Integration of indigenous knowledge systems and modern climate science: Development of a Mobile application to improve smallholder agricultural production

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PREFACE

The work described in this dissertation was carried out in the school of Agricultural, Earth and Environmental Sciences, University of KwaZulu-Natal, under the supervision of Prof. Unathi Kolanisi and Prof Obert Jiri.

Signed:____________________ Date: 24 March 2020

Nomcebo R Ubisi (Candidate)

As supervisors of the candidate we agree to the submission of this dissertation.

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Prof. Unathi Kolanisi (Supervisor)

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Prof. Obert Jiri (Co-supervisor)

DECLARATION

I, Nomcebo Rhulani Ubisi, declare that:

1. The research, except where otherwise indicated, is my original research.
2. This dissertation has not been submitted for any degree or examination at any other university.
3. This dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from those persons.
4. This dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, with the source being detailed in the dissertation and in the references section.

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Date: 24 March 2020

Nomcebo Rhulani Ubisi(Candidate)

ABSTRACT

In sub Saharan Africa, subsistence agriculture underpins rural livelihoods. However, climate change has negatively affected rural smallholder farming due to over-dependence on climate-sensitive rain-fed agriculture. The effects of climate change have become the most critical issue for rural smallholder farmers. Rural smallholder farmers are greatly impacted by climate change and variability, leading to reduced crop yields, crop failure, loss of assets and livelihood opportunities. However, despite such challenges, farming continued to sustain livelihoods in rural areas over the years. Traditionally, African rural smallholder farmers have relied on their indigenous knowledge (IK) to sustain themselves, maintain their cultural identity as well as understanding climate and weather patterns for their decision-making at a farm level. However, the increase in rainfall variability in the past few years associated with climate change has reduced the reliability of IK. To address such challenges, the study suggests the integration of indigenous knowledge with modern climate science at a local level, to enhance the resilience of smallholder farmers to climate change.

The aim of the study was to establish commonly used indigenous knowledge indicators for climate and weather forecasts predictions and smallholder farmers' perceptions on the integration of the two knowledge systems as well as the use of mobile app technology to improve agricultural production in Nkomazi Local Municipality, South Africa. The study information was collected through both qualitative and quantitative research methods. Data were collected from twelve villages, sampling 100 participants, 8 key informant interviews, transact walk conducted with a small group of farmers (maximum 5) and eight focus group discussions in Nkomazi Local Municipality. ArcMap 10.7.1 was used to map the distribution of indigenous indicators used by Nkomazi smallholder farmers and the Poynton model was used to predict the impact of the increasing temperature on smallholder farmers' production using the plant and animal indigenous climate indicators in these villages, and SPSS 25 was used to analyse the quantitative data as well as Excel 2016. Qualitative data was analysed through thematic analysis.

From the transect walks and focus group discussions, the study findings revealed that many of the Nkomazi smallholder farmers relied more on their indigenous knowledge (IK) than on scientific weather forecasts (SWFs) for farm level decision-making. The findings also revealed that elderly people passed down indigenous knowledge to them during field practices and through casual conversation as they were regarded as custodians of the indigenous knowledge systems. However, lack of IKS documentation is been the biggest challenge facing those farmers. Smallholder farmers' indigenous knowledge on weather foresting was compared with empirical evidence from Komati weather station from 1993-2018, and there were similarities on both knowledge systems. Further, it was revealed that there were different indigenous climate indicators utilised by Nkomazi smallholder farmers to predict weather forecasts. These indicators included certain patterns and behaviour of plants and animals, atmospheric, astronomic and human ailments. Animal indicators (31%) were the most commonly used followed by plant indicators (26%). The documentation of major climatic events recalled by the smallholder farmers over the study area agreed with what was collected from the rainfall and temperature data.

Data from the South African Weather Services highlighted that Nkomazi rainfall has reduced greatly in the years 2000 and 2010 with 40 mm/year, with the highest temperature increase in 2003 (34^0). Poynton model predicted the indigenous indicators distribution with increasing temperature by 5^0C. The model predicted negative results with increasing temperature. Meaning that farmers would lose their indigenous indicators for weather predictions to make farm level decisions. Therefore, to address these challenges and help smallholder farmers adapt to the changing environment, the study suggests the need for reliable weather forecasts to guide the farmer's decision-making at a local level. To improve sustainability, efficient documentation of indigenous knowledge and the creation of a framework for integrating the two knowledge systems in weather forecasting is needed. Importantly, there is a great need to create an information dissemination network for weather forecasting within local municipalities. To achieve household food security, both knowledge systems should be integrated for farmers to make informed decisions.

Therefore, mobile App development for rural smallholder farmers will bridge the gap and act as a key driver to reduce smallholder farmers' vulnerability to climate change and enhance resilience to improve productivity as it will focus on improving agricultural production. The mobile application for agricultural and rural development is a software that was designed for the collection and transmission of Indigenous knowledge information and modern climatic data through mobile (Web Application) technology for rural smallholder farmers. This mobile app is meant to provide practical indigenous knowledge system (IKS) used by smallholder farmers. The development of the mobile app will focus on improving agriculture production with functions such as providing climate and market information, increasing access to extension services, facilitating market links ability of sending chats/enquiries to App manager through sending chats and pics by farmers as well as IKS documentation. It will be accessible to smallholder farmers, extension officers and produce buyers. This mobile App will provide significant economic and social benefits among smallholder farmers by reducing product losses, improving agricultural production and providing the opportunity to make our developing country more globally competitive. It will include a non-redundant database (fast) that will include easy capturing of data. This system is user friendly and will be available as a light to load secure Web Application (Both Computer and Mobile). This App will contribute to the field through integrating IKS and modern science. It will assist in transforming, documenting and disseminating IKS information as well as improved accessibility of information through technology and contributing to diffusion of technology as we heading towards the 4th Industrial Revolution (4IR).

Key words: Integration, Indigenous knowledge systems, Indigenous knowledge, modern climate science, mobile application, smallholder farmers, food security

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DEDICATION

This thesis is dedicated to my late mother Busi “Ma-B” Ndlovu who laid the foundation and for my continued intellectual development.

Gone too soon, but I will be forever grateful for the Love and support you gave me, you were and forever will be my Heroine

Rest In Peace Mommy

(1968-2013)

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LIST OF ABBREVIATIONS

DAFF	Department of Agriculture Forestry and Fisheries
CSIR	Council for Scientific and Industrial Research
FAO	Food and Agriculture Organization
FGD	Focus Group Discussion
HSRC	Human Sciences Research Council
IK	Indigenous Knowledge
IKS	Indigenous Knowledge Systems
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
NRF	National Research Foundation
SAWS	South African Weather Services
SCF	Seasonal Climate Forecast
SPSS	Statistical Package for Social Sciences
SWF	Scientific Weather Forecast
RRA	Rapid Rural Appraisal

Chapter 1: THE PROBLEM AND IT'S SETTING

1.1 Introduction to the research problem

Throughout the years, long before the introduction of modern climate scientific methods for climate prediction and weather forecasting, farming continued successfully as a cornerstone for most rural farmers (Zuma-Netshiukhwi, Stigter and Walker, 2013). African communities have always coped with the changing environment (Enock, 2013). In local communities farmers had indigenous ways of using nature for gathering, predicting and interpreting weather (Zuma-Netshiukhwi *et al.,* 2013a). The natural indigenous climate indicators involved the observation of animal behaviour, plant phenology, clouds and moon as well as wind direction. These indicators were used to define the onset and end of the rain season, as well as predicting season quality (Jiri *et al*., 2015). Thus, these natural indicators were mainly used as guidance for agricultural activities to be undertaken by farmers (Zuma-Netshiukhwi *et al.,* 2013a). According to Onyango (2009), due to modernization, indigenous knowledge is viewed as "backward impostors", whilst scientific knowledge is considered superior unlike the 'backward' knowledge indigenous farmers rely on.

On the other hand, national governments have always advised farmers of expected meteorological conditions through extensions of workers and media. However, the reliability of gathering climate information from extension officers has been a challenge. Majority of South African smallholder farmers are resource-poor and reside in rural and remote areas. They do not get the support they need from extension officers, they have poor infrastructure, such as roads, making it difficult for quick and easy dissemination and interpretation of climate information by extension officers, hence it is difficult for them to cope and adapt to climate change (Mudhara, 2010).

However, several studies have highlighted that in most African countries smallholder farmers have access to and utilize mobile phones (Mittal and Mehar, 2012; Rashid and Elder, 2009). According to Mittal and Mehar (2012), Indian smallholder farmers are already adapting to the use of mobile phones as an effective way of communication among themselves. This reveals the potential of using mobile phones as a channel for integration of the indigenous knowledge systems and modern climate science. Nonetheless, due to high levels of illiteracy and lack of education, the use of mobile phones by smallholder farmers becomes limited to making and receiving calls, as only a few farmers know how to use them apart from that (Chikuni and Kilima, 2019). Therefore, there is a need for a simple and basic development of a mobile app that will attract less effort to understand and use, as complex technology is likely to confuse smallholder farmers and render the service meaningless. The integration of indigenous knowledge with modern climate science for indigenous smallholder farmers to receive and access climate information quickly and easily using modern technology will help improve smallholder farmers' agricultural production.

1.2 Problem statement

Smallholder farmers have been receiving support from the governmental extension officers on their agricultural production. One of the challenges of extension workers is limited resources in terms of capacity, geographical location (far distances between the areas allocated to one extension officer) and thus efficiency (time versus transport) to reach the farmers. On the contrary, several studies have reported that a majority of farmers have access and utilize mobile phones. They are already receiving some kind of climate change information from their mobile phones.

As a coping strategy to counteract the challenges of delayed extension services, smallholder farmers relied upon their indigenous knowledge practices to cope and adapt to the adverse environmental conditions. However, some of the observed indicators disappear and no longer reliable due to climate change, resulting in farmers losing their confidence in them. Therefore, this calls for an integration of indigenous knowledge systems with modern climate science, by getting the indigenous information in the context and format that indigenous people are familiar with, can accept and easily understand. More so, modern information systems such as mobile apps could be used to generate and share both indigenous and modern agricultural-climate change science.

1.3 Research Aim

This study aimed to develop a mobile app technology to integrate indigenous knowledge systems with modern climate science to improve agricultural production for smallholder farmers.

1.4 Specific Objectives

The objectives of the study were:

1.4.1 To investigate agricultural advisory services accessible to smallholder farmers.

1.4.2 To explore existing climate channels that inform smallholder farmers' decisions.

1.4.3 To identify, analyse and document indigenous climate indicators used by smallholder farmers over the study areas.

1.4.4 To map and analyse the distribution of indigenous climate indicators in the study area

1.4.5 Assess perceptions of the local communities in using mobile app technology to improve agricultural production.

1.4.6 To develop a mobile application for smallholder farmers to operationalise the integration and dissemination of indigenous knowledge and modern climate science

1.5 Study limits

1.4.7 The results of the study may not be generalised as the study was only carried out in Nkomazi Local Municipality, Mpumalanga province.

1.4.8 There was a limited time to conduct the research; therefore, a large sample could not be taken.

1.4.9 There was limited documentation on the integration of indigenous knowledge systems and modern science.

1.6 Definition of terms

Food Security:

Food security exists when food is available for all people at all times, physically, socially and economically accessible, safe and nutritious food that meets people's dietary needs and their food preferences for an active and healthy life (FAO, 2013).

Indigenous Knowledge Systems (IKS)

Refers to the information and skills gathered from the local communities usually based on culture, that have been used as indicators and prediction measures of some upcoming events or situations (Mittal and Mehar, 2012)

Integration

Is the combination of two or more things so that they effectively work together.

Mobile Application

“Mobile apps are software programs designed to run on smartphones, tablets and other devices” (Costopoulou, Ntaliani, and Karetsos, 2016)

Modern Climate Science:

Modern Climate Science is contemporary science about climate issues also known as climate change.

Smallholder Farmers:

Smallholder farmers’ also known as small-scale farmers usually own small-based plots on which they grow few cash crops and mostly subsistence crops. They rely mainly on agriculture as the main source of livelihood and use family labour (DAFF, 2012).

1.7 Assumptions

1.7.1 It was assumed that all smallholder farmers would participate actively and answer the survey questions honestly.

1.7.2 It was also assumed that the focus group participants would give honest responses during the discussions.

1.8 Organization of thesis laid out as follows:

The thesis is laid out as follows:

Chapter 1: Introduction to the research problem and setting.

Chapter 2: Literature review.

Chapter 3: Study conceptual framework, study design and description of the study area.

Chapter 4: Study findings on the role of indigenous knowledge systems in rural smallholder farmers in response to climate change

Chapter 5: Study findings on demystifying the knowledge: Integrating IKS and modern science for local weather prediction.

Chapter 6: Study findings on the mobile app development and spatial distribution of indigenous climate indicators in Nkomazi local municipality, Mpumalanga, South Africa

Chapter 7: Conclusions and recommendations.

The referencing style used in this thesis is according to the guidelines used in the Discipline of Food Security, University of KwaZulu-Natal, Pietermaritzburg.

1.9 References

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Chapter 2: LITERATURE REVIEW[1]

2.1 Introduction

A review of the literature was conducted to examine the integration of Indigenous Knowledge Systems and Modern climate science to improve smallholder agricultural production. The review covered the conceptual framework, agricultural advisory services accessible to smallholder farmers, existing climate channels that inform smallholder farmers' decisions, available documented indigenous climate indicators used by smallholder farmers, the distribution of indigenous climate indicators as well as the development of mobile application for smallholder farmers as a solution to household food insecurity.

2.2 Conceptual framework

According to Akullo *et al*., (2007), indigenous knowledge refers to the body of knowledge that is native to rural smallholder farmers. Mittal and Mehar (2012) and Shizha (2015) further describes it as the information and skills gathered from the local communities based on culture, that have been used as indicators and prediction measures of some upcoming events or situations. This knowledge system has been used by smallholder farmers in the developing world for improved agricultural production (Sam Ktunaxa, 2011). On the other hand, modern knowledge refers to values, ideas, concepts, and beliefs, which are imparted by extension workers who are trained in scientific agriculture. Though, note should be taken that in some cases the difference between modern science and indigenous knowledge is not distinct enough (Adedipe *et al.,* 2004). For instance, some techniques fall under both indigenous and modern knowledge.

This includes mulching, fallowing and crop rotation for soil conservation and fertility improvement. However, there are still gaps in the literature that have not adequately covered the integration between the two knowledge systems. The framework below (Figure 1) explains the two knowledge systems and the potential gaps the researcher is hoping to fill in the study.

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[1] This chapter has been accepted for publication as follows: Nomcebo R Ubisi, Unathi Kolanisi, Obert Jiri. (2019) Comparative review of Indigenous Knowledge Systems and Morden climate science. Accepted for publication on, *Ubuntu: Journal of Social and Conflict Transformation*

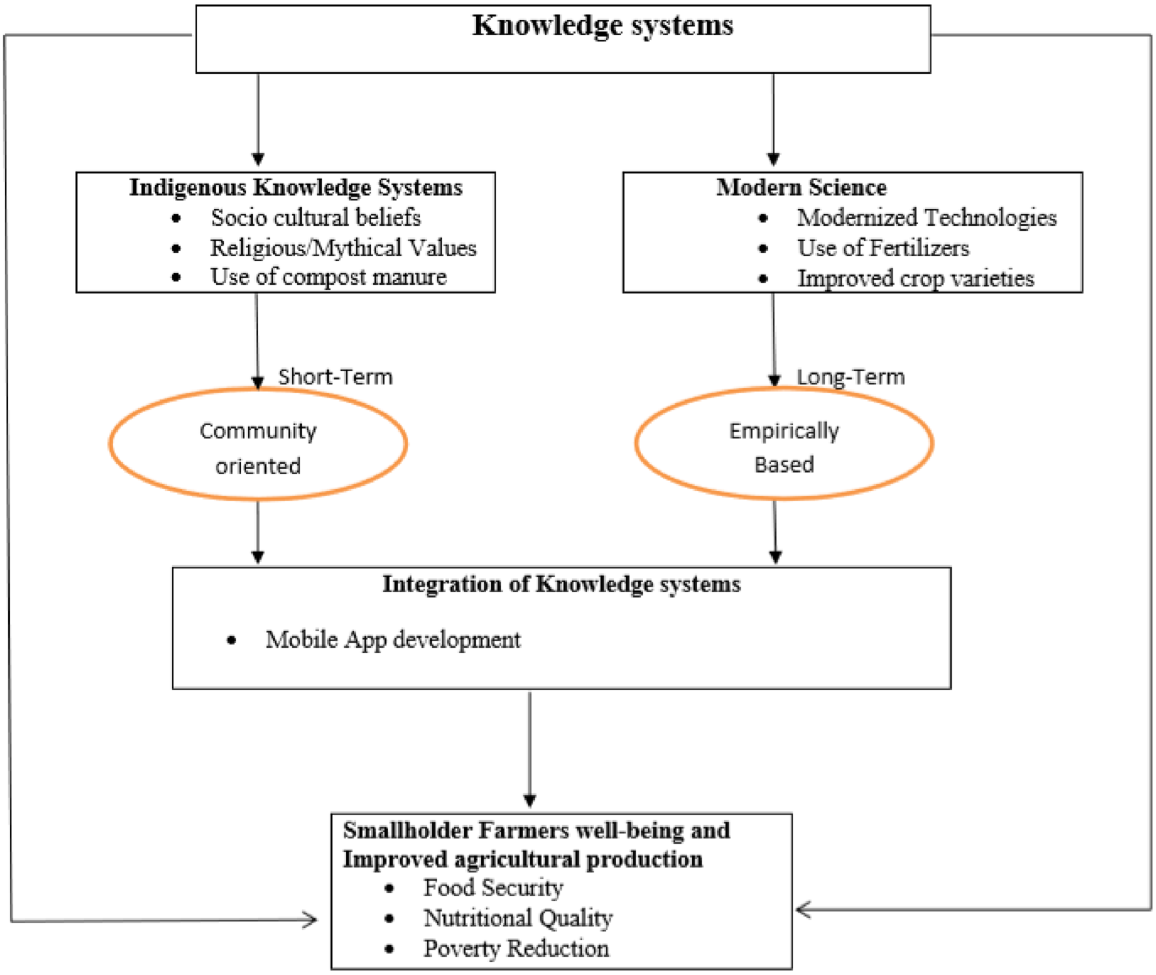

Figure 1: Knowledge System Framework

As highlighted in Figure 1, indigenous knowledge systems are based on social-cultural beliefs, religious, mythical values as well as the use of compost manure. This was supported by Hlatywayo (2017) on the study conducted in Zimbabwe on indigenous knowledge, beliefs, and practices. These skills, knowledge, and practices relating to natural resources were passed down through the cultural learning process from generation to generation (Akullo, Kanzikwera, and Birungi, 2007; Hlatywayo, 2017). Indigenous knowledge systems are community-oriented and mostly use observations for short-term predictions. In agreement, it is a study conducted by Rankoana (2017) on the use of indigenous knowledge in subsistence farming which highlighted that local indigenous farmers us their IK to predict their farming seasons and maintain their crops. Masinde (2012), further elaborates that indigenous farmers feel confident and valued by recognising and sharing the IK as a community and therefore confident to participate in risk reduction initiatives.

Whilst, on the other hand, modern science is knowledge generated by experts using modernised technologies, fertilizers as well as improved crop varieties. This includes the use of weather forecasts generated from weather stations for season predictions. Similarly, (Kooman and Haverkort, 1995), highlighted the use of modern farm machinery such as tractors, improved seeds, harvesters, chemical inputs and threshers as modern science. This knowledge system is based on empirical evidence, which uses model techniques for long-term predictions.

However, indigenous knowledge is under threat due to events such as climate change making it difficult for indigenous smallholder farmers to keep up with the changing environment and emergence of new pests and crop diseases (Ubisi *et al.*, 2017). Therefore, there is a need for scientific intervention to help mitigate some of these challenges. So, both knowledge systems can be integrated to allow documentation of IK, easier and quicker communication between farmers and extension officers and dissemination of important climate information. This integration will bridge the gap of delayed extension services, receiving updated climate information as well as keeping IK information safe and secured for future generations, as Masinde (2012) has highlighted that over the years IK has been slowly disappearing and eroding.

Therefore, mobile App intervention will act as a key possible driver to reduce vulnerability, enhance resilience for rural smallholder farmers, and improve productivity. This integration will give smallholder farmers several levels of risk-preparedness, as using IK alone makes it difficult to foretell climate change issues. Because it is also difficult for IK to forecast beyond a season, while in modern science, this can be achieved by employing technologies such as internet and mobile App. Masinde (2012), also argued the issue of terminologies used in IK, as sometimes one terminology may have more than one meaning. Conversely, incorporating indigenous knowledge systems with modern climate science will improve its relevance and acceptability, in addition to boosting its utilisation among smallholder farmers, a combination of both knowledge systems can lead to innovations, knowledge.

Mobile App can be used for agricultural and rural development through collecting and disseminating IK and modern climatic information by providing practical use of IKS for rural smallholder farmers. The App will enhance smallholder farmers' well-being and improve agricultural production by providing climate and market information, increasing access to extension services, and facilitating market links. Additionally, these authors Brokensha, Warren, and Werner (1980); Thrupp (1989); Flora (2010) and Masinde (2012), suggest a similar relationship that integrating indigenous knowledge and modern science can improve smallholder farmers' livelihoods. This means that farmers can immediately respond to potential climate risks and thus leading to strengthened resilience and self-confidence in their farming systems (Masinde, 2012).

These outcomes will contribute to the achievement of the South African National Developmental Plan, Food and Nutrition Security Policy goals as it aims at ensuring a decent standard of living for people through the provision of basic services and the development of human capacity (Nkwana, 2015). The South African National Developmental Plan also regards food and nutrition security as the country's priority, therefore, this innovation will improve indigenous farmers' food and nutrition security status as poverty reduction will be guaranteed and sustained for a stable and secure world (Masinde, 2012). The advantages of such a mutual relationship between both knowledge systems can be accelerated using mobile App development. This is the thrust of this research: integrating indigenous knowledge systems with modern climate science through the development of a mobile app to improve rural smallholder farmers' agricultural production.

2.3 Food Security crises in South Africa

According to the Food and Agriculture Organization (FAO) report in 2007, about 814 million people in developing countries were undernourished (Labadarios *et al.*, 2011). Recent FAO reports further highlight the state of food insecurity and undernourished people in developing countries to have increased and reached about 815 million (FAO, IFAD, UNICEF, 2017). The effects of food insecurities have become a challenge in many parts of the world including South Africa.

In South Africa, household food insecurity has been influenced by several factors such as climate change, increasing food and fuel prices, unemployment, high energy tariffs and increasing interest rates (Department of Agriculture, 2006). These conditions become a great challenge for ordinary South African citizens. According to the World Bank (2011), the increasing food prices and lack of job opportunities have been the greatest cause of food insecurity in the developing world since 1971. The Statistics South Africa (Stats SA) quarterly survey (2014) also highlighted unemployment to have increased since 2008 (Statistics SA, 2014), while concurrently food and energy price have been on a raise as well. The increase of unemployment coupled with increasing food and energy prices have negatively affected the food affordability and accessibility of the people especially those living on minimum wages (Department of Agriculture, 2006).

According to Altman, Hart, and Jacobs (2009), South Africa is food secure at a national level but experiences food insecurity at a household level. Cock *et al.*, (2013), further elaborates that almost half of the people residing in South African former homelands and townships are living in poverty. The National Planning Commission stated that in 2012 about 40 percent of South African households were living on less than R418 per person monthly. Therefore, due to the escalating food prices own food production at a household level needs to be underlined as a coping strategy for low-income households (Altman, Hart and Jacobs, 2009).

Therefore, as a country, we need to see the possibility of indigenous knowledge as a solution to deal with food insecurity in rural communities and consider the important role this knowledge system can play in dealing with household food insecurity in South Africa. Vorster, Stevens, and Steyn (2008), Jan van Rensburg *et al.*, (2009), (Hart Tim, 2006), Modi, Modi and Hendriks (2006) and (Joyce M. Thamaga-Chitja and Morojele, 2014), conducted studies on indigenous knowledge and food production in South Africa. These studies demonstrated the existence of indigenous knowledge and its potential for improving smallholder household food security. However, it was observed that most agricultural institutions in South Africa tend to ignore indigenous knowledge as a solution to household food security and rural economies.

2.4 Indigenous knowledge systems

Throughout the years, indigenous knowledge (IK) has formed the backbone of rural livelihoods. In most parts of Africa, Asia and Latin American people have been using indigenous knowledge to sustain themselves and maintain their cultural identity (Nelson, 2015). Indigenous knowledge is a form of knowledge that consists of skills and practices or methods of doing things that originated locally and naturally (Enock, 2013). Buthelezi and Hughes, 2014 further describe indigenous knowledge as the body of historical knowledge in the long-term adaptation of humans to the environment. Moreover, Nelson (2015) defines "indigenous knowledge" as traditional knowledge that is used to describe the knowledge systems developed by communities as opposed to the scientific knowledge that is usually referred to as "modern knowledge".

This knowledge comprises a way of knowledge gathered by local people over a period through gathering of experiences as well as their relationship with the environment. It informs the skills and practices of local people, collectively known as indigenous knowledge systems (IKS), which is unique to a given culture (Persens, 2005; Das and Mazumder, 2013; Buthelezi and Hughes, 2014). In this study, IKS is referred to as traditional knowledge used by smallholder farmers to predict weather and seasonal rainfall patterns and used as a decision-making tool. In various cultures, IK evolved into extensive knowledge systems that addressed societal and traditional knowledge issues in human survival and the quality of life, including agriculture, health and water and food security, through the use of climate indicators and prediction measures of some upcoming events (Tharakan, 2015; Mittal and Mehar, 2012).

2.4.1 Indigenous knowledge climate indicators

Since time immemorial smallholder agriculture has been the engine of rural economic growth and the main source of most smallholder farmers' livelihoods in local communities (Komba and Muchapondwa, 2012a). Smallholder farmers had indigenous ways of using nature to predict and interpret weather rather than the modern ways of separating time into minutes, hours, days, weeks, months and years (Enock, 2013; Zuma-Netshiukhwi, Stigter and Walker, 2013b). To cope with the negative impacts of climate change, local communities had other natural indigenous indicators to interpret weather. These indicators involved the observation of animal behaviour, plants, clouds, and moon as well as wind direction (Miriam, 2015; Jiri, Mafongoya and Chivenge, 2015). Such knowledge was used to define the onset and end of the rain season, which also assisted farmers to plan their agricultural activities (Jiri, Mafongoya and Chivenge, 2015; Enock, 2013). A study conducted in the Eastern Cape in South Africa on the application of indigenous knowledge systems in water conservation and management revealed that local people employ indigenous based practices such as water harvesting and water conservation methods to improve water preservation in fragile soils (Mahlangu and Garutsa, 2014). This was further observed in Kenya were smallholder farmers used food preservation methods such as fermentation, honey, herbal plants, and sun-drying to ensure food security (Naanyu, 2013). Farmers also use intercropping and diversification techniques, seed selection, a no-tillage technique for soil conservation and mixed methods to avoid the risks of drought (Altieri, 2004).

As observed in various studies, IK in rural settings is used to predict weather forecast, soil fertility, water detection with other events interpreted from animal behaviour such as birds as well as vegetation changes (Posey, 1985; Ingram, Roncoli and Kirshen, 2002; Nelson, 2015. Zuma-Netshiukhwi *et al.,* (2013b), highlighted that in the South-Western Free State, smallholder farmers observed cloud accumulation and behaviour of cows and calves in the veld as an indication that rains would fall in a few hours or a day's time and employed mixed farming systems with crops, livestock, and agroforestry as an adaptation measure to climate change. These climate indicators were used for short-term planning for the rainy season. However, farmers are faced with some threatening weather and climate hazards such as drought, floods, hailstorms, strong dry winds, and black frost. These are some of the weaknesses and challenges smallholder farmers' face due to a lack of long-term IKS signals to predict weather and other upcoming climate events.

