land tenure complexities often hinder equitable access to agricultural support services (Van Averbeke et al., 2017). Addressing these challenges requires enhanced coordination between government departments, municipalities, and private landowners, alongside expanded maintenance support programs tailored to the needs of smallholder farmers, to ensure sustainable irrigation infrastructure management.

4.3.4 Summary

The condition assessments of the agricultural water infrastructure in Goedverwacht reveal a structurally sound system, with components like the weir, offtake structure, concrete pipe, main canal, and sedimentation tank shows to be in good condition, exhibiting only minor defects such as slight aggregate exposure and the absence of components such as sluice gates. The assessment confirms the infrastructure's reliability, supported by modern materials like PVC pipes, but highlight design limitations, such as reliance on sandbags for flow regulation. In contrast, smallholder farmers' perceptions emphasize practical challenges, including inadequate water storage, lack of metering devices, and difficulties with maintenance due to inaccessible valves and reactive repair approaches. Their uncertainty about the infrastructure's age, old pipe materials and dissatisfaction with church-led maintenance reflect gaps in technical knowledge and support, particularly in the context of Goedverwacht's private land tenure.

Key informants corroborate farmers' reports of insufficient storage and metering, noting that while piped systems dominate, some farmers resort to rudimentary water transport methods like drums and tractors, indicating uneven infrastructure development in the region. Both farmers and key informants highlight the absence of systematic maintenance and documentation, with key informants uncertain about Goedverwacht's infrastructure age (estimated at 10-20 years). While technical assessments recommend proactive measures like cathodic protection and reassessment in 10 years, farmers' ad-hoc maintenance and informants' limited support programs underscore systemic barriers. Bridging these gaps requires enhanced storage, metering, and maintenance support, tailored to Goedverwacht's unique land tenure, to align objective infrastructure quality with farmers' practical needs and ensure sustainable agricultural productivity.

4.4 Water governance policies in Goedverwacht and their effects on water availability for smallholder farmers

4.4.1 Perception of smallholder farmers

Water is an essential resource for sustaining agriculture, livelihoods, and ecosystems, making effective water management critical in regions with limited or contested water supplies. Water management institutions are responsible for regulating the distribution, conservation, and equitable allocation of water resources. However, the presence of illegal water users, those who bypass formal systems, often complicates these efforts, leading to over extraction, resource depletion, and increased competition for water. This results in conflicts among different water users, including farmers, households, and industries, each competing for the limited access to water.

The resolution of such conflicts requires robust mechanisms that are fair, inclusive, and effective in addressing the underlying causes of disputes. A critical element in achieving successful water conflict resolution is ensuring the active participation of all stakeholders in decision-making processes. When local communities, water users, and relevant institutions are involved in the decisions that affect water use, the outcomes are more likely to be equitable, sustainable, and supported by all parties. This section explores the interconnections between water management institutions, illegal water use, water conflict resolution, and participatory decision-making, highlighting the importance of collaborative governance in addressing the challenges of water scarcity and ensuring long-term sustainability.

Water management institutions

The results of the current study show that the Moravian Church manages water resources in Goedverwacht. The church's involvement is due to its role as landowner in Goedverwacht, giving them control over everything (land and water). Farmers mentioned that the Municipality assists with certain issues in the area, such as drinking water-related issues and basic needs for their farming from time to time. However, some farmers accused the church of having poor management skills. Farmer SGoeWD7 expressed: "Yes, there are organisations, the municipality, and the Moravian Church. But the church is not good and it's not helping." Other farmers indicated that there are no organisations ensuring effective water management in the area. Most of these farmers were providing such responses due to their dissatisfaction with the efforts from the church governance related to water and agriculture. They mentioned the existence of a past organisation formed by farmers called Goedverwacht Boere Vereniging, responsible for water management in Goedverwacht for agricultural activities. Unfortunately, due to differences among the farmers, it collapsed, leading to farmers handling their water resource management individually. This situation aligns with findings from Ncube's research, which highlights how weak institutional coordination is, and internal conflicts within community-based organisations hinder effective water governance in the Western Cape (Ncube, 2018). Ncube's study notes that land tenure arrangements, such as the Moravian Church's control in Goedverwacht, often centralize resource management, limiting farmers' access to water and decision-making power.

