Investigating the impacts of climate services among commercial and smallholder farmers to improve the uptake of climate information.

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Abstract

Climate change has impacts on agricultural production through changes in precipitation, temperature, carbon dioxide fertilisation, surface water runoff, and climate variability. These changes affect the ability of a region's agricultural sector to sustain production. South Africa is particularly vulnerable because of poverty, food insecurity, and a low adaptive capacity. Therefore, there is a crucial need for adaptation in the agricultural sector, which requires sufficient climate information to achieve strong climate-resilient development. This research aims to assess how the uptake of climate information can be improved with climate services among commercial and smallholder farmers in South Africa. In this study, a total of 29 respondents were interviewed. These respondents consisted of a seasonal climate forecast provider, two agricultural advisors and 13 Western Cape and Eastern Cape farmers who were a representation of the two main farming systems in South Africa. The interview questions for the seasonal climate forecast provider and agricultural advisors obtained information on the rate of access to and use of climate services, as well as extension support and engagement. The farmer interview questions were designed to elicit farmers' perspective on climate risks, as well as access to and use of climate services, such as seasonal climate forecasts, in agricultural decision-making. According to the results of this study, farmer-researcher engagement and extension support is currently poor. This is demonstrated by the low response rate of 8% of commercial and smallholder farmers who reported using extension services, as well as a lack of awareness and understanding of seasonal climate forecasts. Furthermore, access to climate services and the use of seasonal climate forecasts differed among commercial and smallholder farmers, with 46% of commercial farmers with access but limited use due to lack of trust. In contrast, smallholder farmers had no access and usage due to a lack of awareness and understanding of seasonal climate forecasts. Additionally, the results revealed that both the commercial and smallholder farmers considered networks as an essential enabler to use seasonal climate forecasts. The networks mentioned were the local farmer groups and agricultural co-ops such as GrainSA and Overberg Agri. This research, therefore, recommends improving farmers' knowledge of seasonal climate forecasts through training and the development of accessible, context-specific climate services. Moreover, the dissemination and interpretation of seasonal climate forecasts by local agricultural advisors and extension officers is recommended. This will assist in the improved uptake of climate information and more active engagement among seasonal climate forecast producers, agricultural advisors, agricultural extension officers, and farmers.

Keywords: Climate services; Seasonal climate forecasts; Commercial farmers; Smallholder farmers; South Africa

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To my daughter, always remember you are brave, you are capable and you can accomplish anything your heart desires.

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List of acronyms and abbreviations

ACMAD	African Centre for Meteorological Application and Development
BRACED	Building Resilience and Adaptation to Climate Extremes and Disasters
CMA	Cape Metropolitan Area
CPAC	Climate Prediction and Applications Centre
CSAG	Climate System Analysis Group
CS	Climate services
EC	Eastern Cape
GFCS	Global Framework for Climate Services
IBCS	Intergovernmental Board on Climate Services
NMHS	National Meteorological and Hydrological Services
SADC	Southern African Development Community
SAWS	South African Weather Services
SCF	Seasonal Climate Forecasts
SSA	Sub-Saharan African
UCT	University of Cape Town
WC	Western Cape
WMO	World Meteorological Organization

Chapter 1: Introduction

1.1 Background to the study

Agriculture is vital in Sub-Saharan African (SSA) countries because it is a source of livelihood, employment, and food security (Modi, 2019). It accounts for about 15% of the region's overall Gross Domestic Product (OECD/FAO, 2016). Furthermore, the sector also supports over 60% of the population who rely on agriculture and natural systems for their livelihoods (Nhemachena *et al.*, 2020). The crop sector dominated total agricultural production value from 1990 to 2013, accounting for approximately 85% of total production value (OECD/FAO, 2016). However, this varies among Sub-Saharan African regions, with Western Africa accounting for 90% and Southern Africa accounting for 53%, indicating agroecological differences (OECD/FAO, 2016). Livestock production is likewise diverse, with poultry making up a significant component (OECD/FAO, 2016).

In South Africa, the agricultural sector similarly plays a key role because it provides basic human needs such as food, employment, and strong economic linkages (National Department of Agriculture, 2001). It employs 792 000 people, according to the Statistics South Africa (Stats SA) Quarterly Labour Force Survey (Statistics SA, 2021). From June 2019 to June 2020, net farming income in SA's agriculture sector increased by 46% to R157 billion from June 2020 to June 2021 (Green Cape, 2022). Large-scale commercial farmers with private or corporate ownership and small-scale farmers with subsistence or developing commercial goals make up the sector (Gbetibouo, Ringler and Hassan, 2010; Findlater, 2013). This sector has a direct impact on nutrition and food security, as well as livelihoods, employment, and foreign revenue.

Climate variables like rainfall and temperature, on the other hand, have a considerable impact on the sector's success (OECD/FAO, 2016; Popoola, Yusuf and Monde, 2020). Agriculture is affected by climate change in various ways, making it a vulnerable economic activity to climatic variation and change (Yohannes, 2016). South African populations are particularly vulnerable becasue of poverty, food insecurity, and a lack of adaptive capacity (Sonwa *et al.*, 2017). Furthermore, it is challenging to define adaptative capabilities and methods due to South Africa's diversified agricultural sector (Gbetibouo, Ringler and Hassan, 2010; Findlater, 2013). The large-scale farmers, for example, have more resources and diversification capacity, allowing them to plan for more extended periods. In contrast, small-scale farmers have fewer resources and less diversification capacity, necessitating faster investment returns and increased vulnerability to market fluctuations (Findlater, 2013). Farmers' vulnerability largely differs because of this variability (Gbetibouo, Ringler and Hassan, 2010). As a result, recommendations to address climate change challenges require farmer-specific understanding to propose an agricultural resilience mechanism adapted to this variety of systems (Fellmann, 2012)

1.2 Climate services: An overview

Climate services are the creation, translation, transfer, and application of climate data for both individual and societal decision-making (Carr *et al.*, 2017). They give information that when shared with the agricultural, water, health, and other sectors, supports the development of adaptation plans (United States Agency For International Development, 2020). Climate services are produced using a combination of weather and hydrological data. This offers timely information that may be used to make decisions and assist people to manage the current climate variability and minimise the risk of climate-related disasters (United States Agency For International Development, 2020). The initial purpose of climate services was to increase human security and risk management in response to climate variability and change (Adams *et al.*, 2015). Human security is defined as the absence of fear and the ability to respond to threats. Risk management is the process of identifying, evaluating, and prioritizing risks following resource application to minimize the impact of unfavorable events (Adams *et al.*, 2015).

Climate services officially began on the launch of the Global Framework for Climate Services (GFCS). The GFCS was formed in 2009 during the Third World Climate Conference in Geneva, to be managed by the World Meteorological Organization (WMO-GFCS, 2014). The framework's goal was to help societies handle the risks and opportunities of climate variability and change. The framework is divided into five sections: (i) a user interface platform; (ii) a climate services information system; (iii) observation and monitoring; (iv) research, modeling, and prediction; and (v) capacity building. A High-Level Task Force was established in 2010 to develop the framework's components by the Global Framework for Climate Services (Grasso, 2012). A task team was formed in 2011 to create a draft implementation plan, and the Global Framework for Climate Services office was established that same year. The Intergovernmental Board on Climate Services (IBCS) was founded in 2012 at a World Meteorological Organization Extraordinary Congress to adopt the GFCS implementation plan; the IBCS held its first meeting in July 2013 and its second meeting in 2014 (Grasso, 2012).

In Africa, the following regional centers provide climate information; Climate Services Adaptation Program in Africa, launched under the Global Framework for Climate Services; African Centre for Meteorological Application and Development (ACMAD); IGAD Climate Prediction and

Applications Centre (ICPAC), and Southern African Development Community (SADC) Climate Services Centre (Singh, Urquhart and Kituyi, 2016). The National Framework for Climate Services for South Africa (NFCS-SA) was established as the country's response to GFCS to enable South Africa to implement the requirements of the Global Framework for Climate Services (Department of Environmental Affairs, 2019). The NFCS-SA has a joint project with the South African Weather Service (SAWS) and the Department of Environmental Affairs to enhance the production, availability, delivery, and application of science-based climate monitoring and predictions services (Singh, Urquhart and Kituyi, 2016). The World Meteorological Organization oversees the South African Weather Service, which aims to provide valuable weather and climate information and related products and services. The key dissemination platforms include national climate change information, research, social media, cellphone applications, telephone and email, hard copy, and broadcast media (Ramaru, 2021).

1.3 Climate services in South Africa

Climate services in South Africa is provided by government departments, government research institutions, universities, research institutes, representative organisation, private institutions and individuals (Ramaru, 2021). The National Department of Agriculture ensures extension and advisory services are provided. These services are defined as an active collaboration engagement of all stakeholders, actors, and role-players involved in agricultural, forestry, and fishery value chains to support wise decision-making (Ngaka and Zwane, 2017). Agricultural extension officers in South Africa provide technical assistance to farmers under the authority of the agricultural minister (Bernardi, 2011). Extension services are a provincial mandate overseen by a chief director who is responsible for focusing and coordinating these state services to provide effective, harmonised, and suitable professional, financial and administrative support to personnel and the overall extension and advisory functions (Ngaka and Zwane, 2017).

The agricultural sector needs a range of climate services, such as (a) the assessment of extreme weather and climate events which measures the frequency, duration, and intensity of extreme events and aids in long-term infrastructure investments like the location of dams; (b) climate change projections which are information used to indicate precipitation and temperature patterns in a time frame of 30-50 years; and (c) climate predictions ranging from monthly, seasonal and decadal time scales to assist farmers in deciding on various operational and seasonal decision ranging from variety choice, plot allocation, logistics of practice applications (Bernardi, 2011). Climate services in the form of seasonal forecasts can also assist farmers in planning for adaptation strategies for seasonal variability and reduce risks while short-term, daily to weekly forecasts support farmers in deciding which activities to conduct that same day or week (Singh *et al.*, 2018). Seasonal climate forecasts (SCF) lie between short-term weather forecasts and longer timescales like interannual predictions and climate change projections. They provide a probabilistic indication of how climate variables such as temperature and rainfall may occur in the season ahead and can go from a 1-month prediction lead time up to a year (Soares, Daly and Dessai, 2018). They assist in planting, irrigation, application of chemicals, cultivation and weather-related issues (Garcia *et al.*, 2010). However, farmers may lack the necessary weather preparations and make decisions on general climate patterns. It is for this reason that better climate predictions (3-6 months) are required to help guide appropriate decisions, reduce their impact and benefit from forecasted information (Bernardi, 2011).

1.4 Problem statement

South Africa is anticipated to experience regional variations in the future precipitation. It is anticipated that most of the summer rainfall region of South Africa will experience increased median precipitation and lead to more frequent and severe floods and drought events. In contrast, a significant decrease in precipitation is expected in the western winter rainfall region (Findlater, 2013). These changes in precipitation and temperature will affect the South African environment and economy including impacts on water security on which agriculture depends on (Engelbrecht, 2019). Additionally, the changes in variability will affect the length and success of growing seasons (Sonwa *et al.*, 2017). South Africa's agricultural sector exhibits diverse farming systems which are characterised by both large-scale commercial and smallholder farmers due to economic development and climatic patterns (Gbetibouo, Ringler and Hassan, 2010). The Western Cape makes up 12% of South Africa's total agricultural area (Talanow *et al.*, 2021a) and mostly consists of large-scale commercial operations (Findlater, 2013). The major grain grown is wheat whose productivity is sensitive to reduced rainfall and higher temperatures (Talanow *et al.*, 2021a). In Eastern Cape, agriculture is the main source of livelihood although the vast majority of farms are smallholder farms characterised by low levels of production technology, poverty and a lack of access to markets (Adekunle, 2013). In contrast, commercial farmers rarely face socio-economic constraints like poverty, lack of credit and gender issues (Talanow *et al.*, 2021b); instead, they face challenges such as water availability and management, potential crop losses and managing climate change (Swart, 2016).

Given that crop growth, in particular, depends on climate conditions, agricultural productivity is subsequently vulnerable to climate change (Kgakatsi and Rautenbach, 2014). Therefore, it would be crucial to have advanced warning of potential hazards and extreme climate anomalies on monthly and annual time scales for better agricultural planning and operation (Ogallo, Boulahya and Keane, 2000). Agricultural systems would benefit from knowing what to expect in advance, in addition to the traditional weather information such as; (i) information on time scales less than a month such as daily, weekly, 10-day precipitation amount and intensity, number of rainy days, distribution of wet/dry spells, temperature information on heat waves, cold spells and frosts, (ii) seasonal climate forecast including time of onset of rainfall or drought, or any extreme climate event, its duration and extent, (iii) Inter-annual time scale including the probability that a severe event would persist and (iv) climate change information resulting into significant shifts of the historical patterns of weather and climate (Ogallo, Boulahya and Keane, 2000).

Climate services are thus recognised as a tool for agricultural adaptation, offering knowledge on local climate information, assisting farmers' and institutions' decision-making and supporting a variety of resilient-building measures (Hansen *et al.*, 2019). Access to and the use of climate information can significantly contribute to climate change adaptation (Vaughan *et al.*, 2019). Climate services aim to help people become less vulnerable to environmental stressors and improve their livelihoods (Harvey *et al.*, 2019). They help policymakers and disadvantaged groups make decisions and guide early preparedness (Tall, Coulibaly and Diop, 2018). Climate services can help various users to improve risk management for climate change and variability (Vogel, Steynor and Manyuchi, 2019). Climate services help farmers by enhancing their understanding of possible climate outcomes and assisting them in mitigating outcomes by allowing them to make decisions about specific crops, planting timing, and fertilizer application (Vaughan and Dessai, 2014). Seasonal climate forecasting in particular makes it possible to modify crop management to anticipated weather conditions or take advantage of favourable conditions to reduce the effects of adverse conditions (Ogallo, Boulahya and Keane, 2000). The delivery of seasonal climate forecasts has usually been disseminated on the assumption that all farmers, both commercial and smallholder, have access to such information.