2.4.1.1 Animal Indicators

Indigenous smallholder farmers in rural communities often use animal behaviour, appearance and movement to predict weather (Chang'a *et al.*, 2010). This includes the singing, chirping, and nesting of some birds, which are seen as useful climate indicators for the onset of rains in southern Africa (UNEP, 2008). Additionally, some predictions are made through the observations of arrival of migratory birds (*Bucorvusa byssinicus*), in countries such as Zimbabwe, northern parts of South Africa and Zambia (Orlove *et al.*, 2010) Smallholder farmers from Zimbabwe and Botswana observe sounds from certain insects emerging from hibernation to signal the start of a season (Mapfumo *et al.,* 2015). Moreover, Jiri *et al.,* (2015) highlighted that some indicators are common in most Southern Africa and this contributes to the preservation of several animals across the region.

2.4.1.2 Plant Indicators

During agricultural activities, smallholder farmers observe wild and cultivated plants for climate prediction (Rivero-Romero *et al.*, 2016). As highlighted by Jiri *et al.,* (2015), some studies done in Southern Africa reported that smallholder farmers in rural areas observe certain trees bearing fruits at certain times as an indicator for either a poor or good season. For instance, Brandy bush (*Grewiaflava*) in Botswana bears fruits twice a year, but if they observe that, these shrubs have no fruit at all it indicated serious drought in the next season and late fruiting indicated a good season (Kolawole *et al.*, 2014). Mapfumo *et al.,* (2015), further highlight that in Zimbabwe smallholder farmers observed the disappearance of trees such as Hute, Maroro and Tsambatsi symbolise upcoming droughts. In Uganda, the flowering of coffee trees signals rains coming in a few weeks (Orlove *et al.*, 2010). Therefore, this means that shifting of fruiting patterns of the observed trees or slight change on weather and climate is likely to have an impact on these indicators. These affect the reliability of these indicators, knowing that indigenous forecasts play an important role in predicting and planning for farming seasons by smallholder farmers (Jiri *et al.*, 2015).

2.4.1.3 Atmospheric & Astronomic indicators

In Southern Africa, indigenous smallholder farmers believe that it is important to observe the sequencing of seasons as an indicator for the upcoming season (Orlove *et al.,* 2010; Mapfumo *et al.,* 2015). Also, note should be taken that natural resource-based indicators play an important role in predicting seasons (Roncoli *et al.,* 2002; Kolawole *et al.,* 2014; Mapfumo *et al.,* 2015). These indicators are based on atmospheric and astronomic conditions such as wind directions, sky visibility, rivers, rainfall, water bodies and streams, the appearance of different clouds as well as the moon. According to Rivero-Romero *et al.,* (2016), local people consider these indicators as signs for climate predictions.

Moreover, smallholder farmers interpret the appearance of the moon in two phases; when it appears to be completely bright, it means abundant rainfall, while beige tones are an indicator for the dry season. The moon shape is also taken into consideration when coming to climate prediction, seeing the moon tilted towards the south, it symbolises rain coming, but when tilted north it means dry season coming (Rivero-Romero *et al.,* 2016).

Kolawole *et al.,* (2014), further highlighted that the behaviour of Major River flows is key in indicating the nature of the upcoming season. A free flow of a river in one direction indicates a good season with abundant rains, while a spiral-like flow indicates limited rainfall (Jiri *et al.,* 2015). A study conducted in Zimbabwe showed that there were five regimes observed by smallholder farmers that had indicated the specific rainfall stages for ages (Mapfumo *et al.,* 2015). These observations involved the onset and end of the winter season, the upcoming rains in August after grains processing, marking the end of wildfires in late September, observing the growth of tree leaves in October and marking the start of the rainy season in October/November. However, Mapfumo *et al.,* (2015) further highlighted that these indicators have been affected by changes in rainfall patterns misleading smallholder farmers and not being as reliable as they used to. Essentially, indigenous smallholder farmers relied on these indicators for their farm practices (Jiri *et al.,* 2015).

2.4.2 Accessibility and documentation of indigenous knowledge systems

As stated by Nelson (2015) IK documentation has been a challenge, especially for rural smallholder farmers. Several studies all over the world have suggested some methods for proper documentation of IK. However, the unfortunate part is that most of these methods remain on paper than practical (Rigney, 1999; Turner, Ignace, and Ignace, 2000). Nakata (2002) highlighted that IK documentation methods are more applicable and effective in developed countries. Warren, Slikkerveer, and Titilola (1989) noted that in the USA IK documentation have been archived in the form of databases. These are some of the existing gaps for South African rural smallholder farmers, such as innovations of proper documentation, archiving and disseminating IK for rural smallholder farmers. Warren, Slikkerveer, and Titilola (1989) further propose that the storage and collection of IK should be made readily available to farmers using newsletters, journals, and other media.

Gender inclusivity and transformation is another important component in addressing the indigenous knowledge concept. This knowledge system is gendered in different ways as men and women have different roles and responsibilities in a community (Qun, 2012). Enock (2013) further elaborates on the importance of recognising that certain aspects of indigenous knowledge are gender-sensitive and may be solely practised by either women or men as they express their knowledge differently. However, the challenge with IK is that there are no long-term indigenous climate prediction indicators for extreme climate events. IK indicators seem to provide short-term predictions (Zuma-Netshiukhwi, Stigter, and Walker, 2013a).

Furthermore, the weakness with IK is that it only resides in the head of the beholder. As highlighted by Zuma-Netshiukhwi, Stigter and Walker (2013a) in the study that was conducted at South-Western Free State of South Africa on the use of traditional weather/climate knowledge by farmers, only elderly participants could recall the years which had extremes weather events. This supports the old African proverb quoted by Naanyu (2013) which states that "when a knowledgeable old person dies, a whole library disappears" (Naanyu, 2013). This concept simply means that if we do not care to document the existing IK from our elderly people we might end up with poor documentation of IK which may result in misquoting and misinterpretation by the surviving generation as old people die with their knowledge with no point of reference. According to Lindh and Haider (2010), the importance of documenting IK has been overlooked resulting in some cases being lost. And as observed by Williams, David L.; Muchena (1991) the skills to collect, identify and develop IK into modern functional formats are needed to warrant sustainability. Failure to do so will make it hard for the success of marrying indigenous knowledge and modern science for the growth of rural agriculture.

2.5 Indigenous Knowledge in Agriculture

Long before the introduction of conventional agriculture indigenous knowledge-based agriculture certified the production of a variety of foods (Ogle and Grivetti, 1985). Local people, including smallholder farmers, are custodians of indigenous knowledge systems

(Willett, 1993). These farmers are knowledgeable of their situations including what works and what doesn't work for their farming systems, their available resources and how one change impacts other parts of their system (Ubisi *et al.*, 2017). Indigenous knowledge is vital for resource-poor agriculture, as it provides food security for smallholder farmers at a household level. Indigenous agriculture is based on the understanding local people have and it changes through innovativeness and creativity as well as through contact with other local and international knowledge systems (Warren, 1991). In rural settings, the indigenous knowledge system represent mechanisms to ensure minimal livelihoods. Resource-poor smallholder farmers always planned for their agricultural production and conserve natural resources with the instruments of indigenous knowledge (Naanyu, 2013). This development has been a matter of survival to indigenous people in a rural setting and has been representing generations of experience, careful observations and trial and error experiments (Akullo, Kanzikwera, and Birungi, 2007).

Indigenous farmers heap trash and soil around plants while weeding and make bands as a technique to reduce soil erosion and water run (Junge *et al.*, 2009). Farmers mostly use maize stalks and elephant grass for soil moisture conservation and add manure after decomposition when mulching (Adedipe, Okuneye, and Ayinde, 2004). Smallholder farmers also enhance soil nutrients by adding manure from their livestock (goats, chicken, and cattle) and crop residues like kitchen waste/refuse (Akullo, Kanzikwera, and Birungi, 2007). Early planting is one of the pillars for better production, especially for rain-fed agriculture. Farmers often take advantage of the early rains which are known for lessening pest and disease incidences leading to high yields (Rankoana, 2017). In farm management, smallholder farmers often apply indigenous techniques for weed management to control their farm productivity.

2.5.1 Indigenous Knowledge applications weed management

Indigenous smallholder farmers have developed a multi-storey farming system over the years for weed control. These practices involved intercropping, selective weeding, heaping manures, timing and placement of chemical fertilizers and manure, early planting, tillage and crop rotations to minimise weed spread and competition with crops (G, 2010). Indigenous smallholder farmers also make use of mechanical weed control methods such as hand-hoe weeding and animal-drawn implements (Muoni, Rusinamhodzi, and Thierfelder, 2013). Another technique indigenous smallholder farmers would use is to let the weed grow and cover soil which prevents it from heating up or drying out excessively, thereafter later in the season the farmers would do superficial hoeing and let the weed on the soil surface as protective mulch

(Mertens and Jansen, 2002). This practice helps with nutrients recycle and allow nitrogen assimilation through the bacteria decomposing the plants. This weed management practices sustainably improved yields (Farooq *et al.*, 2011).

2.5.2 Indigenous Knowledge application Pest management

In agriculture, the pest described as any destructive or unwanted insect or animal that attacks crops and livestock (Oxford English Dictionary, 2017). In crop farming, pests such as birds, nematodes, rodents, and insects feed on and destroy cultivated crops, produce and stored seeds (Alabi, Banwo and Alabi, 2006). The FAO implemented some Pest Management programs as interventions to reduce pest threat on food production (FAO, 2017). However, rural smallholder farmers reverted to their indigenous ways of pest management as pesticides are not readily available and financially accessible (Mihale *et al.*, 2009). A lot of studies recorded and recommended the use of indigenous pest management practices as a readily available and ecologically friendly options for rural smallholder farmers (Alabi, Banwo, and Alabi (2006); Gressel (2011); Farooq *et al.*, (2011); Zijlstra *et al.*, 2011).

Indigenous pest management practices have been in existence for over a century in different parts of the world particularly in China (Xu *et al.*, 2008). Citrus growers place nests of the predacious ant Oecophylla smaragdini in orange trees to reduce the damage of insects. India is no different, smallholder farmers in local areas plant a sunflower in wheat fields to aid bio-control of rats by owls at the grain development stage (Sinha *et al.*, 2009).

Scholars such as Alabi, Banwo, and Alabi (2006); Farooq *et al.*, (2011); Gressel (2011) & Banwo and Adamu (2003) have identified different pest management practices for indigenous smallholder farmers. These scholars highlighted that indigenous knowledge pest management practices are mostly based on built-in features in cropping systems, such as crop rotation, intercropping and farm plot location or on specific responsive actions to reduce pest attack, such as plants with repellent, timing of weeding, smoke, use of insecticide action, scarecrows, digging up grasshopper egg masses and traps.

2.5.3 Indigenous Knowledge application in soil fertility management

Smallholder farmers in rural areas have developed various indigenous techniques to improve and maintain soil fertility. These techniques were used to make certain that their land had enough nutrients to provide for household food crops (Chamberlin, 2007, Salami, Kamara and Brixiova, 2010, Zhou, 2010). The use of manure, mulching and composting are common techniques for soil fertility management and have played a crucial role in indigenous smallholder farmers' farming systems (Hepperly *et al.*, 2009, Lyimo, Pratt and Mnyuku, 2012, Chivenge *et al.*, 2009). According to Mkhabela (2003), smallholder farmers in rural Dundee and Nkwezela in KwaZulu-Natal still actively apply these techniques for their farming systems as well as Zimbabwe, Ethiopia (Lupwayi *et al.*, 2000) and Tanzania (Lyimo *et al.*, 2012b).

Crop mulching and the use of poultry and kraal manure have been in practice ever since times in memorial (Rankoana, 2017). Indigenous smallholder farmers have used mulching to conserve soil moisture and keeping soil cool, as well as manure to sustain fertility (Onduru *et al.*, 2008). With the increased soil moisture from this technique, smallholder farmers are then able to plant with certainty that their crops will grow to maturity and that there will be pumper harvests.

Indigenous smallholder farmers can determine when the soil is exhausted. They can identify soil fertility challenges through observations when water retention level reduces substantially; crops become stunted and yellowish causing yield decline (Osbahr and Allan, 2003). The soil colour also tells a lot, if the colour changes from dark or brown to reddish with increased number of stones it means that the soil is exhausted, it then allows the growth of weeds such as embuura, Bidens pilosa, milkweed which indicates soil infertility (Akullo, Kanzikwera, and Birungi, 2007).

Farmers employed various indigenous practices at every stage of the plant growth to cope with soil fertility challenges (Onduru *et al.*, 2008). This includes making mounds by collecting and heaping trash in preparation for planting solanium potatoes, tobacco, sweet potatoes and vegetables which are preferably planted on raised seedbeds (Ojiewo *et al.*, 2013). Techniques such as intercropping groundnuts and maize, beans and maize, agroforestry and millet and maize are practised especially for coffee fruit and trees to improve soil fertility (Mithamo, 2013). Smallholder farmers have also adopted the crop rotation technique for their farming systems over time. According to Akullo, Kanzikwera and Birungi (2007) smallholder farmers in Uganda planted cassava as the last crop during rotation as many farmers believe that cassava is not a heavy feeder and that when its leaves wither and drop, they decompose and add manure to the soil.

2.6 Relevance and utilization of indigenous knowledge in climate change adaptation

In the modern days, climate change is a major threat to sustainable development mainly in sub-Saharan Africa due to high dependency on climate-sensitive resources and low adaptive capacity (Kpadonou, R.A.B, Adégbola, P.Y. and Tovignan, 2012). According to Makuvaro *et* *al.,* (2014), most rural communities are vulnerable because of their great dependency on climate-sensitive resources such as water resources and low adaptive capacity. The effects of climate change have become the most critical issue for rural smallholder farmers from the global to the local level (Kumar, 2014). Literature highlights that the effects of climate change are already felt greatly by smallholder farmers in rural communities as they are experiencing a decline in yields, crop failure, loss of assets and livelihood opportunities (Cherotich, Saidu, and Bebe, 2012). However, based on the research conducted by Ubisi *et al.*, (2017) in Limpopo province (Vembe and districts), there is evidence that while smallholder farmers are facing severe climatic variability in rural communities' indigenous skills to cope with prolonged droughts and severe heat have been developed. In those areas smallholder farmers solely relied on IK as their adaptation strategy, they used it to predict their planting and harvesting seasons by looking at their climate indicators for rain such as moon shape and direction. However, on the other hand, there are concerns over IK relevance for future adaptation amongst other challenges faced by smallholder farmers, as most of the older generation who are knowledge holders of IK will die with the information if we do not find ways to document their science and make it accessible. Therefore, it is important to document and make the IK information available and accessible even for future generations.

2.7 Smallholder farmers in South Africa

Due to their socio-economic position, smallholder farmers are among the most disadvantaged and vulnerable groups affected by climate change and variability (Hazell, 2007, ASFG, 2013). Smallholder farmers in the southern African region are set to be most affected by these climate variations due to poor access to information, low access to technology and dependency on climate-sensitive agriculture (Morton, 2007, Mutekwa, 2009, Oxfam, 2007). Therefore, the impact of climate change and variability threatens and weakens the already vulnerable smallholder farmers whose main source of livelihood is rain-fed agriculture.

South Africa is no different from other countries as climate change is threatening the food security agenda of the country (HSRC, 2018). Climate change has been viewed as a worsening poverty status among the rural population. It presents major threats in achieving the New Sustainable Development Goals which were built on the Millennium Development goals, due to its adverse impacts which undermine all countries' capability to achieve sustainable development (UNDP, 2018). The SDGs aim to encourage development by improving social and economic conditions, eliminating poverty and hunger, and promoting environmental sustainability (UN, 2015).

The changing climate poses a negative impact on overall productivity; soil fertility due to the very hot temperatures accompanied by dry winds leading to erosion, wilting of plants and poor production (DEDET, 2013). Killeen (2008) highlighted that soil is very crucial for the provision of nutrients for plant growth, carbon storage as well as the regulation of the water cycle. The increase in temperature and changing precipitation patterns negatively affects soil quality which results in loss of soil organic matter (Soils Matter, 2013). This negatively affects soil fertility as the rising of air temperatures are likely to speed up the natural decomposition of organic matter and increase the rates of other soil processes (Altieri and Koohafkan, 2008). This degrades soils, which are critical for crop production. The majority of smallholder farmers in rural areas have no or primary level education, therefore it is difficult for them to access information on new technologies on soil management (Wanyama *et al.*, 2010). These farmers mostly practice mono-cropping, which is disadvantageous as it degrades soils even more (Patterson, 2015). Climate change has also affected the erratic rainfalls in South Africa.

Poor infrastructure in rural areas remains the main challenge smallholder farmers face, this is due to erratic rains causing floods, destroying buildings, eroding roads and bridges (Ngigi, and MDG Centre, 2009). In various South African rural areas, smallholder farmers are generally found in remote areas, making it difficult to reach because roads are either in poor condition or non-existent. As a result, there is a long transportation time with high costs, due to inadequate transport infrastructure. According to Louw *et al.*, (2007) transportation of produce to the markets on time is one of the key constraints for smallholder farmers in rural areas. This, therefore, results in loss of quality and late delivery to the markets, leading to products being sold at lower prices or rejected, resulting in a lack of sustainable income for the smallholder farmers, which affect their livelihoods as well as their food security (Baloyi, 2010).

According to Komba and Muchapondwa (2012b), smallholder agriculture is the engine of rural economic growth and the main source of most smallholder farmers' livelihoods. IFAD (2010) estimates that there are about 500 million smallholder farms in the world; in Asia and sub-Saharan Africa smallholder farmers produce up to 80% of the food consumed and support up to two billion people. However, global climate change has increased vulnerability leading to poverty and human food insecurity. According to Dinar (2008) in South Africa the agricultural sector contributes 3.4% to the Gross Domestic Product (GDP) and employs 30% of the labour force, and for the third quarter of 2010 primary agriculture contributed about 3% to the GDP of South Africa whose nominal value was estimated at R667 billion (Chamuka, 2011). However, regardless of the great contribution agriculture has to the economy, it could be greatly affected by climate-related disasters such as erratic rainfalls, floods and extended dry seasons.

In many parts of Africa, the current climate is already marginal concerning precipitation and further warming in semi-arid areas is likely to be devastating to agriculture (Mendelsohn, 2008). Climate may change more rapidly than expected and is projected to have complex, long-term effects on the environment. According to Komba and Muchapondwa (2012b), climate change brings about substantial losses especially to smallholder farmers whose main source of livelihood is derived from agriculture. Dinar (2008) highlighted that yields could fall quite dramatically in the absence of costly adaptation measures. Moreover, Mendelsohn, (2008) stated that the negative impacts of climate change can be significantly reduced through adaptation strategies. Therefore, there is a need for investments to improve agricultural productivity under the risk of climate change (Schlenker and Lobell, 2010).

2.8 Constraints faced by smallholder farmers

Some constraints hinder the growth of smallholder farmers (von Loeper *et al.*, 2016). Some key constraints are lack of physical infrastructures, lack of access to transport produce, Crop production, land and quality of produce (Baloyi, 2010). Besides, Sartorius and Kirsten (2007) also highlighted the lack of land, poor physical and institutional infrastructure as important hindering factors. Crop production constraints have however been one of the key factors affecting smallholder farmers.

2.8.1 Crop production constraints

Akullo, Kanzikwera, and Birungi (2007) highlighted some major constrains in crop production which includes inadequate extension services, lack of knowledge on improved farming methods e.g. results generated by Ubisi *et al.*, (2017) in Limpopo one agricultural extension officer could hardly suffice for all smallholder farmers in their unit. Lack of improved crop varieties and markets coupled with unscrupulous intermediaries who in most cases exploit farmers. Crop pests and diseases are some other constraints that negatively affect farmers' production as well as lack of capital to purchase proper farm equipment's as they still using hand hoes (Baloyi, 2010). Another challenge smallholder farmer’s face is the unpredictable or unreliable weather conditions characterized by droughts and floods in some areas, resulting in a decline in crop production (Ubisi *et al*, 2017).

2.8.2 Road and Transport

In many rural areas in South Africa, smallholder farmers are generally found in remote areas, making it difficult to reach because roads are either in poor condition or non-existent. As a result, there is a long transportation time with high costs, due to inadequate transport infrastructure (Ngigi and MDG Centre, 2009). Furthermore, Louw *et al.*, (2007) highlighted that transportation of produce is one of the key constraints for smallholder farmers in rural areas. Most of the smallholders have no transportation to take their produce to the markets in time. This, therefore, results in, loss of quality and late delivery to the markets and leading to the product being sold at lower prices or rejected (Baloyi, 2010). Moreover, from the moment of harvest, the quality of vegetables begins to deteriorate; meaning that there is a sense of urgency in marketing these products as soon as possible to maintain its fresh value

Therefore, it is obvious that having access to transport is very important as a smallholder. Besides, poor road networks make it difficult to transport produce to markets, this means a lack of sustainable income for the smallholder farmers, which also affects their livelihoods which could result in food insecurity Louw *et al.*, (2007). However, given all that, roads and transportation of products are not the only barriers for smallholder farmers, there are also technological barriers which also have a huge impact on the success of smallholder farmers (von Loeper *et al.*, 2016).

2.8.3 Technological barriers

Baloyi (2010) suggested that one of the great contributors to the progress and smooth running in agribusiness is technological innovation. Having continuous information and communication can lead to high costs saving. The online buying and selling of products can be a good means of minimizing transaction costs in agribusiness (Baloyi, 2010). However, in developing countries, smallholder farmers are poor and have limited access to information technology, with many being poorly linked to international trade due to limited technology (DAFF, 2012). Therefore, the lack of access to technology by smallholder farmers harms their ability to access markets globally, nationally and locally, which limits smallholder farmers to grow and have sustainable livelihoods. Furthermore, for smallholder farmers to achieve those barriers they need market information so they understand the smooth running of agribusiness.

2.8.4 Market Information

In rural areas most smallholder farmers are illiterate and they have little information about market demand, lacking technological skills, which is an obstacle to accessing useful formal institutions that publish technological knowledge (World Bank, 2010). These findings are similar to Joyce M Thamaga-Chitja and Morojele (2014) who stated that in South Africa rural smallholders have been subjected to high illiteracy rates, making access to necessary market information challenging. As a result, this has been an obstacle to receive up-to-date information on issues such as market prices for their products, potential business partners beyond the local level, marketing technologies, as well as agricultural practices. The lack of financial and marketing skills from the majority of the emerging producers is also a problem, thus they are unable to meet the quality standards set by fresh produce markets and food processors (DAFF, 2012).

Besides, the lack of product knowledge leads to a lower quality of production. When market information is readily available to smallholder farmers, they tend to participate in market sales at a lower transaction cost (Baloyi, 2010). A study conducted in Limpopo by Baloyi (2010) highlighted that most smallholder farmers did not have market information especially knowledge of market prices and products that are in demand by the market at a particular time, and the best place to sell their produce. This implication has the potential to affect the food security status of the smallholder farmers, as the inability to sell their farm produce is likely to cause a lack of income. Therefore, if smallholder farmers are equipped with the necessary knowledge and skills they will be able to increase production and understand how markets operate, which will lead to income generation and potentially better livelihoods (Von Loeper *et al.*, 2016).

2.8.5 Quality constraints

Due to the lack of access to market information, most smallholder farmers are not aware of advanced agricultural practices and post-harvest management techniques, resulting in low-quality production (Kibirige, 2013). Furthermore, the majority of smallholder farmers lack on-farm infrastructure such as store-rooms and cold-rooms to keep their produce fresh, as a result, this forms a barrier to penetrate the agricultural markets since quality is very important (Sartorius and Kirsten, 2007).

Moreover, in most cases, formal markets refuse to buy products in small quantities and of poor quality from individual smallholder farmers (Baloyi, 2010). Biénabe *et al.,* (2004) highlighted that due to poor resources that most smallholder farmers have in rural areas (such as land, water, and capital assets) the majority of smallholder farmers produce low-quality products, which in return are neglected by the fresh produce markets. For smallholder farmers to reach their goals there must be interventions taken by integrating indigenous knowledge with modern climate science to help smallholder farmers improve product quality, which could help in poverty reduction.

2.9 Mobile applications for agricultural and rural development

In the developing world, mobile communications technology has been one of the most common ways of conveying messages, services, and data (Qiang, Kuek and Dymond, 2011). The development of mobile applications for agriculture and rural development holds great potential for advancing development. Mobile application can make life easier for rural smallholder farmers through transmitting market information, direct links between farmers, suppliers, and buyers, as well as climate and disease information (Costopoulou, Ntaliani, and Karetsos, 2016).

However, some of the challenges smallholder farmers face are limited resources in terms of capacity due to their geographical location (far distances between the areas allocated to one extension officer) and thus efficiency (time versus transport) to reach the farmers. Therefore, this calls for an integration of indigenous knowledge systems with modern climate science, by getting the indigenous information in the context and format that indigenous people are familiar with, can accept and easily understand. More so, modern information systems such as mobile applications could be used to generate and share both indigenous and modern agricultural-climate change science.

Mobile applications can be used for agricultural and rural development for the collection and transmission of IK information and modern climatic using mobile technology to provide practical use of IKS for rural smallholder farmers. Studies have reported that a majority of farmers have access and utilize mobile phones (Costopoulou, Ntaliani, and Karetsos, 2016). They are already receiving some kind of climate change information from their mobile phones especially in India (Lindh and Haider, 2010). There are a lot of key advantages associated with mobile phones: instant and convenient service delivery, voice communications, accessibility and affordability (Qiang, Kuek and Dymond, 2011).

2.9.1 Existing Agricultural Mobile Applications

As it has been noted by Nelson (2015) and Masinde (2012), in the developing world, IK has been a very important component of development. This has been more evident in the agriculture sector. In support of this, Tabuti, (2012) observed that in Tanzania farmers' indigenous knowledge has been responsible for ensuring food security and improving agricultural productivity. The situation is not any different from that in South Africa. In a related development, Qiang, Kuek and Dymond, 2011 and Nelson (2015) suggest the use of Information Communication Technologies (ICTs) in the documentation and dissemination of IK. According to Costopoulou, Ntaliani and Karetsos (2016); Nelson (2015); Mittal and Mehar (2012); Qiang, Kuek and Dymond (2011) ICTs are important tools in enabling the integration and management of indigenous knowledge and modern science in developing countries. Qiang, Kuek, and Dymond (2011) further highlight that using ICTs to develop a mobile application for rural smallholder farmers' agricultural development will hold substantial potential for advancing development. This mobile app could provide the most affordable ways for smallholder farmers to access information and governance systems that were previously unavailable to them.

The development of the mobile app for rural smallholder farmers will bridge the gap and act as a key possible driver to reduce vulnerability and enhance resilience of rural smallholder farmers to improve productivity, as it will focus on improving agriculture production with functions such as providing climate and market information, increasing access to extension services, and facilitating market links. The App will be accessible to smallholder farmers, extension officers and produce buyers. This mobile application will provide significant economic and social benefits among smallholder farmers by reducing product losses; improve agricultural production and making our developing country more globally competitive Costopoulou, Ntaliani, and Karetsos (2016). The potential development of the mobile app lies in their ability to provide access to useful, relevant information and services.

There are mobile apps that focus on improving the agricultural sector in many parts of the world. Some of these existing Apps include DrumNet from Kenya, VetAfrica which is popular in East Africa, ARCHub and Murimi-Umlimi which was designed for Zimbabwean farmers to get assistance from agricultural experts (AgriOrbit, 2018) (Table 1).

Table 1: Existing Mobile Apps for smallholder farmers

Mobile App Name	**App Description & Capabilities**	**Link**
DrumNet	• Access markets using information technology • Offers information on leading production methods • Has support centres	http://www.comminit.com/content/drumnet-kenya.

VetAfrica	• Information is shared with other app users via a wifi connection • Receive information on proper medication to be administered • Share information through cloud software	http://innovatedevelopment.org/2014/09/01/vetafrica-app-helps-rural-and-remote-farmers-diagnose-cattle.
ARCHub	• App available to download for android phones • Allows communication between farmers, extension officers and ARC officials (researchers) • Have Content such as manuals and videos on production	https://www.mlab.co.za/startup/arc-hub/.
Murimi-Umlimi	• Downloaded from google play • Provides designed for Zimbabwean farmers information on crop production • Provide information on poultry production	https://www.herald.co.zw/murimi-umlimi-app-boost-for-farmers/.

These Apps (Table 1) provide information such as news on crops, market information, receive information on proper medication to diagnose livestock on the spot, creates a medium of communication between farmers, extension officers and facilitate market links (Qiang, Kuek and Dymond, 2011). Users include farmers, cooperatives, produce buyers and input suppliers. However, these existing Apps do not accommodate indigenous farmers, which are the current gaps South African rural smallholder farmers are facing. These Apps mainly focuses on the empirical evidence, which uses model techniques for long-term predictions, and they are not in local languages, which makes it difficult for smallholder farmers in rural areas to practically access them and get the relevant information and services.