Similarly, a study by Goldin et al. (2013), on water governance in South Africa, emphasizes that historical land ownership patterns, particularly in mission-based settlements like Goedverwacht, create power imbalances that complicate equitable water distribution. Farmers expressed the hope to re-establish such a union and address their differences, as it was effective in ensuring a stable water supply. Farmers indicated that they are not actively participating in water management in the area as they are not formally included in the CMA. This again links to their land tenure complexity in Goedverwacht, because governmental structures such as CMAs mainly function in properly demarcated areas.

The WRC supports this observation in its 2019 report, which discusses how CMAs often exclude informally settled or historically complex land tenure areas like Goedverwacht, leading to gaps in formal water management (WRC, 2019). Ncube (2018) further explains that smallholder farmers in such areas are often marginalized from formal water governance frameworks, forcing them to rely on informal arrangements or individual efforts, as seen in Goedverwacht. Additionally, a study by Van Koppen et al. (2014) highlights how South Africa's post-apartheid water reforms, including the NWA have struggled to integrate smallholder farmers in areas with complex land tenure, reinforcing the exclusion of communities like Goedverwacht from CMAs. Another WRC report by Schreiner and Van Koppen (2018) underscores the need for localized water management institutions to address such gaps, supporting the farmers' desire to re-establish a union like the Goedverwacht Boere Vereniging.

Illegal water users

The result from farmers regarding illegal water use suggest that the majority claimed there were no unauthorized water users in the area. They allow individuals who are not part of their farming group to use water, as outlined by farmer SGoeWD11: “No illegal water users in the area. However, we have set a schedule for the farmers who are not with us to access water after all farmers have completed their activities. We specifically permit them to use water after 18h00 in the evening, as all farmers are usually finished by then.” This practice is consistent with findings from a study in the Western Cape, South Africa, where farmers in the Breede River catchment area reported structured water-sharing arrangements with non-members to avoid conflicts over water resources (Muller, 2019). The study notes that farmers often establish informal agreements to allow limited access to water for neighbouring non-group farmers, particularly during off-peak hours, to maintain community relations and reduce disputes.

Some farmers expressed uncertainty about the presence of illegal water users in the area. Only a few farmers acknowledged the existence of illegal water users. Farmer SGoeWD7 reported: “Yes, we have encountered instances of illegal water users. Occasionally, other farmers take water from our pipes”. This observation is supported by a report from the DWS, which highlights instances of unauthorized water abstraction in rural farming areas, particularly in Limpopo and Mpumalanga Provinces, where small-scale farmers occasionally access water from irrigation pipes without formal permission (DWS, 2021).

The report indicates that such incidents are often sporadic and involve neighbouring farmers rather than external parties. In cases where unauthorized individuals were found using water meant for farmers, farmers mentioned addressing the issue through discussions among themselves to resolve the problem of illegal water usage. This approach is corroborated by research conducted in the Olifants River catchment, where farmers reported resolving water-use disputes through local dialogues and community-based governance structures rather than escalating issues to formal authorities (Van Koppen et al., 2014). These discussions often involve water user associations (WUAs) that facilitate conflict resolution and promote equitable water distribution among farmers.

Irrigation water conflicts

Conflicts among shared water users often arise when some farmers use excessive water, deviating from the proposed irrigation schedule. In the study area, farmers commonly reported experiencing conflicts related to water usage. These conflicts encompassed several scenarios: (i) Conflicts with residents who obstruct water flow during summer to create swimming pools, leading to disputes between farmers and residents. These conflicts often escalate in summer when the water demand for irrigation peaks, (ii) summer conflicts arising from low water levels. Research in the Limpopo Province highlights that seasonal water scarcity during summer months frequently leads to disputes among farmers sharing irrigation systems, as reduced river flows and dam levels exacerbate competition for limited water resources (Mapedza et al., 2018). These low water levels strain irrigation schedules, causing friction when some farmers overuse available water, (iii) conflicts emerging when numerous people engage in farming, despite the irrigation system's design allowing for approximately 72 sprinklers to operate simultaneously as highlighted by farmers.

