# Seamless Forecasting of Rainfall and Temperature for Adaptation of Farming Practices to Climate Variability

## Volume 1 – SEASONAL FORECASTS AND SMALLHOLDERS

Report to the
**WATER RESEARCH COMMISSION**

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# EXECUTIVE SUMMARY

## BACKGROUND

The African population is one of the fastest growing in the world and the continent has a large potential for agricultural growth and development (Godfray et al., 2010). The definition of agricultural production strategies that will help prepare Africa for higher demand and worsening climate stresses must take into account various factors including political drive, infrastructure development, technical progress, social livelihood and economic growth. Apart from those, it is imperative to address climate change that directly impacts crop growth and food production in the long term, and in a similar measure climate variability that directly impacts year-by-year production.

Agriculture is highly sensitive to climatic parameters and numerous studies show that Africa will be highly affected by long-term climate changes, mostly in a negative manner (Iizumi et al., 2013; Zinyengere et al., 2013), and adaptation is required (Challinor et al., 2014). In addition to the exploration of long-term adaptation strategies in response to climate change, there is a demand for shorter time scale coping mechanisms, which would make agricultural systems more resilient in the face of climate variability (vs. climate change). Despite a number of limitations to be clearly understood, the value of seasonal forecasts is evident (Fraisse et al., 2006; Hansen and Indeje, 2004; Hansen et al., 2011; Klopper et al., 2006; Meinke and Stone, 2005; Patt and Gwata, 2002). The proposed research is designed to harness seasonal forecasts and impact models' numerical capacity to better prepare agricultural activities to climate variability.

## RATIONALE

Repeated exposure to severe climate events combined with its financial and structural capacity to improve, makes of South Africa a major role player in exploiting climate and crop models' capacity to digest enormous data sets into useful tailored information needed for decision making. Although models are only a partial representation of reality, their exploration capacity is useful and they are already intensively used at larger time and/or space scales (e.g. AgMIP, Rosenzweig et al., 2014). Technical challenges such as forecast skill or spatial representation make shorter time scale studies more demanding. However, these temporal and spatial scales are indispensable to provide appropriate information that farming communities are continuously requesting. International research projects have identified those efforts as a priority to respond to climate risk vulnerability. Although, there are currently no projects in South Africa (see for example foreign initiatives CCAFS-CRAFT or US-AgroClimate), some solid regional studies have been performed at those scales, e.g. Archer et al., 2007; Ziervogel and Downing, 2004; Zuma-Netshiukhwi et al., 2013.

## OBJECTIVES AND AIMS

The proposed research work directly follows on from a previous WRC project (Lumsden and Schulze, 2012), which explored the application of weather and climate forecasts in agricultural decision-making. This included applying weather and climate forecasts within hydrological models to produce hydrological forecasts.

This study explored, proposed and developed ways and approaches to leverage available seasonal forecast information, through robust climate-crop-water integrated assessment of agricultural and water systems, towards better farmers' preparedness to climate variability. The project also applied shorter range weather forecasts in this objective.

The number of partners involved in the project brings a large range of skills and expertise. Each aim is undertaken by the most relevant institution, with a clear effort towards regular community engagement.

| No. | Aim | Report Sections |
|---|---|---|
| 1 | To rigorously document and improve accuracy and skill in, short (1-3 days) and medium (3-10 days) range weather forecasts. | Vol. 2, Ch. 3 |
| 2 | To develop extended range (11 to 30 day) weather forecasts to facilitate fully seamless forecasting. | Vol. 2, Ch. 3 |
| 3 | To render seasonal forecast data available to crop models, including the seasonal production at selected locations in SA. | Vol. 1, Ch. 2,3 |
| 4 | To integrate seasonal forecasts into crop models for seasonal production scenarios, including the seasonal production at selected locations in SA. | Vol. 1, Ch. 4,5,6,7 |
| 5 | To enhance the spatial and temporal resolution of seasonal climate forecasts. | Vol. 2, Ch. 3 |
| 6 | To demonstrate the feasibility and evaluate the benefits of the climate-crop integrated approach virtually (models only with historical data) and in real conditions, at selected locations in SA. | Vol. 1, Ch. 8,9,10,11,12 |
| 7 | To improve understanding of, and possible reduction in, hydrological forecast uncertainties and errors across different time ranges. | Vol. 2, Ch. 9 |
| 8 | To develop and evaluate tailored hydrological and crop forecast products for application in decision-making across different time ranges in selected case studies in KwaZulu-Natal. | Vol. 2, Ch. 4,5,6,7,8 |
| 9 | To summarise feedbacks, particularly on enablers and barriers, which can inform climate and agriculture experts and facilitate future climate-crop integration. | Vol. 1, Ch.13 |

## METHODOLOGY

Stakeholder engagements from the inception to the end of the project tremendously helped to frame the research objectives and advancements, better fitting actual field constraints and farming communities' priorities. These engagements clearly allow to present the projects' advancement in the light of community feasibility and evaluating the benefits, barriers and enablers of the approach in the most grounded way possible. In addition to the smallholder farming communities engaged in Eastern Cape and Limpopo, stakeholders representing commercial perspectives were engaged in KwaZulu-Natal with respect to the application of hydrological forecasts in decision-making.

Integrating forecasts into hydro/crop models is one of the core research challenges of our project. Since it has been done on a long term climate change time scale, we know it is possible to couple seasonal forecasts with crop models. The challenge though comes from our intent to use the forecast-crop model combination as a tool to make crop-relevant weather-based information, or a crop forecast, to provide farming communities with a month to several months lead time decision tool. In this project a particular look was taken at the integration of seasonal forecasts with crop models (see for instance Vol. 1 Chapters 4 and 5). The major challenge in the integration lies in the capacity of the integrated tool/approach to process and produce *relevant* and *useful* information at this decision level.

Given the large workload and various ambitions and aims of the project, as well as the large number of partner institutions, the project execution was driven along two complementary directions:

Volume 1 – A seasonal time scale, led by the University of Cape Town, and mostly focusing on smallholder farmers of Alice, Eastern Cape and Lambani in Limpopo, with the support of the University of Fort Hare and the University of Venda respectively.

Volume 2 – A seamless time scale, led by the University of KwaZulu-Natal and the CSIR, and focused mostly on commercial agriculture in KwaZulu-Natal, with the support of the University of Pretoria and the Agricultural Research Council.

## RESULTS AND DISCUSSION

### Volume 1 – Seasonal forecasts and smallholders

Throughout the project, and the various themes and approaches tested and developed, various enablers and barriers were faced. As rigorous as we make this process, we acknowledge the complexity and local dependency of the following observations. We ground these observations in our experience through and beyond the project, and present it in a way that intent to highlight wider and more generic issues. In this volume 1, we build on the "month to season forecast" integration to crop models and related engagements in the Eastern Cape and Limpopo Province.

The scientific process started with grounding the research within two farming communities in Limpopo and Eastern Cape. The local partners and their network, as well as the direct engagement of the project team with the community, lead to better understanding of the community dynamics and aspirations. This local specific knowledge is related to two communities presented in Chapter 2 and Chapter 3 of this volume, and emphasise the heterogeneity of these communities, in terms of conditions and aspirations, as well as in terms of integration, acceptance and use of seasonal forecast information (see for instance Vol. 1 Chapters 6 and 7). This baseline is necessary to any scientific progress, so to clearly define a baseline, toward the building of a process that can be scaled up within a variable environment, such as is the South African agricultural production scene.

From this necessary understanding, the scientific process came to explore, understand, assimilate accessible numerical data and tools towards building approaches that ingest and digest seasonal forecast information, in order to reveal the most relevant possible information with decision potential, as well as facilitate its reception, understanding and use by farming communities. This would be the approach/methodological knowledge contribution of this project, mostly arising from the crops models' use (Chapter 4) with available seasonal forecasts (Chapter 5) and leading to the definition of (full or subset of) preferred crop management, per farm types, and with consistent response under varying seasonal forecasts (Chapter 12).

As a result of a multi-partner project, partners who have varying skills and interests, the knowledge contribution did not stop here. Significant contributions were made in terms of Indigenous Knowledge in both Limpopo and Eastern Cape, specifically in terms of agricultural decision making, and seasonal time scale, which adequately fit within this project objectives (Chapter 9). In some extent these advances connect with the numerical approach from a reception and a localisation perspective. The former relates to the relation of seasonal forecast with indigenous indicators and consequently the better understanding and assimilation of this information. The latter relates to the potential to ground a possible recommendation into a very specific and very local context either by translation or by further use of indigenous indicators. Such perspective, when/if applicable only improve acceptance and use of seasonal information.

This project also contributed to the highly relevant challenges of acceptance and use. This was addressed through the lens of Ecological Intensification (EI), with particular attention to the farm typology (Chapter 7). We discuss the particular potential of EI for small scale low input farmers, rigorously frame the strength or weakness of EI in that context, which directly feeds into acceptance and use of novel information/techniques (Chapter 10).

The communication of the science process and products always had a predominant role, and the project attracted scientific interrogation towards better communication of specifically seasonal forecast information to rural communities (Chapter 11).

Finally, a noticeable remote sensing effort was successfully lead, focusing on soil moisture and adaptive capacity mapping ambitions. The contribution builds on the significance of soil moisture as a decision parameter for farming communities and demonstrated the potential to use this approach with climate or seasonal forecast information (Chapter 8). Beside the knowledge contribution, this effort also points to a promising direction in the face of the field data scarcity often encountered in rural South Africa, many African countries and the developing world. Where numerical tools are very efficient and offer great accuracy where ground data is plentiful, these qualities are rightfully questionable where field data is scarce. A number of studies, supported by this one, suggested that the increased access and resolution of off-ground data sources could at least in part facilitate the use of data demanding approach, even where field data is scarce.

In academic terms, the project substantially supported capacity building (APPENDIX I), and led to national and international research publications (APPENDIX II).

### Volume 2 – Seamless forecasts and sugarcane

The Mhlathuze catchment case study developed weather and climate forecasts at time ranges including 7-day, subseasonal and seasonal. The methodologies for developing the 7-day and seasonal forecasts (using the CCAM climate model and statistical downscaling of globally available climate forecasts, respectively) are fairly mature, while the forecasts at the subseasonal time scale represent a very new area of research. This time scale bridges the medium and seasonal time ranges, and thus there is a lot of overlap with these ranges in terms of the technical forecast development. The subseasonal forecasts were developed in CCAM as part of a separate seamless forecasting effort at the CSIR across all scales.

The 7-day weather forecasts were applied in the ACRU model linked to the Delft-FEWS hydrological forecasting system to produce forecasts of inflow to Goedertrouw Dam, and crop water and irrigation demand in two dependent subcatchments where sugarcane is grown. Seasonal forecasts of the storage in Goedertrouw Dam were also developed, this being a key need for forecasts amongst sugarcane stakeholders that were consulted. In a further piece of work, the potential to develop seasonal forecasts of sugarcane crop yield and water productivity using the AquaCrop model was explored.

The work done in the Mhlathuze case study was found to be technically challenging. These challenges included the hydrological modelling of the catchment, the development of the ACRU/Delft-FEWS forecasting system and attempting to produce seasonal forecasts of crop yield and water productivity with the AquaCrop model.

In terms of modelling the catchment, the operation of the Goedertrouw Dam was difficult to capture given the complex system of river releases for downstream irrigation and urban/industrial abstractions. Data describing the operation of the system was fairly limited, and required a number of assumptions to be made. Thus, the overall time required to configure the catchment in ACRU was longer than expected.

While the Delft-FEWS system is a powerful tool to enable hydrological forecasting (in terms of managing the large amounts of data associated with this activity), it is not a user-friendly system to configure. This situation is often found in modelling systems where there is a trade-off between utility and user friendliness. Hence the development of hydrological forecasting was somewhat delayed in the project. This resulted in there being little time within the project to convey final results and explore the implication of these with stakeholders. However the technical capacity to use this software that has been developed in the team during the project has been very valuable, and will continue to yield benefits in future hydrological forecasting efforts.

Another technical challenge experienced was in attempting to apply probabilistic-categorical seasonal climate forecasts in AquaCrop to produce crop yield forecasts. While there is value in utilizing a probabilistic climate forecast as uncertainty is quantified in the forecasts, models such as AquaCrop are not designed to utilize this kind of information, as they require a daily time series of weather information as input. It was thus not possible within the timeframe of the project to produce crop forecasts using AquaCrop.

Despite the technical challenges, the results of certain aspects of the agrohydrological forecasting in the Mhlathuze were encouraging. This was particularly so for the 7 day forecasts of crop water requirements, where the correlations with simulated historical values were high ($R^2$ above 0.8 for the two catchments assessed). Although the forecasts of Goedertrouw Dam inflows and net irrigation requirements at the 7 day time scale did not perform as well as those for crop water requirements, it is still believed they have potential to be useful in decision-making. Further research is required to evaluate the benefits of such application.

Research into developing seasonal forecasts of storage in Goedertrouw Dam revealed that there is predictability in autumn storage using the method developed. This method involved correlating historical summer rainfall with autumn storage. This correlation was made after analysing seasonal cycles of rainfall and dam storage and determining the strongest relationships present in the data. The method is simple to apply and forecasts can be produced quickly. A demonstration of how the forecasts could be applied in decision-making was given.

An alternative approach to producing seasonal dam storage forecasts would be to apply seasonal climate forecasts in ACRU. However, this would require downscaling of the seasonal climate forecasts to produce daily time series. This challenge was also encountered in the application of the AquaCrop model to produce crop forecasts. Methods are available to do this, such as through the use of historical analogue weather data or through the application of weather generators, however this adds another layer of complexity to the forecasting development process. The advantage of adopting this approach is that forecasts can potentially be developed for all seasons. The simulation-based approach also allows for exploring the potential to change the management of the dam, in response to forecasts.

## CONCLUSIONS

This project is recognising water and its role in agricultural systems as complex systems evolving at the venture of various communities (e.g. academics or farmers), dealing with information of varying skills and relevance (e.g. skills of seasonal forecast or relevance of time scale), which must be communicated iteratively and facing communications challenges (e.g. language, concepts such as uncertainty, trust) and beyond. While importance and provision must be made for the inclusion of some extent of all those aspects, we believe the improvement of part of these aspects is taking a measurable role in the development of better managed agricultural systems, particularly under global (e.g. population increase, climate change) and national (e.g. wealth and food share, economic development) challenges.

All the good work and knowledge contributions only briefly highlighted above, are accompanied by many limitations and constraints that keep challenging such effort in terms of adoption, operationalization and scaling up amongst others. As the skill of seasonal forecast is varying in space and in time, as the decision maker (farming communities) are exercising in varying conditions and with varying priorities and uncertainties, nuances and reservations must necessarily come as part of the information. We recognise the importance of this complexity, and we are confident that this project contribution to knowledge is measurable and of direct value to future efforts directed to the empowerment of rural farming communities in South Africa.

This project demonstrated the value of using numerical tools, purposefully for the benefit of smallholder farming communities, with the imperative involvement of rural university and extension offices. This process, although clearly facing challenges for operationalization and scaling up, used the appropriate ingredients leading to future development. Amongst the multitude of ways this work can be taken forward, it seems evident that the success of national scale operationalization of this sort of approach must explicitly develop and involve the local university-extension link, which in turns will most likely reinforce the ownership of the combined numerical skills and local relevance.

The heterogeneity highlighted in this project is once again emphasized through the different audiences, decision makers, systems and consequently the responses to climatic factors. As much as better understanding, communication and integration of forecast information is useful for any decision maker, the capacity to produce such information and communicate it timeously is still technically very difficult, mostly due the large uncertainty involved, as well as the technical operationalization of the process, leading to low reliability of its execution on a regular basis. While the weather forecasts on (very) short time horizons remain accurate, its processing through modelling tool does not provide large added value while it requires large computation and interpretation efforts, if it is to improve the decision process. Although this remains a very interesting and promising research avenue for the future, the ambition to progress towards operationalization through better use of forecast information into the decision-making of agricultural practices, must account for the added value of the information produced, against its cost and reliability of production. At this time, operationalizing very short term climate-crop information is very demanding while its benefits for the farming communities are limited compared to the value of the original weather forecast. On the other hand operationalizing crop-based seasonal forecasts information, while being comparatively demanding to produce, offers measurable improvements of the use of seasonal forecast as well as sufficient time to produce it, communicate it, and hopefully integrate it to agricultural decisions.

This recommendation obviously must be considered in the light of the user interest for the information. Likely commercial farmers with extensive access to numerical tools and internet, will be much likely willing and capable of receiving short-term processed information. On the other hand farming communities with limited access to such tools and information on a regular basis, are more likely to prefer seasonal time scale information, through the extension offices, which play a determinant role in communication, interpretation, understanding and most likely integration of this information. While production of useful information, desired information, must be continued, there is no doubt that local stakeholders must be involved, including academics in local university, extension services, as well as farming communities in order to make this information relevant and useful but also to allow for local interpretation, communication and use. As much as the process can be run remotely, and the heavy computation should benefit from high computation capacities at national, governmental and/or educational institutions, the communication, the interpretation and as much expertise as possible must lie within local universities, local government institutions, and ultimately support and encourage the extension offices in their communication with the farming communities.

From a technical perspective, numerous ways exists to progress forward. We are confident that the combination of forecasts and water/crop modelling tools offer a tailored perspective on forecast information that allows for improved agricultural decisions.

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The Water Research Commission for initiating, managing and funding this project.

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The University of KwaZulu-Natal, Council for Scientific and Industrial Research, the University of Fort Hare, the University of Venda, the University of Pretoria and the Agricultural Research Council (Institute for Soil, Climate & Water) for collaborating in the project.

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# CHAPTER 1. PROJECT INTRODUCTION AND OBJECTIVES

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## 1.1. Background

The African population is one of the fastest growing in the world and the continent has a large potential for agricultural growth and development (Godfray et al., 2010). The definition of agricultural production strategies that will help prepare Africa for higher demand and worsening climate stresses must take into account various factors including political drive, infrastructure development, technical progress, social livelihood and economic growth. Apart from those, it is imperative to address climate change that directly impacts crop growth and food production in the long term, and in a similar measure climate variability that directly impacts year-by-year production.

Agriculture is highly sensitive to climatic parameters and numerous studies show that Africa will be highly affected by long-term climate changes, mostly in a negative manner (Iizumi et al., 2013; Zinyengere et al., 2013), and adaptation is required (Challinor et al., 2014). In addition to the exploration of long-term adaptation strategies in response to climate change, there is a demand for shorter time scales coping mechanisms, which would make agricultural systems more resilient in the face of climate variability (vs. climate change). Despite a number of limitations to be clearly understood, the value of seasonal forecasts is evident (Fraisse et al., 2006; Hansen and Indeje, 2004; Hansen et al., 2011; Klopper et al., 2006; Meinke and Stone, 2005; Patt and Gwata, 2002). The proposed research is designed to harness seasonal forecasts and impact models numerical capacity to better prepare agricultural activities to climate variability.

South Africa's repeated exposure to severe climate events combined with its financial and structural capacity to improve, has a major role to play in exploiting climate and crop models capacity to digest enormous data into useful tailored information needed for decision making. Although models are only a partial representation of reality, their exploration capacity is useful and they are intensively used at larger time and/or space scales (e.g. AgMIP (Rosenzweig et al., 2014)). Technical challenges such as forecast skills or spatial representation makes shorter time scale studies more demanding. However, these time and space scales are indispensable to provide appropriate information that farming communities are continuously requesting. International research projects have identified those efforts as a priority to respond to climate risk vulnerability, however, there are currently no projects in South Africa, see for instance (CCAFS-CRAFT) or (US-AgroClimate). Some solid regional studies have been performed at those scales, e.g. (Archer et al., 2007; Ziervogel and Downing, 2004; Zuma-Netshiukhwi et al., 2013).

The proposed research work directly follows on from a previous WRC project (Lumsden and Schulze, 2012), which explored the application of weather and climate forecasts in agricultural decision-making. This included applying weather and climate forecasts within hydrological models to produce hydrological forecasts. This study explored, proposed and developed ways and approaches to leverage available seasonal forecasts information, through robust climate-crop-water integrated assessment of agricultural and water systems, towards better farmer's preparedness to climate variability. Shorter time scales were also considered in the study in an attempt to develop a seamless approach.

## 1.2. Contextualisation

The proposed study provides (i) a deep exploration of local farming communities' needs/expectations with regards to climate-crop seasonal forecasts; (ii) an advanced understanding of climate-crop integration for South African systems; and (iii) tested methodologies to produce agriculturally tailored seasonal forecast information. In the realization of these tasks, the project gives a critical importance to the development of long-term relevant solutions, which is supported by a clear understanding of short (day, weeks, seasonal, inter-annual) and long (decadal, multi-decadal) term challenges through community-driven research.

Unlike to global/continental integrated assessments that prove difficult to downscale with the appropriate local and regional characteristics, the final product of this smallholder-driven project provides local/district relevant information. This local relevance intents to facilitate project outputs replication towards the creation of provincial and national policies that better respond to community and district challenges. The achievement of methodological assessment in real-time conditions, emerges from regular connection with three communities, one in Limpopo, one in Eastern Cape and one in KwaZulu-Natal. Those engagements provided a unique platform for discussion between the research team and the local farming communities and authorities. Those exchanges both grounded local and national academics with field concerns and limitation, as they enabled for knowledge dissemination with farming communities and extension offices. Although this project focuses mainly on smallholder farming and seasonal time scales, it does also incorporate commercial agriculture and shorter time scales (short/medium range and sub-seasonal) through the KwaZulu-Natal case study.

## 1.3. General approach

### 1.3.1. Engagement with communities

Stakeholder engagements from the inception to the end of the project tremendously helped to frame the research objectives and advancements fitting actual field constraints and farming communities' priorities. The larger part of the approach annually engaged with two smallholder farming communities, one in Eastern Cape and one in Limpopo. Both provinces have been described as poor and most vulnerable to disasters (SALGA, 2011). Relationships prior to this project had already been developed through our collective, inter-university involvement with the South African Financial and Fiscal Commission funded project (FFC, 2014). These engagements clearly allow to present the projects advancement in the light of community feasibility and evaluating the benefits, barriers and enablers of the approach in the most grounded way possible. In addition to the smallholder farming communities engaged in Eastern Cape and Limpopo, stakeholders representing commercial perspectives were engaged in KwaZulu-Natal with respect to the application of hydrological forecasts in decision-making.

The project recognises the long term nature of engagement with community, leading to building trust and strengthening exchange of relevant information. Consequently this project built on existing initiatives such as the establishment of the eDikeni water user association by the SA department of Water Affairs and Forestry in 2006, in Eastern Cape. Complementarily, the continued engagement supported through this project, and especially in in Limpopo and Eastern Cape, has explicitly be tuned to develop local universities connections with local communities and their extension officers. We believe it both serves the projects (better integration, for instance through languages), as well as it strengthen the long term engagement of communities with their most likely local university students and academics.

### 1.3.2. Integrating forecasts into hydro/crop models

Here lies one of the core research challenges of the project. It has been done so extensively on a long term climate change time scale, that we know it is possible to couple seasonal forecasts with crop models. The challenge though comes from the intent to use the forecast-crop model combination as a tool to make crop-relevant weather-based information, or a crop forecast, to provide farming communities with a month to several months lead time prevision tool.

#### Numerical integration

A number of technical solutions exist to integrate forecasts information with numerical impact models. In this project a particular look was taken at the integration of seasonal forecasts with crop models (see for instance Vol. 1 Chapters 4 and 5). The major challenge in the integration lies in the capacity of the integrated tool/approach to process and produce *relevant* and *useful* information. This project, once again confirms that usefulness varies from one location to another, due to seasonal forecasts skills, data availability for calibrating the models and other factors. This variability of conditions and farmer's ambitions is addressed in this project through engagements, and resulted in the definition of farmer's typologies (see Vol. 1 Chapters 6 and 7).

#### Forecast lead times

A common staple crop growing period takes about 3-5 months, and some of the critical management decisions are taken up to a few months before sowing. This project's efforts target both very short (day to week) operational decision time scale, as well as intermediate (month to several months) tactical decision time scales.

Data time step resolution

Process-based models strength lies in the step-by-step modelling of the modelled interacting processes. The time step used is a compromise of time/computing complexity and process description. AquaCrop, DSSAT and APSIM for instance use a daily time step, though they can deal with monthly data as well, through the use of a weather generator for instance. In order to limit as much as possible the inner-processing of data from seasonal forecast to crop forecast, we preferred the use and production of daily time step resolution seasonal forecast.

### 1.3.3. Institutional repartition of work

Given the large workload and various ambitions and aims of the project, the project team was driven along two complementary directions.

Volume 1 – A seasonal time scale, led by The University of Cape Town, and mostly focusing on smallholder farmers of Alice, Eastern Cape and Lambani in Limpopo, with the support of the University of Fort Hare, the University of Venda respectively.

Volume 2 – A seamless time scale, led by the University of KwaZulu-Natal and the CSIR, focused mostly on commercial agriculture in KwaZulu-Natal, with the support of the University of Pretoria and the Agricultural Research Council.

The first direction lead to numerous advances using Alice in Eastern Cape and Lambani in Limpopo as case study, and this is reported in Vol. 1 Chapters 2 and 3 put in place the basis of the study reporting on site descriptions and engagements. Chapters 4, 5, 6 and 7 are reporting on the technical aspects allowing to connect crop models with seasonal forecasts, in a context of climate change and climate variability, with a clear ambition to improve the systems. Chapters 8, 9, 10, 11 and 12 report the different ways implemented at different levels, to improve the use of seasonal forecast information by smallholder farmers in these locations. Chapter 8 is reporting on the use of remote sensing data to map soil moisture and adaptive capacity in Eastern Cape. Chapter 9 is exploring the current use of local indigenous knowledge related to weather forecast In Eastern Cape and in Limpopo. Chapter 10 is studying the potential of ecological intensification in those areas. Chapter 11 is interested in the communication of seasonal forecast information to rural communities. Chapter 12 is advancing an approach to make cropping decisions in response to seasonal forecasts. Chapter 13 finally brings together concluding remarks related to seasonal forecasts use to help cropping decision making, specifically with smallholder farmers on the basis of Alice and Lambani case study in Eastern Cape and Limpopo.

The KwaZulu-Natal case study (Vol. 2) was focused on the Mhlathuze catchment in the north of the province. The case study commenced in Chapter 2 with a description of the catchment and the stakeholder engagement undertaken in the project. In Chapter 3 the development and refinement of weather and climate forecasts is detailed. The configuration and verification of the ACRU hydrological model under observed climate conditions is then covered in Chapter 4. Chapter 5 details the linking of ACRU to Delft-FEWS, a hydrological forecasting framework. Chapter 6 then presents the results of short to medium range agrohydrological forecasting, while Chapter 7 presents the results of seasonal dam storage forecasting. Chapter 8 explores the potential to produce seasonal forecasts of crop yield and water productivity for the Empangeni area. Efforts to understand and reduce uncertainties and errors in agrohydrological forecasting are then described in Chapter 9, before conclusions are drawn on the Mhlathuze case study (and more broadly) in the final chapter.

## 1.4. Aims

The number of partners involved in the project brings together a large range of skills and expertise. Each aim is undertaken by the most relevant institution, with a clear effort towards regular community engagement.

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AIM 1 – TO RIGOROUSLY DOCUMENT AND IMPROVE ACCURACY AND SKILL IN, SHORT (1-3 DAYS) AND MEDIUM (3-10 DAYS) RANGE WEATHER FORECASTS (FEEDING INTO AIM 7 and 8)

The aim to improve weather forecasts focused on the 1-7 day lead time which spans both the short and medium time ranges. This aim was linked to the KwaZulu-Natal case study where a variety of time ranges (short range to seasonal) were considered in the endeavour to develop seamless forecasting for application in agricultural decision-making. Although the aim was linked to the KwaZulu-Natal case study, the weather forecasting research was conducted over a much larger domain (southern Africa) given the synoptic scale of the processes that influence weather at a particular location.

The conformal-cubic atmospheric model (CCAM) numerical weather prediction system was applied in the effort to improve short/medium range weather forecasts (Vol. 2, Section 3.1). These efforts focused on increasing the spatial resolution of forecasting and on making refinements to the cumulus parameterization and aerosol schemes.

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AIM 2 – TO DEVELOP EXTENDED RANGE (11 TO 30 DAYS) WEATHER FORECASTS TO FACILITATE FULLY SEAMLESS FORECASTING (FEEDING INTO AIM 7 and 8)

The forecasts developed under this aim (as part of the KwaZulu-Natal case study) are more appropriately classified as “sub-seasonal” forecasts, rather than extended range forecasts which have a strict definition pertaining to the 11-30 day forecast period. The forecasts developed are for a 40 day period. This is in keeping with sub-seasonal forecasts which can range from 40 to 60 days into the future. CCAM, coupled to the CSIRO sophisticated dynamic land-surface model referred to as Atmosphere Biosphere Land Exchange model (CABLE), was applied in the effort to develop sub-seasonal forecasts (Vol. 2, Section 3.2). The sub-seasonal time-scale holds the particular challenge of falling between the shorter range time scales, where initial conditions are the most important consideration in determining forecast skill, and the seasonal time-scale, where boundary conditions are crucial for model skill. As the sub-seasonal time range bridges the medium and seasonal time ranges, this effort is closely linked to forecast development efforts at those time ranges. Hence the work on sub-seasonal forecasting is reported in the context of developing seamless forecasting and includes results across the different time ranges.

### AIM 3 – TO RENDER SEASONAL FORECASTS DATA AVAILABLE TO CROP MODELS, INCLUDING THE SEASONAL PRODUCTION AT 2 LOCATIONS IN SA

This aim, and forecasts used for the smallholder case study in Eastern Cape and Limpopo, does not include the improvement of the currently available seasonal forecasts. However, feedback on the enablers and barriers faced in the development of the climate-crop integrated assessment are provided to encourage seasonal forecast providers and agricultural experts to take those into consideration for future advancements (aim 9). Although the project intention was to use a South African seasonal forecast products, a lack of specific legal sharing framework, and the irregularity of forecast production, made this mostly impossible. Given the project ambition to provide an approach accessible to any user, we used free and accessible CFSv2 forecasts[1]. This effort was tailored for two communities, one in Eastern Cape and one in Limpopo (see respectively Vol. 1 Chapter 2 and 3), and particularly grounded through the annual engagement with local farming communities.

### AIM 4 – TO INTEGRATE SEASONAL FORECASTS INTO CROP MODELS FOR SEASONAL PRODUCTION SCENARIOS, INCLUDING THE SEASONAL PRODUCTION AT 2 LOCATIONS IN SA

After considering multiple process-based crop models, the project proceeded to calibrate 2 DSSAT, and AquaCrop (see Vol. 1 Chapter 4). The DSSAT suite of model was taken forward and integrated with seasonal forecasts (see Vol. 1 Chapter 5). The capacity of DSSAT to simulate large numbers of conditions allows the exploration of large numbers of seasonal scenarios, combined with a number of possible agricultural actions, hence bringing out a notion of confidence and risk related to the presented climate-crop integrated assessments (see Aim 6). Engagements were once again, a major driver toward the calibration, validation and interpretation of the numerical approach. It translates for instance, through the farmer’s typologies defined in both Eastern Cape and Limpopo, specifically with a perspective emphasising the climate variability awareness (see Vol. 1 Chapter 6) and the potential to use Ecological Intensification (see Vol. 1 Chapter 7).

### AIM 5 – TO ENHANCE THE SPATIAL AND TEMPORAL RESOLUTION OF SEASONAL CLIMATE FORECASTS (FEEDING INTO AIM 7 and 8)

Owing to changes in the composition of the project team, the methodology employed (Vol. 2, Section 3.3) moved away from the use of climate models run at SAWS, and instead utilized the output of coupled global models contributing to the North American Multi-Model Ensemble. However, statistical post-processing was still utilized (as originally envisaged) to downscale the global forecast data to a scale more appropriate for use in catchment-scale agro-hydrological forecasting. More specifically, linear statistical procedures were applied to downscale and improve hindcasts (re-forecasts) from the coupled ocean-atmosphere models for the SADC region. This involved the use of Model output statistics to improve the raw climate model output through mean and variance bias correction. The enhancement of seasonal climate forecasts under this aim was directed at the KwaZulu-Natal case study.

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[1] http://cfs.ncep.noaa.gov/

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AIM 6 – TO DEMONSTRATE THE FEASIBILITY AND EVALUATE THE BENEFITS OF THE CLIMATE-CROP INTEGRATED APPROACH VIRTUALLY (MODELS ONLY WITH HISTORICAL DATA) AND IN REAL CONDITIONS, AT 2 LOCATIONS IN SA

The richness of the human resources and skills collected in this project has allowed to use the combination of seasonal forecast information with crop models and other technologies, in ways not necessarily foreseen at the inception (i.e. indigenous knowledge). This variety of approaches and directions are all grounded in engagements with communities and tailored in return for those very communities, making the overall project ambition to improve preparedness to climate variability local specific and valuable. In Eastern Cape, it includes the mapping of soil moisture through remote sensing data (see Vol. 1 Chapter 8), the documentation and use of indigenous knowledge to improve seasonal decision making in Eastern Cape and Limpopo (Vol. 1 Chapter 9), as well as the exploration of ecological intensification acceptance and use, and the production of crop forecast for the 2017-2018 growing season.

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AIM 7 – TO IMPROVE UNDERSTANDING OF, AND POSSIBLE REDUCTION IN, HYDROLOGICAL FORECAST UNCERTAINTIES AND ERRORS ACROSS DIFFERENT TIME RANGES (FEEDING INTO AIM 8)

Research to understand and reduce uncertainty and error in hydrological forecasting in the KwaZulu-Natal case study (Chapter 9) focused initially on characterizing the error in the weather/climate forecasts that are used as input to the hydrological forecasting process. These assessments were approached from a hydrological perspective, which is different to how such forecasts are typically assessed by weather/climate scientists. Other work to address uncertainties and error focused on improved initialization of hydrological models for hydrological forecasting, and on the benefit of incorporating temperature forecasts into the hydrological forecasting framework.

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AIM 8 – TO DEVELOP AND EVALUATE TAILORED HYDROLOGICAL AND CROP FORECAST PRODUCTS FOR APPLICATION IN DECISION-MAKING ACROSS DIFFERENT TIME RANGES IN ONE OR MORE CASE STUDIES IN KWAZULU-NATAL

The Mhlathuze catchment was chosen as a case study for the development of tailored agrohydrological forecasts. These forecasts were primarily aimed at irrigated sugarcane agriculture, as this is a major economic activity in the catchment, and is also a substantial water user. Therefore, any improvements to the management of water and crops in the sector that can be brought about by the availability of agrohydrological forecast has the potential to return economic and environmental benefits. These benefits would extend to the management of water in general in the catchment.

In terms of developing tailored agrohydrological forecasts, engagement with stakeholders revealed the need for seasonal forecasts of the Goedertrouw dam, and the possible benefit that could be derived from developing shorter term forecasts of irrigation water demand for irrigation scheduling purposes. Agrohydrological forecasts were developed through the application of the ACRU hydrological model, coupled to the Delft-FEWS hydrological forecasting system. This involved modelling the hydrology of the Mhlathuze catchment, including dams and abstractions of water for various users (especially irrigation). Coupling ACRU to Delft-FEWS aided in applying ACRU in a forecasting context. The possibility of forecasting seasonal sugarcane yields and water productivity using the AquaCrop model, was also explored.

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AIM 9 – TO FEEDBACK ENABLERS AND BARRIERS TO CLIMATE AND AGRICULTURE EXPERTS TO FACILITATE FUTURE CLIMATE-CROP INTEGRATION

Throughout the whole project, and the various themes and approaches tested and developed, particular attention was given to the enablers and barriers faced. A rigorous collection and details about these enablers and barriers is presented. Relying on the research team wide range of expertise and their professional connections to relevant institutions across South Africa, those feedback are presented as recommendations for improvement and supported by the concrete advances of the project and its engagement with communities. Despite the simple methodology required to provide complete and useful feedback, they rely on regular and frequent questioning through the various steps taken for the realization of the project, understanding the reason of choices made along the way and the consequent recommendation to improve future advances in the field of climate-crop integration.

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# CHAPTER 2. LAMBANI IN LIMPOPO PROVINCE

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Lambani is a village situated in Thulamela Municipality in Vhembe District of Limpopo Province, South Africa. It is located 60 km north of Thohoyandou town and 13 km from the Punda Maria Gate of the Kruger National Park (Botha et al., 2014). Its geographical coordinates are 22°43’ south, 30°50’ east. It lies at an altitude of 497 m. The Thulamela Municipality was established in the year 2000, in terms of the Local Government Municipal Structures Act 117 of 1998. It is the easternmost local Municipality in the District and is made up of 40 wards. The geographical area of the Municipality is approximately 2 966.41 $km^2$ (Thulamela Municipality, 2013).

## 2.1. Background

Lambani village lies in the semi-arid eastern region of Thulamela Municipality. According to Badisa (2011), the amount of rainfall received in Thulamela varies from 1 000-1 200 mm/annum on the western parts to 400-500 mm in areas such as Lambani, which shares borders with the Kruger National Park. Specifically, Lambani is classified as semi-arid because of the low annual rainfall it receives (588 mm) and high evaporative demand (Botha et al., 2014). Most of the rainfall is received in January (averaging 115 mm). The lowest amount of rainfall falls in June and August (6 mm). The period, December-February, is the warmest (average temperature of 27°C) with June-July being the coldest time of the year (average temperature of 19°C). There is no record of frost incidences at any time of the year. As is the case for Limpopo Province and the rest of Vhembe District, agriculture is central to poverty eradication and driving economic growth in Thulamela Municipality. The western parts of the Municipality are blessed with soils that are more fertile than those in the eastern side. In general, the tropical climatic conditions that characterise the municipal area make it suitable for livestock, crop and fruit production (Thulamela Municipality, 2013). Both subsistence and commercial farming are practiced. Common enterprises are vegetables such as watermelons, beans, cowpeas, potatoes, spinach, cabbage, onions, tomatoes, beetroot and carrots. Maize is the main staple food crop. Also common as pulse crops are groundnuts. Macadamia nuts are common in particular in the large-scale commercial farming areas. Mangoes, avocados, bananas and citrus fruits are also commonly grown. The major livestock species are cattle, goats, chickens, pigs and donkeys.

A study on household vulnerability carried out in Lambani (Francis et al., 2014) revealed that agricultural production is mainly of a subsistence nature. Very little is sold in local markets. There are several commercial farms or schemes which target local, national and international markets for their products. The large-scale commercial enterprises significantly contribute to the growth and development of the local economy. The situation presented above highlights the need for exploring the potential of small-scale farming to contribute more to local economic development. The crop growing season for the area ranges from 86 to 96 days (EnviroGIS and ARC, 2007). This limits production under rain fed conditions to fast maturing varieties. It is worth noting that large-scale commercial farms in the area are located close to water bodies such as the Luvuvhu River and thus, irrigation is common.

## 2.2. Climate

The project at hand is dedicated to seamless forecast, ranging from day to several months forecasts. Despite the interest of longer time scale horizons, it does not deal with time horizons beyond a year, hence neither with decadal nor climate change time scales. Yet to better understand local conditions and based on existing knowledge, we relate the current understanding of local climatology and expected long term changes.

### 2.2.1. Historical

The selected study site, Lambani is situated in the Thulamela local municipality of the Vhembe District, the northernmost district of Limpopo province. The climate of Lambani is described using the Punda Maria weather station records (1961-2010). The climate is semi-arid and described in Figure 2-1. Mean monthly temperatures range from 12 to 25°C in July (coldest winter month) and from 21 to 32°C in February (hottest summer month). Rainfall total monthly averages range from 3 mm (August) to 118 mm (January) and add up to an annual average total of 568 mm, with high summer months (October to April) precipitation and dry winters.

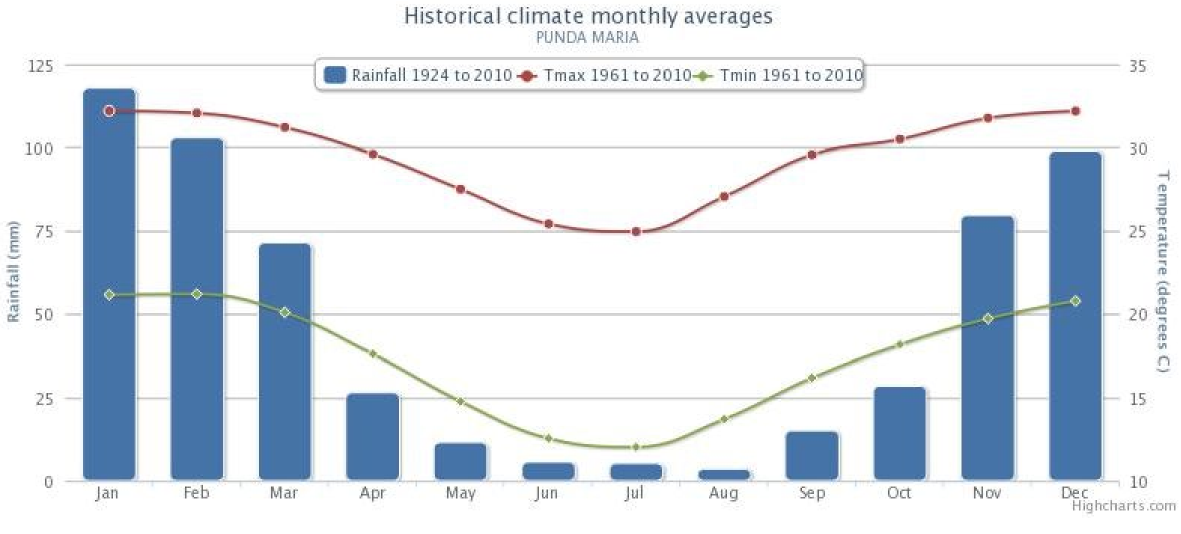

**Figure 2-1 Long term monthly climatology of rainfall totals and monthly averaged minimum and maximum temperatures. These monthly climatology values are calculated from the historical monthly record data of Punda Maria (proxy for Lambani) (CSAG-CIP, 2015).**

### 2.2.2. Near term

The following near-term (2010-2040) information is the results of statistically downscaled CMIP5 GCM data, at the Punda Maria station, as a proxy for Lambani (CSAG-CIP, 2015).

Under RCP4.5, average changes in minimum temperature per month range from +0.7°C to above +1.25°C. Changes in maximum temperatures are estimated to vary from +0.7°C to +1.5°C. Monthly GCM projections differ less than 1°C and 1.4°C (10th to 90th percentile) for minimum and maximum temperatures, respectively. This translates to a strong agreement in projections. Overall, both minimum and maximum temperatures are projected to increase for all months. Increases in minimum temperatures follow a seasonal pattern. The increases are most evident from July to December compared to the change from January to June. There is no significant change in maximum temperatures across seasons. Under RCP8.5, monthly change averages range from +0.7°C to +1.25°C for minimum and from +0.8°C to above +1.5°C for maximum temperatures. Monthly GCM projections differ less than 1.4°C (10th to 90th percentile) for minimum temperatures and up to 1.8°C for maximum temperatures, which still translates to a strong agreement in projections. Seasonality is more defined under minimum temperature than for maximums.

### 2.2.3. Mid-century

The following mid-century (2040-2070) information is the results of statistically downscaled CMIP5 GCM data, at the Punda Maria station, as a proxy for Lambani (CSAG-CIP, 2015). Under RCP4.5, monthly change averages range from +1.5°C to above 2.2°C for minimum and maximum temperatures. Monthly GCM projections differ less than 1.4°C (10th to 90th) percentile for minimum temperatures and less than 1.8°C for maximum temperatures. Temperature projections are robustly showing an increase. Minimum temperatures increase shows seasonality with high increases in September, October and November, and lower increases in March, April and May. This seasonality is weaker with maximum temperatures. Under RCP8.5, monthly change averages range from +1.7°C to +2.8°C for minimum and up to 3°C for maximum temperatures. Monthly GCM projections differ by 1.8°C (10th to 90th percentile) for minimum temperatures and less than 1.8°C for maximum temperatures, which still translates to a strong agreement regarding maximum temperature projections. Overall, there is also an increase in temperatures, all across the year. Projected variations in monthly rainfall reflect both increases and decreases across GCMs. Thus, there is no clear pattern in rainfall projections. However, mid-century projections of rainfall amounts strongly suggest that there would be little change during the dry season (June-August).

## 2.3. Agricultural Systems

As indicated above, agriculture is regarded as a pillar of economic growth and development in Limpopo province. The province accounts for about 10% of the land area of the Republic of South Africa. It is one of the prime agricultural regions in the country (Oni et al., 2012). In general, Limpopo province is dry. A diverse range of soils is found, with most of them being vulnerable to various forms of degradation. Based on its physical characteristics, 37% of Limpopo province is suitable for arable crop farming, 50% for grazing and 13% for wildlife (Oni et al., 2012). Apart from maize production the province has over 50% of available farming units that can be allocated to animal husbandry (The Census of Agriculture, 2002). An estimated 3,749,328 hectares are used for animal husbandry in this Province.

There are approximately 5 000 established farmers. Almost 80% of them practice subsistence agriculture. Production is split between a dual system of commercial farming (70%) and subsistence/semi-subsistence smallholder farming (30%) (Odhiambo and Maghandini, 2008). Smallholder production is practiced in the rural areas where an estimated 89% of the population resides, under low production technology on small (average of 1.5 ha) often marginal parcels of land (Oni et al., 2012). Maize takes the largest share of land for all field crops in the province, followed by sorghum, beans and groundnuts. Fruits, vegetables, tea and sugar are also commonly grown. Food crops are largely produced under rain fed conditions and are often prone to droughts and flooding. In Lambani, crop production is carried out primarily for subsistence with little surplus for the market. Soils in Vhembe District are variable, tending to be sandy in the west, but with a higher loam and clay content towards the east and are generally of low inherent soil fertility (Odhiambo and Maghandini, 2008). Vhembe District contributes 22% of the Gross Geographic Product (GGP) of the province's agricultural sector (BEPA, 2002). Farms in the area rely on irrigation when they are close to water bodies (rivers). High sediment yield is common and occasional flooding also occurs on shallow clayey soils.

Available information on soil and crop management is scattered in various reports. It is not specific to Lambani village. However, Ncube et al. (2016) revealed that maize (variety SNK2147 recommended) was the major crop grown in the village. These authors reported on the results of a simulated production system. The following production and management conditions for two seasons (2006/07) and 2007/08, first and 15th November planting dates and uniform application of fertilizer (75 kg N ha$^{-1}$) on clay soils and planting density of 44 400 plants ha$^{-1}$ were simulated.

## 2.4. Local household and communities

### 2.4.1. Local communities

The Francis et al. (2014) survey revealed that various community-based institutions influenced agricultural activities in Lambani village. Among the institutions were traditional leaders such as the chief and sub-village headmen. Traditional leaders are responsible for allocating land for various uses. Ward Committees (the Ward Councillor serving as the Chairperson and Community Development Worker (CDW) serving as ex-officio member) are the governing structure charged with deepening public participation and championing integrated development in the Ward. For this reason, the Ward Committee should always be a critical player in any development-oriented work introduced in any sector of the local community. Establishing close working relationships with this institution makes it easier to align research activities with government programming and possibly to attract resources that might be needed to supplement those available to run any given project. The CDW is a Ward-based civil servant who coordinates the provision of services to the local community in an integrated manner. On the other hand, Civic Associations operate at village level and serve as pressure groups that advance the interests of grassroots communities. They are responsible for making community-based institutions accountable to the people they lead. There are also farmers' and water users' associations, among numerous other bodies. Most important of these are the individual families or households. The latter constitute the farming units that ensure that food and nutrition security are achieved.

The Limpopo Department of Agriculture and Rural Development has agricultural extension and veterinary officers deployed in Lambani village. Also, other government departments such as Arts and Culture, and Health and Social Development, among others, run programs designed to alleviate poverty and promote sustainable development. Thulamela Municipality and Vhembe District Municipality play various roles, often clearly defined in the integrated development plans. Pastors, nurses, teachers and members of School Management teams are well respected in the local communities. Although their work is not directly linked to their day to day activities, they are important in the drive towards more resilient communities. For this reason, it is important to involve them in the planned research for agricultural development in Lambani village. Unemployed graduates and retired persons residing in Lambani should be regarded as key stakeholders because of the qualifications and experience they have, which can be harnessed to ensure that interventions introduced are better understood and correctly implemented.

### 2.4.2. Household vulnerability

According to Ncube et al. (2016), most households in Lambani village (73%) were moderately vulnerable. The rest were of low (3%) or high (24%) vulnerability. This meant that the latter were in such a desperate state that they would not survive without external support. The moderately vulnerable households referred to those that were likely to regress (becoming highly vulnerable) or get better (low vulnerability). As shown in Table 2-1 there are many factors that might influence the changes articulated here. Introducing sorghum under irrigation; and adoption of a SNKmaize-limited tillage system under irrigation were recommended because the benefits outweighed the costs associated with their uptake.

**Table 2-1 Factors influencing the vulnerability of households in Lambani, Limpopo province (Ncube et al., 2016). ***, **, * Statistically significant at 1%, 5% & 10% significance level.**

| Variable | Lambani (N=2581) | |
|---|---|---|
| | Coefficient | Standard Error |
| Age of Household Head | 0.057*** | 21.960 |
| Sex of Household head | 0.245** | 2.230 |
| Meals Per Day Children | 0.092* | 1.790 |
| Remittances Received | 0.446 | 1.560 |
| Access to Crop Extension Service | -0.446 | 1.250 |
| Receives Food Support | -1.454** | -13.520 |
| Climate Change Knowledge | 0.189** | 2.150 |
| Climate Change Training | 0.054 | 1.100 |
| Indigenous Adaptation | 0.054 | 1.220 |
| Land Ownership | 0.093 | 0.670 |
| Modern Adaptation | 0.084 | 1.450 |
| Low Yields due To Climate Change | -0.008 | -0.100 |
| Low Yields due to Crop disease or Pests | 0.124 | 1.180 |
| Increase in food prices | -0.090 | -0.920 |
| Death of Family Members | 0.254** | 2.370 |
| Community Formal credit Scheme | -0.054** | -1.900 |

## 2.5. Local challenges with impacts on crop production

Residents of Lambani village were said to be facing numerous challenges, with the most distinct ones being a high rate of unemployment and lack of job opportunities (Botha et al., 2014). The same report revealed that more than three-quarters of the households in the village (77%) received monthly incomes averaging less than R1 500. Moreover, Francis et al. (2014) carried out studies in Ward 2 of Thulamela Municipality and observed the following about the households in the area:

- 18% had no access to extension services;
- 32% did not know anything about climate change;
- 37% experienced food shortages most of the time during the year;
- 46% relied on river water for domestic use, which was a considerable health hazard;
- Low asset holdings, including land and livestock; and
- 40% conserved land during cropping.

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# CHAPTER 3. ALICE IN EASTERN CAPE

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## 3.1. Background

Alice is located in the Raymond Mhlaba Local Municipality. The municipality was established after the August 2016 local elections by the merging of Nkonkobe and Nxuba local municipalities in the Eastern Cape Province (The Local Government Handbook, 2017). Raymond Mhlaba local Municipality covers an area of 6 357 km$^2$, with a population of 159 515 and density of 24 people km$^{-2}$ according to Census 2016 results. This population has since increased from 151 379 people in the Census 2011 results (The Local Government Handbook, 2017). The majority of people living in the Raymond Mhlaba Local Municipality reside in villages and farms. Urbanisation is mainly concentrated in Alice and Fort Beaufort. Raymond Mhlaba Municipality has 23 wards and 235 villages. The majority of the population in the municipality is Xhosa speaking, with farming as their main occupation.

The selected site, Alice is geographically located at 32.78°S, 26.85°E at about 520 m above sea level in Raymond Mhlaba Local Municipality which falls under Amathole District Municipality in the central part of the Eastern Cape Province. Alice covers an area of approximately 9.85 km$^2$. The 2011 census showed that the population of Alice was approximately 15 143 people (Statistics SA, 2011).