1.5 Rationale

The relationship between weather, climate information and agriculture in Africa, the type of weather and climate information needed to inform agricultural decisions are the most researched areas in literature. According to Agyekum, Antwi-Agyei and Dougill (2022), the provision of timely and precise weather information could improve the vulnerability of people to climate change risks. Climate information that is produced and disseminated collaboratively provides an incentive for all users of the information to prepare for climate change (Naab, Abubakari and Ahmed, 2019). However, farmer end-users still have a significant need to know what information is available, where to find it, and how to apply it in agricultural or livelihood decisions (Tall, Coulibaly and Diop, 2018). The potential benefit of climate and weather information is reduced if they are available but not used, or if they are not used effectively. Farmers' understanding, adaptive capacities, and ability to effectively respond to climate change are all affected by a lack of access to vital climate information (Popoola, Yusuf and Monde, 2020).

Further work is required to better understand the role that climate services play in South African agricultural decisions; farmers' specific climate information needs, as well as how their efficient use can be increased within the sector. This is particularly true for South Africa; there is limited research aimed at investigating the effectiveness of climate services using qualitative ex-post evaluations. This study responds to the greater need for a better understanding of the role of climate services in the South African agricultural sector and how efficient use can be increased within this sector. This will enable the dissemination of appropriate, context-specific climate services to end users. The knowledge received will be valuable when making recommendations to policymakers and agricultural extension officers regarding robust, efficient climate services/products. Furthermore, the proposed research findings will contribute to the current knowledge of climate services evaluations and its findings will not only highlight the importance of climate services in agriculture but improve community-based monitoring. It is at this point of departure that this research emerges.

1.6 Research questions

1. What is the current rate of access to and use of climate services among commercial and smallholder farmers in South Africa?

2. Does the use of climate services influence farmers' agricultural decisions?

3. How can the access to and flow of dissemination of climate services be improved for better use and uptake?

1.7 Aim

This study aims to assess climate services' role and potential in informing farmers' agricultural decisions, particularly using climate information among commercial farmers in the Western Cape and smallholder farmers in the Eastern Cape, South Africa.

1.8 Objectives

The objectives of this study are to:

1. Investigate various types of climate services produced in South Africa.

2. Assess current access and use of climate services under the different farming systems (commercial and smallholder) and the efficiency of these services in informing agricultural decisions.

3. Determine farmers' barriers and enablers towards increased uptake of climate information.

1.9 Structure of thesis

This thesis is divided into five chapters. After the introduction, Chapter two reviews literature on the role of climate services in the agricultural sector, the effectiveness of climate services and the improvement of agricultural decision-making using weather and climate information. The methods used to achieve the aim and objectives of this dissertation are described in Chapter three. Chapter four presents and discusses the results of this study. This dissertation concludes with Chapter five which summarises key findings.

Chapter 2: Literature Review

2.1. South Africa's agricultural sector

South Africa is classified as a semi-arid country with a highly variable climate and water resource constraints due to the effects of climate change and variability (Ziervogel *et al.*, 2014; Botai, Botai and Adeola, 2018). The climate in the southwest is Mediterranean, while the internal plateau is moderate, and the north-western region is subtropical. It receives 450mm of annual rainfall which varies seasonally, most of which falls in summer, and winter in the southwestern region (Botai, Botai and Adeola, 2018). The agricultural sector in South Africa combines a developed commercial farming sector and a large subsistence sector (Gbetibouo, Ringler and Hassan, 2010). The differences in rural infrastructure development and farming systems emerge from variations in economic growth and climate patterns across South Africa's landscape (Gbetibouo, Ringler and Hassan, 2010).

The diversity of the South African agricultural sector results in varying levels of vulnerability and adaptive capacity as well documented in the literature (Gbetibouo, Ringler and Hassan, 2010; Findlater, 2013). For instance, Gbetibouo, Ringler and Hassan, (2010) in their study on climate change vulnerability in South Africa demonstrated that the Western Cape and Gauteng had a low vulnerability index whereas provinces like Eastern Cape, Limpopo and Kwazulu-Natal were the most vulnerable. The study further examined the three dimensions of vulnerability (exposure, sensitivity, and adaptive capacity) and revealed that the coastal regions of the Western Cape, Kwazulu-Natal and Eastern Cape had the highest exposure, Limpopo, Kwazulu-Natal, and Eastern Cape were the most sensitive provinces and Western Cape had the highest adaptive capacity. They emphasised that the provinces with the highest proportion of small-scale farmers relying on rain-fed agriculture, a prominent level of soil degradation, a high rural population density, high unemployment, low literacy levels, and a low infrastructure index are the most vulnerable. They argued that vulnerability to climate change is spatially differentiated across the farming areas in the country thus, region-specific policies should be developed.

Previous studies have shown that the use of weather and short-term climate information on a daily, weekly, monthly, and seasonal timescale is crucial in decision-making in agriculture (Zuma-Netshiukhwi, Stigter and Walker, 2016; Nkiaka *et al.*, 2019). Climate information such as daily weather forecasts can be used to plan daily farm operations. Seasonal climate forecasts provide estimates of seasonal weather conditions up to three months ahead of the season (FAO, 2019). The information received is used to plan the planting season and make strategic decisions. Early warning information describes hazards and their expected impact, as well as possible responses (FAO, 2019). Indigenous knowledge is based on a community's understanding of the ecosystem and interactions with nature, as well as their experiences in the area (Zuma-Netshiukhwi, Stigter and Walker, 2013) and climate projections show future changes in climate (FAO, 2019). Farmers can use climate information to become more aware of climatic events and reduce the impact of unfavourable outcomes by making decisions about planting timing and fertilizer use (Vaughan and Dessai, 2014). Farmers can benefit from climate-related opportunities if they plan for occurrences and common climate variations (Vaughan and Dessai, 2014).

2.2. Defining Climate Services

Climate services are decision-making support tools that are created through the process of transforming climate information into relevant advisory services that can empower decision makers to manage the risks and opportunities of climate variability and change (Appenzeller, 2016; Tall, Coulibaly and Diop, 2018). There has been a rise in interest in climate services since the launch of the Global Framework for Climate Services (GFCS) in 2009. GFCS is an international initiative focused on improving the development, distribution and use of climate data around the world (Vaughan, Dessai and Hewitt, 2018). Climate services provide information to help people become less vulnerable to environmental shocks and improve their livelihoods (Harvey *et al.*, 2019; Vogel, Steynor and Manyuchi, 2019). They are intended to assist policymakers and disadvantaged groups in making climate-smart decisions and guide early preparedness (Tall, Coulibaly and Diop, 2018). In order to improve decision-making under uncertainty and facilitate and guide early preparedness, climate services must entail reliable access and dissemination, provide adequate engagements that are relevant to the user's needs (Tall, Coulibaly and Diop, 2018).

2.3. The role of climate services in the agricultural sector

2.3.1. Climate services in decision-making

Climate services play an important role in farmers' decision making (Naab, Abubakari and Ahmed, 2019). In their assessment of changes in agricultural decisions following the use of indigenous knowledge and climate, Zuma-Netshiukhwi, Stigter and Walker (2013) and Zuma-Netshiukhwi, Stigter and Walker (2016) found that well-informed decisions could address some of the challenges faced by farmers and the shortcomings in farming. They identified challenges faced by the farmers which were weather and climate-related, demonstrating a lack of access to agrometeorological information and services. Thus, they indicated that farmers need agrometeorological information and services to help increase agricultural production (Zuma-

Netshiukhwi, Stigter and Walker, 2016). Furthermore, they emphasised the importance of sharing agrometeorological knowledge with farmers, extension officers and policymakers for better decision-making.

In a social science literature review, Rose, Keating and Morris (2018) mentioned several factors which influence farmer behaviour. These factors include: personal factors, business factors, family, personal and advisory networks, feeling in control in decision-making, relative advantage, market benefits and information provision education (Rose, Keating and Morris, 2018). They emphasised how crucial the involvement of advisors is in farmers' decision-making. Naab, Abubakari and Ahmed (2019) discovered that in Ghana, agro-meteorological information has been neglected in the delivery of climate services and there was a lack of tailor-made climate information for the local community. Thus, they recommend that mainstreaming climate services should be a priority in order to provide a reliable option for a resilient agricultural sector.

Harvey *et al.* (2019) highlighted that non-government organisations (NGOs) could offer the opportunity for novel ideas of communication and knowledge sharing of climate services. NGOs can play a vital role in ensuring user needs and insights are communicated back to nation-level producers of climate information. This role can include: an improved understanding and use of knowledge in decision-making, innovative ways of how climate information is produced and used, establishing a feedback loop between producers and users and ensuring that information is communicated to a wider audience (Harvey *et al.*, 2019).

2.3.2. Climate services as an adaptation potential

The use of climate information promotes the adoption of adaptation strategies by enhancing sound agricultural practices (Hansen *et al.*, 2011). Climate information is needed to mitigate the effects of climate change and variability and the information contained from meteorological seasonal forecasts together with indigenous knowledge can assist farmers and pastoralists manage crops and livestock to minimise risks during unfavourable conditions and provide benefits during favourable conditions (Chagonda *et al.*, 2010). Chagonda *et al*, (2010) combined seasonal climate forecasts with indigenous knowledge-based seasonal predictions to overcome the challenges seasonal climate forecasts often encounter. These challenges included the lack of localised seasonal climate forecasts, their delayed dissemination, their inaccessibility to all farmers or when farmers are busy, and their failure to offer advice on agricultural strategies (Chagonda *et al.*, 2010). They suggested that seasonal climatic forecasts could be more effective when used in conjunction with indigenous knowledge-based seasonal predictions because they are localized and frequently provide useful information (Chagonda *et al.*, 2010; Chisadza *et al.*, 2015). In addition, Chagonda *et al.* (2010) infer that farmers not only need meteorological information but also need agrometeorological information that is relevant to local conditions and local activities (Chagonda *et al.*, 2010). Therefore, providing climate information that is fit for purpose requires several stages and stakeholders, so agricultural extension officers play a vital role when integrating seasonal climate forecasts and indigenous knowledge-based seasonal forecast (Chagonda *et al.*, 2010).

It is also crucial to combine short and long-term climate information in order for systems to become resilient to current and future climate risks (Singh *et al.*, 2018). This could improve the use of climate information in decision-making at various spatial and temporal scales. Short-term climate information such as weather advisories and seasonal climate forecasts can help users manage short-term risks. While medium and long-term climate information can lead to long-term action and investment in establishing and maintaining climate information,institutional architecture and infrastructure and help to restructure the entire system, which includes producers, communicators, and users of climate data (Singh *et al.*, 2018). However, long-term climate information can also impact short-term actions by motivating short-term responses like choosing temperature tolerant varieties according to a framework developed by Singh *et al.* (2018) to use climate information in multi-scalar decision-making.

Ziervogel, Bharwani and Downing (2006) explored adaptation action employed by farmers in the Vhembe District, in Limpopo. The study revealed that climate information such as seasonal climate forecasts are used as an adaptation measure to climate variability, however, highlights the need for improving support on seasonal climate forecast information so that users understand the probabilistic nature of forecasts. Furthermore, farmers used different adaptation strategies depending on their available resources, knowledge, social capital and personal preference. Ziervogel *et al.* (2010) investigated how seasonal climate forecasts might be used in water resource management focusing on a case study of the Cape Metropolitan Area (CMA) in the Western Cape. They discovered that the use of seasonal climate forecasts is limited due to a lack of awareness. Seasonal forecast information might be better integrated into water resource planning with specialised/user-specific products. Indicators pertaining to the accuracy of seasonal climate forecasts were requested as improvements by water resource managers. They also indicated that better information utilization might be enhanced by more active dissemination, interpretation, and contact between producers and water managers.

2.4 Effectiveness of climate services in agriculture

2.4.1 Evaluation of climate services

Impact evaluations are intended to provide evidence of the actual impact of an intervention (Vaughan *et al.*, 2019). It is challenging to evaluate how much climate services and climate service producers improve agricultural decisions according to Vaughan *et al.* (2019). They state that determining the success of climate services requires assessing their economic value. Furthermore, evaluating climate services should explore the extent to which the problem identified by the climate service is valid and important (Vaughan and Dessai, 2014). The advantage of evaluating climate services is that it provides evidence of useful information for specific decision-making, which will help climate science and climate services to create minimum standards for what is considered robust climate information (Vaughan and Dessai, 2014). These standards give users a criterion by which to measure the quality of the information provided.

The World Meteorological Organization (2015) defines meteorological and hydrological service evaluation as the process of ascertaining the level of service quality, the characteristics of user communities' uptake of the service and the monetary value of those communities. Evaluating the quality of forecasts and other services involves ex-ante and ex-post analysis using actual weather data or surveys to assess perceptions of service reliability and access. To better understand uptake, non-economic social science evaluation methods can be used. These methods reveal information about services such as the user's ability to access, understand and use meteorological or hydrological services for their specific needs (World Meteorological Organization, 2015).