This issue is evident in communal irrigation schemes in South Africa, such as those in the Olifants River catchment, where infrastructure limitations lead to conflicts when too many users access the system concurrently, overwhelming its capacity (Van Koppen et al., 2014). The designed capacity of irrigation systems is often inadequate for the growing number of farmers, particularly in densely populated farming areas, (iv) disputes arising from farmers wasting water by neglecting to repair pipe leaks. A report by the DWS notes that water losses due to unmaintained infrastructure, such as leaking pipes, are a significant source of conflict in South African irrigation schemes, as they reduce water availability for downstream users and increase tensions among farmers (DWS, 2022).

Farmer SGoeWD12 emphasized: “Yes, there are irrigation schedule conflicts among the farmers. Farmers located uphill experience inadequate pressure during summer, particularly in this non-rainfall season. However, farmers positioned below the supply pipeline face no issues as the pressure consistently favours them. This problem is exclusive to the summertime; winter conditions are generally satisfactory, ensuring everyone receives sufficient water. Additionally, variations in soil conditions contribute to conflicts. My farm has dry soil, necessitating extensive irrigation, which differs from other farmers with soil conditions requiring less water”. This account aligns with findings from a study in the Breede River catchment, where topographic differences create unequal water pressure and availability, leading to conflicts between uphill and downhill farmers during dry seasons (Muller, 2019). The study also notes that variations in soil types, such as sandy versus clay soils, contribute to differing irrigation needs, further complicating equitable water distribution and fuelling disputes.

Water conflicts resolutions

Most farmers reported that they resolve conflicts related to water resources through meetings. Farmer SGoeWD14 noted that these meetings are held at a common location and focus on various issues, including water management, allocating funds for pipe repairs, and discussing market prices for their produce. This farmer further highlighted that the agreements made during these meetings are not formally documented but are based on mutual respect among the participants. Some farmers highlighted that it is difficult to resolve their differences because there is a group of people who do not associate with them. There is a group of people that named Rastas who, according to the other groups do not see eye to eye with them. On the issue of conflict resolution, those identified themselves as Rastas said: *"*As one of the chiefs of this area, when there is a problem, we call the farmers together and discuss the issue and try to fix it in a way that every party involved will be satisfied. We solved it by coming together and doing whatever needs to be done*".*

Training in water usage

To address water wastage and promote efficient water use, the government deploys representatives through local municipalities to educate the public on various water-saving methods. Training farmers on effective water-saving techniques is a key recommended strategy for water conservation. In the study area, smallholder farmers have indicated a significant gap in access to such training. Many farmers feel that they have not received adequate education on water-saving practices due to the lack of dedicated facilitators and training programs provided by the government. This absence of structured training programs means that farmers may not be fully aware of or equipped with the latest techniques and technologies for reducing water wastage. However, it is worth noting that some farmers have acknowledged the positive impact of extension officers from the Department of Agriculture.

These officers have been recognized for their efforts in providing valuable information and support related to water conservation. Despite these positive contributions, the general sentiment among many farmers is that more comprehensive and accessible training is needed. Overall, enhancing the reach and effectiveness of training programs, and ensuring that dedicated facilitators are available to support smallholder farmers, could significantly improve water conservation practices in the study area. This would not only help in minimizing water wastage but also contribute to more sustainable agricultural practices.

Participation in decision-making

Accountability at the individual farmer's plot could potentially play a significant role in reducing water wastage and alleviating water shortages. The Moravian Church is the primary landowner of Goedverwacht, thus holds significant authority over water management decisions for the farms that smallholder farmers occupy. Most smallholder farmers report that decisions regarding water allocation and management are made by the Moravian Church, as stated by farmer SGoeWD6. This centralized control means that the Church's policies and decisions directly impact the availability and use of water resources for farming activities. Farmer SGoeWD1 noted: “There is no one who make decisions about the water except the Moravian Church”. This centralized governance structure aligns with findings from a study in the Northern Cape, where institutional landowners, such as churches or community trusts, dominate water management decisions in smallholder irrigation schemes. The study notes that such top-down systems often limit farmers’ ability to influence water allocation, which can hinder local-level accountability and water conservation efforts (Pienaar & van der Schyff, 2017).