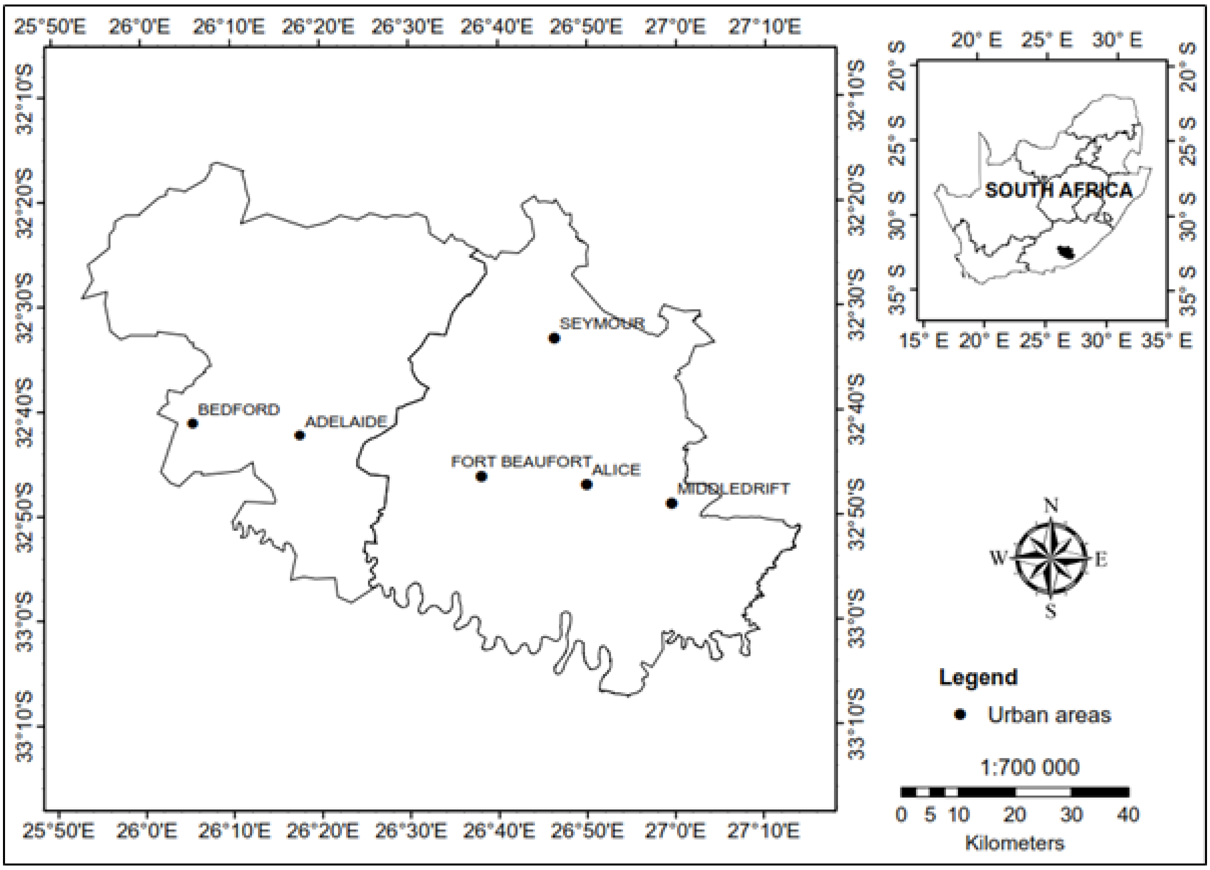

**Figure 3-1 Location of Alice in Raymond Mhlaba Local Municipality in the Eastern Cape Province, South Africa**

### 3.2. Climate

The climate of Alice is semi-arid. The monthly mean temperatures range from 6.3°C to 21.8°C in July (the coldest winter month) and from 17.3°C to 30.2°C in February (the hottest summer month). Rainfall total monthly averages range from 11 mm (July) to 57 mm (January) and add up to an annual average of 425 mm with high summer months (October to April) precipitation and dry winters.

The project at hand is dedicated to seamless forecast, ranging from day to several months forecasts. Despite the interest of longer time scale horizons, it does not deal with time horizons beyond a year, hence neither with decadal nor climate change time scales. Yet to better understand local conditions and based on existing knowledge, we relate the current understanding of local climatology and expected long term changes.

### 3.2.1. Historical

The climate of Alice is described using the Fort Beaufort weather station records (1997-2010) as plotted in Figure 3-2 and summarised in Table 3-1 below.

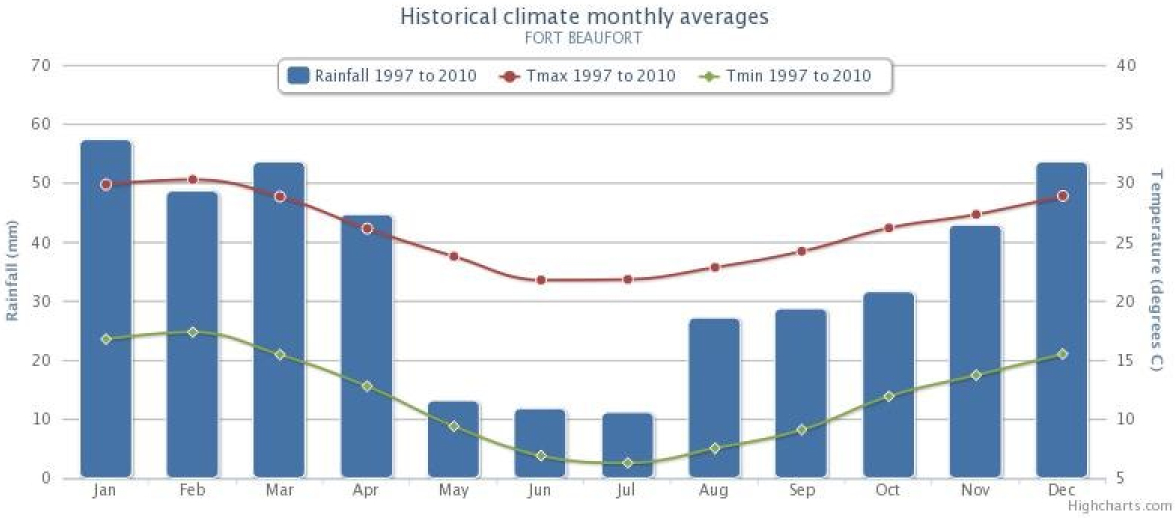

**Figure 3-2 Long term monthly climatology of rainfall totals and monthly averaged minimum and maximum temperatures. These monthly climatology values are calculated from the historical monthly record data of Fort Beaufort (proxy for Alice) (CSAG-CIP, 2015).**

**Table 3-1 Historical climate summary of Alice**

| Variable | | Range |
|---|---|---|
| Temperature | Coldest (July) | 6.3°C to 21.8°C |
| | Hottest (February) | 17°C to 30.2°C |
| Rainfall | July | 11.25 mm |
| | January | 57.47 mm |
| Annual Average Total | 425.5 mm | |

### 3.2.2. Near term

Under RCP4.5, monthly changes range on average from +0.4°C to above +1.2°C for both minimum and maximum temperatures. Monthly GCM projections differ less than 1.2°C (10th to 90th percentile) for minimum temperatures and less than 1.5°C for maximum temperatures, which translates to a strong agreement in projections. The overall message is an apparent increase in temperatures, across the year, for both minimum and maximum temperatures. Minimum temperatures increase only shows some sign of seasonality with high (with wider range) increase inter-season (March-April and October) and low increase in winter (June).

Under RCP8.5, monthly change averages range from +0.6°C to +1.3°C for minimum and from +0.3°C to above 1.1°C for maximum temperatures. Monthly GCM projections differ less than

0.8°C (10th to 90th percentile) for minimum temperatures and less than 1.1°C for maximum temperatures, which translate a strong agreement in projections towards increase (except for 2 GCMs in April for maximum temperatures). Both minimum and maximum temperature increases show a sign of seasonality with high increase from mid-winter until end of summer season (July to March) and low increase spring (April to June).

Rainfall projections vary from a large range of projections (-32 to +14 mm in January) to small ranges (-2 to +7 mm in August). Although those ranges translate changes compared with the baseline, the different change directions (increase vs. decrease) and the accuracy of GCMs to represent baseline period give no clear message about rainfall.

### 3.2.3. Mid-century

Under RCP4.5, monthly change averages range from +1.1°C to above 1.7°C for minimum and maximum temperatures. Monthly GCM projections differ less than 1.2°C (10th to 90th) percentile for minimum temperatures and less than 1.4°C for maximum temperatures, which translate a strong agreement in projections. The overall message is a clear and confident increase of temperatures, all across the year, for both minimum and maximum temperatures. There is no clear signal of seasonality.

Under RCP8.5, monthly change averages range from +1.7°C to above +2.4°C for both minimum and maximum temperatures. Monthly GCM projections differ by 2.7°C (10th to 90th percentile) for minimum temperatures and less than 1.1°C for maximum temperatures projections. The overall message is a clear increase in temperatures, all across the year, for both minimum and maximum, but no clear sign of seasonality.

Projections of monthly rainfall changes vary from large range of projections (-20 to +5 mm in January) to smaller ranges (-5 to +5 mm in October). Although those ranges show some changes from baseline, the various projections (increase vs. decrease) produce no clear message about whether rainfall (totals or intensity) will increase or decrease.

## 3.3. Agricultural Systems

The Eastern Cape Province is one of the largest provinces in South Africa in terms of surface area. It is divided into three main regions: eastern, western and central. Agriculture plays a key role in the province. In the Eastern Cape, shallow soils with depleted soil organic matter and nutrients are common; negatively impacting crop production (Gichangi, 2007). Soil type is mostly sandy loam with 64.2% sand, 16.0% silt and 19.8% clay (Mandiringana et al., 2005). The majority of the farming population is resource-poor smallholder farmers, depending on maize as the staple crop. However, maize yields are low, averaging less than 1.8 t $ha^{-1}$ under rain fed systems and less than 3 t $ha^{-1}$ under irrigation (Fanadzo, 2007). In some locations, maize cropping is limited. The surrounding villages, being rural in nature, actively engage in subsistence farming with a focus on livestock. Historically, the area has been known as a producer of beef and citrus (Ngqangweni et al., 2001). However, over the past 13 years this sector has been in decline – largely due to the closure of government organisations (e.g. Ulimocor) which lent support to this sector. In the Eastern Cape province of South Africa, livestock farming is an important agricultural practice that complements crop production.

Livestock ownership is the wealth of the farmers. Eastern Cape has the highest percentage of livestock, especially cattle and sheep compared to the other eight provinces of South Africa (Department of Economic Development and Environmental Affairs, 2009). In the province, small scale livestock farming is quite prominent (Nkonki, 2007). Of the total livestock contribution from the province, over 65% comes from communal areas (Eastern Cape Development Corporation, 2003). In the smallholder sector, livestock is used for home consumption but on limited basis. Farmers also use manure from livestock to fertilise their fields.

Alice is located in a district in which the agriculture sector has been in decline in the recent past and the agricultural sector as a whole is operating at 30% of its capacity (SDF, 2012). While maize is the staple crop, yields obtained by most smallholder farmers in and around Alice are far below potential, averaging less than 1.8 t ha$^{-1}$ under rain fed conditions with an average of less than 3 t ha$^{-1}$ under irrigation (Fanadzo, 2007). The surrounding rural areas (72%) actively engage in subsistence farming with a focus on livestock. Historically, the area has been known as a producer of beef and citrus. The lack of much needed technical support has reduced the productivity of the area, and it is now estimated that the agricultural sector in Nkonkobe as a whole is operating at approximately 30% of its capacity.

The length of the growing season in Alice averages 135 days and ranges from 91 to 164 days (Ganyani, 2011), allowing for a range of crop types and varieties. Whilst marketing skills are listed among the key shortfalls amongst the local farmers, there is a (dysfunctional) fresh produce market in Alice, which has the potential to play an active role in supporting the marketing of local produce if there is targeted capacity building to support this. Adding to this mix are the potential challenges that a changing climate, along with possible increases in the occurrence of extreme climatic events (especially droughts) may impose, there arises a glaring need to strengthen crop and livestock production against hazards. Impacts of climate change on crop-livestock systems will be heterogeneous as partly demonstrated by previous studies.

## 3.4. Local household and communities

### 3.4.1. Local communities

Alice farmers are organized into community-based cooperatives based on agricultural products produced. Other stakeholders include eDikeni Water Users Association and Alice Farmers Association (Nofemele T, personal communication, 15th January, 2015). SA LED Network (2013) also state that Alice communities have tried to work closely with the relevant sector departments in the past years in order to assist rural communities and various cooperatives, e.g. through the Siyazondla and the Comprehensive Agricultural Support Programme (CASP) by the Department of Agriculture, as well as through the King Sandile Development Trust (KSDT). This included support to crop (largely fruit and vegetable home growers) and livestock smallholder farmers (sheep / wool growers, poultry) as well as citrus producers, mainly through the transfer of land and infrastructure improvements (renovations, fencing, irrigation schemes). eDikeni Water Users Association has also been established for Alice farmers to administer water issues related to agriculture more particularly focusing on cultural and religious practices associated with water use as well as the role of traditional governance systems in Water Resources Management (Kapfudzaruwa, 2009).

Some of the government-based institutions that Alice farmers work with, include the Research Centres and Departments at the University of Fort Hare, the Agricultural Research Council, the Eastern Cape Rural Development Agency, and the Dohne Research Institute under the Department of Rural Development and Agrarian Reforms. These institutions focus on research and training of farmers (Nofemele T., personal communication, 15 January, 2015). For instance, both Lovedale College and Fort Hare University are involved in agricultural and food sustainability programmes around Alice communities.

### 3.4.2. Household vulnerability

The majority (about 83%) of the interviewed households in the Eastern Cape were moderately vulnerable to climate change disasters while only 5% had low vulnerability to climate change disasters. Those that were highly vulnerable to climate change disasters constituted 12% of the interviewed households. The household vulnerability index scores ranged from 0 to 0.797. The mean household vulnerability score was 0.6 with a standard deviation of 0.099 implying that the majority of the households encountered moderate vulnerabilities to climate change disasters.

Table 3-2 shows the results of the ordinal regression model for the three Household Vulnerability Index (HVI) categories. It found that an increase in the age of the household head increases the likelihood of the household being classified as moderately or highly vulnerable in Alice. Elderly households are more vulnerable because they are not engaged in productive and income-generating activities. Similarly, the sex of the household head was found to be an important vulnerability of Alice households.

**Table 3-2 Factors influencing the vulnerability of households in Alice, Eastern Cape (Ncube et al., 2016). ***, **, * Statistically significant at 1%, 5% & 10% significance level.**

| Variable | Alice (N=1513) | |
|---|---|---|
| | Coefficient | Standard Error |
| Age of Household Head | 0.195*** | 4.600 |
| Sex of Household head | 0.019*** | 4.710 |
| Meals Per Day Children | -0.221*** | -2.550 |
| Remittances Received | -0.358* | -2.020 |
| Access to Crop Extension Service | 0.051*** | 2.750 |
| Receives Food Support | 0.3789* | 1.820 |
| Climate Change Knowledge | -0.587*** | -3.720 |
| Climate Change Training | 0.3298* | 1.660 |
| Indigenous Adaptation | -0.257 | -1.550 |
| Land Ownership | -0.0.72 | -0.270 |
| Modern Adaptation | -0.3269*** | -1.900 |
| Low Yields due To Climate Change | -0.858*** | -4.110 |
| Low Yields due to Crop disease or Pests | 0.000 | 1.450 |
| Increase in food prices | -0.035 | -0.230 |
| Death of Family Members | 0.281 | 1.230 |
| Community Formal credit Scheme | -0.128** | -2.860 |

Households that receive external food support were found to be more likely to be highly vulnerable in Alice. Households also receive external support through remittances. Financial support helps households to deal with shocks to their livelihoods, and so households that receive remittances are more likely to be in the low-vulnerability category. The flow of remittances is often from migrant workers in urban areas to rural areas.

Participation in formal saving schemes in the village is also associated with lower levels of vulnerability. Households that participate in formal savings schemes in the village are more likely to be classified as lowly vulnerable. Community savings in the village are equally important because of the highly variable income of the poor and the frequency and magnitude of extreme climatic events such as drought and floods. Sustainable and reliable access to savings provides the family with an effective cushion against shocks and allows them to keep their productive physical assets (such as livestock) even in times of crisis.

Households with some knowledge of climate change are less likely to be highly and moderately vulnerable than households with less knowledge. This suggests the need for educational programmes that enhance knowledge on the risks of climate change. In Alice where the majority of households are highly dependent on crop production, households with access to extension services are less likely to be highly or moderately vulnerable.

### 3.5. Local challenges with impacts on crop production

In South Africa, particularly in the Eastern Cape Province, climate change is seemingly increasing the vulnerability of households to income losses, poverty and food insecurity, with this becoming most visible in rural communities. The high vulnerability of most communities to climate change related problems in the Eastern Cape Province is propelled by the high poverty incidence since the majority of these people are heavily dependent on rain fed agriculture, livestock production and government social grants for their livelihood (Gbetibouo and Ringler 2009; Zhou et al., 2013; Ndhleve et al., 2014). The majority of people in the province live in rural areas and depends on agriculture as their main economic activity. However, this sector is more vulnerable to climate change and this puts the lives of the poor in the region at risk.

A section of Raymond Mhlaba Municipality (formerly the Nkonkobe Local Municipality), the home to Alice, has a vulnerability score of 4 (Turpie and Visser, 2013) in the assessment of vulnerability of South African municipalities to the impacts of climate change and variability on a scale of 1-5, with a score of 5 being the most vulnerable to the impacts of climate change and variability. The Alice score (4) is even higher than the provincial average (2.49) as reflected in Figure 3-3.

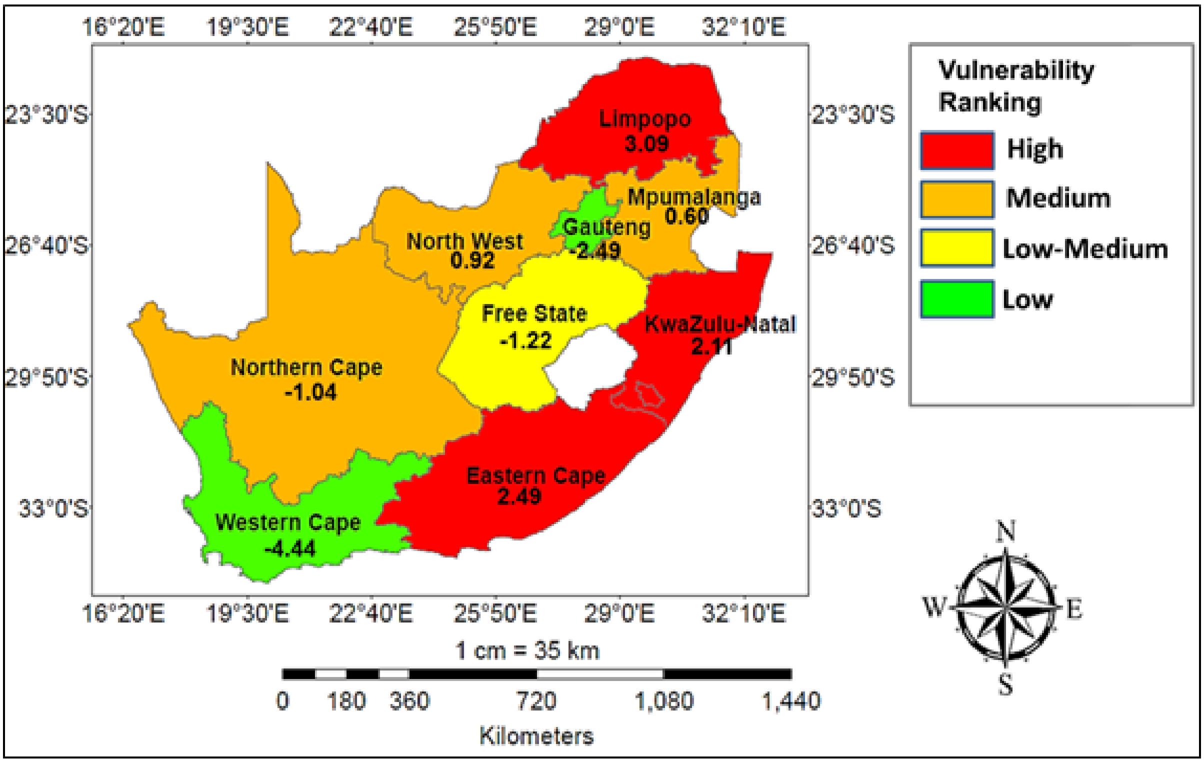

**Figure 3-3 Map of vulnerability indices and rankings of agriculture in South Africa to climate change (Adapted from Gbetibouo & Ringler, 2009)**

Extreme weather events like droughts, gradual increases in temperatures, increased variability in annual rainfall and greater prevalence of events such as droughts and floods are becoming more common. These changes are seemingly having a damaging effect on the poor.

It is established through survey information that Alice is vulnerable to disasters, owing to poor physical conditions for farming and to a dependency on social grants. Simulated impacts of climate change also anchor this assertion by showing robust negative impacts on maize production in Alice. The decline in maize yields in Alice is projected to persist further into the mid-21st century and the current vulnerability to climate change will likely be exacerbated.

Domestic electricity supply constraints and increasing oil prices come into play to drive the price of food, and with rising food prices, poverty is aggravated. High energy prices raise food prices through increased costs of production and transportation and the rising food prices in South Africa pose serious problems for the urban and rural poor.

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# CHAPTER 4. MODELLING CROPS

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## 4.1. Background

Cropping systems mostly can be modelled through (1) statistical or (2) process-based models. In the first case, statistical relationships are leading from major input factors into a targeted output. In the second case, a mathematical model describe the plant-soil-air interconnected processes and simulate, step by step, intermediary (e.g. phenological stages) and final crop outcomes. Both approach present strengths and weaknesses.

Below sections present 2 process-based crop models widely used and which performances have been tested globally (i.e. DSSAT and AquaCrop, although APSIM was considered, is was later not used). Any of these would suit the project goals toward the production of seasonal crop forecast. It is evident that the exploration of statistical modelling options would as well benefit the effort of better preparedness to climate variability (e.g. Malherbe et al., 2014), but was not part of the scope of this project.

Process-based model would have a significant advantage in the context of this project in that it would facilitate easier exploration of the influence of changes in management (e.g. relating to land use or dam operation) on the availability of water for irrigation. Thus potential management responses to weather/climate forecasts can be investigated. A process-based hydrological model (ACRU) that will be used in the project is described in Volume 2.

### 4.1.1. DSSAT – Decision Support System for Agrotechnology Transfer

A review by White et al. (2011) suggested that the DSSAT family of crop models is the most widely used for climate change impact studies globally. DSSAT is a simulation model for crops that describes daily phenological development and growth in response to environmental factors (soils, weather and management). The model includes subroutines to simulate soil and crop water balance and nitrogen balance, and has the capability to simulate the effects of nitrogen deficiency and soil water deficit on photosynthesis and pathways of carbohydrate movement in the plant (Iglesias et al*.,* 2000). The model requires daily weather values of maximum and minimum temperatures, precipitation and solar radiation. Soil information needed includes details of target soil characteristics; drainage, runoff, evaporation and soil water holding capacity amounts, and rooting preference coefficients for each soil layer and initial soil water content (Jones et al*.,* 2003). Crop characteristics are determined through crop and cultivar specific genetic coefficients.

The different components of DSSAT are brought together by a soil-plant-atmosphere module that computes soil evaporation and plant transpiration. Daily weather values as well as soil properties and current soil water content, by layer, are required as input. In addition, leaf area index (LAI) and root length density for each layer are needed. The module first computes daily net solar radiation, taking into account the combined soil and plant canopy albedo then calculates potential evapotranspiration (ETo) using one of two options. Firstly, the Priestley and Taylor (1972) method that requires only daily solar radiation and temperature or the Penman-FAO (Doorenbos and Pruitt, 1977) which requires further data including wind and humidity. DSSAT has a management module that determines when field operations are performed by calling sub modules. These operations can be specified by users. They include planting, harvesting, applying inorganic fertilizer, tillage, irrigating and applying crop residue and organic material (Jones et al., 2003). Such broad user specified management options make DSSAT particularly suitable for simulating specific cropping systems like smallholder farming systems common in southern Africa. However, they also add to large data demands of the model.

DSSAT models have been used in studies to simulate the collective effects of climate change, plant genetics, management practices, and soil conditions on the growth, development, and yield of various crops (maize, sorghum, sugarcane and beans) at varying scales in southern Africa (Jones and Thornton, 2003; Chipanshi et al., 2003; Walker et al., 2006; Knox et al., 2010; Thornton et al., 2011).

### 4.1.2. AquaCrop – crop water productivity model

Application of modelling techniques can be essential to agriculture for defining and understanding the basic interaction of soil-plant-water system. The model used to develop recommendations to improve water use efficiency, simulation runs with a model conducted to assess yield response to water, the outputs from the model are utilised to formulate recommendations. AquaCrop uses a relatively small number of parameters spontaneously to provide balance simplicity, accuracy and robustness. The accuracy based on accurate plant physiological and soil water budgeting processes.

AquaCrop is a crop water productivity model which is grounded on basic and complex biophysical processes, developed by the Food and Agricultural Organisation. It simulates yield response and address conditions where water is a key limiting factor in crop production. It uses categorical and built-in parameters and input variables requiring simple methods for their determination. AquaCrop is the dynamic crop growth model developed to predict yield response to water of herbaceous crops (Steduto et al., 2009; Raes et al., 2009; Hsiao et al., 2009). On this study, AquaCrop was selected for its applications which include, assessing water limited and attainable crop yield at a given agro-climatological zone; assessing rain-fed crop production on a long-term; developing irrigation schedule for maximum production as part of farming adaptation strategies; simulating crop sequences and carrying out future climate scenario analyses; evaluating the impact of low fertility and of water-fertility interactions on yields; and most importantly supporting on-farm decision making on water allocation and scenarios for strategic adaptation (Allen et al., 1998; Doorenbos and Kassam, 1979).

AquaCrop uses the key yield response proportional factor (Ky) approach by:

1. Dividing relative evapotranspiration (ET) in soil evaporation (E) and crop transpiration (Tr) to avoid confounding effect of the non-productive use of water (E),
2. Obtaining biomass (B) from the product of water productivity (WP) and cumulated crop transpiration,
3. Expressing the final yield (Y) as the product of B and Harvest Index (HI),
4. Normalising Tr with reference evapotranspiration (ETo), to make the B-Tr relationship applicable to different climatic regimes,
5. Running daily time steps (calendar or growing degree days), to more realistically account for the dynamic nature of water stress effects and crop responses.

AquaCrop is water-driven and the importance is that the crop growth and production are driven by the amount of water transpired (Tr). The relation between B and Tr remains fundamental for AquaCrop (Figure 4-1). AquaCrop consists of sub-model components which includes: the soil and its water balance; the crop and developments characteristics; growth and yield; the atmosphere with its thermal regime; rainfall; evaporative demand, $CO_2$ concentration, agronomic practices (for example, irrigation and fertilization).

Food production is profoundly a product of the soil-plant-atmosphere continuum (SPAC) and operated by farmers and decision makers in the farming sector. Agro-climatic parameters such as rainfall and temperature are the determining factors on crop status, biomass and yield. The use of AquaCrop simulating model contributes in the optimal management SPAC system for the benefit of humankind toward proper understanding and integration of climate, soil and crops.

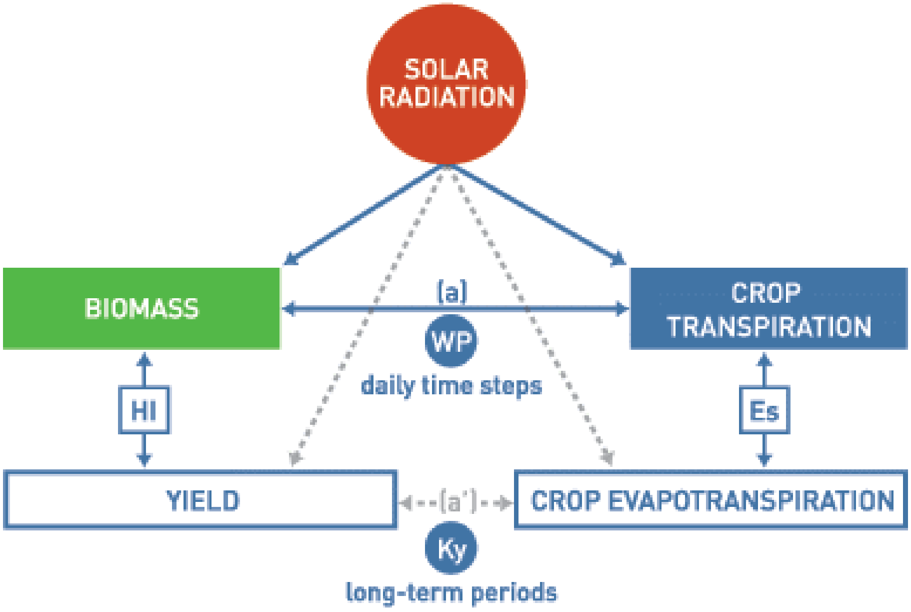

**Figure 4-1 A schematic representation of AquaCrop intuitive parameters**[2]

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[2] http://www.fao.org/nr/water/aquaCrop_about.html

The importance of AquaCrop model in this study is its unique capability as it allows the user to assess crop responses under different climate scenarios in terms of water availability, temperature regimes and soil types. It is a model that simulates growth, productivity and water use of a crop day by day, as affected by changing water availability and environmental conditions. AquaCrop will be set up for three different agroclimatological zones, namely, Empangeni location for sugarcane productivity, Alice and Lambani for maize productivity.
The use of AquaCrop provides a better understanding on crop phenology and physiology as well as the general overview of crop growth and aids in water efficiency and nutrient management. Given different scenario on sugarcane productivity, the control of vegetation growth and manipulation of sugar production is prospective; the latter is possible by the application of knowledge on phenological growth phases for maximising cane yields and sugar salvage. AquaCrop model require input data, which entails environmental conditions, and crop data. The input data was arranged as follows, climate, crop, management and soil then simulation data generated based on simulation period and initial conditions, which are constituted, based on initial water content, soil layer thickness and soil salinity. AquaCrop 6.0 follows well-organised simulation processes, which consider simulation of the early development of the cover under water stress, simulation of root deepening in a dry subsoil, simulation of soil water stress, simulation of canopy cover decline, simulation of cold stress and calibration and simulation of salinity stress. It has a possibility to specify the degree of weed management, penetrability of a soil horizon and specify gravel in a soil horizon.

## 4.2. Calibration and validation

### 4.2.1. Data requirement

Maize Climate Requirements

Maize cultivation occurs under divergent physical conditions and maize is a stable food for many in the ground of African continent, a feed for livestock and raw material for many industrial products. Maize is cultivated and produced in semi-arid, tropical and temperate latitudes. The critical and detrimental temperature to the yield if surpassed is 32°C. Flowering crop stages flourishes at temperature ranging 18 to 25°C with the night temperature of about 14°C. However, the most important factor is a frost-free period ranging from 120-140 free days for damage control. Since, the maize crop is very vulnerable to frost at all growing stages; therefore, maize cultivation in temperate latitudes is limited.

The required annual rainfall for maize production ranges from about 500 to 750 mm and higher for moisture provision. Frost occurrences are detrimental to the crops vitality but water deficiency is the most yield-limiting factor that hinders good yield production. To attain a yield of about 3 152 kg ha$^{-1}$, between 350 to 450 mm of rain is required. It is also crucial that correct cultivars or maize varieties properly selected based on the climatic conditions. The amount, distribution and efficiency of rainfall during the planting season in the most important factor toward successful maize production. Pre-planting rainfall, contributes to initial soil water content, which additional tremendously contributes for meeting the crop requirement. The soil water content demand for maize starting from initial stage increases rapidly up to the flowering stage, before decreasing as it reaches senescence stage. Thunderstorms and high wind speed can cause severe losses in final yields, since the leaves are torn-off most especially near tasselling stage, stem breakages, lodging or leaf shredding may occur. Increased radiation increases the rate of evapotranspiration and thus yields tend to be negatively correlated with radiation unless if there is sufficient soil water.

Maize Soil Requirements

Maize production is suitable on a variety of soil types and soil forms; provided the soil has no restrictive layers such as hardpan and the soil pH lower than 4.5 unless lime application programme is in place. The most preferred and conducive soil type entail the following characteristics, such as, favourable physical properties, good soil drainage, optimal soil water content and well balanced soil fertility. The selected study sites to conduct AquaCrop simulation runs is Alice and Lambani, with the soil type Oakleaf, Hutton and Clovelly, respectively.

The Clovelly soil form constitute of Orthic A and yellow-brown Apedal B-horizons, which consists of a series of very deep, very poorly drained, very slowly permeable soils. These soils formed in moderately thick accumulations of herbaceous organic material overlying very fluid clayey alluvial sediments. These soils are on broad coastal marshes that are nearly continuously flooded with brackish water. Slope ranges from 0 to 0.2% (Soil Classification Group, 1996). Oakleaf soil form constitutes of Orthic A and Neocutanic B horizons, its surface horizon may have been darkened by organic matter and occurs in unconsolidated material, transported. Hutton soil form constitutes of Orthic A and red Apedal B soil horizon, the Hutton series consists of very deep, poorly drained soils that formed in alluvium from mixed sources. Hutton soils are on floodplains, stream terraces, and depressions and have slopes of 0 to 4%, with very slow permeability (Soil Classification Group, 1996).

### 4.2.2. DSSAT Model Output

For calibration only, climate was produced based on the best available daily data with regards to geographical proximity, data length and quality. Daily minimum and maximum temperatures as well as rainfall were used. Alice (Eastern Cape) climate characterization was done based on the Fort Beaufort station historical daily records. For Lambani (Limpopo), the Punda Maria station historical daily records were used. Both records were made available from CSAG public records[3]. Process-based crop models require complete daily data sets to run and observations inevitably include missing data. Those have been filled with the Modern Era Retrospective-Analysis for Research and Applications (MERRA). Potential evapotranspiration (ETo) was not available at either station and was estimated at a daily time scale using temperature and rainfall from the historical climate record, latitude and altitude based on Allen et al. (1998).

Calibration and validation were performed using experimental trials obtained from published research papers. The DSSAT (v4.5) model (Jones et al., 2003) was calibrated and validated for maize at both study locations with experiments that consisted in a range of treatments that varied by location and season. Model calibration was achieved through tuning phenology and growth coefficients of a crop variety respectively by minimizing the differences between

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[3] Original data obtained from the Computing Centre for Water Research (CCWR) and the South African Weather Service (SAWS)

observed and simulated crop yields for a season's simulation trial. Only one season was used for calibration at each research site due to data constraints. Initial soil water was estimated by running the model 3 months prior to planting date. Crop varieties calibrated were identified from reported trials. The cultivars identified and used per location are shown in Table 4-1. The coefficients were adjusted from varieties already found in the DSSAT database that were within a similar growth category (early maturing, medium maturing, etc.). The established cultivar parameters were applied for model validation. Soils were identified from published reports and used to identify similar soils within the DSSAT database.

**Table 4-1 Bio-physical conditions and agronomic management strategies used for calibration**

| Location | Alice | | Lambani | |
|---|---|---|---|---|
| Crop | Maize hybrid: PAN6777 | | Maize hybrid: SNK2147 | |
| Soil | Loam | | Clay | |
| Plant density | 45 000 plants ha$^{-1}$ | | 44 400 plants ha$^{-1}$ | |
| Fertiliser application | Basal:<br>13 kg N ha$^{-1}$ | Top:<br>13 kg N ha$^{-1}$ | Basal:<br>20 kg N ha$^{-1}$ | Top:<br>10 kg N ha$^{-1}$ |
| Planting dates | Mid November | | Mid November | |

In Lambani, given the short average growing season for that area, a short season maize variety (SNK2147) was set up for local conditions in Vhembe District using an experiment carried out over 2 seasons, 2006/07 and 2007/08 (Odhiambo, 2011). The 2006/07 season was used for calibration and the 2007/08 season for validation. The results are shown in Table 4-1. Using the available data, the crop model (DSSAT) was found to be able to simulate maize yields in response to climate and agronomic management. The model was able to simulate observed yield within a 5% relative difference (RD) as shown in Table 4-2.

A long season maize cultivar was setup for simulating maize yields (PAN6777) in Alice, owing to the long growing season. Calibration was performed using the 2009/10 cropping season (Fanadzo et al., 2010). Validation was performed over 2 seasons, i.e. 2005/06 and 2007/08 (Fanadzo et al., 2009). Using the available data, DSSAT was found to be suitable for simulating maize yields in response to climate and agronomic management in Alice. Maize yields were simulated within a 7% relative difference (RD) as shown in Table 4-2.

Any additional data would likely result in higher confidence in the ability of the crop model to simulate yields under specific condition in the study locations. Given the available data, the model performs well. Further confidence should be obtained from expert consultations during site visits and experience with the model in previous work done by the researchers with the model in various agro-ecological environments and crops in southern Africa, where a strong relationship between simulated and observed yields were obtained as shown by Zinyengere et al. (2015). However, while there is considerable confidence in the model simulation ability in the study locations, decision makers need to take spatial and temporal limitations into consideration when interpreting the numerical outcomes.

**Table 4-2 Simulated and observed yields per season and management conditions for calibration and validation of DSSAT for each location**

| Location | Seasons | Planting dates | Fertiliser kg N ha$^{-1}$ | Planting density Plants ha$^{-1}$ | Observed kg ha$^{-1}$ | Simulated kg ha$^{-1}$ | RD % |
|---|---|---|---|---|---|---|---|
| Alice | 2009/10 | 10/11 | 60 | 40 000 | 4507 | 4527 | 0.44 |
| | 2005/06 | 10/11 | 60 | 40 000 | 3853 | 3611 | 6.28 |
| | 2005/06 | 10/12 | 60 | 40 000 | 4286 | 4000 | 6.7 |
| | 2007/08 | Mid Nov | 60 | 41 125 | 3800 | 3985 | 4.87 |
| Lambani | 2006/07 | 15/11 | 75 | 44 400 | 4 900 | 4861 | -0.82 |
| | 2007/08 | 01/11 | 75 | 44 400 | 7 400 | 7045 | -4.8 |

### 4.2.3. AquaCrop Model Output

Alice, Eastern Cape

The study area investigated was Alice, a town located in the Eastern Cape Province of South Africa (32°44’S; 26°54’E), with an altitude of 520 m. The annual rainfall for Alice is ranges from about 386 mm of rains per annum, with good rains arising mainly during summer season (Figure 4-2). Alice receives the highest amount of rains in March with the average of 58 mm followed by November at 45 mm. The lowest rains occur during winter months in June and July 8 mm and 7 mm respectively. Figure 4-2, indicates that rainfall distribution in Alice varies with months. For Farmers, it is crucial to adopt and produce summer and winter crop, the essence of understanding when to plant and what to plant remains paramount for improved crop productivity.

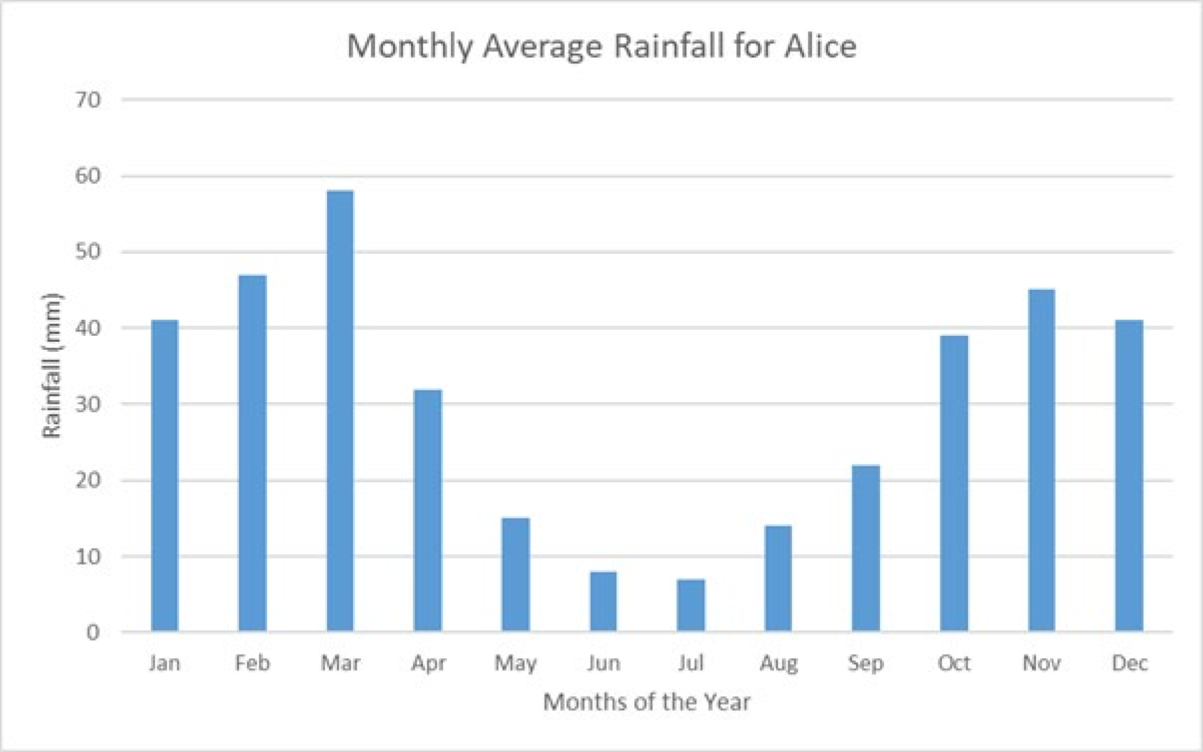

**Figure 4-2 Alice monthly average rainfall (ARC-ISCW databank)**

The monthly distribution of maximum temperature, minimum temperature and average temperature as presented in Figure 4-3. The monthly average temperature for Alice range from 25°C to 29°C form November to April, with the lowest temperature received in June and July which can decrease to about 5°C. In June to July the Alice surroundings are at its coldest temperature.

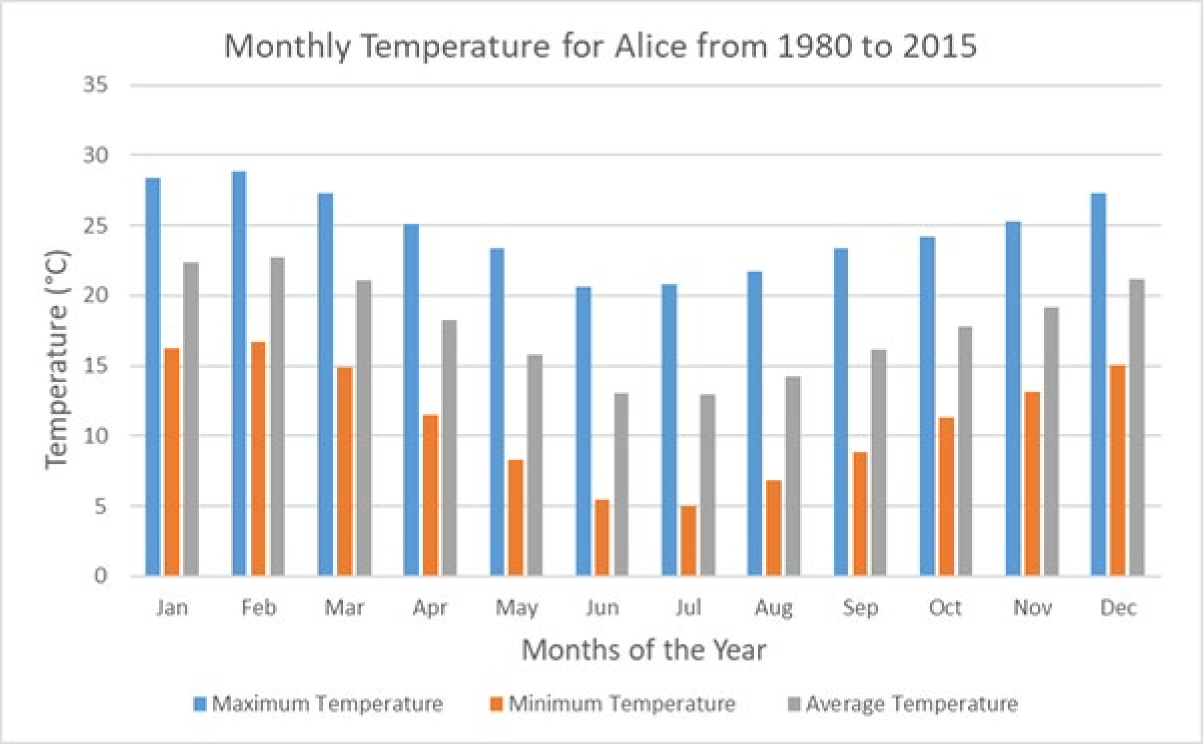

**Figure 4-3 Lambani monthly maximum, minimum and average temperature (ARC-ISCW databank)**

The utilised climate to conduct simulation runs for Alice region started on 8 May 2008 to 30 December 2015 and different planting dates were selected to assess the best planting dates given climatic conditions during the growing season. The growing degree days were put into consideration to attain its significance in relation to final yield productivity. The field conditions prior planting were assumed to be moderate soil fertility with a soil profile of sandy loam with water table varying depth and salinity, and the initial conditions of soil water content at particular depths simulation period varied from 15 November to 5 April. As it is a norm, under optimal climatic conditions crop productivity is expected to increase significantly. During planting season 15 November 2008 to 13 April 2009 the simulated biomass ranged at 32.118 t ha$^{-1}$ with the dry yield of 15.417 t ha$^{-1}$, with the accumulated degree days amounted to 1 680°C and an estimated evapotranspiration of about 700 mm.

On simulation run on the 30 November to 20 April the biomass was recorded at 31.706 t ha$^{-1}$ with dry mass of 15 t ha$^{-1}$, yet the evaporative water productivity of 3.03 kg m$^{-3}$ (yield) water and the harvest index rated at 48% remained the same. Only a decline of biomass of 0.412 t ha$^{-1}$ was observed. The optimal biomass produced was the same for the actual produced and the potential produce with the. On the second planting date which simulation occurred on the 15 December to 5 May biomass remained at 32.118 t ha$^{-1}$ with dry yield at 15.417 t ha$^{-1}$ with the evaporative water productivity of 3.03 kg m$^{-3}$ (yield) water, the crop characteristics were attuned at crop development with no water, fertility and salinity stress (Figure 4-4), the growing degrees accumulated to 1 704.0°C.

Simulation run with the planting date on the 5 January to 26 May indicated no significant changes in biomass production as it remained the same as the biomass production obtained on 15 November planting date beside a slight change on evaporative water productivity of

3.04 kg m$^{-3}$ water. However, it is crucial to mention that maize production produced in late December to early January has to be consumed or/and sold as a fresh produce, in avoidance for the effect of on-set of frost which may cause observable effects on crops. It is also worthwhile to mention that the ground water or water table was assumed to be varying depth and salinity during simulation runs at 1.62 m.

Based on the analysis, Alice region has a remarkable potential for maize productivity. Sequential planting for continuous supply of maize as green and or dry requires proper selection of planting dates based on the availability of soil water content and climate condition. The confirmed maize planting calendar constructed on the analysis starts as early as 15 November to 1st week of January, hence the farmers has to place in consideration the soil fertility, soil water content, rainfall distribution and cultivar availability. It is however, critical for the farmers to continually follow the weather forecast, climate prediction as well of most importance the cultivar varieties and innovative technologies toward improved maize productivity. As represented below in Figure 4-4, the description of on crop characteristics and development on a given growing cycle, with emphasize the critical crop growth stages which require non-limited crop growth conditions.

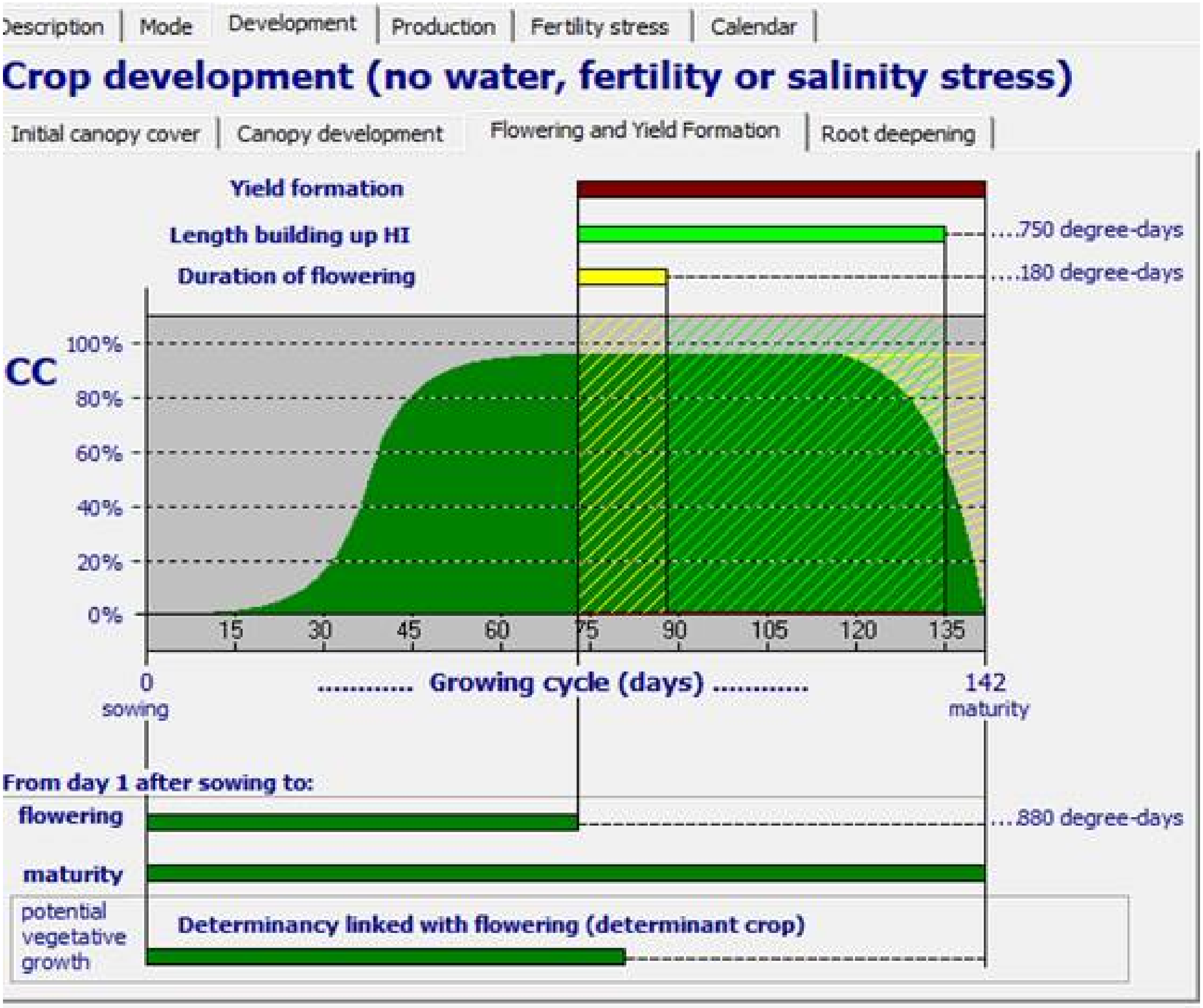

**Figure 4-4 Crop development for a growing cycle limited conditions**

Lambani

The second study area investigated for maize production was Lambani a rural village located in Limpopo Province of South Africa with the weather station located at (24º52'S; 28º17'E), with an altitude of 460 m. According to the long-term climate data from 2006 to 2015, the annual rainfall for Lambani ranges about 655 mm per annum with an evaporative demand of about 1395 mm. Most rainfall received from November to February, with the highest rains received in January at 60 mm, December getting about 38 mm monthly average rainfall. May to August are the lowest rainfall months getting less than 4 mm (Figure 4-5).

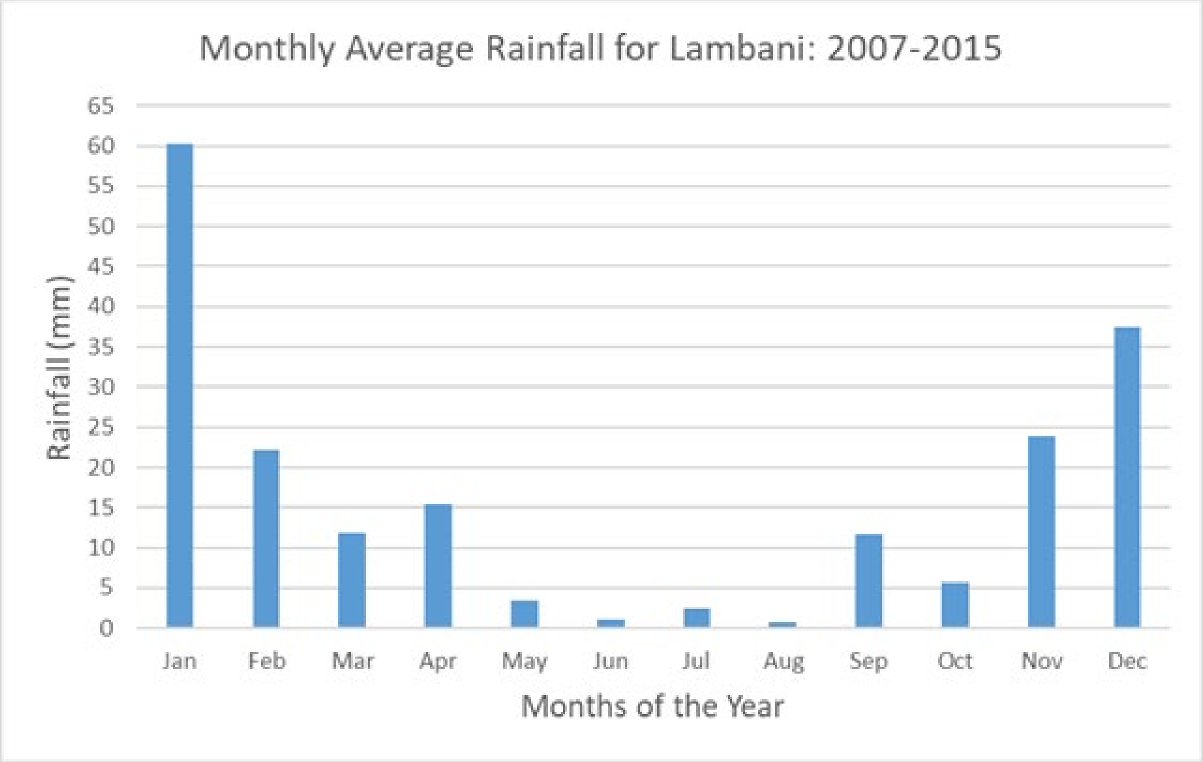

**Figure 4-5 Monthly average rainfall for Lambani (ARC-ISCW databank)**

According to Figure 4-6, the maximum temperature from September, October, November, December, January and February are the warmest months with an average temperature of above 30°C and June and July are the coldest months with an average temperature of 19°C and the minimum temperature can decrease to as low as 8.5°C. Thus, these temperature readings indicated that Lambani is a frost-free region throughout the year.