2.10 Comparative review of Indigenous Knowledge and Modern Science

In most rural areas, indigenous knowledge mainly influences smallholder farmers' decisions on their farming systems. This was highlighted by Ubisi *et al.*, (2017) on the study conducted in Limpopo, during the focus group discussions, smallholder farmers stated that they solely depended on their IK because they lack modern inputs so they use locally available resources for their livelihoods as they had very limited access to climate information. Most of their crops were planted because they were preferred for household consumption. Indigenous knowledge techniques are cheap and readily available in most cases, it creates social harmony and cohesion, its concepts are easy to understand as elderly, parents, and grandparents pass knowledge orally using the local language as their main source of information (Akullo, Kanzikwera, and Birungi, 2007). However, indigenous knowledge is lost through deaths of the knowledge system information source which are elderly people as there is no formal documentation of such knowledge (Akullo, Kanzikwera, and Birungi, 2007)

As generations come and go there are different challenges for different generations. For instance, the emerging of new pests and diseases that did not exist in the past, and people's attitudes shifting from agriculture being a livelihood provider to a lucrative business entity (Alabi, Banwo and Alabi, 2006). National governments have always advised farmers to use modern agricultural techniques such as using practising soil conservation methods like mulching, contour ploughing, and planting in rows as well using improved seeds. According to Akullo, Kanzikwera, and Birungi (2007), smallholder farmers in Uganda appreciate the advantages of using modern technologies as both efficient and effective in terms of labour required during its application. The use of IK by smallholder farmers in rural areas was also observed in Malawi by Kalanda-Joshua *et al.,* (2011) that initially, African farmers have used indigenous knowledge (IK) to understand weather and climate patterns and the decisions they were making about crops and farming practice from it, making IK the most reliable for the farmers.

While modern science knowledge is global, indigenous knowledge is local (Nelson, 2015). Both knowledge systems are continually influenced by internal experimentation, creativity and by contact with external systems. These knowledge systems are dynamic and intertwined with power and human relationships ranging from social to political and economic. Indigenous knowledge is geographically specific and more qualitative, and use indicators specific to a location for short term predictions (Roncoli, 2006). However, tools used in IK cannot reliably predict for example the distribution and duration rainfall. On the hand, modern science looks at the long-term global perspective (Hansen, 2002; Masinde,2012; Zake, 2015). Below is a table adapted from Masinde (2012) these tables display the comparison between Indigenous and modern science (Table 2)

Table 2: Comparison between Indigenous knowledge and modern science

Indigenous	**Modern Science**
Communication is usually oral	Communication is usually written
Forecast methods are seldom documented	Forecast methods are more developed and documented
Application of forecast output is less developed	Application of forecast output is more developed
Use biophysical indicators of the environment as well as spiritual methods	Use of weather and climate models of measurable meteorological data
Explanation is based on spiritual and social values	Explanation is theoretical
Taught by observation and experience	Taught through lectures and readings
Adapted to local conditions and needs	Formulated at a larger scale and lacks relevance at the local level
Refers to rainfall duration and distribution and it is aligned to crop-weather indicators	Refers to rainfall quantity at a regional level
It is language-based and qualitative	It is number-based
It is holistic – it covers a large number of variables qualitatively	Covers small number of variables quantitatively
It is a way of live – looks at both the process of knowing and the knowledge itself. It is explicit in its social-context aspect and it is an integral part of people‘s culture	Has no social context
It has rules of the knowing process‘	It is based on rules of science, that is evidence, repeatability, and quantification

Nevertheless, Ubisi *et al.,* (2017), highlighted that smallholder farmers are willing to integrate both knowledge systems to solve their problems. As Kalanda-Joshua *et al.,* (2011) further argue that the climate variability experienced now has reduced confidence within the farmers' indigenous knowledge because there are new pests and diseases emerging and the agricultural sector is becoming diverse thus there is a need to integrate both knowledge systems.

2.11 South African government interventions to assist smallholder farmers

The South African government has tried to intervene, and have come up with a strategy, by employing agricultural extension officers as a way to deal with this issue. Extension officers are important in bringing recent technologies, providing relevant information and resolving problems experienced by farmers through research (Kapungu, 2013). However, there hasn’t been much success; it has been found that there is no close relationship between the farmers and the extension officers because they do not go to the farmers' plots often (Baloyi, 2010). However, the FAO (2013) came up with different results from a study they conducted. It was found that the government placed agricultural extension services in the area intending to provide services from experts to smallholder farmers for improved productivity (FAO, 2013). However, there was a decline in funding for extension officers from the government, which resulted in rural smallholder farmers being unable to access expert advice on crop productivity. This has affected their productivity and their ability to participate in markets (Kapungu, 2013).

2.12 Summary

Indigenous knowledge is mostly kept in the elderly's memories and activities. This knowledge system is expressed in cultural values, dances, rituals, stories, beliefs, proverbs, plant species, animal breeds, agricultural practices, and local languages and taxonomy. These forms of communication are vital to indigenous farmers' decision-making processes and for the preservation and spread of indigenous knowledge (Akullo, Kanzikwera, and Birungi, 2007). This knowledge system has been used by local communities to protect their natural resources and for their farming systems. However, Indigenous knowledge alone has become limited to the success of indigenous farmers due to the changing climate. Indigenous smallholder farmers have been experiencing season changes as well as the emergence of new pests and diseases making it difficult for them to predict their planting seasons. Therefore, different studies have highlighted the integration of the two knowledge systems as a potential driver to this existing climate challenges. Therefore, this study proposes the introduction of integrating IK with modern science through a mobile App. Mobile application can be used for agricultural and rural development for the collection and transmission of IK information and modern climatic through the use of mobile technology to provide practical use of IKS for rural smallholder farmers

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Chapter 3: Study Conceptual Framework, study design and Description of the Study Area

3.1 Introduction

This chapter outlines the background information regarding the study area and research methods used in the study. An overview of the livelihood activities of the Nkomazi municipality is highlighted. Included in this chapter are the study conceptual framework, sampling technique, data collection, and data analysis techniques.

3.2 Study Conceptual Framework

The conceptual framework of the study presented in Figure 2 shows the linkages of integrating IK and Modern climate science through the development of a Mobile Application for improved smallholder farmers' agricultural production, livelihoods, food security, and nutrition status. Mobile app development for rural smallholder farmers holds great potential for advancing development and can make life easier for farmers through having better access to market and climate information, better access to extension services as transmitting information on the emergence of new pests and disease will be quicker and easier.

The App will also help farmers to have better market links and distribution networks as it will be accessible to both farmers and buyers. Another important factor of mobile app development is the documentation and dissemination of indigenous knowledge. As highlighted in chapter two, one of the key challenges our country is facing is the lack of IK documentation. Therefore, this mobile app seeks to provide significant economic and social benefits among smallholder farmers by reducing product losses; improve agricultural production, more accurate assessments of pasture health as well as less exploitation of farmers by intermediaries. The potential development of the mobile app lies in their ability to provide access to useful, relevant information and services, as well as improved agricultural production to contribute towards food security, nutrition status and livelihoods for rural smallholder farmers.

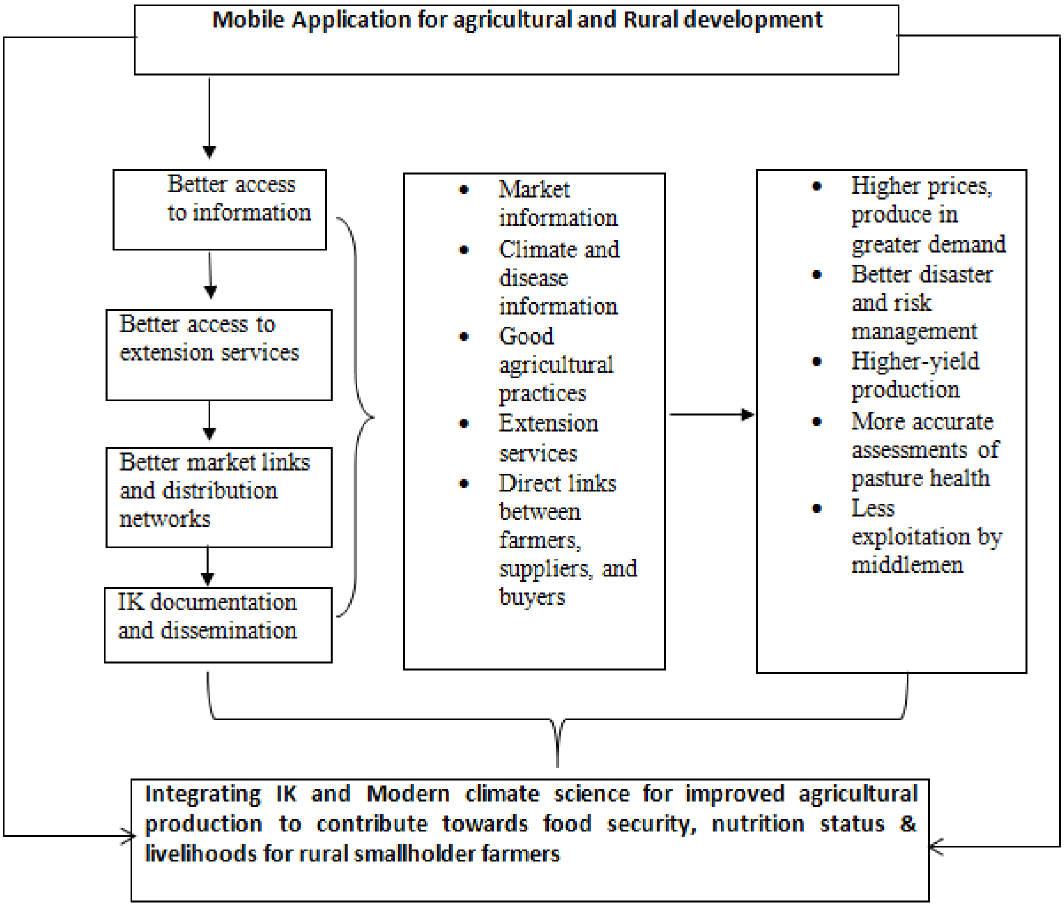

Figure 2: The study Conceptual framework

3.3 Description of the study area

The study was conducted in Mpumalanga province (Figure 3), which is the second-smallest province in the country bordering Swaziland and Mozambique (Stat SA, 2011). Mpumalanga provinces cover about 76 495 km^2 with a population size of about 4 335 964, holding the sixth most populous in South Africa (Mpumalanga Municipalities, 2018). This province is sited in the eastern part of the country (longitude 30.6167 and latitude -29.8167) 494 m above sea level. Mpumalanga province harbours people with diverse cultures and languages. About 27.7% of the total population in Mpumalanga province speak siSwati, followed by 24.1% of isiZulu, 10.4% being xiTsonga and 10.1% speaking isiNdebele (South Africa’s languages, 2016).

The province is divided into Highveld and Lowveld regions. Mpumalanga climate is very diverse, it receives summer-rainfall. The Highveld have cold frosty winter with moderate summers, and the Lowveld region receives mild winters and subtropical climate (Mahlangu E E and Sekgota M G B, no date). Some of the best performing sectors in the Highveld region include mining and manufacturing, whilst in the Lowveld region manufacturing of products from agricultural material is best-performed (Mpumalanga Municipalities, 2018). This province is further divided into three district municipalities namely; Ehlanzeni, Gert Sibande and Nkangala, which are subdivided into 17 local municipalities (Mpumalanga Municipalities, 2018). The provincial headquarter is located in Mbombela (previously Nelspruit) the capital city and business hub of the province.

Approximately 68% of the province's land area is used for agricultural purposes (Lehohla, 2016). This sector is characterised by a combination of emerging crop farming, subsistence farming, livestock and commercialised farming (Mpumalanga Municipalities, 2018). Major crops cultivated in the province are maize, wheat, sugar cane, barley and some leguminous crops (Lehohla, 2016). Also cultivated in the province are subtropical and deciduous fruits, vegetables, cotton, citrus, tea, coffee and tobacco (Mpumalanga Municipalities, 2018).

This study focused on the Ehlanzeni district mainly Nkomazi local municipality due to the availability of a great number of indigenous smallholder farmers residing in the area and practising crop farming. Ehlanzeni district is divided into four local municipalities namely; Bushbuckridge, Nkomazi, Thaba Chweu and city of Mbombela (Mpumalanga Municipalities, 2018).

3.3.1 Nkomazi Local Municipality

Nkomazi Local Municipality sits within the eastern part of the Ehlanzeni District Municipality of Mpumalanga Province. This local municipality is located between the North of Swaziland and East of Mozambique (IDP, 2014). Nkomazi is linked to Mozambique by a railway line and the main national road (N4), forming the Maputo Corridor. This local municipality is also connected to Swaziland by two provincial roads (IDP, 2014). The Nkomazi Municipality is 4786.86 km^2 in extent, which is 23% of the Mpumalanga Province and Ehlanzeni District Municipality landmass respectively (Census, 2011).

According to Census 2011, the population for the Nkomazi municipality was sitting at 273 095. Because the Nkomazi municipality is mostly a rural area, the municipality suffers from a high rate of unemployment; as a result, it is struggling to attract investments (IDP, 2014). Other factors adding to the high rate of unemployment is the shortage of skills and illiteracy rates. As highlighted in chapter two, generally applicable throughout the country, unemployment is at the heart of poverty within the municipality (IDP, 2014). Furthermore, most people in the rural and farm areas are more involved in agricultural activities for livelihood. Though most of the areas in Nkomazi have access to roads, some areas still need bus, tarring of streets and road which connect them to other areas; some villages experience challenges in connection with community facilities and neighbouring areas which cannot be accessed during rainy seasons (IDP, 2014).

Nkomazi Local Municipality is generally warm and subtropical with summer rainfall. It receives summer rainfall from October to March, with mild winter temperatures and hot humid summer (Census, 2011). The rainfall precipitation annually for the municipal area varies between approximately 750 and 860mm (IDP, 2014). These communities have the potential to produce or manufacture goods that can be sold to the public and alleviate poverty but due to the lack of market stall and vendor stalls, there is no space to sell their products (IDP, 2014).

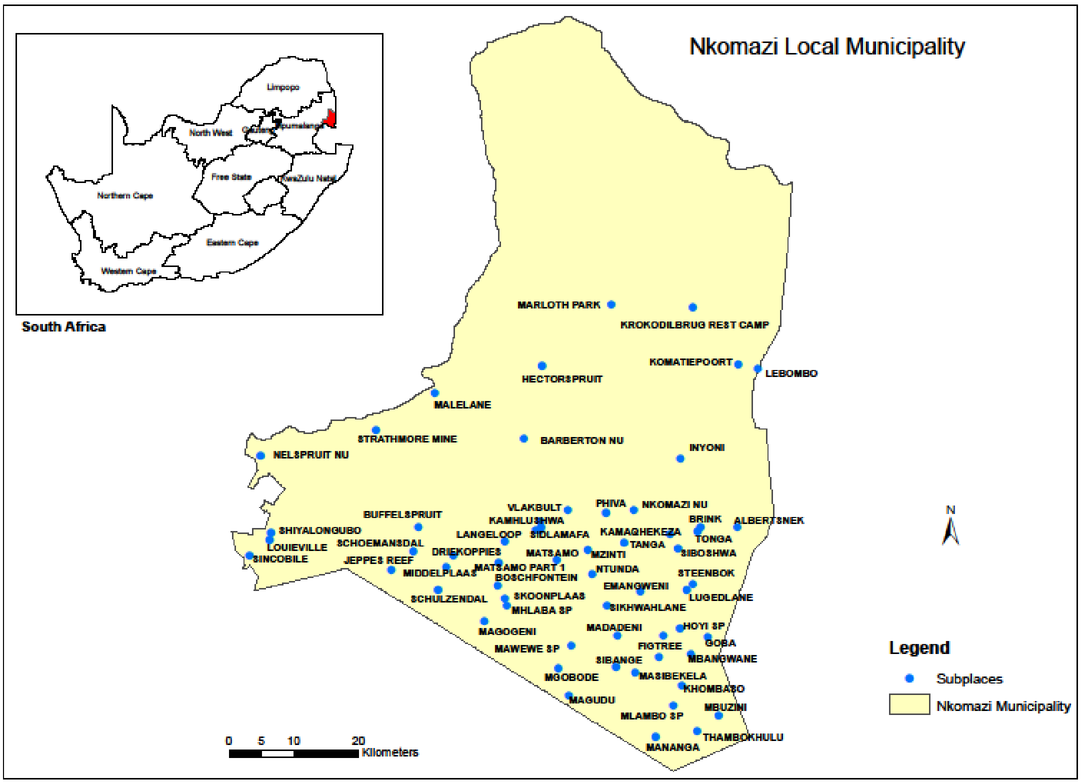

Figure 3: Study area map

3.4 Research study design

A cross-sectional mixed method approach was used in this study for a comprehensive purpose of understanding and validation. Qualitative research was used to seek an understanding of the perspective or situation by looking at the first-hand experience to provide data that is meaningful (Tewksbury, 2009). Qualitative data was collected through focus group discussions with smallholder farmers to probe farmer's use of their indigenous climate indicators and if they find them useful. In this study, the focus group discussions provided the researcher to further explore the issues that could not be easily unpacked or explained through the questionnaires.

The quantitative research method mainly uses numerical analysis to reduce data into numbers or percentages, unlike the qualitative method. This method uses close-ended questions. In this study, the quantitative method was used to compare responses across the participants because all participants were asked identical questions in the same order to allow for significant comparison of responses across participants and study sites (Crossman, 2014). The questionnaires were administered to individual farmers to provide information on agricultural advisory services accessible to them, existing climate channels that inform smallholder farmers' decisions, as well as their indigenous climate indicators. Collecting both, qualitative and quantitative data roughly the same time provides a comprehensive analysis of the research problem (Creswell, 2014).

3.4.1 Sample size

The formula used to calculate the adequate sample size in cross-sectional study is

$$n = \frac{Z_a^2\, p(1-p)}{d^2}$$

Where Z_a is the z-score from the standard normal distribution. The value of Z depends on the desired significance level, a. p represents the expected adoption rate of technology among smallholder farmers. The rate that can be obtained from similar studies and d is the margin of error. Note that, a lower margin of error requires a larger sample size (Pourhoseingholi, Vahedi, and Rahimzadeh, 2013).

In general, the adoption rate of technology ranges between 6% and 93% (Masere, 2015). Using the adoption rate of 93%, and assuming a confidence level of 95% i.e., Z = 1.96 and 5% margin of error, the minimum sample size required to estimate the true adoption rate of technology is

$$n = \frac{1.96^2\; 0.93(1-0.93)}{0.05^2} = 100$$

The minimum sample size required when the population is known (i.e, the total number of farmers in Nkomazi local municipality) is calculated as below:

$$n' = \frac{n}{1+n/N} = \frac{100}{1+100/933} = 90.3$$

Where N is the total population size equals 933.

Therefore, the study sample size is 90.3, which can be rounded up to 100.

3.4.2 Sampling procedure

A purposive random sampling was utilized in the study based on the type of crops produced. Firstly, there was a purposive selection of local municipality with the highest production of crops in the district. Secondly, a purposive selection of villages in the local municipality was done and lastly about 100 farming households that were mainly into crop production were selected randomly from the list of smallholder crop farmers obtained from the extension officers from the local municipality.

The study was conducted in twelve villages namely; Ntunda, Mzinti, Mbuzini, Jeeps Reef, Driekoppies, Magogeni, Tonga, Boschfontein, Kamaqhekeza, Buffelspruit, Sibange, and Madadeni in Nkomazi local municipalities, Mpumalanga province. These villages were selected based on their reliability on agriculture as a source of livelihood and still used indigenous knowledge systems on their farm systems. The participants were sampled based on their participation in crop production for least four farming seasons, applying their indigenous knowledge systems for farm practices, over the age of 50 and willing to participate. Participants for the focus group discussions were smallholder farmers who were willing to participant and share their wealth of experience in using indigenous knowledge.

3.4.3 Data collection Tools

Both quantitative and qualitative research methods were used to collect data in this study. Data was collected through structured questionnaires, which targeted indigenous smallholder crop farmers. Data were also collected through a series of in-depth formal and informal interviews, focus group discussions as well as meetings with the community elderly smallholder farmers. Interviews enabled the collection of data among the smallholder farmers as a general technique to explore the existing wealth of experiences that have been enriched through generations (Enock, 2013). The elderly smallholder farmers were treated as key informants (5 in each village) in the study area to help generate specific social and technical indigenous knowledge on weather forecasting, disaster preparedness as well as agricultural planning. Interviews (3 in each village) helped gathered information through probing the smallholder farmers' perceptions, attitudes, feelings and beliefs about the critical role of integrating indigenous knowledge systems and modern climate science using mobile app technology to improve agricultural production. Participants that participated in the interview were not included in the surveys.

3.4.3.1 Transect walk

Transact walk was used as a data collection tool to interview the farmers about their farming practices and their indigenous knowledge systems. A transect walk was conducted with a small group of farmers (maximum 5) to observe their farming systems and indigenous knowledge indicators. The farmers were mainly leaders as stated by the communities and those who have been farming for a longer period who could share their farming experiences and provide critical perspectives towards indigenous knowledge systems.

3.4.3.2 Survey

Questionnaires are tools used for collecting data in survey research; this tool included a set of standardized questions (Enock, 2013). In this study, questionnaires were used to collect information collected about the demographics of participants, socio-economic characteristics, agricultural advisory services available to them, existing climate channels that inform their decisions and indigenous climate indicators. This tool was also used to explore agricultural production and smallholder farmers' adaptation strategies towards climatic shocks, in the form of an interview. Questionnaires and interviews were both used for that collection in individual farmers by the research team.

3.4.3.3 Focus group discussions

Focus Group Discussions (FGDs) were conducted with up to eight people per session among the smallholder farmers in each study area. Farmers who participated on the focus group discussion volunteered to be part of the discussions. A Rapid Rural Appraisal (RRA) was conducted to help establish general indigenous knowledge that exists within the farmers and how this could be integrated into weather forecasting and disaster management. The information collected through the participation of smallholder farmers was used to establish categories of knowledge that exist within the farmers.

A trained facilitator conducted the focus group discussions. A recorder and pictures were used to document indigenous climate indicators used by smallholder farmers over the study area in each session. Oral and written consent was requested from participants before the beginning of each session.

A SWOT (Strength, Weakness, Opportunities, and Threats) analysis was conducted to assess perceptions of the local communities in using mobile app technology to improve agricultural production. Towards the end of each session, the facilitator provided a summary of the discussion and the participants were asked to verify if the information was correct.

3.4.4 Data collection procedure

Permission to collect data in Nkomazi local municipality was approved by the Mpumalanga Department of Agriculture, Rural Development, Land and Environmental Affairs (DARDLEA). Data was collected through face-to-face interviews from smallholder farmers addressing the application of indigenous knowledge on their farming systems and a detailed questionnaire written in English and translated to local languages (siSwati) served as the data collection tool. The questionnaire was designed to address the study objectives and to ensure strict adherence to statistical specifications for accuracy. The Provincial Department of Agriculture allowed the research to be supported freely by communicating to the Nkomazi local municipality's extension officers. The extension officers helped in securing appointments with productive indigenous crop smallholder farmers in their localities where questionnaires were administered.

Questionnaires were arranged in questions to address issues related to indigenous knowledge systems and smallholder farmers' agricultural crop production. The questionnaire cut across generalities about socioeconomic characteristics of smallholder farmers, crop cultivated, land characteristics, agricultural advisory services, indigenous knowledge indicators, existing climate channels and smallholder farmers' perceptions in using mobile app technology to improve agricultural production. The questionnaire was divided into four sections of A-D (questionnaire attached as appendix A).

Section A was based on the socio-economic features of the smallholder farmers in the study area. Cultivated crops and land characteristics. Questions were ranging from the respondent's gender, their age, marital status, educational status, home language, employment status, level of income as well as an income source.

Section B covered questions on crops cultivated in the study area and land characteristics such as the owner of the farm, land tenure, size of the farm, perceived land's fertility and who manages the farm. The respondents were also asked if they were aware of climate change and what were their existing climate channels as well as their agricultural advisory services.

Section C was based on smallholder farmers’ observation of climate change and their indigenous climate indicators. Questions that looked into how climate change affected crop production over the years, livelihood and the impact on food security in the study area were asked. The indigenous climate indicators that smallholder farmers used in the study areas were asked.

Lastly, section D was on smallholder farmers' perceptions of using mobile app technology to improve agricultural production. The researcher tried to know if the farmers were willing to integrate the indigenous knowledge with modern science and where they also willing to use the mobile app to receive information.

Firstly, the researcher explained the objectives of the study to the participants during the interviews.

3.4.5 Mobile Application Development

The mobile application for agricultural and rural development is software that was designed for the collection, documentation, and transmission of Indigenous knowledge information and modern climatic data through mobile technology for rural smallholder farmers. This mobile app aimed at providing practical IKS used by smallholder farmers.

The development of the mobile app focused on improving agriculture production with functions such as providing climate and market information, increasing access to extension services, and facilitating market links. The app is accessible to smallholder farmers, extension officers and produce buyers. This mobile application provides significant economic and social benefits among smallholder farmers by reducing product losses; improve agricultural production and making our developing country more globally competitive. The potential development of the mobile app lies in their ability to provide access to useful, relevant information and services.

3.4.6 Data analysis

A Statistical Package for Social Sciences (SPSS) version 25.0 was used for data analysis. Quantitative data were manually coded and analysed using descriptive statistics and frequencies. Microsoft excel 2010 statistical package and ArcMap 10.7.1 was used to analyse and map the distribution of indigenous climate indicators in the study areas. Frequencies were done to investigate and present agricultural advisory services accessible to smallholder farmers, existing climate channels that inform smallholder farmers' decisions and indigenous climate indicators used by smallholder farmers over the study areas. Focused group discussions were important in balancing and weighing the information collected through interviews to produce generalisations that represent the indigenous knowledge that exists in the study areas, FGD were analysed by thematic analysis. Thematic analysis involves the arrangement of raw data into conceptual groups and creating themes or concepts based on the issues tackled during the interviews and the key focus of the study.

3.5 Reliability and validity

This section confirms the validity of the research work, through the way the information was gathered. It shows how the research tool was tested against ambiguity.

The questionnaire was pre-tested and piloted on ten respondents before data collection to improve its reliability. However, the respondents used in the pretesting were not interviewed in the main interview. This was done to ensure that the translation from English to siSwati was accurate and to identify ambiguous questions.

Questionnaires were distributed to participants by the researcher and clear instructions were given to the participants with the assistance of the extension officers. Enumerators were trained to understand the questions and to probe for additional information where necessary. Furthermore, a trained facilitator who spoke the local language conducted the focus group discussions. Towards the end of each session, the facilitator provided a summary of the discussion and the participants were asked to verify the information collected. More so, the transect walks, key informant interviews, focus group discussions and the survey tools were employed for validation of data through cross verification from two or more sources (see Appendix A, B, and C).

The mobile app validation was done through a re-visit to eight indigenous smallholder farmers who participated in the study, aged between 50-65 years for them to use the app and confirmed the recorded indicators with their meaning.

3.6 Ethical consideration

To ensure this research was ethically acceptable and abide by the University of KwaZulu-Natal's policy on ethics, the ethics committee of the institution approved the research proposal (see Appendix E). A written consent was provided by the provincial department of agriculture to carry out this study within the confines of the province (see Appendix D), a letter was sent to the local municipality, and the extension officers responsible for rural smallholder farmers within the municipality provided authorisation to access their database and other information that helped this research work. Transect Walk (see Appendix B), Focus group discussion guide (see Appendix B). The smallholder farmers provided oral and written consent before the beginning of each session (see Appendix A). The study findings and recommendations will be present back to the communities in completion of the study

3.7 Summary

This chapter presented information about the study area, the sample selection methods and ways in which data was collected and analysed. The focus was mainly on the research topic: Integration of indigenous knowledge systems and modern climate science: Development of a Mobile application to improve smallholder agricultural production. Data was collected in Nkomazi local municipality, Mpumalanga province. Data collection was mainly based on smallholder farmers' responses and was conducted in the form of focus group discussions, survey questionnaires and transect walk, intending to do a comparison of farmers' responses. In this study focus group discussions and transect walks with farmers verified each other and were used as participatory tools to provide insight into how useful did farmers perceive the use of mobile app technology to improve agricultural production. These tools provided an opportunity for the researcher to uncover sensitive and nuanced information that could not be gleaned so easily using survey-based methods. The findings of the study were discussed in detail in chapters four, five and six.