Adams *et al.* (2015) adopted a different strategy, creating an ethical framework for climate services with the goal of ensuring that climate services are used effectively to manage climate risks and improve human security. Firstly, they identified four core values that are ethically required for climate services to be created and provided namely, (i) Integrity, which entails being honest in the conduct of practice; (ii) Transparency, which concerns the relationship between climate service providers and user communities; (iii) Humility, which entails providing information that is honest and transparent and (iv) Collaboration, which entails the engagement of all stakeholders involved. The authors considered the above-mentioned values should be used to guide climate service providers as they develop, disseminate and elaborate tools and products. Consequently, they developed principles of practice and principles of products to engage climate service providers. Principles of practice included the following, (i) Climate service providers should communicate their judgements, (ii) Providers should communicate their principles of practice; (iii) Providers should engage with communities of practice; (iv) Providers should engage in co-exploration of knowledge; (v) Providers should understand climate as an additional stressor; (vi) Providers should provide metrics of the value of their products; (vii) Providers should communicate appropriately; (viii) Providers should articulate processes for refreshing and revising the information; (viiii) Providers should have procedures in place for evaluation and monitoring of processes and products; (x) Providers should disclose conflicts of interest and (xi) Providers and users should share climate information outcome. Climate service products, according to product principles, should include detailed descriptions of uncertainty; they should be credible; they should be robust and fit for purpose and products should be documented. They concluded that the identified values and principles should serve as a guide in informing climate services.

Soares, Daly and Dessai (2018) focused on seasonal climate forecast valuation, identifying them as a type of climate service. They indicated that when compared to other available information, a seasonal climate forecast's value is determined by its ability to influence decisions and actions. They reviewed the main factors that they believed influence the value of seasonal climate forecasts in decision-making. These factors included forecasts, the decision maker, the context of the decision and the link between science and society. Within these factors, they explained that the attributes of a seasonal climate forecasts such as accuracy, timeliness, spatial and temporal resolution can determine if the forecast aligns with decision-making; the value of forecasts varies among decision-makers and is influenced by a decision-maker's issues of interpretation, cognitive biases and heuristics as well as a social position like gender, social status and education. Furthermore, they elaborated that there are constraints to seasonal climate forecast use and the level of trust between producers and users. They concluded that a variety of factors affect an individual's ability to access, interpret and act on seasonal climate forecast information.

2.4.2 Barriers of climate information use

Diouf *et al.* (2019), Diouf *et al.* (2020), Henriksson *et al.*(2020), Partey *et al.* (2020) and Antwi-Agyei *et al.*(2021) took a similar approach in investigating the determinants of climate information use among farmers and focused on gender. Their studies revealed that men are more likely to access climate information than women which can be attributed to gender roles often played by women in society (Antwi-Agyei *et al.*, 2021). Additionally, men are more inclined to use climate information because of ease of access to communication devices which can also be attributed to socio-cultural norms (Partey *et al.*, 2020). As such, Henriksson *et al.* (2020) suggested that a greater range of options for accessing forecasts is needed to fulfil the special demands of women, and empowerment is a key component impacting women's ability to obtain climate information. Furthermore, it is crucial to consider gender-specific aspects for appropriate decision-making in the agriculture sector to increase access to climate information services (Diouf *et al.*, 2019).

Bruno Soares and Dessai (2016) investigated the barriers to the use of seasonal climate forecasts, as well as current drivers and enablers of seasonal climate forecasts use in European organisations in different sectors. Using in-depth interviews and workshops they discovered that primary perceived barriers to the use of seasonal climate forecasts included a lack of reliability. This was linked to issues of accuracy and uncertainty. Additionally, lack of relevance, lack of awareness and the timing of seasonal climate forecasts were recognised as barriers. They also identified enablers among organisations that used seasonal climate forecasts, which were mostly related to the relationship between producers and the level of resources and expertise within an organisation. Other enablers included the relevance of seasonal climate forecasts and knowledge-seeking behaviour.

Similarly, Nkiaka *et al.* (2019) conducted a systematic literature review to identify barriers to the uptake and use of weather and climate services in Sub-Saharan Africa. Issues of awareness, understanding and access were the most common barriers. Other barriers included relevancy and capacity, lack of trust and institutional barriers which could be attributed to the inaccessibility of weather and climate services and poor disaster management using early warning systems. They further revealed that belonging to a social group, having access to credit and having a mobile phone were all vital factors which influenced the uptake of weather and climate services. Given the significance that local farmer-based organizations play in the uptake of weather and climate services in local areas, they proposed that weather and climate services explore cooperating with them. This view agrees with a suggestion made earlier by Amwata, Omondi and Kituyi (2018), of institutionalising climate services through farmer groups and extension workers. These findings complement those of Antwi-Agyei *et al.* (2021) and Muema *et al.* (2018) who identified similar barriers such as awareness of climate change, the terminology used in communicating climate information, reliability and lack of trust. In addition, Antwi-Agyei *et al.* (2021) highlighted the inadequate information on seasonal climate forecasts for long-term planning, the low accessibility of climate information, the high rate of illiteracy, the disconnection between climate information and the smallholder farmers' needs and timeliness.

At the municipal level, Spires and Shackleton (2018) highlighted barriers which included cognitive and normative barriers such as personal beliefs, lack of trust and suspicion; social barriers relating to lack of coordination with organisations; resource barriers related to issues of knowledge, financial and lack of skilled human resources and barriers associated to the broader municipal environment and needs. These findings agree with finding made by numerous authors (Vogel, 2000; Johnston *et al.*, 2004; Hansen *et al.*, 2011; Johnston, 2014) and Shackleton *et al.* (2015) in their study synthesising empirical literature from Sub-Saharan Africa to understand the process of climate change adaptation. Steynor and Pasquini (2019) explored climate services through the psychological lens, arguing that in order to better inform the provision of climate services for adaptation, it is important to understand climate change risk perception. Set against the belief that this may evoke a reconsideration of how climate services are conducted in Africa, they believe that this process can inform appropriate collaboration, the appropriate content and format of products and services that provide climate information, the selection of suitable channels for communication and dissemination mechanisms and the identification of relevant timelines for climate-related decision making.

2.4.3 Improvement of agricultural decision-making using weather and climate information

Zuma-Netshiukhwi, Stigter and Walker (2016) undertook a case study approach in Free State after observing the lack of access to tailor-made weather and climate knowledge. They provided training to farmers on the application of weather forecasts and climate predictions as well as other science-based information services and agrometeorological knowledge and advisories. The developed agrometeorological advisories helped farmers make decisions about crop type selection, cultivar selection, planting date selection and management strategies by advising and guiding farmers based on seasonal conditions. Agrometeorological knowledge and advisories additionally assisted farmers make the decision to increase stock production and improve the sustainability of animal production. A noticeable change was observed in the farmer's decision-making and management practices from using only indigenous knowledge to more science-based climate information (Zuma-Netshiukhwi, Stigter and Walker, 2016). Furthermore, the study affirmed that the uptake of agrometeorological knowledge differs among farmers. Farmers with more resources were more familiar with weather forecasts, climate predictions and agrometeorological knowledge.

As admitted by Steynor and Pasquini (2019) and evidenced in various studies of climate services, the broader viewpoint on climate service production and dissemination is not always appropriate. This is therefore an area for further research to provide more all-inclusive, farmer-specific climate services. Following the research of Chagonda *et al.* (2010), Johnston (2014), Hansen *et al.* (2019) and Steynor and Pasquini (2019); this study investigates farmers' specific climate information needs and factors influencing the uptake of climate information. This investigation follows the methodology used by a number of authors including Ziervogel and Calder (2003), Zuma-Netshiukhwi, Stigter and Walker (2016), Johnston (2014) and Harvey *et al.* (2019). This study suggests that while there is an emerging notion about the need for climate service provision among farmers and how they can be tailored to be user-specific, there are diverse views on how it can be implemented. The current study expands on this, to emphasize the missing gap in a three-way engagement between smallholder and commercial farmers, seasonal climate forecast producers and local agricultural extension officers and advisors. Finally, it highlights barriers and enablers in the uptake of climate information.

Chapter 3: Methodology

3.1 Study area

3.1.1 Selection of study areas

The study areas are Western Cape (WC) and Eastern Cape (EC) Provinces. The WC covers an area of 129 449 km^2 making it the fourth largest province in South Africa. It is located on the Southwest coast (Partridge, Morokong and Sibulali, 2020). The province consists of one metropolitan area and five districts divided into twenty five municipalities (Statistics South Africa, 2018b). Based on the 2016 Western Cape Community Survey, the population was 6,3 million which increased from the 5,8 million population in 2011 (Statistics South Africa, 2018b). EC covers an area of approximately 169 000km^2 making it the second largest province after Northern Cape (Hamann and Tuinder, 2012). The province consists of two metropolitan areas and six districts divided into thirty-one municipalities. The population increased from 6,6 million in 2011 to 7 million in 2016 (Statistics South Africa, 2018a). The two provinces were selected because they offer an opportunity for comparison due to the contrasting environmental and socio-economic conditions (Gbetibouo, Ringler and Hassan, 2010). A study by Gbetibouo, Ringler and Hassan (2010) on the vulnerability of the farming sector in South African provinces revealed that Western Cape had a low vulnerability index while Eastern Cape was among the most vulnerable provinces to climate change and variability. Additionally, they revealed that Western Cape had the highest adaptive capacity index among other provinces while Eastern Cape was the most sensitive. Furthermore, the 2016 Statistics South Africa Community Survey on agricultural households revealed Eastern Cape had the most households involved in agricultural activities as the main source of food ranking at 52,7% while Western Cape ranked the lowest among all provinces with 24,5% of households involved in agricultural activities as the main source of food (Lehohla, 2016).

A total of 29 respondents were interviewed. These respondents consisted of a seasonal climate forecast provider, two agricultural advisors and 13 Western Cape and Eastern Cape farmers who were a representation of the two main farming systems in South Africa. Due to SARS-CoV-2 (Covid 19) the number of farmers interviewed was a limitation because data collection was intended for August and unfortunately then the country was on Lockdown Alert Level 3 where gatherings were limited. The farmers interviewed in Western Cape and Eastern Cape were wheat and maize farmers respectively. According to the Department of Agriculture, Land Reform and Rural Development's Trends in the Agricultural Sector 2021 Report, the two crops contributed to the field crop production during the 2020/21 period. Maize production increased by 7,1% while wheat production increased by 38.1%. Figure 1 below presents the four study areas chosen for this research.

3.1.2 Study area map

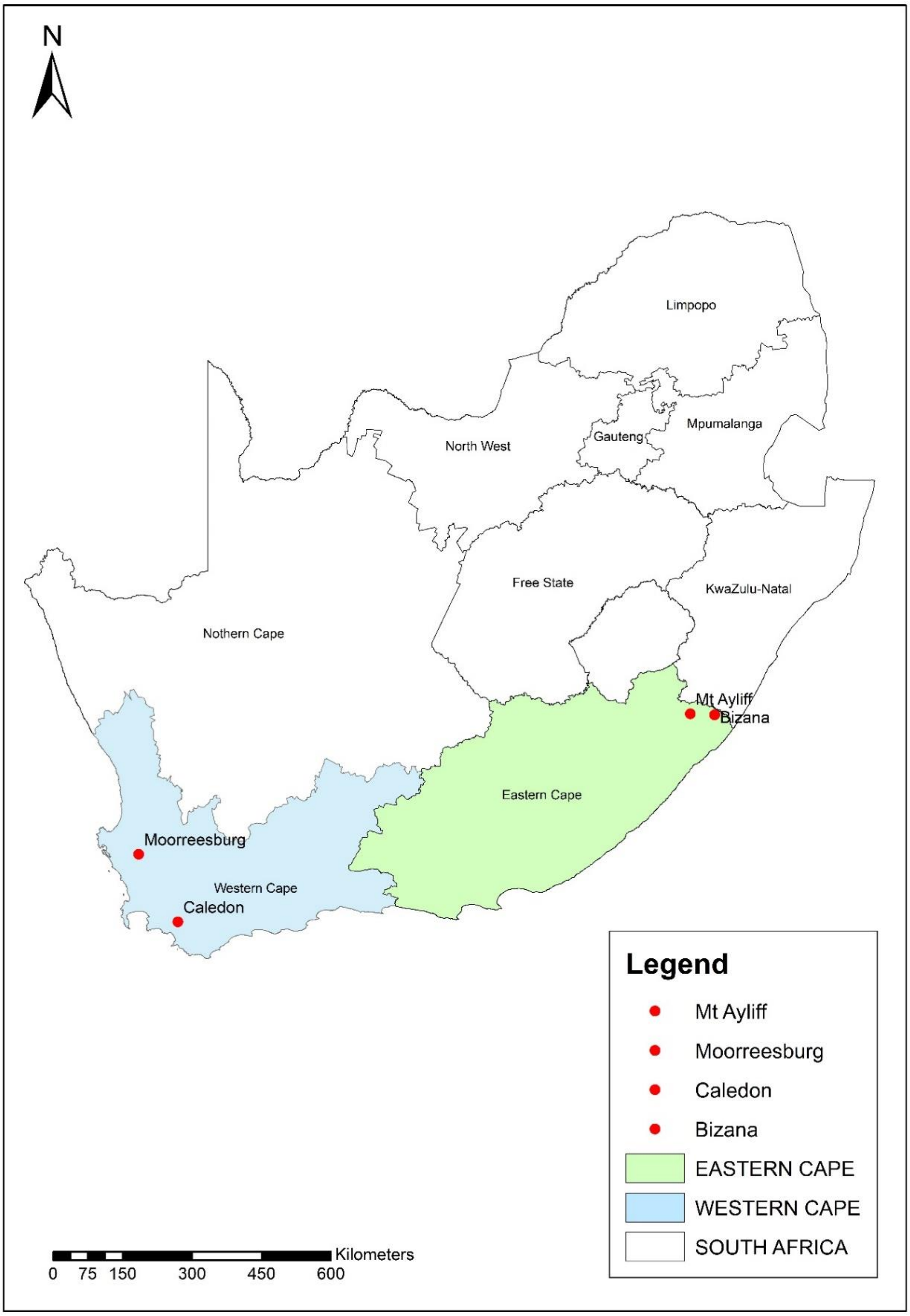

Figure 1: Map of the study area

The descriptions of these areas are provided in the subsections below.