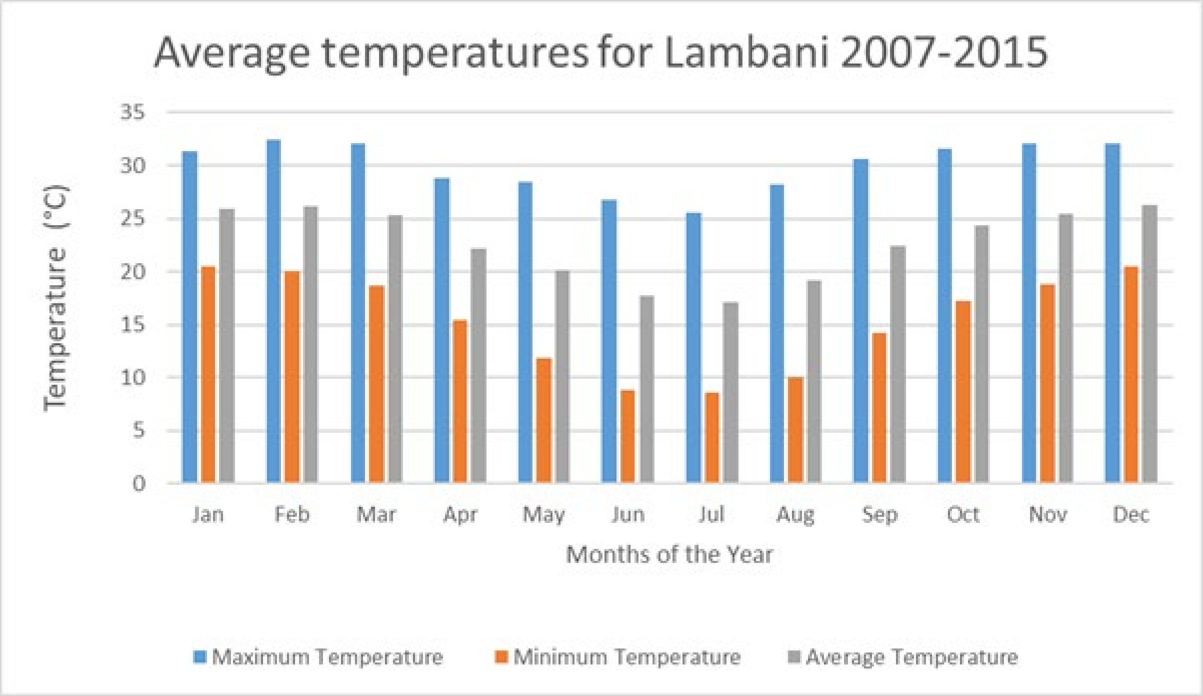

**Figure 4-6 Monthly maximum, minimum and average temperature for Lambani (ARC-ISCW databank)**

In comparison of monthly rainfall (Figure 4-7), it is noticeable that rainfall amount and distribution vary on monthly basis. The summer season months receive high amount of rainfall comparing to winter months. Lambani rainfall amounts observed to be lower comparing to Alice except for January month, whereby, Lambani region exceeded Alice region with approximately 20 mm of monthly average rainfall.

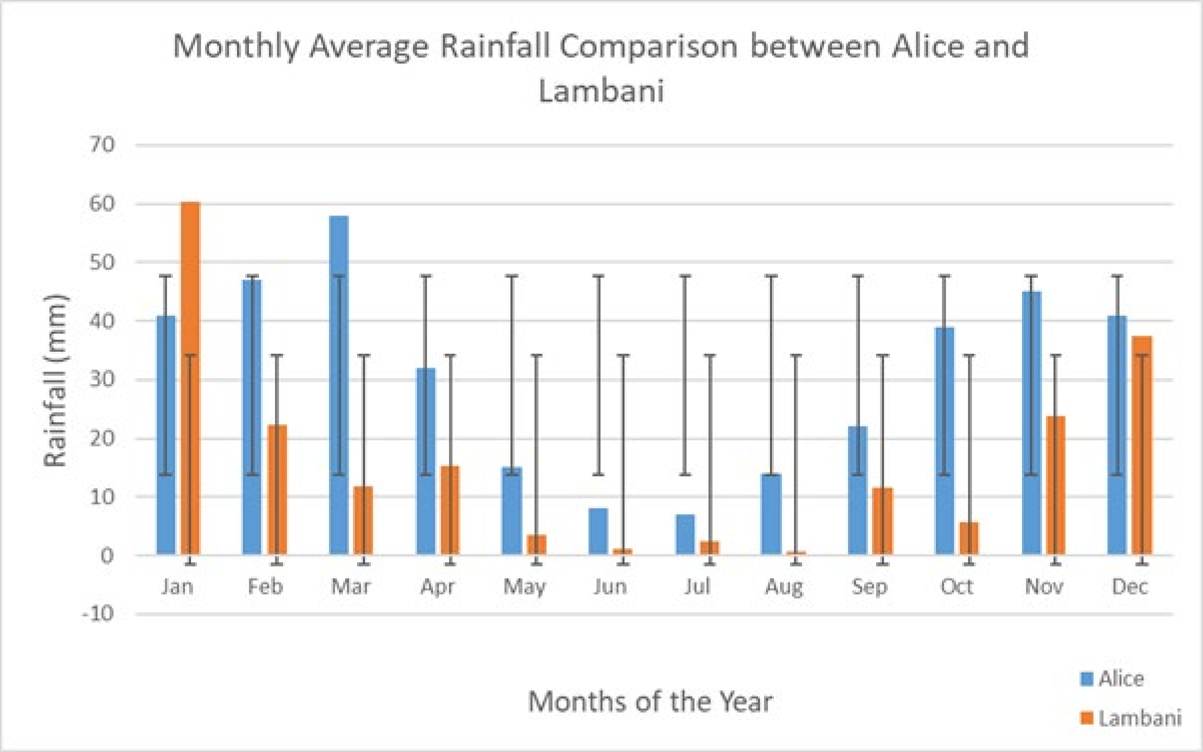

**Figure 4-7 Rainfall monthly comparison for Alice and Lambani**

In Figure 4-5, Figure 4-6 and Figure 4-7, one can deduce that Lambani region window-planting period in much wider comparing to Alice region, since Lambani is a frost-free region with higher amount of rainfall received during December/January months. Thus, caution must be diligently, taken into consideration, since the planting dates may be influenced by the occurrence of floods. In Lambani region there is a high potential of flood occurrence that may result in the swamping of planted seeds or seedlings.

According to the runs conducted using AquaCrop under rain fed conditions with moderate soil fertility. The soil profile investigates was Clovelly which constitute of high clay soils content at different layers. The groundwater assumed to be at varying depth and salinity. A number of successive runs conducted starting from 15 November 2006 to 24 February 2007, which resulted to 11.220 t ha$^{-1}$, 1 704°C, 342.9 mm of evapotranspiration with the receipt of about 758.19 mm of seasonal rains and the evapotranspired water productivity of 2.26 kg m$^{-3}$ water. The calculated biomass production on planting date 30 November 2006 to 10 March 2007 indicated 14 t ha$^{-1}$ with water use efficiency of about 2.7 kg m$^{-3}$ water with the growing degrees of 1 714°C. An observation on the planting date 15 December 2006 to 25 March 2007, the biomass production increased to 16.438 t ha$^{-1}$ with the evapotranspired water productivity of 2.85 kg m$^{-3}$ water with harvest index of 45.6% which is higher to the planting dates occurred previously and the stomatal closure decreased to 29%.

The observation on biomass production increased to 18.148 t ha$^{-1}$, although delayed germination of 6 days occurred. During the 30 December 2006 growing season the growing degree days accumulated to 1 704.2°C, with evaporation at 349.3 mm and the seasonal rainfall accumulated to 450 mm. With the evapotranspirated rate of 2.41 kg m$^{-3}$ water the harvest index was indicated to be 35.9%. Cultivar selection to be selected with cautious since early senescence could be highly expected as determined by rainfall distribution as the season progresses. Biomass production decreased tremendously on the simulation run planting date 10 January 2007 and beyond indicated to 5.210 t ha$^{-1}$ with evapotranspired water productivity of 1.29 kg m$^{-3}$ water, however, the potential biomass under unlimited conditions is 15.622 t ha$^{-1}$. During late planting the evapotranspiration increased to 625 mm and the accumulated to 1 812.5°C.

Lambani station indicated a dynamic climatological exterior which indicates that decision making processes are critical for improved crop productivity. Lambani region is known of its high evaporative demand, flood occurrences and highly erratic rainfall with indeed frost free window period. Maize production is possible from as early as November month to late January of the following year. However, thoughtfulness in planting dates selection and consideration of successive planting for improved biomass production should be considered toward food security. During the occurrences of floods intervention from local municipality and other stakeholders remains a requirement to ensure food security in such an area. During simulation runs and climate data analysis it was observed that rainfall distribution varies from season to season and year to year, therefore, Lambani region has indicated to be the most vulnerable to climatic conditions, hence it is recommended that stakeholder engagement should be an ongoing activity to secure food security and adaptive strategies within this region.

## 4.3. Adoption of Weather Forecast/Seasonal Prediction

The most critical factors to consider when running AquaCrop are the initial soil water contentment, initial soil salinity, initial crop cover and root depth. Simulation period in relatedly linked with growing cycle, whereby planting date is the start of simulation period. AquaCrop is also equipped to simulate the effects of climate change on crop production, which mainly determined by crop response to climatic parameter. During this investigation, the most scrutinised application of AquaCrop was the impact of water productivity, yield forecast, and the effect of climate change and scenario analysis for optimising field management.

The impact of climate variability on agriculture is affected by *El Niño*/Southern Oscillation phenomenon. The major challenge in using seasonal predictions in agriculture is to assess and capture the economic benefits for farmers to attain secured food security. Climate variability has enormous impact not only on agriculture but, human health and on the well-being of communities. The drought event that occurred during the 2015/16 *El Niño* caused devastating drought at all agroclimatological zones within the region of South Africa and the impact of drought remained noticeable. Therefore, crop simulation models such as AquaCrop are essential to develop decision support scenarios toward food security and decision-making and crop forecasting. Therefore, proper understanding of seasonal predictions plays crucial role as an entry point towards seasonal planning and management. Seasonal rainfall prediction vary from Above-Normal, Normal, Below-Normal seasonal rainfall conditions. The seasonal prediction is in three-month periods. Under Above-Normal to Normal seasonal prediction farmers has a variety of scenario options to choose from such as the selection of short, medium or long cultivar; early or late planting; sequential planting; high plant density, high fertiliser, frequent weeding, good top dressing, crop diversification to mention a few. Under Below-Normal seasonal prediction scenarios, farmers has a pool of other scenarios to select from such as, drought tolerant crops; short to medium cultivars; medium to low plant density; early planting dates; minimized fertilizer application and frequent weed control.

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# CHAPTER 5. LINKING SEASONAL FORECASTS AND CROP MODELS

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## 5.1. Background

Smallholder farming is characterized by low capital investment and input usage, limited farming skills, poor market access, and poor crop and livestock productivity. Most smallholder farmers practice rain-fed farming and have highlighted seasonal weather variability as the greatest threat to livelihood (Thomas et al., 2007).

Southern Africa experiences high seasonal rainfall variability. As a consequence, rain fed crop yields vary from 15% to 60% relative to mean yield (Lumsden and Schulze, 2007). Crop yield variability affects food security, with severe impacts being experienced amongst resource constrained, rain fed dependant, smallholder farming households, in semi-arid agro-ecologies of southern Africa (Sivakumar et al., 2002). In this largely weather driven agriculture, seasonal forecast information has the potential to improve farmers' preparedness to seasonal weather variability (Johnston et al., 2004).

Seasonal forecasts provide information on the magnitude and direction of weather parameters at specific temporal and spatial scales (Klopper et al., 2006), with rainfall and temperature being the defining key parameters. Forecasts can be very short (few hours), short (6 hours to a few days), medium (3 to 9 days) and long term (beyond 9 days) range. Dynamic and statistical forecasting are the most commonly used methods to produce seasonal forecasts. Statistical forecasts mathematically relate large scale meteorological climate features to local conditions (Tumbo et al., 2010).

Seasonal forecasts have a wide range of potential applications which include agricultural policy formulation, insurance, crop and climate risk management (Nelson et al., 2002; Hansen, 2005). Specifically, they present potential for seasonal farm management tactical decisions such as crop and cultivar selection or soil water conservation. To date they are mostly used in short term operational decisions such as planting, fertilizer application and harvesting. Despite this potential, the uptake of seasonal forecast information is greater amongst commercial farmers compared to small scale farmers (Vogel, 2000). The limited uptake in small scale farming is attributed to limited confidence in forecasts (Martin et al., 2000), lack of awareness, reluctance to change existing farming practices, limited financial resource base (Bruno-Soares and Dessai, 2015), complexity in forecast format and untimely dissemination of information (Vogel, 2000). The lack of sufficient financial resource base also limits the uptake of seasonal forecast where response mechanisms need financing (Bruno-Soares and Dessai, 2015). The value of seasonal forecast information can be enhanced through implementation of corresponding farm management decisions. This has increased the need for coping and adaptation strategies at specific temporal and spatial scales (Stone and Meinke, 2005).

Coping mechanisms are short term techniques utilized in response to sudden and unforeseen changes in weather. In contrast, adaptation techniques are long term cropping system adjustments in response to expected long term climatic conditions (Nelson et al., 2008). Farm decisions relating to climate variability management are undertaken based on a wide range of complex and intertwined aspects which are socio-economic, access to agricultural and climatic related information and institutional support (Nhemachena and Hassan, 2008). Climate variability management strategies can be tactical and strategic, with tactical being short term and strategic being long term (Smit and Skinner, 2002). Smallholder farmers use a combination of management aspects to reduce the impacts of climate variability. Extensive field and modelling research has been undertaken to evaluate climate risk adaptation management strategies based on historical weather and expected long term changes, within southern Africa (Rusinamhodzi et al., 2011; Verhulst et al., 2011; Nyagumbo et al., 2015; Mupangwa et al., 2016). Limited research has however been undertaken to evaluate the suitability of these practices as preparedness strategies given seasonal forecast information (Hansen et al., 2006).

Crop models provide the means of conducting prior ex-ante assessment of the response benefits of these practices to given seasonal information (Hansen, 2005). They provide alternate off-field cost effective, less complex and risky means of assessing yields in response to seasonal forecast information interacting (Jones et al., 2003). Crop models have been widely used in yield prediction using seasonal forecasts information in the USA (Shafiee-Jood et al., 2014); Europe (Cantelaube and Terres, 2005), Australia (Nelson et al., 2002) and East Africa (Hansen and Indeje, 2004). There is however limited research on the use of crop models with seasonal forecasts within southern Africa (Hansen et al., 2006). The incompatibility between the spatial and temporal scope of forecast information and process-based crop model requirements which leads to inefficient prediction of yields has been the major challenge in predicting crop yields given specific seasonal forecast information to crop models (Hansen et al., 2006).

Therefore, the literature review provides an in-depth assessment of the potential for integration of seasonal forecast information with crop models in sustainable climate variability management under smallholder farming systems in southern Africa. Specifically, it aims to show how seasonal forecast information can be used to identify crop management practices best suited to expected seasonal weather. The review also aims to assess the potential application of modelling tools to evaluate the effectiveness of alternative farm management practices in small scale farming with the aim of minimising the impacts of climate variability. Overall, this research aims to assess the state of the integration of seasonal forecast information with crop models to improve farm management decision making to enable sustainable climate variability management in smallholder farming systems of Southern Africa.

## 5.2. Seasonal forecasts

Seasonal forecasts describe the projected estimation of the state of the atmosphere at specific spatial and temporal scale. Key variables in seasonal forecast information are rainfall and temperature but occasionally include variables of interest at specific temporal and spatial scales, e.g. hail storms, hurricanes, etc. (Klopper et al., 2006).

There are 3 main approaches widely used in developing seasonal forecasts: (1) observations (2) statistical models and (3) dynamical models. The observation approach is based on assessment of the historical, current and future weather and climate as a basis for future weather and climate prediction. Weather data is collected from a network of weather stations on land, sea, mobile and satellite devices. The approach is highly applicable in locations with sufficient high quality historical data. The approach is utilised for development of statistical models and validation of dynamic models (Goddard et al., 2001). Reliability however reduces when forecasting future climate given evidence of increased climate variability (Huang et al., 1996).

Statistical forecasting is hinged on the mathematical relationship between historical, current or expected values of predictor values and the predictand. Regression models are the most common statistical forecasting technique. The skill of statistical seasonal forecast may however be low for non-ENSO seasons, which are characterised by non-increase in Sea Surface Temperatures (SST) which is not easily detected compared to extreme warming and cooling characterising *El Niño* and *La Niña* seasons, respectively (Holbrook et al., 2009). This can be improved through addition of atmospheric predictors in the statistical model (Goddard et al., 2001).

Dynamical forecasting utilises models that mimic the land-ocean-atmosphere systems to predict climate. The most commonly used models are the hybrid models which comprise an atmospheric model coupled to ocean general circulation models (GCM) or an intermediate ocean model (Yoon et al., 2012). Dynamical forecasting accounts for a wide range of land, sea and atmospheric variables thus there is greater confidence in the predictions. Parameterisation of the models is however complex especially ocean and atmospheric thermodynamics thus there is potentially reduced confidence in predictions (Doblas-Reyes et al., 2006).

Seasonal forecasts are usually issued as temporal summaries of at least monthly time scale (Figure 5-1). Seasonal weather forecasts can be classified as (a) now-casting (NC); (b) very short-range forecast (VSRF); (c) short-range forecast (SRF); (d) medium-range forecast (MRF); (e) long-range forecast (LRF) based on the time scale of the given forecast. A typical forecast can be up to a maximum time of 3 months at a width of 100 km$^2$ (WAMIS, 2003). Due to the chaotic nature of the atmosphere that reduces the certainty in prediction, forecasts are usually issued out in probabilistic terms. The format in which seasonal forecasts are issued differs with the intended target audience and method of forecasting. Seasonal forecast information is usually communicated via government extension workers, radio, internet and television (Ziervogel, 2004; Figure 5-1).

Use and uptake of seasonal forecast information is highly dependent on the quality of the forecast. Consideration of forecast quality is important in enhancing uptake as well as production and issuing out of forecast in format compatible with the end user. The quality of forecast is determined by a combination of factors which are reliability, resolution, sharpness, robustness, certainty and skill.

Forecasts should be communicated in user specific formats. Crop modellers utilize them in daily weather parameter format (Hansen et al., 2006). Farmers prefer them in ‘categorical and definitive’ qualitative formats as ‘no, normal or high’ rainfall as opposed to probabilities and complex numerical expressions which may not auger well with their literacy levels (Patt and Gwata, 2002; Vogel and O'Brien, 2006). Forecasts should also be communicated with sufficient lead time enabling change in management conditions (Stone and Meinke, 2006). Farmers have highlighted that 'good' forecasts should be availed to them with corresponding management information and expected crop yields (Johnston et al., 2004).

Skill is a key aspect of seasonal forecast quality that is essential in the use, uptake and confidence in the use of forecasts. Skill is affected by a range of aspects chief among them lead time, model accuracy, parameters being forecasted and time of the season.

The skill of statistical seasonal forecast may, however, be low for non-ENSO seasons, which are characterised by non-increase in Sea Surface Temperatures which is not easily detected compared to extreme warming and cooling characterising *El Niño* and *La Niña* seasons respectively (Holbrook et al., 2009). Limited skill maybe also attributed to a longer time lag of at least year. Skill however improves as the lead time decreases to few months to days (Jones et al., 2000). Skill also varies with geographical location within the globe with tropical regions having greater prediction skill than higher altitudes. Within the tropics regions experiencing ENSO events however tend to have greater skill (Harrison et al., 2007). There is greater skill from one tiered models that are based on ocean-atmosphere interactions compared to two tiered models based on sea surface temperature (SST) anomalies (Landman et al., 2012). Skill can be improved in several ways including through use hybrid forecast systems that can combine dynamical and statistical downscaling (Yoon et al., 2012).

Skill also varies with geographical location where there is greater prediction skill in the north western and central parts of southern Africa compared to north eastern South Africa (Yuan and Tozuka, 2014). Specifically, rainfall prediction skill is low in the Western Cape Province of South Africa and was greater in the Limpopo province within South Africa, based on the 2-tiered approach of the ECHAM4.5-MOM3-DC2 coupled model at 1-month lead-time for the December-January-February (D-J-F) period (Landman et al., 2012).

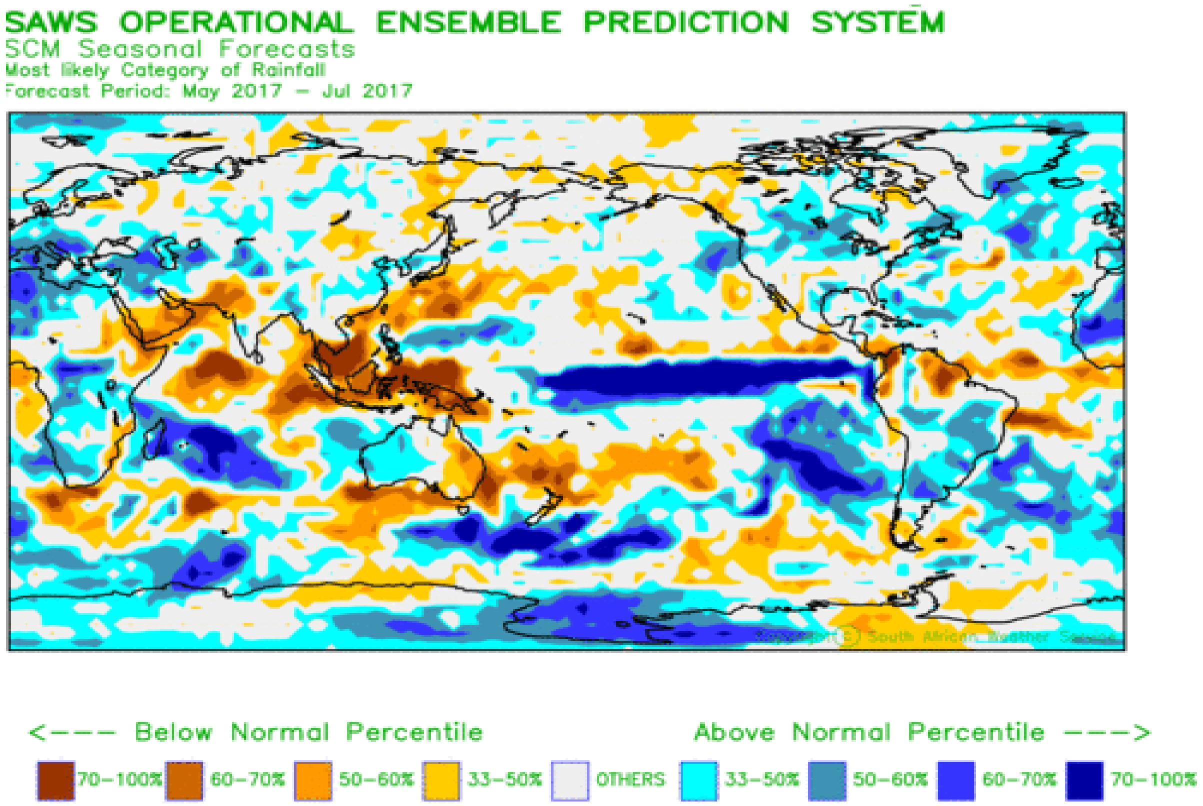

**Figure 5-1 Global seasonal precipitation forecast for the period May-July 2017 issued by the South African Weather Service (SAWS, 2017).**

## 5.3. Crop models

Within climate research, crop modelling tools have been mainly used in prediction of yields under climate change (Zinyengere et al., 2014) and to a limited extend under climate variability (Ambrosino et al., 2011) in the southern African region. The similarity in the meteorological input data format of climate change and variability, and of seasonal forecast data warrants the use of such an approach in yield prediction at shorter time scale. Process-based and empirical modelling are the dominant approaches used in yield prediction in Southern Africa.

### 5.3.1. Empirical crop modelling

Statistical crop modelling

Statistical modelling involves the formulation of mathematical relationships between historical weather and crop yields. Statistical crop models have been designed to operate on a multi-seasonal and regional scale. They are thus suitable for assessment of inter seasonal and regional crop yield variability (Hertel and Rosch, 2010). Rainfall and temperature temporal summaries are the predictor values whereas crop yields is the predictand (Estes et al., 2013). In contrast to process based crop models, statistical models have reduced data requirements with rainfall and crop yields for calibration being the key parameters (Jones et al., 2003; Holzworth et al., 2014). Statistical models have an in-depth evaluation of model accuracy through confidence interval and coefficient of variations and determination (Hertel and Rosch, 2010). Statistical models have limited applicability under future conditions since they are based on historical relationships which may not hold in future due to climate variability and change (IPCC, 2007). Whilst statistical models are greatly reliable in prior experienced events, they are much less reliable in simulating crop yields under changing conditions such as changing climate and climate variability. The statistical relationship alters due to increased climate change and variability. The reduced data requirements minimises computing demand but however limits assessment of coping and adaptation strategies, since they do not incorporate crop management aspects like variety and soil information. The reduced data demand makes also makes their use ideal in Africa, where data collection from on farm and on station trials is limited due to poor skill, financial resources and non-optimal management (Lobell and Burke, 2010). Statistical models have limited accuracy in simulating vegetative and reproductive development, plant water balance and pest dynamics (Krishna, 2003). Statistical crop models are therefore compatible with seasonal forecast information which is mostly issued out as temporal and spatial summaries (Figure 5-1). They however cannot be used for predicting location specific crop yields due to the coarse spatial resolution (Apipattanavis et al., 2010).

<u>Ricardian method</u>

Coupling of statistical models with additional tools such as socio-economic models will report crop yield changes in economic terms which improve their usefulness in climate variability impact management (Mendelsohn et al., 1994). The method assesses the impact of climate change based on the net farm income, with farm land value being a key factor (Bello and Maman, 2015). The approach presents crop yield changes under climate change in monetary terms. The approach assumes that farm productivity and opportunity cost is reflected on farm land value. With regards to climate the approach assumes that farm management decisions in climate change and variability are based on the profitability of the strategy. Decision making in smallholder farming systems is, however, based on different socio-economic and bio-physical aspects some of which cannot be accounted for by the Ricardian approach (Nhemachena and Hassan, 2008). Variations in land use in response to climate variability and change will lead to changes in land uses and values (Bello and Maman, 2015). This approach is designed to increase value to the statistical crop modelling approach and especially the otherwise limited future applicability due to increased seasonal variability. The prices attached to the commodities are constant whereas prices fluctuate in reality, leading to under and over-estimation of losses and gains respectively (Zinyengere et al., 2013). However, the approach is advantageous in regions or countries with functional land markets. Use of the approach in southern Africa is, therefore, limited by unregulated and weak land markets. Land valuation in is challenging in smallholder farming systems of southern Africa since most of the land is state owned, hence there may be inconsistencies.

The Ricardian approach has been applied in sub Saharan countries which include Kenya, Senegal, Zambia and Ethiopia. The approach is less suitable for small-scale farming, where land use decisions are based on a wide range of socio-economic aspects compared to profitability in commercial farming (Bello and Maman, 2015). The Ricardian approach is limited by the reliance on historical relationships which may not exist in the future. There is therefore limited reliability when used to predict future crop yields and profitability based on seasonal forecast information due to increased frequency of extreme climatic events which may not have been accounted in the formulation of the statistical relationship The approach has been used in the Eastern and Southern Africa in assessing economic impacts of different climate scenarios and opportunities for climate change management in small scale farming systems (Mano and Nhemachena, 2006; Bello and Maman, 2015; Gadédjisso-tossou et al., 2016).

The Ricardian approach is compatible with seasonal forecast information since climate data is required in summary format which is similar to seasonal forecast format. The approach however fails to account for in season weather variability since climate is accounted for at a coarse seasonal summary scale. The approach can therefore not effectively used for assessment of climate variability management.

### 5.3.2. Process-based crop modelling

This is the most common approach used in the region in simulating crop yield response to weather. Process-based crop models mimic the plant phenological and physiological processes (Basso et al., 2013). These processes interact with given weather data, soil and management applied to produce the consequent crop yield response on minute, daily and seasonal time steps (Hoogenboom et al., 2004). Despite the advances in understanding the underlying plant phenological and physiological phenomena coupled with information technological advancements, crop growth complexity render crop models incapable of completely mimicking crop growth and development. A wide range of crop models have thus been developed based on the phenological and physiological phenomena of interest (Holzworth et al., 2014). Process-based crop models can be based on the (1) concept of radiation (2) nitrogen and (3) water use efficiency (Challinor et al., 2009).

The most widely used process-based crop models in Africa are APSIM (Holzworth et al., 2014), DSSAT (Jones et al., 2003) and AQUACROP (Raes et al., 2009; Steduto et al., 2009a, 2009b). The APSIM model has been used for sugarcane yield prediction using seasonal forecast information (Nelson et al., 2002). Nelson et al. (1999) developed the whopper cropper model which integrates seasonal forecast information and APSIM model derived crop yields with a range of farm management decisions. DSSAT cropping systems model is also a widely-used process-based crop model. DSSAT has been extensively used in yield prediction using daily climate change data in Southern Africa (Ngwira et al., 2014; Zinyengere et al., 2014). Process-based models mimic the cropping systems under study, and the reliability increases with the availability of initial conditions data. It is therefore beneficial to have extensive measured field data for accurate parameterisation and calibration of crop models. Evaluation of climate change and variability options will also be based on adjusting the observed parameters in the model. Process-based crop models simulate crop management aspects which include: crop rotation, intercrops, crop calendar, different crop types and varieties, fertility, irrigation, mulching and tillage (Jones et al., 2003; Holzworth et al., 2014). The simulated management aspects are also some of the research recommended climate change and variability strategies (Ajani et al., 2013).

Process-based models require meteorological data in a daily format for the entire growing season. The key meteorological parameters are minimum and maximum temperature, solar radiation and rainfall (Holzworth et al., 2014). Therefore, they are not directly compatible with seasonal forecast information which is issued out in temporal and spatial summaries.

Advances in climate science and modelling has led to improvements in downscaling seasonal forecast information to the daily weather format which is compatible with process crop models (Hansen and Indeje, 2004). DSSAT, a process-based crop model, has been used in maize and peanut yield predictions using seasonal forecast information. Seasonal forecast information was utilised in the daily weather format as RCM and GCM data and dynamically and statistically downscaled data (Shin et al., 2010).

## 5.4. Seasonal forecast information and crop models

### 5.4.1. Challenges in linking seasonal forecast information and crop models

Extensive research work has been undertaken involving seasonal forecasts interacting with cropping systems using crop models in North and South America (Jones et al., 2000; Fraisse et al., 2006; Morss et al., 2010; Wang et al., 2012; Shafiee-Jood et al., 2014). In East and West Africa Hansen and Indeje (2004) and Mishra et al. (2008) simulated maize and sorghum yields respectively. Despite the extensive research, Hansen et al. (2006) highlighted the inefficiencies and challenges in connecting seasonal forecast information to crop models. This is highly attributed to the spatial and temporal scale and format of seasonal forecast information and format of the climate input data required in process-based crop models (Hansen and Indeje, 2004).

Seasonal forecasts are issued as spatial and temporal summaries. Process-based crop models, however do not run on average seasonal weather values. Instead daily crop growth and development depends on the seasonal rainfall distribution at a daily time step. Similarly crop models require weather data in a daily step format (Jones et al., 2003). Use of global circulation models (GCM) is a potential solution, since they simulate weather on a daily time step, a format compatible with process-based crop simulation models. GCMs, do however have poor resolution, where forecasts are produced at a coarser spatial scale of 10 000 km$^2$. Downscaling grid cell to ground level to increase the spatial resolution further compromises the large-scale consistency of the GCMs. This potentially affects daily weather variability, often through increase in the frequency of rainfall events thus reducing the confidence in simulated yields (Baron et al., 2005).

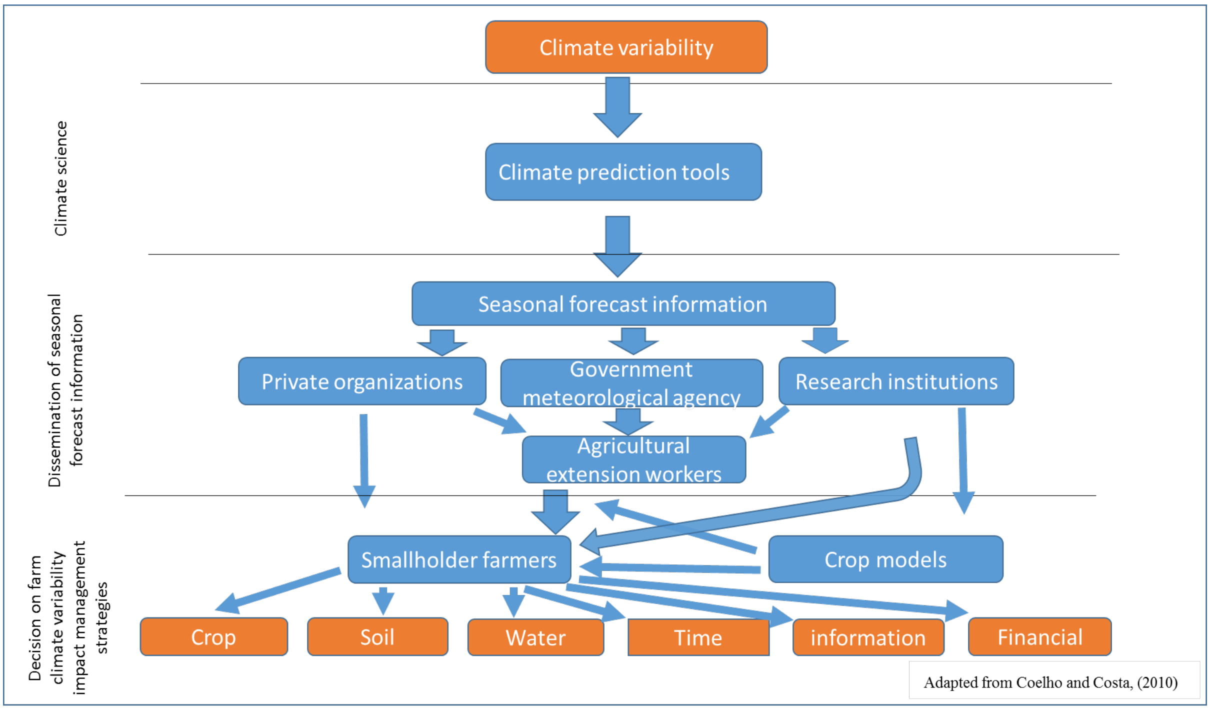

**Figure 5-2 Conceptual framework representing production of seasonal forecasts to decision making by the smallholder farmers (adapted from Coello and Costa, 2010)**

### 5.4.2. Approaches for linking seasonal forecast information and crop models

Hansen and Indeje (2004), evaluated methodologies for improving the connectivity between climate and crop models. Methods assessed include use of historical analogues, probability-weighted historic analogues, stochastic disaggregation, statistical prediction and daily climate model output.

Global Climate Models (GCM)

GCMs are computer-based tools that predict future climate based on the interaction between current, present and future land-sea-atmospheric dynamics at coarser to finer spatial and temporal scale. Notable examples include HadGEM (Collins et al., 2008), ECHAM (Roeckner et al., 2003) and GFDL (Anderson et al., 2004). GCM produces climate parameter data at a daily time step, which is compatible with process-based crop models. GCM output from the HadCM2 have been used as weather inputs to the CERES-Wheat crop model for assessment of the impacts of climate change on wheat production in France (Mavromatis and Jones, 1999). Similarly, Challinor et al. (2005), used an ensemble of 7 GCMs to simulate groundnut yields using General Large Area Model for annual crops (GLAM). GCMs however have poor spatial resolution as they predict future weather at the 10 000 km$^2$ scale. Efforts to improve the spatial resolution from the 10 000 km$^2$ scale leads to increased distortion of daily weather variability. However, this is normally biased towards increased frequency of rainfall events.

Several studies have been undertaken to reduce frequency bias thus increasing the spatial and temporal resolution of GCMs in forecasting weather. Applying a simple shift calibrates the GCM output to match the observed mean local climate. This can be undertaken through (1) addictive shift which is more appropriate for temperature and solar radiation, and (2) multiplicative for rainfall intensity to suit spatial means (Hansen et al., 2006). Other attempts have also been made to correct GCM daily bias through correcting rainfall frequency and intensity. The approach by Ines and Hansen (2006) reduces the frequency of rainfall events in GCM to match the average long term frequency for specific time periods. To correct the rainfall intensity, Schmidli et al. (2006) have also used simple multiplicative shifts after calibrating rainfall frequency.

### Stochastic disaggregation

Forecasts are often issued in the form of monthly or seasonal summaries. To connect this information to crop models, temporal forecasts are disaggregated into daily weather data. Stochastic weather generators create a series of synthetic daily weather data with statistical characteristics to similar expected climate. Stochastic disaggregation captures the high frequency variability of specific weather parameters scale whilst reproducing the low frequency of highly variable weather events. This can be undertaken through (1) calibration of a stochastic weather generator and (2) restriction of the simulated daily weather data parameters to those of the expected forecast (Apipattanavis et al., 2010).

(1) Stochastic weather generators are parameterised with the statistical properties of the forecast. Some of the methods utilised in conditioning weather generator parameters include (a) estimating parameters from seasons with similar predictor value (b) regressing parameters against predictors (c) multivariate statistical downscaling of GCM outputs and (d) estimation of parameters based on forecast shifts from climate means. Conditioning of parameters related to rainfall requires prior assumptions about the potential influence on rainfall statistical parameters. Stochastic weather generation however requires multiple replicates to generate forecasts with considerable accuracy. Reliance on historical data reduces the ability to reproduce non-linear simulations and climate events of high variability (Hansen et al., 2006).

(2) The alternative approach restricts the magnitude of daily weather parameter data to suit the temporal statistical characteristic of the forecast. This can be undertaken through (a) additive shifts which restrict non-rainfall parameters, e.g. temperature and solar radiation values to match the target means. (b) With regards to rainfall, the trial and error approach is utilised until the frequency and intensity is similar to the target means. Hansen and Ines (2005) have used this approach in disaggregating monthly forecasts to daily weather data for USA and Kenya for use as inputs into the CERES model. This approach however does not make assumptions about statistical parameters of historical rainfall events. Restricting the magnitude of daily weather parameter data to suit the temporal statistical characteristic of the forecast leads to high correlation between parameters of observed and stochastically generated precipitation outputs. The approach is less expensive, flexible and easily extrapolated for use in diverse climate states (Hansen et al., 2006). The ability of the stochastic aggregation to produce daily meteorological data improves the connectivity between process-based crop models and seasonal forecasts.

### Analogue method

This is the most common approach used in linking seasonal forecasts to crop models. It involves assessing and categorizing historical climate predictors and corresponding daily weather. Weather forecasting is conducted through, assessing the current predictors and then placing them in historical categories. The daily weather data of the category with similar predictors to the current year of interest will be used as the weather forecast. This approach is suitable for use whenever historical data is available. When historical weather data is limited, the sample size is reduced, so as the number of categories to fit the future predictors, thus compromising the methodology and forecast quality. Where there is increased confidence in the predictor values resembling a specific historical season, the probability-weighted historic analogues approach is preferred (Hansen et al., 2006). This approach combines the analogue and regression approach. *K-nearest* neighbour (KNN) method weighs the predictor variables and assigns a probability on the likelihood of the occurrence of that particular season. To further improve the efficiency of the analogue approach, the analogue can be combined with the GCM approach. This approach creates Southern Oscillation Index (SOI) phases by clustering GCM generated forecasts of SOI. Forcing historical Sea Surface Temperatures (SST) on long term GCM data leads to the SOI predictions (Stone et al., 2000).

### Statistical yield prediction

Previously discussed approaches condition weather data for input into the crop model. The statistical yield prediction approach conditions crop model output based on the forecast. Crop yields are simulated with historical weather data and are used as statistical predictions (Hansen et al., 2006). Several approaches have been put forward to improve statistical predictions. These include non-linear regression, normalised transformation of linear regression, and generalized linear models and nonparametric models (Hansen et al., 2006). Linear regression has been used as a function of GCMs within the semi-arid regions of Kenya using the Mitscherlich function. Transformation is preferred when there is a poor correlation between the predicted climate and crop simulated response. Transforming the yields will correct the non-linearity and non-normality of regression residues. Generalized linear models have the potential to improve the benefits of linear regression but have however not been used in any notable research (Hansen and Indeje, 2004).

## 5.5. Climate change and variability management strategies

Recent research towards climate change, has increased the body of knowledge on climate change management strategies (Table 5-1) (Graham et al., 2011; Zinyengere et al., 2014; Ncube et al., 2015). Some of the climate change management strategies have been concurrently suggested as options for coping with climate variability in Europe (Olesen et al., 2011). The same approaches can potentially be used in managing climate variability given seasonal forecast information in southern Africa. In addition to classification of climate variability risk management strategies into coping and adaptation (Valdivia and Quiroz, 2003). Smit and Skinner (2002), identified and characterized the management options into (1) technological developments (2) government programmes (3) farm financial management and (4) farm production management typologies. These management typologies aimed to enhance the understanding of various types and forms of adaptation options with the aim of encouraging targeted use to enable sustainable uptake. Technological developments are climate management options that utilize novel information technology, scientific inventions and knowledge (Benhin, 2006). Government interventions include laws, regulations and policies gazetted to enhance uptake of climate risk management techniques. Farm financial management involves financial products utilized by farmers to cushion themselves from climate risk (Smit and Skinner, 2002). Farm production management involves changes in cropping or farming systems to enable adaptation to climate variability. Among these options are ripping, cultivars of varying season lengths and time of sowing (Cooper et al., 2007). Farm management strategies can be further categorized into soil, water, timing and crop practices (Table 5-1).

**Table 5-1 Farm management strategies for potential integration with seasonal forecast information for improved climate variability management in smallholder farming systems of southern Africa**

| Management category | Climate variability management strategies | Adap. | Cop. |
|---|---|---|---|
| | Intercropping and multi cropping on the same piece of land (Mtambanengwe et al., 2012) | x | |
| | Changes in plant density by altering intra and inter-row spacing (Mtambanengwe et al., 2012) | x | |
| | Indigenous grains crops: millet; sorghum (Ajani et al., 2013) | x | |
| | Drought and heat tolerant crops and varieties (Bishaw et al., 2013) | x | |
| | Diversify crop types and crop varieties (Bishaw et al., 2013) | x | x |
| | Open pollinated varieties (Mubaya, 2010) | x | |
| | Agro-forestry (Asfaw et al., 2014) | x | |
| | Reducing crop acreage (Bryan et al., 2009) | x | |
| | Integrated insect pest management (Bishaw et al., 2013) | x | x |
| | Crop rotations (Ajani et al., 2013) | x | |
| | Cultivation of cover crops or live mulch (Ajani et al., 2013) | x | |
| Soil | Organic farming: fertilisers, manure; mulching (Ajani et al., 2013) | x | |
| | Conservation agriculture: Mulch; minimum tillage; Ripping (Mubaya, 2010) | x | x |
| | Improved nutrient use efficiency (Ajani et al., 2013) | x | x |
| | Fallowing (Benhin, 2006) | x | |
| | Water efficient crops-sorghum or millet (Mapfumo et al., 2014) | x | |
| Water | Mulching-grass, residues, muck, peat, compost, plastic (Benhin, 2006) | x | x |
| | Irrigation (Mapfumo et al., 2014) | x | x |
| | Water harvesting: Basins, ripping; pot holing (Bishaw et al., 2013) | x | x |
| | Chemicals to reduce evapo-transpiration (Benhin, 2006) | x | x |
| | Revising planting dates, early and late; new crop calendar (Ajani et al., 2013; Mijatovic et al., 2009) | x | |
| Time | Early harvesting; maturing crops and varieties (Mijatovic et al., 2009) | x | x |
| | Crops of different season lengths (Mapfumo et al., 2014) | x | |
| | Replanting (Mapfumo et al., 2014) | | x |
| Improved information | Traditional forecasting: animals, birds, fruits (Ajani et al., 2013) | x | |
| | Global Climate Model based seasonal forecasting (Bishaw et al., 2013) | x | x |
| Financial | Crop insurance (Benhin, 2006) | x | |

## 5.6. Discussion

### 5.6.1. Current and potential application of integration of seasonal forecast information with crop models

In-depth research has been undertaken in linking crop models and seasonal forecast information to enhance farmer decision making especially in climate risk management. In Australia, Nelson et al. (2002) developed the whopper cropper software that integrates weather data at a daily time step with crop models to inform decision making amongst farmers. Crop yields are simulated using APSIM, a process-based crop model and seasonal forecast information is generated based on the analogue approach which utilises the historical daily weather data. The tool also gives information on crop productivity of different crop types given specific weather information under different farm management decisions. The software has been utilised in Australia to enable decision farm management making in the face of future climate patterns.

In North America Jones et al. (2000) assessed the potential productivity of different cropping systems (rain fed and irrigated soybean, maize, peanut wheat) to the ENSO phases (*La Niña, El Niño* and *Neutral*) for assessment of potential intervention. This was based on the analogue approach which classified historical climate data (1949-2000) into 3 ENSO phases. The study made use of DSSAT a process-based crop model, for simulating crop yields.

Within North America, Shafiee-Jood et al. (2014) integrated seasonal forecast information based on 2 GCMs, CFSv2 and ECHAM4 with the Soil and Water Assessment Tool (SWAT), a process-based model. The study assessed crop productivity and economic benefits from improved forecasting skill and the economic consequences of inaccurate forecast predictions. GCMs inaccurately predicted the 2012 drought but also highlighted the need for bias correction to improve prediction skill. Fraisse et al. (2006) also used a web-based tool 'AgClimate' that integrates seasonal forecasts with DSSAT. The seasonal forecast information was based on the different ENSO phases within North America. The tool therefore provides information on crop productivity under different crop management strategies under different ENSO phases.

Crop models have been successfully integrated with seasonal forecasts in Europe under the DEMETER project. Forecast data from Global coupled atmosphere-ocean climate models were integrated with JRC, a process-based crop model. The GCM outputs had a low resolution and were downscaled using statistical downscaling. The study assessed wheat yields based on projected seasonal weather for assessment of opportunities for climate risk management intervention (Cantelaube and Terres, 2005).

In East Africa, Hansen and Indeje (2004) assessed maize yields in East Africa given seasonal forecast information based on different techniques to link seasonal forecast information to crop models. The study assessed the feasibility and effectiveness of the strategies to link seasonal forecast information to crop models. The study did not however determine the corresponding strategies that can be utilised to minimise climate risk upon successful linking of seasonal information to crop models. Limited research has been undertaken in linking seasonal forecast information to crop models in Southern Africa. There is therefore need to undertake similar research to integrate seasonal forecast information and crop models based on Southern African conditions. Limited research has been undertaken to couple crop models with seasonal forecast information for improved climate variability management among smallholder farmers. Within southern Africa, research has been limited to correlating crop yields with historical ENSO phases and assessment of historical farm management intervention decisions (Vogel, 1995).

Within southern Africa seasonal forecasts also do not provide information on management decisions corresponding to specific seasonal forecast information. There is therefore, a need to pair and evaluate the corresponding management decisions to given seasonal forecast information. There is also additional need to evaluate their effectiveness in reducing the impacts of weather hazards under different seasonal forecasts in small scale farming systems. Process-based crop models are capable of directly and indirectly simulating key management farm management decisions highlighted in Table 5-1. Similarly, they are also capable of simulating crop yields based on specific weather conditions.

Knowledge of crop yields corresponding to given forecast information increases the value of seasonal forecast information and potentially motivates smallholder farmers to make the necessary farm management decisions. Yield predictions have also been based on historical weather data. Future and historical yield simulations however offer information of great benefit to researchers for knowledge purposes. Assessing crop yields on a seasonal time scale however offers greater benefits to small scale farmers who can potentially make prior farm management decisions, e.g. mulching, water harvesting, etc. There is therefore a need for regular evaluation of the impacts on crop yields of the forecasted seasonal weather in smallholder farming systems.

### 5.6.2. Linking seasonal forecast information to crop models

This review article highlighted several approaches that can be utilized to effectively integrate seasonal forecast information to crop models. These included analogues, probability weighted analogues, stochastic disaggregation and statistical yield prediction approaches. Research by Hansen and Indeje (2004) however shows that the methodologies highlighted in Chapter 5 account for 28-33% in maize yield variations. Thus, there is need for improvements in the approaches to link seasonal forecast information to crop models to significantly account for all the contribution to crop yields. This discussion also aims to evaluate the techniques for improving the conversion of seasonal weather forecast information from seasonal forecast information in the summary format to weather parameter values at the daily time step format which is compatible with process-based crop models in southern Africa for yield prediction in smallholder farming systems (Hansen and Indeje, 2004).

Converting seasonal forecast information to a daily weather format compatible with crops model is one of the key challenges realized from this review. GCM, stochastic modelling and analogue techniques produce forecast data in a format compatible with process-based crop models. This reduces the need for technical expertise and committing of potential errors in converting forecasts into the daily weather format compatible with crop models. Despite the compatibility, the coarse resolution of at least 100 x 100 km in GCMs presents challenges leading to failure in accounting for local climatic variations. Advances in atmospheric science have increased spatial resolution to 50 x 50 km (Cantelaube and Terres, 2005) but the approach distorts daily rainfall variability which is a key driver of physiological and agronomic processes (e.g. soil erosion and crop-water-atmospheric relations). Attempts to improve the accuracy increases frequency of low intensity rainfall events which introduces bias when crop yields are predicted from the resultant data.

The statistical prediction approach predicts crop yields based on predictor variables through repeated conditioning of the crop model yield outputs. This therefore minimises compounding of errors associated with downscaling seasonal forecasts into the daily weather format and interaction with process-based crop models. The approach however assumes a direct linear relationship between the predictor and crop yields, which is not characteristic of normal crop growth and development (Hansen et al., 2006). Crop growth and development follows a non-linear pattern due to the multiple parameters that determine the processes.

Similar to the analogue approach, there is greater confidence in the daily sequence outputs from stochastic disaggregation since they are based on historical weather patterns. The approaches however, cannot produce out-of-parameterised events such as non-previously experienced extreme rainfall, temperature, dry, heat spell long duration (Hansen and Ines, 2005). This is a major downside in building an approach aimed at predicting phenomenon requiring unusual decision making, among which are cases with low occurrence frequency and potentially unexperienced events, e.g. climate change and variability. There are however greater chances of predicting parameters of extreme variability, e.g. extreme high and low rainfall and temperatures using the non-parametric-based mode of the stochastic disaggregation approach since it is not based on historical climate data (Hansen et al., 2006). Therefore, this is best suited to the southern African context where the region is experiencing increased frequency of climate variability. The non-parametric approach is flexible therefore it can be applied in a range of climates with limited financial and technological resources research (Wilks and Wilby, 1999).

The analogue approach is advantageous when utilised at the spatial and temporal scale at which the historical weather data is available (Hansen et al., 2006). In southern Africa, weather data collection is dominant in urban areas, research sites and locations of special interests. The analogue approach has limited applicability in areas where there is limited weather data collection, especially in smallholder farming agro-ecologies. Although the approach is useful in conditions where historical climate of high quality is available, it is difficult to use in African agriculture which faces challenges in skill, financial resources and management of weather data collection. Increased climate variability reduces the confidence in the analogue approach, as anthropogenic factors influence immediate future weather. There is greater confidence in the use of historical analogues when seasons under consideration are characterised by higher probability of the occurrence of climate phenomenon, e.g. *La Niña* or *El Niño*.