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Chapter 4: The role of indigenous knowledge systems in rural smallholder farmers in response to climate change: Case study of Nkomazi Local Municipality, Mpumalanga, South Africa[2]

4.1 Abstract

Climate change and variability have direct negative impacts on rural smallholder farmers. These impacts involve extreme climatic events such as excessive temperatures, prolonged droughts and floods, which affect people's livelihoods. This study was conducted in Nkomazi Local Municipality, Mpumalanga, South Africa. The main objective of the study was to investigate indigenous weather and climate indicators used by smallholder farmers and the role of indigenous knowledge in their farming systems. The research used qualitative methods, including focus group discussions and key informant interviews. The findings indicated that farmers observed animal behaviour, plants, atmospheric indicators and human ailments to predict weather.

4.2 Introduction

Climate change effects are most critical long-term global challenges, especially for African rural smallholder farmers due to high dependency on climate-sensitive resources and low adaptive capacity (Kpadonou *et al.,* 2012; IPCC, 2007). The effects of climate change have become the most critical issue for rural smallholder farmers from the global to the local level (Kumar, 2014). Climate change is an important phenomenon that requires close attention, as it directly affects rural smallholder farmers food security (Vilakazi, 2017). According to Cherotich *et al.,* (2012), climate change effects are felt greatly by rural smallholder farmers, as they experience a decline in yields, crop failure, loss of assets and livelihood opportunities.

However, despite such challenges, farming continued successfully in rural areas over the years. Rural smallholder farmers have been relying on their indigenous knowledge (IK) to sustain themselves and maintain their cultural identity (Charles *et al.*, 2014). Indigenous knowledge systems (IKS) refers to cultural, traditional and local knowledge that is unique to a specific society or culture (Mapara, 2009). Since time immemorial, indigenous knowledge has formed

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the backbone of rural livelihoods. However, different perceptions are given to IK holders ranging from being undermined and belittled due to their lifestyle. Different terms are used to define IK namely ethnoscience, village science, people's science, folk-ecology and local knowledge (Mapira and Mazambara, 2013). This study refers to indigenous knowledge holder as ethnic groups, which are culturally distinct with different identity from the national society.

Indigenous knowledge are forms of knowledge collected from the local communities based on skills and practices that originated locally and have been used as indicators and prediction measures for upcoming events or situations (Mapara, 2009; Risiro *et al.*, 2012; Elia, Mutula and Stilwell, 2014; Jiri, Mafongoya and Chivenge, 2015). Smallholder farmers always had indigenous ways of using nature for gathering, predicting and interpreting weather. To cope with the negative impacts of climate change, local communities had natural indigenous indicators to interpret weather. These indicators involved the observation of animal behaviour, human ailments, atmospheric indicators, worms, wild fruits, birds, plants, clouds and moon as well as wind direction among others (Risiro *et al.*, 2012; Kipkorir, Mugalavai and Songok, 2012; Zuma-Netshiukhwi, Stigter and Walker, 2013; Elia, Mutula and Stilwell, 2014; Jiri, Mafongoya and Chivenge, 2015) . The indigenous climate indicators used by smallholder farmers are mainly local and well understood in specific areas (Mapara, 2009). IK follows beliefs, processes and specific language which the local weather and climate are predicted, assessed and interpreted by the locals, implying that IK on weather and climate are qualitative (Soropa *et al.*, 2015). Risiro *et al.*, (2012) and Enock (2013) further elaborates on IK as a knowledge system that is location-specific at a village level mostly and plays a major role in helping farmers to prepare for timing and distribution on their farming practices using indigenous climate indicators.

Most smallholder farmers in Southern Africa uses the indigenous climate indicators for weather predictions to make critical short-term decisions for their farming practices and adaptive measures (Jiri, Mafongoya and Chivenge, 2015). Similar observations were highlighted by Rankoana, 2016); Ubisi *et al.*, (2017) in Limpopo Province, as well as Kipkorir *et al.,* (2012) in Kenya. These studies underlined some evidence that though smallholder farmers are facing severe climatic variability in their communities' indigenous skills to cope with prolonged droughts and severe heat have been developed. In those areas smallholder farmers solely relied on IK as their adaptation strategy, they used it to predict their harvesting and planting seasons by looking at their climate indicators.

In general, indigenous knowledge is passed down from generation to generation by elderly people during field practices and through casual conversation as they are regarded as custodians of indigenous knowledge system (Govender *et al.,* 2013). However, Goddard *et al.*, (2010) highlight that IK is under threat due to the lack of documentation in the context of weather and climate. Documentation of IK in a local language and English becomes important for information sharing and preservation of indigenous indicators that have demonstrated to be useful for smallholder farmers. Scholars such as Noyoo (2007) and Kolawole *et al.,* (2014) have presented the importance of documenting the IK as most of the older generation who are knowledge holders of IK will die with the information without passing it down, so if we do not find ways to document their science and make it accessible it will be knowledge lost. As the old African proverb will state, "when an old knowledgeable person dies, a library is lost". Therefore, it is important to document and make the IK information available and accessible even for the future generation.

Nkomwa *et al.*, (2014) further highlighted the importance of understanding the perception of local people on climate before interventions. Therefore, this research is based on the notion that including IK in climate change policies can lead to positive and effective adaptation strategies that are locally relevant to smallholder farmers. However, because IK is specific to a site, it is important to assess indigenous knowledge specific to an area to come up with localised policies. Therefore, this study investigated the role of indigenous knowledge systems, farmer's adaptive measure and indigenous climate indicators used by Nkomazi smallholder farmers in response to climate change.

4.3 Description of the Study area

The study was carried out in Mpumalanga province within twelve villages of the Nkomazi local Municipality namely; Ntunda, Mzinti, Mbuzini, Jeeps Reef, Driekoppies, Magogeni, Tonga, Boschfontein, Kamaqhekeza, Buffelspruit, Sibange and Madadeni of the Ehlanzeni District Municipality. Nkomazi Local Municipality sits within the Eastern part of the Ehlanzeni District Municipality of Mpumalanga Province, which is situated within the Northeast part of the Mpumalanga Province. Nkomazi Local Municipality is generally warm and subtropical with summer rainfall. It receives summer rainfall from October to March, with mild winter temperatures and hot humid summer (Census, 2011). The rainfall precipitation annually for the municipal area varies between approximately 750 and 860mm (IDP, 2014). (See chapter 3 for a detailed description of the study area).

4.4 Data Collection and Analysis

The study was based on the primary data collected in Nkomazi Local Municipality, Ehlanzeni district. Qualitative method was used to collect data through key informant interviews and eight focus group discussion made up of 8 to 12 participants. Transect walks were conducted with five key informants, each session had at least one elder known for rain prediction expertise and considering age as well, participants were 50 years and above. Discussions were first held separately between men and women to ensure active participation especially from women who were not free to express themselves in the presence of men due to cultural norms. Also because different genders may have different IK used for different purposes.

Qualitative research method was employed mainly to seek farmers' perceptions of climate change, understanding their indigenous knowledge systems, their indigenous climate indicators, and their responses to climate change as well as the role of IK on their farming systems. This method was found appropriate for this study as smallholder farmers were regarded as experts of their situation and have first-hand experience, so we aimed at finding meaningful answers and experiences of farmers concerning their indigenous knowledge systems on crop production.

The local extension officer provided a list of households and the smallholder farmers were randomly selected from there. A total representative population of 90 smallholder farmers in Nkomazi, Ehlanzeni district participated in this study. This sample reflected the proportion of a total number of smallholder farmers in Nkomazi.

Focus group discussions were conducted and facilitated by a trained facilitator. A recorder and pictures were used to document indigenous climate indicators used by smallholder farmers over the study area in each session. A written and oral consent was requested from farmers before the beginning of each session. Qualitative data obtained from the focus group discussions and key informant interviews were thematically analysed. Data was compiled, transcribed and categorised into different trends, themes, concept and patterns.

4.5 Results and Discussion

4.5.1 Demographics

A total number of 90 smallholder farmers participated in this study, with a high proportion of females than males (62 females and 28 males). The age distribution was between 50 and 80 years. Majority of the smallholder farmers were household heads with primary education and farming as their livelihood source. A high number of participants stated that they have used indigenous knowledge for more than 30 years on their farming systems. Additionally, the farmers had some adaptive measures put in place to cope with climate change effects, but still, women had limited resources as compared to men yet they are the main drivers of rural agriculture.

4.5.2 Indigenous Knowledge weather and climate Indicators

Smallholder farmers in Nkomazi Local Municipality have historically utilised several indigenous indicators for weather and climate prediction based on cultural and environmental beliefs. From the thematic analysis, most common indicators used by Nkomazi farmers to predict weather and climate were categorised into four groups: (i) Animal indicators; (ii) Plant indicators; (iii) Atmospheric indicators (iv) Human ailments. These indicators were used to make farm-level decisions concerning their farming systems such as planting time and selection of crop types. Table 3 gives a summary of the indigenous climate animal indicators used by Nkomazi smallholder farmers to predict weather and climate and inform decision on farming systems.

Table 3: IKS climate Animal indicators by Nkomazi Smallholder farmers

Indigenous Indicators	**Description**	**Interpretation**
Birds "sparrow" *(Passeridae)*	Flying of sparrow at altitude	Rains about to come
Locust *(Megacheilacris bullifemur otongae)*	Appearance in abundance	Drought season is upcoming
Grasshoppers *(Acridomorpha)*	Appearance in abundance	Good season with rain
Ants "termites, crickets, spiders" *(Formicidae)*	Collecting food	Rain season about to come
Frogs (makutlwa, *Rhaebo haematiticus)*	Crocking sounds	Excessive rains coming soon
Worms (tinhlonhloti, Earthworms; *Lumbricina*)	Presence of worms in abundance	Worms signified high rains in the season to come

One of the most common indicators used by the farmers were behaviour of some animals such as birds, locusts, ants, frogs and worms (Table 3). Farmers highlighted the appearance of a local bird known as inkontjane (sparrow) as an indicative of rain coming in a day, while frog's croaking sound was an indicator for immediate rain. This was similar to what was observed by

Elia *et al.,* (2014) in Tanzania. Additionally, the respondents also stated that the appearance of small birds without tiles locally known as *tindzayana (*English name could not be identified) indicate dry season. Both men and female highlighted these observations. The farmers also reported high emergence of ants and termites (*tinhlwa and mahlabozi*) in their fields collecting grass and storing food indicates good rains for the planting season, crickets and spiders also become more active as sign of upcoming rains and it shows that there will be a good harvest. However, in contrary occurrence of termites without wings indicates a prolonged dry spell together with the colourful locust locally known as “mara-mara”. Similarly, Kalanda-Joshua *et al.*, (2011), highlighted that the emergence of grasshoppers (dziwala) and birds known as chikhaka in Nissa Malawi to indicate drought. While on the other hand appearance of grasshoppers in abundance locally known as *mashosho* in Nkomazi symbolises good harvest year with rains and good production. These findings were similar to what was highlighted by Risiro *et al.*, (2012); Nkomwa *et al.*, (2014) and Basdew *et al.*, (2017) that smallholder farmers use nature as indigenous climate indicators to predict the upcoming seasons.

Furthermore, the male respondents reported that the emergence of small worms in the soil mark fertility and rainy season. However, the respondents were unaware of the specific species names but could identify them. In agreement with these findings, Kalanda-Joshua *et al.*, (2011) highlighted that the outbreak of armyworms in Nessa Malawi indicated good rainfall season. Contrary to this, female smallholder farmers in Nkomazi reported the abundance of armyworms to signify drought, while Mopani worms indicated an abundance of rain in the coming season.

Table 4: IKS climate Plants indicators by Nkomazi smallholder farmers

Indigenous indicators	**Description**	**Interpretation**
Gauva tree (*Psidium guajava*), Thunduluka (Fig tree), marula tree (*Sclerocarya birrea*)	More fruits produced	Good season with an abundance of food and rain
eMakwakwa (*strychnos spinose)*, eMantulwa (*Vangueria infausta)*	Abundance of fruits	Food scarcity and drought
Mango tree *(Mangifera indica)*	Abundance of fruits	Droughts in the upcoming season
Leafy vegetables “Amaranthus” *(Amaranthus retroflexus)*	Abundance of leafy vegetables	Good season with abundance of food rain

As highlighted by Elia *et al.,* (2014), rural smallholder farmers use plant phenology such as flowering, fruits bearing as well as sprouting of tree leaves to predict weather. Table 4 provides a summary of plant indicators that the community use to predict weather and climate, inform decision on farming activities. Nkomazi smallholder farmers' mentioned specific trees producing many fruits such as guava tree, miracle fruit tree locally known as mathunduluka, marula tree locally known as muganu as well as leafy vegetables such as amaranths locally known as imbuya and inkakha to indicate a good planting season with good rains. However, the farmers also reported that abundance of fruits from trees locally known as makwakwa (*strychnos spinose)* and emantulwa (*vangueria infausta)* signalled drought and food scarcity in the coming season.

Table 5: IKS climate Atmospheric indicators by Nkomazi Smallholder farmers

Indigenous Indicators	**Description**	**Interpretation**
Temperature	Cold temperatures	Low rainfall to come in the next season
	Hot temperatures	Heavy rains coming in next season
Clouds	Appearance of dark clouds	Signifies rain coming within the next few hours
Wind direction	Heavy easterly winds	Strong east winds indicate good season
	North winds	High rains coming in the next season
	Strong east winds around august	Good season, whilst weak winds reflect dry year
visibility	Mist in the morning	Clear weather during the day and light rains might occur
Rainfall	Low summer rains	To experience warmer winter
	High summer rains	To experience cold winter

Changes in weather elements such as observing dark clouds, north winds as well as hot temperatures were cited indicators for heavy rains in the next coming season (Table 5). A majority of female smallholder farmers in Nkomazi stated to have observed the appearance of dark clouds as a signal for heavy rain coming in few hours, as highlighted by Zuma-Netshiukhwi *et al.,* (2013) observation of dark clouds are well known as an indicator for heavy rains and this explanation is also scientifically related. However, on the other hand, male farmers noted winds blowing from the north to come with heavy rains. Too hot temperatures that usually take place between September and December signified heavy rains as well. These observations helped in preparations of land for the coming season, which is summer. This correlates with findings from Risiro *et al.*, (2012). Furthermore, the farmers highlighted cold to symbolise low rainfall in the coming season, whilst observing mist in the morning indicated clear weather during the day and light rains might occur. In contrary to these findings, Risiro *et al.*, (2012) reported that Chimanimani, Zimbabwe farmers had different observations, were to them having a hazy morning meant very high temperatures during the day. These contradictions might be due to the different geographical area.

Additionally, heavy easterly winds around August signified good upcoming season, whereas weak winds reflect dry year. It was also reported that primarily, high temperatures between September and October indicated good rains. However, nowadays the tables had turned farmers are now experiencing prolonged cold seasons crippling into October due to prolonged dry seasons. Moreover, low summer rains is an indication of warmer winter, while high summer rains signal cold winter. In general, farmers were of the view that high summer rainfall led to cold winter vice versa. Charles *et al.*, (2014) findings are opposing these observations as the farmers had different observations when it came to rainfall variations. This observation supports Mapara (2009) statement that some indigenous climate indicators are areas specific.

Table 6: IKS climate Astronomic indicators by Nkomazi Smallholder farmers

Indigenous Indicators	**Description**	**Interpretation**
Moon shape	Half-moon facing the east	No rain to come
	Downward crescent shape	High rainfall within the next few days
	Moon with a halo	Good and continuous rains coming within two weeks
	Bright moon	Winter seasons approaching
	Full moon (not tilted)	Drought and dry spells

Stars	Sun and milk way positioned on the North	Winter has started
	Sun and milk way at the centre	It's a beginning of the summer season

The appearance of the moon in the sky helps farmers to predict seasons. The respondents highlighted that the moon goes through several changes in terms of size, shape and colour (Table 6). The farmers reported that seeing a half-moon facing east means there is no expected rains, but having downward crescent shape signals high rainfall in the next three days. These findings are in agreement with a research that was conducted in Limpopo by Ubisi *et al.*, (2017) and Risiro *et al.*, (2012) in Zimbabwe. The Nkomazi smallholder farmers further elaborated that a moon with a halo was a good indication of good and continuous rains to come within about two weeks, Basdew *et al.,* (2017), reported similar findings on a study conducted in Limpopo South Africa. Majority of farmers also stated observation of a very bright moon to symbolise that winter is approaching and no expected rain. Moreover, it was also highlighted that a full moon (not tilted) locally known as inyeti is an indication of drought and dry spells in the coming season. These farmers regarded the moon as a disaster-warning tool and guided them.

Several female farmers also said to have observed the visibility and changing position of stars (locally known as lilanga netinkanyeti) to foretell predictions in a particular season. Observing the sun or milk way positioned on the North signified the starting of winter. Also, the farmers stated that when the milk way slightly shifts to the centre it signals the beginning of the summer season. However, in contrary similar observations were recorded by Elia *et al.,* (2014) in Tanzania but with a different meaning. Elia *et al.,* (2014) reported that farmers from Chibelela village used the position and visibility of stars to predict rainfall. Further observations were that when the sun is positioned towards the north-west it meant the beginning of a summer season, and if it is positioned southwest during rainy season signified imminent rain.

Table 7: IKS climate human ailments indicators by Nkomazi Smallholder farmers

Indigenous Indicators	**Description**	**Interpretation**
Sweat	Excessive sweating on cloudy days	Rain coming in a few hours

Joints	Painful joints or operations	Humid or cold weather coming in a day

Human ailments (table 7) such as excessive sweats and painful joints were also regarded as climate indicators. Majority of farmers reported that when they experience excessive sweat on cloudy days is an indication that rain is more likely to be coming in a short period or a few hours. A closer assessment of these responses demonstrates that when farmers are experiencing painful joints or operations signals humid or cold weather coming in a day. In support of these findings Risiro *et al.*, (2012), also highlighted that community members of Chimanimani, Zimbabwe used human ailments as a biological weather forecast indicator. These farmers said to have used these indicators for weather predictions over time.

4.5.3 Smallholder farmers' perceptions of causes of Climate Change

Most smallholder farmers in Nkomazi believed that the climate is changing based on their observations. The observed changes were mainly related to low rainfall, too hot temperature, drying of wetlands and strong winds. The farmers also highlighted prolonged dry spells as one of the signs that there is a change in climate. Due to the changes of the climate farmers reported to have shifted planting seasons from October to December due to late rains. These responses are in agreement with Soropa *et al.*, (2015) findings in Zimbabwe as well as Nkomwa *et al.*, (2014) in Malawi. These researchers reported that smallholder farmers in those areas observed late rains and warming temperatures as indicators of climate change.

Nkomazi smallholder farmers had different perceptions of the causes of climate change. The different perceptions were grouped into three categories being natural phenomenon, spiritual and cultural. Most farmers reported that the changes in weather and climate were caused by depletion of the ozone layer due to deforestation and release of gases from cars and industries. In agreement with these findings is the IPCC (2007) report, which stated that human activities play a key role in causing climate change.

However, a majority of farmers strongly believed that it was God's will and there was nothing they could do about it. While on the other hand others highlighted that God is angry hence they experiencing climate change. These farmers believed that this is a punishment from God, as people no longer live according to his commandments. For example, *"we have people of the same gender getting married"*. In the past, during drought seasons the chief would call all community members to gather and pray for rain, but now it is not happing people are doing their things. In support of this assertions Mubaya *et al.,* (2010) reported that some smallholder farmers in Zimbabwe perceived climate change to be a punishment from God, as they no longer practice some ceremonies such as "*mukwerera"* asking rain from God. Soropa *et al.*, (2015) further elaborated on this subject as they had similar findings from a study conducted in Murehwa.

Additionally, disrespect of cultural values was reported to be another major issue leading to climate change. These include celebration of the first-fruit rituals "*incwala ceremony*", brewing of traditional beer, incestuous behaviour, doing the *"lisekwana ritual*" were by young boys will go get lisekwana tree branches for the king once a year for heavy rain to come between November and December, inappropriate burial as people are now having burials during the week even in the afternoons. Allowing pregnant women to go to the fields and bathing at sacred places such as "*manjolo*" a lake only, the mnisi clan are supposed to go practices rituals for rain to come could be causing factors of climate change. It was also mentioned that due to these factors even when the rain comes it comes with rain-induced diseases such as cholera. Rankoana (2016) who noted that farmers in Limpopo, South Africa stated that the cause of climate change is due to cessation of cultural activities supports the study factors.

4.5.4 Indigenous knowledge in climate change adaptation

In this study, climate change is perceived as changes in rainfall patterns as well as temperature. Nkomazi farmers observed below normal rainfall with unpredictable patterns become frequent and increased temperatures resulting in prolonged droughts and uncommon floods. These mentioned effects decreased yield production harming food and nutrition security for the smallholder farmers. These observations were also supported by Kalanda-Joshua *et al.*, (2011); Ubisi *et al.*, (2017) Soropa *et al.*, (2015) and Rankoana (2016) who noted that climate change has a huge impact on smallholder farmers due to their reliability on climate-sensitive resources.

However, the smallholder farmers reported to be grappling these climate change impacts for their sustainable livelihoods. Majority of the Nkomazi smallholder farmers had adaptive strategies in place to respond to climate change effects. These farmers were aware of the indigenous knowledge climate indicators in the area. Smallholder farmers in the study area highlighted to have employed their IK climate indicators for making farm-level decisions concerning season quality predictions, crop selection, land preparation, planting, harvesting and weeding. This knowledge system is used to adapt to climate change and variability based on local experiences to improve crop production. The adaptation measure the Nkomazi smallholder farmers used involved changing planting dates, observing nature (plants, animal behaviour, atmospheric indicators) to predict season quality, mulching, mixed cropping and change of crops. These are some of the measure IK adaptations Limpopo smallholder farmers have employed as well (Rankoana, 2016).

Majority of the respondents in this study highlighted that IK helps in predicting the upcoming season. According to Basdew *et al.,* (2017) IK acts as a coping or adapting strategy to climate change using indigenous methods such as rain-water harvest by using drums and buckets during rains. Nkomazi farmers adapted to this strategy and used saved water for irrigation during times of minimal rainfall. From the focus group discussions, it was noted that the participants regard indigenous knowledge to be more precise as it is derived from their experiences on a local scale, easy to understand, predict seasonal change, it has high-resolution knowledge-sharing networks and been working for generations.

4.6 Conclusions and recommendations

The study established the reliability, use and existence of indigenous knowledge in weather prediction among Nkomazi smallholder farmers. The study also identified the local climate indicators used by the smallholder farmers for weather and climate predictions. The farmers use animal indicators, plant indicators, atmospheric indicators and human ailments to predict weather.

From the focus group discussions, it was learned that many of the Nkomazi smallholder farmers relied more on IK than on scientific weather forecasts (SWFs). Key findings revealed that the majority of smallholder farmers in their adaption deems the use of IK at a local level essential to climate variability and change. Even though the farmers highlighted the use of IK to be crucial for weather predictions, the study findings also showed that a lot of farmers relied mainly on their indigenous knowledge and own experience on their farming systems and decision-making. During the focus group discussions, it was also observed that age is an important factor in explaining and interpreting indigenous knowledge indicators. In spite of a large number of smallholder farmers indicating that they apply IK on weather and climate prediction, elderly farmers had a better understanding on forecasting the patterns of rainfall, droughts and temperatures for the upcoming seasons. The study further revealed that smallholder farmers were of the view that their local climate indicators were better off than the scientific weather forecast because they have limited access to anyway. This is due to uncertainty on the scientific weather forecasts and inability to understand and interpret it, which is one of the critical factors that forces farmers to continue using their IK despite the increasing effects of climate change and the availability of, and need to use, SWFs.

Furthermore, it was highlighted during the focus group discussions that indigenous knowledge is on the wane because some of the local climate indicators are disappearing due to climate change. In this regard, to assist the smallholder farmers, access to timely and accurate climate information is needed. Therefore, an important finding of this study is that IK features very prominently in weather prediction and adaptation by Nkomazi smallholder farmers. However, owing it to disappearing of local climate indicators, its use is on wane. In the end, this could lead to complete loss of IK. Therefore, there is a need to ensure that smallholder farmers have timeous access to accurate climate information. Therefore, integration of indigenous knowledge systems with modern climate science. This integration could be done by getting indigenous information in the context and format that indigenous people are familiar with, can accept and easily understand.

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Chapter 5: Demystifying the knowledge: Integrating IKS and modern science for local weather prediction[3]

5.1 Abstract

Improving food security for rural smallholder farmers needs suitable risk management strategies related to climate such as appropriate climate information to assist smallholder farmer decision-making at a local level. In South Africa, the government has made progress in providing climate-related services. However, there are still major gaps relating to downscaling weather forecasts to the local level, as well as producing reliable, user-friendly and timely information. Data were collected from 100 interviews, 8 key informant interviews and 8 focus group discussions in Nkomazi Local Municipality. 1993-2018 rainfall and temperature data for the study site was corroborated with data collected through surveys, focus group discussions and key informant interviews. In Nkomazi Local Municipality, women dominated the farming sector (63%). Findings from the focus group discussions revealed that a high number of smallholder farmers in Nkomazi relied on their indigenous knowledge (IK) for weather prediction through observing animal behaviour, plants and atmospheric as well as human ailments. Of all the respondents, 93% of the farmers had some knowledge of IK. About 78% of the respondents found IKS more reliable than scientific forecasts. Some of the great challenges facing the farmers today is the lack of IK documentation and the loss of IK climate indicators due to climate change and variability. Indigenous knowledge is mainly disseminated orally from generation to generation with no reference point, creating an inter-generational gap between its custodians, which are mainly elderly people, and the upcoming generation. To improve sustainability, efficient documentation of indigenous knowledge and creation of a framework for integrating the two knowledge systems in weather forecasting is needed. Importantly, there is a great need to create an information dissemination network for weather forecasting within local municipalities. To achieve food security among rural smallholder farmers both knowledge systems should be integrated for farmers to make informed decisions.

Keywords: Food Security, Integration, Indigenous Knowledge Systems, Modern Science, Smallholder Farmers

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5.2 Introduction

Ethno-meteorological knowledge has shown an important role in smallholder farmers' capability to invent climate change adaptation strategies (Jiri et al., 2015). Smallholder farmers formulate weather and climate expectations through observations on historical patterns (Orlove et al., 2010). According to Kolawole et al (2014) and Orlove et al (2010), IK shows practical emphasis that is solid and oriented towards planning for agricultural practices and reveals enthusiasm that allows for the integration of new elements.

Smallholder farmers always had indigenous ways of using nature to predict and interpret weather rather than the modern ways of separating time into minutes, hours, days, weeks, months and years (Enock, 2013; Zuma-Netshiukhwi et al., 2013). To cope with the negative impacts of climate change, local communities had other natural indigenous indicators to interpret weather. Smallholder farmers assessed and predicted weather and climate through local observations of animals behaviour, plants, astronomical indicators and meteorological (Chang'a et al., 2010; Jiri et al., 2015; Miriam, 2015; Soropa et al., 2015). Such indicators were used to define the onset and end of the rain season, which also assisted farmers to plan their agricultural activities (Enock, 2013; Jiri et al., 2015). As highlighted by Jiri et al., (2015), that in most cases, smallholder farmers are mainly interested on the quality of the season, the beginning and end of the rainy season so they make preparations decisions of what to grow.

Though IKS is acknowledged for its great contribution to smallholder farmers' welfare and associated with good advantages, it is also clouded with challenges. Majority of rural smallholder farmers mainly rely on IKS for their farm practices. However, the challenge with IK is its limited indigenous climate prediction indicators for long-term climate events, as IK indicators provide short-term predictions (Zuma-Netshiukhwi et al., 2013). Some concerns over IK relevance for future adaptation amongst other challenges faced by smallholder farmers is that some of their climate indigenous indicators are disappearing, resulting in reduced farmers' confidence. Smallholder farmers that are mostly indigenous knowledge holders rely mostly on agriculture for food; however, they are vulnerable to climate change. These farmers face direct and indirect impacts of climate change that threatens their livelihoods and survival (Ajani, 2014). According to the Department of Agriculture (2008), IKS contribution to South African agriculture remains informal, due to limited skills and tools to encourage rural smallholder farmers to open up and share IKS related information. This challenge remains a weakness in implementing IKS.