However, some farmers do not agree with or do not recognize the Moravian Church as the rightful landowner. This disagreement could lead to conflicts or lack of compliance with the water management decisions imposed by the Church. Such disputes may complicate efforts to implement effective water conservation practices and could exacerbate issues of water mismanagement. This issue is corroborated by research in the Northwest Province, where contested land tenure between smallholder farmers and institutional landowners has led to resistance against imposed water management rules, undermining cooperative governance and sustainable water use (Cousins, 2013). These disputes often arise from historical land ownership issues, creating barriers to effective resource management.

Some smallholder farmers work on land that is borrowed or allocated by other farmers. Farmer SGoeWD1: “I am not directly involved in decision making because I operate under an older farmer who directly makes decisions”. These individuals are often not involved in the decision-making process regarding water management, as their role is limited to working the land according to the directives of the landholders. This point of view was mainly common in those who classified themselves as Rastas, where most young farmers operate under the experienced older farmers. This lack of involvement in decision-making can lead to a disconnect between those managing the land and those responsible for its efficient water use, potentially resulting in less effective water conservation practices. A study in KwaZulu-Natal highlights similar dynamics in communal irrigation systems, where younger or tenant farmers working on allocated land are frequently excluded from water management decisions, leading to inefficiencies and inequitable water distribution (Tapela, 2015). This exclusion reduces their incentive to adopt water-saving practices and perpetuates reliance on the directives from more established farmers.

4.4.2 Perception of key informants

Extension officers' roles and responsibilities

The results suggest that the extension officers are involved in advising other farmers on the process of applying for boreholes in the West Coast district. They assist with the application process and the installation of water meters. These meters are crucial for monitoring water usage at the farm level, ensuring that water management practices are adhered to and that any issues can be promptly identified. Extension officers also play a role in encouraging their peers to adopt water-saving practices. This includes advising farmers who use boreholes to be mindful of their water consumption, as well as those who draw water from dams and rivers. Promoting water conservation is essential for maintaining sustainable water usage, especially in areas where water resources are limited.

For farmers connected to municipal water mains, the installation of water meters is a key task. These meters help in monitoring water usage and ensuring that water resources are used efficiently. Although some officers believe that water management is the sole responsibility of farmers, they step in to provide support when farmers face financial constraints. This assistance might include help with securing funds for water-related infrastructure or other essential resources needed for farming activities. This suggests that in areas like Goedverwacht, extension officers' roles are limited due to constraints imposed by land tenure issues. As a result, smallholder farmers receive minimal support, and the DoA in the West Coast primarily identifies opportunities that are less politically sensitive to help.

Other organisation challenges

According to extension officers from the Western Cape DoA, they often work alone in the region, which limits their ability to address the wide range of problems that farmers face. This solitary approach can lead to gaps in support and hinder effective problem-solving. It should be noted the absence of unions at the farm level within the smallholder farming community in the West Coast district, means that they interact with individual farmers rather than organized groups. Unions in South Africa are often effective in facilitating communication between individuals and organisations, which could help address this gap. In Goedverwacht, the lack of a union means that extension officers could reduce challenges by encouraging the formation of unions or forums where farmers could speak with one voice on issues affecting their farming. However, land politics in the area may be a factor preventing such initiatives. Extension officers have also expressed concerns about the availability of land for smallholder farmers, believing that local municipalities should take a more active role in facilitating land access. Expanding farming activities in the West Coast district could benefit smallholder farmers, but securing suitable land remains a significant challenge. Another issue is that municipalities sometimes relocate smallholder farmers to smaller, less productive farms, which impacts their ability to maintain livelihoods and reduces agricultural productivity. Additionally, extension officers face difficulties when assisting with borehole drilling, as sites are often chosen randomly, leading to inefficiencies and wasted resources when no water is found. This not only results in additional costs but also hampers the farmers' ability to use water resources effectively