### 5.6.3. Seasonal forecast information and small scale farm management decision

Seasonal forecast information has been beneficial to some sectors smallholder farmers in Southern Africa specifically in the North-Western province of South Africa. During the 1997/8 season, there was an intensive awareness campaign on the impending *El Niño* and its corresponding impacts on crops. Smallholder farmers became more aware and conscious of the future seasonal weather patterns. Smallholder farmers responded through making a range of corresponding farm management decisions, e.g. reduction in land area, increased moisture conversation, off-farm activities, etc. (Vogel, 2000). This therefore proves that given seasonal forecast information, smallholder farmers can make the appropriate tactical farm management decisions (Table 5-1). The choice of farm management decision is highly dependent on household socio-economic and biophysical farm characteristics, e.g. finance literacy. Some of these climate variability management decisions can be simulated using process-based models, e.g. cropping system, alternate seed varieties, water harvesting, conservation agriculture, irrigation and nutrient efficiency (Jones et al., 2003; Holzworth et al., 2014).

Seasonal forecast information predicting no deviation from the normal rainfall patterns would not prompt changes in farm management decisions. On the contrary forecasts predicting below normal rainfall would prompt farmers to be in a risk averse mode, where they would choose to reduce crop population and land area. Reduction in cropping density minimizes crop water demand, thus the limited soil moisture will lead to attainment of considerable crop yields. Reducing land area would ensure attainment of considerable yields and minimizing economic losses. In response to forecast information predicting high rainfall, farmers seeking to maximize productivity, would increase plant density and cropping area so as to maximize yields from the excess soil moisture (Mapfumo et al., 2014).

Plant breeders have developed a range of varieties that produce relatively high yields in different agro-ecologies and under different season lengths. Given seasonal forecast information predicting low rainfall farmers should choose to cultivate small grains, short season or hardened crops, which maximize outputs (WAMIS, 2003). Dry season forecast will prompt farmers to avoid use of expensive commercial seeds and instead use retained seed, since the chances of high financial returns are low. Forecasts predicting high rainfall, potentially leads farmers to sow long seasoned hybrid crops that make maximum utilization of the growing conditions, thus higher yields (Cooper et al., 2007).

Water harvesting is potentially effective in conserving soil moisture in smallholder farming systems. To increase the amount of water available to crops, at least 60% of farmers in drier agro-ecologies from southern Africa use potholing. Potholing is usually undertaken by farmers without draught power using manual hand hoes (Mubaya, 2010). Seasonal forecast information predicting below normal rainfall will motivate farmers to prepare water harvesting techniques. On receiving forecast information predicting very high rainfall which leads to floods, farmers will not make potholes especially in heavy soils to minimize waterlogging. Farmers with light textured soils however may keep permanent potholes despite the forecast information since light textured soils recurrently lead to low crop yields due to their poor holding capacity. In response to forecast information predicting below normal rainfall, farmers with access to draught could make rip lines between planting rows. The rills accumulate water during rainfall events, thus crops will access moisture stored within the rip lines (Preez, 2006).

Resource endowed farmers may prepare to use irrigation in response to forecast information predicting low rainfall (Preez, 2006). Use of irrigation in tandem with forecast information improves farmers' resilience to climate variability. Long term seasonal forecasts prior to the beginning of the season provide an overall idea of the season. Smallholder farmers can therefore prepare for use of irrigation. Irrigation efficiency is improved through use of very short term weather forecasts, which provide information at short time scales of less than 5 days with higher confidence. Weather forecasts will determine when rains and dry spells are expected. This avoids irrigation immediately prior to rainfall, thus increasing efficiency and cost benefit ratio. Meteorological parameters like wind also affect irrigation where winds exceeding certain thresholds will render irrigation ineffective or will need increased volumes and power to increase the wetting (WAMIS, 2003).

Forecasts also enable smallholder farmers to make management decisions on choice of cropping systems. Given a forecast predicting low rainfall, farmers can choose moisture conserving cropping systems, e.g. conservation agriculture. Conservation cropping systems favour soil moisture through minimum tillage, mulching and rotation (Thierfelder et al., 2016). On the contrary, forecasts predicting high rainfall will prompt farmers to make farm management decisions that minimize rainfall damage on crops, e.g. ripping, conventional agriculture.

Use of seasonal forecast information potentially increases nutrient use efficiency in smallholder farming systems. Rainfall and temperature are the two main meteorological factors affecting fertilizer application efficiency. Excessive leads to excessive soil erosion and leaching thus causing pollution of underground water sources. Given seasonal forecast information predicting high rainfall farmers can split apply different formulations and split fertilizer to minimize losses (WAMIS, 2003). Low rainfall would lead to underutilization of the fertilizers. High temperatures cause volatilization of granular fertilizer and necrosis of foliage by foliar fertilizers (Ajani et al., 2013).

## 5.7. Conclusion

The review highlighted how seasonal forecast information can be coupled with crop models as a potential tool to enhance climate variability management in smallholder farming systems. The article highlighted how evolution of atmospheric science has increased the understanding and confidence in climate prediction. Observations and dynamic models are the most efficient and effective approaches of developing seasonal forecasts. These approaches are realistic since they are based on historical weather data and utilise multiple variables in forecasting respectively. Addition of value to seasonal forecast information through crop yield prediction is potentially highly effective through use of process-based crop models. These are driven by physiological processes leading to crop growth and development compared to statistical or Ricardian crop models which use direct mathematical relationships to predict yields. Incompatibility of crop models and seasonal forecast limits the exploitation of the value of seasonal forecast and crop models in climate variability management. Use of GCM and analogues is more feasible and effective in linking seasonal forecasts and crop models compared to stochastic disaggregation and statistical prediction. GCMs are based on the interaction between multiple predictor variables and the analogue is approach is hinged on historical weather data. GCMs are challenged by poor resolution but can be improved with use of supercomputing. The analogue approach can be modified using probability weighted historical analogues. There is therefore greater confidence in forecasting climate change and variability compared to stochastic disaggregation and statistical prediction. In response to climate variability, and given specific seasonal forecast information, a wide range of farm management decisions can be made by smallholder farmers. These range from soil, water, crop, information and finance-based strategies. A significant portion of the management decisions can be potentially simulated using process-based crop models, e.g. DSSAT, APSIM. Process-based crop models, e.g. DSSAT have management decision modules which enables evaluation of the various climate variability management strategies, e.g. alternate crops; mulching; irrigation. Despite the challenges and potential for improvement the review shows a range of potential sustainable approaches to forecast climate, link seasonal forecast to process-based crop models and simulate crop yields. Integration of seasonal forecasts and crop models is essential in preliminary assessment of potential sustainable climate variability management strategies. Seasonal forecasts have been successfully integrated with crop models in North and South America, Europe and East Africa. There is therefore limited work research that has been undertaken in southern Africa in integrating seasonal forecast information and crop models in Southern Africa. Research on the integration of seasonal forecast and crop models in Southern Africa, potentially allows for preliminary assessment and for farmers to be equipped with skills and knowledge on potential climate variability management strategies given certain specific seasonal forecast information.

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# CHAPTER 6. AWARENESS AND RESPONSE TO CLIMATE VARIABILITY

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## 6.1. Background

Small-scale farmers face many challenges which include soil infertility, limited input access, poor literacy, poor infrastructure, markets and climate risk. Climate risk has been highlighted by small scale farmers as one of the greatest threats to their livelihood (Thomas et al., 2007).

Climate risk threatens livelihood strategies through increased climate variability and frequency of extreme rainfall and temperature events with rainfall and temperature being the key parameters. While climate variability is a natural geo-physical phenomenon that has always been occurring, anthropogenic forcing has led to the increased frequency and intensity of unprecedented climate variability (Rosenweig and Solecki, 2005). This has been manifested through a shift towards delayed onset and early cessation of rainfall (Weldeab et al., 2013), and increased frequency of mid-season dry spells, droughts and floods in South Africa (Brown et al., 2012). Mean temperatures have increased by 0.7°C during the period 1960-2003 in South Africa (Kruger and Shongwe, 2004). The patterns are expected to continue with projected temperature increases of up to 4°C by 2100 within the southern African region (Serdeczny et al., 2016). Coupled with increased variability, rainfall is projected to decrease by 5-10% within the next 50 years within the southern African region (Durand, 2006). Maize yield losses of up to 50% per year in southern Africa have been attributed to increased rainfall variability during the past 25 years (Ray et al., 2015).

In an effort to minimize the impacts of climate variability small scale farmers have always responded to climate variability through use of traditional coping and adaptation techniques (Ncube and Lagardien, 2014). Despite use of the current traditional climate risk management strategies smallholder farmers face recurrent yield and productivity losses due to increased climate variability in the form drought and related climate hazards (Mpandeli et al., 2015). There is therefore need for among other strategies, e.g. new technology and crop varieties, reinforcement of current climate variability management strategies in small scale farming systems (Mapfumo et al., 2015). On the other hand, there is an ever increasing large body of knowledge churned from research on climate variability management and is becoming available in the public domain (Cooper et al., 2007). Despite the availability of a wide range of adaptation options there is increased evidence that small scale farmers are increasingly failing to respond to the current climate change and variability due to poor uptake of the novel climate variability management strategies (IPCC, 2007).

The limited uptake of recommended strategies is potentially attributed to the relatively high initial costs of changing cropping systems (FAO, 2001), system and agro-ecology incompatibility (Mazvimavi and Twomlow, 2009), weak institutional support (Ngwira et al.,

2014) and the general risk aversion associated with small-scale farmers (Knowler and Bradshaw, 2007). Use of blanket recommendations ignoring the underlying socio-economic and cultural aspects has been highlighted as one of the leading causes of poor adoption (Twomlow et al., 2008). There is therefore need for a comprehensive review of the agro-ecological and socio-economic conditions under which specific coping and adaptation options are effective (Giller et al., 2009). There is also need to assess the currently adopted options and the factors responsible for their uptake and extrapolate to other agro-ecologies. Small scale farmers are heterogeneous in terms of agro-ecology and resource endowments and hence transfer of appropriate technology requires careful targeting (Giller et al., 2009). There is therefore need for utilisation of the farm typology approach to enable increased understanding of current farmer socio-economic, bio-physical, agro-ecology and cultural conditions to enable better determination, suggestion and recommendation of appropriate climate variability management strategies.

The farm typology approach categorises farmers into different categories based on the predominant socio-economic, bio-physical, agro-ecology and cultural conditions. It unpacks and disaggregates farmer diversity to enhance understanding and analysis of farming systems. This is essential in identifying domain specific intervention strategies (Chikowo et al., 2014). The approach is essential in problem diagnosis and recommendation of challenge specific solution in small-scale farming systems (Perret and Kirsten, 2000). The approach has been utilized in identifying farmer type specific crop-livestock integration strategies in smallholder farmers (Mkuhlani et al*.,* upcoming). Chikowo et al. (2014) assessed the potential for sustainable soil fertility improvement in different typologies.

Improved climate variability management can be achieved through a broad range of management alternatives and technological advances. This article therefore highlights the potential for use of the farm typology approach to enhance climate variability management in smallholder farming systems. This was achieved through determination, suggestion and recommendation of climate variability strategies that are compatible with the farmer’s socio-economic, bio-physical and cultural conditions. The research also sought to increase the understanding of the farmer perceptions, current challenges and potential climate variability management strategies in smallholder farming systems of South Africa.

## 6.2. Materials and methods

### 6.2.1. Study area

The study was based on Lambani and Nkonkobe communities in the Eastern Cape and Limpopo provinces respectively of South Africa. Lambani, is located at 22°58’S, 30°26’E and 596 m.a.s.l within the Vhembe district which is about 180 km from Polokwane. Mean temperatures range from 25 to 40°C and 22 to 26°C in summer and winter respectively. The average precipitation is 800 mm per annum with most of the rainfall being received from October to March. The rainy season is also characterized by mid-season dry spells with high rainfall variability (Mzezewa et al., 2010). Small scale farmers in Limpopo are characterized by small land holdings of less than 1.5 ha. The major crops cultivated in the Limpopo province are cereals and vegetables. Maize is the most commonly cultivated cereal whereas tomatoes, cabbages, beetroots, onions and butternuts are the most commonly cultivated vegetable crops. Farming is mostly use for subsistence purposes with the balance sold to the market for income (Baloyi, 2010).

Nkonkobe community is located at 32°47′S; 26°38′E and 1200 m.a.s.l. within the Amathole district of the Eastern Cape Province. The area receives 640 mm of rainfall per annum received from October to March. There is a wide temperature range from 4 to 38°C in July and February respectively, with occasional incidences of frosts and snow between May and July. There is greater diversity of soil types due to the fluctuating topography where the altitude can be as low as 535 m.a.s.l. Key agricultural activities are vegetable and livestock production for commercial and subsistence purposes respectively. In Nkonkobe community, farming systems vary from sole crop and livestock production to mixed farming. The most commonly cultivated crops are potatoes, tomatoes, cabbage, spinach, beetroot, carrots and maize. Cattle are however the key livestock species (Adekunle, 2014).

The locations were chosen since most smallholder farmers in these areas are highly rain fed dependant. The areas however receive relatively low rainfall with high variability. The Eastern Cape and Limpopo provinces are home to a significant proportion of resource constrained small scale farming households. The research outputs are therefore of greater significance to the small-scale farmers in these communities (Ncube et al., 2015).

### 6.2.2. Farmer classification

#### Qualitative typology approach

The qualitative farm typology approach utilizes key informants with sufficient knowledge on the study subject. Key informants can also be professional experts knowledgeable in specific aspects, e.g. local farming systems (Kuivanen et al., 2016). In this research farmer categories were developed separately during discussions on current farmer diversity with key informants who are the local agricultural extensions workers in both Lambani and Nkonkobe. The farmer typologies were developed based on the observations and experience of socio-economic and bio-physical characteristics accrued through engagement with local farming communities. In Lambani, discussions on farmer diversity were held with local agricultural extension officers from the Lambani community in Mhinga village, Lambani. Similarly, discussions on farmer diversity were held with local agricultural extension workers in Nkonkobe district. Discussions with the local agricultural workers in both locations were guided by the following socio-economic variables: age of household head (HHH); household size; employment status; education of HHH; assets; income; total land area; crop types cultivated; cropping area; crop yields; livestock types; livestock numbers and food security status. These characteristics have been used earlier to classify smallholder farmers (Berre et al., 2016). This led to the development of expert-based small scale farmer typologies in the Lambani and Nkonkobe communities.

#### Snowball approach

The snowball sampling approach is a non-probability sampling technique where existing study subjects recruit future subjects from their acquaintances. The approach violates the principles of sampling but is however highly suitable for assessing vulnerable and non-easily accessible populations. There is however bias since the samples are not randomly selected. There is also need for prior knowledge to make validations of the initial referrals (Atkinson and Flint, 2006). Within the context of this study, discussions were held with key informants on small scale farmer diversity in both Lambani and Alice, South Africa. The key informants, referred the researchers to specific farmers fitting in different farm categories.

Within this research, upon development of small scale farmer typologies, local agricultural extension officers pinpointed farmers who belonged to different categories. Small scale farmers belonging to different farmer categories were interviewed on their perceptions to climate patterns and strategies and challenges in managing climate variability. Farmer perceptions were based on the observations and experiences of the smallholder farmers to historical and current climate patterns. Data on strategies and challenges faced by farmers in managing climate change was based on the farmers' experiences in managing climate variability.

Assessment of the improvement of climate variability management was based on the qualitative assessment of the strategies used by each of the farmer type in managing climate variability. In addition, it was also based on consideration of various challenges in managing climate variability faced by the different small-scale farmers in Lambani and Nkonkobe communities of South Africa.

## 6.3. Results

### 6.3.1. Smallholder farmer classification

The study realised different types of farmers as depicted by the 3-distinct small scale farmer categories within the Lambani community which are mixed farming, horticultural farming and off-farm income dependant (Table 6-1). Mixed farmers practice both crop and livestock production and earn income from both crops and livestock sales. They earn income from government social grants for the elderly since they are at least 60 years of age. Horticulture farmers are mostly younger to middle aged farmers aged 18-35 years. Their source of income and livelihood is horticultural farming. The most commonly produced horticultural crops are vegetables which include tomatoes, cabbages and carrots. Off-farm income dependant smallholder farmers are mostly informally employed farmers whose major source of income are off-farm activities and to a lesser extent farming. The engage in off-farm income activities like motor mechanics, bricklaying; carpentry, etc. Off-farm income dependant smallholder farmers also cultivate cereal crops like maize though on a smaller scale as minor crops.

Similar to Lambani, the study realised different types of farmers within the Nkonkobe as depicted by the 5 different farmer categories (Table 6-2). The classes are social welfare dependant, enterprising pensioners, struggling subsistence, horticultural dependant and cooperative crop farmers. Social welfare dependant farmers are usually of old age, poorly educated and unemployed. They practice semi-subsistence farming with occasional crop sales. Their major source of income is government social grants for the elderly, remittances from urban areas and occasional crop produce sells. Enterprising pensioners are educated and are usually retired from private and public sector. They mainly cultivate maize, tomatoes and cabbages. Their major sources of income are crop sales and occasional livestock sales. Struggling subsistence farmers fall within a wide age group of 20-90 years. They cultivate few crops, which include maize and a few legumes on about 0.25 ha. Most of the income comes from child support grants and government social grants for the elderly and occasional crop produce sales. Horticultural dependant farmers are usually middle aged, not well educated farmers whose main source of income is horticultural crop sales. They cultivate vegetable crop which include tomatoes, lettuce, cabbages, beans and peas. Cooperative crop farmers are a diverse group of farmers mainly produce tomatoes, lettuce and cabbages for sale. They have relatively easier access to grants and loans due to being targeted by government grants and cooperative targeted financial support systems.

**Table 6-1 Major small scale farmer categories in Lambani community, Limpopo Province, South Africa**

| | Mixed farming | Horticulture farming | Off-farm income dependent |
|---|---|---|---|
| Age of HHH | > 60 | 18-35 | 35-65 |
| Household size | 5 | 3 | 5 |
| Dependents | 3 | 1 | 3 |
| Education of HH | No education | Matric grade 12 | Matric grade 12 |
| Employment | Unemployed, usually pensioners | Unemployed | Informal employment |
| Major source of income | Crop and livestock farming | Farming | Off-farm activities |
| Other sources of income | Government grants and remittances | | Farming |
| Arable land (ha) | 3 | 1.5 | 2 |
| Cultivated area (%) | 75 | 90 | 50 |
| Major crops | Maize | Vegetables: tomatoes | Vegetables, minor legumes |
| Minor crops | Vegetables, minor legumes | Green mealies | Maize |
| Maize yields (t ha$^{-1}$) | 1.5 | 0.25-0.5 | 0.5 |
| Cattle | 15 | 0 | 5 |
| Goats | 10 | 0 | 5 |

**Table 6-2 Major small scale farmer categories in Nkonkobe municipality, Eastern Cape Province, South Africa**

| Variable | Social welfare dependent | Enterprising pensioners | Struggling subsistence | Horticulture dependent | Cooperative crop farmers |
|---|---|---|---|---|---|
| Age of HHH | 71 | 68 | 20-90 | 37 | 35-65 |
| Household size | 4 | 4 | 6 | 5 | 5 |
| Education | Poorly educated | Educated | Poorly educated | Secondary school | Poorly educated |
| Employment | Unemployed | Retired private sector and public sector workers | Unemployed | Unemployed | |
| key livelihood activities | Government grants and remittances | Crop produce and occasional livestock sales | Children and government grants | Horticultural crop sales | Horticultural crop sales |
| Other income sources | Semi-subsistence farming | Pension | Occasional crop produce sales | | Non-horticulture crop sales |
| | Occasional crop produce sales | Remittances | | | |
| Land area | 2 ha | 3 ha | 1 ha | 1.5 ha | 10 ha |
| Cultivated land | 0.25 | 2.5 | 0.4 | 1.2 | 7.5 |
| Cattle | 2 | 14 | 0 | 0 | 2 |
| Goats | 0 | 4 | 1 | 0 | 0 |
| Crops | Maize; Few vegetables | Maize; Tomatoes; Cabbages | Maize; Few legumes | Tomatoes; Cabbages; Peas; Beans | Tomatoes; lettuce; Cabbages |

### 6.3.2. Farmers perceptions to climate patterns

In an effort to improve climate variability management, the study assessed farmer perceptions within each of the farmer types in both Lambani and Nkonkobe. In Lambani, all farmers within the 3 farmer type categories highlighted that climate patterns are changing. Both Mixed and off-farm income dependant farmers highlighted increased frequency of extreme temperature events as the signs of climate change. They also highlighted increased rainfall variability. Horticultural farmers highlighted that climate change is being manifested through extreme low and high temperature events.

**Table 6-3 Perceptions of different small scale farmers in Lambani, Limpopo province, South Africa to current climate patterns**

| Mixed farming | Horticulture farming | Off-farm income dependent |
|---|---|---|
| Climate is changing | Climate is changing | Climate is changing |
| Increased frequency and intensity of drought | Increased frequency and intensity of extreme low and high temperatures | Frequent low rainfall events |
| Rainfall pattern has changed | | Extreme low winter temperatures |
| High temperatures | | |

Similar to Lambani, small scale farmers across all farmer categories in Nkonkobe highlighted that climate patterns are changing (Table 6-3). Climate change was characterised by increased frequency of dry spells and extreme low and high temperature events. Horticulture dependant farmers highlighted the increased reduced frequency and intensity of winter rains. This also includes increased frequency of extreme high temperature events. Struggling subsistence farmers highlighted increased start of the rainfall season.

**Table 6-4 Perceptions of different small scale farmers in Nkonkobe, Eastern Cape province, South Africa to current climate patterns**

| Social welfare dependent | Enterprising pensioners | Struggling subsistence | Horticulture dependent | Cooperative crop farmers |
|---|---|---|---|---|
| Change in climate patterns | Change in climate patterns | Changing climate patterns | Changing climate patterns | Increase frequency and severity of droughts |
| Increased severity of droughts | Increased frequency of dry spells | Increased variation in start of rainfall season | Reduced frequency and intensity of winter rains | Increased frequency of high temperature events |
| Reduced frequency and intensity of winter rains | Extreme low and high winter and summer temperatures | Extreme low and high temperature events | Extreme high temperature events | |

### 6.3.3. Climate change and variability management

Generally, each farmer group has a range of different strategies utilised in managing climate variability. Amongst the different farmer categories established earlier, all farmers highlighted the use of irrigation as one of the key strategies in managing climate change and variability. Small scale farmers in Lambani, Limpopo however highlighted other different strategies currently used in managing climate change and variability. Mixed farming practising farmers use both crop- and livestock-based strategies in managing climate change and variability. Horticultural farmers reduce fertiliser and pesticide application to reduce chemical toxicity. Off-farm income dependant farmers reduce cropping area under cultivation or do not plant at all. They also cultivate drought tolerant crops and crop types.

**Table 6-5 Current strategies utilised in climate change and variability management amongst the different small scale farmers in Lambani, Limpopo province, South Africa**

| Mixed farming | Horticulture farming | Off-farm income dependent |
|---|---|---|
| Intercrops with legumes | Irrigation | Irrigation, e.g. drip |
| Staggered planting dates | Reduce fertilizer use | Drought tolerant crop and crop types |
| Water harvesting, e.g. potholes | Reduce pesticide use | Reduce cropping area |
| Irrigation, e.g. flood, furrow | | Do not plant |
| Reduce cropping area | | |
| Mulching | | |
| Cattle manure | | |

In Nkonkobe community, all farmers except social welfare dependant and enterprising pensioners utilise irrigation as one of the strategies to manage climate change and variability. Social welfare dependant and struggling subsistence farmers use crop-based climate change and variability strategies. These include intercropping, mulching, water harvesting and reduction in cropping area. Horticulture dependant farmers use water reservoirs, organic amendments and seed diversification. Cooperative crop farmers utilise irrigation and use of cattle manure.

**Table 6-6 Current strategies utilised in climate change and variability management amongst the different small scale farmers in Nkonkobe community, Eastern Cape province, South Africa**

| Social welfare dependent | Enterprising pensioners | Struggling subsistence | Horticulture dependent | Cooperative crop farmers |
|---|---|---|---|---|
| Intercrop | Different crop types and varieties | Mulch | Irrigation | Irrigation |
| Reduce cropping area | Irrigation | Water harvesting | Water reservoirs | Application of manure |
| Mulch | Reduce fertilizer use | Intercrop | Organic amendments | |
| | Cattle manure | | Different crop types and varieties | |

### 6.3.4. Challenges in managing climate change and variability

Most of the farmers in both Lambani and Nkonkobe face financial challenges in trying to manage climate variability (Table 6-7 and Table 6-8). Finance is critical for setting up, servicing and maintenance of current irrigation equipment and technology. Specifically, in Lambani, mixed farming and horticulture farming-based farmers face financial challenges. Mixed farming and off-farm income dependant farmers face knowledge and labour shortages as well as finance to pay for energy (Table 6-7).

**Table 6-7 Challenges in climate change and variability management amongst the different small scale farmers in Lambani community, Limpopo province, South Africa**

| Mixed farming | Horticulture farming | Off-farm income dependent |
|---|---|---|
| Low water levels | Financial resources | lack of knowledge |
| Siltation | Shortage of water | Shortage of labour |
| Financial resources | | |
| Power shortages, e.g. irrigation | | |
| Climate information | | |
| Maintenance | | |
| Shortage of labour | | |
| lack of knowledge | | |

In Nkonkobe, all farmer categories except cooperative crop farmers highlighted finance as one of the challenges in managing climate change and variability. Social welfare dependant farmers have limited access to irrigation infrastructure and limited access to labour for farm operations. Enterprising pensioners also highlighted irrigation as a challenge. They also highlighted the need for more climate information. Cooperative crop farmers highlighted improved access to extension as the key challenge in managing climate change and variability. Social welfare dependant and horticulture dependant farmers highlighted challenges related to lack of climate information (Table 6-8).

**Table 6-8 Challenges in climate change and variability management amongst the different small scale farmers in Nkonkobe community, Eastern Cape, province, South Africa**

| Social welfare dependent | Enterprising pensioners | Struggling subsistence | Horticulture dependent | Cooperative crop farmers |
|---|---|---|---|---|
| Finance, e.g. farm operations | Improved irrigation equipment | Finance, e.g. reservoir; irrigation | Finance, e.g. improve operations | Improved access to extension |
| Irrigation, e.g. tanks; pumps | Climate information | | Climate information | |
| Labour, e.g. operations | | | | |

## 6.4. Discussion

### 6.4.1. Small scale farmer diversity

Assessment of the diversity in small scale farming systems of South Africa is critical in assessing opportunities for improving climate variability management. This is attributed to the differences in socio-economic and bio-physical characteristics especially education, finance, access to technology, irrigation, extension, etc. Consequently, the degree of vulnerability and potential for adaptation also differs with farmer type. Consideration of farmer diversity through assessing socio-economic and bio-physical characteristics is therefore key in when prioritising or assessment climate change and variability adaptation options.

The study attempted to follow this approach in unmasking and assessing current farmer diversity in South Africa to assess opportunities for future intervention. The existence of several small-scale farmer categories in the Lambani and Nkonkobe communities in Limpopo and the Eastern Cape is a manifestation of the increased diversity amongst small scale farmers in South Africa. This is supported by findings by Pienaar and Traub (2015) who assessed farmer diversity within the small scale farming communities of South Africa. The study acknowledged that though farming in South Africa can be broadly categorised into commercial and small scale farming, there is greater diversity amongst small-scale farmers in South Africa, which was evident through the realisation of 7 different farmer categories. The small-scale farming classes are: (1) young, male headed salary dependant (2) old female headed social welfare dependant (3) old male headed pension dependant (4) large female headed (5) female headed and remittance dependant (6) emerging intensive farming and (7) educated, formally employed and well of households. Within the context of climate change variability management, increased farmer diversity warrants the need for increased diversity in climate variability management strategies.

Specifically, farmer diversity was experienced in the small-scale farming communities of Nkonkobe, Eastern Cape where 5 farmer categories were realised. The categories are (1) *social welfare dependent* (2) *enterprising pensioners* (3) *struggling subsistence* (4) *horticulture dependent* (5) *cooperative crop farmers*. The current study realised *horticulture dependent* and *cooperative crop farmers* who were however not realized in another farm typology studies (Perret and Kirsten, 2000; Kelly and Metelerkamp, 2015). This is potentially attributed to the evolution of rural societies. The evolution is attributed to the dynamism of livelihood strategies where some small-scale farmers are now focusing on horticultural; crops to get income on short term basis which is the main activity of *horticulture dependent* and *cooperative crop farmers*. Cereal crops have relatively lower market prices compared to vegetable crops hence *horticultural dependant* farmers have developed a preference for high value horticultural crops. Similarly, *cooperative crop farmers* have developed a preference for vegetable crops. The realisation of the *horticulture dependent* and *cooperative crop farmers* may also be attributed to the use of the expert-based typology. This may have led to the agriculture extension workers identifying typologies that are common or intriguing within the communities compared to the most predominant farmer categories, which is a limitation of the expert-based farm typology development (Berre et al., 2016).

The study also realized *social welfare dependent* and *struggling subsistence* farmers who are usually old small scale farmers who practice subsistence farming but receive extra income through government grants. *Struggling subsistence* farmers have larger resource constrained households with many dependents. They receive child support grants from the government hence they can purchase food and other commodities. Thus, *social welfare dependent* and *struggling subsistence* farmers may not be enthusiastic on farming since they have alternate livelihood sources through government grants.

Greater farmer diversity was also realised in Lambani, Limpopo province through the realisation of 3 major farm typologies: *mixed farming, horticulture farming* and *off-farm income dependent*. Mudau (2010) realized similar diversity expressed through 4 small scale farmer categories: *highly intensive maize growers*, *vegetable growers*, *diversified maize growers* and *intensive diversified growers*. Both studies realised small scale farmers who produce horticultural crops by specialising in vegetables, e.g. tomatoes. The difference in the types of small scale farmers realised in the 2 studies is attributed to the objective, geographical extend and target communities of the research. The current study focused on a large geographical area hence included many farm categories which included *mixed farming*, which rear livestock as well. On the contrary, Mudau (2010) only realized intensive crop farming related categories which was attributed to the geographical extend and target community which was a small geographical area, Mamuhohi Irrigation Scheme. The nature of farm categories also differs with the intended use of the information. Small scale farmer categories developed by Perret et al. (2005) for the Ga-Makgato and Sekgopo communities were different from those realised in the current study. Perret et al. (2005) assessed farm typology at a coarse holistic rural community level and realised 9 farmer classes which generally described general livelihood options in rural community which contrasted with the current study which assessed diversity amongst small scale farmers with the objective of assessing the potential climate change and variability management.

With regards to the current study, *mixed farming* farmer type is predominant amongst farmers of at least 60 years of age. Aged farmers are generally risk averse and are conservative hence they produce crops and rear livestock. In addition, the bias towards crop livestock farming is attributed to the socio-economic cultural values of the African small scale farming community, which highlighted accumulation of livestock as a sign of wealth and also risk insurance (Wenhold et al., 2007). *Horticulture farming* households are concentrated amongst the 18-35 age group due to evolving socio-economic dynamics in small scale farming communities. They have modern habits and tastes hence they would want to earn more income. They are also shrewd and enthusiastic therefore undertake horticultural farming with greater profits compared to field crops with low profits. The main source of income for *off income dependant farmers* are off-farm activities, e.g. carpentry, mechanics, etc. Farming activities are therefore undertaken by the spouse.

### 6.4.2. Farmers perceptions to climate patterns

Assessment of farmer perceptions is one of the approaches towards sustainable improvement of climate variability in small scale systems. Assessment of perceptions to climate variability is an assessment of the state of awareness of the farmers to the climate patterns. This provides an opportunity for improving climate variability management. Within this study, perceptions of small scale farmers to climate variability were similar across all categories in both Limpopo and the Eastern Cape. Farmers generally highlighted that climate patterns are changing relative to historical years. The farmers highlighted increased frequency of extreme temperature events and rainfall variability. The change in climate patterns highlighted by small scale farmers correspond to the findings by researchers. Mzezewa et al. (2010) found that for the past 40 years' rainfall patterns within the Limpopo province, South Africa are skewing towards the occurrence of increased frequency of low rainfall events, with many rainfall events of low rainfall intensity of less than 5 mm. It has also been realised that over the last 4 decades 97% of the daily rainfall events were precipitation of less than 20% accounting at least 54% of the total rainfall (Mzezewa et al., 2010). Rainfall analysis by Gbetibouo (2009) realised that the mean annual rainfall in Limpopo was 525 mm per annum which ranges from 271 mm to 900 mm, and highly subject to rainfall variability. Gbetibouo (2009) found that small scale farmer's climate perceptions were highly correlated with climate records within Limpopo. Small scale farmers realised increase in temperatures and perceive future increase in temperatures and this corresponds to the increase of 1°C during the last 40 years from climate records and also projected increase of 4°C within the next half century (Serdeczny et al., 2016). Minimum temperatures of 15 and mean maximum of 24°C (Gbetibouo, 2009).

The study realised that the perceptions of small scale farmers to climate change were similar across different small scale farmer categories in different locations. Gbetibouo (2009) also realised that there were no significant differences in the perceptions to climate patterns amongst the different categories of small scale farmers. Notable differences in perceptions would only arise when small scale farmers were also compared to urban residents who did not realise any significant changes in climate change.

According to Muller and Shackleton (2013) small scale farmers in the Eastern Cape have realised notable changes in the climate patterns over the past 20 years. About 20% of commercial farmers however highlighted that they do not realise notable changes in climate patterns. Perception of small scale farmers are similar to the findings of this study, where farmers have highlighted that climate patterns are changing. The current study also highlighted that there is increased frequency and severity of droughts, which is also in agreement with the findings by Muller and Shackleton (2013) where small scale farmers have highlighted experiencing increased intensity and duration of droughts. Small scale farmers also highlighted delayed and unpredictable onset of rainfall, a phenomenon similarly highlighted by Muller and Shackleton (2013). In the current study small scale farmers did not highlight change in wind patterns as part of changing climate patterns but Muller and Shackleton (2013) highlighted that farmers have experienced changes in wind patterns over the last 20 years in the Eastern Cape Province. Small scale farmers did not highlight increase in extreme high rainfall events, a phenomena highlighted as being on the increase in the study by Muller and Shackleton (2013). The difference in perception is attributed to the micro-climate zones, which is explained by the higher climate variability experienced across the Eastern Cape Province.

Increased frequency of weather events as manifested through low and high temperatures and rainfall which has been highlighted by smallholder farmers is of critical importance to small scale farmers. Though the study did not assess or attempt the correlation between yield productivity and corresponding climate patterns, historical studies have highlighted that extreme weather events lead to the greatest yield losses. Yield losses due to climate extremes pose a greater threat to livelihood. There is therefore need to for increased emphasis on minimising the impacts of these extreme weather events through use of a range of available climate variability management strategies.

### 6.4.3. Climate change and variability management

Climate variability is a natural occurring phenomenon, as a result small scale farmers have always used climate risk and variability management strategies to cope and adapt. Small scale farmers across the different categories in Limpopo and Eastern Cape currently utilize a range of strategies in managing rainfall and temperature risk. The current study therefore assessed the strategies utilised by different types of small scale farmers in climate change and variability management. Similar studies have led to the realisation of farmer type specific management strategies in the Western Cape of South Africa (Ncube and Lagardien, 2014).

Within the Lambani community the current study realised that *mixed farming* households utilised many strategies that are based on both crops and livestock. This is highly attributed to greater farming experience amongst the aged farmers, which has enabled them to gather knowledge and experience from their predecessors and also from informal on farm experiments. The ownership of livestock motivates the use of manure in managing rainfall variability amongst aged small scale farmers. Despite the experience and availability of cattle most strategies are crop-based since most livestock-based strategies like use of cattle manure require labour which may be challenging considering that the farmers are aged as well. Strategies utilised by *horticultural farming* dependant farmers are short term and are based and designed to minimise the immediate risk posed by low rainfall and high temperatures. Irrigation is one of the major strategies utilised in climate variability and change management amongst all farmer categories and irrigation is key to horticultural crop production. *Horticultural farming* dependant farmers are highly dependent on irrigation for vegetable crop production. They have therefore invested heavily in irrigation infrastructure and development. Extreme temperature and low rainfall events, which are evidence of climate change are some of the key challenges in vegetable production. *Horticultural farming* use irrigation as the principal climate change and variability management strategy since irrigation minimises both rainfall variability and temperature hazards. Income has a greater influence amongst the *off income dependant* small scale farmers. They utilise a combination of both adaptation and avoidance based strategies. This is attributed to their ability to purchase drought tolerant seeds since they have the financial resources. They can also afford to reduce cropping area or not to crop since they can purchase food as they have alternate sources of income. *Horticultural farming* based households have also resorted to the production of high value vegetable crops with quick returns

Within the Eastern Cape, the strategies currently used by both *social welfare dependant* and *struggling subsistence* farmers are similar. The strategies utilised are crop-based strategies which mainly enhance water retention, e.g. mulching. The strategies also do not require financing and technique hence they are compatible with *social welfare dependant* and *struggling subsistence* farmers who are less educated and less resource endowed compared to the other farmer categories. Similar to *mixed farming* farmers in Lambani, *enterprising pensioners* utilise both crops and livestock-based strategies and are mostly aged farmers with greater farming experience. The Eastern Cape Province also has *horticulture dependant* farmers who are similar in characteristics to the *horticultural farming* households in Limpopo.

*Cooperative crop farmers* utilise fewer strategies to manage climate risk and are limited to irrigation and manure use only. They mainly produce vegetable crops and have invested heavily in irrigation, similar to *horticulture farming* households in Lambani. Irrigation minimizes both rainfall and temperature related climate hazards. Cooperatives are comprised of many individuals, hence there is abundant labour hence they utilise cattle manure application as a climate risk management strategy.

### 6.4.4. Challenges in managing climate variability and change

This study highlighted that small-scale farmers are aware of the changing climate patterns and the associated risks. Despite the availability to farmers of several strategies to managing climate variability, not all farmers make the necessary management decisions and the corresponding amendments to the cropping systems to managing climate risk. In addition, the recurrent current loss in farm productivity in seasons of increased extreme weather events, e.g. drought highlights the ineffectiveness of the current strategies and the need to reinforce them. Assessment of the current challenges in managing climate variability amongst small scale farmers is therefore an alternative entry point for improved climate variability management.

This research highlighted lack of financial resources as one the key challenges in implementing climate variability management strategies in South Africa. This was highlighted in both Eastern Cape and Limpopo provinces of South Africa. Amongst *mixed farming* and *horticulture farming* households in Limpopo, financial resources are key for financing, repairing and maintenance of irrigation equipment. Small scale farmers in the Limpopo province are increasingly becoming more attracted to market gardening as a source of livelihood. They also view irrigation as a solution to climate risk hence irrigation is one of the most common strategies to manage climate change and variability. In addition, most of the challenges highlighted by *mixed farming* and *horticulture farming* are related challenges in irrigation, e.g. power shortages. *Mixed farmer* households also highlighted rainfall variability, transportation loses, competition for water resources and siltation hence irrigation is not effective. *Off-farm income dependant* small scale farmers do not highlight finance as a challenge in managing climate risk since they have financial resources (Mudau, 2010).

In the Eastern Cape Province, small scale farmers also highlighted finance as one of the challenges faced in managing climate change and variability in small scale farmers. *Cooperative crop farmers* highlighted access to information about crop agronomy as a challenge in managing climate risk. There is need for improved agronomic management, efficiency and productivity before introducing climate risk management strategies so as to increase sustainability of climate risk management. The information lack was related to agronomy of crops.

*Enterprising* pensioners and *horticulture dependent* however highlighted lack of climate information as a challenge in managing climate risk. Provision of climate information prior to planting enables farmers to make management decisions enhancing coping and adaptation to climate risk. Mpandeli (2006) also highlighted that one of the sustainable strategies of coping and adapting to climate risk is the provision of climate information as seasonal forecast information. It can also be reiterated that small-scale farmers have used indigenous climate forecasting methods in managing climate risk. Integration of indigenous and scientific seasonal forecast information will however increase the resilience of small scale farming systems to climate change and variability.

Climate risk management also takes a holistic approach as current farming systems have been found to be highly inefficient. There is therefore need to increase the efficiency of current cropping systems through proper agronomic management practices before introducing climate management strategies. The challenges highlighted by Mpandeli and Maponya (2014) therefore need to be addressed for effective climate variability and change management. Mkuhlani et al. (2016) used a similar approach of increasing efficiency of smallholder farming systems before introducing crop livestock integration scenarios in small scale farming systems. There is therefore need to improve crop management in off-farm income dependant small scale farmers, as they are part time farmers hence they do not place much emphasis or focus in farming.

## 6.5. Conclusion

The research highlights increased farmer diversity in small scale farming systems of Lambani and Nkonkobe in South Africa. Diversity is attributed to the varying socio-economic characteristics of the farmers. These largely being age, education, financial resources and farmer goals. In Lambani the research highlighted *mixed farming*, *horticultural farming* and *off-farm income dependant* farmers whereas in Nkonkobe the research highlighted *social welfare dependant*, *enterprising pensioners*, *struggling subsistence*, *horticultural dependant* and *cooperative crop* farmers. Increased farmer diversity has a bearing on the vulnerability and effectiveness of climate change adaptation strategies as it determines what strategies can be utilised by specific farmers. This also applies to challenges faced by different farmers in managing climate variability. Perception of small scale farmers to the different climate patterns are generally similar across all farmer types regardless of the location. Farmers highlighted increased frequency and intensity of extreme low and high temperature, low rainfall and droughts. Due to increased farmer diversity climate variability management differs amongst the different farmer types and locations. Farmers practising mixed farming utilise both crop and livestock-based strategies. Horticulture dependant farmers mainly utilise short term strategies which mainly minimise the impact of extreme temperature events. Resource constrained farmers mainly utilise non-finance requiring strategies that minimise water loss. In trying to manage climate variability farmers face many challenges chief among them being finance which are mostly needed for financing irrigation equipment, especially amongst small-scale farmers. Irrigation therefore remains a perceived sustainable solution to climate risk in small-scale farmers. Resource constrained and educated farmers highlight the need for climate information to better manage climate variability. This therefore increases the need for targeted use of seasonal forecast information to manage climate variability in small scale farming in South Africa. Farmer diversity can therefore be utilised to better improve climate risk management amongst small scale systems of South Africa.

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# CHAPTER 7. ECOLOGICAL INTENSIFICATION POTENTIAL

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## 7.1. Background

In southern Africa, smallholder farming is dominated by dryland crop production. The average regional grain yields ranged between 0.3 and 2.2 t $ha^{-1}$ during the period 2008-2012 (FAO, 2014). South Africa is generally considered as a food secure nation (De Cock et al., 2013), but many households in rural areas are food insecure (Pereira, Cuneo, and Twine, 2014). This is because agricultural productivity in the smallholder, sometimes referred to as the subsistence sector in the rural areas is poor. About 35.2% of the South African population living in rural areas, rely on agricultural activities for their livelihoods, are amongst the poorest and most vulnerable (Tibesigwa, Visser and Turpie, 2014). The rural farming households are particularly vulnerable to climate and other disaster risks because they are mostly dependent on rain fed traditional agriculture (Mwenge Kahinda and Taigbenu, 2011; Kong et al., 2014) and have a low adaptive capacity due to low technical, financial and infrastructural constraints (Gbetibouo, Ringler and Hassan, 2010).

In South Africa and most surrounding countries in southern Africa, agriculture and agricultural related activities contribute to most of the employment in rural areas (Dercon and Gollin, 2014). Given the socio-economic challenges of poverty and unemployment, smallholder agriculture has the potential to generate more employment, income and improved livelihood opportunities in rural areas of South Africa (Shisanya and Hendriks, 2011; Mpandeli & Maponya, 2014). Improving agriculture is, therefore, highly considered as a viable and sustainable alternative in minimising rural poverty in South Africa and other sub Saharan African (SSA) countries (Adekunle, 2014; Thamaga-Chitja and Morojele, 2014; Shisanya and Mafongoya, 2016). With proactive technical and policy support, smallholder farmers can realise their potential to become competitive in their agricultural production activities. Improvement of smallholder farming is thus, a high priority in South Africa's fight against rural poverty (Aliber and Hall, 2012; Kepe and Tessaro, 2014).

There is a wide ranging debate on the manner in which agricultural innovations are being promoted in Sub-Saharan Africa (SSA) to improve agricultural production and sustainable livelihoods through smallholder farming (Wainaina et al., 2016). Technologies on sustainable land use and improved agricultural productivity have been developed, promoted and scaled out in the past 30 years in SSA (Bidogeza et al., 2009). However, some of these technologies have only been partially adopted (Giller, et al., 2009, 2015), and indeed most have not been fully adopted (Wainaina et al., 2016). This is because most interventions are not reflective of smallholder farmer circumstances, fail to acknowledge their social views, perception of their environmental realities and strategies used to meet their food security needs (Nhantumbo et al., 2016). This has failed to stimulate effective engagement between farmers, extension services and researchers to trigger adoption. Therefore, a paradigm shift in fostering agricultural intervention in South Africa and SSA is needed before scaling such interventions out (Whitbread et al., 2010; Sanyang et al., 2016). Agricultural technologies/interventions aiming to enhance production, income and household livelihoods, must capture the contrasting biophysical circumstances within and across the heterogeneous agro ecologies in smallholder agriculture in SSA (Baudron et al., 2015; Giller et al., 2015). Furthermore, the differing socio-economic circumstances within the sector must be considered.

Effectively identifying and integrating major issues that guide smallholder farmers' decision making is therefore important to unlock current technology adoption traps and mismatch of farmer technologies in this sector (Nhantumbo et al., 2016). A practical way to understand smallholder farmers' farming systems and production levels include identifying performance, efficiency levels, challenges and constraints and opportunities. Furthermore, understanding the vulnerability of the farming systems to climate change, social, economic and biophysical shocks and impacts could enhance unlocking adoption traps. Different modelling frameworks can be used to achieve the above. However, a successful farming system analysis model requires the establishment of farm typologies. Farm typologies are where farm households with similar production goals, biophysical and resource endowments are grouped together to effectively classify the heterogeneity of farmers' motivations and socio-economic circumstances related to their farming systems (Bidogeza et al., 2009; Chikowo et al., 2014; Chenoune et al., 2015). The classification criteria depends on the goal of the typology and the kind of data available. Furthermore, agricultural scientists are being encouraged to develop farm typologies to support a more tailored approach to agricultural development and innovation.

In SSA two models of fostering agricultural development and innovation to improve smallholder agriculture have gained momentum namely sustainable and ecological intensification. The two are closely linked in terms of definitions, principles and practices, thus, creating some confusion in their meaning, interpretation and implications (Wezel et al., 2015). However, some differences do exist between these two models. The major difference being the role played by nature in the actual design of the farming systems (Tittonell, 2014), and in the possible synergies between food security (livelihoods), global change adaptation and mitigation. In this study, we focus mainly on ecological intensification. Ecological intensification, a means of increasing agricultural production and environmental services while reducing the need for external inputs and capitalising on ecological processes that support and regulate primary productivity in agro ecosystems (Tittonell, 2014). This paradigm of ecological intensification can guide farming systems design in heterogeneous households with limited access to resources to produce more with less external inputs. Furthermore, the paradigm aims to achieve a healthy environment that provides multiple ecosystem services (Tittonell and Giller, 2013). This paradigm considers farmers' social views, perceptions of their realities and strategies used to meet their food requirements. In this paper, we illustrate the expert-based approach to build typologies to guide in targeting ecological intensification technologies for smallholder farmers in marginal areas in South Africa.

## 7.2. Methods

### 7.2.1. Study site

The study was conducted in Lambani, a village in Vhembe District in Limpopo province South Africa. Vhembe district is largely rural with 90% of the population residing in the rural areas. According to Mpandeli & Maponya (2014), agricultural production is considered the main contributor to employment and livelihoods. The district average annual rainfall is approximately 820 mm. Subsistence or smallholder agriculture accounts for 70% of the farming activities in the district whilst the other 30% is commercial agriculture.

### 7.2.2. Typology construction

An expert-based approach was chosen to enhance local relevance and socio cultural aspects of interventions. Five key informants, field- based agricultural extension workers who work in the study area were identified. Four of the agricultural extension workers specialised in crops and one specialised in livestock. The agricultural extension workers were informed that the objective was to develop an expert-based typology so as to classify smallholder farmers based on predominant socio economic characteristics, resource endowments and production objectives. The typology was constructed through a focused group discussion done with the five agricultural extension workers. Based on their knowledge and experience in the area three farmer typologies were identified based on the major the source in which gross maximum income was earned. The farm types were namely the cereal- and livestock-based (Type 1), the horticulturalbased (Type 2) and the off-farm income dependent farmers (Type 3).

### 7.2.3. A survey to identify challenges, constraints and opportunities for ecological intensification in different farm types

Agricultural extension officers identified farmers which were assumed to fit into each of the above typology. About 16 cereal and livestock-based farmers, 7 horticultural-based farmers and 17 off-farm income dependent farmers were identified and interviewed. The interviews sought information on the types of crops grown, yields obtained, crop preferences and production objectives. Farmers were asked to identify major constraints and challenges to their current crop and livestock farming practices. Farmers' perceptions on their potential solutions to their production constraints and objectives were sought by means of open ended questions. Ecosystem services have particular relevance in Sub-Saharan Africa (SSA), where the majority of the human population dwell in rural areas and rely on ecosystem services for their living through smallholder farming, pastoralism and fisheries (Egoh et al., 2012). To produce knowledge for targeting ecological intensification of agriculture, farmers need to provide information on key ecosystem services needed in their farming context. Farmers' perceptions were sought on key ecosystem services needed in Lambani village to target ecological intensification to improve agricultural productivity.

## 7.3. Results

### 7.3.1. Farming system patterns

Results from the survey revealed average farm size of 2 ha for Type 1 and 3, with Type 1 exhibiting the largest average cropped area of 1.5 ha. Type 2 had the smallest average farm size of 1.5 ha which corresponded to the smallest cropped area. Maize, the most consumed staple crop in South Africa, was the major crop grown by Type 1 and 3 farmers although the yields obtained were very poor averaging 1 t $ha^{-1}$ and just above 0.5 t $ha^{-1}$ for Type 1 and 3, respectively. Type 2 farmers only produced maize a minor crop for household consumption as green mealies. They cited very poor maize crop yields and high chances of crop failure. Type 2 farmers also highlighted that financial returns from crops like maize, cowpea and groundnuts were often not worth the effort when set against the risks of producing those crops under rain fed conditions. All farmer types were involved in vegetable production with only type 2 farmers growing vegetables as their major crops and primarily as a cash crop and major source of income. The results indicated that Type 2 farmers were preferred and mainly interested in high value horticultural crops grown on a small area and could grow them throughout the year. Type 1 and 3 farmers are involved in legume and vegetable production on a small scale mainly for household consumption and rarely as cash crops. Cowpea and groundnuts being the major legume crops grown by this category of farmers.

### 7.3.2. Farm types challenges and constraints

Identification of crop and livestock production constraints and challenges in relation to specific farm type households is therefore key in designing potential interventions aimed at improving agricultural productivity and livelihoods. The typology revealed that all farm types faced different challenges and constraints to their agricultural activities although poor seasonal rainfall distribution and amount and poor irrigation infrastructure were common constraints among all the farm types. A significant proportion of Type 1 farmers also cited poor access to inputs as well as high input costs especially fertilizer. This was mainly because cereal crops which they grow are input demanding with regards to fertilizer and other chemicals. Furthermore, they pointed out shortage of livestock feed especially during the dry season and drought years leading to loss of livestock or crop damage by livestock during the dry season. Type 2 farmers cited poor access to markets as well as high incidences of pest and diseases in their fields. This is because they cultivate horticultural crops which are prone to pest and diseases and are perishable hence need to be marketed quickly to minimise post-harvest losses. Furthermore, they highlighted poor access to pesticides despite having significant financial resources. Type 2 farmers cited lack of mechanization and draught power as the major challenge to increase area under crops. Type 3 farmers cited lack of access to inputs, lack of livestock feed during the dry season and drought years as well as damage of crops by livestock during the dry season.

### 7.3.3. Opportunities for ecological intensification

Ecosystem services have particular relevance in SSA, where the majority of the human population dwell in rural areas and rely on ecosystem services for their living through smallholder farming, pastoralism and fisheries (Egoh et al., 2012). Enhanced ecosystem service provision is therefore critical for building resilience and improving food and nutrition security for smallholder farmers in SSA. The farmer typology identified three key ecosystem services needed for each farm type to improve agricultural productivity. All farm types, proposed soil and water conservation as a key ecosystem services they would benefit from to increase agricultural production. This is because Lambani village is associated with low rainfall and high rainfall variability (Mpandeli, 2014), and another significant concern was the general perception that Lambani had become drier over the years. Insufficient rainfall over the years is resulting in water shortages for both domestic and agricultural purposes. Ecosystem services and processes that enable them to conserve this important resource both in and off-farming lands are therefore very vital for their livelihoods.

A significant proportion of the Type 1 farmers also proposed, nutrient recycling as a key ecosystem service they would benefit from. This is mainly because they cultivate cereal crops which have a high nutrient demand. Most soils in Southern Africa's smallholder are inherently infertile. Biophysical constraints such as depletion of soil fertility because of low fertilizer use and high rates of nutrient mining are common among smallholder farmers in South Africa and the region beyond (Zingore, 2016). Ecosystem services and processes that increase soil fertility in their fields are therefore critical. Lastly provision of forage and fodder was identified as key ecosystem services they would benefit from to improve livestock productivity. Livestock is a key component of South African smallholder farming systems and is increasingly viewed as an important pathway for rural households to escape poverty. Low quality and quantity of feeds are a major constraint limiting livestock productivity among smallholder farmers. This is highly contributing to farmers' livestock losses particularly in the dry season due to lack of forage, fodder and water. Ecosystem services and processes that provide forage and fodder are important and could benefit Type 1 farmers.