Moreover, the weakness with IK is that it only resides in the head of the beholder. Zuma-Netshiukhwi et al (2013) highlighted the use of indigenous weather and climate knowledge study conducted at South-Western Free State of South Africa. Only elderly participants could recall the years that had extreme weather events. This supports the old African proverb quoted by Naanyu (2013) which states: "When a knowledgeable old person dies, a whole library disappears" (Naanyu, 2013). This concept simply means that if the existing IK is not documented from our elderly people, that knowledge would be lost, which may result in, misquote and misinterpretation by the surviving generation as old people die with their knowledge with no point of reference. According to Lindh and Haider (2010), the importance of documenting IK has been overlooked, resulting in some cases being lost. As observed by William and Muchena (1991) the skills to collect, identify and develop IK into modern functional formats are needed to warrant sustainability. Failure to do so will make it hard for the success of marrying the two knowledge systems for the growth of rural agriculture (DeWalt, 1994).

Therefore, the study suggests that farmers should not solely rely on one knowledge system but take advantage of the strength, innovativeness, and creativity of both IKS and modern science. Indigenous knowledge systems and modern climate systems should be recognised as complementary sources of wisdom. Both knowledge systems are complementary sources of wisdom and can be integrated by getting the indigenous information in the context and format that indigenous people are familiar with can accept and easily understand.

5.3 Description of the Study area

The study was carried out in Mpumalanga Province (Figure 3) within the Nkomazi Local Municipality (25.7097° S, 31.7195° E). The Nkomazi Local Municipality is located between the North of Swaziland and East of Mozambique. The Nkomazi Municipality is 4786.86 km^2 in extent, which is 23% of the Mpumalanga Province and Ehlanzeni District Municipality landmass respectively (Census, 2011). The local municipality is generally warm and subtropical with summer rainfall, receiving summer rains from October to March of approximately 750mm and 860mm, with mild winter temperatures and hot humid summer (Census, 2011; IDP, 2014). (See chapter 3 for a detailed description of the study area).

5.4 Data Collection

The study was based on primary data collected in Nkomazi Local Municipality, Ehlanzeni district as well as secondary data from the South Africa Weather Services Komati station. Both qualitative and quantitative research methods were used to collect data in this study. Data was collected through structured questionnaires, which targeted indigenous smallholder crop farmers. Data were also collected through a series of in-depth formal and informal interviews transect walk, focus group discussions as well as meetings with the community elderly smallholder farmers. Interviews enabled the collection of data among the smallholder farmers as a general technique to explore the existing wealth of experiences that have been enriched through generations (Enock, 2013). The elderly smallholder farmers were treated as key informants during the transect walk to help generate specific social and technical indigenous knowledge on weather forecasting, disaster preparedness as well as agricultural planning. Interviews helped gathered information through probing the smallholder farmers' perceptions, attitudes, feelings and beliefs about the critical role of integrating indigenous knowledge systems and modern climate science using mobile app technology to improve agricultural production. In this study focus group discussions and transect walks with farmers verified each other and were used as participatory tools to provide insight into how the farmers perceive the integration of the two knowledge systems. These tools provided an opportunity for the researcher to uncover sensitive and nuanced information that could not be gleaned so easily using survey-based methods.

5.4.1 Rainfall and temperature data

Rainfall and temperature data from 1993-2018 (25 years) for the Nkomazi region was collected by the South African Weather Services Komati station. This was the only data available in records for this area.

5.4.2 Sampling

A sample of 100 smallholder farmers participated during the study in Nkomazi Local Municipality. The local extension officer provided a list of households and the smallholder farmers were randomly selected from there.

5.5 Data Analysis

A Statistical Package for Social Sciences (SPSS 25.0) was used for questionnaire data analysis. Focus group discussions were analysed through content analysis by identifying themes, concept, patterns and trends.

Seasonal forecast for the 1993 to 2018 rainfall season was compared with IKS indicators to determine the reliability of the indicators.

5.6 Results

5.6.1 Socio-economic profiles of the respondents

The study findings revealed that there were more female (63%) respondents than males (37%) in Nkomazi Local Municipality. The age distribution of the participants' ranged from 50 to 90 years. About 10% of the smallholder farmers had primary education, another 10% with matric and only 2% had post-secondary education with diplomas. Majority of the farmers relied on farming activities (63%) as their main source of income, with an average of R1500-R2000 (24%). Only 4% of the participants relied on full-time job for their income. Most farmers (78%) relied on their indigenous knowledge for their farm practices and decision-making at a local level. About 88% of the participants revealed that they were willing to use cell phones for receiving agricultural information. These findings highlight the willingness of these farmers to integrate indigenous knowledge with modern science or technology.

5.6.2 Local observations and impacts of climate change

In Nkomazi Local Municipality, the respondents noted that compared to the early 1970s, smallholder farmers have experienced several extreme events due to climate change (Figure 4). Most farmers experienced an increase of crop failure (51%) as the biggest influence of climate change. This impact has negatively affected the farmers' livelihoods as they mainly depend on agriculture for survival. Some farmers have highlighted human disease outbreaks (17%) as climate change impact, whilst 18% of the farmers seem not to know of any impact. These smallholder farmers also stated to have observed livestock deaths (2%) to be the least severe climate-related risks (Figure 4).

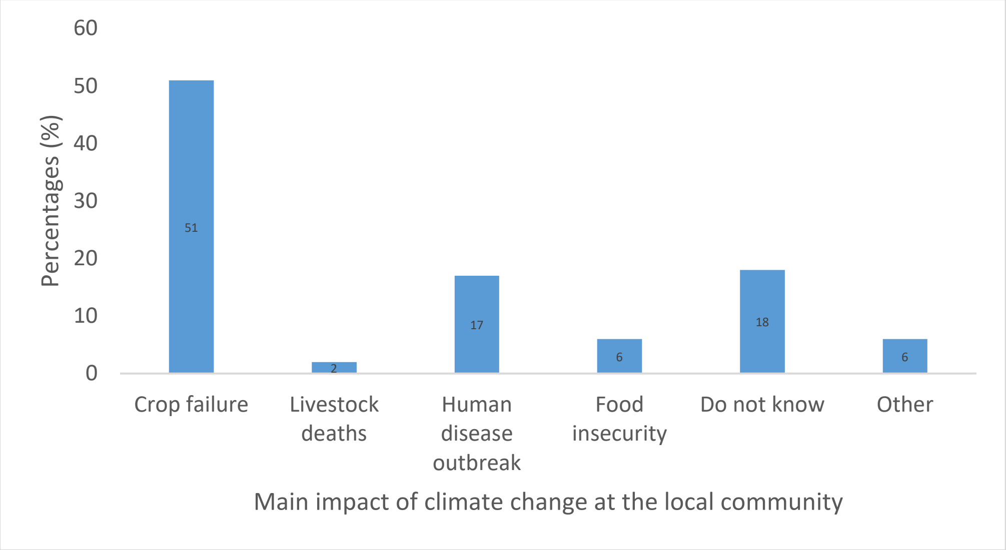

Figure 4: Impacts of climate change on Nkomazi smallholder farmers

5.6.3 Nkomazi smallholder farmers' observations of weather changes

More than 51% of Nkomazi smallholder farmers' perceived very hot seasons as the major impact of climate change followed by prolonged droughts (34%), with a few having observed floods (8%) and 3% said to have not observed any changes in their area.

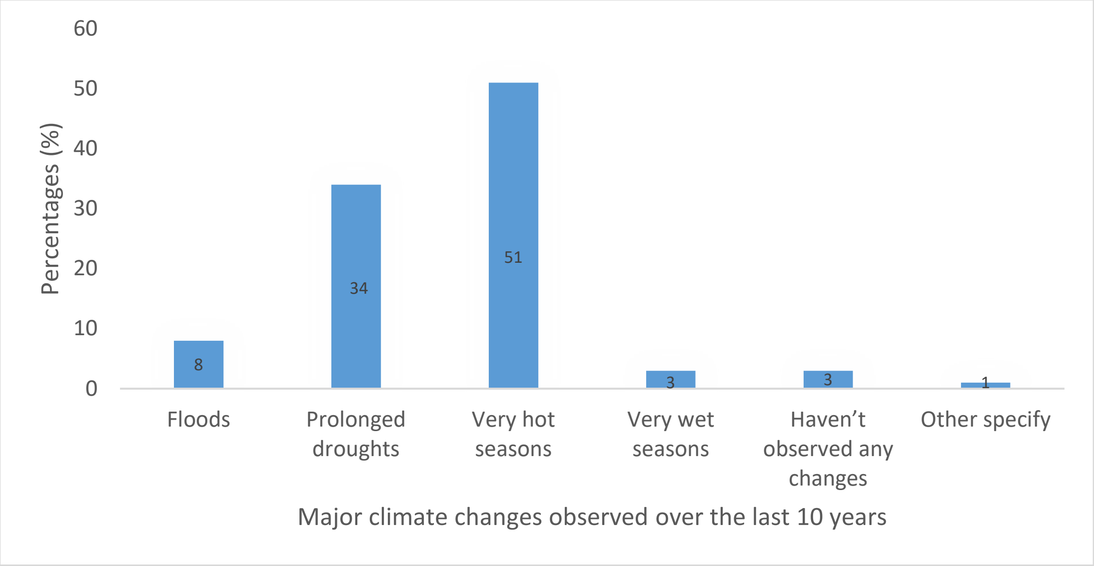

Figure 5: Farmer observations of climate change and its impact

5.6.4 Smallholder farmers' adaptation strategies to climate change and variability

Adaptation to climate change and variability by applying indigenous knowledge was the main coping and adaptation strategy in Nkomazi (65%) (Table 8). A combination of changing dates of planting (34%) and mixed cropping (27%) was a prevalent strategy. Building water-harvesting schemes (20%) and crop and variety diversification (19%) were also carried out the smallholder farmers. Adaptation through the assistance of extension officers was the least common strategy used by Nkomazi smallholder farmers (16 %) (Table 8). However, it is important to note the importance of social beliefs in climate adaptation, as they are the basis of indigenous adaptation strategies to climate change and variability.

Table 8: Smallholder farmers' adaptation strategies to climate change and variability

		Percent (%)
How did you adapt to those changes	Applied indigenous knowledge	65
	Assistance of extension officers	16
	Didn't do anything	17
	Other	2
Which indigenous adaptation measures have you used to deal with the changing climate	Crop and variety diversification	19
	Changing dates of planting	34
	Built water harvest scheme	20
	Mixed Cropping	27
	Total	100

5.6.5 Indigenous climate forecast indicators in Nkomazi Local Municipality

Smallholder farmers in Nkomazi local Municipality predict and assess indigenous climate forecast through experience and locally observed climate indicators such as animals (31%), plants (26%), atmospheric (23%) as well as human ailments (20%). As indicated in Table 9, a most of the farmers (31%) acknowledged the reliability of animal indicators for their farm production, whilst only 20% used human ailments for rainfall prediction in that area.

Table 9: Indigenous climate forecast indicators in Nkomazi Local Municipality

Indicators	Percent (%)
Animal indicators	31
Atmospheric indicators	23
Plant indicators	26
Human ailment	20
Total	100

5.6.6 Sources of climate change information that the farmers relied upon

While most of the respondents reported having observed the climatic changes on their own, farmers to farmers support were the most common source of information (31%) followed by radio (18%) (Table 10). These sources included the use of television (15%) with extension officers (10%) and internet (7%) at the lowest.

Table 10: Sources of climate change information that the farmers relied upon

Response	Percent (%)
Radio	18
Internet	7
TV	15
Farmer to Farmer	31
Family member	10
Extension officer	10
Other	9
Total	100

5.6.7 Relationship between gender and IKS reliability

The results show a high number of female farmers (51%) who relied on IKS as compared to male farmers (27%) (Figure 6).

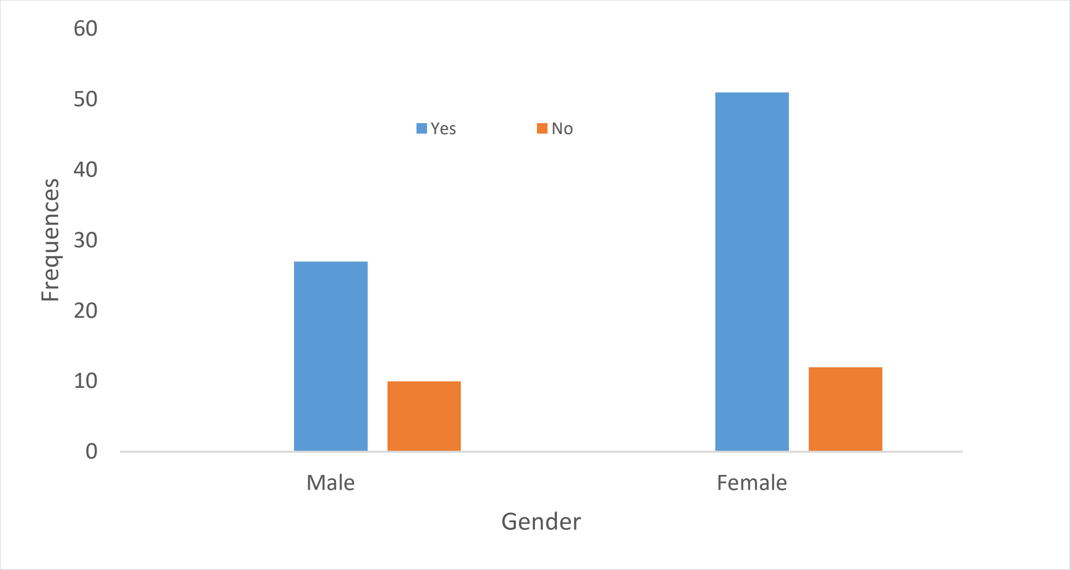

Figure 6: Relationship between gender and IKS reliability

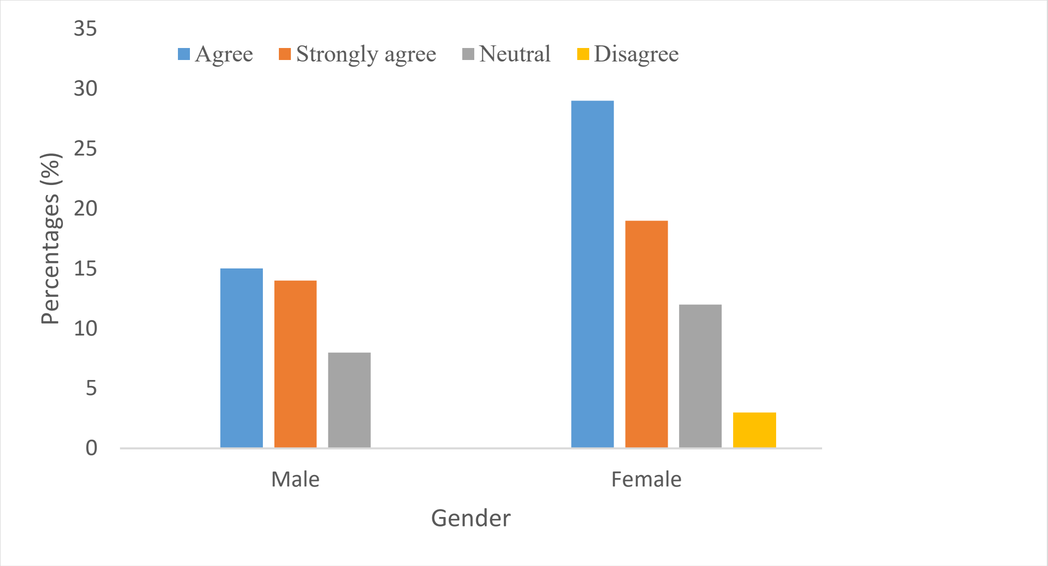

Figure 7: Relationship between gender and IKS reliability

Figure 7 highlight 29% of female farmers to have agreed that the application IKS has made a difference in their crop production, whilst only 15% of males had agreed to it (Figure 7).

5.6.8 Forecast for 1993/2008 rainfall variability in Nkomazi Local Municipality

The average annual rainfall variation of Nkomazi Local Municipality ranges from 40 mm to 700 mm (Figure 8).

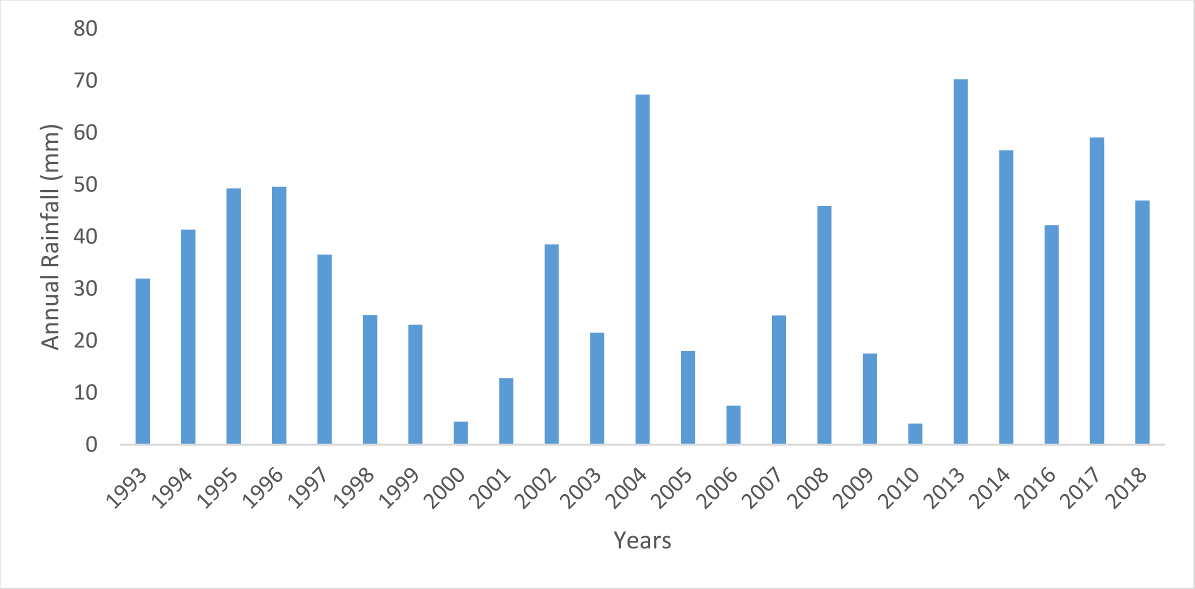

Figure 8: Average annual rainfall in Nkomazi Local Municipality

5.6.9 Forecast for 1993/2008 temperature variability in Nkomazi Local Municipality

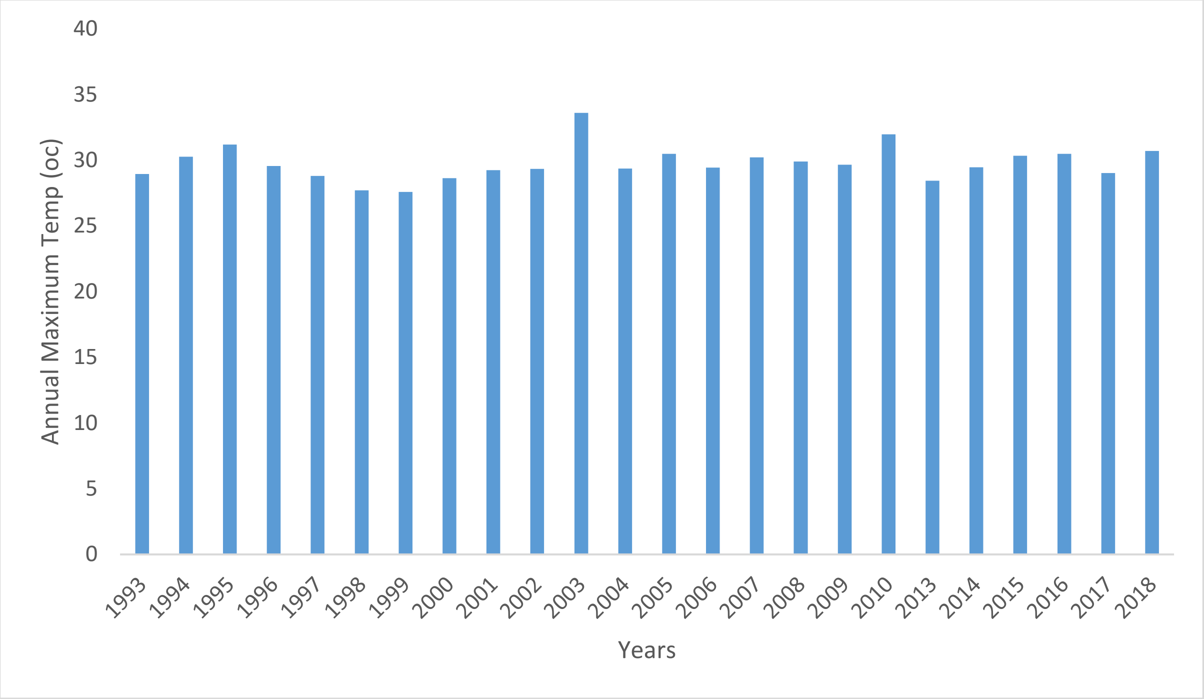

Figure 9: Annual average maximum temperature for Nkomazi Local Municipality

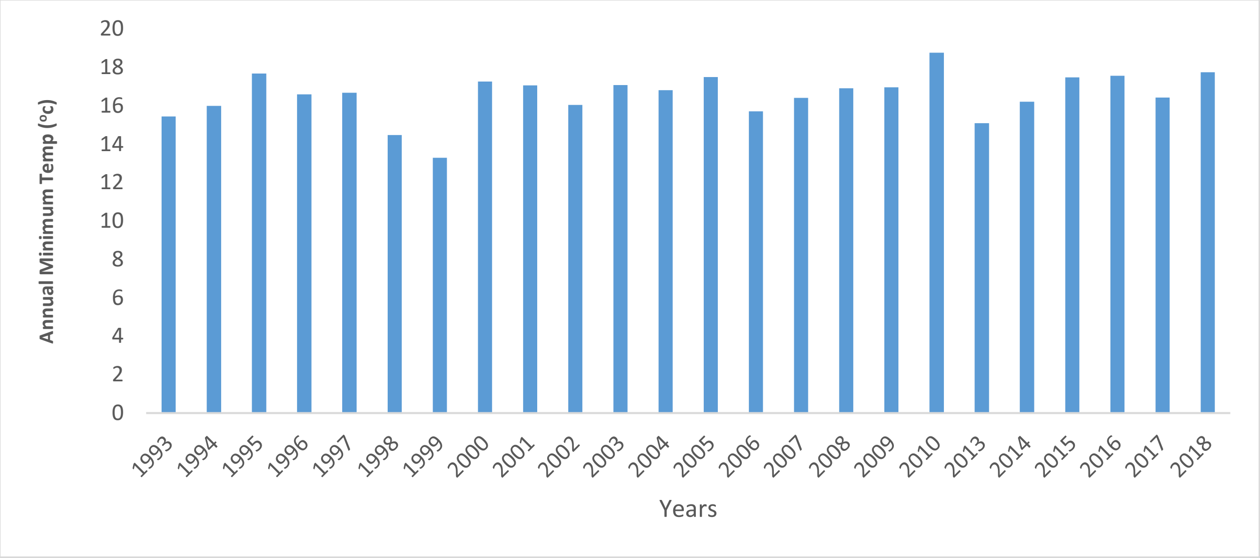

Figure 10: Annual average minimum temperature for Nkomazi Local Municipality

5.7 Discussions

5.7.1 Impacts of climate and weather changes in Nkomazi

Some of the obvious climate change impacts in the area was the disappearance of some plant and animal species they used to have as climate indicators and crop failure (Figure 4). The farmers revealed that seasonal weather patterns have changed, they no longer receive rainfall as before, and they start to experience hailstones without forewarning resulting in devastating their crops. In agreement with these findings, Rankoana (2016) also highlighted that Limpopo smallholder farmers have experienced erratic rainfall patterns as well as prolonged droughts affecting their crop production. Therefore, this means that the local observations on climate change impacts are a universal challenge for indigenous smallholder farmers.

Temperature increase in the Nkomazi region is one of the effects that affect both human beings, livestock and crops (Figure 5). Notably, smallholder farmers have experienced environmental changes such as prolonged droughts as well as too hot seasons leading to drying up of wetlands and spring water. The respondents highlighted these effects as indicators of climate change. In this study, climate change is also perceived as changes in rainfall patterns as well as temperature. There are observations of a severe increase in temperature traced back to the year 2010, which are responsible for excessively very hot seasons.

Similarly, smallholder farmers from Nessa, Mulanje, Malawi have experienced a reduction in rainfall since 1971 with increasing temperatures (Kalanda-Joshua *et al.*, 2011). However, some of the participants were of the view that these impacts are due to angry ancestors and is also a punishment from God.

5.7.2 Smallholder farmers’ uses of IKS in climate change adaptation

Access to accurate weather forecast is very important when it comes to planning and decision making on crop management. A majority of Nkomazi smallholder farmers uses IKS on their agricultural activities however; some have raised some concerns as some indicators are disappearing due to climate change. The respondents stated that *"We do wish to apply some of the scientific techniques, but we find it hard to understand the terminology, hence we sometimes rely on radio for some hazardous warning such as a flood."* Tanzania smallholder farmers also raised such concerns, as they revealed that they relied more on IKS than on seasonal climate forecasts (SCFs) due to the uncertainty about SCFs despite its availability and need to use it (Elia, Mutula and Stilwell, 2014). Rogers (2003) further emphasises the virtual advantage and observability as a key factor in the adoption of innovations.

During the focus group discussions, the smallholder farmers further highlighted that things have changed from the past.

Farmers used to know when climate indicators predicted a good season but these days it is hard to tell because some of those indicators have disappeared due to climate change and variability. Therefore, as a coping strategy, the farmers plant crops when they see enough rain falling in that season, however, the fear of crops not reaching maturity is always there as rainy seasons are now short.

5.7.3 Usefulness of Indigenous Knowledge Systems in Agricultural planning

Importantly IKS can be applied in climate change adaptation. A study conducted in the Eastern Cape, South Africa on application of indigenous knowledge systems in water conservation and management, revealed that local people employ indigenous based practices such as water harvesting and water conservation methods to improve water preservation in fragile soils (Mahlangu and Garutsa, 2014). Nkomazi smallholder farmers are no different. These farmers heap trash and soil around plants while weeding and make bands as a technique to reduce soil erosion and water run. The farmers said to have used this technique for the longest time and it has worked for them.

Figure 11: IKS techniques used by Nkomazi smallholder farmers

During the focus group discussions, the smallholder farmers also highlighted that they use maize stalks and elephant grass (Figure 11) for soil moisture conservation and add manure after decomposition when mulching, and enhance soil nutrient through adding manure from their livestock (goats, chicken, and cattle) and crop residues like kitchen waste/refuse.

More techniques were further observed in Kenya where smallholder farmers used food preservation methods such as sun drying, honey, fermentation, and herbal plants to ensure food security (Naanyu, 2013). Additionally, majority of farmers in Nkomazi stated, *"We employ measures such intercropping and diversification techniques, seed selection, no-tillage technique for soil conservation and mixed methods to avoid the risks of drought and climate change."* Hence, early planting is one of the pillars for better production especially for rain-fed agriculture; therefore, farmers often take advantage of the early rains, which are known for lessening pest and disease incidences leading to high yields.

Additionally, Nelson (2015) observed that IK in rural settings is used to predict weather forecast, soil fertility, water detection with other events interpreted from animal behaviour such as birds as well as vegetation changes. Nkomazi smallholder farmers observed cloud accumulation and animal behaviours such as cows in the veld as an indication for rain in a few hours or a day. However, such climate indicators are used for short-term planning for the rainy season, this then results to smallholder farmers being unable to predict and plan for some threatening weather events such as drought, black frost, floods, hailstorms and strong dry winds. These are some of the weaknesses and challenges Nkomazi farmers face due to lack of long-term IKS signals to predict weather and other upcoming climate events.