3.1.2.1 Moorreesburg, Western Cape

Moorreesburg falls under the Swartland Local Municipality, in the jurisdiction of the West Coast District Municipality. The Swartland Local Municipality is bordered to the west by the Atlantic Ocean, to the south by the City of Cape Town, to the east by the Cape Winelands District, and to the north and northeast by the municipalities of Saldanha Bay and Bergrivier. The Swartland region experiences a Mediterranean climate with hot dry summers and cool moist winters (Crookes and Strauss, 2017). The long-term average annual rainfall is 398.2mm, which falls from April to September. The summer temperatures can reach a high of 40°C but largely remain between 15 – 27°C; winters are frost free with some low-lying areas as an exception reaching below 2°C (Crookes and Strauss, 2017).

The region is known for its grain production and grazing land and agricultural household activities including livestock production, poultry production, vegetable production and other crops (Statistics South Africa, 2018b).

3.1.2.2 Caledon, Western Cape

Caledon falls under the Theewaterskloof Local Municipality, in the jurisdiction of the Overberg District Municipality. The Overberg is south of the Cape Winelands and southwest of the Klein Karoo. The boundaries of the Overberg include the Hottentots-Holland mountains in the West, the Riviersonderend mountains in the north, the Atlantic and Indian Oceans in the south and the Breede River in the East (Crookes and Strauss, 2017). The annual average rainfall in Overberg is 650mm with the highest rainfall in the Grabouw area (1010mm) and the lowest in Barrydale (350mm).

The Overberg compromises 11.6% of the Western Cape's agricultural production which includes grain farming, wheat, yellow canola, fruit, fish production, barley, youngberry, livestock, and grapes. Agriculture in Caledon varies with grain production, stock farming and wool being the most abundant.

3.1.2.3 Bizana, Eastern Cape

Bizana is a rural town located in the Winnie Madikizela-Mandela Local Municipality under the jurisdiction of the Alfred Nzo District Municipality. In 2016, the population of Winnie Madikizela-Mandela Local Municipality was 319, 948 (Statistics South Africa, 2018a). According to the Köppen-Geiger climate classification, it falls under the warm temperate climate, fully humid with warm summer (Peel, Filayson and McMahon, 2007). The rainfall season in Alfred Nzo District Municipality occurs in summer from December to February.

3.1.2.4 Mt Ayliff, Eastern Cape

Mt Ayliff is in the Umzimvubu Local Municipality under the jurisdiction of the Alfred Nzo District Municipality. According to the Köppen-Geiger climate classification, it falls under the warm temperate climate, fully humid with warm summer (Peel, Filayson and McMahon, 2007). The rainfall season in Alfred Nzo District Municipality occurs during the summer season, from December to February.

3.2 Methods

3.2.1 Interviews

In qualitative research, interviewing is a common method of gathering data to guide participants in answering a specific research question (Stuckey, 2013). Structured, semi-structured, and unstructured interviews are three types of qualitative research interviews. Structured interviews have a set of pre-determined questions and only allow the interviewee to respond to a restricted number of them (Gill et al., 2008), semi-structured interviews have crucial open-ended questions and allow for the discovery of fresh insights while unstructured interviews contain minimal organization and no preconceived theories (Gill et al., 2008; Rowley, 2012). Open-ended questions yield responses that are meaningful, unanticipated by the researcher and explanatory in nature. Another advantage of interviewing method is that they allow the researcher the flexibility to probe initial participant responses (Stuckey, 2013).

Face-to-face interviews have a higher response rate than other methods of data collection and they are commonly used when collecting primary data from smallholder farmers (Hox and De Leeuw, 1995). Additionally, other methods such as telephone or email surveys are not ideal as poor smallholder farmers would not necessarily have access to these. The approach of data collection through interviews is widely used, by Talanow *et al.* (2021) and other various studies (Sekaleli and Sebusi, 2013; Hosu, Cishe and Luswazi, 2016; Guido *et al.*, 2020; Henriksson *et al.*, 2020; Talanow *et al.*, 2021b) have successfully used the interview approach to establish the perception of farmers on a specific matter, which made it a suitable method for the present study.

3.2.2 Farmer-researcher participatory approach

According to Orabi (2018), this type of research arose as a solution to the development of inappropriate technologies by scientists at research stations with the purpose of building farmer capacity and to use knowledge. Orabi (2018) listed four types of farmer participatory research: researcher-managed on-farm trials, consultative researcher-managed on-farm trials, collaborative farmer-researcher participatory research and farmer-managed participatory research. In researcher-managed on-farm trials, the researcher leads and works in farmer fields to validate research finding or develop the technology. In consultative researcher-managed on-farm trials, the researchers talk to farmers about their needs where farmers provide information on agricultural practices and knowledge of the local environment. In collaborative farmer-researcher participatory research, farmers and researchers work together to identify a problem, a management, and an implementation plan. In farmer-managed participatory research farmers are the main actors in problem identification, designing of solutions and developing a prototype.

The present study used the consultative researcher-managed participatory approach because it was integral in understanding seasonal climate forecasts among farmers, as well as barriers and enablers of uptake of climate information.

3.3 Data collection

3.3.1 Ethical consideration of the study

Prior to the study commencing, an ethical approval was received from the University of Cape Town (**FSREC 064 – 2021)** to conduct this research (attached as Appendix 1).

Informed consent and voluntary participation: The participants were briefed prior to the interviews about the purpose of the research, their role as participants, the duration of the interview and all the procedures to follow. In this study, consent was secured from each participant verbally.

Privacy and confidentiality: The researcher retained confidentiality and privacy by ensuring that all the participants and the information shared were collected in a confidential manner. This was done by a verbal agreement between the researcher and each participant that there would be no illegal access to the information and that all information will be solely used for the purpose of this study. Additionally, the information will be published in a way where none of the participants will be identifiable.

No harm to participants: In this study, the participants were not exposed to any harm because the information required did not pose any danger to the participants.

Limitation to this study: Due to SARS-CoV-2 (Covid 19) the number of farmers interviewed was a limitation because data collection was intended for August and unfortunately then the country was on Lockdown Alert Level 3 where gatherings were limited. The study proposed to interview a seasonal forecast provider, 4 agricultural extension officers from Bizana and Mt Ayliff and 20 farmers in Western Cape and Eastern Cape. However, due to limitations such as the availability of farmers and agricultural extension officers, only 13 farmers were interviewed in Western Cape and 13 in Eastern Cape. The agricultural extension officers had to be removed from the participants because during the data collection process they were not available, however 2 agricultural advisors from Overberg Agri in Moorreesburg and Caledon were used instead. Having time to interview more farmers and the agricultural extension officers would have improved the depth of this research. However, it is important to note that given the study aim, the interviewed participants were an adequate representation to have societal, theoretical, and political significance and impact.

3.3.2 Interviews with seasonal climate forecast provider and agricultural advisors

This study employed a qualitative research approach. The first objective of this study which is investigating the various types of climate services produced in South Africa was obtained through a literature review of climate services in South Africa and solicited from a seasonal climate forecast provider and two agricultural advisors. The interview schedule for seasonal climate forecast provider and agricultural advisors are attached as Appendix 2 and 3, respectively. The rate of access to and use of climate services, particularly seasonal climate forecasts and extension support and engagement between farmers and agricultural advisors were the focus of the interviews with seasonal climate forecast provider and agricultural advisors. The involvement of a seasonal climate forecast provider and agricultural advisors offered an opportunity to identify commercial and smallholder farmers' climate information needs, frequency of access and ideal communication channels. Additionally, it provided knowledge exchange and mutual learning experience as evidenced by (Kumar *et al.*, 2021). Furthermore, the information provided evidence on the strengths and weaknesses of the existing climate services available to farmers.

3.3.3 Interviews with commercial and smallholder farmer

The second objective of this study which assessed current access to and use of climate services under the different farming systems (small-scale & large-scale) and the efficiency of these services in informing agricultural decisions was solicited from commercial wheat and smallholder maize farmers. Farmer data collection was conducted using a purposive sampling technique in consultation with Overberg Agri in Caledon and Moorreesburg and GrainSA in Kokstad. Farmers were selected within operational areas of both Overberg Agri and GrainSA. Purposive sampling is a technique common in qualitative evidence synthesis in order to prevent unmanageable analysis due to large data sets (Ames, Glenton and Lewin, 2019). The purpose of engaging commercial and smallholder farmers was to highlight farmers' perception of climate change and implemented coping strategies as well as access to and use of seasonal climate forecasts in different farming systems.

The interview schedule for commercial farmers is provided in Appendix 4 and for smallholder farmers is attached as Appendix 5. The interview schedules were created with the assistance of the researcher's supervisor and a UCT-CSAG staff member who has experience in creating and administering interviews to farmers. The original version was created in English and the Afrikaans version was translated by UCT-CSAG staff member and the Xhosa version was translated by the researcher. The interviews with farmers were conducted in the farmers' language of preference between Afrikaans, English and Xhosa and each interview session lasted for 1 hour – 1.5 hours. The data was collected from thirteen commercial wheat farmers in Western Cape in September 2021 with one farmer at a time. Whereas sixteen smallholder maize farmers were interviewed in Eastern Cape in October 2021 in a group setting with four farmers in the same room. The reason for this was because the farmer houses are located far apart and it was easier to conduct the interviews in one venue, a community hall and farmer houses in some cases. This resulted in three smallholder farmer interviews being discarded because the respondents gave the same answers to questions and were deemed invalid. Thus, the reason for thirteen smallholder farmers' respondents.

3.3.4 Participatory process: Understanding a seasonal climate forecast

The third objective of this study was to determine farmers' barriers and enablers towards increased uptake of climate information was achieved through the presentation of a seasonal climate forecast sample. Similar to Kumar *et al.* (2021) uptake of climate information is defined as access to and use of climate information services in agricultural decision-making. A seasonal climate forecast sample was presented to commercial and smallholder farmers during the interviews (see Appendix 6). The seasonal climate forecasts sample was created with the assistance of a seasonal climate forecast modeller at UCT-CSAG and it included two maps for above-normal and below-normal rainfall for the April-May-June rainfall season. The farmers were informed that the seasonal climate forecast was merely an example created for research purposes and not an official forecast. The purpose of using the farmer-researcher participatory approach allowed the researcher to collect data on farmers' ability to interpret and understand a seasonal climate forecasts and identify any barriers farmers experience in using a seasonal climate forecast. Additionally, farmers' biographical information was collected to better understand the farmers.

When the seasonal climate forecast sample was presented, each farmer was asked to identify the location of their farm within the regions and interpret the probability of rainfall that their farm region falls under on the above-normal and below-normal maps. Following this, farmers were asked to comment on the accuracy of the seasonal climate forecast and asked what decisions they would make following the reception of a seasonal climate forecast.

3.4 Data analysis

3.4.1 Interviews

The collected audio-recorded data from the seasonal climate forecast provider and the two agricultural advisors' interviews were organised and transcribed in Microsoft Word and the results were presented in tables and graphs in Microsoft Excel. The collected audio-recorded data such as the farmer interviews in Afrikaans were translated to English and transcribed by MMJ Solutions while the farmer interviews in Xhosa were translated to English and transcribed by the researcher. The transcribed and audio-recorded responses were collected and organised into one location and converted into applicable formats. This provided an opportunity to set up the data so that it could be imported into the qualitative data analysis software package, NVivo. The advantage of using this software is that it provides the opportunity to work with a range of data formats including text and both categorical and qualitative surveys. The third phase of analysis was generating memos from the transcripts; this was done to describe initial reflections about the data. Thereafter, the data was coded. A code is described as a short, descriptive word or phrase that assigns meaning to the data (Braun and Clarke, 2006). This study used the deductive approach which is data-driven and has formulated theories about the data. Therefore, the coding was conducted with specific questions in mind and identified particular features in the data set (Braun and Clarke, 2006; Busetto, Wick and Gumbinger, 2020; Lester, Cho and Lochmiller, 2020). The codes were then used to formulate the thematic framework which provided the main themes identified in the data and provided a descriptive theory of the pattern under investigation (see Appendix 7). The coded data were then analysed in Microsoft Excel using frequency distribution and the results were presented in tables and graphs.