Type 2 farmers proposed water quality, pest and disease suppression as key ecosystem services needed for them to improve productivity. Type 2 farmers mostly grow their horticultural crops under irrigation. Therefore, ecosystem services that enhance water quality are important to prevent eutrophication of the water bodies resulting in increased water supply and reduced salinity in their agricultural fields. Horticultural crops are water demanding, therefore a clean and constant water supply is very important and would be beneficial to Type 2 farmers. Weeds, insects and pathogens infestation a major challenge to their horticultural farming activities, demand constant labour and pesticides to treat them, hence Type 2 farmers require pest suppression ecosystem services that can prevent and control incidences of pests in their fields. This because incidences of pest and diseases have been found to manifest strongly in horticultural crops.

Type 3 identified pest and disease suppression and nutrient recycling as key ecosystem services needed for them to improve productivity. Like Type1 farmers they are involved in cereal crop production which is nutrient demanding hence would benefit from nutrient recycling ecosystem services and to improve soil fertility for improved crop productivity. They also benefit from pest and disease suppressing ecosystem services and processes because their involvement in horticultural crop production which is highly susceptible to pest and diseases.

## 7.4. Conclusion

This study was in response to the need to identify the heterogeneous farming system patterns and diversity in smallholder farmers in South Africa to target ecological intensification in the design and implementation agricultural development interventions and technologies. The construction of an expert-based farm typology is the first step to identify diversity of the 3 farm types in Lambani a village in Vhembe district, Limpopo, South Africa. Farmers can be distinguished based on their sources of income, household involvement in both on and off-farm activities and the diversity of the farmers' agricultural land use. An expert-based typologies offered a more contextualized representation of farming system heterogeneity in terms of challenges, constraints and opportunities faced by farmers of the 3 identified farm types. Different types of farmers are expected to pursue different trajectories in farm system design for targeting ecological intensification to harness ecosystem services that flow from the agroecosystems under study.

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# CHAPTER 8. SOIL MOISTURE AND ADAPTIVE CAPACITY MAPPING

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**Purpose** – This paper presents a case study-based approach to identify resource-poor communities with limited abilities to cope with the adverse effects of climate change. The study area is the Nkonkobe Local Municipality, in the Eastern Cape which is one of South Africa's provinces ranked as being extremely vulnerable to the adverse effects of climate change due to high incidences of poverty and limited access to public services such as water and education. Although adaptive capacity and vulnerability assessments help to guide policy formulation and implementation by identifying communities with low coping capacities, policy implementers often find it difficult to fully exploit the utility of these assessments because of difficulties in identifying vulnerable communities. The paper attempts to bridge this gap by providing a user friendly, replicable, practically implementable and adaptable methodology that can be used to cost-effectively and timeously identify vulnerable communities with low coping capacities.

**Approach** – A geostatistical approach was used to assess and evaluate adaptive capacities of resource-poor communities in the Nkonkobe Local Municipality. The geospatial component of this approach consisted of a multi-step Geographical Information Systems (GIS) based technique that was improvised to map adaptive capacities of different communities. The statistical component used demographic indicators comprising literacy levels, income levels, population age profiles and access to water to run automated summation and ranking of indicator scores in ArcGIS 10.2 to produce maps that show spatial locations of communities with varying levels of adaptive capacities on a scale ranging from low, medium to high.

**Findings** – The analysis identified 14 villages with low adaptive capacities from a total of 180 villages in the Nkonkobe Local Municipality. This finding is important because it suggests that our methodology can be effectively used to objectively identify communities that are vulnerable to climate change.

**Social implications** – The paper presents a tool that could be used for targeting assistance to climate change vulnerable communities. The methodology proposed is of general applicability in guiding public policy interventions aimed at reaching, protecting and uplifting socio-economically disadvantaged populations in both rural and urban settings.

**Originality/value** – The approach's ability to identify vulnerable communities is useful because it aids the identification of resource-poor communities that deserve priority consideration when planning adaptation action plans to deliver support and assistance to those least capable of effectively coping with the adverse effects of climate change induced vulnerabilities.

**Keywords** Adaptive capacity, vulnerability assessment, climate change, geostatistical techniques, Nkonkobe Local Municipality, South Africa.

## 8.1. Background

Adaptive capacity assessment is a significant component of vulnerability assessments because it aids the identification of resource-poor communities deserving priority consideration during the formulation of strategic responses to climate change (Gbetibouo, 2009) and the allocation of resources and provisioning of assistance. It is also useful in that it assists the governing of adaptation actions by facilitating effective and timely implementation of planned response measures. Climate change driven afflictions are often difficult to respond to because climate change is a long-term continuous change in average weather conditions (Davis, 2011; IPCC, 2007; Marshall, 2014; Ramamasy and Baas, 2007; Rayner and Minns, 2015) with persistent adverse effects that require implementation of objectively informed interventions. Because climate change occurs over long periods of time, the persistence of changes associated with it implies that interventions designed to mediate its effects have to be robust enough to enable vulnerable communities to cope with unpredictable stochastic events. The unpredictable nature of these events and their severity and duration often require recourse to high levels of flexibilities which resource-poor communities are often unable secure because their adaptive capacities are limited by poverty (IPCC, 2007).

Because low levels of flexibilities undermine the implementation of interventions by overstretching limited resources, the placement of well-versed adaptation strategies planned to augment human capacities to handle deteriorating climate conditions is critical since adoption of effective strategies requires official acknowledgement of the non-transient character of current trends in climatic change (Hamandawana, 2007). The assessment of adaptive capacity provides decision makers on global, regional, national and local levels useful information that helps to improve climate change adaptation policies (Juhola and Kruse, 2015; Smith et al., 2010).

Such information is extremely necessary in regions of the world like Southern Africa which is widely considered to be extremely vulnerable to climate change because of limited livelihood options, poorly developed infrastructure (Ziervogel et al., 2006), different forms of human insecurity (Davies et al., 2010), the high prevalence resource-poor households (IPCC, 2007) and dependence on climate-sensitive sectors notably agriculture (Ambrosino et al., 2010). Resource-poor communities are usually situated within rural areas which are susceptible to drought (Phaswana-Mafuya and Olsson, 2008). In South Africa, observations over the 43 years before year 2003 point to a steady increase in temperatures with projections estimating increases by 1.2°C by 2020, 2.4°C by year 2050 and 4.2°C by the year 2080 while rainfall is projected to reduce by 5.4%, 6.3% and 9.5% by year 2020, 2050 and 2080 respectively (Kruger and Shongwe, 2004). In similar studies, Department of Environmental Affairs (2013) and Erasmus (2014) have also pointed out to future increase in temperatures and rainfall reductions within South Africa with the latter being corroborated by a reported 4% decrease for the rest of Southern Africa during the last century (UNECA, 2011). Although the reliability of this estimate is contestable, Southern Africa has exhibited high inter-annual rainfall variability from the beginning of the second half of the last century (Conway et al., 2009) which is likely to force much of South Africa's rural agriculture out of production (Bauer and Scholz, 2010). These scenarios are indicative of climate change in the entire country and signal immediate need to embrace appropriately informed intervention strategies.

The work done by Gbetibouo et al. (2010) in ranking South Africa's provinces' vulnerability to climate change-related problems shows that the Limpopo, Eastern Cape and KwaZulu-Natal Provinces are highly vulnerable to climate change-related problems due to their high dependency on rain-fed agriculture, densely populated rural areas, large numbers of small-scale farmers, and high rates of land degradation. Although this paper is not intentioned to provide a countrywide perspective of the pervasive nature of climate change induced vulnerabilities, a synoptic overview of synchronous events can help to illustrate the perversity of climate-induced vulnerabilities in South Africa. In 2004, KwaZulu-Natal Province, which borders the Eastern Cape Province in the north east was hit by a severe drought that left more than 700 000 people without water after boreholes, rivers and wells dried up with this drought having been preceded by similar others in 1979, 1980, 1983 and 1992-1993 (Reid and Vogel, 2006). In the Eastern Cape Province, consecutive droughts occurred in the years 1992, 2004 and 2009 (International Federation of Red Cross, 2004; ADM, 2012; Amathole District Municipality, 2010) with the most severe being experienced in Nkonkobe Local Municipality. The magnitude and severity of the 2004 drought became evident in Nkonkobe Local Municipality when 1063 farmers submitted applications for drought relief support (ADM, 2004). This situation was followed by reports in July 2009, of critically low dam levels in Hogsback town which falls under the Eastern Cape Province's Nkonkobe Local Municipality (ADM, 2012; Amathole District Municipality, 2010). Thereafter, Nkonkobe Local Municipality was declared a drought disaster area by Amathole District Municipal council in February 2017 (Dayimani, 2017). These scenarios argue for the need to assess adaptive capacities in the Eastern Cape Province's Nkonkobe Local Municipality because most communities its communities do not have adequate capacities to cope with climate change-related problems due to high incidences of poverty occasioned by the majority of the people's dependence on rain-fed agriculture, livestock production and government social grants (Gbetibouo and Ringler, 2009; Ndhleve et al., 2014; Zhou et al., 2013). Nkonkobe Local Municipality's low adaptive capacity is further aggravated and evidenced by its low Human Development Index (HDI) of 0.60 which is very low according to the HDI report of United Nations (Nkonkobe Local Municipality, 2012). The HDI indicates the status of a place in terms of development (Nkonkobe Local Municipality, 2012). Nkonkobe's HDI of 0.60 suggests that this municipality is still poorly developed for which reason it is ranked as being highly vulnerable to disasters associated with climate change. A perceptive inference from these scenarios and statistics is that adaptive capacities are spatially variable and coextensive (Adger et al., 2003) to the extent that it is extremely important to objectively identify hotspot areas in order to direct interventions to areas where they are most needed by using optimally selected indicators.

The choice of indicators for determining adaptive capacity is linked to a wide range of factors that are related to a community's demographics and socio-cultural arrangements (Wongbusarakum and Loper, 2011). Demographics are statistical data linked to the population and precise groups surrounding it. By identifying likely climate change impacts and conveying them in a map format with strong visual elements, hotspots maps can communicate issues in a manner that may be easier to interpret than text (De Sherbinin, 2014). Hence the main objective of this paper was to delimit areas in Nkonkobe Local Municipality which are least capable of effectively coping with the adverse effects of climate change by providing a spatially explicit resource-based identification of communities.

## 8.2. Adaptive capacity conceptual framework

This section begins by defining adaptive capacity as commonly used in the literature and proceeds to provide a brief overview of selected examples of adaptive capacity assessments by different authorities with the latter being intentioned to shed light on the strengths and limitations of conventional techniques that have been used to assess adaptive capacity in different areas.

Adaptive capacity is defined as the ability of people to overcome the adverse effects of climate change (Frankel-Reed et al., 2011; Heltberg and Bonch-Osmolovskiy, 2011; IPCC, 2012). Since climate change impacts are presently witnessed, adaptation should also be conspicuous in present society (Adger et al*.,* 2005). The adaptive capacity of a system affects its vulnerability to climate change by varying exposure and sensitivity (Adger et al., 2007; Gallopín, 2006; Yohe and Tol, 2002). The assessment of adaptive capacity is complex and may be prejudiced intensely by a few key characteristics, or by an extensive range of social characteristics (Wongbusarakum and Loper, 2011). For example, villages with varied income sources and additional livelihood alternatives are likely to have greater adaptive capacities to effects of climate change than those without (Brooks et al., 2005). The shaping of adaptation policy can be promoted by diversion from climate impacts assessment to adaptation priorities (Adger et al., 2005; Burton et al., 2002). This prioritization of climate change adaptation is important because climate change it is already occurring, and will occur with greater urgency in the future at a range of scales.

The choice of indicators for an adaptive capacity assessment for communities at municipal or provincial level is limited by the type and level of demographic data available from data providers. In South Africa, Statistics South Africa (StatsSA, www.statssa.gov.za) is the national statistical service provider mandated to timely produce accurate and official statistics in order to advance economic growth, development, and democracy.

The work done by Ellis (2000) in developing a rural livelihoods framework can be used as a basis for empirically building an adaptive capability index. In this framework, adaptive capacity is conceptualized as an evolving property of various forms of human, natural, physical, social, and financial capital from which rural livelihoods are derived with the flexibility to substitute between them being a reaction to exterior pressures. Equilibrium amongst these five capitals is unnecessary, since low levels of one capital can be offset by proficiently using another (Ellis, 2000). Adaptive capacity is high when non-farm income sources less directly affected by climate change supplement on-farm income sources.

Seminal works by authors (Adger et al., 2005; Burton, 1998; Burton et al., 2002) also provide discussion on adaptive capacity and propose typologies of adaptation to climate change. Burton (2002) argues that at the end of the day climate policy decisions are made by governments which have responsibility for the success or failure of the policies they adopt. The purpose of policy-related research for adaptation to climate change is not to decide or advocate policy, but to provide the policy makers with policy choices upon which they can base their judgements (Burton, 2002). The review work by Bahadur et al. (2010) identifies sixteen conceptualisations of adaptive capacity within the context of climate change as a hazard. A capital-based approach for conceptualizing adaptive capacity (Bahadur et al*.,* 2010; Mayunga, 2007) is most appropriate for South Africa because the suggested indicators are related to demographic data which is readily available and easily accessible (www.statssa.gov.za).

The work done by Faling et al. (2012) on actions taken by South African local municipalities in strategizing for climate change provides evidence supporting the view that the formation of strategies for climate change adaptation in South Africa is still nothing more than sophisticated rhetoric in most areas. However, the generalizability of this observation is constrained by the fact that the study focused on municipalities in Northern Cape and Western Cape Provinces without giving due attention to the Eastern Cape Province where there is one of the highest incidences of poverty in South Africa.

In a similar vein, Grecksch (2015) assessed adaptive capacity of water governance in the Keiskamma River Catchment in Eastern Cape Province using the Adaptive Capacity Wheel (ACW) framework. This assessment revealed medium adaptive capacity in this area and raised awareness among decision makers and the public by providing information on possible climate change effects and possible adaptation measures. Detailed assessments that demonstrate the usefulness of the ACW are provided by van den Brink et al. (2011) and Grecksch (2013). Their works provide a framework that supports the adaptive capacity assessment which was conducted in the Keiskamma River Catchment. Although these assessments demonstrate the usefulness the ACW framework, nationwide use of this framework is undermined by its inclination to provide aggregated scenarios and inability to show exact locations of places with varied adaptive capacities.

Although an exhaustive overview of initiatives similar to those outlined above is outside the scope of this work, a brief presentation of the work done by Weis et al. (2016) in developing an adaptive capacity index for Grenada is helpful because it provides useful insights on wide-ranging possibilities that can be considered under different situations. Weis and co-authors assessed Grenada's adaptive capacity to flooding by mapping asset-based resource indicators of adaptive capacity comprising: 1) human and civic resources; 2) healthy population as a resource; and 3) economic resources. Their study was useful because unlike most assessments that have tended to be confined to sub-national constituencies, it provided a spatially co-extensive approach that can be used to guide policy formulation at national level the only downside being that it fails to adequately accommodate resource-poor communities at village level, where policy interventions are supposed to make a difference within municipalities by helping to alleviate the intractable difficulties confronting those least capable of helping themselves.

The examples outlined above have been presented in order to demonstrate that adaptive capacity can be cost effectively assessed by using data most countries already have without overstretching limited resources by attempting to compile new information. Tools and techniques to do this are readily available and all that is needed is to tap on what is already accessible. This accessibility prompted the authors to share with those interested how GIS can be used to assess and map adaptive capacity. GIS may be defined as a computer-based tool for mapping, querying and analysing spatially referenced data (Quan et al., 2001). GIS mapping can capture subnational variations in vulnerability by combining spatial data layers, generally by converting each layer to a unitless scale and aggregating the layers to reveal vulnerability levels (De Sherbinin, 2014). Although various methods of assessing adaptive capacity exist, GIS-based assessment of adaptive capacity is increasingly becoming popular because of its ability to produce information in map formats that provide comprehensible visual depiction of spatial variabilities in adaptive capacities.

GIS-based mapping offers the advantage that it can be applied at multiple scales, which is extremely useful because not only can it handle vulnerability assessments for large areas but also it is also capable of effectively producing intelligible maps for small areas thereby overcoming limitations confronting other approaches that are not able to provide disaggregated assessments at municipal levels. Because of this limitation, non GIS-based methods often produce vulnerability assessments in which municipal disasters, food and water insecurities are, in many instances, analysed at an aggregated national level giving rise to poorly targeted policy interventions. Although it is widely accepted that identification of villages with low adaptive capacities at municipal level is critical in the formulation of well-targeted adaptation and mitigation policies and strategies, this has been difficult to accomplish due to absence of methodologies that are capable of downscaling national-level data to municipal levels where policy interventions can be translated into action by engaging resource poor communities. Although data is in most cases usually available at national level, lack of equivalent datasets at municipal-level continues to be problematic (National Disaster Management Centre, 2005). This study attempts to bridge this gap by providing a step-by-step illustration of how GIS can be used to produce regional-level adaptive capacity information in the form of maps that accurately indicate villages in need of adaptation support. The ability of the proposed methodology to identify and show these villages is helpful because it enhances the effectiveness of wide-ranging interventions by assisting policy implementers to direct assistance where it is needed.

## 8.3. Materials and methods

### 8.3.1. Study area

Figure 8-1 shows the location of Nkonkobe Local Municipality in the Eastern Cape Province of South Africa.

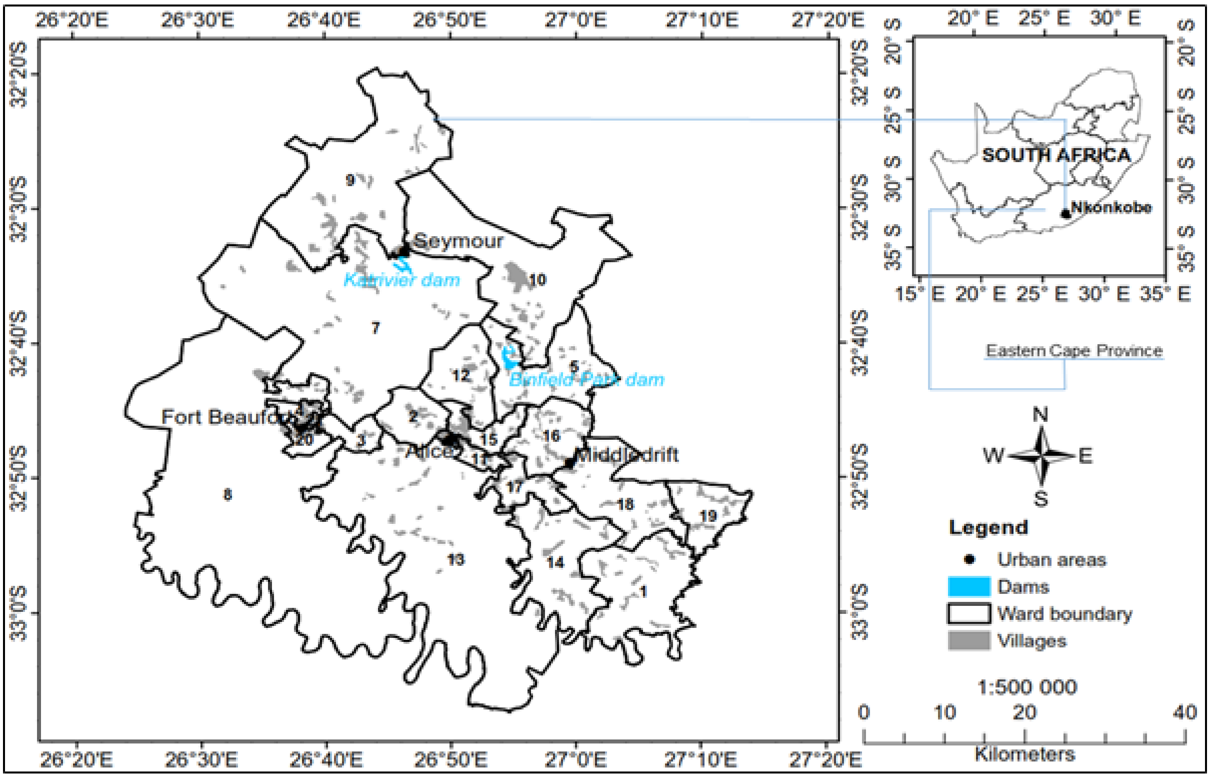

**Figure 8-1 Geographic location of Nkonkobe Local Municipality in the Eastern Cape Province, South Africa including ward boundaries**

Nkonkobe is a countryside municipality comprising of 21 wards, covering an area of approximately 3 725 km$^2$ and has an average population density of 43 people per square kilometre (Nkonkobe Local Municipality, 2012). The major towns in Nkonkobe include Alice, Middledrift, Fort Beaufort and Seymour. The majority of the population (72%) resides in villages and farms whilst the remaining 28% resides in urban settlements (Nkonkobe Local Municipality, 2012). The entire municipality has a dispersed settlement pattern where pockets of developed urban centres are surrounded by scattered undeveloped rural villages, which implies great costs to provide basic infrastructure and services (Nkonkobe Local Municipality, 2013).

The area's climate is semi-arid with mean monthly temperatures that range from 6.2 °C to 20.8 °C in July and 17.2 °C to 36.0 °C in February; a wet summer season that begins in October and ends in April, a dry winter season that covers the remaining months of the year and average annual rainfall not exceeding 600 mm. This semi-arid climate poses serious problems by compromising the abilities of local communities to adapt to the adverse effects of climate change by inducing scarcities in the availability of basic requirements notably food and water. The majority of the population in Nkonkobe Local Municipality is highly dependent on natural resources and agriculture which are substantially influenced by rainfall and precipitation patterns. This limitation also provides part explanation of why this municipality was deemed suitable for assessment of the adaptive capacity of resource-poor households to climate change.

### 8.3.2. Categories and sources of data that were used

Data used in this study was categorized as digitized village layer and census data. Statistics South Africa (StatsSA) provided the digitized village layer and 2011 census data (the most recent census survey date) in a raw table format at the municipal enumeration level.

### 8.3.3. Methods

The adaptive capacity of households to climate change was determined by adopting a multi-step GIS-based mapping of indicators that were simultaneously analysed and averaged to determine the magnitude of adaptive capacity. Several adaptive capacity indicators were purposefully selected to enable spatial comparisons and the description of complicated reality in a comprehensible manner aided by the Nkonkobe Integrated Development Plan (IDP) for 2012-2017 (Nkonkobe Local Municipality, 2012) and expert knowledge which provided additional information and insights during the selection of assessment indicators. The selection of these indicators was based on the definition of adaptive capacity provided by Heltberg and Bonch-Osmolovskiy (2011) and the type and level of demographic data available for Nkonkobe Local Municipality. The following indicators (Table 8-1) were selected on the basis of the logic described above and used to assess adaptive capacity within the municipality.

**Table 8-1 Description of input indicators used for assessing adaptive capacity**

| Narrative Indicator | Rationale | Ranking |
|---|---|---|
| Literacy levels | Specified adaptive capacity within the villages basing on highest level of education. | Villages were given a score of 0 to 5 depending on the highest level of education. Villages with the least level of education were given a rating of 0. The ranking was as follows: No schooling = 0, Some Primary = 1, Completed Primary = 2, Some Secondary = 3, Completed Secondary = 4, Higher = 5. |
| Income levels | Villages with a low income levels are less likely to have access to credit and less resilient to climate change. | Villages were given a score of 0 to 4 depending on income profiles. Wards with the lowest income profiles were given a rating of 0. Ranked by Divided annual income into groups: No Income = 0, R1-R9 600 = 1, R9 601-R19 600 = 2, R19 601-R38 200 = 3, R38 201 or more = 4. |
| Age profiles | These were used to identify villages in which there were significant numbers of children or old people. Villages with majority being children or old age are most likely to be less resilient to climate change by virtue of being economically inactive. | Villages scored between 0 and 3 and divided into three age groups; 0-14: Child (score of 0), 15-39: Young (score of 2), 40-59: Old (score of 3): Over 60 (score of 1). |
| Water access by source type | Specified the degree of adaptive capacity within the villages basing on water sources mainly utilized by different villages. | Other sources = 0, Surface water = 1, Ground water =2, Regional water scheme = 3. |

Shapefiles were created for each input indicator by linking the Microsoft Excel table for each indicator to the attribute table of the digitized-village shapefiles using the Join operation in ArcGIS 10.2 in order to allow expression as spatial layers that could be aggregated with other layers to spatially depict adaptive capacity levels. The demographic data from StatsSA was analysed at village-level because this was the lowest level at which the required information was available.

The following customized Python algorithm (Algorithm 8.1) was used to automatically assign scores to villages in the attribute table for village income levels. The same algorithm was also used for the same purpose to assign scores to the other 3 indicators (Literacy levels, Income levels, Age profiles) after being modified by changing the table names, field names and row numbers for each indicator following the criteria shown in Table 8-1.

**Algorithm 8.1. Algorithm that was used to automatically assign scores for village income levels**

```
import arcpy module
specify file input location for income data attribute table
declare table_array for fields = [“No_income”,”R1_to_R9600”,… ,”R38201_or_more”]
declare array for max_value field
declare array for max_value_fieldname
declare array for assigned_score field
add max_value, max_value_fieldname, assigned_score fields to table_array
set cursor in table_array to update = true
with arcpy_UpdateCursor in table_array, put cursor at first row
        for row in cursor
                find maximum value
        find field name of maximum value
        find assigned score
        update rows
```

The geoprocessing algorithm was executed in ArcGIS 10.2 Python window using the Python execfile command.

A map was generated for each of the four indicators in the ArcMap 10.2 interactive environment based on the assigned scores in order to reveal detailed spatial variations for each indicator. Thereafter, all attribute tables were examined to identify villages with the lowest scores for each indicator. Adaptive capacity scores (Table 8-2) were determined by automatic generation of a new shapefile and attribute table where the previously calculated scores from the 4 indicators were imported into and summed up for each village using automated Python geoprocessing algorithms (Algorithm 8.2 and Algorithm 8.3). All indicators were assigned equal weighting due to limited availability of indicator data for the municipality but this limitation did not compromise the reliability of results because expert knowledge and the Nkonkobe IDP for 2012-2017 (Nkonkobe Local Municipality, 2012) confirmed that all indicators were equally important for adaptive capacity assessment.

Adaptive capacity scores were calculated in the attribute table (Table 8-2) as the sum of the indicator scores.

**Table 8-2 Illustration of the evaluation of adaptive capacity in the attribute table**

| Village | Ward number | Access to water | Literacy levels | Income levels | Age profile | Adaptive Score | Adaptive Capacity |
|---|---|---|---|---|---|---|---|
| $V_1$ | $W_1$ | 3 | 5 | 4 | 3 | 15 | HIGH |
| $V_2$ | $W_2$ | $S_1$ | $S_2$ | $S_3$ | $S_4$ | . | . |
| . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . |
| $V_{180}$ | $W_{21}$ | 3 | 3 | 2 | 0 | 8 | MEDIUM |

$V_1 \ldots V_{180}$ – village names; W – ward numbers; $S_1$, $S_2$, $S_3$, $S_4$ – indicator scores. Adaptive scores ranged from 1-15.

The following Python algorithm (Algorithm 8.2) was used for automated creation of a new shapefile and attribute table and joining of Age_Profile scores to the IndicatorScores table.

**Algorithm 8.2. Algorithm that was used for automated creation of a new shapefile and attribute table and joining of Age_Profile scores to the IndicatorScores table**

```
import arcpy module
import env module from arcpy
set the workspace
specify input feature class
specify output location
specify output_feature_class
list fields to be retained as myfields = ["MP_NAME", "WARD_NO", "Res_Age"]
create an empty field mapping object
for field in myfields
        create individual field map
        add field map to field mapping object
        copy feature class using ["MP_NAME"] as matching field for rows  store in output_feature_class in output location
```

Thereafter, Algorithm 8.3 was used for joining of the remaining 3 indicator scores to the IndicatorsScores attribute table using village name as the linking field.

**Algorithm 8.3. Algorithm that was used for joining of the remaining 3 indicator scores to the IndicatorsScores table using MP_NAME as the linking field**

```
import arcpy module
import env module from arcpy
set the workspace environment
join IncomeScores_field to IndicatorScores table using JoinField_management operation
join LiteracyScores_field to IndicatorScores table using JoinField_management operation
join WaterScores_field to IndicatorScores table using JoinField_management operation
```

Since the highest attainable adaptive capacity score from the summation of the four highest indicator scores was 15 (Table 8-1), the computed adaptive capacity scores were automatically ranked into low-medium-high adaptive capacity as follows: Scores of 1-5 = LOW; Scores 6-10 = MEDIUM; Scores of 11-15 = HIGH using the following geoprocessing Python algorithm (Algorithm 8.4) that was run by executing the Python execfile command. A field for the ranked adaptive capacity scores was also automatically generated and added to the attribute table.

**Algorithm 8.4. Algorithm that was used for automated summation and ranking of the four indicator scores**

```
import arcpy, math modules
specify file location of adaptive_capacity attribute table
add fields = ["Water_score","Assigned_score","Literacy_score", "Res_Age"] into array
declare array for adaptive capacity_ score field as total
declare array for adaptive capacity field as rating
add total and rating fields to adaptive_capacity table
with arcpy UpdateCursor in adaptive_capacity table, put cursor in first row
    for row in cursor
        sum indicator scores to total
    if total <= 5 then
        rating = “LOW”
    elseif total >5 and total <=10 then
     rating = “MEDIUM”
    else rating = “HIGH”
    update rows
```

An adaptive capacity map was generated in the ArcMap 10.2 interactive environment based on the rankings. Alice, Middledrift, Fort Beaufort and Seymour were excluded from the assessment of resource-poor communities because their classification as urban areas in Nkonkobe Local Municipality disqualifies them from being considered resource-poor communities.

Villages with low adaptive capacity were extracted from the attribute table using a geoprocessing algorithm (Algorithm 8.5) and displayed both in the Python window and a shareable separately created text file (*.txt).

**Algorithm 8.5. Algorithm that was used to automatically generate list of villages with low adaptive capacity**

```
import arcpy, csv system modules
specify file location of IndicatorScores attribute table
add array fields = ["MP_NAME", "WARD_NO", "Adaptive_Capacity"]
specify output textfile location
set counter = 0
print heading
with output file open
        enable csv writer to output file
        write title specified to output file
        write fields and contents to output file
        with SearchCursor in first row and field in attribute table:
                for row in cursor:
                 if Adaptive capacity = "LOW" then
         add 1 to count
         write row to output file
        print count and row
```

## 8.4. Results

### 8.4.1. Spatial distributions of indicators used to assess adaptive capacity

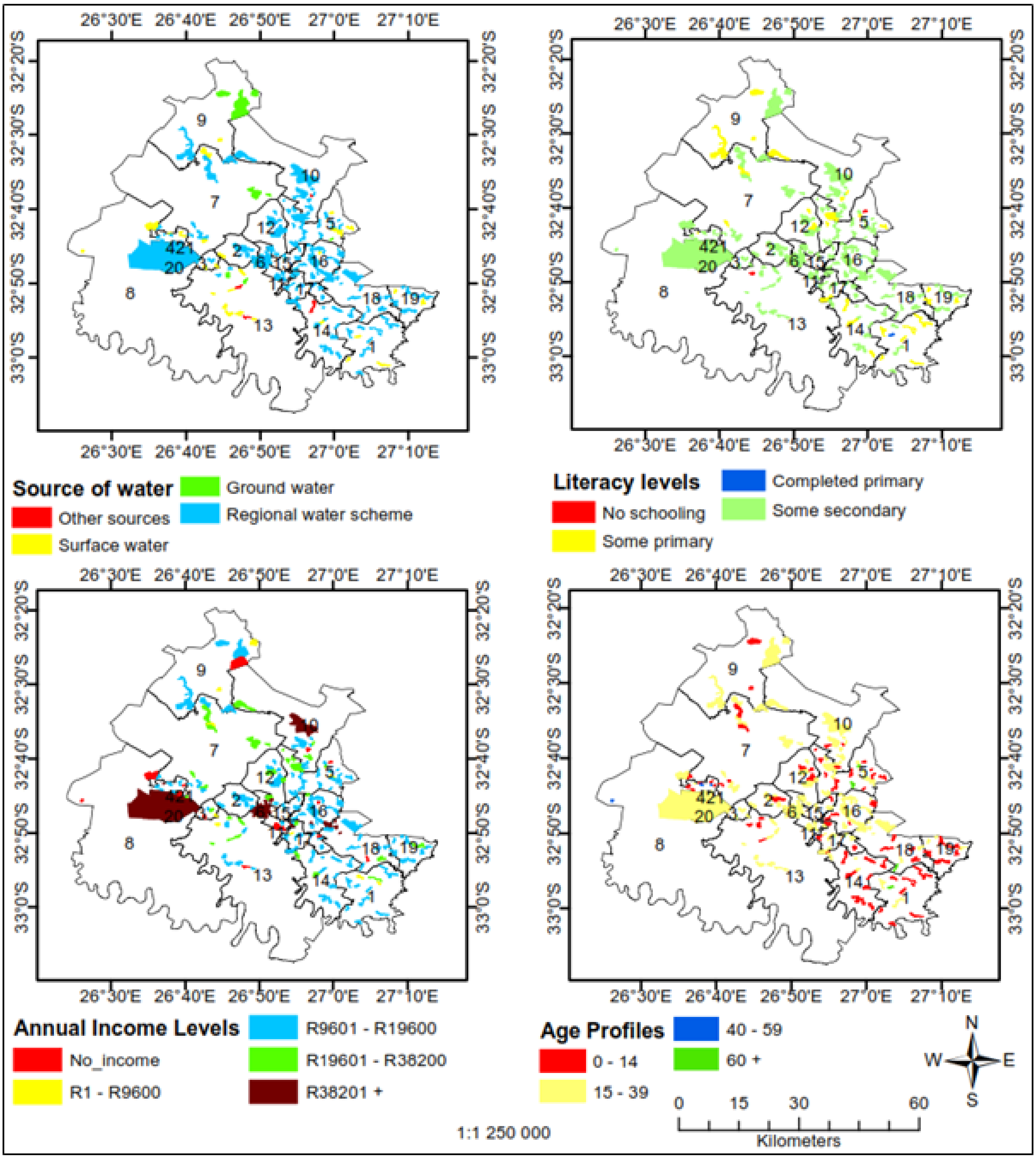

**Figure 8-2 Maps produced from indicators that were used to assess adaptive capacity**

Figure 8-2 shows maps that were produced from the four indicators that were used to assess adaptive capacity.

Figure 8-3 shows distributions of adaptive capacities that were obtained by mapping the ranked adaptive capacity scores that were calculated as explained in Table 8-2 in order to capture spatial variations in the abilities of individual villages to mitigate adverse effects of climate change. As explained earlier, major towns within the municipality (Fort Beaufort, Alice, Seymour and Middledrift) were excluded from the analysis because they have very few resource-poor communities.

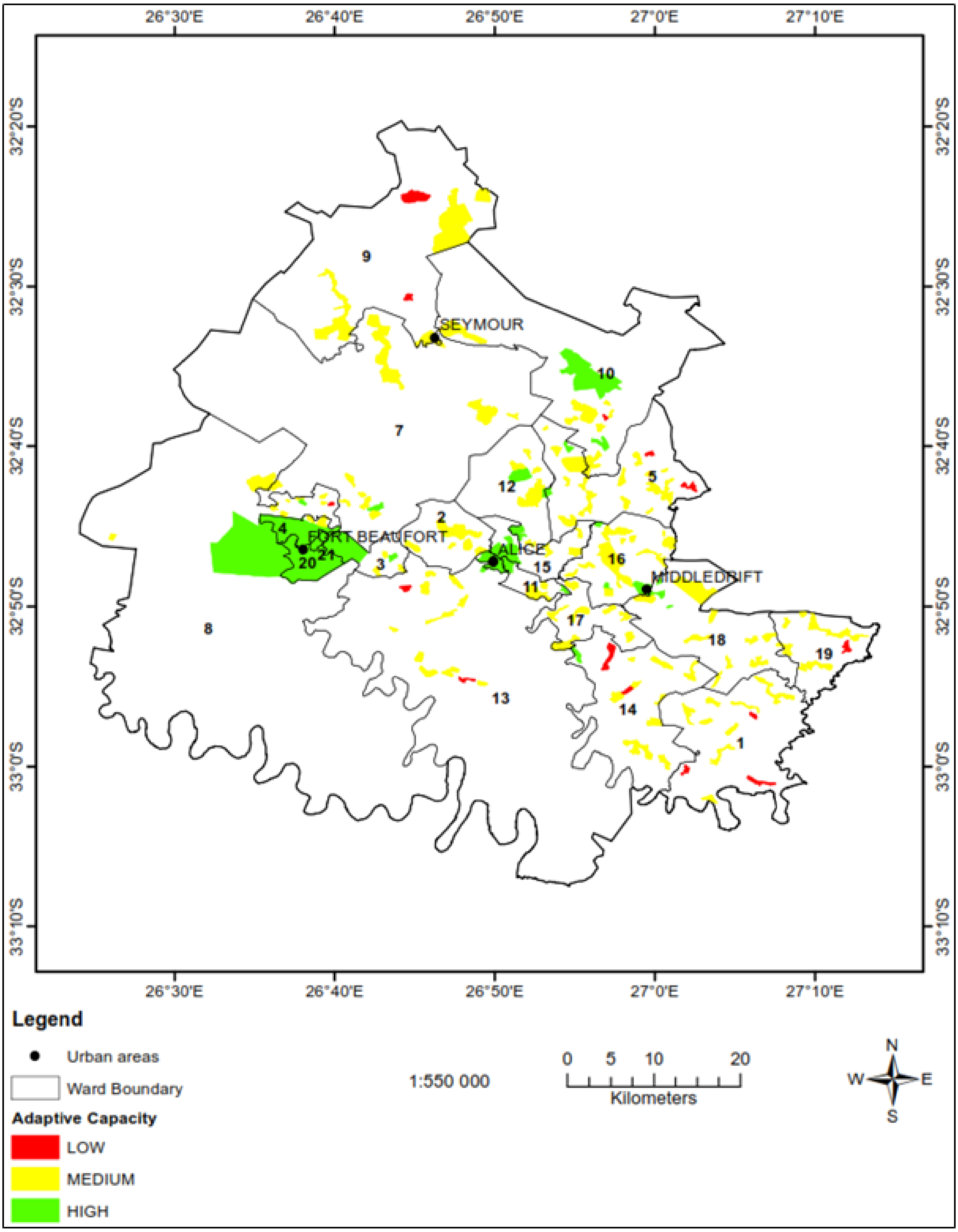

**Figure 8-3 Adaptive capacity map for Nkonkobe Local Municipality**

Table 8-3 shows the numbers villages by ward number that were identified as having low adaptive capacity.

**Table 8-3 Villages with low adaptive capacity in Nkonkobe Local Municipality**

| Village | Ward number |
|---|---|
| Qamdobowa | 1 |
| KwaKulile | 1 |
| Mdeni B | 5 |
| Ndlovura | 5 |
| Luzini | 8 |
| Wellsdale | 9 |
| Cairns | 9 |
| Mmangweni | 10 |
| Lebanon | 13 |
| Mpozisa | 13 |
| Mavuzamezini | 14 |
| eMgwanisheni | 14 |
| Qutubeni | 16 |
| Ntonga | 19 |

### 8.4.2. Discussion

The primary objective of the study was to provide a methodology that can used to objectively map adaptive capacity by using purposefully selected demographic data.

Access to water

The sources of water by source type in wards 1-21 (Figure 8-2) affect the resilience of communities by influencing the availability of water. Although names of villages are provided in this discussion, the names are not shown in the maps to avoid overcrowded labelling. Ward 13 is most underdeveloped in terms of water access due to limited availability of regional water schemes. Four villages (Mmangweni in ward 10, Allandale and Mpozisa in ward 13, and Mavuvumezini in ward 14) are severely water stressed and get water from non-natural other sources comprising water vendors and water tankers.

Literacy levels

Figure 8-2 indicates degree of disaster awareness to climate change issues within the households. Two villages (Mdeni B in ward 5 and Lebanon in ward 13) have the majority of people with no schooling and need the greatest attention concerning schooling. Although the majority of people in the municipality attended secondary school, awareness and practical implementation of climate change adaptation strategies requires additional traits like changes in individual attitudes and engagement, by being willing and able to connect with climate change issues since knowing alone without motivation and ability to take action is not enough (Lorenzoni et al., 2007). General lack of these traits especially ability to take action due to poverty related constraints implies that disaster awareness to climate change issues is modest if not marginal.

### Annual income levels

Figure 8-2 indicates villages with and without income with the latter being unlikely to have access to credit and poorly resilient to most shocks linked to climate change. Thirteen villages were revealed to be having majority of the people as having no income. Villages deemed as the poorest in the municipality are mostly in wards 6, 11, 15, 16 and 13 where the majority of people have the least income levels. These observations are again consistent with findings by Ziervogel et al. (2006) in the Ga-Selala village of Sekhukhune District Municipality where 58 (87.9%) out of 66 interviewees did not have any household income.

### Determination of resilience by age profiles

Resilience by age profiles (Figure 8-2) was based on the reasoning that children and old people have low resilience by virtue of being economically inactive compared to their economically active counterparts of intermediate age. A total of 70 villages were identified as having the majority of the people in the ages between 0-14 years with 4 villages having the majority of people above 60 years of age. These two age profiles have the lowest coping capacity by virtue of being economically inactive. The intermediate age group has high resilience due to the majority of people having employment and recognisable awareness of climate change-related issues. The wards with high numbers of villages with low resilience to climate change are wards 5, 14, 17, 18 and 19.

Basing on the indicators used, low adaptive capacities were established in 14 villages of wards 1, 3, 4 and 5 (Table 8-3) while medium level adaptive capacity was established in 146 villages from a total of 180 villages in the municipality. The results fit within the current planning and regulative framework in that they are providing information which will aid government in formulation of suitable climate adaptation policies. The need for information which aids in formulation of suitable climate adaptation policies at local municipal level has been reflected in the current Nkonkobe Local Municipality 2012-2017 Integrated Development Plan (IDP) under disaster management sector plan (Nkonkobe Local Municipality, 2012). The results can also be implemented as part of Nkonkobe Local Municipality's next IDP as a reflection of the previous adaptive capacity status. The presented results also support the improvement of service delivery by government to rural communities by providing information useful to municipal and government authorities on target communities with the least access to public services such as water and education.

When methodology is implemented in a wider context such as provincial level, the results are extremely helpful in the guiding formulation of provincial or national climate change response strategies and development action plans. Overall, results produced by using this methodology at any spatial extent assist to fulfil the main objective of the National Climate Change Response Plan White Paper (NCCRP) of South Africa (Department of Environmental Affairs, 2011) which is to boost climate change adaptation and effectively manage inevitable climate change impacts through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity using cost-effective and implementable methodologies. Government, research institutions and civil societies are therefore encouraged to use the methodology with more appropriate available datasets to map adaptive capacity in rural Eastern Cape and other rural areas of South Africa. For example, in Joe Gqabi District Municipality which has been declared a drought disaster area (De Kock, 2016), the methodology can be applied using available data from StatsSA to map adaptive capacity of communities to climate change to produce results which will aid in disaster management sector planning in the Joe Gqabi 2017-2018 IDP. However, in order to appropriately compare adaptive capacities for different locations, there has to be a consensus on the choice of indicators to be used for each of the locations.

## 8.5. Conclusion

The aim of the study was to provide a cost-effective, time saving, replicable and user friendly case study-based approach to assess the adaptive capacities of resource poor households by systematically identifying villages with low adaptive capacities to the adverse effects of climate change. This was accomplished by identifying a multi-tiered suit of specific resources that need to be provided to villages that are vulnerable to scarcities and shortages of specific resources. The assessment conducted was able to provide a comprehensive overview of the spatial distributions of coping capacities at a municipal level. However, in order to apply the methodology at larger scales, the datasets need to be also confined to large scale such provincial or national level. The major advantages of the methodology are that it is time-saving, cost-effective, user friendly replicable and capable of offering tremendous scope for aiding quick climate policy decision-making by facilitating verifiable and objective identification of villages with low adaptive capacities to climate change. The social implication of the presented methodology is in guiding public policy interventions aimed at reaching, protecting and uplifting socio-economically disadvantaged populations in both rural and urban settings.

The methodology presented in this paper is extremely helpful because timely identification of communities with low adaptive capacities aids the implementation of intervention strategies by enabling policy implementers to direct assistance to those who are unable to cope with adverse impacts of climate change. Policy implementers, that is, governments and stakeholders such as research institutions and civil societies interested in mitigating the adverse effects of climate change are therefore urged to seriously consider using this methodology in identifying resource poor communities deserving priority consideration when delivering support and assistance.

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# CHAPTER 9. INDIGENOUS KNOWLEDGE FORECASTING INDICATORS

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## 9.1. Eastern Cape: Rainfall forecasting indicators

### 9.1.1. Background

Climate change has played a significant role in shaping global agricultural production. Research on climate change has dominated private and public institutions globally. The public and private sectors' goal is to enhance agricultural production through a broad range of strategies that will support long term sustainability in the face of climate variability (Mtambanengwe et al., 2012). Agriculture is regarded as one of the most weather-dependent of human activities (Qian et al., 2014). consequently smallholder farmers tend to rely more on rainfall for their activities hence the need for more reliable climate and weather forecasts. Reliable weather and climate forecasts can assist farmers with the selection of appropriate tillage systems, crop varieties and planting dates (Kalanda-Joshua et al., 2011). Smallholder farmers are more vulnerable because of their dependence on the natural environment (Ncube et al., 2016; Parry et al., 2007; South African Weather Services, 2015).

Indigenous knowledge (IK) forecasting is one of the tools that many smallholder farmers have used and can still use for mitigation and adaptation to climate change. Local communities become uncertain when it comes to adaptation strategies because they are not part of the solutions. With the focus on indigenous knowledge there is a great chance that communities will adapt and utilize strategies that are put in place to address climate change and variability. Traditionally, farmers have also relied on indigenous knowledge to understand weather and climatic patterns (Kalanda-Joshua et al., 2011). Farmers were also able to determine timing of rainfall by making use of indigenous forecasting indicators. This allowed farmers to determine planting seasons (Mtambanengwe et al., 2012). IK forecasting methods are said to be driven by need, focus on locality and timing of rains (Speranza et al., 2010). Most of the IK forecasting methods used by farmers involve the observation of local indicators.

According to (Chang'a, Yanda, & Ngana, 2010) some of the indicators farmers use to observe and determine weather forecasts include the monitoring of the behaviour of animals, birds and the presence of insects and plants. Farmers also observe the intensity and direction of winds and interpret the movement of stars (Nganzi, 2015). Farmers use IK indicators at different times of the year, the indicators are usually observed after harvesting up until a new rainy season begins (Roncoli et al., 2009).

### 9.1.2. Methods

Study area

The study was conducted in four villages in Raymond Mhlaba Municipality (Balfour, Tyatyora, Kya Mnandi and Mbizana. Raymond Mhlaba Local Municipality administratively falls within the Amathole District Municipality. The climate of Raymond Mhlaba is semi-arid with annual rainfall not exceeding 600 mm. The rainfall season in the municipality is from September to April; with an estimated annual rainfall of 580 mm. This municipality was selected as the study area because farming is one of the main activities that locals rely on, with a majority of people being engaged in subsistence farming (Nkonkobe IDP, 2012). Moreover, many of the smallholder farmers in the study area still rely on indigenous knowledge.

Methods

Participants were purposively selected and their details were obtained from the Raymond Mhlaba farmers Association. Questionnaires were used to collect information on the indicators farmers observed for weather forecasting. The questionnaire contained three sections and combined structured and semi-structured questions. Open ended questions were included to allow participants to give detailed information. The topics covered in the questionnaires included the indicators farmers used and their meanings. Participants were of the ages between 22 and 84, since the elderly are more knowledgeable and have vast experience in using IK forecasting indicators.

### 9.1.3. Results

Farmers assess, predict and interpret weather conditions by observing their surrounding environment. They observe the behaviour of certain plants, animals and insects. They also observe the meteorological and astronomical indicators. The survey focused on rainfall indicators that farmers used in the study area. Results from the survey revealed that most farmers relied on indigenous knowledge forecasting. These indicators were useful in assisting farmers to make farm level decisions. Farm level decisions such as considering different crop varieties, in cases were indicators showed that there will be scarcity of rainfall high value crops such as maize were not planted. Through the observation of these indicators farmers were also able to make decisions on planting dates. Farmer’s especially the elderly who were more experienced with the use of forecasting indicators make use of multiple indicators to be certain of the forecasts. They observe multiple indicators such as animal and plant behaviour together with meteorological indicators. The reliability of indicators is mostly based on farmers’ perceptions and experiences. Farmers were asked to rate the reliability of the identified indicators by using ranking scores of 1 to 5. Most of the farmers ranked the identified indicators as reliable.

Some of the common indicators identified by farmers in the study area included singing birds which were a sign of a good rainfall season (Table 9-1). The most common bird they observed was Thekwana (lightning bird); this bird indicates the onset of the rainfall season. Another bird that farmers observed was Intsikizi (Ground Hornbill bird). this bird often appears after drought but its presence shows a good rainfall season. Farmers also reported that the presence of frogs and frogs making noise was an indication the coming of rains. The direction where wind is blowing from serves as an indication of whether to expect rain or not. Most farmers reported that the South Westerly winds usually indicates the onset of rainfall. Farmers indicated that they also observe plant phenology, the time when plants shade leaves is an indication of good rains.

**Table 9-1 Summary of indicators**

| Indicator | Description | Reliability |
|---|---|---|
| Rainy season | | |
| Warm temperatures | Indicate a high rainfall season | Reliable |
| Flowering of trees (*Umqonci*) | Indicate a start of a high rainfall season | Very reliable |
| Germination of new leaves | Indicate a good rainy season | Very reliable |
| Singing of certain birds (Thekwana – *lightning bird*)<br>Intsikizi (Ground Hornbill bird) | Indicate a start of a high rainfall season | Very reliable |
| Movement of certain birds | Indicate a good rainfall season | Reliable |
| Presence of certain frogs | Indicate the onset of rain | Reliable |
| Wind direction (South Westerly winds) | Indicate rainfall onset | Very reliable |

### 9.1.4. Conclusion

The study focused on documenting indigenous forecasting (IK) indicators that farmers observe daily. The presence or absence of climatic indicators assist farmer's make informed decisions about their activities. Through the use of IK indicators farmers are able to make decisions about planting and harvesting dates, crop varieties, irrigation patterns and many other decisions. Farmers use IK indicators at different times of the year, indicators are usually observed after harvesting up until a new rainy season begins. Input from smallholder farmers about their use of IK will help improve agricultural practices.

## 9.2. Limpopo: Approaches to forecasting rainfall

### 9.2.1. Background

Increasingly, people are relying on both print and electronic media for climate information that meteorologists observe and update regularly. Despite these advances and adoption of western science, some smallholder crop farmers continue to rely on indigenous techniques to forecast the nature of forthcoming seasons and adapt agricultural activities to climate variability. This study originated from the realisation that non-conventional crops such as Bambara nuts (*Vigna subterranea*) are becoming increasingly important in addressing food insecurity and nutrition in the smallholder farming sector. Despite this emerging trend, it is not clear how climate variability influences the crop's productivity. Nor are the indigenous approaches that farmers use to forecast rainfall and disseminate knowledge on this phenomenon clear. Thus, the current study was carried out to identify and document indigenous approaches that smallholder farmers use to forecast rainfall, temperature and adaptation practices relating to Bambara nuts.

### 9.2.2. Methods

The study was conducted in the villages of Xigalo and Ha-Lambani, both located in the Vhembe district. These villages were chosen to represent the Va-Tsonga and Vha-Venda communities with a considerable *V. subterranea* produced by smallholder farmers. Xigalo is located in Collins Chabane local municipality while Ha-Lambani is under Thulamela local municipality. The two areas are 71.5 km apart, with Xigalo situated in a lower lying area compared to Ha-Lambani village. Respondents were selected using a convenience and snowball sampling technique. Smallholder farmers and community elderly were selected through references from key informants and agricultural extension officers. Triangulation of participatory methods and techniques was used to collect qualitative data from respondents. These included key informant interviews, learning circles, photovoice, one-on-one interviews, and narrative inquiry. Ethical protocols were adhered to throughout the project process. Ethical approval was sought from University of Venda Research Ethics Committee. Respondents signed consent forms to show their willingness to participate voluntarily. Feedback of results was shared with some of the respondents in Ha-Lambani village.