5.7.4 Uses of IKS climate forecast indicators for weather prediction

The different climate indicators used to predict rainfall in Nkomazi are given in Table 9. Nkomazi farmers highlighted that they rely more on IKS than conventional science. According to Kalanda-Joshua *et al* (2011), Nessa smallholder farmers are no different as they also highlighted that they rely on their indigenous knowledge for farm-level decisions. Nkomazi farmers observed indicators such as the behaviour of some fauna and flora, temperatures, certain type of winds as well as moon phases. Chang'a *et al.*, (2010) further highlighted the use of indigenous knowledge in seasonal rainfall prediction in Tanzania. The findings revealed that the farmers observed the flowering of specific plants such as Mihemi and Mikwe tree between July-November to signal a good rainfall season, as well as the behaviour of Dudumizi bird. Nkomazi smallholder farmer has also observed that clouds formation as an indicator for rainfall. The farmers stated that grey clouds at a low altitude means lots of rain coming, whilst whitish darker clouds at a higher altitude means a lot of rain accompanied by lightning, thunder or even hail.

5.7.5 Sources of climate change information

The responses from smallholders highlighted that some of the daily, weekly, monthly and seasonal weather forecasts, as well as climate change and variability were mainly from other sources they could rely on. During the focus group discussions, smallholder farmers revealed that the dissemination of climate and weather information methods widely used in Nkomazi included village meetings, exchanging information and advice with other farmers. These findings are similar with those of Ubisi *et al.,* (2017) who reported that majority of smallholder farmers in some parts of Limpopo relied on radio as their main source of climate information as well as Lyamchai *et al* (2011), who reported that almost 75% of respondents in Lushoto accessed climate information through radio. However, there is great potential for improving the dissemination of climate and weather information from other sources such as the use of a mobile app.

5.7.6 Indigenous Knowledge systems reliability

During the focus group discussions, a majority of farmers acknowledged the using of indigenous knowledge in everyday activities, especially for crop production activities to spirituality. The study findings highlighted that female farmers mostly rely on IKS as compared to male farmers (Figure 6), this might be due to the fact that female farmers are mainly custodians of crop production in rural areas as their meant to stay home and take care of their families while men go look for hard labours else were. Similar findings were observed in

Limpopo province South Africa, were the majority of crop producers were mainly females as compared to male farmers (Ubisi *et al.*, 2017).

Furthermore, Nkomazi farmers revealed that IK was still vital to them, yet, scientist think it is somewhat backward. Over the years, *"we have used IKS successfully especially in preparation for drought seasons, through planting fast-maturing crops, changing planting mode and weeding patterns, seed storage, seed selection and changing to early planting days"*. However, these farmers also noted that adapting indigenous knowledge to climate change effects is a challenge. Among all other challenges, accompanying IKS reliability is the lack of a reliable source of income as well as filling the inter-generational gap among IKS holders and the young generation.

5.7.7 Modern science weather Forecast for 1993/2008 rainfall variability

The trend analysis of the annual rainfall data for Nkomazi local municipality is shown in Figure 8. The analysis shows a rise and fall of rainfall in the municipality from 1993 to 2018. The lowest rainfall amount was recorded in the year 2000 and 2010 (40 mm/year). The highest amount of rainfall was recorded in 2013 (700 mm/year). These findings are in agreement with what was highlighted during the focus group discussions as farmers stated to have experienced drought seasons in year 2000 and 2010. *"We had experienced droughts all year round with our dams and rivers drying up as a result of little rain received."* Majority of the respondents interviewed have stated that the amount of rainfall received is becoming less, it is no longer, as it used to be like during their childhood years, however, some highlighted that the amount of rainfall is increasing especially since 2013. The farmers believed that this causes of decreased rainfall were due to people's behaviour that had led to God punishing them, the key informants stated that it was due to angry ancestors as people no longer practice their rituals. The farmers further revealed that the last period of good rains in the area was in the past 30 years since then the rain has been unpredictable. According to FAO (2013), the distribution of rains have a huge impact on crop production, if too much rain is received in a short period which might be more than half of the seasonal rain might result in soils being waterlogged, floods and plants not growing well. Therefore, rainfall distribution in an area says a lot about crop production in a season. Over the period 2013-2018, the seasonal trends show an increase in rainfall amount as compared to 2005-2010. The driest year was 2013 with an annual mean rainfall of 700 mm.

5.7.8 Modern science weather forecast for 1993/2008 temperature variability

The participants in the study were able to recall and mapped out years extreme temperatures in the area, but could hardly recall events after the year 1995. However, scientific weather forecast played an important role in recording the empirical data from 1993-2018. In general, Figure 9 shows the annual average maximum temperature for the Nkomazi Local Municipality for the 1993-2018 period (25 years). This data was analysed for trends and variability, then compared with the participants' perceptions. From the Komati weather station, 2003 had the highest temperature increase (34^0C) which led to smallholder farmers experiencing excessively hot and dry summer. The smallholder farmers further elaborated that due to the prolonged droughts with limited rains they have experienced crop failure, livestock deaths (Figure 4) as well as deteriorating water levels in dams and rivers. Kalanda-Joshua *et al.*, (2011), supports these observations, as similar findings were recorded in Nessa, Malawi. The smallholder farmers also reported that remarkable temperature changes were between 2010 and 2013, similarly to the scientific records from SAWS Komati weather station.

Figure 10 shows the annual minimum temperature trends from 1993-2018 in Nkomazi Local Municipality. The analysis highlights that 2010 (19^0C) had the highest minimum temperature followed by 1995 (18^0C). The results also indicate that 1999 (13^0C) had the lowest minimum temperature followed by 2014 (15^0C). Similarly, minimum temperature data analysed in figure 8 was supported by the farmers' observation in the area. During the focus group discussions, smallholder farmers revealed that since the year 2010, the area (Nkomazi) is becoming warmer than in the past, minimum temperatures are no longer cool and low like before. The farmers perceive that there has been an increase in the average minimum temperatures in the past 10-15 years. These findings imply that the municipality is becoming more prone to droughts because of the increasing temperatures and reduced rainfall. *"We experience too hot temperature, even during the night were we expect to have cool temperatures, and our bodies sweat profusely and with an increase in mosquito biting."* These findings were supported by Kalanda-Joshua *et al.,* (2011), in highlighting that Nessa smallholder farmers from Malawi also observed that their area is becoming warmer than it was in the past, their results show a positive increase of temperature during 1971-2003.

5.7.9 Potential integration between indigenous knowledge systems and Modern climate science

Though the two knowledge systems are categorised differently to describe seasonal phenomena by scientist and indigenous smallholder farmers, there is an overlap between them concerning climate and weather forecast, resulting in IK being potentially useful for science weather forecasting mainly in tracking change (Hinkel *et al.*, 2007; Kolawole *et al.,* 2014). Both knowledge systems are produced through validation, observation and experimentation, signifying that there is a meeting point between them. Furthermore, Hinkel *et al.,* (2007) highlighted that IK is without any regulation and involves a measure of spirituality that is lacking in the scientific forecast. Therefore, these findings entail the necessity for a suitable platform where scientist and indigenous farmers can work together to formulate adaptation strategies against climate variability and change.

The study findings from focus group discussions revealed that Nkomazi smallholder farmers were willing to integrate modern science into their indigenous forecasting methods. The willingness of these smallholder farmers to integrate their information could work well with modern science, as it will allow them to come up with weather forecast that would be coordinated with the smallholder farmers' priorities and would be more acceptable to them. For example, science forecast focuses on coarse spatial analysis not the risks in drier sub-regions in moist regions, allowing integration of IK of spatial variability in climate patterns for the identification of areas at risk for drought

Rural smallholder farmers do not fully embrace scientific forecasting due to a couple of reasons such as lack of ownership, which has contributed, to limited usage of meteorological information disseminated by the government. These effects have resulted to climate scientist being under pressure to the continued and participatory learning with smallholder farmers as users of the disseminated scientific information and encourage effective outreach programmes for the information to realise its full potential.

However, as highlighted by Kolawole *et al (*2014) and Ogallo (2010), there is a need for a built-up working strategy between scientist, policymakers and indigenous smallholder farmers. This will help create a partnership that will capitalize on the usage of available climate information using indigenous climate indicators and the use of other culturally relevant analogies for climate communication. This can be achieved using media/internet, contact workshops and public lectures. This strategy will assist climate scientists in the developing new means of communication for their weather forecast, where indigenous smallholder farmers can partake as agents and consumers of the knowledge system so to develop an interest and understanding on the scientific weather forecast

Though many praises are going up to indigenous knowledge systems, it should be noted that indigenous knowledge has its challenges. The main IKS challenges highlighted by Nkomazi smallholder farmers involve the disappearing of their indigenous climate indicators due to climate change and variability, negative perception about IK, lack of IKS documentation for future reference, as well as the erosion of culture and tradition due to modernization. "*The fact that people no longer perform their traditional rituals for their ancestors and no longer praying to God for forgiveness of sins are the main reasons we experiencing prolonged droughts without rains".* Moreover, the farmers stated that IK is perceived as the success of some agriculture-related projects, and climate scientists tend to view reliance on IK for weather forecasting with scepticism. For these reasons, when it comes to the application of IKS our country is still at the knowledge stage instead of the conceptual stage, where this knowledge system is implemented and used for smallholder farmer productivity. Therefore, the farmers suggested that there should be some form of engagement with them before implementing new developments especially when it comes to indigenous knowledge.

In agreement to these findings, Onyango (2009), highlighted that due to modernization, indigenous knowledge is viewed as "backward impostors", whilst scientific knowledge is considered superior unlike the 'backward' knowledge indigenous farmers rely on.

Additionally, IKS needs to be documented in a context of weather forecasting to keep its relevance to modernization. This expands on the concern raised by Lantz and Turner (2003), that IK is orally disseminated by its custodians who tend to have short term memories, though they need to rely on it. Therefore, documentation of IK in English and local language becomes very important for sufficient information sharing and preservation of indigenous climate indicators that are useful to smallholder farmers. Notably, the smallholder farmers' indigenous knowledge is in-depth and its custodians that are mainly elders are dying without passing down the knowledge.

The smallholder farmers perceived that climate change has affected some of their indigenous climate indicators, limiting their confidence in relying on those indicators as a source for their farm practice decision making. Over the past decades, scientific knowledge has overtaken indigenous knowledge in agricultural practice. *"In the past, early warning systems on upcoming climate shocks as well as disasters were traditionally channelled through the use of cultural and religious methods such as songs, poems and oral literature. Unfortunately, these methods have lost recognition in the context of adapting to climate variability and change."*

Elaborating from these findings, Osbahr and Allan (2003) have noted that in the past decade, there has been an emerging view emphasising the use of indigenous knowledge as an important component for agricultural practices, highlighting that scientific knowledge need to enhance indigenous knowledge instead of modernizing it.

Although there is a shift heading to IKS recognition in climate change adaptation in smallholder farmers' farm practices, there is evidence showing instability on increasing temperatures and rainfall variation in the area (Figure 8, 9 & 10), resulting in smallholder farmers losing confidence on IK hence increasing farmers vulnerability to climate change. Additionally, the farmers highlighted that the use of scientific knowledge on their farm practices have been a problem because it does not incorporate indigenous knowledge, which they are used to. However, 88% of the Nkomazi smallholder farmers were willing to apply scientific climate forecast on their day-to-day farm-level decision making, only when these weather forecasts are integrated with their local indigenous forecasts to increase their adaptive capacity.

5.7.10 Advantages of integrating IKS and modern science

In local communities, over the years climate change has made it difficult for smallholder farmers who mainly rely on their IK for farm-related decisions climate change adaptation. Indigenous knowledge is an important element in the development process and the livelihoods of farmers. However, there is a pressing need to make provision for scientific information to assist the process of policy and decision-making. For such integration, science alone cannot do it but can assist in facilitating the platform for indigenous knowledge to be incorporated decision-making and adaptation strategies. According to Mapira and Mazambara (2013), incorporating these two knowledge systems should not be done at the expense of the other. Scientific knowledge should complement rather than compete with indigenous knowledge. However, the argument on how IKS can be best integrated with modern science is one of the most important questions facing local communities and policymakers.

Regarding smallholder farmers in Nkomazi Local municipality, farmers highlighted that they are willing to accept and apply modern science on their farming systems only if it is integrated with what they already know. During the focused group discussions, Nkomazi farmers acknowledged that the integration between the two knowledge systems would help improve their farming practices, concerning their planting and harvesting practices. According to Sraku-lartey (2014), integrating these two knowledge systems needs careful attention, as it will require multiple changes to occur between government and institutions. However, it is important to keep in mind that scientific and indigenous knowledge is made up of different methodologies and ideologies but can be very beneficial to each other.

From the study findings, it has been observed that the integration between IKS and modern science can be achieved by tying up information from both spheres of knowledge in a logical and meaningful manner. Institutions such as the Department of Agriculture can collaborate with local smallholder farmers through gathering scientific and indigenous climate information and make it readily available and accessible, using a mobile app. This integration will assist in coming up with integrated solutions for climate change adaptation. The study findings in table 10 highlighted that the Nkomazi smallholder farmers' source of climate information is mainly from farmer to farmer advice (31%), radio (18%) and TV (15%). These findings reveal that though the smallholder farmers rely mainly on their IKS for farm practices, they also do use scientific information such as daily temperatures and rainfall variability disseminated on radio and TV, which shows the integration in the use of information from the two knowledge systems by the Nkomazi smallholder farmers. Therefore, creating a platform for IKS and modern climate science information to be available and accessible to rural smallholder farmers will be of benefit, as farmers will have access to use sustainable methods drawn from what is currently used and what can be added from science. As the findings above reveals that farmers are already using or integrating both knowledge systems

5.8 Conclusion and recommendations

This study has demonstrated how Nkomazi smallholder farmers utilise the indigenous knowledge for decision making on their farms as well as to forecasting weather conditions in their area. These farmers have relied on their indigenous knowledge for their farm practices in many generations. Their key indigenous climate indicators involved animal behaviour, plants, and atmospheric as well as human ailments. It was also established that climate variations from scientific forecast were documented by the South African Weather Services (SAWS) Komati station from 1993 to 2018. The results from minimum and maximum temperatures showed an increase in temperatures and a decline in rainfall especially in 2010.

The study findings also revealed some of the challenges smallholder farmers face in utilising scientific weather forecasts, which were mainly lack of understanding and not specific to their local area. However, lack of documentation was another problem in IK reliability and disappearance of climate indicators due to climate change among others. During the focus group discussions, farmers highlighted that IK is passed down from generation-to-generation through oral expertise which makes it hard to sustain and preserve it for future generations. Therefore, there is a need for systematic documentation and establishment of a framework for integrating indigenous knowledge and scientific weather forecasts for future generation.

The smallholder farmers in the area can achieve such integrations through the establishment of proper information dissemination network that will be easy to understand. Dissemination channels such as community-based organisations, local schools, use of mobile App and local churches especially in highly religious churches as well as integration of weather forecasting for both knowledge system into the departments of agriculture policies would greatly enhance the farmers' food security. Importantly, for easier understanding of the scientific weather forecasts by the majority of the smallholder farmers, the disseminated weather forecasts information should be translated into their native language. Therefore, there is a need to integrate the smallholder farmers' indigenous knowledge and scientific weather forecasts by having both scientific and local indigenous custodians working together to produce accurate and comprehensive weather forecasts for better production and adaptation to climate change. The study suggests the integration of indigenous knowledge systems with modern climate science, by getting the indigenous information in the context and format that indigenous people are familiar with, can accept and easily understand and put it in a modern information system such as mobile Apps that will generate and share both indigenous and modern agricultural-climate change science.

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Chapter 6: Spatial distribution of indigenous climate indicators and mobile app development for rural smallholder farmers

6.1 Abstract

This study aimed to map and analyse the spatial distribution of the indigenous climate indicators used by smallholder farmers in Nkomazi Local Municipality. It also aimed at developing a mobile app for collecting, transmitting and documenting indigenous knowledge information and modern climatic data for rural smallholder farmers. The Poynton model was also used to predict the distribution of the plant and animal indicators if the temperature continues to rise by at 5^0C. Twelve villages were sampled with 100 participants applying both qualitative and quantitative research methods. ArcMap 10.7.1 was used to map the distribution of indigenous climate indicators in these villages, and SPSS 25.0 was used to analyse the quantitative data. Qualitative data was analysed through thematic analysis. Mostly used indicators smallholder farmers relied on for weather predictions included animals (31%) followed by plants (26%). The Poynton model predicted negative results with a 5^0C temperature increase, meaning that if the hot temperatures continue rising, the farmers' indigenous indicators will decline or disappear, making it difficult for the rural smallholder farmers to make informed farm-level decision. These are the negative effects climate change has on the rural smallholder farmers. Therefore, the study suggests an integration of the IKS and modern science using the mobile app developed to adapt to climate change, have access to updated agricultural information and ability to make informed farm-level decisions.

Keywords: Indigenous knowledge, climate indicators, smallholder farmers, spatial distribution, mobile app,

6.2 Introduction

Long before the introduction of conventional agriculture, IK based agriculture certified production of a variety of foods (Ogle and Grivetti, 1985). Local people, including smallholder farmers, are custodians of indigenous knowledge systems (Willett, 1993). These farmers are knowledgeable of their situations including what works and what does not work for their farming systems, their available resources and how one change impacts other parts of their system (Ubisi *et al.*, 2017). Indigenous knowledge is vital for resource-poor agriculture, as it enhances food security for smallholder farmers at a household level. Indigenous agriculture is based on the understanding local people have and it changes through innovativeness and creativity as well as through contact with other local and international knowledge systems (Warren, 1991). In rural settings, indigenous knowledge systems represent mechanisms to ensure minimal livelihoods for smallholder farmers. Resource-poor smallholder farmers always planned for their agricultural production and conserve natural resources with the instruments of indigenous knowledge (Naanyu and Macopiyo, 2013). This development has been a matter of survival to indigenous people in rural settings and has been representing generations of experience, careful observations and trial and error experiments (Akullo, Kanzikwera and Birungi, 2007). However, some of the challenges smallholder farmers face are limited resources in terms of capacity due to their geographical location (far distances between the areas allocated to one extension officer) and thus efficiency (time versus transport) to reach the farmers as well as the negative impact of climate change and lack of IK documentation. Therefore, these factors highlight the importance of creating an information dissemination network that will also preserve IKS for weather forecasting within local municipalities.

In the developing world, mobile communications technology has been one of the most common ways of conveying messages, services and data (Qiang *et al.,* 2011). Mobile App development for rural smallholder farmers holds great potential for advancing development. Mobile application can make life easier for rural smallholder farmers through transmitting market information, direct links between farmers, suppliers, and buyers, as well as climate and disease information (Costopoulou *et al.,* 2016). Therefore, this creates a great opportunity for the integration of indigenous knowledge systems with modern climate science by getting the indigenous information in the context and format that indigenous people are familiar with, which they can accept and easily understand. More so, modern information systems such as mobile applications could be used to generate and share both indigenous and modern agricultural-climate change science.

Mobile App can be used for the collection and transmission of IK information and modern climatic information for smallholder farmers' agricultural sustainability and rural development, and to provide practical use of IKS. Studies have reported that a majority of farmers have access to and utilize mobile phones (Costopoulou *et al.,* 2016). In actual fact, they are already receiving some kind of climate change information such as weather from their mobile phones, especially in India (Lindh and Haider, 2010). There are a lot of key advantages associated with mobile phones: instant and convenient service delivery, voice communications, accessibility and affordability (Qiang *et al.,* 2011)**.**

The development of the mobile App for rural smallholder farmers will bridge the gap and act as a key possible driver to reduce smallholder farmers' vulnerability to climate change and enhance resilience to improve productivity as it will focus on improving agricultural production. This App will operate with functions such as providing market links, increasing access to extension services, climate and market information and IKS documentation. The App will be accessible to smallholder farmers, extension officers and produce buyers. This mobile App will provide significant economic and social benefits among smallholder farmers by reducing product losses; improving agricultural production and providing the opportunity to make our developing country more globally competitive. The potential development of the mobile App lies in its ability to provide access to services, useful and relevant information.

6.3 Description of the Study area

The study was conducted in twelve villages of the Nkomazi Local Municipality, Mpumalanga province, within Ehlanzeni district (25.7097° S, 31.7195° E). Nkomazi Local Municipality is found on the eastern part of Ehlanzeni District Municipality of Mpumalanga Province. The Nkomazi Municipality is 4786.86 km² in extent, which is 23% of the Mpumalanga Province and Ehlanzeni District Municipality landmass respectively (Census, 2011). This Province receives summer rainfall, with mild winter and hot humid summer (Census, 2011). The rainfall received varies between approximately 750 and 860mm (IDP, 2014)

6.4 Methodology

Documentation, identification and analysis of local climate indicators used for seasonal forecast in Nkomazi Local Municipality were conducted. Majority of participants in Nkomazi were mainly Swati and Tsonga people. Twelve villages (Ntunda, Mzinti, Mbuzini, Jeeps Reef, Driekoppies, Magogeni, Tonga, Boschfontein, Kamaqhekeza, Buffelspruit, Sibange and Madadeni) were sampled based on the accessibility to the villages and their willingness to participate. Hundred participants were randomly selected based on their farming activities, who were mainly crop producers and the age factor contributed as well, only people who were 50 years and above participated in this study. ArcGIS 10.7.1 was used to map the geographic distribution of the indigenous climate indicators used by smallholder farmers in those villages. To create a prediction model with increasing temperature, Poynton model was used.

6.5 Data Collection

The study was based on the primary data collected in Nkomazi Local Municipality, Ehlanzeni district. Qualitative method was used to collect data through key informant interviews and eight focus group discussion made up of 8 to 12 participants. Each session had at least one elder known for rain prediction expertise and considering age as well, participants were 50 years and above. Discussions were first held separately between men and women to ensure active participation especially from women who were not free to express themselves in the presence of men due to cultural norms. Also because different genders may have different IK used for different purposes.

Qualitative research method was employed mainly to seek farmers' perceptions of climate change, understanding their indigenous knowledge systems, their indigenous climate indicators, and their responses to climate change as well as the role of IK on their farming systems. This method was found appropriate for this study as smallholder farmers were regarded as experts of their situation and have first-hand experience, so we aimed at finding meaningful answers and experiences of farmers concerning their indigenous knowledge systems on crop production.

Focus group discussions were conducted and facilitated by a trained facilitator. A recorder and pictures were used to document indigenous climate indicators used by smallholder farmers over the study area in each session. A written and oral consent was requested from farmers before the beginning of each session. Qualitative data obtained from the focus group discussions and key informant interviews were thematically analysed. Data was compiled, transcribed and categorised into different trends, themes, concept and patterns.

6.6 Data Analysis

A Statistical Package for Social Sciences (SPSS) version 25.0 and Microsoft excel 2010 statistical package was used for questionnaire data analysis. Focus group discussions were analysed through content analysis by identifying themes, concept, patterns and trends. ArcMap for mapping the distribution of IKS in the different villages was also used.

6.7 Results and Discussions

6.7.1 Socio-economic profiles of the respondents

The study findings revealed that there were more female (63%) respondents than males (37%) in Nkomazi Local Municipality (Figure 12). The participants' ages ranged from 50 to 90 years. About 10% of the smallholder farmers had primary education, another 10% with matric and only 2% had post-secondary education with diplomas. Majority of the farmers relied on farming activities (63%) as their main source of income, with an average of R1500-R2000 (24%). Only 4% of the participants relied on full-time job for their income

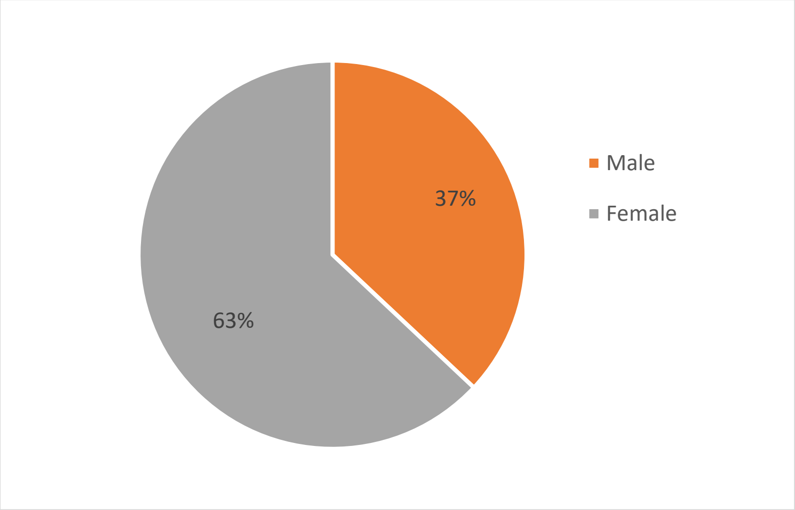


Figure 12: Percentages of Male and females respondents

6.7.2 Seasonal calendar with months and activities happening

Table one below shows months of the year recorded in English and siSwati, as well as activities taking place in agricultural timing as used by Nkomazi smallholder farmers before the influence of climate change. The siSwati names of the months are as derived from interviews with the farmers.

Table 11: Months of the year with agricultural activities

Months of the year in English	Months of the year in siSwati	Agricultural activity
• January	• Bhimbidvwane	• Harvesting season (maize)
• February-March	• iNdlovana	• Harvesting season (maize)
• March	• iNdlovulenkulu	• Harvesting season (maize)
• April	• Mabasa	• Drying up the harvested maize
• May	• iNkhwenkhweti	• Drying the harvested maize and storing it

		for next season, while planting vegetables
• June	• Nhlaba	• Planting season for vegetables
• July	• Kholwane	• Store harvested maize grain for planting season
• August	• iNgci	• Start with field preparation while waiting for spring rains
• September	• iNyoni	• Expecting early spring rains for soil preparations
• October	• iMphala	• Continue with soil preparations and tillage
• November	• Lweti	• Planting season of maize mainly
• December	• iNgongoni	• Continue with planting season and soil preps

During the focus group discussions, smallholder farmers highlighted the different agricultural activities happing each month for their crop production. However, these farmers did highlight that a lot has changed; they no longer do things like before, due to prolonged droughts and delayed rains. Some farmers stated that they have noted some changes in some plants species expected to shade their leaves at a certain period around August and grow new leaves by November. This was observations were used as for detecting rainfall season. This period was used to prepare fields for maize plantation, as farmers would expect wet season.

6.7.3 Events documented from indigenous knowledge

Smallholder farmers revealed some of the major events they experienced from 1970-2018. This information was reconstructed through the participants' memories (Table 12). However, during the discussions, there were debates on whether the weather changes were due to angry ancestors, punishment from God or just a natural climate change process. Table 12 further highlights some events memorised by farmers.