Chapter 4: Results and Discussion

4.1 Climate risks experienced by farmers

The results for climate risks observed by smallholder and commercial farmers in the past 10 years are summarised in Figure 2 and 3. All interviewees (n = 26) were aware of climate change and attributed the local climatic events they experienced within the past 10 years to global climate change and variability. The most prevalent climate risks observed by smallholder farmers were increased rainfall (54%), rainfall seasonality (46%), stronger winds (31%) and increased temperature (31%). A few smallholder farmers reported observations of droughts (8%), and none observed changes in decreased rainfall and rainfall intensity. The dominant climate risks among commercial farmers were a decrease in rainfall (62%), floods (46%), increased temperature (31%) and rainfall intensity (31%). The farmers in Moorreesburg and Caledon reported that the two areas experienced intense rainfall during the month of May which may have influenced the high response of floods and rainfall intensity. None of the commercial farmers reported observations of a decreased temperature, rainfall seasonality and increased rainfall. Figures 2 and 3 present the responses made by smallholder and commercial farmers respectively on climate risks they had observed in the past 10 years.

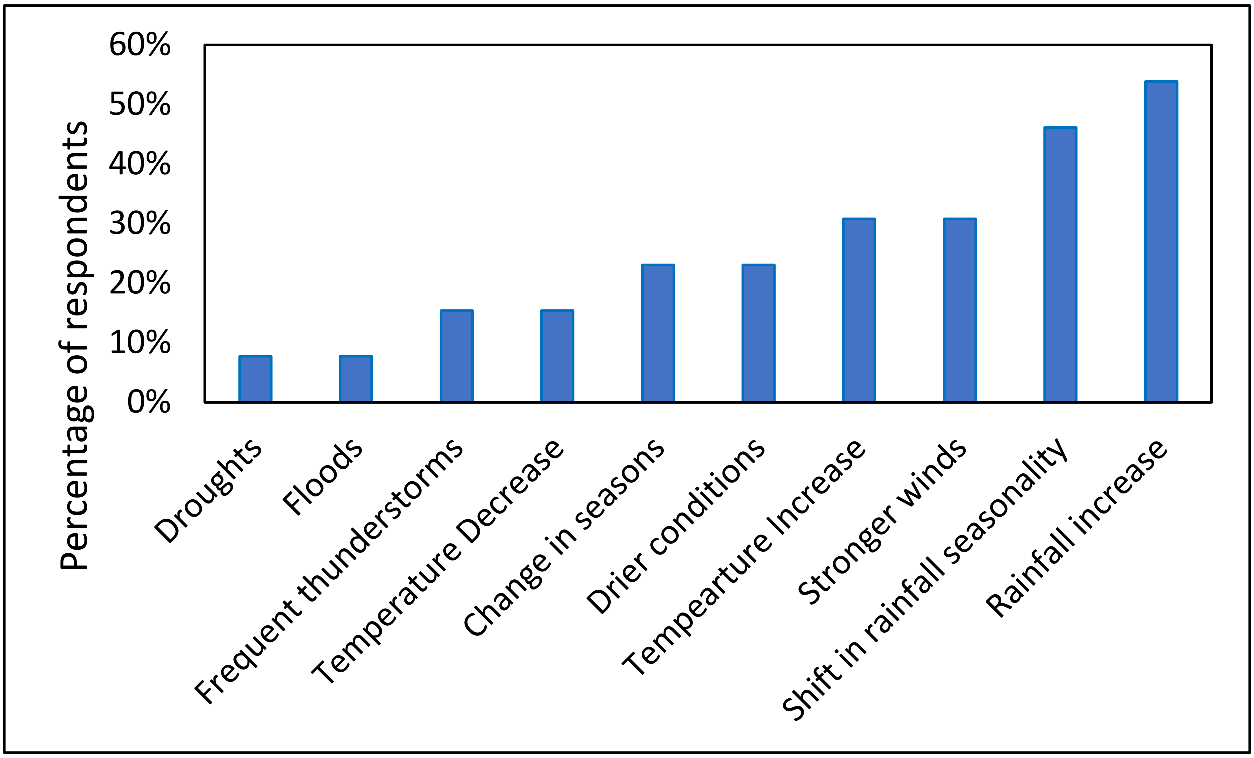

Figure 2: Climate risks observed by smallholder farmers

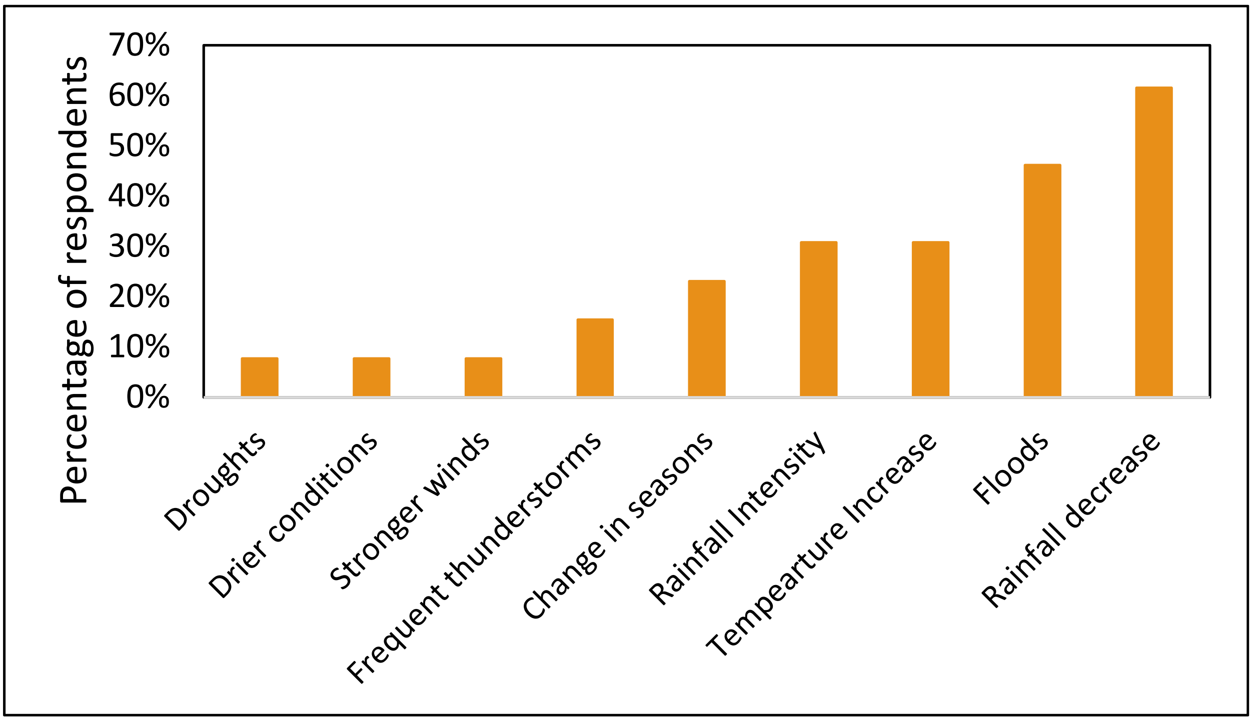

Figure 3: Climate risks observed by commercial farmers

4.2 Farmers' adaptation alternatives in response to observed climate risks

The adaptation strategies varied among smallholder and commercial farmers with soil and water conservation practices (85%) with the highest response among commercial farmers. This was an indication that commercial farmers have knowledge of using conservation agriculture as adaptation mechanisms to climate risks. The second dominant adaptation strategies among commercial farmers were practice and behavioural responses (31%). These responses included using adaptive crops and changing planting time. Most smallholder farmers (69%) reported not using any adaptation strategies to respond to climate risks. These farmers all shared the same sentiments about lacking knowledge of strategies they can use to cope. 23% of smallholder farmers reported using practice and behavioural responses. In terms of using information and research (weather forecasts) to cope, only 8% of smallholder farmers reported this and none of the commercial farmers use the information and research strategies to cope. The low response rates of smallholder farmers (0%) using warning and observation systems and commercial farmers (8%) using climate information implies that the usage of forecasting systems and climate information as an adaptation strategy to climate risks is relatively poor among farmers. Table 1 represents the types of adaptation strategies used by smallholder and commercial farmers and the different categories they are classified under. Figure 4 shows the adaptation strategies employed by smallholder and commercial farmers to respond to climate risks.

Table 1: Adaptation strategies used by smallholder and commercial farmers

Categories	Types of adaptation strategies
Information & Research	• Use climate information (weather forecasts)
Warning & observation systems	• Drought forecasting • Seasonal climate forecasts
Practice & behavioural responses	• Adaptive crops • Changing planting timing
Soil & water conservation practices	• Mulching • Crop diversification & rotation • Minimum/no-tillage
Policy & Institutional	• Increasing extension support

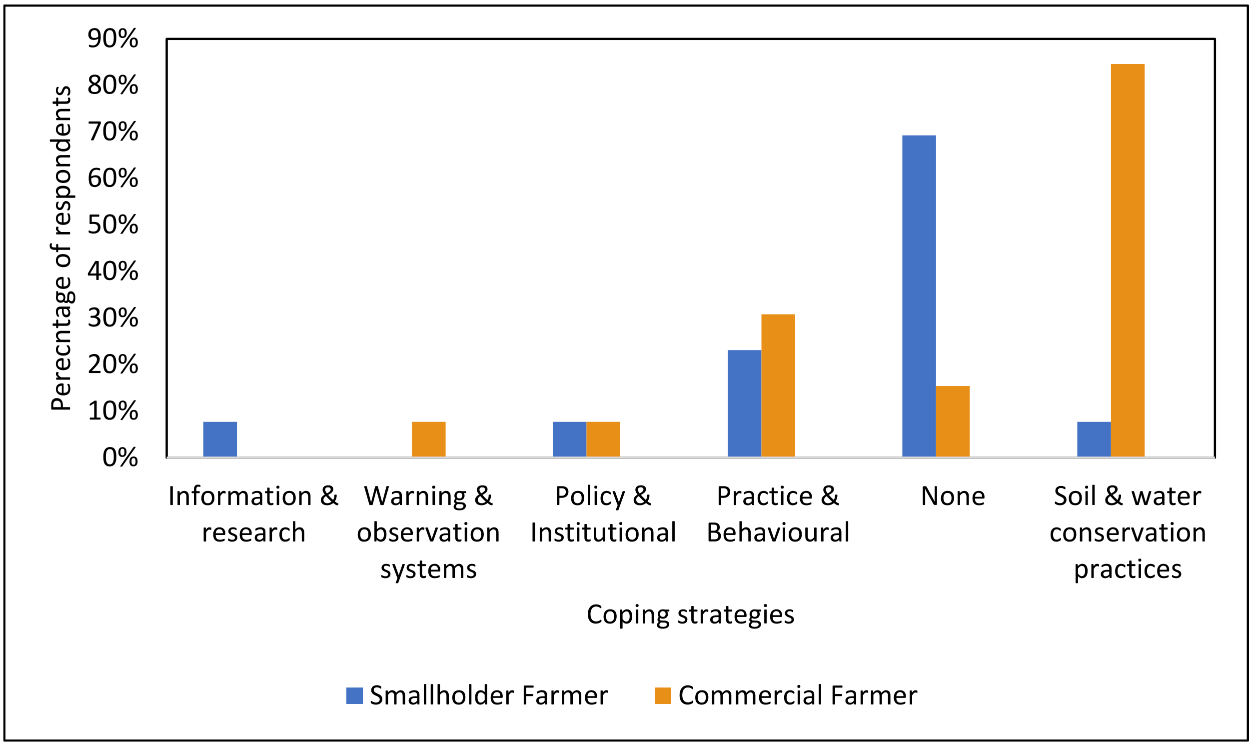

Figure 4: Adaptation strategies used by smallholder and commercial farmers

4.3 Access to climate information

Only 8% (n=13) of smallholder farmers reported not having access to any climate information and a majority have access to the weather forecast (92%). In contrast all the interviewed commercial farmers (n=13) reported having access to some kind of climate information. A majority of commercial farmers have access to weather forecasts (38%) followed by access to seasonal climate forecasts (31%). 23% have access to historical climate information and 8% have access to indigenous knowledge. The 92% of smallholder farmers with access to weather forecasts access it via broadcast media (Television and radio) and smartphone weather App (AccuWeather) while commercial farmers who have access to weather forecast accessed it through broadcast media, print media (newspapers), internet using smartphone weather Apps (AccuWeather, Yr, Windy and Ventusky) and South Africa Weather Services and agricultural advisory platforms like Overberg Agri, Santam and academic research institution (University of Pretoria and UCT's Climate System Analysis Group). The extracted quotations below show the differences in access to climate information among smallholders and commercial farmers. Figure 5 below presents farmers' responses to the climate information they have access to.

Question: What type of climate information do you have access to?