### 9.2.3. Results

The results show that *V. subterranea* is customarily planted during the summer season, after early rainfall. Early rainfall is known locally to decompose dried corn stalks. Prior the ploughing period, rainfall is predicted based on observations of multiple indicators, such as human behaviour, plant phenology, animal phenology, bird phenology and insect phenology. The meanings derived from the indicators are locally based due to differences in culture and traditional beliefs. These traditional beliefs justify planting times and the conservation of V. subterranea. A close relationship between conservation of V. subterranea and adaptation strategies was said to exist. It was evident that most commonly used conservation strategies were rainmaking ceremonies, planting after the summer rains, hoeing weeds, soaking seeds before planting, hilling or earthing up around the base of the V. subterranea plant and storing the legumes in traditional vessels and sacks.

The conservation practices mentioned above are done and depend on the climate conditions, Smallholder farmers use rainfall signs to differentiate planting times and prepare for the ploughing season of *Vigna subterranea*. Results on the rainfall signs used by both communities to predict rainfall are shown below in Table 9-2, Table 9-3 and Table 9-4, respectively.

**Table 9-2 Rainfall signs used by Va-Tsonga people in Xigalo community**

| Rainfall signs | Phenological type | Description |
|---|---|---|
| a) Morning star (Mahlahle) | Celestial | The star sign appears in the morning during the early days before the rainfall |
| b) Evening star (Gongomelo) | Celestial | The star sign appears in the evening during the early days before rainfall |
| c) Cumulonimbus clouds (Mapapa) | Celestial | A sign of good rainfall |
| d) Wind gust (Xihuhuri) | Atmospheric | The wind gust disrupts the rainfall. It is associated with low chance of rainfall |
| e) Traditional copper bangle (Sindza) | Personal ornaments | A dark bracelet symbolizes the clouds while a brighter bracelet indicates a hot temperature and low chances of rainfall |
| f) Mopane worms (Matomani) | Insect | Mopane worms indicate a low chance of rainfall |

**Table 9-3 Rainfall signs used by Vha-Venda people in Lambani community**

| Rainfall signs | Phenological type | Description |
|---|---|---|
| a) Fluffy white cumulus<br>b) Clouds (Makole) | Celestial | Sign of good rainfall |
| c) Ground Hornbill (Dandila) | Birds | The sound of the bird is considered a warning about rainfall |
| d) Female calves | Domestic animals | The high birth rate of female calves is associated with rainfall |
| e) Human female babies | Human phenology | The high birth rate of human female babies is associated with rainfall |
| f) Levubu River sound | Natural stream water | The strange sound of the river is known to symbolize rainfall |

**Table 9-4 Common rainfall signs used in in Xigalo and Lambani communities**

| Rainfall signs | Phenological type | Description |
|---|---|---|
| a) Milky Way Galaxy | Celestial | A galaxy of six stars begins to appear in June, a sign of summer rainfall. It is also used a clock to differentiate planting times. |
| b) Red circle moon shape | Lunar | A red circle around the moon that represents water appears before rainfall |
| c) Swallows birds | Birds | The sound of the Swallows birds is used to warn of rainfall |
| d) Blooming trees | Flowering plant | Trees such as mangoes and lychees begin to bloom in September as a sign of rain |

### 9.2.4. Conclusion

Most common rainfall signs are derived from phenological types such as celestial, domestic animals, insect, flowering plant, birds and lunar. Significant differences: 18 signs of rainfall were revealed, including 7 among the Tsonga people and 6 among the Venda people. Similarities: Both communities had 4 common rainfall signs used to predict forthcoming seasons. There is a need to improve the use of seasonal forecasts in smallholder farming practices. Taking the results of the study into account, incipient policy interventions should consider the adoption of supplementary techniques in order to understand the need to improve seasonal forecasts in the smallholder farming sector. In addition, the results can be used to inform policy interventions on climate action, which is the 13th of the 17 SDGs, to promote community resilience to climate change.

The behaviour of birds, insects, domestic animals are used to predict rainfall in other countries (Changa et al., 2010; Mahoo et al., 2015; Gwenzi et al., 2016; Kagunyu et al., 2016; Okonya et al., 2017; Fitchett & Ebhuoma, 2018). The use of signs such as Mopane worms, traditional bangle, and human perspiration differs from that documented in the broader literature. Smallholder farmers depend mainly on celestial and lunar signs to forecast rainfall that disappears over time. This calls for alternative approaches that can be used to forecast rainfall to combat the negative effects of climate variability. There is need to conserve the environment and nurture phenological signs for future use.

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# CHAPTER 10. ECOLOGICAL INTENSIFICATION APPLICATION

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## 10.1. Background

During the past two decades, Sub Saharan Africa (SSA) has been at the centre of debates on how to revitalise smallholder agriculture. This has led to a major transformation of agricultural food production (Sanchez, 2015). Most countries, especially South Africa, cropping systems now consist of improved varieties through crop specialization and a lot of application of external inputs such as fertilisers and pesticides (Malézieux, 2012). However, productivity and stability has remained a major concern for these conventional agricultural systems, especially in Africa, where the use of chemicals and fertilizers is being promoted and mainstreamed into food production systems. Moreover, the conventional intensification model based on high input use of chemicals and fertilizers has showed its limit not only in the developed world but also in Africa with consequences such as social disparities and environmental concerns such as loss of biodiversity, loss of local cultivars, disease and pest resistance, deforestation, reduction in water quality, and poisoning due to misuse of chemical pesticides. In addition, the high yielding varieties have contributed to the overlook on local landraces and prompted the loss of genetic diversity, and local practices and knowledge associated to locally adapted cultivars.

South Africa is food secure as a nation, but most rural households are food insecure nation (De Cock et al., 2013; Musemwa et al., 2015). This is because South Africa has a dual agricultural economy, comprising well-developed commercial farms and many smallholder subsistence farms (Thamaga-Chitja & Morojele, 2014). Commercial farms are mainly large-scale, capital intensive and export oriented, accounting for around 90% of the total agricultural production and covering about 86% of the country's agricultural land. Smallholder subsistence agriculture is still largely confined to the former homelands. Much of this land is severely overcrowded, with average land holdings of 0.5 to 1.5 ha per household. Agricultural production consists mainly of staple foods for household consumption. Relatively few products find their way into local or other markets. Production may take place in gardens, demarcated fields or on open rangeland. The smallholder subsistence farms, in contrast, rely on traditional methods of production (Calzadilla et al., 2014). It is highly differentiated by race, class and gender, with large numbers of very poor black women producing purely for household consumption and a small "élite", mainly men, producing on a much greater scale. South Africa is heavily reliant on its conventionally intensive large-scale commercial mono-crop farming systems for food production. Hence it has become one of the four largest users of pesticides and fertilisers in Sub-Saharan Africa (SSA) (Michael et al., 2014). Smallholder agriculture in South Africa is less developed and resourced. It is mainly occupied by rural households, which are poor, less educated and have limited resources and thus practising low input agriculture compared to their commercial counterparts (Thamaga-Chitja & Morojele, 2014). However, the lack of agricultural sustainability in both the commercial and smallholder sector is increasingly becoming worrisome (Van der Laan et al., 2017). South Africa therefore requires a more sustainable approach to agricultural intensification, for food production as or both current and future generations are at risk as most rural households are food insecure.

Most South African smallholder farmers reside in areas with inferior agricultural potential, practising rain fed agriculture and heavily rely on ecosystem services for better livelihoods. Constraints and challenges faced by smallholder farmers in the rural areas of South Africa that contribute significantly to food insecurity include those linked to poor soil fertility and degradation (Bloem et al., 2009, Materechera, 2010, Sithole et al., 2016, Muzangwa et al., 2017). soil and water challenges (Mwenge Kahinda & Taigbenu, 2011, Botha, et al., 2012, Zerihun et al., 2014, Botha et al., 2015, Moswetsi et al., 2017) and pest and diseases especially in vegetable production (Betek, & Jumbam, 2015, Phophi & Mafongoya, 2017). Food insecurity is further exacerbated by the seasonal and climate variability and change impacts experienced in these rural areas of South Africa (Calzadilla et al., 2014; Shisanya & Mafongoya, 2016). The scarcity of farmland in the former homelands for agricultural expansion, the high levels of environmental degradation and increased vulnerability of smallholder farmers to climate change and variability urge to seek new pathways to sustainably improve and intensify food production systems. The intensification options need to be evaluated and appropriate choices made based on site-specific biophysical, economic, and social conditions. Mis-managed agricultural intensification could com-promise food production, food safety, food security and ultimately increase unemployment and environmental degradation. This situation calls for the development of appropriate methods of agricultural intensification for food production and conservation of natural resources such as land, water, and forests for future generations. For sustainable agricultural production, a change in practices as well as change in paradigms is necessary. For instance, it has become crucial to increase the production while reducing environmental damages on natural resources. The change in paradigm will consist in rectifying the current conventional intensification model. Attempts to rectify the negative effects of the current conventional model of agricultural intensification, two models namely, sustainable and ecological intensification have gained momentum scientific and development world.

There are many ecological intensification options being promoted in smallholder agriculture in SSA. However the interaction between ecological intensification to avoid environmental degradation, and the same approach to adapt to climate change has not been much explored especially in smallholder agriculture in SSA and especially in South Africa (Webb et al., 2014). Here we examine the benefits of using ecological farming practices, as well as their potential and limitations to mitigate the above four major constraints faced by smallholder farmers in South Africa This paper aims to

(i) Identify and explore options for ecological intensification to support smallholder farmers in achieving food security, reducing environmental degradation, build resilience and adapt to climate change in South Africa.
(ii) Understand the socioeconomic and biophysical constraints affecting and enablers for improved uptake of the options in smallholder agriculture.
(iii) Understand what can be done to improve the future uptake of the options in smallholder.

## 10.2. Materials and methods

### 10.2.1. Study region

This study was conducted Amathole District, Raymond Mahlaba Municipality in the Eastern Cape province and Vhembe District, Thulamela Municipality in Limpopo province of South Africa. These two provinces have the most smallholder farmers in South Africa where 52% and 60% of the households in Eastern Cape and Limpopo provinces are poor respectively. Furthermore, the provinces are mainly rural and highly dependent on rain fed agriculture. Most of these smallholder farming households experience severe food insecurity.

### 10.2.2. Data collection approach

The data collection process involved two stages

Stage 1: Identifying and grouping of specific ecological intensification options,
Stage 2: Focus group discussions with local experts and farmers on the uptake of the ecological intensification options.

### 10.2.3. Diagnosis and identification of potential ecological intensification options

A wide range of technological options exist to helps solve the constraints and challenges, reduce vulnerability and increase resilience of smallholder farmers. In this study, an intense literature review to identify ecological intensification options common in South African smallholder agriculture was carried out. Furthermore, a literature search on potential ecological intensification options and practices in smallholder agriculture in South Africa was done. A long list of specific options/ practices was drawn up. The 17 options/ practices listed below were then categorised as follows: (i) ecologically-based soil and water conservation strategies (ii) ecologically-based soil fertility enhancing and management strategies (iii) ecologically-based pest suppression strategies and (iv) ecologically-based seasonal variability and climate change adaptation strategies. Although some options/ practices tended to overlap in the four categories because they can serve as options/ practices in those categories. While this paper does not purport to be exhaustive in documenting every ecological intensification options that can be practiced in the smallholder agricultural sector in South Africa, it attempts to provide an overview of common practices in general use smallholder agriculture in South Africa. The options/practices for ecological intensification which are common in the two study areas are outlined in detail from the literature sources cited below.

**Table 10-1 ecological intensification common practicesd and literature sourced**

| Option to use | Source |
|---|---|
| Crop rotations | Ndwandwe & Mudhara, 2008; Thierfelder et al., 2013 |
| Trap crops | Finch & Collier, 2012; Phophi & Mafongoya, 2017 |
| Use of biological control agents | Grzywacz et al., 2014 |
| Plant extracts | Grzywacz et al., 2014 |
| Field sanitation Intercropping | Bloem et al., 2009, Rusinamhodzi et al., 2012, Masvaya et al., 2017 |
| Cover cropping | Murungu et al., 2011; Dube et al., 2012 |
| Animal manure | Mkhabela, 2017; Materechera, 2010 |
| Conservation Agriculture | Sithole et al., 2016; Muzangwa et al., 2017 |
| Legumes | Gwata & Mzezewa, 2013 |
| Agroforestry | Kelso & Jacobson, 2011; Zerihun et al., 2014 |
| Roof top water harvesting | Mwenge Kahinda & Taigbenu, 2011, Denison & Wotshela, 2012 |
| In situ rainwater harvesting | Biazin et al., 2012 |
| Mulching | Botha et al., 2012 |
| Polycultures | Hitayezu et al., 2016 |
| Varietal mixtures | Mnkeni & Mutengwa, 2014 |

### 10.2.4. Focus group discussions to explore on the uptake of the options

The focus group discussions were conducted in two steps. First meetings were held with knowledgeable key informants mainly agricultural extension officials to supply missing information, eliminate bias and validate our literature review findings to gain a general depiction of the validity and relevance of the 17 ecological intensification options in the two Municipalities namely Raymond Mahlaba and Thulamela in the Eastern Cape and Limpopo provinces respectively. In both municipalities we contacted four agricultural extension officers from the Eastern Cape Department of Rural Development and Agrarian Reform (DRDAR) and another four agricultural extension officials from the Limpopo Department of Agriculture (LDA). We gathered useful information on ecological intensification options and practices being promoted, government initiatives and efforts in implementing ecological intensification options. The discussions with the agricultural extension officials made clear that several relevant ecological intensification options in which they are directly or indirectly involved were taking place. These discussions were instrumental in enabling the facilitation of the focus group discussions by the agricultural extension workers in the study areas. The meeting further came up with a description of how the practices or options could be defined and described to farmers for their better understanding (Chapter 7). A questionnaire to guide during the focus group discussion with farmers was then created which asked farmers the following questions.

The second phase involved focused group discussions with smallholder farmers in the study areas. Using a snowball sampling approach extension officers identified 29 and 57 farmers from Raymond Mahlaba and Thulamela Municipality respectively to participate in the study. Agricultural extension officials in study areas facilitated the focused group discussions. The agricultural extension officials translated the questions into the local languages namely Xhosa and Venda in the Eastern Cape and Limpopo provinces respectively. The discussions sought to describe in detail the practical aspects of the practices/ options and to identify how these options/ practices contributed to their farming efforts in addressing the four main challenges namely (i) soil fertility (ii) pest and disease (iii) soil and water and (iv) climate related constraints.

In Raymond Mahlaba Municipality five focused group discussions in five villages namely Amathola basin, Mazotsheni, Tyali, Krwakrwa and Adelaide were held. In Amathola basin and Mazotsheni villages the farmers practice agroecology, receive training and technical support in agroecology from Oxfam South Africa. In Adelaide and Tyali, focused group discussions were done with farmers specialising in the production of horticultural crops. In Krwakrwa village focused group discussions were done with farmers who specialise in growing cereals and legumes and rearing of livestock. In Thulamela Municipality farmers which belonged to the three farm classes identified in an earlier study by Rusere et al. (2017) participated in the study. Three focused group discussions with cereal- and livestock-based, horticultura- based and off-farm income dependent farmers were held in three villages namely, Saselamani, Mhinga, Ha Lambani respectively.

## 10.3. Results

During the discussions smallholder farmers in the two municipalities noted that the above ecological intensification options and practices were consistent with their farming activities and efforts. The technologies are not ranked or ordered in terms of their importance are but are presented to explain and highlight their availability and their associated impact on the farming efforts of smallholder farmers in South Africa. To explore the context within which the above technologies are used, their strength and weaknesses/ limitations in their farming efforts and farmer perceptions on what can be done to improve uptake and out scaling of these options in smallholder farming systems. The themes are presented below with summarised responses from smallholder farmers.

**Table 10-2 Ecologically-based pest suppression strategies in different farm types in smallholder agriculture**

| Farm type | Common EI options for pest suppression | Strength | Weakness/ limitations | What can be done to improve them |
|---|---|---|---|---|
| Cereal and livestock-based farm | • field sanitation<br>• land fallowing | • Breaks pest & disease life cycles<br>• Suppress weeds<br>• Slows down epidemic rates<br>• Reduces inoculum levels | • lack of technical support<br>• labour intensive | • technical & extension support<br>• staggered planting |
| Horticultural-based farms | • intercrops<br>• polycultures<br>• varietal mixtures<br>• crop rotations<br>• plant extracts<br>• field sanitation | • breaks pest and disease life cycles<br>• Suppress weeds<br>• Slows down epidemic rates<br>• Reduces inoculum levels<br>• locally available<br>• cheap | • land limitations<br>• unaware of crops to use<br>• lack of technical support<br>• competition for resources<br>• labour intensive | • Identifying ideal crops<br>• technical and extension support<br>• staggered planting<br>• training and awareness |
| Off-farm income-based farms | • field sanitation<br>• land fallowing | • breaks pest & disease life cycles<br>• Suppress weeds<br>• Slows down epidemic rates<br>• Reduces inoculum levels | • unaware of crops to use<br>• lack of technical support<br>• competition for resources<br>• labour intensive | • Training and awareness<br>• Technical and extension support |

**Table 10-3 Ecologically-based soil fertility strategies in different farm types in smallholder agriculture**

| Farm type | Common EI options for soil fertility management | Strength | Weakness/ limitations | What can be done to improve them |
|---|---|---|---|---|
| Cereal and livestock-based farm | • intercrops with legumes<br>• rotations with legumes<br>• application of manure<br>• Conservation agriculture (CA)<br>• land fallowing | • legumes fix nitrogen<br>• Increase soil organic matter<br>• cheap & locally available<br>• increased soil biological activity | • Unaware of crops to use<br>• Competition for resources<br>• Difficult to transport manure to the field<br>• Insufficient quantities of manure<br>• Labour intensive<br>• Weeds<br>• competing uses for organic resources | • Identifying ideal crops<br>• technical & extension support<br>• staggered planting<br>• advice on manure handling and application rates |
| Horticultural-based farms | • compost<br>• manure<br>• crop rotations<br>• intercropping | • increases soil organic matter<br>• increases soil biological activity<br>• locally available<br>• cheap | • Unaware of crops to use<br>• Competition for resources<br>• Insufficient quantities of organic manure<br>• Labour intensive<br>• Weeds<br>• land limitations | • Identifying ideal crops<br>• technical & extension support<br>• staggered planting<br>• training and awareness<br>• advice on manure handling and application rates |
| Off-farm income-based farms | • compost<br>• manure<br>• crop rotations with legumes<br>• intercropping with legumes | • increases soil organic matter<br>• increases soil biological activity<br>• locally available<br>• cheap | • Insufficient quantities of organic manures<br>• labour intensive<br>• Weeds | • Training and awareness<br>• Technical and extension support |

**Table 10-4 Ecologically-based soil and water conservation strategies**

| Farm type | Common EI options for soil and water conservation | Strength | Weakness/ limitations | What can be done to improve them |
|---|---|---|---|---|
| Cereal and livestock-based farm | • intercropping<br>• application of animal manure<br>• Conservation agriculture (CA)<br>• land fallowing<br>• mulching<br>• rooftop rain water harvesting<br>• In situ rain water harvesting | • reduced runoff<br>• manure is locally available & cheap<br>• increased rain infiltration<br>• reduced water evaporation<br>• mulch locally available | • Unaware of crops to use<br>• Competition for resources<br>• Difficult to transport manure to the field<br>• Insufficient quantities of manure<br>• Increased incidences of termites during mulching<br>• trade-offs for mulch use<br>• CA and in-situ rainwater harvesting labour intensive<br>• Weeds | • Identifying ideal crops to use as intercrops and as live mulch<br>• technical and extension support<br>• staggered planting<br>• advice on manure handling & application rates |
| Horticultural-based farms | • application of animal manure<br>• application of compost<br>• mulching<br>• in situ water harvesting<br>• roof top water harvesting | • reduced runoff<br>• increased infiltration<br>• reduced evaporation<br>• grass used for mulching locally available<br>• manure locally available & cheap | • Insufficient quantities of organic manure<br>• Increased incidences of termites during mulching<br>• in situ water harvesting is labour intensive<br>• Weeds<br>• land limitations | •<br>• technical and extension support<br>• staggered planting<br>• training and awareness<br>• advice on manure handling & application rates |
| Off-farm income-based farms | • application of manure<br>• intercropping<br>• rooftop water harvesting | • reduced runoff<br>• increased infiltration<br>• manure locally available and cheap<br>• water harvested can be used for both domestic and agricultural purposes | • Insufficient quantities of organic manures<br>• labour intensive | • Training and awareness<br>• Technical and extension support |

**Table 10-5 Ecologically-based climate change adaptation strategies**

| Farm type | Common EI options for soil and water conservation | Strength | Weakness/ limitations | What can be done to improve them |
|---|---|---|---|---|
| Cereal and livestock-based farm | • varietal mixtures<br>• Polycultures<br>• Application of animal manure<br>• Conservation agriculture (CA)<br>• mulching<br>• rooftop rain water harvesting<br>• In situ rain water harvesting<br>• Agroforestry (AF) | • enhance harvest security<br>• maximisation of land<br>• reduce vulnerability<br>• increased biodiversity<br>• increased resource efficiency<br>• increased infiltration | • Unaware of ideal varieties & crops to use<br>• Competition for resources<br>• quantities & handling challenges of manure<br>• Mulching applicable on a small scale<br>• Increased incidences of termites during mulching<br>• trade-offs for mulch use<br>• labour intensive<br>• lack of AF germplasm | • Awareness<br>• Identifying ideal varieties and crops<br>• technical & extension support<br>• staggered planting<br>• advice on manure handling and application rates<br>• Farmer training<br>• Avail AF germplasm |
| Horticultural-based farms | • Varietal mixtures<br>• Polycultures<br>• application of organic manures<br>• mulching<br>• in situ water harvesting<br>• roof top water harvesting<br>• agroforestry | • enhance harvest security<br>• maximisation of land<br>• reduce vulnerability<br>• increased biodiversity<br>• increased resource efficiency<br>• Increased infiltration<br>• build up termites when mulching | • Unaware of ideal varieties & crops to use<br>• Competition for resources<br>• quantities and handling challenges of manure<br>• Mulching applicable on a small scale<br>• Increased incidences of termites during mulching<br>• land limitations | •<br>• technical and extension support<br>• staggered planting<br>• training and awareness<br>• advice on manure handling & application rates |
| Off-farm income-based farms | • Polycultures<br>• application of organic manure<br>• mulching<br>• roof top water harvesting<br>• Agroforestry | • enhance harvest security<br>• maximisation of land<br>• reduce vulnerability<br>• increased biodiversity<br>• increased resource efficiency<br>• Increased infiltration | • Insufficient quantities of organic manures<br>• labour intensive<br>• Increased incidences of termites during mulching | • Training and awareness<br>• Technical and extension support |

**Table 10-6 Ecologically-based pest suppression strategies in smallholder agriculture, Raymond Mhlaba Municipality, Eastern Cape**

| Farm type | Common EI options for pest suppression | Strength | Weakness/ limitations | What can be done to improve them |
|---|---|---|---|---|
| Cereal and livestock | • field sanitation<br>• land fallowing | • Breaks pest and disease life cycles<br>• Suppress weeds<br>• Slows down epidemic rates<br>• Reduces inoculum levels | • lack of technical support<br>• competition for resources<br>• labour intensive | • Identifying ideal crops<br>• technical and extension support<br>• staggered planting |
| Horticultural-based farms | • intercrops<br>• polycultures<br>• varietal mixtures<br>• crop rotations<br>• plant extracts<br>• field sanitation | • breaks pest and disease life cycles<br>• Suppress weeds<br>• Slows down epidemic rates<br>• Reduces inoculum levels<br>• locally available<br>• cheap | • land limitations<br>• unaware of crops to use<br>• lack of technical support<br>• competition for resources<br>• labour intensive | • Identifying ideal crops<br>• technical and extension support<br>• staggered planting<br>• training and awareness |
| Agro-ecology | • intercrops<br>• polycultures<br>• crop rotations<br>• varietal mixtures<br>• Plant extracts<br>• use of biological control agents, e.g. ladybirds<br>• field sanitation<br>• land fallowing | • breaks1 pest and disease life cycles<br>• Suppress weeds<br>• Slows down epidemic rates<br>• Reduces inoculum levels | • unaware of crops to use<br>• lack of technical support<br>• competition for resources<br>• labour intensive | • Training and awareness<br>• Technical and extension support |

**Table 10-7 Ecologically-based soil fertility strategies**

| Farm type | Common EI options for soil fertility management | Strength | Weakness/ limitations | What can be done to improve them |
|---|---|---|---|---|
| Cereal and livestock-based farm | • intercrops with legumes<br>• rotations with legumes<br>• application of manure<br>• cover cropping<br>• Conservation agriculture (CA)<br>• land fallowing | • legumes fix nitrogen<br>• Increase soil organic matter<br>• cheap and locally available<br>• increased soil biological activity | • high seed cost<br>• Unaware of crops to use<br>• Competition for resources<br>• Difficult to transport<br>• manure to the field<br>• Insufficient quantities of manure<br>• Labour intensive<br>• Weeds<br>• competing uses for organic resources | • Identifying ideal crops<br>• technical and extension support<br>• staggered planting<br>• advice on manure handling and application rates |
| Horticultural-based farms | • compost<br>• manure<br>• crop rotations<br>• intercropping | • increases soil organic matter<br>• increases soil biological activity<br>• locally available<br>• cheap | • Unaware of crops to use<br>• Competition for resources<br>• Insufficient quantities of organic manure<br>• Labour intensive<br>• Weeds<br>• land limitations | • Identifying ideal crops<br>• technical and extension support<br>• staggered planting<br>• training and awareness<br>• advice on manure handling and application rates |
| Agro-ecology | • intercrops with legumes<br>• rotations with legumes<br>• application of manure<br>• green manuring<br>• cover cropping<br>• Conservation agriculture (CA)<br>• land fallowing | • increases soil organic matter<br>• increases soil biological activity<br>• locally available<br>• cheap | • Insufficient quantities of organic manures labour intensive<br>• Weeds | • Training and awareness<br>• Technical and extension support<br>• Avail low cost germplasm |

### .Table 10-8 Ecologically-based soil and water conservation strategies

| Farm type | Common EI options for soil and water conservation | Strength | Weakness/ limitations | What can be done to improve them |
|---|---|---|---|---|
| Cereal and livestock -based farm | • intercropping<br>• application of animal manure<br>• Conservation agriculture (CA)<br>• land fallowing<br>• mulching<br>• rooftop rain water harvesting<br>• In situ rain water harvesting<br>• Gelesha | • reduced runoff<br>• manure is locally available & cheap<br>• increased rain infiltration<br>• reduced water evaporation<br>• mulch locally available | • Unaware of crops to use<br>• Competition for resources<br>• Difficult to transport manure to the field<br>• Insufficient quantities of manure<br>• Increased incidences of termites during mulching<br>• trade-offs for mulch use<br>• CA and in situ rainwater harvesting labour intensive<br>• Weeds | • Identifying ideal crops to use as intercrops and as live mulch<br>• technical and extension support<br>• staggered planting<br>• advice on manure handling and application rates |
| Horticultural-based farms | • application of animal manure<br>• application of compost<br>• mulching<br>• in situ water harvesting<br>• roof top water harvesting | • reduced runoff<br>• increased infiltration<br>• reduced evaporation<br>• grass used for mulching locally available<br>• manure locally available and cheap | • Insufficient quantities of organic manure<br>• Increased incidences of termites during mulching<br>• in situ water harvesting is labour intensive<br>• Weeds<br>• land limitations | • technical and extension support<br>• staggered planting<br>• training and awareness<br>• advice on manure handling and application rates |
| Agro-ecology | • application of manure<br>• intercropping<br>• rooftop water harvesting<br>• Gelesha<br>• conservation agriculture<br>• mulching<br>• rooftop rainwater harvesting<br>• In situ rain water harvesting | • reduced runoff<br>• increased infiltration<br>• manure locally available and cheap<br>• water harvested can be used for both domestic and agricultural purposes | • Insufficient quantities of organic manures<br>• labour intensive<br>• high seed cost | • Training and awareness<br>• Technical and extension support |

**Table 10-9 Ecologically-based climate change adaptation strategies**

| Farm type | Common EI options for soil and water conservation | Strength | Weakness/ limitations | What can be done to improve them |
|---|---|---|---|---|
| Cereal & livestock -based farm | • varietal mixtures<br>• Polycultures<br>• Application of animal manure<br>• Conservation agriculture (CA)<br>• mulching<br>• rooftop rainwater harvesting<br>• In situ rain water harvesting<br>• Gelesha<br>• Agroforestry (AF) | • enhance harvest security<br>• maximisation of land<br>• reduce vulnerability<br>• increased biodiversity<br>• increased resource efficiency<br>• increased infiltration | • Unaware of ideal varieties and crops to use<br>• Competition for resources<br>• quantities and handling challenges of manure<br>• Mulching applicable on a small scale<br>• Increased incidences of termites during mulching<br>• trade-offs for mulch use<br>• labour intensive<br>• lack of AF germplasm | • Awareness<br>• Identifying ideal varieties and crops<br>• technical and extension support<br>• staggered planting<br>• advice on manure handling and application rates<br>• Farmer training<br>• Avail AF germplasm |
| Horticultural-based farms | • Varietal mixtures<br>• Polycultures<br>• application of organic manures<br>• mulching<br>• in situ water harvesting<br>• roof top water harvesting<br>• Agroforestry | • enhance harvest security<br>• maximisation of land<br>• reduce vulnerability<br>• increased biodiversity<br>• increased resource efficiency<br>• Increased infiltration | • Unaware of ideal varieties and crops to use<br>• Competition for resources<br>• quantities and handling challenges of manure<br>• Mulching applicable on a small scale<br>• Increased incidences of termites during mulching<br>• land limitations | •<br>• technical and extension support<br>• staggered planting<br>• training and awareness<br>• advice on manure handling and application rates |
| Agro-ecology | • varietal mixtures<br>• Polycultures<br>• application of organic manure<br>• mulching<br>• roof top water harvesting<br>• in situ rainwater harvesting<br>• Agroforestry<br>• Gelesha | • enhance harvest security<br>• maximisation of land<br>• reduce vulnerability<br>• increased biodiversity<br>• increased resource efficiency<br>• reduced evaporation Increased infiltration | • poor market access<br>• lack of locally adapted germplasm<br>• Insufficient quantities of organic manures<br>• labour intensive<br>• Increased incidences of termites during mulching<br>• competing uses for organic resources | • Training and awareness<br>• Technical and extension support<br>• Avail low cost locally adapted germplasm<br>• Avail AF germplasm |

## 10.4. Discussion

### 10.4.1. The strength of ecological intensification options in different farm types in smallholder agriculture

We explored various possible options for ecological intensification in different smallholder farm types in two rural provinces of South Africa. Our results suggest that farmers are often doing the best they can with available resources, and within the confines of their current knowledge to ecologically intensify their cropping systems. The farm typologies in Limpopo and Eastern Cape revealed crop sanitation to be an important strategy for crop protection among all type of farmers. Farmers involved in the production of cereal crops and legumes did not consider incidences of pest and diseases as a major challenge in their farming efforts but in their small home gardens and mainly relied on land fallowing and crop sanitation practices such as roguing reduce the inoculum levels, minimise the spread of the pest and pathogens and eliminate potential host of the pest and pathogens. Thus, reducing the high costs of production incurred through application of external inputs. However, horticultural-based farmers who are heavily affected by incidences of pest and diseases noted the importance of crop diversification options for crop protection. Crop diversification options such intercropping, polycultures and crop rotations helps break pest, disease, and weed cycles in horticultural cropping systems. Use of plant extracts to control crop insect pest is mainly done on small scale by horticultural and agroecology farmers but not common with the other type of farmers. Use of biological control agents was generally not common in smallholder farmers as most farmers were unaware of the methods except agroecology farmers in Raymond Mahlaba Municipality in the Eastern Cape who noted that they were aware of the potential of lady birds in controlling insects but had never being exposed to such biological control methods.

In cereal-based farming systems were nutrient limitation is major challenge, inclusion of legumes in cropping systems through crop diversification options such intercropping, rotations and polycultures helps to fix nitrogen and improve soil fertility to enhance crop productivity and smallholder incomes, while reducing the high costs of production incurred through exogenous application of inorganic fertilizers. In the Eastern Cape where cover cropping with grazing vetch and oats is common, subsequent cereal crops will not only give higher grain yields for human consumption but also higher stover yields that can be used for livestock feed. Furthermore, diversified cropping systems in smallholder farming systems help to improve soil structure and soil biological diversity thus enhancing nutrient recycling. Another option for ecological intensification that is widely used by all smallholder farmers in all farm types in South Africa to counter nutrient limitations in soils is application of organic resources such animal manure, crop residue and compost. Farmers benefit from incorporating organic resources into their farming systems as this option improves crop productivity in both short and long term. Thus, this option is sustainable and locally adapted for smallholder farmers in South Africa. Regarding Conservation Agriculture (CA) cereal- and livestock-based and agroecology famers revealed that CA had potential to improve soil fertility through inclusion of legumes which fix nitrogen and enhancing microbial activity and nutrient recycling through residue retention. However, uptake of CA among the smallholder farmers was limited.

Insights from the discussions revealed that implementing ecologically-based rain water harvesting systems such as roof top water harvesting, in situ water harvesting, conservation agriculture and *Gelesha* reduces the risks of production failure through dry spell and drought proofing. A common water harvesting approach among the farmers was the roof top water harvesting system which enabled them to capture rain and runoff for both domestic and agricultural purposes in their homestead gardens. Cereal- and livestock-based, and agroecology farmers revealed that in situ rainwater harvesting and components for CA, e.g. through minimum soil disturbance and use of organic resources such as animal manure and crop residue were effective in increasing infiltration, reducing runoff and reducing evaporation. In the Eastern Cape, an indigenous practice of water harvesting and soil conservation called *Gelesha* is very common among farmers. The practice involves tilling the land immediately after harvest. The perceived benefit is to ensure increased infiltration of rain, dew, and frost and reduce runoff thus increasing water availability for the next crop. With ecologically-based rainwater harvesting systems farmers are therefore willing to invest in variety and cultivar mixtures, more crop types and this has potential to increase biodiversity thus, enhancing overall farm productivity and resilience to changing climatic patterns. In addition, water in ex situ dams can be stored and used for livestock which provide extra income. This further enables smallholder farmers to diversify their livelihoods into both livestock and mixed cropping systems.

Insights from the discussions revealed that ecologically-based climate change adaptation strategies enhance food security in all farm types in South Africa smallholder systems. Options such as crop diversification for, e.g. polycultures, intercropping and crop rotations helps to intensify cropping systems by producing cereals, vegetables and legumes. With long cropping cycles, staple cereal crops tend to be more vulnerable to environmental threats and risk of crop failure. In contrast, vegetables and legumes have shorter cycles, are faster growing, require little space, and thus can be considered less risk-prone. Vegetables and legumes are grown in small spaces such as backyard or home gardens with minimal resource application. Leaves, tender pods, and immature grains of some legumes (such as snap bean, chickpea, pigeon pea, cowpea, vegetable soybean, etc.) are consumed as vegetables, while for most others the mature grains are either consumed as such, or as sprouts or in various processed products. Ecologically-based water harvestings systems can act as adaptation tools to climate change in all farm types by reducing exposure and vulnerability, increasing resilience to the potential adverse impacts of climate change. In cereal-based cropping systems in situ rainwater harvesting, CA, Gelesha reduces the risks of production failure through dry spell and drought proofing. Farmers are therefore willing to invest in variety and cultivar mixtures, more crop types and this has potential to increase overall farm productivity and resilient to changing climatic patterns.

Agroforestry an option to ecologically intensify smallholder farming systems is mainly serving as climate change adaptation strategy. Most of the smallholder farmer in rural areas of South Africa grow and use fruits trees and derive other benefits from trees around and within their agricultural landscapes. Fruit collected from indigenous trees by rural communities are used for subsistence purposes and traded to generate cash to enhance resilience of smallholders to current and future climate risks including future climate change. Furthermore, other non-fruit trees such as acacia in their agricultural landscapes provide forage fodder to their livestock farming systems especially during the dry season and drought years further contributing to resilience of agricultural systems when faced with climate related challenges. This enables smallholder farmers to diversify livelihoods in cases of severe crop failure by reducing exposure and vulnerability and increasing resilience to potential impacts of climate extremes Use of Agroforestry (AF) to improve soil fertility and soil and water conservation was not common among all the farmers but noted potential benefits of addition of nutrients through fixation, nutrient recycling through increased soil organic matter.

Options for ecological intensification fits well within the contrasting biophysical and socio-economic conditions of the heterogeneous smallholder farms in South Africa and represent a feasible pathway to reduce environmental degradation, increase sustainability and resilience of farming systems to climate change impacts and enhance. For instance, use of ecological intensification options by farmers is influenced by farm type and characteristic. The development of farm typologies helped to show that promotion of blanket recommendations is not effective. Therefore, development of farm specific ecological intensification options in smallholder agriculture within and across agro-ecologies in South Africa is vital.

### 10.4.2. Limitations of current and potential ecological intensification options

Insights from the discussions revealed that these options do not always succeed in enhancing household food security and better livelihoods in different farm types and agroecological regions. Although most farmers acknowledged to be aware of the above ecological intensification options, they lacked knowledge and skills to needed for out scaling of these options. These results concur with Muzangwa et al. (2017) who asserted that most farmers lacked knowledge and skills in CA to increase uptake and out scaling in their farming systems. Knowledge and awareness is particularly critical in crop diversification options such as crop rotations and intercropping as most farmers noted that they were unaware of ideal cultivars/ varieties and crops to use and when to intercrop so as reduce crop competition. With regards to AF farmer awareness and training on other agroforestry practices for soil fertility and soil and soil and water conservation are critical for enhancing the benefits of agroforestry as an option for ecological intensification.

The potential and out scaling of these options were limited due to limited access, availability and affordability of germplasm. In Eastern Cape for example farmers revealed that issues relating to laws prohibiting retaining of seed by farmers as a major obstacle in implementing crop diversification options. These findings are in agreement with studies by Zerihun et al. (2014) who asserted that although agroforestry is common in smallholder farming systems in South Africa it is mainly through production of fruit trees around their homesteads and cropping fields. The lack of high-quality AF tree germplasm has long been recognized as a major challenge to widespread adoption of AF for soil fertility and soil and water conservation in Southern Africa. Furthermore, studies on crop diversification options by () noted that resource-poor smallholder farming households appear willing to grow different crops in SSA but only at low levels. Labour requirements, seed access and appropriate genotypes are barriers to crop diversification hence limit the potential of ecological intensification in smallholder farming systems in SSA. High cost of germplasm and other production related cost de-incentivise farmers to adopt new technologies. Respondents indicated that many of the technologies have been exposed to smallholder farmers through government sponsored programmes (free and heavily subsidised) and this suggest farmers have not experienced the real costs of these technologies. This further explains the perceived behaviour of farmers not to out-scale technologies at the end of the projects or programmes.

The availability of land and labour seems to be also a concern in intensifying their farming systems. Smallholder farmers in South Africa farm on less than 2 ha, most often on less than 1 ha. For instance, horticultural farmers, who mostly crop on less than 1 ha perceived fallowing to be a good strategy for pest control but its potential was limited by land limitations and perceptions on underutilisation of land as they have farm throughout the year. Most smallholder farmers grow maize as it is the staple crop. Therefore, the major challenge that many farmers face is how to diversify their cropping systems through crop rotations, intercrops and polycultures to realise the ecological benefits given the limited land availability and that maize must be grown yearly for subsistence purposes. This demonstrates that insufficient land availability in South Africa smallholder sector. This has negative implications for sustainability and farm income, especially for emerging young horticultural farmers on less than 1 ha of land. Furthermore, due to rapid urbanisation in South Africa most farming is done by elderly, others engaged in off-farm income activities and with a few young people in the rural areas engaged in smallholder agricultural activities. The increased labour demands for some of the ecological intensifications options such as intercropping polycultures conservation agriculture, in situ rain water harvesting make out-scaling of the options a challenge considering their increased labour demands and limited labour availability in smallholder agriculture. With adequate access user and environmentally friendly machinery to reduce the labour burden of these options, smallholder agriculture can contribute to an increased agricultural growth, rural development and have a positive impact on environmental sustainability, biodiversity conservation, food security and farm income.

Technical and extension support to support smallholder farmers to ecologically intensify their cropping systems is lacking. This asserts that there is dearth of adequate and technically qualified extension personnel at field level to adequately support ecological intensification of food production systems in smallholder farming systems in South Africa. Other studies done in the two provinces of South Africa also indicate poor technical competency of extension agents. Farmers emphasised lack of technical and extension support services in most ecological intensification options such as conservation agriculture, intercropping, crop rotations among others. This implies that extension agents need new technical knowledge and skills to show farmers the proper application of these options if acclaimed benefits of these ecological intensification options in cropping systems are to be realised. With adequate access to farmer support services, smallholder agriculture can contribute to an increased agricultural growth, rural development and have a positive impact on environmental sustainability, biodiversity conservation, food security and farm income.

## 10.5. Conclusion

Options for ecological intensification have shown promise at local scale. However, smallholder farmers are likely to adopt, out scale and utilize ecological intensification options more widely if they enhance resilience to climate change and variability. Furthermore, adoption and out scaling will likely increase if they are adequately trained on the beneficial aspects associated with them. For instance, extension personnel could enhance uptake of ecological intensification options through participatory approaches. Participatory on-farm experimentation of ecological intensification options coordinated by extension support should be conducted in a participatory manner where smallholder farmers are actively involved. This approach could help raise awareness, and impart farmers with agronomic skills in variety selection, planting time, cropping density of sole and intercropped crops and cropping patterns. This approach could help in tailoring information transfer and ensure that farmers receive and understand the required information.

This study also identified gaps in knowledge that require further research to deepen our understanding on the potential and impact of ecological intensification in smallholder agriculture in South Africa. Ecologically inspired approaches rely on biodiversity to enhance resilience. Therefore, the starting point should be to observe the biodiversity patterns, map them and determine their effectiveness in promoting various agroecosystem services. Crop diversity is the heart of ecological intensification. Therefore, crop cultivars of various crops, including native species and old landraces among smallholder farmers should examined. Consequently, the most responsive cultivars which are well adapted to their biophysical and socio-economic environment should be selected and supplied to smallholder farmers to help in seed multiplication. The starting point should be with legumes and cereals crops and later modelled to other crops.

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# CHAPTER 11. COMMUNICATING SEASONAL FORECAST TO RURAL FARMING COMMUNITIES

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## 11.1. Background

Climate variability and change has amplified many climate related ecosystem events (draught, floods) in the various parts of the world, and made nature hazards a growing concern (Schonhart et al., 2016; Ubisi et al., 2017). The uncertainties associated with temperatures, rainfall and water predication has left the population in many localities vulnerable to the caprices of weather uncertainties (Crops and Southern, 2015; Debela et al., 2015; Ndamani and Watanabe, 2013; Nel and Sumner, 2008). Climate variability affects the significance of improved seasonal forecast information (Hansen et al., 2011). The climatic variations affects the scientific capability of estimates, data required to estimate and potential advantage of enhanced forecasts (Buizer et al., 2012). The reading will look at addressing the problem of communicating climate variability and change. Secondly, how best can the issues of climate variability and change be explained. Thirdly, who is mostly affected by the possible climate variability and change impacts in agriculture? Fourthly, the early warns of the global climate variability and change impacts. Lastly, the effect of climate variability and change to food production.

### 11.1.1. The effect of climate variability and change to food production

Climate variability and change is considered to be the primary source of fluctuations in worldwide food production, mainly in the semi-arid tropics (Buhaug et al., 2015; Diemen et al., 2017). There is a need to increase the understanding and interpretation of the forecasted climate information to minimize the risk on crop production. Empirical studies on African agriculturists have suggested that seasonal forecasts information can offer assistance to farmers to reduce their vulnerability to dry spell and climate extremes, thereby maximizing production opportunities (Adamgbe and Ujoh, 2013; Batisani and Yarnal, 2010; Debela et al., 2015; Kotir, 2011; Tiamiyu et al., 2015; Waha et al., 2011). Fewer advances have been made in evaluating the extent and impact of climate forecast, especially among vulnerable populaces, such as rural small-scale farmers in Africa (Madzwamuse, 2010; Turpie and Visser, 2015). To contribute towards a better understanding and in catalysing further action to empower rural communities (smallholder farmers) with knowledge and skills on climate forecast and crop modelling for adaptation to climate change, this study focus on exploring the approaches, methods, and tools to communicate seasonal forecasts information in developing countries. Climate change and variability has a large influence over agricultural productivity on small-scale farmers in semi-arid regions.

### 11.1.2. The warning signs of global climate variability and change impacts

The ever-increasing greenhouse gases have already initiated change in warming the planet and this will, in turn, cause escalation of future climates and also affect changes in precipitation patterns (Harvey et al., 2014; IPCC, 2007; Msowoya et al., 2016). Agriculture is expected to be largely affected by global climate change impacts (Cline, 2008). Müller and Cramer (2011) state that crop production vary from place to place because of the impacts of climate change, and production varies from crop to crop (Msowoya et al., 2016; Schonhart et al., 2016). The changes in temperatures and increase with warm-wet climate change can reduce crop production in parts of the world (Gohari et al., 2013; Schlenker and Lobell, 2014). There is a significant change in food production (Msowoya et al., 2016) and impoverished countries have a higher risk to climate change effects due to less resilience (Msowoya et al., 2016; Müller and Cramer, 2011).

### 11.1.3. Who is mostly affected by the possible climate variability and change impacts on agriculture?

Most of the African countries practice rain fed agriculture and in tropical and subtropical areas of Africa is sensitive to climate change (Amjath-Babu et al., 2016; Auffhammer and Schlenker, 2014; Mendelsohn, 2008). Many studies have established that climate change impacts agriculture (Roudier et al., 2011; White et al., 2011; Zhu et al., 2011) and the studying of the possible climate change impacts on agriculture is important to ensure sustainability in the sector. Food insecurity has increased in Sub-Saharan Africa because of frequent droughts and floods, indicating the region’s vulnerability to climate change (Msowoya et al., 2016). Higher food prices in Sub-Saharan Africa are indicative of the adverse effects of climate change (Ringler, 2010).

In Sub-Saharan Africa it is anticipated that the effects of climate change on dry land agriculture will be more intense if compared to other regions of the world, since the region have lower precipitation rates and higher baseline temperatures than most other places in the globe (Amjath-Babu et al., 2016; Kotir, 2011; Müller and Cramer, 2011). Considering the anticipated increase in variability of precipitation and increasing temperatures, it is anticipated that the practicality of dryland farming will be influenced (Amjath-Babu et al., 2016; Schlenker and Lobell, 2014; Seo, 2010). Smallholder farmers are exposed to famine in this continent as a result of climate change (Apata, 2011).

### 11.1.4. How can we communicate the issues of climate variability and change and seasonal forecasting in developing countries

Explaining the issues of climate change effects on crop production to the rural smallholder farmers is complex (Kiem and Austin, 2013). Rural smallholder farmers historically have used traditional coping strategies and indigenous knowledge to adapt to climate change (Tall et al., 2014). The ever increasingly unpredictable climate variability has made it difficult for rural smallholder farmers to adapt (Hansen et al., 2011). hence there is need to successfully communicate accessible climate science to agriculturalists in order to create and assess mitigation and adaptation techniques (Tall et al., 2014).

The complexity of climate change implies that suitable approaches, strategies, and devices or tools to communicate the issue and its different consequences are critically required. Article 6 of the United Nations Framework Convention on Climate Change (UNFCCC) clearly addresses the significance of climate change communication with the common public and emphasizes the need to engaging the different partners in debating this issue. The Intergovernmental Panel on Climate Change (IPCC) has, in connection with its 5th Assessment Report (AR5), engaged on a major communication and information outreach programme to promote the report and its results. Elsewhere, however, the proper communication of matters related to climate change is not taking place as it should.

Where is the problem in communicating climate issues in developing nations? The complexity of the problem, whose scope entails not only increases in temperature, but also erratic rainfall, extended droughts, and extreme events on the one hand, as well as decreases in agriculture and livestock production, property losses and a variety of other consequences on the other, requires a holistic understanding of the causes and effects of climate change (Buizer et al., 2012). The uncertainty remains about how small-scale farmers in semi-arid regions would use seasonal forecasting information and crop models, in crop management decisions. Given modern driving force to the application of climate predictive data towards improving crop productivity among small-scale farmers (Amjath-Babu et al., 2016). there is need to explore effective approaches, methods, and tools to communicate the use of seasonal forecasting information and crop models in making crop management decisions. It is against this background that this reading focus on assessing the potentials, means and methods to communicate climate change information to empower small-scale farmers in the developing countries.

### 11.1.5. Addressing the problem of communicating climate information or seasonal forecast information

The question of by what means should uncertainty be communicated, is one confronted by scientific researchers in many fields. In the event that uncertainty is not satisfactorily communicated, it can cause beneficiaries to encounter a false or wrong sense of certainty, maladaptive decision-making and, in case that it is discovered, reduced trust in communicators (Taylor et al., 2015). While communicating climate information or seasonal forecast information, the forecasters confront quid pro quo between abundance (level of detail given). vigour (fitting reflection of unwavering quality and impediments). and the ease with which data can be understood and utilized (Joslyn and LeClerc, 2012; Klemm and McPherson, 2017; Lewandowsky et al., 2014). To add on, some components of uncertainty is due to the failure to anticipate human behaviour and its aggregate effect on the earth's climate (Briley et al., 2015). The uncertainty is because natural variability and future climate predictions that rest on a number of changing factors within a climate system (Buisson, n.d.; Lewandowsky et al., 2014). More so, uncertainty is because of the failure to foresee human behaviour and its total impact on the earth's climate (Aides, 2009).

There is a need for consistency as uncertainty can be awkward and can lead to uneasiness, while consistency makes individuals feel secure (Aides, 2009; Blumenthal, 2017; Rayner, 2017). Therefore when communicating complex subjects like worldwide climate change, it is critical to discover compelling ways to communicate intrinsically uncertain information (Bruno

Soares and Dessai, 2016). The researchers need to developed terminology to communicate uncertainty and seasonal forecasts through everyday language that is easily understandable by rural small-scale farmers in the developing countries. Secondly the communicators need to put that uncertainty into framework easily understood by the targeted audiences, show what is known with a great degree of confidence and what is moderately ineffectively understood. Also through bridging the gap amongst forecasters and rural smallholder farmers, through different forums that bring together scientists, forecasters, extension works and farmers. Fourthly, overcoming language barriers, simplifying the substance of forecast bulletins, and guaranteeing that they highlight potential actions or decisions based on the forecast will render forecast information significant and more effortlessly engaged by communities. Lastly, building trusted local community actors (for example agricultural extension workers) as well as through the use of media like community radio to relay climate information to the rural smallholder farmers will overcome communication system barriers.

### 11.1.6. Conclusion

A climate forecast is valuable to a specific beneficiary only in a case where it is adequately skilful, opportune, and pertinent to actions that the beneficiary can take to make it conceivable to attempt or embrace behavioural changes that make strides results. To make strides in predictive expertise in developing countries and for climatic parameters for which exceptionally limited expertise presently exists, hence expanding the potential for forecasts to be valuable in modern locales. Therefore, there is need to improve the communication of seasonal forecasting in order to increase food production. The implications of poor communicating climate forecasting information, has an effect on food insecurity in the developing countries. These implications can be averted by bridging the gap between indigenous and scientific knowledge. Through the integration of the indigenous and scientific knowledge, an effective tool and methods for improving the seasonal forecast information will be established. More so, after establishing an effective tool and methods, a communication network based on trust and accuracy of the information communicated. The network should start at local scale working upwards, this will help in better understanding of the communication concept, methods, tools and approaches to improve rural smallholder farmers in developing nations.

## 11.2. An example of Communication through Seasonal forecast Newsletters

The project has been disseminating monthly seasonal forecast newsletters from October 2017 to April 2018. The newsletters have information on the weather forecast for the next 3 to 9 months for Limpopo and Eastern Cape. The information is generally related to rainfall and temperature dynamics. After every 3 months the project has been developing the quarterly newsletter which in addition to the general temperature and rainfall forecast also had information on sustainable intensification, remote sensing and indigenous forecasting. For the sake of the report Quarterly Newsletters for Limpopo and Eastern Cape were selected.

Each Newsletter contain a disclaimer in first page, recognising that the material and methods presented are under development, and that it is NOT recommended to account for the information presented in decision making at this stage, but to participate in the development of better indices, information and communication.

Similarly each Newsletter is ending, with contacts and further reading material, for accessing or better understanding seasonal forecast and crop models, and an acknowledgement to WRC and all project partners**.** As an example we present 2 earlier Newsletters.

### 11.2.1. Newsletter: Lambani in Limpopo

December 2017: Use of seasonal forecast information Quarterly newsletter

A. Cumulative rainfall

What did we compute

- Cumulative rainfall
- 8 seasonal forecasts (October 2017-July 2018)

Resulting indices

- Most forecasts predict rainfall of below historical average.