Table 12: Indigenously documented events

Years	Event took place
1970-1979	• Had rainy seasons on time with good crop production; still had the indigenous climate indicators available for weather predictions. Temperature and rainfall were normally distributed with normal weather seasons, winter was cold and summer was hot as expected.
1980-1989	• Had experienced extreme drought in the country, had yellow maize donated from outside countries to cope with food scarcity
1990-1999	• Started experiencing prolonged hot seasons, with emergence of new crop species such as purple sweet potatoes, macadamia nuts as well as new mango fruits. With the emergence of foot mouth disease on livestock
2000-2011	• Increased droughts, as well as floods, were experienced during this period, with a change in rainfall patterns and rivers starting drying-up as well as floods around 2006. Started having malaria outbreaks cholera.
2012-2018	• Prolonged droughts, loss of crop production due to water scarcity with a lot of Malaria outbreak cases leading to death of people

Nkomazi farmers noted that during the 1970s rainy season were on time with a normal temperature distribution allowing them to have good production. However, during the 1980s *"the country was hit by an extreme drought that we could produce enough maize for our sustainability, ended up getting yellow maize donated to us by our neighbouring countries*”. Furthermore, the farmers revealed that in the 1990s, they started observing prolonged hot seasons with new crops species emerging such as purple sweet potatoes, macadamia nuts as well as new mango fruits, as well as the foot mouth disease on livestock. In the early 2000s, the respondents noted that though they had droughts seasons they were also hit by floods as well as malaria and cholera incidences escalating, with local concoctions no longer effective. These effects continued until around 2012 causing waterborne diseases such as diarrhea. The farmers further highlighted that the extreme weather events such as increased temperatures lead to major crop losses as well as drying of wetlands and huge damage on infrastructure such as schools and roads from floods. *"We have observed some wetlands that used to retain water for long but now are exposed, as well as the disappearance of some plants and animal, were used for climate forecasting; these are the obvious indicators of climate change".*

6.7.4 South African historical climatic recorded climatic events

The limitation to available long-term meteorological station with sufficient coverage to give sufficient illustrations of the variations of a region's climate in both space and time has been the greatest restriction to the recording of historical climate. However, South Africa is better off, as it has a good network of temperature and rainfall recording stations compared to the rest of Africa. Therefore, this makes it easy to do trends and variability investigations over multiple decades. (Department of Environmental Affairs, 2013). However, recently the climate trend analyses focused on few weather stations of SAWS as well as the Computing Centre for Water Resources of the Department of Water and Sanitation (DWS) in some cases also stations (Midgley *et al.,* 2016). Below are the scientific records of the South African climatic trends for 1960-2012 (adapted from; *Department of Environmental Affairs, 2013*)*;*

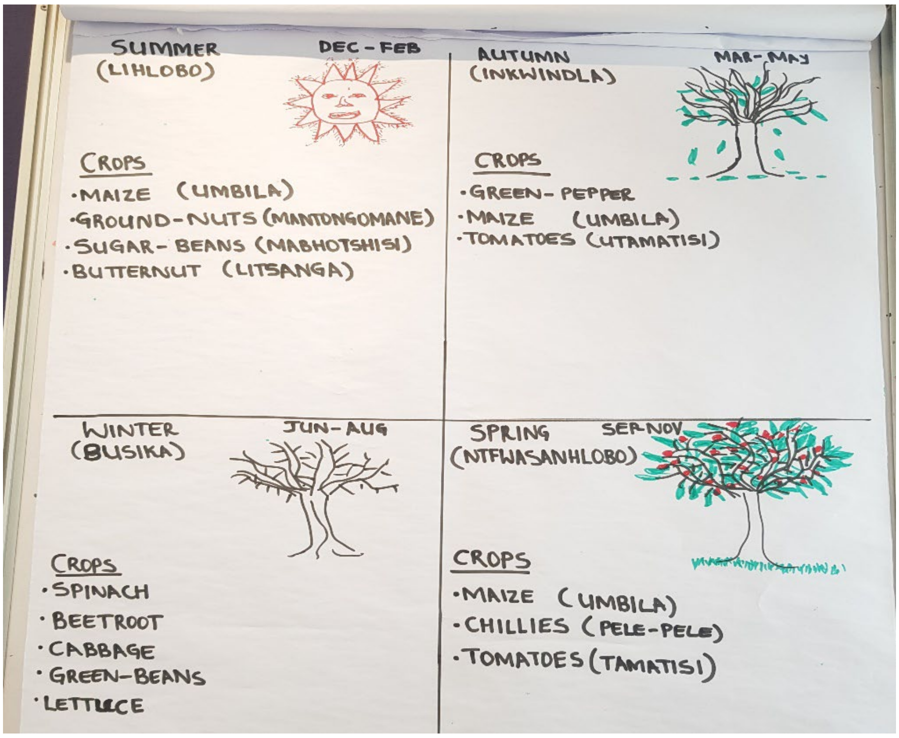
- There has been an increase on the mean annual temperatures by roughly 0.7°C which is double the observed global average reported by the forth Assessment Report of the Intergovernmental Panel on Climate Change
- Overall, there have been great decreases in cold extremes and increases in hot extremes mainly in the Northern and Western interior of the country
- There has been a shift in rainfall seasonality and intensity
- There has been a reduction in rainfall in almost all hydrological zones for the autumn months. There are fewer rainy days, which implies an increased dry spell duration as well as an increase in the intensity of rainfall events.

These records indicate that there have been changes in rainfall and temperatures over the past five decades in South Africa, as detected in the SAWS and ARC weather station data (Midgley et al., 2016).

Regarding table 12, there is a similarity of the historical climatic events observed by the indigenous smallholder farmers with meteorologists. However, the smallholder farmers highlighted that they started noticing and experiencing drought between the 1980s, while the scientific findings had records from the 1960s. This is because indigenous smallholder farmers could only respond based on their memories without any documentation. Nonetheless, both knowledge systems highlighted similar key observations, which were increased dry spells duration, change in rainfall patterns, increase on the mean annual temperatures, fewer rainy days and a shift in seasonality. Therefore, this shows the relevance of both knowledge systems, as this proves that there is a meeting point between them.

6.7.4 Smallholder farmers' seasonal calendar for crops grown in different seasons

Nkomazi smallholder farmers cultivate different crops in different seasons. During the focus group discussions, farmers highlighted some of their main crop grown in the area. This includes crops such as maize, groundnuts, sugar-beans, butternut, green pepper, tomatoes, okra, spinach, cabbage, green beans, lettuce and chillies. Figure 13 was taken during the focus group discussions highlighting the different crops grown with some in Swati names.



SUMMER DEC - FEB
(LIHLOBO)

CROPS
- MAIZE (UMBILA)
- GROUND-NUTS (MANTONGOMANE)
- SUGAR- BEANS (MABHOTSHISI)
- BUTTERNUT (LITSANGA)

AUTUMN MAR-MAY
(INKWINDLA)

CROPS
- GREEN- PEPPER
- MAIZE (UMBILA)
- TOMATOES (UTAMATISI)

WINTER JUN-AUG
(BUSIKA)

CROPS
- SPINACH
- BEETROOT
- CABBAGE
- GREEN-BEANS
- LETTUCE

SPRING SEP-NOV
(NTFWASANHLOBO)

CROPS
- MAIZE (UMBILA)
- CHILLIES (PELE-PELE)
- TOMATOES (TAMATISI)

Figure 13: Crops grown in Nkomazi Local Municipality

6.7.5 South African seasonal calendar used by extension officers

It is of great importance for smallholder farmers to make informed decisions on crop selection. Farmers should know specific crops to grow all year round, as this will assist in planning their production for the upcoming growing season. Table 13 highlights the South African seasonal calendar for crop production used by extension officers.

Table 13: seasonal calendar for crop production *(Table adapted from Arc, 2013)*

Crop	Sowing time	Transplanting time	Harvesting time
Maize	Jun. /Aug. Dec./Feb.		Sep. /Nov. Jan./Mar.
Beetroot	Jan./Feb.	Thin out at a later stage	May/Jun.
	Mar./Apr.		Jul./Aug./Sept.
	Jul./Aug.		Nov./Dec.

Green beans	Aug./Sept.		Nov./Dec.
	Oct.		Jan./Feb.
	Jan.		Apr.
	Feb./Mar.		May/Jun.
Cabbage	Beginning of Feb.	Mar.	Jun./Jul.
	End of Mar.	May	Aug./Sept.
	Jun./Jul.	Aug./Sept.	Nov./Dec.
	Aug./Sept.	Oct./Nov.	Dec./Jan.
Butternut	Aug./Sep.		Dec. — Feb.
	Jan.		Mar./Apr.
Lettuce	Feb.	Thin out 5 — 7 days after germination	May/Jun.
	Apr.		Jul./Aug.
	Jun.		Sept./Oct.
	Aug.		Nov./Dec.
Tomatoes	Aug./Sept.	Oct.	Jan. — Mar.
	Nov.	Dec.	Mar./Apr.
	Dec.	Jan.	Apr./May

Table 13 highlights the sowing, transplanting and harvesting time of some vegetables grown in Nkomazi. This seasonal calendar shows the different months of possible sowing and harvesting specific crops.

However, the smallholder farmers main concern was the forever-changing climate, stating that seasonal calendars provided by extension officers are sometimes hard to follow because now there is a shift in seasonality and they no longer receive rains as they used to, so now they plant some crops as rains come. However, The two seasonal calendars balance each other, except the fact that the scientific calendar is well documented with specific months recorded with specific activities, while the indigenous calendar is based on seasonal observations. For example, both calendars highlighted the harvesting time of the butternut to be between December-February. These observations yet again reveals the integration or meeting point of these knowledge systems. Therefore, this proves that there might be a different approach in doing but the results are the same.

6.7.5 Indigenous climate indicators used by Nkomazi smallholder farmers for weather prediction

Nkomazi smallholder farmers observe climate variability based on their experiences by interacting with the environment. The study findings highlighted that indigenous knowledge exists among Nkomazi smallholder farmers; they use local climate indicators for weather forecasting and seasonal predictions. The indigenous climate indicators used to predict weather from the twelve villages namely; Ntunda, Mzinti, Mbuzini, Jeeps Reef, Driekoppies, Magogeni, Tonga, Boschfontein, Kamaqhekeza, Buffelspruit, Sibange and Madadeni were animal behaviour, plant phenology and atmospheric indicators in weather forecasting.

Table 14: Indigenous climate indicators in Nkomazi villages

Village name	Animal indicators (%)	Plant indicators (%)	Atmospheric indicators (%)	Human ailments (%)
Tonga	13	63	0	25
Magogeni	50	17	33	0
Driekoppies	33	33	17	17
Mbuzini	64	29	0	7
Mzinti	38	31	8	23
Ntunda	14	21	36	29
Boschfontein	33	17	17	33
Kamaqhekeza	40	20	20	20
Buffelspruit	0	50	25	25
Sibange	20	0	60	20
Madadeni	43	29	29	0
Jeppes Reef	29	0	43	29
Total % per indicator	31	26	24	19

Table 14 highlights the different percentages of indigenous climate indicators used in the twelve sampled villages in Nkomazi. Out of the four categories of indigenous indicators, animal indicators (31%) had the highest percentages among the others. Smallholder farmers from Mbuzini relied mostly on animal indicators (64%) than Buffelspruit. Plant indicators we ranked second (26%), with Tonga having the highest percentages (63%), followed by Buffelspruit at 50%. However, it was revealed that some villages did not use plants as indicators for weather predictions, which were Sibange and Jeppes Reef. Atmospheric indicators were ranked third (24%) whilst human ailments (19%) was ranked lowest amongst the four categories. Similar findings were observed by Risiro *et al.*, (2012); Nkomwa *et al.*, (2014) and Basdew *et al.*, (2017) that rural smallholder farmers use indigenous climate indicators for weather predictions. Another reason for animal indicators being ranked the highest among the others, it was because in those villages farmers had a lot of livestock as well, which they could assess their behaviour for weather predictions.

6.7.6. Spatial distribution of Indigenous climate indicators in Nkomazi

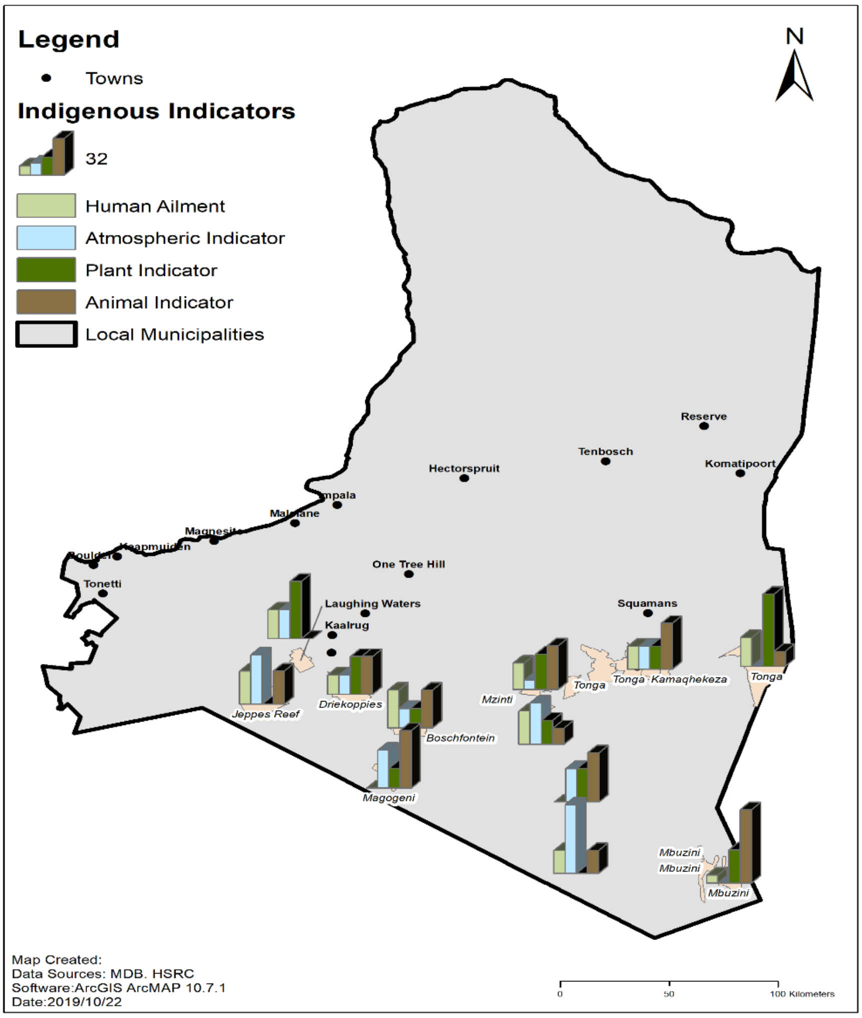


Figure 14: Spatial distribution of indigenous climate indicators categories in Nkomazi

The negative effects of climate change have altered the geographical range of some indigenous indicators. Changes in climate variability drives the distribution of indigenous climate indicators at an area. In Nkomazi Local Municipality, smallholder farmers have noted some change in climate variability affecting the distribution of certain indicators especially plant species (Figure 14). Farmers highlighted that in the past 50 they have observed the disappearance of some species as well as a shift in climate zones. Plant species interact with the environment differently, and its distribution depends on the climate. Therefore, any change on the climate variability affects its distribution, which as a result affects the decision making of farmers for their farm practices.

6.7.7 Spatial distribution of dominating indigenous climate indicators used for weather prediction in Nkomazi

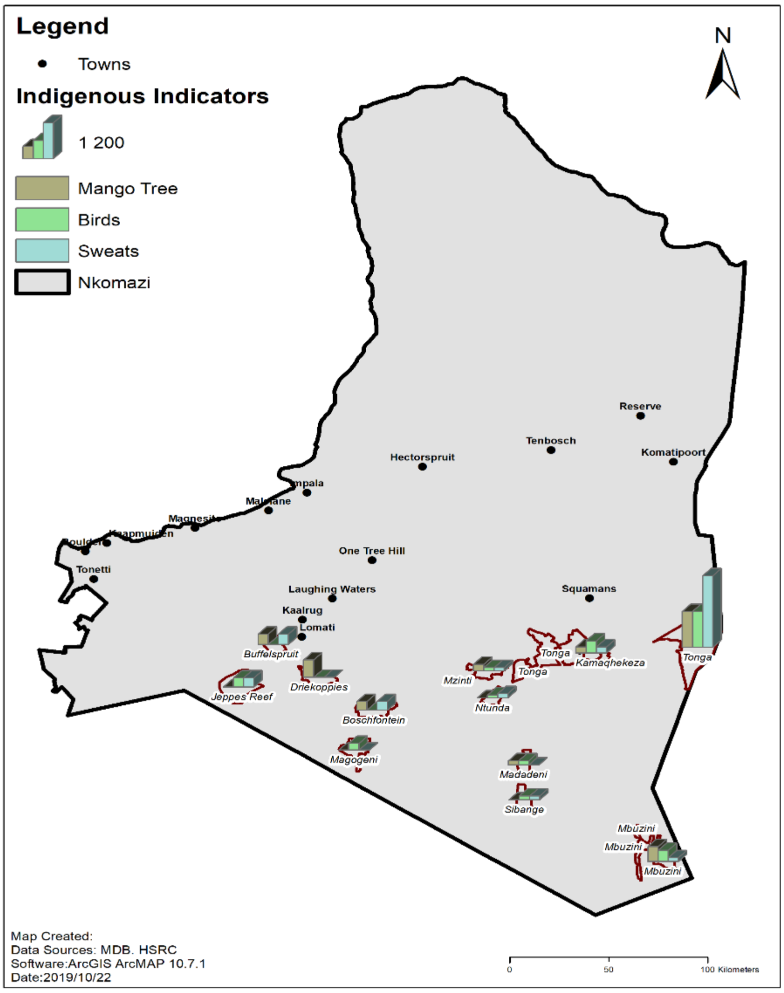


Figure 15: Spatial distribution of dominating indigenous climate indicators used for weather prediction in Nkomazi

The baseline information on the distribution of indigenous climate indicators was estimated using data collected from the study area. Plant species are immobile organisms, which makes it a bit challenging to easily notice any shifts in their distribution. However, due to climate change experienced in the area over the past decades, farmers have noticed a change in the distribution of some plant species. Studying the distribution map above (Figure 15), the Western sites of the municipality were mostly dominated by the use of mango tree to predict the weather changes, whilst the Eastern sites were dominated by the use of sweats as predictors. However, Overall Tonga has the highest indicators in the province. Ntunda has the lowest indicators in the municipality.

6.8 Poynton Indigenous indicator model

According to the Department of Environmental Affairs, South African temperature is expected to increase greater than 4^0C across the country and greater than 6^0C in the Northern interior, central and Western sites before the end of this century 2099 (Developing *et al.*, 2013). The department further elaborated that the country is expecting an increase in the number of heat-wave days and very hot days to be common. Therefore, this means that there are high chances for the loss or decline of potential indicators in the area for weather predictions. However, though they were five categories of indigenous climate indicators identified in the study area, focus will be given to only two categories (plant and animal indicators) for modelling purposes, because they were ranked as mostly used indicators than the others. The model aims at predicting the distribution of the indigenous climate indicators utilised by Nkomazi smallholder farmers for weather predictions with increasing temperature at an estimate of 5^0C. The model will assist in predicting the location and distribution of plants and animal indicators in the twelve villages sampled. This will help assess the possible changes in the climate conditions that are relevant to species distribution.

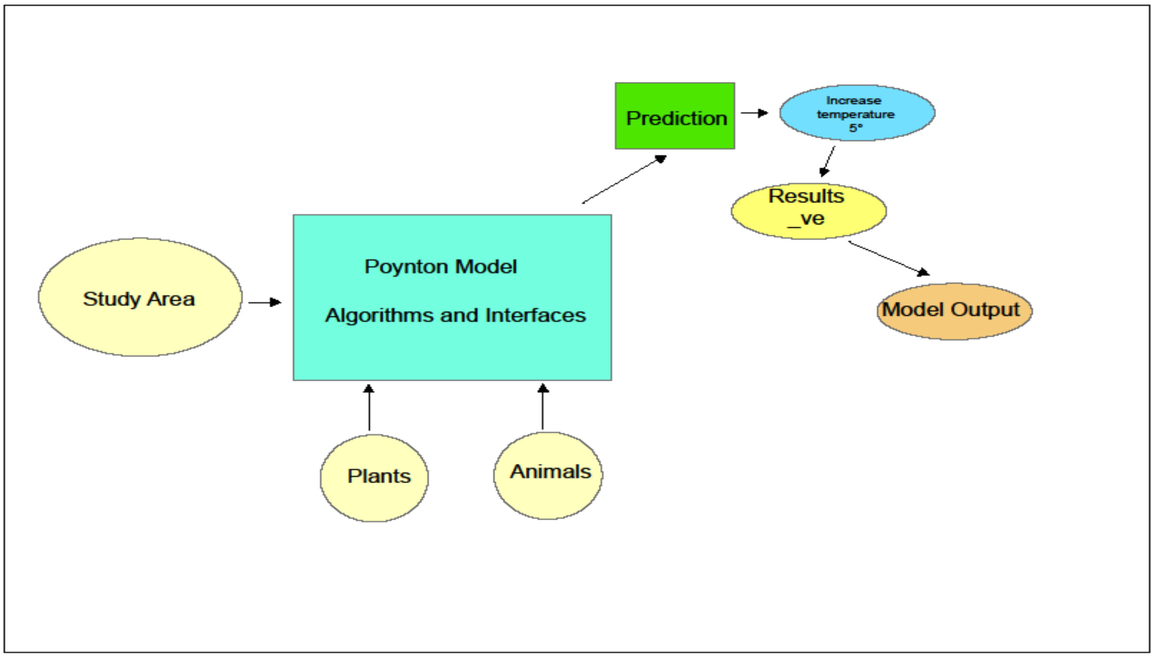


Figure 16: Model predicting the distribution of the indigenous climate indicators with temperature increase

The Poynton model approach was used to predict the distribution of the plant and animal indicators with a 5^0C temperature increase (Figure 16). This model is based on the assumption that the current distributions of the indigenous climate indicators for weather predictions in

Nkomazi are at equilibrium with the current climate conditions in the area. This model predicts a shift in areas where the indicators are currently dominant with a 5^0C temperature increase. Therefore, it predicts the relationship between temperature increases with the distribution of indigenous climate indicators in the study area. This highlights the prediction of the distribution of the indicators as to whether the impacts of climate change with increasing temperatures will allow the indicators to adapt to new climate conditions or disappear.

Therefore, based on the model predictions the observed distribution of plants and animals indigenous climate indicators will decline (with negative/–ve results) due to temperature increase and climate change scenarios, and due to difficulties keeping up with the changing environment (Figure 16). Similar findings were observed in South Korea were a prediction model was used to predict the distribution of subalpine species and as a resulted the model predicted a decrease of the species distribution by 2050 and 2070 due to climate change (Graham *et al.,* 2011). Therefore, these findings support what was highlighted by Cherotich *et al.,* (2012) that, the increase in climate has a negative impact on the distribution of the indigenous knowledge indicators. Again, it also supports the fact that the two knowledge systems need to be integrated as we cannot solely rely on one knowledge system but take advantage of the strength, innovativeness, and creativity of both knowledge systems.

6.9 Conclusions

In Nkomazi Local Municipality, smallholder farmers estimated the onset of growing season through the observations of natural climate indicators. These indigenous communities have been applying unique indigenous knowledge systems, culture and expertise since the olden days. However, the study findings highlighted that climate variability has been unpredictable due to false onset resulting in replanting of crops. As a result, this has caused some strains on the majority of smallholder farmers who are resource-poor to meet expenses of replanting lost crops. The study highlighted the spatial distribution of the indigenous climate indicators used by smallholder farmers in Nkomazi Local Municipality using the Geographical Information System (GIS) tools. It was revealed that animal indicators (birds) ranked the most used indicator than others, especially in Mbuzini. However, the farmers also revealed increasing temperatures due to climate changes were among their major concerns. Therefore, the Poynton model was used to predict the impact of the increasing temperature could have on smallholder farmers' production. The model predicted negative results with increasing temperature. Meaning that farmers would lose their indicators for weather predictions to make farm-level decisions, causing a miss understanding on what and when to plant certain crop species.

Therefore, as a result this will have a negative impact on their food security status, as there is a shift on their seasonal calendar, which they rely on for weather predictions. These challenges revealed the need for an integration of indigenous knowledge and modern science to help adapt to climate change and improve their food security status.

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Chapter 7: Development of a Mobile application to improve smallholder agricultural production

7.1 Mobile App Development

The mobile application for agricultural and rural development is software that is designed for the collection, transmission and documentation of Indigenous knowledge information and modern climatic data through mobile (Web Application) technology for rural smallholder farmers. This mobile app is meant to provide practical indigenous knowledge system (IKS) used by smallholder farmers. Results from the study findings were transmitted and documented on the mobile App in a simple, efficient and site-specific manner to assist farmers in planning their farm activities. This was done in anticipation of making long-term appropriate adjustments to increase smallholder farmers' resilience to climate change. The mobile app development will also assist the smallholder farmers to navigate the challenges of climate change and lack of access to timely and accurate climate information. Based on the study results, it is recommended that the application coverage extends through spatial analysis and mapping of rainfall and temperature characteristics at a village level.

A mobile app was developed for windows and android operating system because it is an open-source operating system and cost-effective (Figure 7.1). The Android Operating System incorporates numerous mobile applications, which offers flexibility to developers of applications. Therefore, these factors among others had led to the decision of developing a mobile App for rural smallholder farmers for accessibility of timely and accurate information, integrating with their indigenous knowledge systems. This App has been created to be user-friendly for smallholder farmers, even those aged 50years and above and is cost-effective.

The App home page consists of functions such as documented indigenous knowledge indicators with their interpretations, pests and diseases currently affecting farmers in the study area, the announcements page on updated news, a page for questions that will allow farmers to chat and ask questions as well as uploading pictures. There is also a daily weather update for the Nkomazi Local Municipality, and a page about "us" the App developers as well as a key function for the App manager namely "admin" which is not available for the primary users. The admin function allows the App manager to have control and validate every information uploaded on the App.

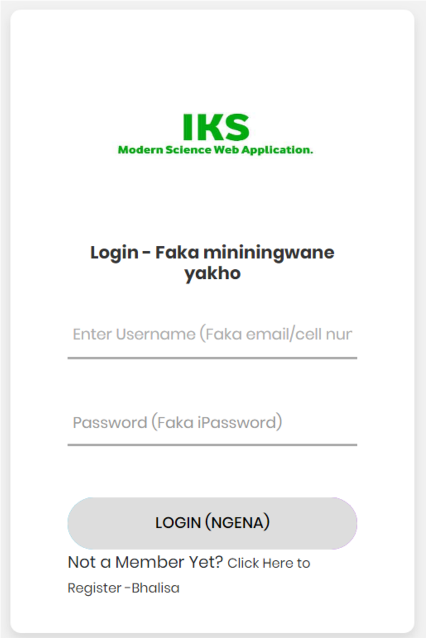

Figure 17: Mobile App Login page

7.2 Project Scope

7.2.1 Situation / Problem / Opportunity

Many business systems serve a different purpose; the IKS Web Application aims to group all the most important services/functionalities in a simplified and related to the rural and farming community.

7.3 Project Goals

The development of the mobile app focused on improving agriculture production with functions such as providing climate and market information, increasing access to extension services, and facilitating market links. The app will be accessible to smallholder farmers, extension officers and produce buyers. This mobile application will provide significant economic and social benefits among smallholder farmers by reducing product losses; improve agricultural production and making our developing country more globally competitive. The potential development of the mobile app lies in their ability to provide access to useful, relevant information and services. Below are different indigenous climate indicators used by rural smallholder farmers, (i) Animal indicators; (ii) Plant indicators; (iii) Atmospheric indicators (iv) Human ailments. These indicators are used to make farm-level decisions concerning their farming systems such as planting time and selection of crop types.

The mobile app is meant to have functions that will include a non-redundant database (fast) that will include easy capturing of data. This system shall be user-friendly and be available as a light to load secure Web Application (Both Computer and Mobile).

The vision of the project is to improve efficiency and service levels of business operations.

7. 4 In Scope

7.4.1 In-Scope: People:

- Smallholders Farmers
- Local community
- Application manager (Extension Officer)

7.4.2 Process System:

- Dot Net IKS Web Application System with SQL Database.

7.4.3 Location:

- Centralized system hosted in .co.za at first

7. 5 Out of Scope: People:

- Government
- Customers

7.5.1 Process System:

- Outlook (emailing)

7.5.2 Location:

- .co.za and every device that can access the web browser.

7.6 Project Objectives:

- Objectives / Deliverables
- A system that can be accessed through the web.
- A system with a secure login.
- A system that allows users to register and Create Database (Information and Pictures) will grant access.
- Upload updated information (e.g. weather, pest and diseases info, available market links) View/Provide information on crop production.
- A secure system with validations of all inputs.
- Allow roles, some things to be viewed by higher users like Directors.
- Upload / Document farmers indigenous knowledge:
    - Information uploaded in local language.
    - Must be able to easily access the Web Application via Mobile Phone and Computer (deployment of App).
    - Must be able to share/report (ability to take and upload pictures) via

the App to application managers

- Ask questions (queries) - (Cover simple Chart feature for Queries.
- Need to register or have a user name so it will easy to locate or identify them.

7.7 Project Risks

Table 15: Project risks and mitigation strategies

Risk	Mitigation Strategy
At the time of deploying, we might have to manually add the first user.	This can be solved by deploying a database with a first user.
System maintenance might affect using the system	We will have to do it overnight but give users an SMS alert

7.8 Mobile App validation

The mobile app was validated with Nkomazi smallholder farmers and they confirmed the recorded indicators with their meaning

7.9 Accessing the App:

The Mobile application "IKS web App" developed in this study can be accessed from ikswebapp.co.za (register as a user)

Chapter 8: Conclusion and recommendations

The main conclusions and recommendations of the study are discussed in this chapter. This study aimed to develop a mobile app technology to integrate indigenous knowledge systems with modern climate science to improve agricultural production for smallholder farmers. The objectives of the study were: (i) To investigate agricultural advisory services accessible to smallholder farmers; (ii) Explore existing climate channels that inform smallholder farmers' decisions; (iii) Identify, analyse and document indigenous climate indicators used by smallholder farmers over the study areas; (iv) Assess perceptions of the local communities in using mobile app technology to improve agricultural production; (v) Development of a mobile application for smallholder farmers.