Smallholder farmer, participant 4: *"I have access to the televised weather forecast"*

Commercial farmer, participant 2: *"Okay so there are different websites that we use, Yr is one of them that we use, and we have got AccuWeather. There is a guy, Phil Hugo, I will just ask Jacque if I have got his name right, it is on Overberg Agri's server, he is quite accurate, and he is weather, that is what he does, his life, he lives weather, so he does it for across the whole country. So ja, he is quite accurate, so we use him as well, AccuWeather and Yr, but there are a lot of weather stations you can use, not all of them are accurate then, so we try and look for the one that is the most accurate, so we use two or three of them, just to be sure, I mean we compare them to each other.*

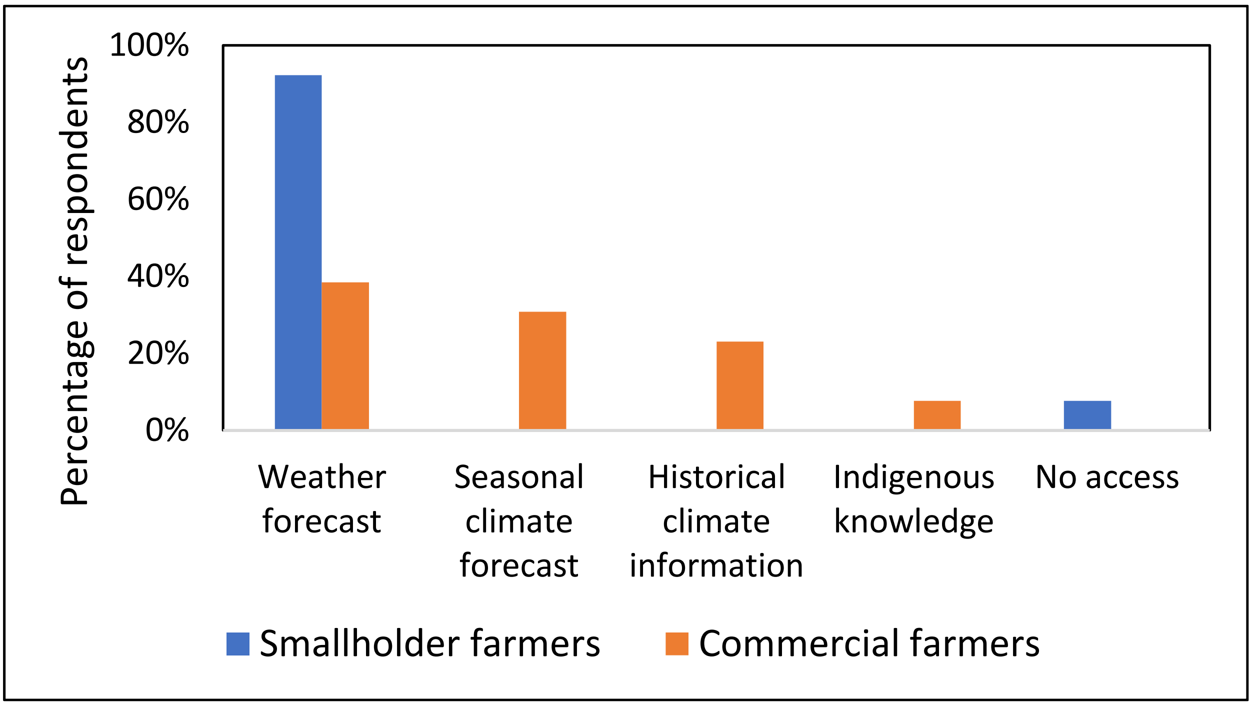

Figure 5: Climate information accessed by smallholder and commercial farmers

4.4 Awareness of seasonal climate forecasts

Figure 6 below displays farmers' response to awareness of seasonal climate forecast. In the context of this study, awareness meant having knowledge of what a seasonal climate forecast is. A majority of smallholder farmers (54%) had no knowledge of seasonal climate forecasts, 31% were knowledgeable and 15% did not respond. In comparison, an extremely high percentage, 85% of commercial reported having knowledge of seasonal climate forecasts, 15% did not respond and none of the commercial farmers reported no knowledge. The results display a significant contrast in terms of seasonal climate forecast awareness which highlights the difference in knowledge of the provision of science-based knowledge and research. Figure 6 presents farmers' responses to seasonal climate forecast awareness.

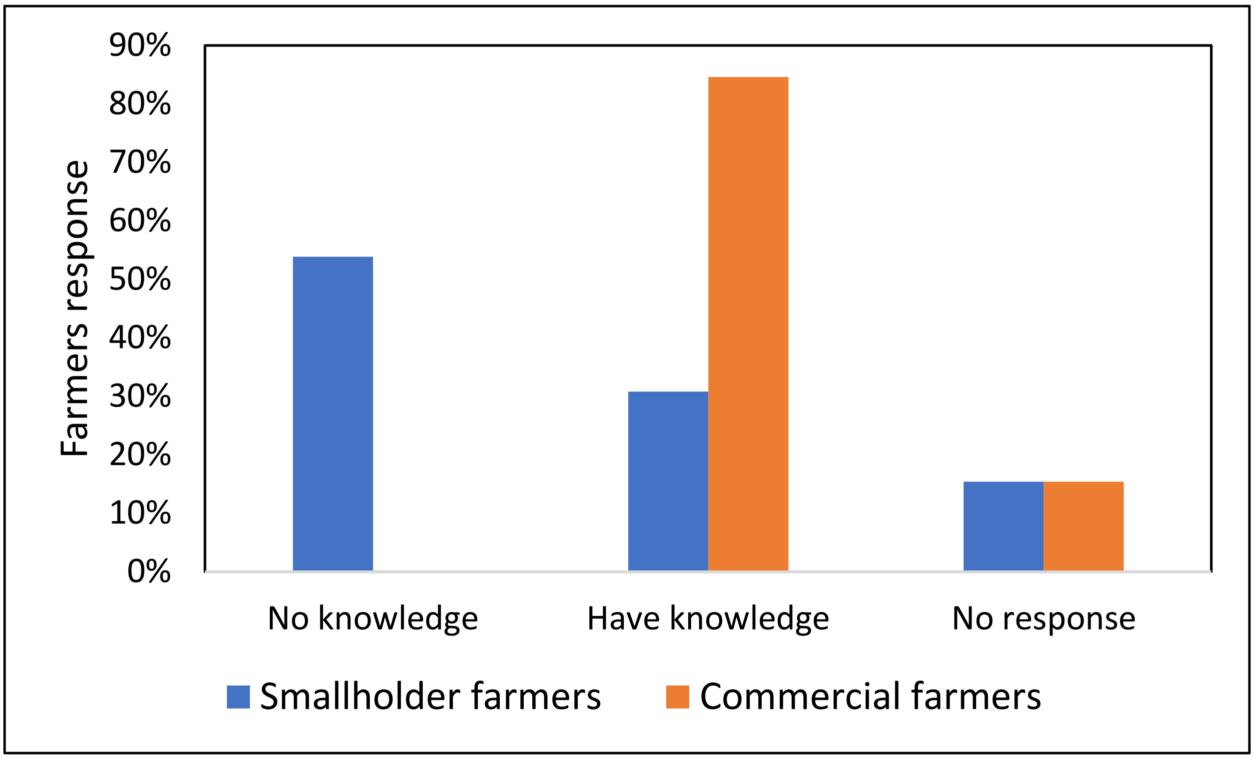

Figure 6: Farmers' awareness of seasonal climate forecasts

4.5 Use of seasonal climate forecasts

Farmers' response to using seasonal climate forecasts is presented in Table 2. Out of the 31% of smallholder farmers who reported awareness of seasonal climate forecasts, 23% reported using seasonal climate forecasts while 8% reported not using seasonal climate forecasts. It was realised, during the interviews that the smallholder farmers who reported using seasonal climate forecasts used the terms seasonal forecast and weather forecast interchangeably because they thought these two were the same. While 46% of commercial farmers reported using seasonal climate forecasts and 54% of farmers reported not using seasonal climate forecasts.

The commercial farmers who reported using seasonal climate forecasts mentioned making important agricultural decisions such as cultivar and crop selection, deciding on the timing of planting, fertiliser application period and during harvest. The farmers who reported not using seasonal climate forecasts for farming decisions mentioned that they stick to planting time and rarely move this based on a seasonal climate forecast. They felt that seasonal climate forecasts are not always accurate and therefore making decisions based on them could be a huge financial risk.

Table 2: Percentage of farmers using seasonal climate forecasts

Use of seasonal climate forecasts	Smallholder farmers All samples (n=13)	Commercial farmers All samples (n=13)
Yes	3 (23%)	6 (46%)
No	1 (8%)	7 (54%)

4.6 Barriers and enablers to seasonal climate forecasts

During the interviews, an example of a seasonal forecast was presented and included as Appendix 6. Through this exercise, farmers were asked, “What might be the challenges that you face in using a seasonal climate forecast?” A majority of farmers referred to a number of barriers, the most important barriers mentioned by smallholder farmers included incomprehensibility (not easy to understand,28%), lack of knowledge (17%), delivery medium of seasonal climate forecasts (11%) and lack of trust (11%). Additional barriers included the accuracy of seasonal climate forecasts (6%) and language (6%). Among commercial farmers, 25% pointed to the accuracy of seasonal climate forecasts, uncertainty (20%), and incomprehensibility (not easy to understand, 15%). Other barriers cited by commercial farmers included delivery medium (10%), lack of trust (10%) and language (5%).

When farmers were asked what enablers influence their decision to use seasonal climate forecasts, a majority of the famers, both commercial and smallholder alluded to networks as an essential factor in overcoming the barriers of knowledge access, adding to knowledge accumulation. The networks mentioned were the local farmer groups and agricultural co-orps such as GrainSA and Overberg Agri. There were a number of ways in which GrainSA, and Overberg Agri provided support to the farmers. According to the farmers, these included assisting with the purchase of certified seeds and fertilizer, conducting farm trials on new seed varieties and training farmers with agronomic practices. Additionally, the smallholder farmers mentioned support for farm implements such as a tractor which is received from the Department of Agriculture, Fisheries and Forestry.

4.7 Discussion

4.7.1 Climate risks and implemented adaptation strategies

All interviewed farmers were aware of climate change. The reported climate risks included increased rainfall and a shift in rainfall seasonality which were observed by 54% and 46% of smallholder farmers respectively. Other observed climate risks included droughts, and rainfall intensity observed by 31% of commercial farmers. Both smallholder and commercial farmers expressed the same opinion regarding the effects of increased rainfall and floods on their farms. One smallholder farmer cited that excessive rainfall causes the maize to rot. The commercial farmers mostly mentioned comprised wheat quality which leads to decreased yield and negative effects financially. The rainfall intensity reported by commercial farmers (31%) was influenced by a recent event and was not necessarily a long-term observation.

The identified climatic events identified by the framers in this study coincide with literature regarding projected climate change for South Africa. These include higher temperatures, altered precipitation patterns and more intense extreme weather events including droughts and floods (DEDEA, 2011). The Eastern Cape is expected to experience the highest temperature increases towards the north-west interior while coastal areas display the lowest increases. The increased temperatures will result in increased intensity of droughts. In terms of future projections for precipitation, stable or slightly increasing precipitation with increasing intensity more likely in the east is expected (DEDEA, 2011). Projections for Western Cape include a drying trend from west to east with decreasing winter precipitation, a shift to regular rainfall and rising temperatures (Midgely, 2005). Late summer increases in precipitation in the interior and to the east. The southwest winter rain is likely to shorten (Midgely, 2005).

Many of the farmers acknowledged the risk of climate change and as such implemented adaptation strategies to respond to the changing climate. The responses made by the farmers revealed that some farmers, mostly commercial, used adaptation strategies. A wide range of adaptation strategies were implemented but the most mentioned among 85% of commercial farmers aimed to conserve soil and water. For example, one farmer mentioned using minimum/no-tillage farming, crop diversification, rotation, and mulching. The other common strategy was practice and behavioural responses, used by 31% of commercial farmers. This strategy involves changing planting timing and using adaptive crops. Another commercial farmer (Participant 1) cited that using the same crop varieties in a changing climate would result in crop failure. He further added that it is important to adapt to the challenges you face as a farmer, he has shifted to planting quicker maturing wheat. In contrast, only 23% of smallholder farmers use practice and behavioural response. Most smallholder farmers (69%) mentioned they do not use any adaptation strategies to respond to climate risks. These farmers mentioned a lack of knowledge, local soil composition and lack of financial capabilities. One smallholder farmer (Participant 1) mentioned that sorghum and taro (potato of the tropics) are some of the climate-tolerant crops and would survive under dry and hot conditions. However, they do not have the financial means to purchase seeds. The other adaptation strategies, information and research, warning and observation systems and policy and institutional responses were low for both smallholder and commercial farmers.

Modifying farming practices is one of the responses to try and maintain agricultural production levels in the changing climate (Vincent *et al.*, 2013). The strategies implemented by the farmers in this study can be identified as both long-term coping strategies because they aim to reduce people's vulnerability to adverse effects of climate change (Assan *et al.*, 2018). From the results, majority of the smallholder farmers lack knowledge of adaptation strategies compared to commercial farmers. These findings are supported by Maponya and Mpandeli (2012) and Maponya, Mpandeli and Oduniyi (2013)'s views, that smallholder farmers struggle to adapt to the rapidly changing climate due to challenges of lack of land, illiteracy, lack of skills, limited access to resources, inability to detect the occurrence of extreme hydrological and meteorological events due to low technology adoption and lack of awareness. A farmer's ability to effectively cope and adapt to climate change is influenced by the level of knowledge as inferred by (Bello *et al.*, 2013). The low response of using policy and institutional responses as an adaptation strategy indicates that more farmers need to be exposed to extension services for awareness of climate change adaptation. Similarly, using climate information increases the awareness levels and adaptive capacity of farmers (Dinku et al., 2015; Vogel, Steynor and Manyuchi, 2019) Furthermore, extension support increases a farmer's chances of taking up adaptation strategies (Bello *et al.*, 2013). This is because farmers with extension support have better chances of being aware of climatic conditions, educational training and management practices (Bello *et al.*, 2013; Nkeme and Ndaeyo, 2013; Ubisi *et al.*, 2017).