Water governance challenges

Effective water governance is crucial for managing water resources and ensuring their sustainable use, particularly among smallholder farmers. Several challenges have been identified by the key informants in this context: Farmers who are not connected to municipal infrastructure often do not address water leakages on their own. This neglect leads to significant water wastage, which exacerbates water scarcity issues. There are no systems in place to measure the amount of water used by farmers. This lack of measurement contributes to inefficient water use and hinders efforts to manage water resources effectively. Groundwater usage fees are not sufficiently high to incentivize conservation. This results in minimal financial pressure on farmers to reduce their water consumption and manage resources more responsibly. Farmers sometimes face difficulties in accessing adequate water resources, which impacts their ability to maintain production levels. This scarcity complicates efforts to support them and affects their overall productivity. Farmers' production interests can be influenced by the availability of water, and navigating the registration process for water rights can be complex. This can hinder their ability to effectively manage and utilize water resources. Some smallholder farmers are resistant to adopting new water management practices or technologies. They may prefer traditional farming methods and are reluctant to follow advice or incorporate modern techniques that could improve water efficiency.

4.4.3 Summary

Smallholder farmers and key informants in Goedverwacht shared concerns about water governance but differ in their perspectives due to their roles and experiences. Farmers view the Moravian Church, the primary landowner, as the dominant yet ineffective water management authority, expressing dissatisfaction with its skills and lamenting the collapse of the farmer-led Goedverwacht Boere Vereniging. They report managing illegal water use through community agreements, such as scheduled access for non-group farmers, and resolving irrigation conflicts often caused by excessive use, seasonal shortages, or infrastructure limits through informal meetings based on mutual respect. However, social divisions (e.g., between “Rastas” and smallholder farmers) and the Church’s centralized decision-making limit their participation and conflict resolution efforts. Farmers also highlight a significant gap in water-saving training, noting inadequate access to structured programs despite some support from extension officers.

Key informants focused on systemic challenges and their advisory roles rather than community-level dynamics. They assist with borehole applications, water meter installations, and promoting water-saving practices in the West Coast district but are constrained by land tenure issues and the absence of farmer unions in settlements such as Goedverwacht, which could enhance communication. Unlike farmers, they do not emphasize illegal water use or specific irrigation conflicts; instead, addressed broader issues like water leakages, lack of usage monitoring, and farmers' resistance to new practices. Both smallholders and key informants agreed on the need for better training and institutional support, but farmers emphasized practical, localized issues (e.g., conflicts, exclusion from decision-making), while informants highlighted structural barriers (e.g., land access, inefficient governance), reflecting their differing vantage points in the water governance landscape.

4.5 Implications of the results

The results presented in this study have several significant implications for the smallholder farmers in Goedverwacht and for broader agricultural water management practices. The lack of water storage infrastructure highlighted in the study underscores the vulnerability of farmers during dry periods. This suggests that without proper storage systems, even regions with adequate water resources can face significant challenges in water management. The absence of storage not only affects crop irrigation but also leaves farmers dependent on inconsistent water availability, exacerbating the impact of climate variability. Investing in water storage solutions could be a critical strategy to enhance agricultural resilience, particularly in areas prone to droughts or irregular rainfall.

The socio-political factors identified as primary barriers to effective water management imply that governance structures play a pivotal role in addressing water challenges. The fact that Goedverwacht is not part of the municipal governance structure and lacks institutional support suggests that areas with private ownership or informal governance may face greater difficulties in accessing resources or support for infrastructure improvements. The absence of strong institutional frameworks can also hinder collaboration among farmers and authorities, potentially leading to disputes and inefficient resource use. This indicates the need for a more formalized governance model that integrates smallholder farmers into broader water management policies.