8.1 Conclusions

The study established the existence, use, and role of indigenous knowledge (IK) and indigenous knowledge systems (IKS) in weather prediction for farm-level decision-making in the Nkomazi Local Municipality. The study also identified the indigenous climate indicators used by farmers from the twelve villages sampled namely; Ntunda, Mzinti, Mbuzini, Jeeps Reef, Driekoppies, Magogeni, Tonga, Boschfontein, Kamaqhekeza, Buffelspruit, Sibange, and Madadeni. The smallholder farmers used animal indicators; plant indicators; atmospheric indicators and human ailments for weather predictions and making farm-level decisions concerning their farming systems such as planting time and selection of crop types. It was also learned that elderly people as custodians transmitted indigenous knowledge from one generation to another through observations and experience verbally.

Key findings indicated that though the Nkomazi smallholder farmers relied mainly on their indigenous knowledge for weather predictions and farm-level decision-making for many generations. However, at first, during the focused group discussion, smallholder farmers did not embrace scientific forecasting information. This is because they lacked a sense of ownership, so, that has added to the partial acceptance of the meteorological information disseminated. The farmers highlighted that modern science will be more acceptable to them if it is integrated with what they already know.

Although local farmers and scientists view the two knowledge systems differently when defining seasonal phenomena, there is a significant overlap between them, especially regarding climate and weather forecasts. Both knowledge systems have weather produced through validation, experimentation, and observation, suggesting a meeting point between them. Nkomazi smallholder farmers were willing and open to the idea of integrating new information into their indigenous methods. This will work at an advantage for climate scientists, as it will give them the ability to design forecasts that would be acceptable and of priorities to smallholder farmers.

However, the majority of the smallholder farmers were of the view that indigenous climate indicators were better predictors of weather forecast than scientific forecasting, to which they have limited access to. The smallholder farmers found scientific weather forecast to be not of use to them because they lacked understanding and believed that it was not specific to their local area. However, despite the great uses of IK for farm practices, the results show that indigenous knowledge had its challenges due to climate change and lack of documentation. The results have shown that smallholder farmers in the study area have recognised changes in weather patterns. The smallholder farmers highlighted that they were losing some of their indigenous climate indicators they familiar with due to the changing environment. The farmers stated to have had experienced increased daily temperatures with decreased rainfall. These findings were validated with empirical data from the Komati weather station during 1993-2018. Poynton model was used to predict the impact of the increasing temperature could have on smallholder farmers' production. The model predicted negative results with increasing temperature. Meaning that farmers would lose their indicators for weather predictions to make farm-level decisions, causing a miss understanding on what and when to plant certain crop species. Therefore, these challenges revealed the need for an integration of indigenous knowledge and modern science to help adapt to climate change and improve their food security status.

Therefore, in this regard, there is a need to assist the rural smallholder farmers with timely, accurate and simplified weather forecast. The study suggests the integration of indigenous knowledge with modern climate science to increase rural smallholder farmers’ resilience to climate change. This integration will assist farmers in making informed decisions concerning their farm practices. The advantages of using modern science is the availability of chemicals for pests, innovative technologies like mobile app as well as tested agricultural solutions. Therefore, the integration of the two knowledge systems for weather predictions will assist farmers improve their crop yields as well as livelihoods. In so doing, smallholder farmers will be able to receive updated climate information regularly, and help them adapt to climate change with increased yields and sustained livelihoods. As a result, this will improve their food security status.

Therefore, the study concludes that there is a need for systematic documentation and the establishment of a framework for integrating indigenous knowledge and scientific weather forecasts for the future generation. This integration can be achieved through the establishment of a proper information dissemination network that will be easy to understand. Dissemination channels such as community-based organisations, local schools as well as use of mobile App. To achieve this integration the study proposed a mobile app development. Therefore, the mobile app was designed for collecting, transmitting and documenting indigenous knowledge information and modern climatic data for rural smallholder farmers. The development of the mobile app will assist smallholder farmers to navigate the challenges of climate change and access to timely and accurate climate information. The mobile app has been created to be user-friendly for smallholder farmers and cost-effective. The mobile app home page consists of functions such as documented indigenous knowledge indicators with their interpretations, pests, and diseases currently affecting farmers in the study area, the announcements page on updated news, a page for questions that will allow farmers to chat and ask questions as well as uploading pictures. The approach of integrating these knowledge systems was achievable through mapping the distribution of climate indigenous indicators within the twelve sampled villages, which helped with the collection and documentation of existing indigenous climate indicators of the study areas and added into the mobile app functionalities, together with scientific data collected from the Komati weather station. The mobile app was validated with the smallholder farmers, and they agreed to the recorded indicators with their interpretations.

8.2 Recommendations for Policymakers

- Government support should be provided for the growth of IKS, by having local, regional and national IKS centres
- Policymakers should come up with educational policies that would allow IKS component to be added to school curricula (secondary, tertiary and extension training institutes) to promote its sustainability
- Policymakers should come up with policies that will work hand-in-hand with the department of Agricultural, Land Reform and Rural Development accomodating communities and Digital Technologies and Women, Youth and persons with Disabilities

8.3 Recommendations for improvement of the study

- Further studies should be conducted on the use of IKS at a local, regional and national for transfer of knowledge from one ecological zone to another similar zone in a different part of the world
- Identify priority problems for smallholder farmers at a local level with the some agro-ecological zones
- Support should be provided for field methodologies for recording IKS

8.4 Study critique

- This study was conducted in Nkomazi local Municipality, therefore, the study findings cannot be used to draw conclusions or generalizations for all smallholder farmers in South Africa
- Due to financial constraints, the study was limited to Nkomazi Local Municipality

APPENDIX A: Survey Questionnaire

University of KwaZulu-Natal

Name of Interviewer : ……………………………………………………………………
Date : ……………………………………………………………………
Province : ……………………………………………………………………
District : ……………………………………………………………………………….
Municipality : ……………………………………………………………………………….
Farm/Village name : ……………………………………………………………………………….
Contact details : ……………………………………………………………………………….
Enumerator name : ……………………………………………………………………………….

All the information provided here will be treated as STRICTLY CONFIDENTIAL. The information you give to us is required for research purposes only. Personal details and socio-economic details of respondents shall be kept confidential and no mention of names shall be made in the final report that shall be compiled. The data will be stored in electronic form after being captured from the questionnaires. Finally, your participation in the study is voluntary. If you decide to participate, you have the right to withdraw at any stage without any penalty.

For purposes of record, it is hereby required that consent is given by means of signing the declaration below by the respondent prior to the beginning of the application of the application.

I………………………………………………………………………………. (Surname & Initials) hereby declare that I understand the purpose of this document and nature of the research project, and I grant the permission for it to be conducted with me as a respondent.

Signature ……………………………………Date …………………………………..

Section A: Socio-economic demographics

1. **Gender**

0=Male	1=Female

2. **Age**

3. **Marital Status**

0=Single	1=Married	2=Widowed	3=Divorced	4=Separated from spouse	5=Refused to answer

4. **Are you the household head?**

0=Yes	1=No

5. **What is the highest level of education that you have ever completed?**

No schooling	00
Grade 0	01
Sub A/Grade 1	02
Sub B/Grade 2	03
Grade 3/Standard 1	04
Grade 4/Standard 2	05
Grade 5/Standard 3	06
Grade 6/Standard 4	07
Grade 7/Standard 5	08
Grade 8/Standard 6/Form 1	09
Grade 9/Standard 7/Form 2	10
Grade 10/Standard 8/Form 3	11
Grade 11/Standard 9/Form 4	12
Grade 12/Standard 10/Form 5/Matric	13
National Technical Certificate I	14
National Technical Certificate II	15
National Technical Certificate III	16
Diploma/certificate with less than Grade 12/Std 10	17
Diploma/certificate with Grade 12/Std 10	18
Degree	19
Postgraduate degree or diploma	20
Adult Basic Education and Training (ABET)	21
Recognition of Prior Learning (RPL)	22
Other (specify)	23
Do not know	98

6. **What language do you speak mostly at home?**

	Mostly spoken at home
Sesotho	01
Setswana	02
Sepedi	03
Siswati	04
IsiNdebele	05
IsiXhosa	06

IsiZulu	07
Xitsonga	08
Tshivenda/Lemba	09
Afrikaans	10
English	11
Other African language	12
European language	13
Indian language	14
Other (specify)	15

7. **What is your current employment status?** (WHICH OF THE FOLLOWING BEST DESCRIBES YOUR PRESENT WORK SITUATION?)

Unemployed, not looking for work	01
Unemployed, looking for work	02
Pensioner (aged/retired)	03
Temporarily sick	04
Permanently disabled	05
Housewife, not looking for other work	06
Housewife, looking for other work	07
Husband, not looking for other work	08
Husband, looking for other work	09
Student/learner	10
Self-employed – full time	11
Self-employed – part time	12
Employed part time (if none of the above)	13
Employed full time	14
Other (specify)	15

…………………………………………………………………..

8. **Total household income per month**

No income	01
R1 – R500	02
R501 –R750	03
R751 – R1 000	04
R1 001-R1 500	05
R1 501 – R2 000	06
R2 001 – R3 000	07
R3 001 – R5 000	08
R5 001 – R7 500	09
R7 501 – R10 000	10
R10 001 – R15 000	11
R15 001 – R20 000	12
R20 001 – R30 000	13
R30 001 – R50 000	14
R 50 001 +	15
(Refuse to answer)	97
(Uncertain/ Do not know)	98

9. **Which of the income sources is your major source of income?**

0=Pension	1=Farming	2=Part-time job	3=Full-time job	4=Social-grant	5=Other specify

Section B: Land characteristics and Crop Cultivated

10. Means of land ownership

0=Allocated (communal)	1=Inherited	2=Borrowed	3=Rental	4=Bought	3= Other Specify

11. How long have you been farming?

0=Less than 5yrs	1=6 to 10years	2=11 to 20years	3=Over 20 years	4=Other specify

12. What is the total size of your farm?

0= Less than 1 ha	1=greater than 1 and less 2.5ha	2= Greater than 2.5	3= Do not know

13. Size of the land usually cultivated?

0= Quarter of the land	1= Half of the land	2= Total area	3= Other specify

14. How do you perceive your land's fertility?

0= Very fertile	1= Fertile	2= Infertile	3= Do not know

15. Who manages the farm?

0= Individual	1= Family members	2= Farmers' group	3= Corporation/ Company farm	4= Trust	5= Other (Specify)

16. What is the farm produce used for from your land?

0= Home consumption	1=Commercial purposes	2= Animal feed	3= Other (Specify)

17. Do you sell your farm produce?

0= Yes	1=No	2= Sometimes	3= Other (Specify)

18. If answered yes or sometimes in Q17, what is the estimated proportion of produce sold?

0= Quarter of produce	1= Half of the produce	2=Sell everything	3= Other (Specify)

19. To whom do you sell?

0= Local People	1= Agent	2= Commercial Market	3= Other (Specify)

20. **Which crops do you grow at present?** (Rank levels of crops grown in the second column – 1 for mostly grown crop)

Crop	**Rank**
0= Cereals (maize, wheat, barley, sorghum, millet)	
1= Legumes (beans, peas, soya, lentils, peanuts)	
2= Vegetables	
3= Other (Specify)	

21. **How do you select the crop(s) to grow?** (Rank levels of reason in the second column – 1 for mostly grown crop)

	Reason	**Rank**
1	Early maturity	
2	Resistance to disease	
3	Resistance to drought	
4	High yield potential	
5	Easy market access	
6	Easy management of crop	
7	Human consumption	
8	Other	

22. **Who mainly influences your crop selection?**

0= Extension officers advise	1= Farmer to farmer advise	2= NGOs advises	4= My Indigenous Knowledge	5=Other specify

Section C: Climate Change observations

23. **Have you ever heard about climate change?**

0=Yes	1=No

24. **Do you receive information on climate change?**

Yes	No

25. **What is your most reliable source of information on your farming systems?**

0=Radio	1=Internet	2=TV	3=Farmer to Farmer	4=Family member	5=Extension officers	6 =Other specify

26. **What major changes in weather have you observed in your community over the last 10 years?**

0= Floods	1= prolonged droughts	2= very hot seasons	3= very wet seasons	4=haven't observed any changes	5=Other specify

27. What is the main impact of these changes on the local community?

0= Crop failure	2= Livestock deaths	3= Human disease outbreak	4= Food insecurity	5= Do not know	6= Other Specify

28. Have you experienced low crop yields over the past 10 years?

0= Yes	1= No

If answered No, skip to Q39

29. How severe has the loss been over the past 10 years?

0= Very severe	1= Moderately severe	2= Not severe	3= Other specify

30. What do you think where the causes of the yield decline?

0=Natural causes (droughts, hails, floods)	1= Pest damage	2=Disease outbreak	3= Lack of farm inputs	4= Lack of water	5=Do not know

31. Other specify..

32. How did you adapt to those changes?

0= Applied indigenous knowledge	1= Assistance of extension officers	2= Didn't do anything	3=Other Specify

33. What impacts has climate change had on food security?

	Strongly agree	Agree	Neither agree nor disagree	Dis-agree	Strongly disagree	(Do not know)
Increased employment	1	2	3	4	5	8
Decreased employment	1	2	3	4	5	8
Increased income	1	2	3	4	5	8
Reduced income	1	2	3	4	5	8
Scarcity of food	1	2	3	4	5	8
Reduced food prices	1	2	3	4	5	8
Increased food prices	1	2	3	4	5	8
Lack of local markets	1	2	3	4	5	8
Other (specify)						

Section D: Agricultural advisory services

34. Are there institutions/organisations that provide farm support systems?

0=Yes	1=No

If answered No in Q40 skip to Q42

35. **If yes, please provide the institutions/organisation's support service.**

Institutions/organization	**Support provided**
0= Farmer organizations	
1= NGOs	
2= Family member	
3= Media	
4= Extension officers	
5=Other specify	

Section E: Indigenous knowledge systems

36. **Do you rely on your indigenous knowledge for farm practices?**

0=Yes	1=No

37. **What are your indigenous climate indicators?**

List of indigenous indicators	**Its uses**

38. **Does your indigenous knowledge make a difference in your crop production?**

0=strongly agree	**1=agree**	**2=neutral**	**3=disagree**	**4=strongly disagree**

39. **Your historical background of indigenous knowledge.**

0=Passed down to you	1=Gained through personal	2= Other Specify

40. **Which months did you experience shortages of agricultural-based foods the most?**

0= Dec-Feb	1= March-May	2= June-Aug	3= Sep-Nov

41. **How did you apply your indigenous knowledge to cope with these shortages?**

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42. **Which indigenous adaptation measures have you used to deal with the changing climate?**

0=Crop and variety diversification	1=Changing dates of planting	2=Build water harvest scheme	3= Mixed Cropping	4= Other specify

Section F: Use of Mobile App for improved agricultural production

43. **Do you have a Mobile phone?**

0= Yes	1= No

If answered no in Q50, skip to Q 56

44. **If answered yes in Q50, is it an android/smart phone?**

0= Yes	1= No

If answered no in Q51, skip to Q 56

45. **If yes, what do you use it for?**

0= Receiving/making calls	1= Sending Messages	2= Internet	3= Weather	4=Other specify

46. **Do you belong to any social network?**

0= Yes	1= No

47. **If yes, which social networks do you use more frequently?**

0= Facebook	1= Twitter	2= WhatsApp	4= Instagram	5=Other specify

48. **Are you familiar with using a mobile app store?**

0= Yes	1= No

49. **Would you like to receive agricultural information on you cell phone?**

0= Yes	1= No

50. **What kind of information would you like to receive?**

0= Weather	1= Pests and diseases	2= Markets	3= other specify

51. **How often would you like to receive information**

0= Daily	1= Weekly	2= Monthly	3= Yearly	4=Other specify

THANK YOU FOR YOUR COOPERATION

APPENDIX B: Focus group discussion guide

1. Describe your understanding and experience of climate change impact on your production system

2. What kind of support system do you receive with regards to your farming practises?

- *Mention them, describe their contribution on farming system*
- *Reliability and timeliness of receiving services/information, how do they deliver services/information (channels used)*

3. The role of various institutions/organisation that advise you about climate change support systems.

- *Mention their names and support they provide*
- *How important are they to you*
- *Reliability and timeliness of receiving services/information , how do they deliver services/information*
- *How useful are they?*

4. How long have you been farming, and how has the environment changed from then till now?

5. Would you like to use Mobile phones to receive agricultural information?

- *Market information*
- *Agricultural practices*
- *Post-harvest management techniques*
- *Weather*

6. What kind of information would you like to receive through the mobile App?

7. Which indigenous climate indicators do you use for your farming system?

8. How do you apply your indigenous knowledge in Agriculture?

- *Pest control*
- *Soil fertility*
- *Weed management*
- *Water harvest*

9. How do you use your indigenous knowledge to adapt to climate change?

- *Droughts*
- *Floods*

10. In your own words, how would you define indigenous knowledge?

11. Which farming systems would you consider indigenous?

12. Historical background on your Indigenous knowledge

- *Was it passed down to you?*
- *How was your indigenous knowledge passed down to you?*
- *Was it gained through personal experience?*

13. What constrain are you facing in your farming systems?

- *Crop production constraints*
- *Road and Transport*
- *Technological barriers*
- *Market Information*
- *Quality constraints*

APPENDIX C: Transect Walk

Municipality……………………..

Date:……………………………..

Village……………….……………

14. Which agricultural areas do you think have been affected by climate change, describe what you think happened and what is being done & by who? (e.g. fields, dams, rivers *etc*)

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15. Has your crop production system changed over years? Explain how it has changed and what influenced change?

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16. When affected by climate change shocks, how do you deal with it?

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17. What informs your farming decision?

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18. How do you apply your indigenous knowledge in Agriculture?

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19. Which indigenous climate indicators do you use for your farming system?

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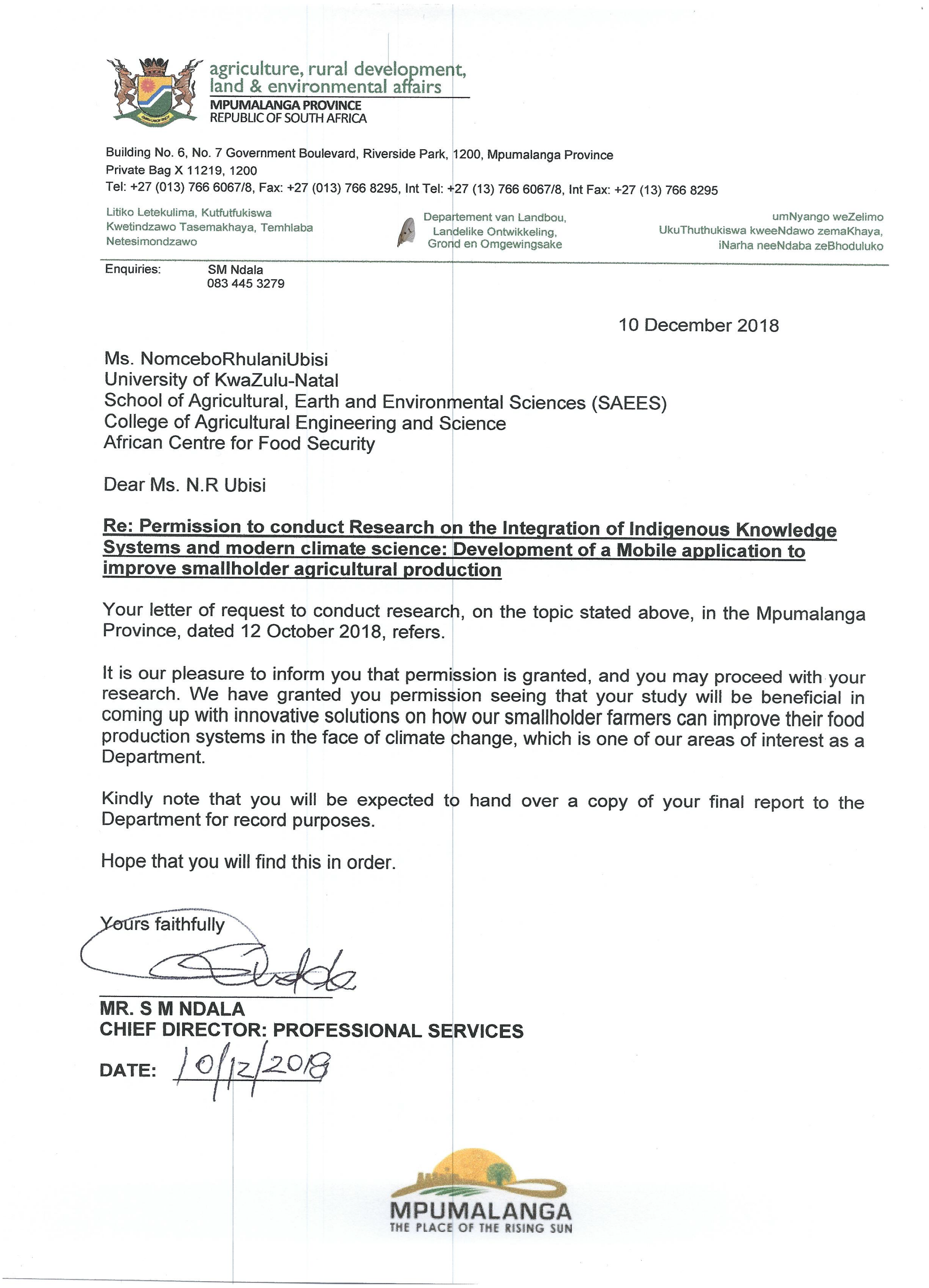
OBSERVATIONS

Elements under observation	**Observations**
20. Farming system	
21. Crop management system	
22. Soil type	
23. Farm size	
24. Indigenous knowledge systems	
25. Crops planted	
26. Access to agricultural–based resources	**Scale:** **Poor** **Bad** **Good**

APPENDIX D: Approval letter from Mpumalanga Department of Agriculture



agriculture, rural development,
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Kwetindzawo Tasemakhaya, Temhlaba
Netesimondzawo

Departement van Landbou,
Landelike Ontwikkeling,
Grond en Omgewingsake

umNyango weZelimo
UkuThuthukiswa kweeNdawo zemaKhaya,
iNarha neeNdaba zeBhoduluko

Enquiries: SM Ndala
083 445 3279

10 December 2018

Ms. NomceboRhulaniUbisi
University of KwaZulu-Natal
School of Agricultural, Earth and Environmental Sciences (SAEES)
College of Agricultural Engineering and Science
African Centre for Food Security

Dear Ms. N.R Ubisi

Re: Permission to conduct Research on the Integration of Indigenous Knowledge Systems and modern climate science: Development of a Mobile application to improve smallholder agricultural production

Your letter of request to conduct research, on the topic stated above, in the Mpumalanga Province, dated 12 October 2018, refers.

It is our pleasure to inform you that permission is granted, and you may proceed with your research. We have granted you permission seeing that your study will be beneficial in coming up with innovative solutions on how our smallholder farmers can improve their food production systems in the face of climate change, which is one of our areas of interest as a Department.

Kindly note that you will be expected to hand over a copy of your final report to the Department for record purposes.

Hope that you will find this in order.

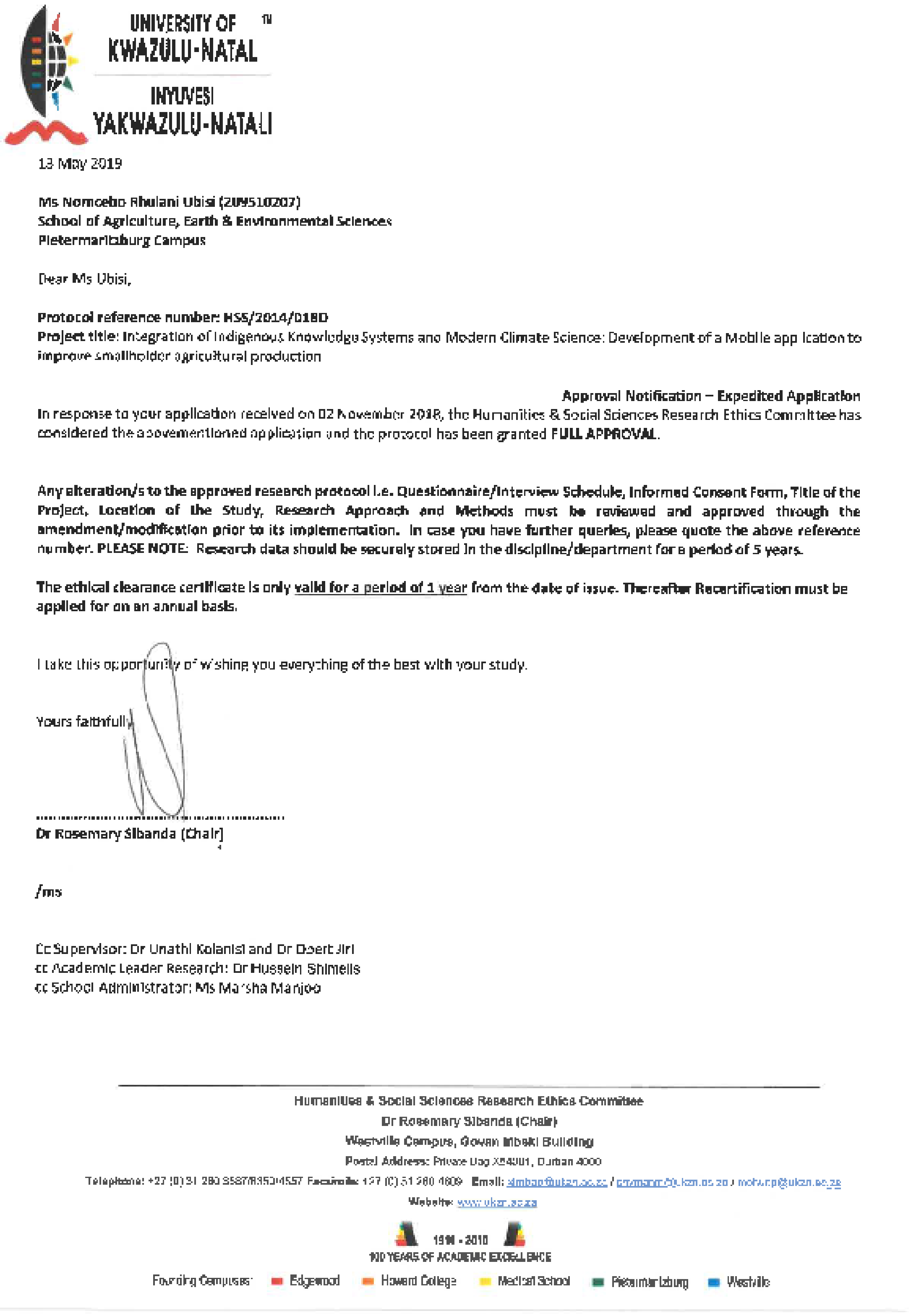
Yours faithfully

MR. S M NDALA
CHIEF DIRECTOR: PROFESSIONAL SERVICES

DATE: 10/12/2018

MPUMALANGA
THE PLACE OF THE RISING SUN

APPENDIX E: Approval letter from the University of KwaZulu-Natal



UNIVERSITY OF KWAZULU-NATAL

INYUVESI YAKWAZULU-NATALI

13 May 2019

Ms Nomcebo Rhulani Ubisi (209510207)
School of Agriculture, Earth & Environmental Sciences
Pietermaritzburg Campus

Dear Ms Ubisi,

Protocol reference number: HSS/2014/018D
Project title: Integration of Indigenous Knowledge Systems and Modern Climate Science: Development of a Mobile application to improve smallholder agricultural production

Approval Notification – Expedited Application

In response to your application received on 02 November 2018, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL**.

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment/modification prior to its implementation. In case you have further queries, please quote the above reference number. PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 1 year from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

……………………………………………
Dr Rosemary Sibanda (Chair)

/ms

Cc Supervisor: Dr Unathi Kolanisi and Dr Obert Jiri
cc Academic Leader Research: Dr Hussein Shimelis
cc School Administrator: Ms Marsha Manjoo

Humanities & Social Sciences Research Ethics Committee
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