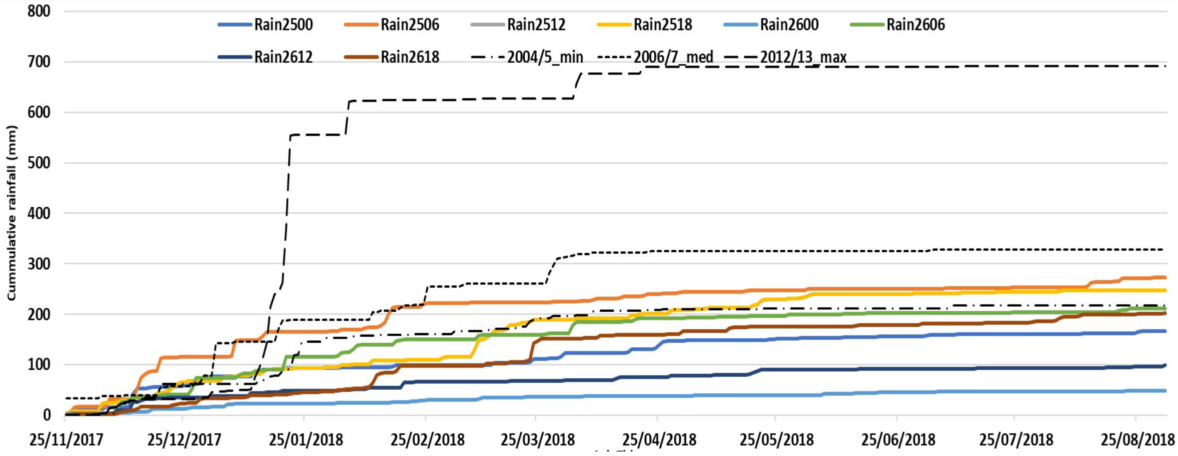

**Figure 1: Cumulative rainfall for 8 forecasts for Lambani, Limpopo (November 2017-August 2018)**

B. Dry days

What did we compute

- Dry day: less than 1 mm per day
- Accounted for periods of more than 10 consecutive days

Resulting indices

- Equal chances of having dry spells the whole year
- Dry spells: mid-Dec, mid-Jan, end-Jan, mid-Mar-end-Apr.

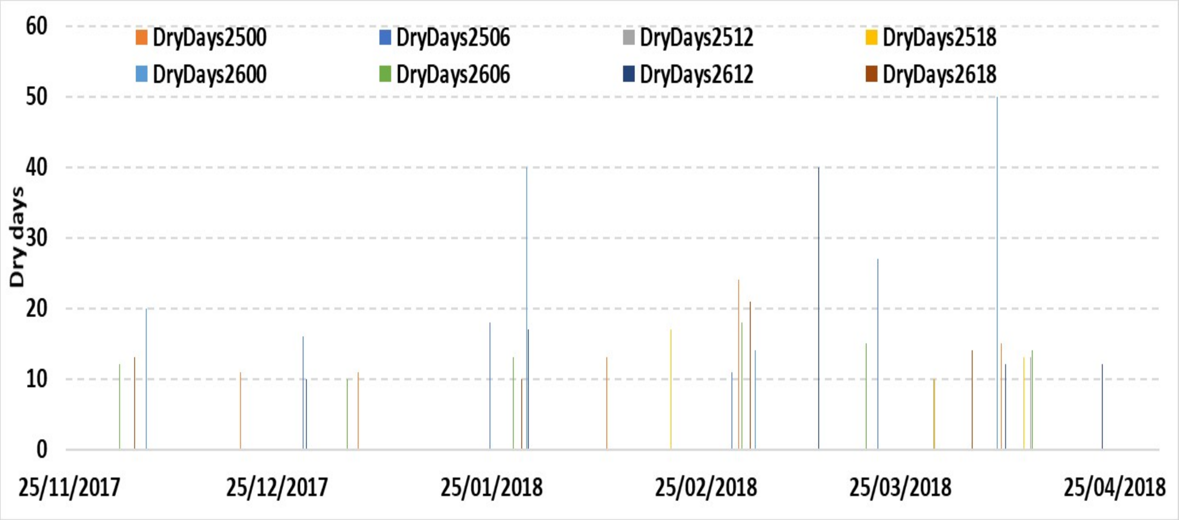

**Figure 2. Dry days in Lambani, Limpopo during the period August 2017-July 2018**

C. Extreme temperatures

What did we compute

- Days where temperatures are greater than 32°C
- Between November 2017 and August 2018

Resulting indices

- Increased frequency of high temperatures till mid-March 2018.

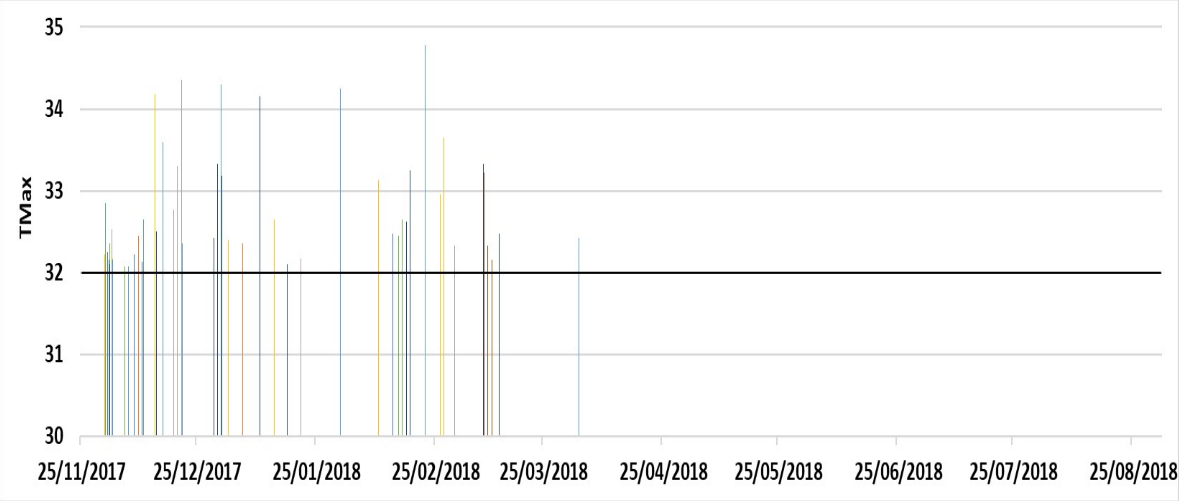

**Figure 3. Frequency temperatures above 32°C for Lambani, Limpopo (November 2017-August 2018)**

D. Indigenous approaches

Indigenous approaches to forecasting rainfall for adaptation of Bambara nuts. Bambara nuts is one of the non-conventional legumes that have become increasingly important in the current changing climate environment. It plays a huge role in food security and nutrition as it can grow and survive under high temperatures in the events of dry seasons. Although the Bambara nut is drought tolerant, it is not yet clear how the productivity of the legume is affected by climate variability and how smallholder farmers apply indigenous knowledge to forecast climatic conditions. In addition, the resilience of local communities to climate variability has always been derived from Indigenous Knowledge Systems (Figure 4).

**Figure 4. Community engagement on integrated use of seasonal forecast, Ha-Lambani village, Thulamela municipality, October 2017**

Thus, the identification and documentation of Indigenous approaches used in smallholder farming systems through community engagement will help to better understand the challenges and successes of the practices to achieve appropriate strategies for dissemination of seasonal forecasts. The next newsletter will provide local knowledge gained from smallholder farmers in *Ha-Lambani* village of Thulamela municipality, Limpopo province.

E. Ecological intensification

It is that time of the year when farmers are deciding what, when and how to plant. Here are some tips on how to intensify cropping lands to enhance food security and adapt to climate variability.

Diversifying crops

Maize is the most common crop and can be simultaneously cultivated with other crops. Maize can be intercropped with legumes. Farmers are encouraged to grow indigenous vegetables such as pumpkins that are hardy compared to exotic vegetables.

Enhancing soil fertility and crop protection

Application of organic amendments such as animal manure common ecologically sustainable soil fertility enhancing strategies. By now most these organic manures must be incorporated into the cropping fields to maximize crop benefits. Use of organic amendments can be augmented through maize-legume rotations or intercrops to enhance soil fertility whilst breaking pest and disease life cycle.

Adapting to climate variability and change

Farmers are increasingly questioning how they can cope with climate variability. This can be done through mixed cropping and water harvesting systems. Farmers can also grow fruits and forage trees around their cropping fields and homesteads to supplement food security as well act as a source of income for the household.

Conclusion

Ecologically intensifying brings multiple short and long-term benefits and further enhancing sustainability of our farming systems.

### 11.2.2. Newsletter: Raymond Mhlaba in Eastern Cape

December 2017: Use of seasonal forecast information Quarterly newsletter

A. Cumulative rainfall

What did we compute

- Cumulative rainfall
- 8 seasonal forecasts (November 2017-October 2018)

Resulting indices

- Most forecasts predict rainfall of above historical average.

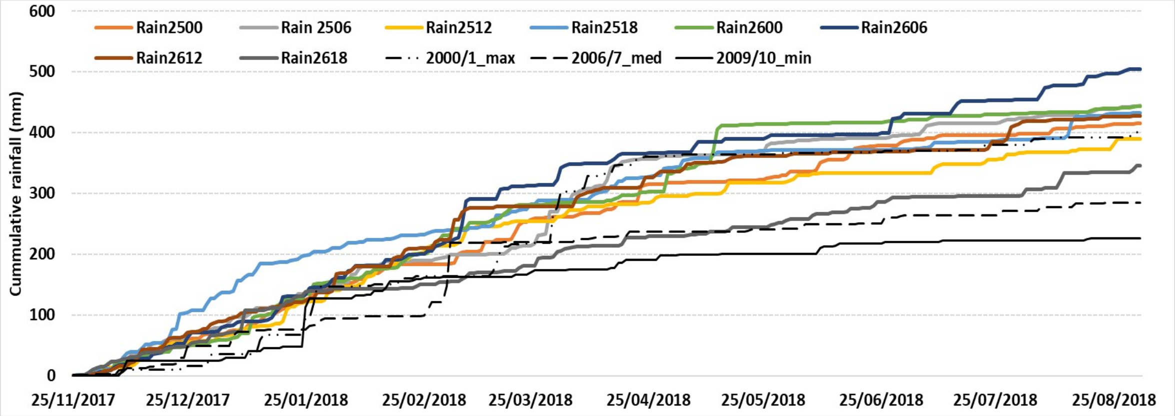

**Figure 1. Cumulative rainfall for 8 forecasts for Raymond Mhlaba, Eastern Cape (November 2017-October 2018)**

B. Dry days

What did we compute

- Dry day: less than 1 mm per day
- Accounted for periods of more than 10 consecutive days

Resulting indices

- Increased chances of dry spells End-Dec, and end of season (end-March) onwards.
- Dry spells: mid-Nov, end-Dec, end-January, end-February, mid- and end-March and mid-April

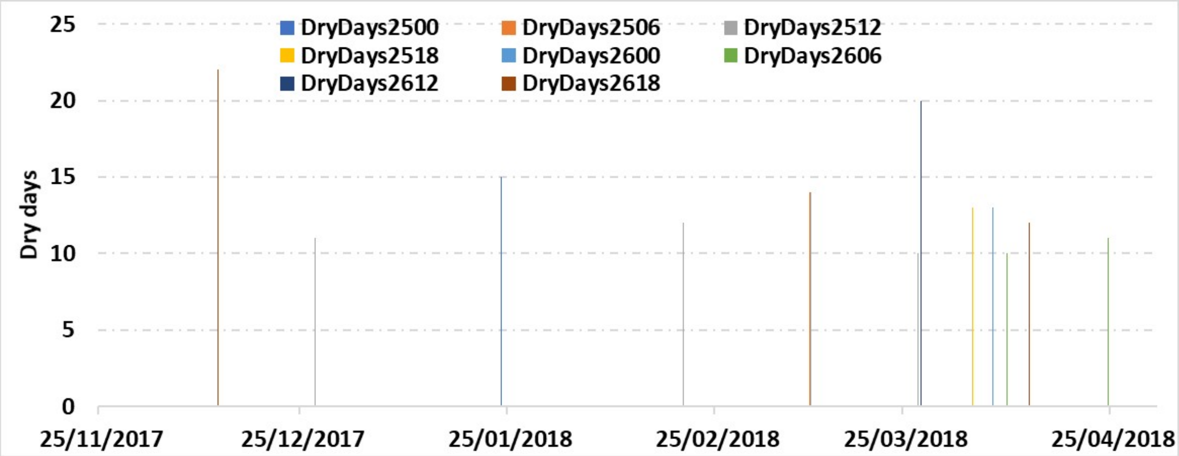

**Figure 2. Dry days in Raymond Mhlaba, Eastern Cape during the period November 2017-October 2018**

C. Extreme temperatures

What did we compute

- Days where temperatures are greater than 26°C
- Between November 2017 and August 2018

Resulting indices

- Increased frequency of high temperatures till mid-March 2018.
- Greater frequencies of high temperatures: end of December, mid-January, mid-February and mid-March (2017/18).

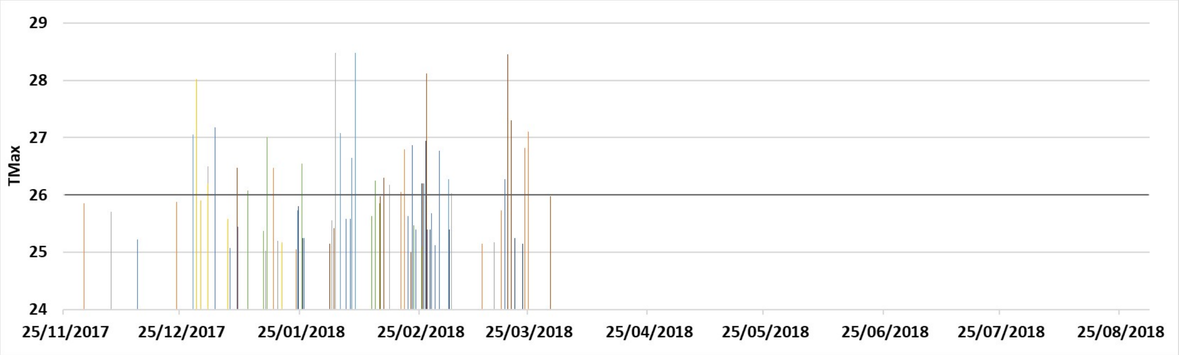

**Figure 3. Frequency temperatures above 26°C for Raymond Mhlaba, Eastern Cape (November 2017-October 2018)**

D. Soil moisture information

Crop production systems are highly dependent on soil water availability. Reliable monitoring of soil moisture is key in future agriculture. Knowledge of specific crop water requirement increases farming efficiency and productivity. Currently, soil moisture monitoring is dependent on ground sensors, which however only provide spot measurements. Moreover, due to their cost, sensors are quite rare across some critical agricultural areas in especially in Raymond Mhlaba Municipality where water sources are scarce and the need of a smart use of irrigation is an urgent need.

Remote sensing acquires information using satellite technology without ground contact (Figure 4). Using satellite remote sensing however can provide an economic option to monitor across large and remote areas and allows farmers to know soil moisture content and helps irrigation scheduling. Soil moisture information will be provided in form of maps covering the whole Raymond Mhlaba municipality in the next newsletters.

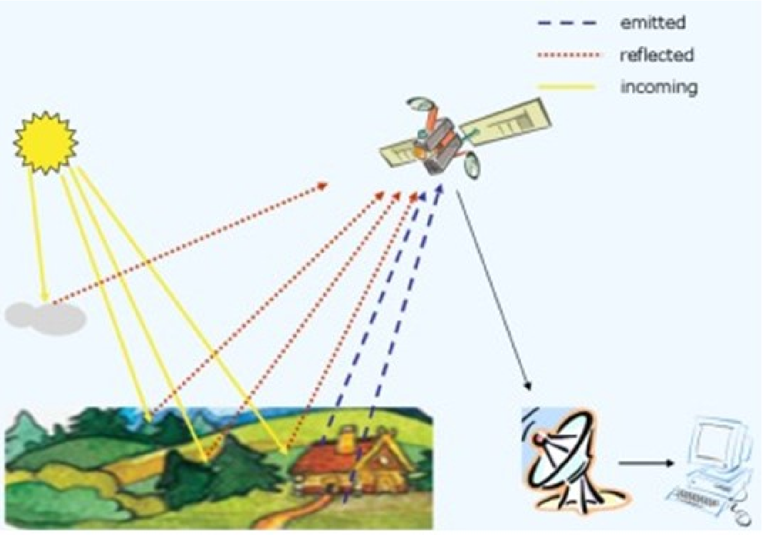

**Figure 4. The remote sensing process**

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It is that time of the year when farmers are deciding what, when and how to plant. Here are some tips on how to intensify cropping lands to enhance food security and adapt to climate variability.

Diversifying crops

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Application of organic amendments such as animal manure common ecologically sustainable soil fertility enhancing strategies. By now most these organic manures must be incorporated into the cropping fields to maximize crop benefits. Use of organic amendments can be augmented through maize-legume rotations or intercrops to enhance soil fertility whilst breaking pest and disease life cycle.

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Conclusion

Ecologically intensifying brings multiple short and long-term benefits and further enhancing sustainability of our farming systems.

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# CHAPTER 12. ENHANCING FARM MANAGEMENT DECISION MAKING USING INTEGRATED SEASONAL FORECAST INFORMATION AND CROP MODELS SMALL-SCALE FARMING SYSTEMS OF SOUTH AFRICA

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## 12.1. Background

Small-scale farmers are vulnerable to climate variability as they are highly dependent on rain fed agriculture. Climate variability has been gradually increasing since the industrial revolution and is projected to significantly increase in the future (IPCC, 2014). Specifically, projections show intra- and inter-seasonal increase in frequency of extreme temperature events. These are predicted to be coupled with increased variability in the onset and cessation of rainfall. The occurrence of mid-season dry spells is also projected to increase within the Southern African region (Tadross et al., 2009).

Since 1980, climate variability has contributed to significant crop yield losses of at least 50% amongst crops such as maize and soybean (Ray et al., 2015). Climate variability is projected to increase maize yield variability of as high as 85% between extreme rainfall seasons in Southern Africa (Mkuhlani et al., 2019). Increased inter-annual maize yield productivity increases food insecurity especially amongst resource constrained small-scale farmers. The impacts are less severe amongst the usually resource endowed commercial farmers. They can therefore either initiate coping strategies or sustain some losses. The impacts of climate variability are projected to be particularly severe in semi-arid to arid agro-ecologies (World Bank, 2007). Seasonal forecast information can potentially be used to enhance climate variability management (Hansen et al., 2009).

Seasonal forecast information potentially enables small-scale farmers to make farm management decisions in preparation for the incoming agricultural cropping season (Chung et al., 2014). Seasonal forecast information can inform small-scale farmers on the corresponding farm management decisions as well as farm resource allocation (Ziervogel, 2004). Seasonal forecast information can therefore enable farmers to cope and adapt to rainfall variability for that particular cropping season. Seasonal forecast information contains information on the state of the atmosphere on a seasonal scale. Seasonal forecasts usually contain information on temperature and rainfall but parameters such as wind, humidity can also be included depending with intended use and target users. Accuracy of seasonal forecasts is highly dependent on the forecasting horizon with short term forecasts being more accurate (Zhang, 2014). To increase the value of forecasts, seasonal forecast information can be integrated with crop models producing crop yield forecasts (Hansen et al., 2009). Crop yield forecasts are of potential value to small-scale farmers as this enables them to evaluate the response of crops to projected seasonal forecast information. Linking seasonal forecast information and crop models however presents significant challenges to researchers. The challenges are attributed to the spatial and temporal format of seasonal forecast which is incompatible with the daily weather format required by process-based crop models (Hansen et al., 2009).

Advances have been made in linking crop models and seasonal forecast information to enhance farmer decision making. Integrated seasonal forecast information and crop models have been used in crop yield forecasting in South America (Apipattanavis et al., 2010), evaluate optimal fertilizer application rates and pasture productivity to determine sheep stocking rates in Australia (Asseng et al., 2012a,b). Specifically, within Africa, Sultan et al. (2010) evaluated productivity and profitability from cultivating different crop types in West Africa using statistical and dynamical seasonal forecasts integrated with the General Algebraic Modelling System (GAMS). a bio-economic model. In Burkina Faso, Mishra et al. (2008) integrated ECHAM v.4.5 forecasts a general circulation models (GCMs). with the SARRA-H, a process-based crop model to predict Sorghum productivity. The study evaluated productivity of traditional, improved and hybrid maize varieties. The study also compared the effectiveness of downscaling techniques such as: multiple linear regression, stochastic disaggregation, principal component regression and stochastic disaggregation (Mishra et al., 2008). In Kenya, Ines and Hansen (2006) assessed the feasibility of integrating seasonal forecast information and DSSAT crop model for maize yield prediction. The GCM-based forecast data was downscaled and the rainfall was bias corrected using the multiplicative shift approach. Hansen et al. (2009) integrated stochastically downscaled ECHAM v.4.5 GCM forecast data with APSIM. The study assessed the optimal maize sowing date and fertilizer application rates in the semi-arid regions of Kenya. Such research is potentially beneficial to small-scale farmers.

Using integrated seasonal forecast and crop models, farmers can potentially make farm management decisions that increases productivity (Mishra et al., 2008). Specifically, farmers can make decisions such as crop type, variety and organic ground cover that potentially lead to the attainment of high yields. Such research potentially minimizes the impact of climate variability through prior determination of the feasible climate variability management strategies. Given the increased variability in the commencement of rains, researchers can enhance decision making on the planting date. Small-scale farmers also face challenges in managing fertility whose effect is correlated with climate. Researchers can therefore evaluate the fertilizer type and rates corresponding to the projected weather (Zinyengere et al., 2011). Such information can then be disseminated to small-scale farmers. Agricultural extension workers are literate and frequently interact with small-scale farmers and serve as a sustainable medium of dissemination of such information to small-scale farmers (Ziervogel, 2004).

These assertions however need to be evaluated under South African conditions. The research therefore sought to assess the feasibility of integrating seasonal forecast information and process-based crop models under South African conditions. The research also assessed the potential application of the integrated ‘seasonal forecast information and crop model’ tool in decision making amongst small-scale farming systems in terms of forecast variability and consequences for yield projection. Using the 2017/18 rainfall season as a case study, the research also sought to identify farm management decision process given multiple combinations of management strategies under multiple seasonal forecasts.

## 12.2. Materials and methods

### 12.2.1. Sites

The study was based on Nkonkobe and Lambani communities in Eastern Cape and Limpopo provinces respectively, in South Africa. The two communities were chosen for this study because most small-scale farmers in these regions practice rain fed agriculture. The locations are also characterized by relatively low annual precipitation of high rainfall variability. Both the Eastern Cape and Limpopo provinces are home to significant proportions of resource-constrained small-scale farmers. The research is therefore potentially beneficial to small-scale farmers from these locations (Ncube et al., 2016).

Nkonkobe, located within Raymond Mhlaba municipality (32°47′S, 26°38′E; 535-1200 m.a.s.l) receives about 640 mm of rainfall per annum, mainly between October and March. Daily mean temperatures range from 4°C to 38°C in winter and summer respectively. Occasional incidences of frost and snow are experienced during the winter period between May and July (Adekunle, 2014). The most predominant soil types are Oak leaf (SCWG, 1991) with patches of Valsriver and alluvial derived micas (Mandiringana et al., 2007). The main farming activities are vegetable and livestock production for commercial and subsistence purposes, respectively. In Nkonkobe, farming systems vary from sole crop or predominantly livestock production to mixed farming. The most commonly cultivated crops are: potato, tomato, cabbage, spinach, beetroot, carrot and maize whereas cattle are the major livestock species kept (Adekunle, 2014).

Lambani, located within the Vhembe district (22°58'S, 30°26'E; 596 m.a.s.l) experiences mean temperatures range from 25 to 40°C in summer and 22 to 26°C in winter. Precipitation is about 800 mm per annum with most being received from October to March. The rainy season is characterized by mid-season dry spells with high rainfall variability (Mzezewa et al., 2010). The most predominant soils in the Lambani community are dystrophic, red and yellow well drained clays (SCWG, 1991). Small scale farmers in Limpopo operate on land holdings averaging less than 1.5 ha. Maize is the most commonly cultivated cereal whereas tomatoes, cabbages, beetroots, onions and butternuts are the major vegetable crops. Crop production and livestock rearing are mostly carried out to meet household subsistence needs with the balance being sold to supplement income (Baloyi, 2010).

### 12.2.2. Seasonal forecast information

Seasonal forecast information for this study was based on the Climate Forecast System version 2 (CFSv2) model. CFSv2 is a coupled ocean-atmosphere-land model, developed by the National Centers for Environmental Prediction (NCEP). The model has a resolution of about 0.9° x 0.9° (Yuan et al., 2011). CFSv2 was selected as it was easily accessible through simple web downloads compared to other forecasts which were only accessible upon purchasing. Some of the forecasts also demanded high computational and technical capacity and also involved a lot of bureaucracy to access them. Seasonal forecast information was contained in *ncdf format* files. Using *Python,* seasonal forecast data was extracted for Nkonkobe, Eastern Cape (32°47'S, 26°38'E) and Lambani, Limpopo (22°58'S, 30°26'E). The study extracted 23 seasonal forecast data sets, for each day for the period, 1-23 October

2017. The extracted weather data included: minimum and maximum temperature, rainfall and solar radiation for the two locations for 9 months. Previous research has shown that there is greater forecasting skill in Limpopo compared to the Eastern Cape in South Africa. This is attributed to the limited capacity of GCMs to account for most factors defining weather in the Eastern Cape compared to Limpopo, where there is less oceanic influence (Landman et al., 2012; Landman and Beraki, 2012).

### 12.2.3. Farmer classification

Small-scale farmers in Lambani and Nkonkobe were classified using the qualitative farm typology approach based on the predominant socio-economic characteristics (Chapter 6). The qualitative typology approach is hinged on key informants who have in-depth knowledge of the farming systems and the community at large. These are usually local traditional leadership, locally based national government employees such as agricultural extension workers. In this study, local agricultural extension officers were the key informants in both Lambani and Nkonkobe. In both cases, the following socio-economic variables were used to help establish the farmer typologies: age of household head (HHH); household size; employment status; education of HHH; assets; total land holding; types of crops cultivated; size of area cropped; crop yields; livestock types; livestock numbers and food security status. In Lambani, farmers were classified into three categories: *mixed farming*, *horticultural farming* and *off-farm income-dependent.* In Nkonkobe, the farmer categories were five: *social welfare-dependent*, *enterprising pensioners*, *struggling subsistence*, *horticulture-dependent* and *cooperative crop* farmers.

### 12.2.4. Calibration of the crop model

DSSAT v4.7, a process-based dynamic crop model was utilized to simulate crop yields (Jones et al., 2003). Such models are capable of predicting most aspects of crop growth and development through mimicking plant phenological and physiological processes (Basso et al., 2013). Process-based crop models simulate crop management aspects such as: crop rotation, intercrops, crop calendar, different crop types and varieties, fertility, irrigation, mulching and tillage (Jones et al., 2003; Holzworth et al., 2014). These management aspects that can be simulated by the DSSAT model are similar to some of the strategies we focus on in the current study. Relying on growth processes, process-based models can replicate those process outside of their conditions of development. In contrast, empirical models have limited capability in simulating vegetative and reproductive development, plant water balance and pest dynamics outside of their calibration conditions (Krishna, 2003). Empirical models produce simulations outputs restricted to the limits of historical conditions under which they were parameterized. With climate models predicting an increase in climate variability, empirical crop modelling lacks the capacity to simulate crop yields under different climatic conditions.

The DSSAT 4.7 model was calibrated based on the measured and observed biophysical and socio-economic data collected from farmers during community engagement activities such as household surveys and focus group discussions for both Lambani and Nkonkobe. Daily weather data for: maximum and minimum temperatures, rainfall and solar radiation; was acquired from the South African Weather Service for 2010-2016. Soil data describing soil texture, mineral and nutrient content, soil water dynamics was extracted for both Lambani, Limpopo (Table 12-1) and Nkonkobe, Eastern Cape (Table 12-2) (Fanadzo et al., 2010; SCWG, 1991; Mzezewa et al., 2010). Crop yield data for maize, cabbage, tomato, dry and green bean was extracted from farmer interviews, whereas phenological data was extracted during interviews with agricultural extension workers and literature. Effective calibration of the DSSAT model would include evaluation of the model's capability to simulate phenological aspects such as emergence, silking and maturity dates for each crop, season and location. Such data was however not available from farmers, hence the study relied on the relevant literature.

The root mean square error (RMSE) was utilized to evaluate the ability of the DSSAT model to effectively simulate crop yields. The calibrations compared simulated and measured crop yields from 2011/12 to 2015/16 seasons. A value above 30% is an indication of the model's inability to appropriately simulate the parameters under study (Moriasi et al., 2007). RMSE values for all crop yields across the different farmer categories and agro-ecologies were less than 30% (Table 12-3 and Table 12-4). The DSSAT model was therefore considered as suitable to predict crop yields in the conditions described above.

**Table 12-1 Soil data characteristics used to calibrate the DSSAT v4.7 model for Lambani, Limpopo South Africa**

| Characteristic | 0-30 cm | 30-120cm | >120cm |
|---|---|---|---|
| Lower limit ($cm^3/cm^3$) | 0.12 | 0.12 | 0.13 |
| Upper limit ($cm^3/cm^3$) | 0.26 | 0.26 | 0.29 |
| Saturation ($cm^3/cm^3$) | 0.49 | 0.49 | 0.49 |
| Extractable water ($cm^3/cm^3$) | 0.14 | 0.14 | 0.16 |
| Root distribution ($cm^3/cm^3$) | 0.78 | 0.42 | 0.11 |
| Bulk density ($g/cm^3$) | 1.1 | 1.1 | 1.20 |
| pH | 5.5 | 5.4 | 5.3 |
| Nitrogen (%) | 0.06 | 0.06 | 0.09 |
| Organic carbon (%) | 1.94 | 1.09 | 1.7 |

**Table 12-2 Soil data characteristics used to calibrate the DSSAT v4.7 model for Nkonkobe, Eastern Cape, South Africa**

| Characteristic | 0-30 cm | 30-120cm | >120 cm |
|---|---|---|---|
| Lower limit ($cm^3/cm^3$) | 0.137 | 0.137 | 0.06 |
| Upper limit ($cm^3/cm^3$) | 0.27 | 0.27 | 0.16 |
| Saturation ($cm^3/cm^3$) | 0.38 | 0.38 | 0.27 |
| Extractable water ($cm^3/cm^3$) | 0.14 | 0.14 | 0.16 |
| Root distribution ($cm^3/cm^3$) | - | - | - |
| Bulk density ($g/cm^3$) | 1.6 | 1.6 | 1.6 |
| pH | 6.0 | 6.0 | 6.0 |
| Nitrogen (%) | 0.13 | 0.05 | 0.01 |
| Organic carbon (%) | 0.7 | 0.22 | 0.02 |

**Table 12-3 Root mean square error (RMSE) values comparing measured and model simulated yields across different crops and farmer categories in Limpopo, South Africa**

| Season | Crop | RMSE Grain (%) | RMSE Stover (%) |
|---|---|---|---|
| Mixed farmers | Maize | 29.0 | 17.7 |
| Horticultural dependant farmers | | 17.5 | 29.1 |
| Off-farm income dependant farmers | | 24.4 | 12.4 |
| Mixed farmers | Tomato | 28.2 | 25.3 |
| Horticultural dependant farmers | | 29.0 | 28.5 |
| Off-farm income dependant farmers | | 23.8 | 28.0 |
| Mixed farmers | Groundnut | 26.7 | 16.3 |
| Mixed farmers | Dry beans | 23.6 | 19.5 |
| Horticultural dependant farmers | Cabbage | - | 12.6 |

**Table 12-4 Root mean square error (RMSE) values comparing measured and model simulated yields across different crops and farmer categories in Eastern Cape**

| Farmer category | Crop | RMSE Grain (%) | RMSE Stover (%) |
|---|---|---|---|
| Social welfare dependant farmers | Maize | 29.8 | 21.1 |
| Enterprising pensioners | | 27.4 | 13.6 |
| Struggling subsistence farmers | | 17.0 | 28.7 |
| Horticultural dependant farmers | | 29.5 | 16.9 |
| Social welfare dependant farmers | Groundnuts | 28.0 | 25.5 |
| Enterprising pensioners | Tomatoes | 28.1 | 16.2 |
| Horticultural dependant farmers | | 27.0 | 23.1 |
| Cooperative crop farmers | | 21.9 | 19.3 |
| Enterprising pensioners | Cabbages | - | 22.2 |
| Horticultural dependant farmers | | - | 5.7 |
| Cooperative crop farmers | | - | 6.7 |
| Struggling subsistence farmers | Dry beans | 18.3 | 19.2 |
| Horticultural dependant farmers | Green beans | 28.8 | 14.1 |

### 12.2.5. Integration of crop models and seasonal forecast information

A literature review was conducted on the techniques to integrate seasonal forecast information and process-based crop models (Chapter 5). The aim of the review was to determine the most feasible technique to integrate seasonal forecast and crop models under southern African conditions that produce seasonal forecast information at a daily time step, at relatively high resolution (Hansen and Indeje, 2004). The GCM approach is more feasible to integrate seasonal forecast and crop models. The approach produces seasonal forecast data at a daily time step which is compatible with input data requirements for process-based crop models. GCM-based forecasts are easily accessible. The GCM approach requires less computational capacity and skills to access and extract the data. The statistical prediction assumes a direct linear relationship between the predictor and crop yields, which is not characteristic of normal crop growth and development (Hansen et al., 2006). The approach therefore leads to under or over-estimation of crop yields. Stochastic disaggregation cannot produce out-of-parameterized events such as non-previously experienced extreme rainfall, temperature, dry, heat spell (Hansen and Ines, 2005). Stochastic disaggregation demands greater computational capacity as well as skill to extract the data. The analogue approach has limited applicability in areas where there is limited weather data collection, especially in small-scale farming agro-ecologies. Increased climate variability reduces the confidence in the analogue approach, as anthropogenic factors influence immediate future weather.

### 12.2.6. Farm management strategies

The research evaluated combinations of five management strategies: planting dates, fertilizer use, organic amendments, different crop types and varieties. The study assumed that small-scale farmers rarely uses a single strategy to manage climate variability, but rather use a combination of the different available strategies (Nda Nmadu and Dankyang, 2015). Multiple application levels of each strategies were considered, leading to a total of 48 different potential combinations of applied strategies (Table 12-5). Each of the combination of strategies was then evaluated for productivity under the bio-physical and socio-economic conditions of each small-scale farmer category (Chapter 6). The study assumed that the amount of fertilizer applied to the crops was directly proportional to the degree of resource endowment. For instance, resource constrained farmers would therefore be unable to purchase and apply more fertilizer compared to resource endowed farmers. On the contrary resource endowed farmers had financial resources and were therefore able to apply high fertilizer rates. The amount of fertilizer applied to each farmer category in the different scenarios were listed in Table 12-6 and Table 12-7. The DSSAT model can only effectively account for nitrogen compared to other elements hence the fertilizer was described in nitrogen terms only (Jones et al., 2003). The pattern was similar in seeding rate where resource constrained farmers have limited financial resources such that they are unable to purchase seed leading to lower seeding rates and planting populations (Table 12-8 and Table 12-9). Simulations were conducted for maize, cabbages, dry bean, green bean and tomatoes. These crops were selected as they were cultivated by farmers across all farmer types and locations. The study could not however simulate yields for crops such as onions, sweet potato, lettuce and butter nuts (Jones et al., 2003).

**Table 12-5 Potential combination of the climate variability strategies amongst small-scale farmers**

| Variety | Organic amendments | Fertilizer | Irrigation | Combination code |
|---|---|---|---|---|
| Short (SH) | No amendments (NO) | Fertilizer (FE) | Irrigation (IR) | SH-NO-FE-IR |
| | | | No irrigation (NR) | SH-NO-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | SH-NO-NF-IR |
| | | | No irrigation (NR) | SH-NO-NF-NR |
| | Grass mulch (GR) | Fertilizer (FE) | Irrigation (IR) | SH-GR-FE-IR |
| | | | No irrigation (NR) | SH-GR-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | SH-GR-NF-IR |
| | | | No irrigation (NR) | SH-GR-NF-NR |
| | Maize mulch (MM) | Fertilizer (FE) | Irrigation (IR) | SH-MM-FE-IR |
| | | | No irrigation (NR) | SH-MM-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | SH-MM-NF-IR |
| | | | No irrigation (NR) | SH-MM-NF-NR |
| | Compost (CO) | Fertilizer (FE) | Irrigation (IR) | SH-CO-FE-IR |
| | | | No irrigation (NR) | SH-CO-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | SH-CO-NF-IR |
| | | | No irrigation (NR) | SH-CO-NF-NR |
| Medium (ME) | No amendments (NO) | Fertilizer (FE) | Irrigation (IR) | ME-NO-FE-IR |
| | | | No irrigation (NR) | ME-NO-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | ME-NO-NF-IR |
| | | | No irrigation (NR) | ME-NO-NF-NR |
| | Grass mulch (GR) | Fertilizer (FE) | Irrigation (IR) | ME-GR-FE-IR |
| | | | No irrigation (NR) | ME-GR-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | ME-GR-NF-IR |
| | | | No irrigation (NR) | ME-GR-NF-NR |
| | Maize mulch (MM) | Fertilizer (FE) | Irrigation (IR) | ME-MM-FE-IR |
| | | | No irrigation (NR) | ME-MM-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | ME-MM-NF-IR |
| | | | No irrigation (NR) | ME-MM-NF-NR |
| | Compost (CO) | Fertilizer (FE) | Irrigation (IR) | ME-CO-FE-IR |
| | | | No irrigation (NR) | ME-CO-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | ME-CO-NF-IR |
| | | | No irrigation (NR) | ME-CO-NF-NR |

| Variety | Organic amendments | Fertilizer | Irrigation | Combination code |
|---|---|---|---|---|
| Long (LO) | No amendments (NO) | Fertilizer (FE) | Irrigation (IR) | LO-NO-FE-IR |
| | | | No irrigation (NR) | LO-NO-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | LO-NO-NF-IR |
| | | | No irrigation (NR) | LO-NO-NF-NR |
| | Grass mulch (GR) | Fertilizer (FE) | Irrigation (IR) | LO-GR-FE-IR |
| | | | No irrigation (NR) | LO-GR-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | LO-GR-NF-IR |
| | | | No irrigation (NR) | LO-GR-NF-NR |
| | Maize mulch (MM) | Fertilizer (FE) | Irrigation (IR) | LO-MM-FE-IR |
| | | | No irrigation (NR) | LO-MM-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | LO-MM-NF-IR |
| | | | No irrigation (NR) | LO-MM-NF-NR |
| | Compost (CO) | Fertilizer (FE) | Irrigation (IR) | LO-CO-FE-IR |
| | | | No irrigation (NR) | LO-CO-FE-NR |
| | | No fertilizer (NF) | Irrigation (IR) | LO-CO-NF-IR |
| | | | No irrigation (NR) | LO-CO-NF-NR |

**Table 12-6 Nitrogen fertilizer applied (kg ha$^{-1}$) to different crop within the different farmer categories in the Eastern Cape Province.**

| Crop | Application at Days after planting | Social welfare dependant (kg ha$^{-1}$) | Enterprising pensioners (kg ha$^{-1}$) | Struggling subsistence (kg ha$^{-1}$) | Horticultural dependant (kg ha$^{-1}$) | Cooperative crop (kg ha$^{-1}$) |
|---|---|---|---|---|---|---|
| Cabbage | 0 | 21 | 49 | 28 | 70 | 63 |
| | 14 | 22.5 | 52.5 | 30 | 75 | 67.5 |
| | 28 | 22.5 | 52.5 | 30 | 75 | 67.5 |
| | 45 | 22.5 | 52.5 | 30 | 75 | 67.5 |
| | 60 | 22.5 | 52.5 | 30 | 75 | 67.5 |
| Dry bean | 0 | 4.2 | 9.8 | 5.6 | 14 | 12.6 |
| | 42 | 8.4 | 19.6 | 11.2 | 28 | 25.2 |
| Green Bean | 0 | 11.1 | 25.9 | 14.8 | 37 | 33.3 |
| | 30 | 16.8 | 39.2 | 22.4 | 56 | 50.4 |
| | 60 | 16.8 | 39.2 | 22.4 | 56 | 50.4 |
| Maize | 0 | 7.5 | 17.5 | 10 | 25 | 22.5 |
| | 35 | 20.7 | 48.3 | 27.6 | 69 | 62.1 |
| Peanut | 0 | 3.3 | 7.7 | 4.4 | 11 | 9.9 |
| Tomato | 0 | 15 | 35 | 20 | 50 | 45 |
| | 42 | 21 | 49 | 28 | 70 | 63 |
| | 84 | 15 | 35 | 20 | 50 | 45 |
| | 120 | 15 | 35 | 20 | 50 | 45 |

**Table 12-7 Nitrogen fertilizer applied (kg ha$^{-1}$) to different crop within the different farmer categories in the Limpopo Province**

| Crop | Days after planting | Mixed (kg ha$^{-1}$) | Horticultural dependant (kg ha$^{-1}$) | Off-farm income dependant (kg ha$^{-1}$) |
|---|---|---|---|---|
| Maize | 0 | 51.8 | 70 | 37.1 |
| | 14 | 55.5 | 75 | 39.75 |
| | 28 | 55.5 | 75 | 39.75 |
| | 45 | 55.5 | 75 | 39.75 |
| | 60 | 55.5 | 75 | 39.75 |
| Dry bean | 0 | 10.36 | 14 | 7.42 |
| | 42 | 20.72 | 28 | 14.84 |
| Maize | 0 | 18.5 | 25 | 13.25 |
| | 35 | 51.06 | 69 | 36.57 |
| Peanut | 0 | 8.14 | 11 | 5.83 |
| Tomato | 0 | 37 | 50 | 26.5 |
| | 42 | 51.8 | 70 | 37.1 |
| | 84 | 37 | 50 | 26.5 |
| | 120 | 37 | 50 | 26.5 |

**Table 12-8 Plant density utilized in simulations for crops within the different farmer categories in the Eastern Cape Province**

| Crop | Social welfare dependant (plant population per m$^2$) | Enterprising pensioners (plant population per m$^2$) | Struggling subsistence (plant population per m$^2$) | Horticultural dependant (plant population per m$^2$) | Cooperative crop (plant population per m$^2$) |
|---|---|---|---|---|---|
| Cabbage | 0,9 | 2,1 | 1,2 | 3 | 2,7 |
| Dry Bean | 5,4 | 12,6 | 7,2 | 18 | 16,2 |
| Green Bean | 7,5 | 17,5 | 10 | 25 | 22,5 |
| Maize | 1,3 | 3,1 | 1,8 | 4,4 | 4,0 |
| Peanut | 4,5 | 10,5 | 6 | 15 | 13,5 |
| Tomato | 0,6 | 1,4 | 0,8 | 2 | 1,8 |

**Table 12-9 Plant density utilized in simulations for crops within the different farmer categories in the Limpopo Province**

| Crop | Mixed (plant population per m$^2$) | Horticultural dependant (plant population per m$^2$) | Off-farm income dependant (plant population per m$^2$) |
|---|---|---|---|
| Cabbage | 2.2 | 3 | 1.6 |
| Dry Bean | 13.3 | 18 | 9.5 |
| Maize | 3.3 | 4.4 | 2,3 |
| Peanut | 11.1 | 15 | 8.0 |
| Tomato | 1.5 | 2 | 1.1 |

After calibration of the DSSAT crop model, crop yield simulations were conducted based on the 48-different potential climate variability management strategies (Table 12-5) under 23 sets of different seasonal forecast and under different farmer types (Figure 12-1).

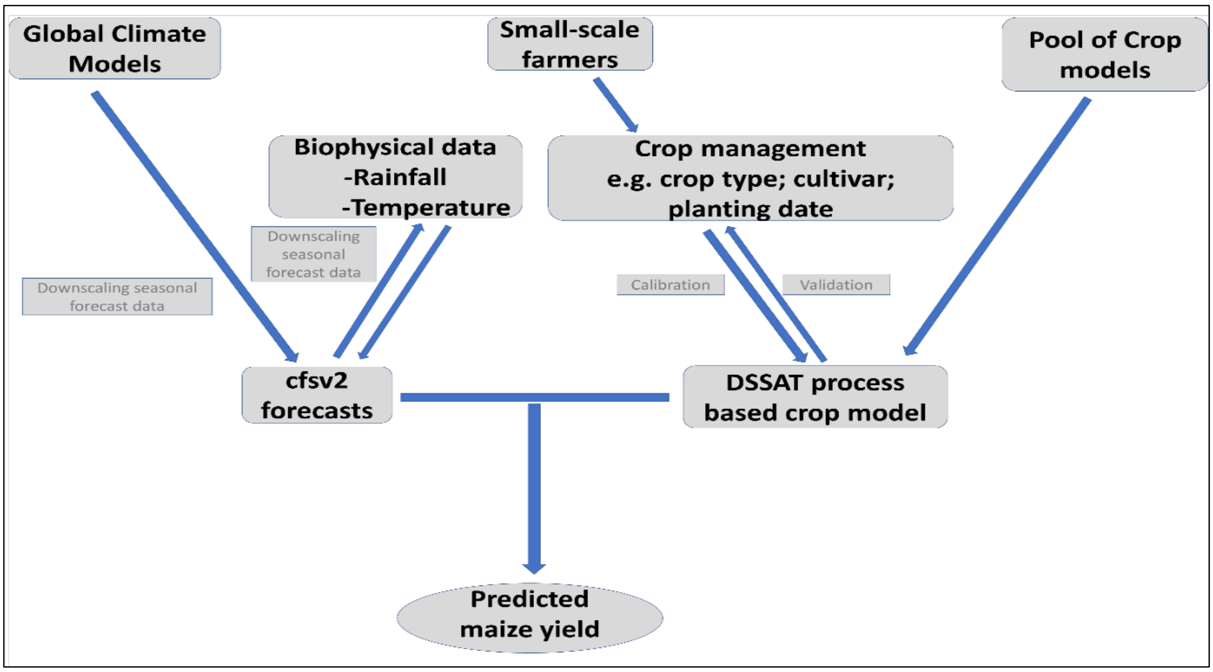

**Figure 12-1 Conceptual framework of the process of integrating seasonal forecast information and crop models for decision making in small-scale farmers**

## 12.3. Results

### 12.3.1. Seasonal forecast variation

The CFSv2 model was used to forecast rainfall and temperature for the 2017/18 season for both Limpopo and Eastern Cape. The forecasts outputs for minimum and maximum temperature were displayed in boxplots (Figure 12-2 and Figure 12-3). There was notable seasonal forecast variability in daily minimum temperature across both locations. In Eastern Cape, the variation was greater in October and June and is lower from November to May but it is constant throughout the season in Limpopo. There is therefore slightly greater variation in minimum summer temperatures the Eastern Cape compared to Limpopo. There is slightly greater variation in summer maximum temperatures for both Eastern Cape, and Limpopo for the months of October, November, December and January. In Limpopo variation in maximum temperatures is higher from October to March but the variation reduces from April to July.

Minimum temperature

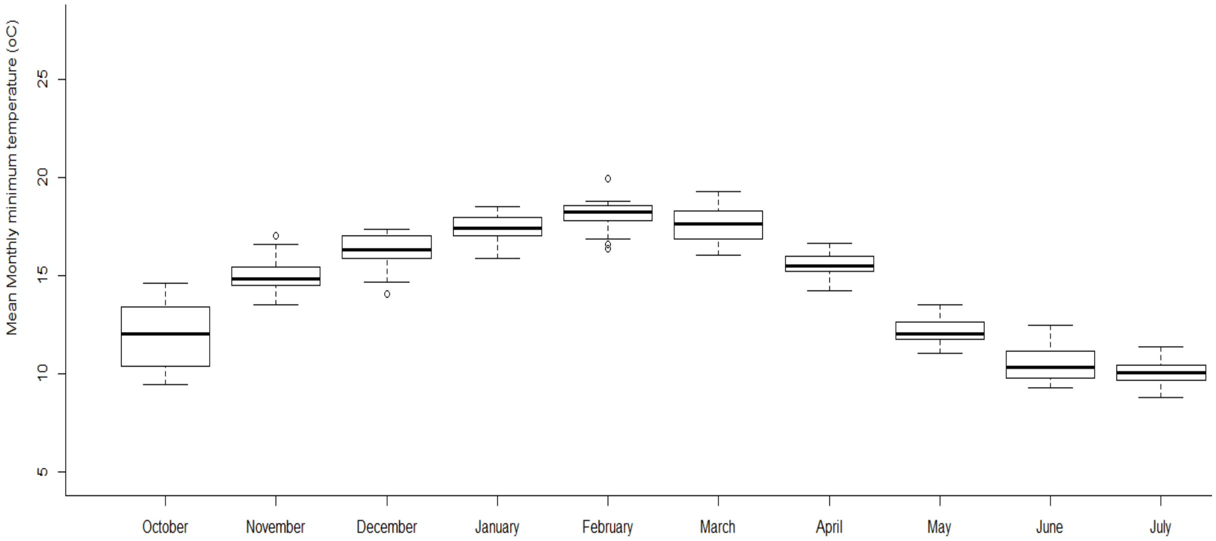

**Figure 12-2 Mean minimum monthly temperatures from 23 seasonal forecasts for the 2017-18 cropping season in Nkonkobe, Eastern Cape, Limpopo, South Africa**

Maximum temperature

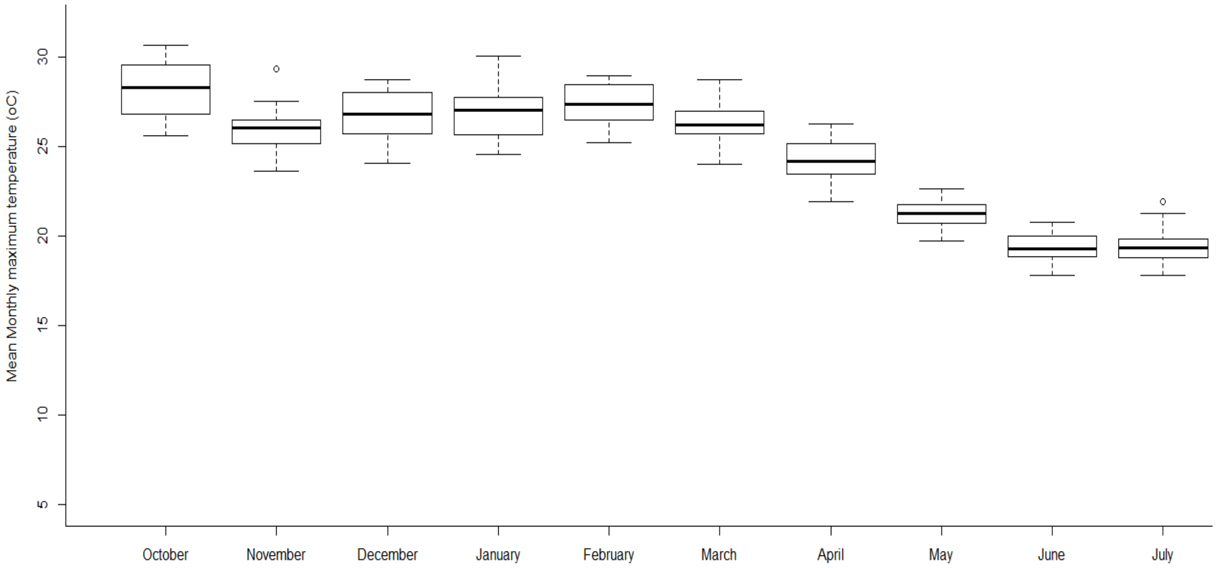

**Figure 12-3 Mean maximum monthly temperatures from 23 seasonal forecasts for the 2017/18 cropping season in Lambani, Limpopo, South Africa**

Rainfall

The general rainfall trends of measured daily historical rainfall (2000-2016) were compared to the 23 rainfall forecasts for the 2017/18 season. The outputs were displayed in line graphs (Figure 12-4 and Figure 12-5). Rainfall forecasts show notable seasonal variation between Eastern Cape and Limpopo, South Africa. Almost all forecasts in Eastern Cape were outside historical rainfall trends. In contrast, in Limpopo, about 90% of the forecasts were within historical range. For Eastern Cape, the cumulative forecasted rainfall ranged from 720 mm to 1 400 mm per season. The lowest cumulative in-season historically measured rainfall was 300 mm in 2008/9 compared to the maximum historical in-season rainfall of 510 mm in 2000/1 (Figure 12-4. In the Limpopo province, the minimum cumulative historical measured rainfall was 245 mm in the 2004/5 season compared to the maximum of 745 mm in the 2012/13 season. Of all the 23 rainfall forecasts only 2 had a cumulative seasonal rainfall larger than 745 mm, thus the seasonal rainfall forecasts were mostly within the boundaries of historically measured cumulative rainfall (Figure 12-5).