The findings concerning water-related conflicts and competition, such as disputes between smallholder farmers and the interference from community members creating swimming pools, imply that informal water management practices are insufficient for ensuring equitable water distribution. These conflicts, if not addressed, can strain community relations and negatively impact agricultural productivity of the smallholder farmers. The implication here is that more formalized, transparent, and fair systems for water allocation and conflict resolution are needed to reduce tensions and ensure that all users have equitable access to water.

The issues with irrigation infrastructure, such as water pressure loss, leakage, and the absence of formal maintenance programmes, point to the inefficiencies in the current system. Therefore, the poorly maintained infrastructure can lead to water wastage, reduced irrigation efficiency, and increased costs for farmers. It highlights the importance of investing in regular maintenance and ensuring that responsibilities for infrastructure maintenance are clearly defined and adhered to. This also suggests that farmers need better access to tools, training, and resources for maintaining their irrigation systems.

The results emphasize the need for sustainable water use practices and educational programs to improve water management. Without proper education and training, farmers may continue to use water inefficiently, leading to long-term sustainability challenges. Promoting efficient water use, including adopting modern irrigation techniques and technologies, could significantly improve water conservation and help mitigate the impact of fluctuating water availability. Overall, the study's results suggest that improving water management in Goedverwacht requires a multi-faceted approach that addresses infrastructure, governance, conflict resolution, and education, with a strong emphasis on sustainability and equitable access to resources.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5 Conclusions

This study assessed the water availability of smallholder farmers in the Goedverwacht historical settlement, the condition of the water infrastructure, climate change impacts on water resources and the regulatory frameworks governing water management in the study area.
The results indicate that smallholder farmers in Goedverwacht contend with a range of water-related challenges in their agricultural practices. However, these challenges appear to be more closely associated with socio-political factors rather than a fundamental scarcity of water resources or the poor condition of the water infrastructure.

The water measurement results indicate that the Goedverwacht has an adequate water supply for the smallholder farmers, to meet the needs of irrigation and other agricultural activities. Results indicate the absence of water storage infrastructure(tanks) for irrigation purposes during dry periods, that significantly impedes the capacity of smallholder farmers to manage water resources effectively. The implementation of water storage systems emerges as a potentially crucial strategy for mitigating the ad bverse effects of low rainfall. As reported by smallholder farmers, the lack of storage facilities is largely attributed to insufficient support from governmental and institutional entities in the study area. Notably, Goedverwacht is not part of the municipal governance structure, as it is privately owned by the Moravian church, which further exacerbates the lack of institutional assistance particularly to smallholder farmers. This lack of governance was cited by key informants as a major impediment to facilitating more comprehensive engagement with smallholder farmers in Goedverwacht, especially considering the ongoing disputes over land ownership. These land tenure issues, which have been well documented in a previous study such as the WRC project (Ncube, 2020), continue to hinder both agricultural development and collaborative efforts to improve water management in Goedverwacht.

The results from smallholder farmers also noted perceptible changes in stream levels over the study period (20 years), however, these stream fluctuations have not significantly influenced the overall water availability for agricultural purposes. Some challenges identified by the smallholder farmers include interference from community members who divert water to create swimming pools at the diversion weir, leading to conflicts with smallholder farmers as they are blocked from accessing water for irrigation and agricultural activities. Other identified challenges are tensions that arise from the perceived inequities in irrigation practices, with upstream water users suspected of extracting disproportionate amounts of water relative to those downstream. The study identified a persistent problem with a loss of water pressure in irrigation pipelines during periods of low rainfall, which exacerbates difficulties in accessing water for crop irrigation. Although downstream farmers believed that upstream farmers were taking more water, the actual issue appears to be closely related to low water pressure caused by the design and location of the distribution pipeline. This system may have been built during a time of water abundance, without consideration of future climate change impacts. Farmers noted that water was sufficient during the rainy season.