4.7.2 The landscape of farmers access to climate information

In this study, climate information refers to all data relating to historical information, current weather information, forecast information and traditional knowledge that farmers use in their daily farming and planning. The interviews with farmers revealed that weather forecast is the most accessible type of climate information compared to the others, seasonal forecasts, historical information, and traditional knowledge. This was reflected by the 92% of smallholder farmers and 38% of commercial farmers who admitted to having access. Additionally, the results revealed that accessibility to climate information differs among smallholder and commercial farmers, with most smallholder farmers having access to only weather forecasts and some having no access to any climate information. In contrast, commercial farmers have access to several types of climate information such as weather forecasts with 38% of commercial farmers with access to this type of climate information), 31% with access to seasonal forecasts, 23% with access to historical information, and only 8% with access to traditional knowledge. When farmers were asked how they access climate information, smallholder farmers mostly mentioned broadcast media (Tv and radio) and smartphone Apps whereas commercial farmers mentioned broadcast and print media (Tv, radio and newspapers), smartphone Apps and agricultural advisories.

The findings of this study highlight the existing difference in relation to the accessibility of climate information among interviewed smallholder and commercial farmers. The quoted extracts below present evidence of this.

Smallholder farmer, participant 2: "*We have no way of knowing this beforehand which affects us badly when it comes to planting be it with maize, butternut, cabbage, beans. We never know when it will rain or when we will have droughts"*

Commercial farmer, participant 2: "*Okay so there are different websites that we use, Yr is one of them and we have got AccuWeather, there is a guy, Phil Hugo, I will just ask Jacque if I have got his name right, it is on Agri's server(Overberg Agri), he is quite accurate, and he is weather, that is what he does, he lives weather, so he does it for across the whole country. So, he is quite accurate, so we use him as well, AccuWeather and Yr, but there are a lot of weather stations you can use, not all of them are accurate then, so we try and look for the one that is the most accurate, so we use two or three of them, just to be sure, I mean we compare them to each other."*

The revelation of broadcast media as the major channel used by farmers to access climate information gives an indication that media can still play a crucial role in the dissemination of climate information than extension services as inferred by (Popoola, Yusuf and Monde, 2020) in their investigation of information sources and constraints to smallholder farmers' adaptation to climate change in Amathole District Municipality, Eastern Cape Province, South Africa.

4.7.3 Use of seasonal climate forecast for agricultural decision making

The results show three findings. First, that only a portion (46%) of commercial farmers use seasonal climate forecasts. The type of decisions these commercial farmers made after receiving a seasonal climate forecast are agricultural management decisions which is exemplified by the response provided by the interviewed seasonal climate forecast provider who cited that information received before the season helps them deduce which cultivar to plant, either plant short season cultivar or long-term season cultivar. They may also decide on fertilizer options which require rain because it increases yield, and together with fertilizer are chemicals which they may want to apply (pesticides, herbicides). Thirdly, they decide on input decisions like implements, if they plant less than they do not plan for a lot of costs on harvesting and weeding and tilling. So, if they are renting equipment, there is a reduction in costs but if they own their own equipment then they do not use it and lend those to other farmers. It is also worth noting that the decisions taken after the reception of seasonal climate forecasts are decisions also available to knowledgeable smallholder farmers.

The second finding from the results further conveys that the use of seasonal climate forecasts in decision-making among commercial farmers is subjective and that awareness does not always lead to the use of seasonal climate forecasts. The decision to use a seasonal climate forecast to guide agricultural decision-making is dependent on a farmer's perception of seasonal climate forecasts and the farmer's goal. This was revealed when other commercial farmers reported that even though they can understand and interpret the information contained in a seasonal climate forecast, they stuck to their normal planting timing and this decision was not influenced or shifted due to information received from a seasonal climate forecast.

Thirdly, smallholder farmers have limited access to financial resources and lack of access to enable them to make appropriate decisions. The decisions taken after the reception of a seasonal climate forecast may be linked to using adaptive crops which do not favour the smallholder farmer's financial resources. This finding is supported by Popoola, Yusuf and Monde, (2020) where they found that the smallholder farming sector is especially faced with the challenges of having to cope with and/or adapt to changing climate conditions as they are at a more disadvantaged position due to multiple factors one of which is their lack of access to agricultural information.

4.7.4 Barriers and enablers to the uptake of seasonal climate forecasts

The results of the interviews revealed several key barriers that limit the use of seasonal forecasts among smallholder and commercial farmers. This study classified the reported as cognitive and behavioural barriers and technical/product-related barriers. Of the behavioural and individual barriers, lack of knowledge on seasonal climate forecasts was reported by smallholder farmers only which highlights the difference that exists among the two groups of farmers in terms of access to resources and information. Lack of trust and accuracy as cognitive and behavioural barriers was revealed in three diverse ways. Firstly, a few commercial farmers attributed this barrier to their past experiences where the seasonal climate forecast gave incorrect predictions. Secondly, when one commercial farmer (Participant 2) reported using historical rainfall data. This conveyed dispositional change where the farmer cited trusting a familiar source of information over seasonal climate forecasts and resistance to change. Thirdly, one commercial farmer (Participant 7) reported that to overcome the lack of trust barrier, a post-season analysis of what the pre-season predictions were would be beneficial to farmers.

Technical/product-related barriers such as language and understandability of seasonal climate forecasts were reported by both smallholder and commercial farmers with farmers citing that the terminology used is too complex to understand. Some smallholder farmers mentioned that seasonal climate forecasts would be essential when communicated in the local language of IsiXhosa. The delivery of seasonal climate forecasts as a technical/product-related barrier was attributed to the channels used to disseminate the seasonal climate forecasts. These channels are not easily accessible to all farmers. Uncertainty as a technical/product-related barrier was associated with the probabilistic information contained in seasonal climate forecasts and farmers do not always know what the probabilities mean and often misinterpret them.

The main enablers identified by both groups of farmers were largely related to networks at a farmer's disposal as well as ongoing relationships with knowledgeable scientists and seasonal climate forecast producers. These two sources assist in knowledge accumulation. These findings are supported by Bruno Soares and Dessai (2016) and Spires and Shackleton (2018) in their views of enabling factors that increase climate information uptake.

Chapter 5: Conclusion

5.1 Introduction

The aim of this study was to assess the impact of climate services in informing farmers' agricultural decisions towards better uptake and use of climate information among commercial and smallholder farmers. It employed a three-way type of engagement with commercial and smallholder farmers, seasonal climate forecast producers and agricultural advisors through face-to-face interviews. The interview questions for the seasonal climate forecast provider and agricultural advisors were used to obtain information on the rate of access to and use of climate services, particularly seasonal climate forecasts and extension support and engagement between farmers and agricultural advisors. The farmer interview questions were designed to elicit farmers' views on climate risks, access to and use of climate services particularly the use of seasonal climate forecasts in agricultural decision-making. A farmer-researcher participatory approach was used to determine farmers' barriers and enablers to climate information uptake. These provided inputs for qualitative analysis. Using this evidence this study: (i) investigated the various types of climate services produced in South Africa, (ii) assessed current access and use of climate services under the different farming systems (commercial and smallholder) and the efficiency of these services in informing agricultural decisions and (ii) determined farmers' barriers and enablers towards increased uptake of climate information.

5.2 Key findings

Based on the results of the objectives of this study the following conclusions were made.

To accomplish the first objective, a seasonal climate forecast producer and agricultural advisers were interviewed for information on the current state of climate services. The findings showed that although commercial and smallholder farmers interact with climate services in numerous ways, they are mostly curious about how the season would be. From a seasonal climate forecast producer's perspective, farmers do use seasonal climate forecasts. However, they find them complicated and will often use them in conjunction with other information at their disposal. The seasonal climate forecast producer emphasised that the active monitoring of the perceived value of seasonal climate forecasts among farmers through constant engagement would bridge the gap of disconnection of information. He further added that this would require an intermediary with local knowledge of agriculture in addition to climate information. Farmers also have Agri businesses (Santam, Overberg Agri and GrainSA) providing advisory services and products to them. In addition to advisory services, smallholder farmers in the study have support from agricultural extension officers from the Department of Agriculture assisting with implements.

To achieve the second objective of this study, commercial and smallholder farmers were interviewed. The literature illustrates that the agricultural sector must play a substantial role in mitigating and adapting to the effects of climate change (Vuren *et al.*, 2009). Therefore, it is crucial to better understand farmers' perspectives on climate change, their adaptation strategies and the factors that influence their choice to adapt farming practices (Bryan *et al.*, 2009). This was evaluated in the current study to better understand the driving forces and hunger for using climate data. Many of the interviewed farmers acknowledged the risk of climate change and as such implemented adaptation strategies to respond to the changing climate. The strategies implemented by the farmers in this study can be identified as both long-term adaptation strategies because they aim to reduce people’s vulnerability to the adverse effects of climate change. Particular strategies that came up in this study included no-tillage, changing planting time, using adaptive crops, using climate information, using forecasting systems and increasing extension support. The low response rate of smallholder farmers (0%) using warning and observation systems suggests that the usage of forecasting systems as an adaptation strategy to climate risks is relatively poor. Similarly, the low rate of 8% of commercial farmers using climate information suggests the relatively poor use of climate information as an adaptation strategy. However, the access to climate services differed, commercial farmers have access to the weather forecast, seasonal climate forecasts and indigenous knowledge. In contrast, smallholder farmers’ access to weather forecasts was limited, via broadcast media and smartphone Apps (AccuWeather).

Furthermore, farmers were asked about the type of climate information they use to inform their agricultural decisions. The use of warning and observation systems, particularly seasonal climate forecasts, was poor due to smallholder farmers' lack of access to and awareness of seasonal climate forecasts and commercial farmers' lack of trust in them, their limited comprehension, and their cognitive resistance to them. As a result, seasonal climate forecasts were not used as effectively as they could have been. The type of decisions taken by commercial farmers after receiving a seasonal climate forecast are agricultural management decisions, such as deciding on a cultivar to plant, either a short-season cultivar or a long-term season cultivar, fertilizer options, and input decisions like implements. Evidently, seasonal climate forecast use among commercial farmers is subjective, and awareness of seasonal climate forecasts does not always lead to use. The decision to use a seasonal climate forecast is based on a farmer's perception of the usefulness of seasonal climate forecasts and goals. The smallholder farmers have limited financial resources, which constrains their ability to make appropriate decisions. The decision after receiving a seasonal climate forecast might be linked to using adaptive crops that do not favour their financial means, leaving them faced with the challenge of not adapting to the changing climate.

To achieve the third objective of this study, an example of a seasonal climate forecast was presented to commercial and smallholder farmers, and they were asked to interpret the information on it. The purpose of this was to determine how seasonal climate forecasts could be improved and presented more effectively for better uptake. The results of the interviews revealed several key barriers that limit commercial and smallholder farmers from using seasonal climate forecasts. This study classified these barriers as cognitive and behavioural and technical/product-related barriers. Out of the behavioural and individual barriers, the lack of knowledge on seasonal climate forecasts was reported by smallholder farmers only which highlights the difference that exists among the two groups of farmers in terms of access to resources and information. Among commercial farmers, cognitive and behavioural barriers such as lack of trust and accuracy were revealed in three diverse ways. Firstly, a few commercial farmers attributed this barrier to their past experiences where the seasonal climate forecast gave incorrect predictions. Secondly, when one commercial farmer reported using historical rainfall data which conveyed dispositional change where the farmer cited trusting a familiar source of information over seasonal climate forecasts and resistance to change. Thirdly, a commercial farmer noted that to overcome the lack of trust barrier, a post-season analysis of what the pre-season predictions were would be beneficial to farmers. Additionally, under technical/product-related barriers uptake was constrained by the following, farmers not understanding seasonal climate forecast probabilities, the complex visual presentation of seasonal climate forecasts, issues with accuracy and uncertainty and the communication channels used. Engagement with seasonal climate forecast producers and knowledge and resource capacity were all identified in this study as the enablers to using seasonal climate forecasts.

5.3 Importance of this study

Agriculture is an economic activity that is reliant on climate for its success (Yohannes, 2016). In developing countries, it is a fundamental provider of employment and livelihoods hence food security, productivity and livelihoods will be impacted by the effects of climate change (Yohannes, 2016). The agriculture sector in South Africa contributes significantly by meeting essential human requirements including food, employment, and strong economic linkages (National Department of

Agriculture, 2001). Maize, wheat, sugar cane, and sorghum are the main crops, while groundnuts, sunflowers, dry beans, tobacco, and potatoes are minor ones. Apples, pears, grapes, peaches, and dried fruits are significant fruits (Benhin, 2006). As a result, because South Africa is the region's primary source of food, the negative consequences of climate change there would have an effect on both the nation and the southern African region (Benhin, 2006).

This study highlighted the limited interaction between climate information institutions, agricultural advisories, extension officers and farmers. It emphasised the significance of institutions and government in implementing climate adaptation among farmers by providing climate change support programmes. It recommends increasing engagement by doing post-season analysis to address issues pertaining to engagement, feedback, trust and motivation amongst farmer end-users and seasonal climate producers. The study further indicated the ways in which South Africa’s dual agricultural sector differs when it comes to development as well as the different challenges faced by commercial and smallholder farmers. It provided evidence of how farmers’ access to, use and uptake of climate information can be improved. Firstly, by providing training on seasonal climate forecast interpretation to address the issue of awareness among smallholder farmers. Secondly, expanding access to climate information by using a combination of dissemination channels (radio, face-to-face dialogues) and exploring using extension services or membership associations (GrainSA and Overberg). Lastly, the identified barriers and enablers experienced by farmers when using seasonal climate forecasts could contribute to an improved seasonal climate forecast format that farmers can understand and find useful.