In response to these disputes over water usage, farmers generally rely on informal conflict resolution strategies, such as direct communication, although such efforts frequently fail to resolve the underlying issues. Considering these constraints, farmers have resorted to irrigating at unconventional hours, such as late at night or early morning, when water demand is lower, to circumvent the pressure loss and ensure adequate irrigation. Smallholder farmers in the study area have reported persistent leakages within the irrigation system, particularly pipe bursts while others highlighted no experienced leaks in the system. They have expressed concern that, in such cases, the absence of nearby shut-off valves severely hampers their ability to isolate and repair the affected sections promptly.

According to the farmers, this lack of control valves indicates that the irrigation infrastructure is poorly designed. However, findings from the condition assessment of the infrastructure appear to contradict these claims, revealing that the system is, in fact, structurally sound. There is, however, a notable absence of documentation regarding the age and design specifications of the irrigation infrastructure, and the farmers themselves provided conflicting accounts regarding its age. While some farmers characterize the infrastructure old and constructed from asbestos piping, observations during the transect walk revealed that the pipes are made from PVC, a material that adheres to the SANS standards for water systems. Within the study area, smallholder farmers generally report addressing maintenance issues as they arise, indicating a lack of a formalized maintenance protocol.

Farmers indicated that responsibility for the maintenance of the infrastructure was initially intended to fall under the jurisdiction of the landowner, the Moravian Church of South Africa, which is perceived by the farmers as the authority over the land. According to the farmers, they typically enter into lease agreements with the Church for periods of 9 years and 11 months, which further strengthens their expectation that the church, as the landowner, should assume responsibility for the maintenance of the irrigation system, as stipulated in their contracts. Particularly among female farmers, it was noted that they frequently undertake repairs themselves, although some do hire external contractors to fix maintenance issues.

This reflects a heterogeneous approach to infrastructure management among the smallholder farmers, highlighting the absence of a coordinated, systematic effort to maintain the irrigation system and mitigate water losses. Such variability in maintenance practices suggests an urgent need for more organized and consistent strategies to ensure the efficient management and sustainability of the irrigation infrastructure

5.1 Recommendations

Based on the conclusions of the study, several recommendations can be made to address the water-related challenges faced by smallholder farmers in Goedverwacht. The establishment of water storage infrastructure is essential. The lack of storage facilities for irrigation purposes during dry periods has significantly hindered farmers' ability to manage water effectively. Investing in the construction and maintenance or supply of tanks of water storage systems would help farmers better manage water resources during dry spells, improving irrigation efficiency. This initiative requires strong government and institutional support, as such systems have been beneficial in commercial farming operations.

Another crucial recommendation is to strengthen institutional support and governance. The study highlights that Goedverwacht's private ownership and absence of formal governance structures have led to limited institutional assistance. A more robust governance framework should be created to foster communication and collaboration between farmers and relevant authorities. Such a framework could address issues like land tenure disputes and ensure that farmers have access to necessary resources for effective water management.

The study also emphasizes the need for improved conflict management, particularly regarding water disputes among community members and smallholder farmers. While farmers often resort to informal conflict resolution methods, these have proven largely ineffective. A formalized dispute resolution committee should be established to manage water conflicts and ensure fairer water distribution. This approach would help prevent tensions and encourage cooperation within the community.

To address issues related to irrigation infrastructure, a formalized maintenance program should be implemented. The current lack of a coordinated maintenance approach, where farmers rely on ad hoc repairs, has led to inefficiencies and poor water management. The Moravian Church, as the landowner, should assume a more active role in infrastructure maintenance, in line with the lease agreements with farmers. In addition, addressing water pressure loss due to persistent leaks in the irrigation system are crucial. Ensuring prompt repairs can prevent further water loss and improve the reliability of the system.

Promoting sustainable water use practices is vital, especially considering fluctuating water availability and pressure issues. Encouraging water-saving irrigation technologies and more efficient water management strategies can help minimize waste and ensure that water resources are used effectively. Additionally, the development of educational programs on water management is essential. These programs should focus on teaching farmers how to properly maintain their irrigation infrastructure, adapt to changing climatic conditions, and manage water efficiently. By implementing these recommendations, smallholder farmers in Goedverwacht can improve their water management practices, reduce conflicts, and enhance agricultural productivity.

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