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Appendix 1: Ethical clearance

UNIVERSITY OF CAPE TOWN
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22 September 2021

Sinazo Nyudwana
Department of Environmental and Geographical Science

Investigating the impact of climate services on farmers' livelihood, food security, and agricultural development towards the better uptake (and use) of climate information.

Dear Sinazo Nyudwana

I am pleased to inform you that the Faculty of Science Research Ethics Committee has approved the above-named application for research ethics clearance, subject to the conditions listed below.

- Permission is given for in-person research.
- The applicant is requested to secure the permission of the department COVID-19 Compliance Officer and the Head of Department prior to commencing any in-person fieldwork.
- Restrictions on involving human participants in research must be adhered to, given current concerns about the spread of Covid-19. Please ensure that you are aware of and comply with UCT policy on this, as communicated by management.
- Implement the measures described in your application to ensure that the process of your research is ethically sound; and
- Uphold ethical principles throughout all stages of the research, responding appropriately to unanticipated issues: please contact me if you need advice on ethical issues that arise.

Your approval code is: **FSREC 064 – 2021**

I wish you success in your research.

Yours sincerely

Dr Melissa Densmore
Acting Chair: Faculty of Science Research Ethics Committee

Appendix 2: Questionnaire for seasonal climate forecast producer

DEPARTMENT OF ENVIRONMENTAL & GEOGRAPHICAL SCIENCE

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Project Title Investigating the impact of climate services on farmers' agricultural development towards the better uptake (and use) of climate information.

Questions:

1. What climate services products are available for end users and why are these products used?
    - Are farmer end-users able to act on information provided? Why/Why not?
2. As a seasonal forecast disseminator, what kind of farmer end-user problems or decisions do you try to address when creating climate services?
3. What prior research do climate services producers conduct to understand the needs of farmer end-users?
4. Would you, in your knowledge, say a climate service producer like SAWS uses agricultural extension officers to conduct the research in understanding farmer needs?
5. Is there an active procedure of monitoring, evaluation, and learning to enable reflection on the process for modification of the service?
6. Do you think if there was an active procedure to constantly monitor farmers' perception of seasonal forecast it would bridge the gap of the disconnection of information?
7. How confident are you in your skill of interpreting seasonal forecasts (SF)?

Appendix 3: Questionnaire for agricultural advisor

DEPARTMENT OF ENVIRONMENTAL & GEOGRAPHICAL SCIENCE

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Project Title Investigating the impact of climate services on farmers' agricultural development towards the better uptake (and use) of climate information.

Questions:

1. What is Overberg Agri?
2. What services does Overberg Agri offer to farmers and what is your role as an agricultural advisor?
3. What climate related issues are mostly a challenge to farmers?
4. Which strategies does Overberg Agri assist the farmers with to overcome these challenges?
5. What type of climate or weather information does Overberg Agri have access to?
6. Given the risks that you are aware of, that farmers experience in terms of managing climate related issues, what knowledge and experience do you as an advisor then bring to ensure that farmers make effective decisions in managing those risks?
7. The interviewed farmers mentioned using Overberg Agri site as a source of weather information, is there a plan in place that monitors the rate of access and use of the website information?
8. In your opinion, what additional information do you think would be useful for the Caledon and Moorreesburg community in making decisions and maybe on your side, as an agricultural advisor, what additional information do you think you would need to make your job effective to farmers?

Appendix 4: Questionnaire for commercial farmers

DEPARTMENT OF ENVIRONMENTAL & GEOGRAPHICAL SCIENCE

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Project Title Investigating the impact of climate services on farmers' agricultural development towards the better uptake (and use) of climate information.

Crop farmers perception on climate change and seasonal forecasts:

1. Have you seen any changes in the climate over the past 10 years? If so, please describe them

2. No, I have not seen any changes in the climate over the past 10 years. Please elaborate

Probing questions:

- What do you think of the recent climate patterns?
- What effect have these climate changes had on your farm?

Climate risk and strategies used:

3. Which of the below listed strategies do you use to overcome climate/weather related issues?

Information & research

Warning & observation systems

Practice & behavioural responses

Policy & institutional

Other

Probing questions

- What risks do you face in trying to manage climate/weather related issues?

Access to climate services: seasonal forecast:

4. What type of climate/weather information do you have access to?

Probing questions

- How is this information accessed?

Use of climate services and seasonal forecast outputs:

5. Do you use seasonal forecasts for any decisions? If so, explain how

Probing questions

- What has been your experience using seasonal forecasts (SCF)?

6. Do other farmers (farmers' association, social circle) influence your decision/s to use climate services/seasonal climate forecasts (SCF)?

7. If yes, is it the decision to use services or general farming decisions?

Probing questions

- How do the other farmers influence your decision?

Efficiency of climate services and seasonal forecasts:

8. What are the impacts of using seasonal forecasts?

Probing questions

- How do the seasonal climate forecasts (SCF) help you perform your job?
- What might motivate you to continue using seasonal climate forecasts (SCF)?
- How certain of the results are you when using the seasonal climate forecast (SCF)?

9. Please elaborate on the accuracy of the seasonal forecast

Probing questions

- How easy are seasonal forecasts to interpret and understand?

10. What might be the challenges and difficulties that you face in using climate services/SCF?

Biographical information:

1. Number of years as a farmer:

2. In which district/geographical location is your farm located?

3. Do you have other farming activities/businesses in this or other districts?

4. How many tons per hectare is your farm?

Appendix 5: Questionnaire for smallholder farmers

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Project Title Investigating the impact of climate services on farmers' agricultural development towards the better uptake (and use) of climate information.

Izimvo zabelimi bezityalo malunga noqikelelo lwemozulu:

1. Ingaba lukhona na utshintsho oluphawuleyo kwimozulu kwiminyaka elishumi edluleyo? Ukuba ngaba lukhona, nceda uchaze
2. Hayi, akukho tshintsho ndiluphawuleyo kwiminyaka elishumi edluleyo. Nceda unikise ngengcazelo ethe vetshe

Imibuzo yokuvavanya:

- Luthini uluvo lwakho malunga nemozulu yangoku?
- Ingaba olutshintsho le moyezulu luyichaphazele njani ifama yakho?

Umngcipheko lwemozulu nezisombululo zokoyisa:

3. Kwezi zisombululo zokoyisa umngcipheko lwemozulu zibhalwe ngazentsi, Ingaba usebenzisa eziphi?

- Ulwazi nophando
- Inkqubo zezilumkiso nokuqaphela
- Indlela enza ngayo izinto amafama
- Iziko nemigaqo nkqubo

Imibuzo yokuvavanya:

- Ingaba bukhona na ubuzaza odibana nabo kwinzame zokusombulula ingxaki ezithi zize nemoyezulu?

Ukufikeleleka kwenkozo zemozulu: uqikekelelo lwamaxesha emozulu

4. Loluphi ulwazi lwemozulu olufikelelekayo kuwe?

Imibuzo yokuvavanya

- Olulwazi ufikekela njani kulo?

Ukusetyenziswa kwenkonzo zemozulu nokuqikelelwa kwamaxesha emozulu:

5. Ingaba usebenzisa uqikelelo lwamaxesha emozulu ukuthatha eziphi izigqibo? Ukuba kunjalo, nceda unike ingcazelo ethe vetshe

Imibuzo yokuvavanya

- Zithini izimvo zakho ngokusebenzisa uqikelelo lwamaxesha emozulu?
- Ukuba akunjalo, ungalusebenzisa ulwazi olufumana koqikelelo lwamaxesha emozulu?

6. Ingaba amanye amafama anayo impembelelo kwizigqibo zakho zokusebenzisa ulwazi loqikelelo lwamaxesha emozulu?

7. Ukuba kunjalo, sisigqibo sokusebenzisa ulwazi loqikelelo lwamaxesha emozulu okanye sisigqibo sokulima?

Imibuzo yokuvavanya

- Ingaba amanye amafama anayo impembelelo kwizigqibo zakho?

Ukusebenza ngokufanelekileyo kwenkonzo zemozulu noqikelelo lwamaxesha emozulu:

8. Zithini iziphumo zokusebenzisa uqikelelo lwamaxesha emozulu

Imibuzo yokuvavanya

- Uqikelelo lwamaxesha emozulu lukunceda njani ukwenza umsebenzi wakho?
- Yintoni enokukhuthaza uqhubekeke usebenzisa uqikelelo lwamaxesha emozulu?
- Uqiniseke kangakanani ngeziphumo zokuqikelelwa kwamaxesha emozulu?

9. Nceda unikise ngengcazelo ethe vetshe malunga nokuchaneka koqikelelo lwamaxesha emozulu

Imibuzo yokuvavanya

- Kulula kangakanani ukutolika nokuqonda uqikelelo lwamaxesha emozulu?

10. Ithini imiceli mngeni odibana nayo ekusebenziseni uqikelelo lwamaxesha emozulu?

Inkcukacha ngobomi bakho

1. Uneminyaka engakanani ungumfama?

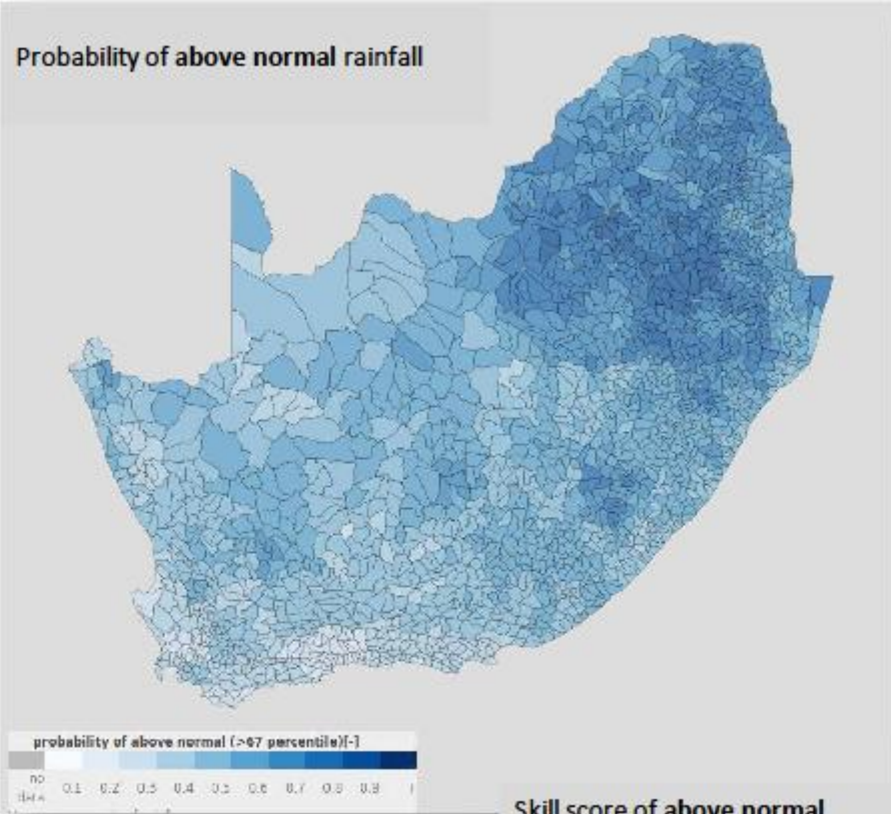
2. Ifama yakho iphantsi komphi umasipala?

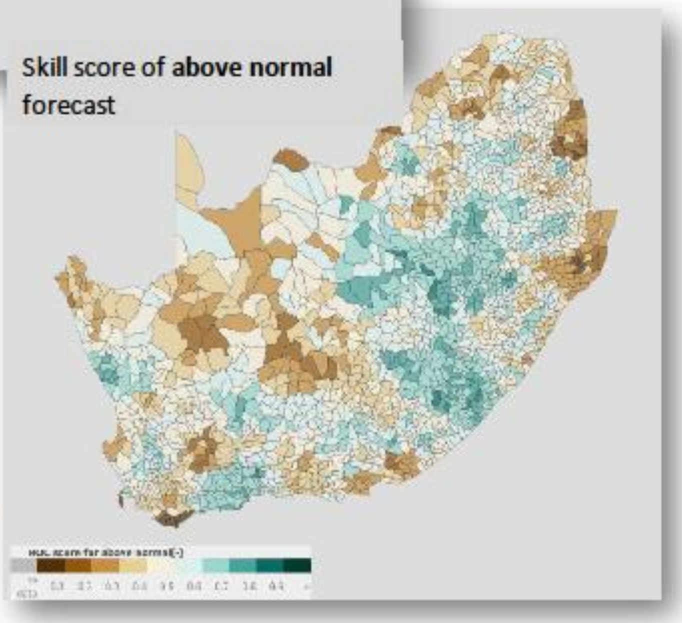
3. Ingaba ikhona eminye imisebenzi yezolimo oyenzayo okanye ishishini phantsi kwalo masipala uhlala kuye okanye omnye masipla?

Appendix 6: Seasonal climate forecast

Seasonal Forecast for October – December

Note: This is not an official forecast and has been constructed as an example of a seasonal forecast for the purposes of this NRF research project





On average, 33% of seasons are below normal, 33% are normal, and 33% are above normal.

A forecast for a **wetter than average** season has a probability **higher than 33% for the above normal category**

A forecast for a **drier than average** season has a probability **higher than 33% for the below normal category** (next page)

Only where skill score is greater than 0.5 does the forecast have any real skill

Appendix 7 Thematic framework