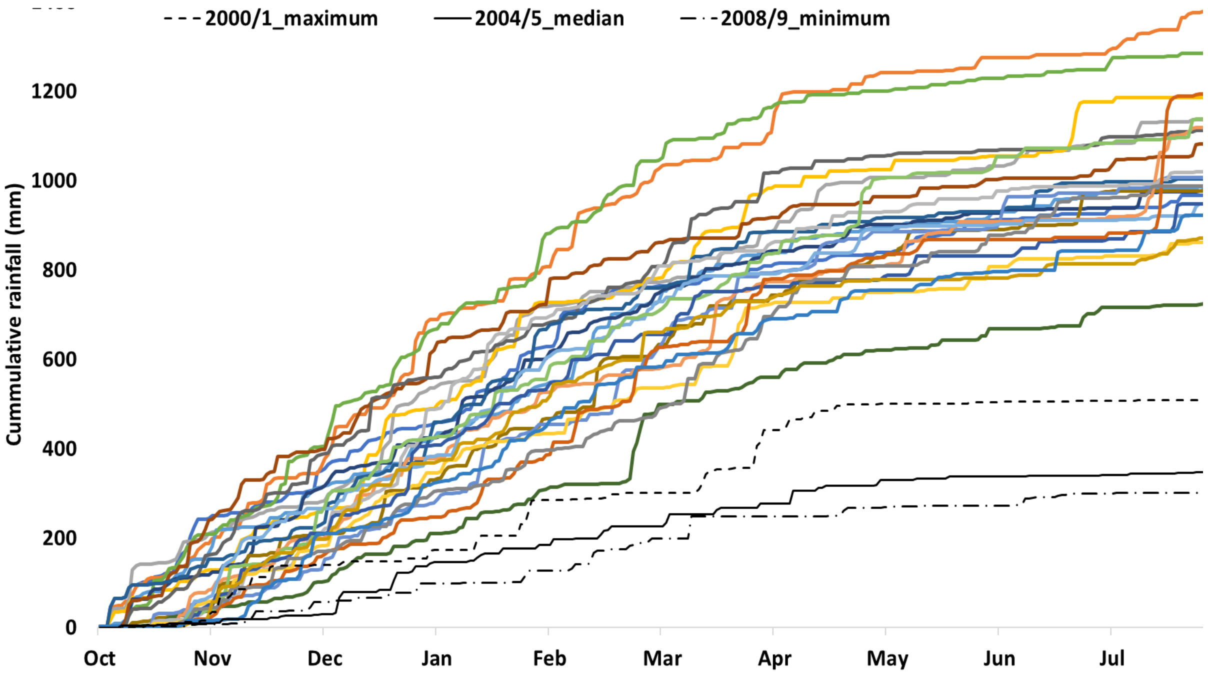

**Figure 12-4 Cumulative daily rainfall from 23 seasonal forecasts for the 2017/18 cropping season and historical seasonal minimum, median and maximum seasonal rainfall in Nkonkobe, Eastern Cape**

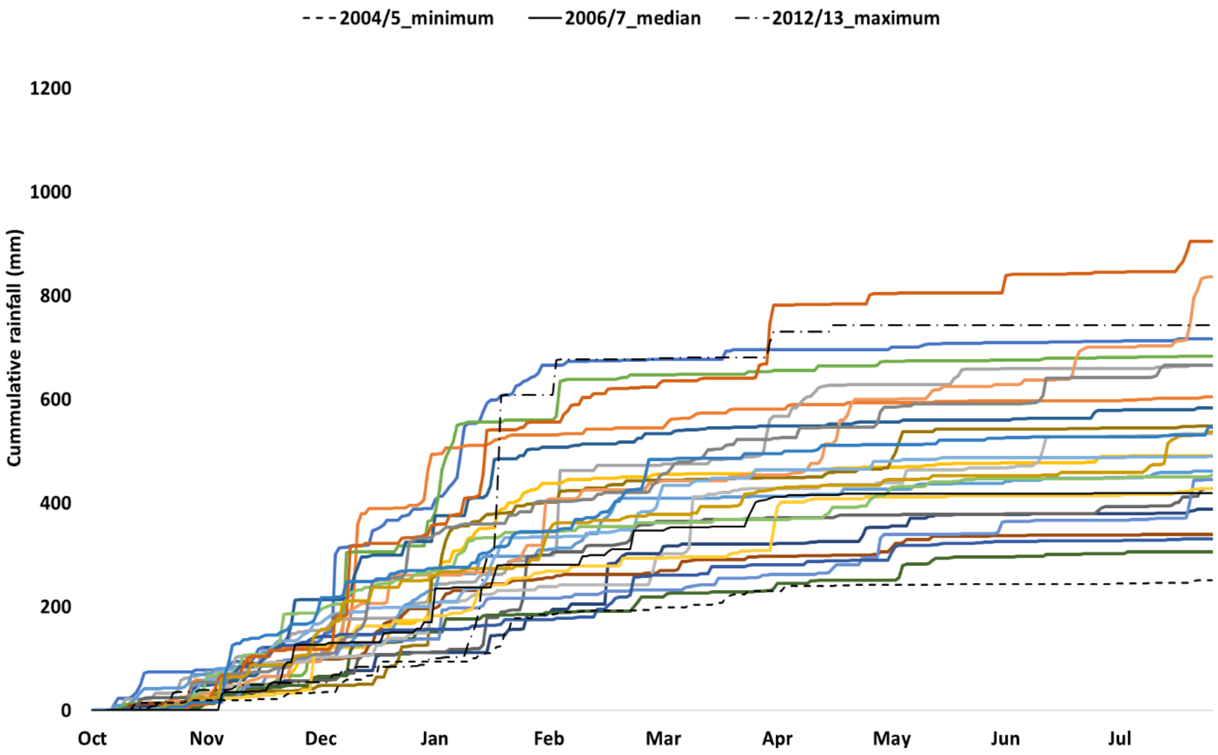

**Figure 12-5 Cumulative daily rainfall from 23 seasonal forecasts for the 2017/18 cropping season and historical seasonal minimum, median and maximum seasonal rainfall in Lambani, Limpopo, South Africa**

### 12.3.2. Crop yield variation in response to seasonal forecast

The study evaluated the productivity of 48 strategies under different seasonal forecasts and sowing dates throughout the season. The study utilized box plots to assess crop yield variation from the 23 different forecasts within each planting period (Figure 12-6 to Figure 12-11). For comparing yield variation resulting from the 23 different forecasts, the study selected the strategy with compost, long seasoned variety, fertilizer and irrigation CO-LO-FE-IR across the different crops and locations (Table 12-5).

Overall, there was notable variation in crop yield across the different seasonal forecasts in all crops and locations. In both locations the yield variation was greater towards the end of the season. In all crops except maize, yield variation was greater in the Eastern Cape compared to Limpopo. The highest maize yields were obtained in Limpopo compared to the Eastern Cape. In the Eastern Cape crop yields, generally decreased as the season progressed whereas the yields increased as the season progressed in Limpopo. In addition, the sowing window was generally narrow in the Eastern Cape compared to Limpopo for all crops except for Cabbage. It extended to April for most crops whereas it was early in December in the Eastern Cape.

In the Eastern Cape, early seeding led to higher yields in the Eastern Cape, across all forecasts. In a cropping season that spanned from October to May, yields gradually decreased due to delayed planting conducted towards the end of the season. Sowing after December leads to low maize yields. On the contrary, in Limpopo, yields were relatively lower early in the season but gradually increased as due to delayed sowing conducted towards the end of the season, peaking in the middle of the season in most cases.

Specifically, there was significant maize yield variation in both locations. In both locations, maize yield variation amongst the 23 seasonal forecasts was lower from yields resulting from earlier planting dates. Maize yield variation was relatively higher with later planting dates towards end of the season. Maize yield variation amongst the different seasonal forecasts was zero, early-December and mid-February for Eastern Cape and Limpopo respectively, as the yields were zero in each of the forecasts in each planting window (Figure 12-6 and Figure 12-7). In the Eastern Cape the highest yields of about 4 300 kg ha$^{-1}$ were obtained by sowing early in the season, i.e. early October. On the contrary, maize yields were lower from late planting dates towards the end of the season. This was in contrast to Limpopo, where maize grain yields were lower on early planting and relatively higher on late planting mid-January. The maize planting window was longer in the Limpopo province compared to the Eastern Cape. The planting period was mid-October to mid-December for Eastern Cape and extended to mid-February for Limpopo.

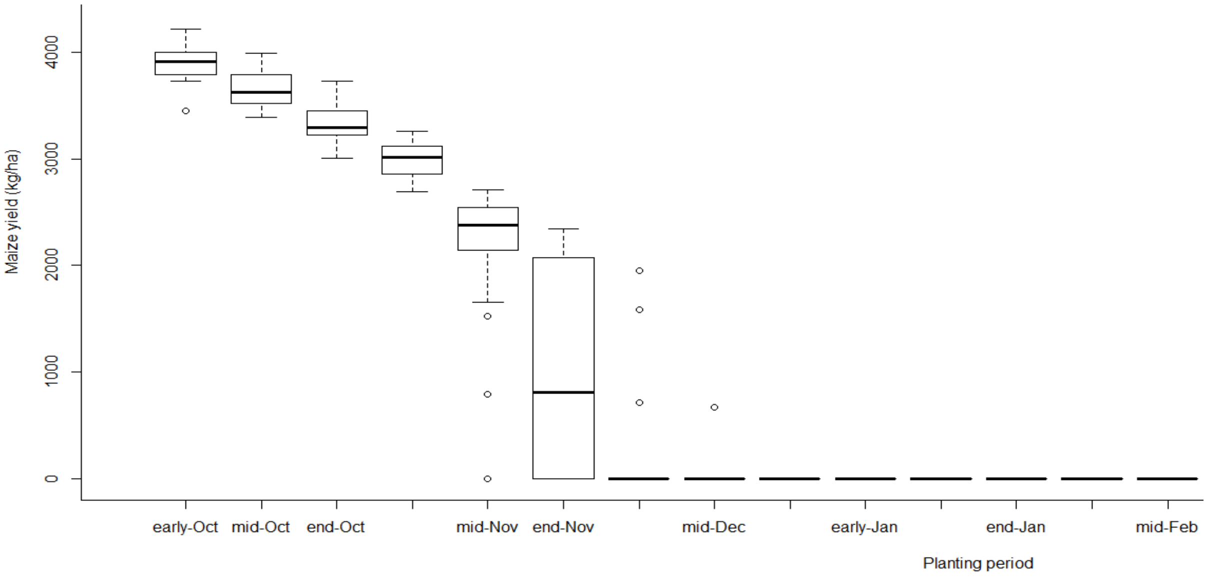

**Figure 12-6 Distribution of maize grain yields from the different seasonal forecasts within different planting periods for the 2017/18 season in Eastern Cape, South Africa**

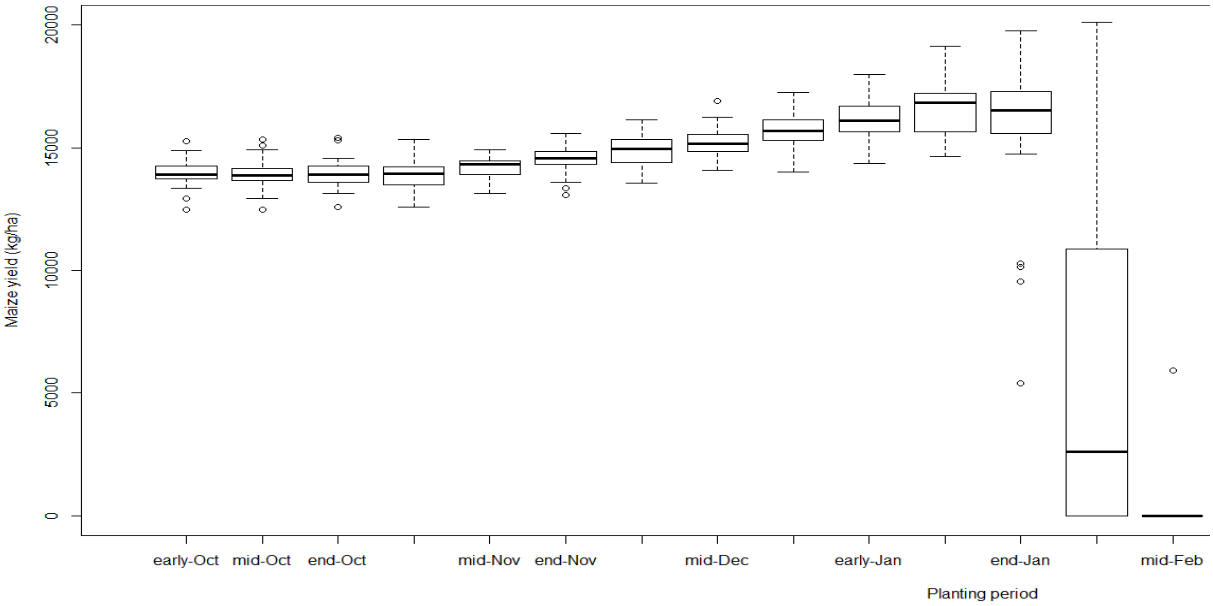

**Figure 12-7 Distribution of maize grain yields from the different seasonal forecasts within different planting periods for the 2017/18 season in Limpopo province, South Africa**

Similar to maize, there was notable variation in dry bean yields in both locations. Dry bean yield variation amongst the 23 seasonal forecasts was greater in late planting towards the end of the season for both locations. There were however differences, as in the Eastern Cape yield variation amongst the seasonal forecast reduced with, with delayed planting towards the end of the season. This was in contrast to Limpopo where yield variation was greater in planting dates around mid-December, which is in the middle of the planting window. In the Eastern Cape, dry-bean yields were higher with early seeding in mid-October and they gradually reduced with delayed planting towards of the end of the season. In contrast, early seeding did not lead to higher yields in Limpopo. Instead the yields fluctuated whilst increasing with delays in planting peaking in mid-November and mid-March. In contrast to maize the planting window for both Eastern Cape and Limpopo was similar for dry-bean ending in early-March and mid-April respectively.

There was notable green bean yield variation throughout the season. Yield variation was however more notable in November and January. The planting window extended until January which was shorter than dry beans. The maximum yields were obtained from seeding in the periods, early and late November.

There was notable variation in peanut yields in both locations. The greater peanut yield variation amongst the 23 seasonal forecasts was realized in yields resulting from delayed planting dates towards end of the season for both locations. Highest yields were obtained in early-November for both locations. There were however notable differences in the planting window, where it extended to early December and end of February respectively (Figure 12-8 and Figure 12-9).

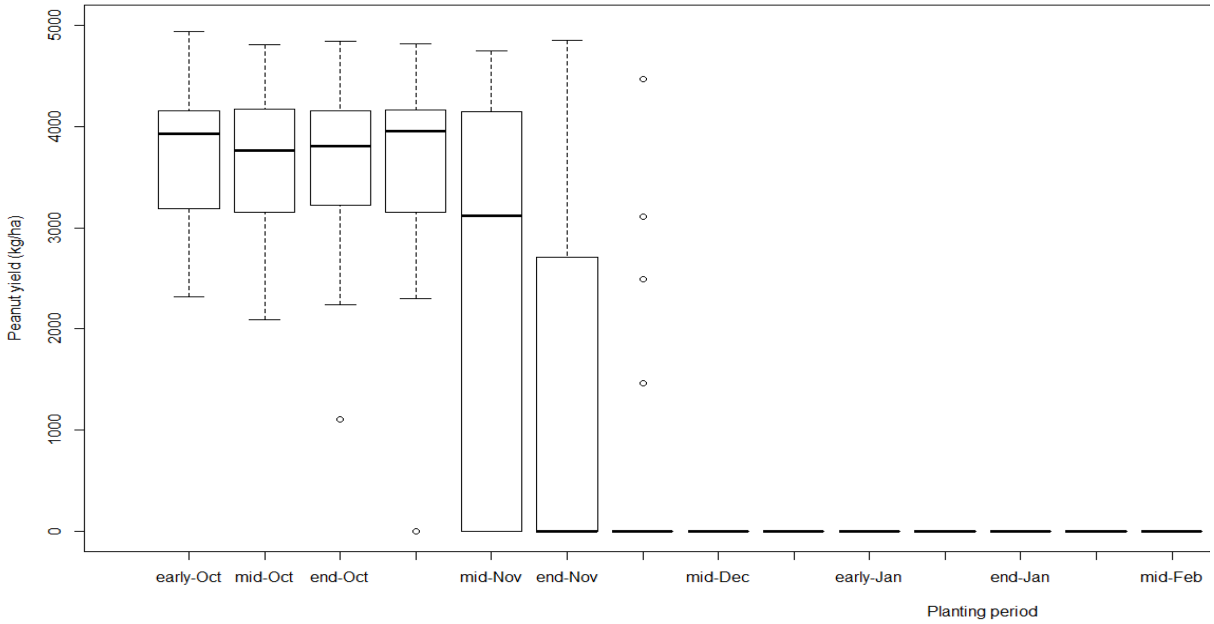

**Figure 12-8 Distribution of peanut grain yields from the different seasonal forecasts within each planting period for the 2017/18 season in Eastern Cape, South Africa**

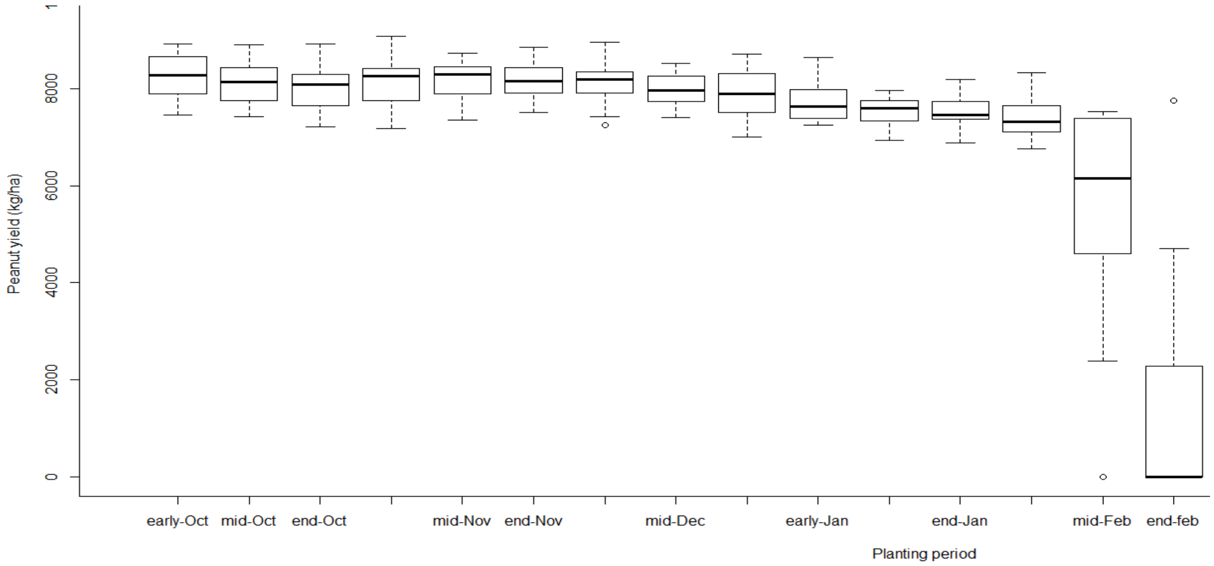

**Figure 12-9 Distribution of peanut grain yields from the different seasonal forecasts within each planting period for the 2017/18 season in Limpopo province, South Africa**

There was notable cabbage yield variation across the 23 different seasonal forecasts within each planting period in both locations. In the Eastern Cape, yield variation decreased with delayed planting dates. In contrast, the cabbage yields across the different seasonal forecasts fluctuated in different planting dates throughout the season but peaked with later planting dates towards the end of the season. The highest yields in the Eastern Cape were obtained on planting in early October compared to Limpopo where planting in late January led to the highest yields. The sowing window also differed where in Eastern Cape the window extended to early February but extended to mid-March in Limpopo.

There was notable variation in Cabbage yield across in all the planting periods in both locations. The variation was however greater in the Eastern Cape compared to Limpopo. In Limpopo the highest yields were realized from sowing in the period end of December whereas the highest yields were obtained towards the need of the season at end of January in Limpopo. In contrast to all crops the planting window was greater in the Eastern Cape compared to Limpopo. It extended to April in the Eastern Cape whereas it extended to early February in Limpopo (Figure 12-10 and Figure 12-11).

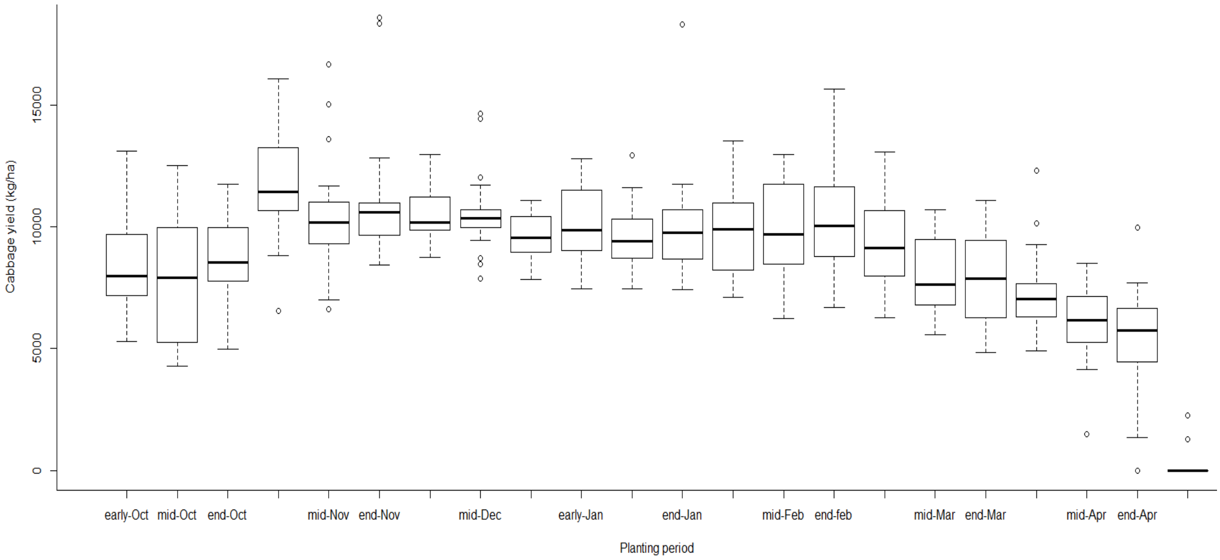

**Figure 12-10 Distribution of cabbage yields from the different seasonal forecasts within each planting period for the 2017/18 season in Eastern Cape**

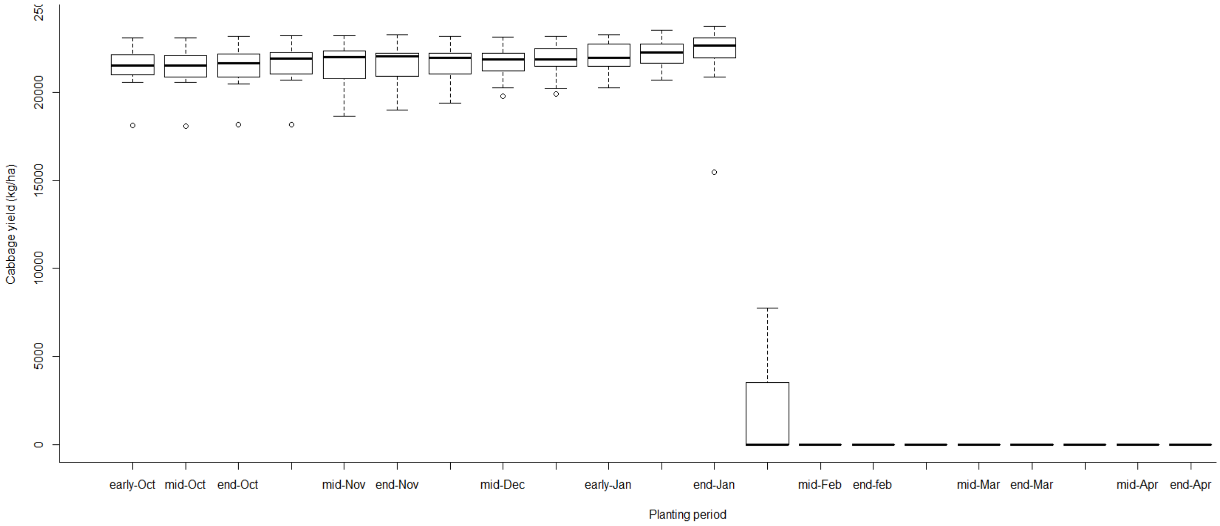

**Figure 12-11 Distribution of cabbage yields from the different seasonal forecasts within each planting period for the 2017/18 season in Limpopo province**

### 12.3.3. Crop forecast-based decision-making process

This part of the study aimed to identify the process of identifying at least a set of farm management strategies leading to the highest yields for each crop and different farmer types, given a range of different seasonal forecasts. The study used heat maps to describe yield variations between the different farm management practices and seasonal forecasts. The 'red' and 'yellow' colours indicated relatively 'low' and 'high' crop yields respectively. The dendrogram clustered the farm management practices and seasonal forecasts leading to similar crop yields.

### Uniform farm management decision making

There were instances where there was a low decision capacity and low sensitivity to climate. This was manifested through uniform performance from all the farm management decisions. Forecast insensitivity was manifested as the performance of farm management decisions was uniform across all forecasts of notable variability. Decision making would therefore be challenging as the performance of all the different farm management decisions was uniform.

Specifically, there were instances where neither varying farm managements nor varying forecasts led to differences in crop productivity, as highlighted by the uniform 'red' colour, which is an indication of relatively lower yields (Figure 12-12 and Figure 12-13). The crop yields were relatively lower across most farm management strategies and different seasonal forecasts interactions. There is a relatively lower chance of such kind of a decision since about 9% of the scenarios in this study led to state of inconclusive decision making. In at least 99% of the farm management and seasonal forecast scenario combinations, the productivity was similar. Any decision making will lead to similar productivity.

The pattern was specific for tomato production, amongst cooperative crop farmers for mixed farmers in Limpopo (Figure 12-12). South Africa. In most cases farm management decisions leading to high productivity were generally similar. They were similar due to the similar colour code across all scenarios. There were some instances where there were slight differences in the ideal farm management decisions due to the alternating 'faint red' and 'dark red' colours. Despite the minor differences, there were no notable differences in the overall decision-making process (Figure 12-13).

In both cases the medium maturity tomato varieties were the most common strategies. Despite the uniform performance of the different farm management decisions, between tomato yields for cooperative crop farmers in the Eastern Cape and mixed farmers in Limpopo, South Africa, there were minor differences for cooperative farmers. Strategies with irrigations showed slightly higher yields compared to other strategies but there were minor differences as observed by the similarity in the colour codes. In both cooperative crop farmers in the Eastern Cape and mixed farmers in Limpopo, South Africa, less than 1% of the cases GRMENFIR and NOMEFEIR in Eastern Cape and Limpopo had the highest yields.

**Figure 12-12 Tomato yields under different seasonal forecasts (x axis) and different practice combinations (y axis) amongst mixed farmers in Limpopo, South Africa**

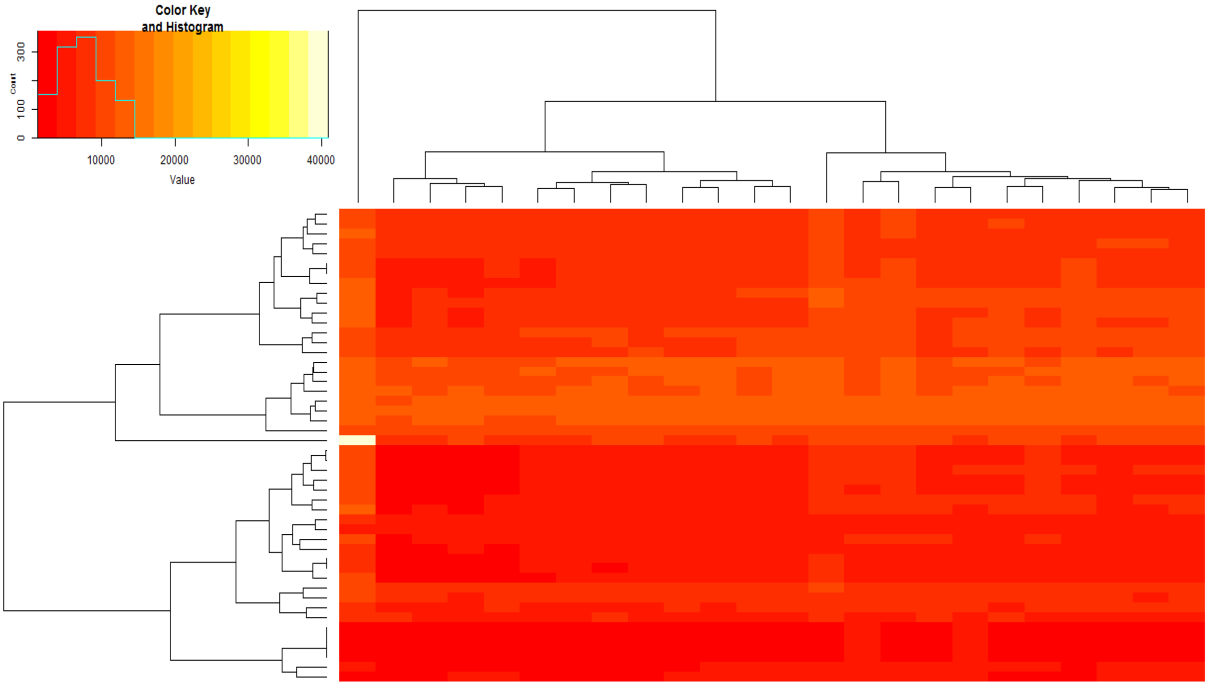

**Figure 12-13 Tomato yields under different management strategies (y axis) and seasonal forecasts (x axis) for mixed farmers in Limpopo, South Africa**

Specifically, there were some instances where the management systems leading to the highest yields were consistently similar across all seasonal forecasts. The pattern leads to consistent decisions across all the forecasts. This therefore implies that these strategies are resilient to climate variability as they lead to consistently higher yields across all forecasts. The pattern was consistent in about 51% of all the case studies. The strategies with organic amendments, fertilizer and irrigation consistently had higher yields across all forecasts. The strategies with no irrigation consistently had relatively lower yields as illustrated by the deepening red colour (Figure 12-14). Strategies with long seasoned varieties, fertilizer and irrigation showed relatively high yields but no organic amendments such as NO-LO-FE-IR, led to relatively lower yields across compared to similar strategies with organic amendments such as grass, e.g. GR-LO-FE-I|R. The pattern was consistent across all the forecasts for each of the crops and farmer types.

Specifically, for social welfare dependant farmers in the Eastern Cape, South Africa, farm management decision strategies that consistently led to higher maize grain yields contained long seasoned varieties, organic amendments, fertilizer and irrigation. In this scenario, there some instances, where the highest yields were derived from strategies with no fertilizer. This was particularly in strategies with compost manure. This was in contrast to Figure 12-14 where the all farm management decisions with no fertilizer led to lower yields across all forecasts. The lowest maize yields were derived from strategies with no irrigation and mostly with long seasoned varieties as well as short season varieties with no fertilizer and irrigation. Some strategies with no irrigation also led to relatively higher yields of about 4-6 t ha$^{-1}$ across all seasonal forecasts. The pattern was consistent across all crops, farmer types in the 2 locations except in peanuts. In contrast to Figure 12-12, the highest yields were also derived from different types of varieties. The highest yields were however still realized from long seasoned varieties and then short seasoned varieties (Figure 12-15).

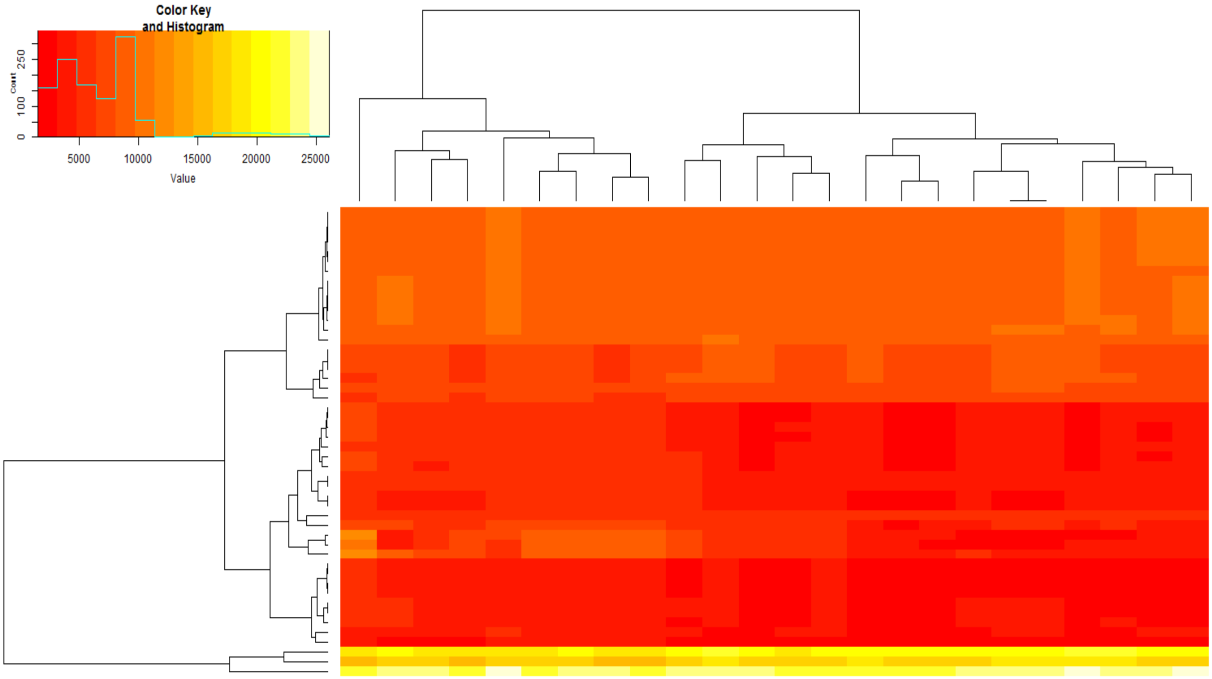

**Figure 12-14 Maize yields under various practice combinations (y axis) and different seasonal forecasts (x axis) amongst mixed farmers in Limpopo, South Africa**

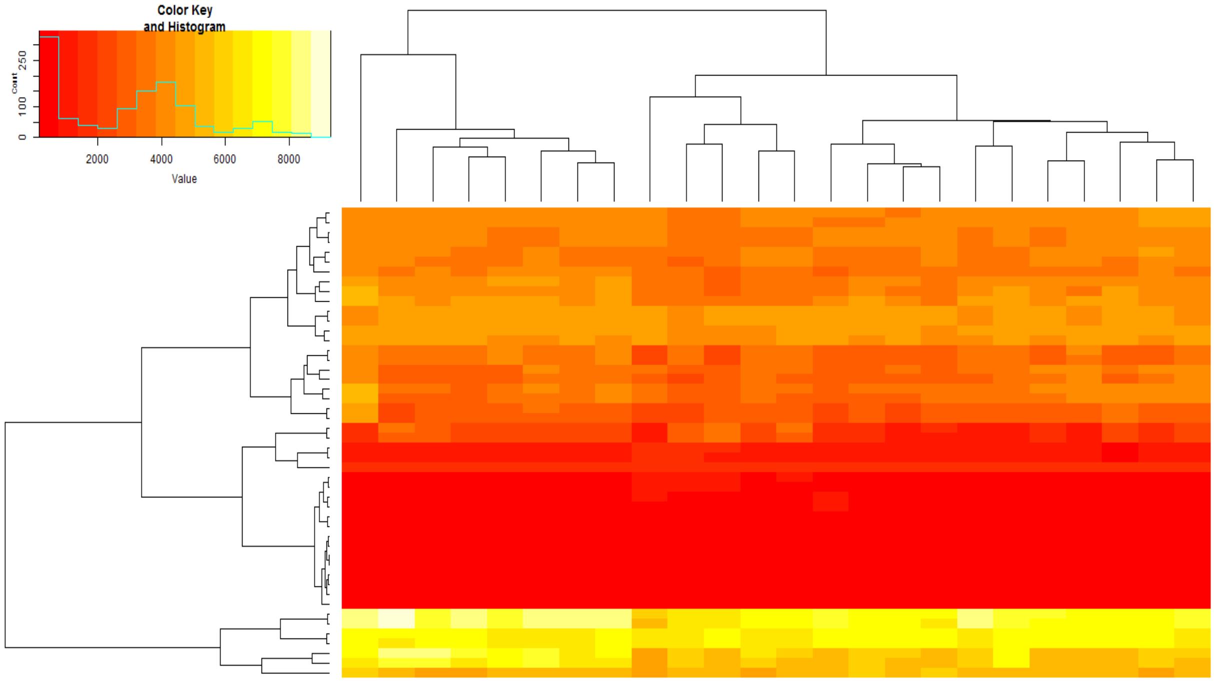

**Figure 12-15 Maize yields under different management strategies (y axis) and seasonal forecasts (x axis) for social welfare dependant farmers in Eastern Cape, South Africa**

### Climate specific farm management decisions

There was greater decision-making capacity for farm management decisions and greater sensitivity for seasonal forecast information. The greater decision capacity was manifested through the contrasting colour codes which denotes leads to easier decision making. Climate sensitivity was manifested through the contrasting colour codes which denotes strong sensitivity to some farm management decisions compared to other decisions.

Specifically, there were instances where the productivity of farm management decisions differed amongst the different forecasts. Specifically, some strategies led to higher crop yields under certain seasonal forecasts but led to lower yields under same management but different strategies. Some seasonal forecasts had consistently higher yields compared to some forecasts. The pattern was consistent in about 40% of all the cases.

Specifically, in Figure 12-16, under off-farm income farmers in peanuts, in the Eastern Cape, farm management decisions containing long seasoned varieties, fertilizer and irrigation led to higher yields amongst all forecasts except from forecasts 01 and 11. Forecasts 24, 03 and 21 had higher peanut yields under maize mulch, medium varieties, no fertilizer and no irrigation, whereas other forecasts showed lower yields under the same strategies. Strategies with medium varieties, organic amendments and irrigation such as CO-ME-NF-IR and GR-ME-NF-IR led to higher peanut yields in some forecasts such as 24, 12 and 13 compared to all other forecasts which showed relatively lower peanut yields.

The pattern was similar and more pronounced for green beans amongst mixed farmers in Limpopo, South Africa (Figure 12-17). Most of the strategies leading to lower yields did not contain irrigation and the pattern was uniform and consistent amongst all forecasts, e.g.

COMEFENR. There were also strategies such as GRLOFENR that led to lower yields amongst about 42% of the forecasts and also led to higher yields amongst 52% of the forecasts. Most of the strategies leading to higher green bean yields under mixed farmers in Limpopo, South Africa contained irrigation with no organic ground cover as well as varying maize varieties even as short seasoned varieties.

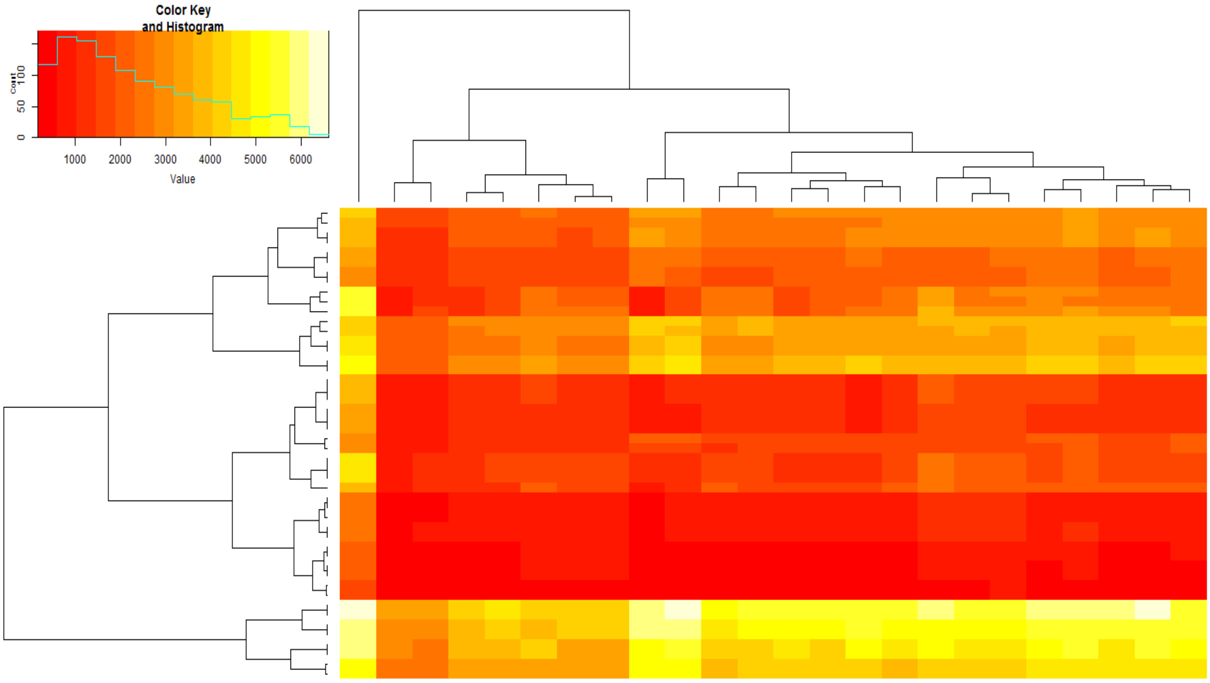

**Figure 12-16 Peanut grain yield under different management strategies (y axis) and seasonal forecasts (x axis) for off-farm income farmers in the Eastern Cape, South Africa**

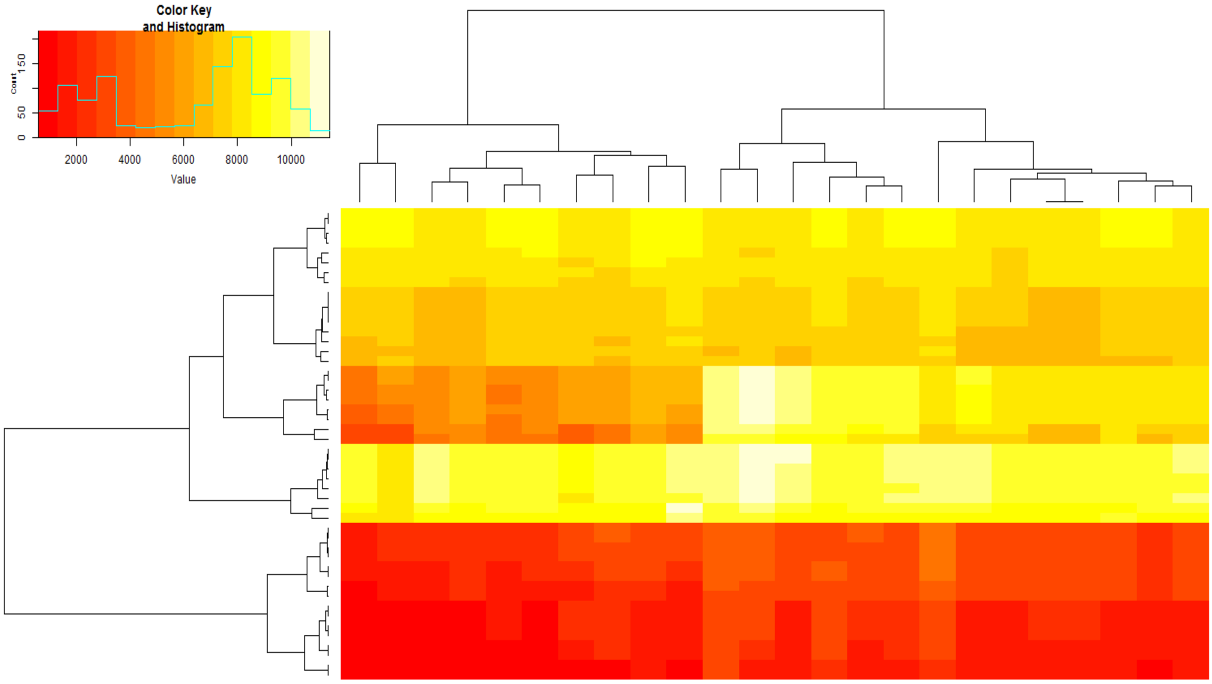

**Figure 12-17 Green bean production under different management combinations (y axis) different seasonal forecasts (x axis) amongst mixed farmers in Limpopo, South Africa**

## 12.4. Discussion

### 12.4.1. Forecast variability and crop productivity

The yield variation across the different crops and locations was attributed to the notable variation in the CFSv2 seasonal weather forecast information across all parameters in both the Eastern Cape and Limpopo provinces. There are multiple factors that determine weather, within a specific agro-ecological zone. In contrast to atmosphere-land interaction, there are many oceanic-atmospheric-based determinants of weather that have not been accounted for by scientific research. Global climate models would therefore have to account for determinants of weather to effectively predict future weather. There is therefore a greater day to day variation in temperature and rainfall, leading to notable crop yield variation (Landman et al., 2012).

There was also notable increased crop yield variation from sowing periods towards the end of the season across all crops and locations. This was attributed to the increased rainfall variability towards the end of the cropping season. Increased rainfall variability leads to reduced planting opportunities which is associated with extreme rainfall variability biased towards low rainfall events. This therefore increases the chances of crop failure, hence increased yield variability resulting from seeding dates towards the end of the season.

The CFSv2 forecast extends to 9 months and for this study the forecast period was from October to June. The DSSAT model cannot therefore simulate yield outside the boundaries of the 9-month period. The model therefore did not produce yields for planting dates beyond April (Jones et al., 2003).

Generally, the highest yields were realized by sowing early in the season in the Eastern Cape. Early seeding increases the crop's chance of being exposed to greater solar radiation, increased soil nitrogen mineralization (Cregger et al., 2014). This therefore causes early vigorous crop growth. When the crop experiences mid-season dry spells, the crop would have already acquired tolerance due to initial vigorous growth. Delayed sowing would therefore cause low yields as this increases the crop's chances of sensitive phonological growth stages coincides with mid-season dry spells, leading to lower yields (Nyagumbo et al., 2016). A day's delay in planting leads to about 5% yield loss in maize (Shumba et al., 1999). The major cause of yield loss as the season progresses is the increased rainfall and temperature variability as the season progresses.

On the contrary early sowing did not lead to the highest yields in Limpopo, but the highest yields were determined from sowing in the middle of the cropping season. There is increased rainfall variability earlier in the season in Limpopo. In addition, the precipitation intensity is relatively lower. This therefore reduces the amount of water available for crop growth and development earlier in the season. This increases the chances of crop failure as well as low yields. Sowing in the middle of the season, will make the crop germinate and develop after the early season and mid-season droughts have passed. This therefore increases the chances of higher germination as well as higher crop yields.

The planting window was generally shorter in the Eastern Cape compared to Limpopo across all crops. The effective sowing window for Limpopo ranged from October-April. This was in contrast to Eastern Cape where the effective planting date range was relatively short from October to December. Poor skill and overestimation of crop yields in the Eastern Cape, led to over estimation of rainfall. The forecast rainfall range was outside the historical range. Overestimation of rainfall led to over-extension of the growing period of crops, such that the crop growing period is extended thus delaying maturity. The planting window was thus greater than for Limpopo. This was despite the fact that from historical records, Limpopo receives greater rainfall compared to the Eastern Cape.

The study realized notable variation in seasonal forecast as well as yield forecasts across all locations and crops. Most rainfall forecasts for Limpopo are within the historical range of measured weather data whereas most forecasts in the Eastern Cape were not within historical range. Previous research which has realized in South Africa there is higher skill in North eastern, western and central regions of South Africa (Landman et al., 2012). There is limited forecasting skill in the South-eastern region, which is occupied by the Eastern Cape province of South Africa. The lower skill in regions on the boundaries of the oceans, such as the Eastern Cape, is therefore potentially attributed to the inability of the models to account for most of the factors that determine weather, as well as the additional ocean-based climate determining factors. In contrast to the Eastern Cape, crop yield forecasts and corresponding recommendations from Limpopo are therefore likely to be within historical range, since there is a linear relationship between rainfall and crop yields.

### 12.4.2. Decision making process

When faced with a range of potential farm management decisions researchers and farmers potentially face challenges on the most appropriate choice. The study has largely classified farm management decision making into (1) low decision capacity and low climate sensitivity. (2) Greater decision capacity and low climate sensitivity. (3) Greater decision capacity and greater climate sensitivity. The study did not however realize another potential decision-making scenario where there can be (4) low decision capacity and greater climate sensitivity.

Under the low decision capacity and low climate sensitivity scenario, there are challenges in decision making as all the management decisions have uniform regardless under the different climate conditions. Given such a scenario a farmer would have challenges in the choice of farm management decisions. This is compounded by the lack of climate sensitivity. From the study such a choice however only exists in about 9% of the total scenarios hence the chances of a farmer facing the scenario are relatively lower.

On the other hand, it is potentially relatively easier to make farm management decisions where there is greater decision making capacity and lower climate sensitivity. The scenario is highly useful as there is a clear pattern and distinction of the range of different farm management decisions. A researcher or farmer can therefore distinguish the ideal farm management decision. The scenario is however not very useful if the research aims to assess climate or forecast variability as there is low sensitivity to climate. There is a greater chance of farmers experiencing such as decision-making scenario, as it occurred in about 51% of the scenarios in this study.

It is also relatively easier to make farm management decisions under the scenarios where there is both greater decision capacity and greater climate sensitivity. There are notable differences in the performance of farm management decisions across the difference seasonal forecasts, hence it is relatively easier to select farm management decisions. To a farmer distinguishing the management decision of choice is however challenging as there is need to separate and analyse the characteristics of the different climate forecasts. For climate and variability management analysis the scenario is useful as one can make farm management decisions that correspond to specific climate conditions. Such decision-making scenario was observed in about 40% of the scenarios hence there is chance that such may not occur but it I however worth noting.

The study did not however exhibit the low decision capacity and greater climate sensitivity decision making scenario. Such scenario would be the most challenging in decision making as there is low decision capacity. The further challenge is the increased climate sensitivity which could be a manifestation of increased climate variability. This is the most challenging for a farmer as they will not be able to make decisions under greater climate under forecast variability.

### 12.4.3. Crop management strategies

Strategies that led to higher yields contained organic residues such as maize, grass and compost, long seasoned varieties, fertilizer and irrigation. This was consistent across all forecasts. Organic cover increases the amount of soil moisture. Soil water is critical in crop growth and development. Increased soil moisture enhances and prolongs crop growth and development leading to higher yields. The degree of yield increment differs with quantity and type of organic ground cover. Low quantities of mulch reduce moisture conservation leading to reduced yields. Mulch has proved to be effective in conserving soil moisture amongst farmers in Southern Africa. Past research shows that use of mulch leads to significant increase in yields under drier conditions as well as in soils of lower holding capacity. Mulching increases crop yields by as high as least 50% (Thierfelder et al., 2014). Farmers cannot be restricted to the use of grass, maize mulch and compost used in the study. Farmers can also make use of the diverse array of organic amendments such as leaf litter and residues from leguminous crops such as sunhmep, tephrosia and mucuna. Use of greater quantities of mulch can however lead to waterlogging with consequences in leaching and ultimate crop yields loss (Wang et al., 2017). The combination of strategies is potentially more reliable for use by farmers as about 51% of the simulations contained organic ground cover, fertilizer and irrigation.

There were some strategies where the different strategies led to contrasting yields under different forecasts. This was dominant in 40% of the simulations. Specifically, for peanut about 10% of the forecasts had lower yields under organic residues, long seasoned varieties, fertilizer and irrigation. This may have been attributed to the higher rainfall of above 1 100 mm received in the forecasts as well as the additional irrigation. This therefore led to excess water available for crop growth and development. Thus causing; leaching and ultimately low yields. Farmers who have limited resources can therefore not use irrigation as there is sufficient soil moisture from the rainfall (Wang et al., 2017).

Most farmers prefer strategies that conserve soil moisture or minimizes soil moisture demand. Use of fertilizer does not increase or reduce soil moisture but however enhances the effectiveness of other strategies to manage climate risk. Fertilizer increases nutrient availability to crops, therefore increasing efficient utilization of supplementary or conserved soil moisture. Use of crop residues, potentially leads to nitrogen ‘lock up’ due to microbe activity. Use of fertilizer therefore minimizes nitrogen ‘lock up’ by providing supplementary fertilizer (Liu et al., 2016). Application of fertilizers is critical when there is insufficient soil moisture. Application of fertilizer under water limited conditions cause fertilizer toxicity. During moisture limited conditions fertilizer can therefore not be applied as this leads to reduced yields and financial losses (Liu et al., 2016).

Use of different crop varieties can be utilized in managing climate risk. Due to climate variability there has been irregular commencement and cessation of the rainfall season. Short seasoned varieties increase chances of increasing crop production under reduced season length. When forecasts predict long season or high rainfall the farmer can cultivate long seasoned varieties. Long seasoned varieties, maximize all the available resources as they have more cobs and leaves thus leading to higher yields (Seed Co, 2010). This study therefore repeatedly realized high yields higher yields under higher yields under strategies involving long seasoned varieties. This was due to increased soil moisture for crop growth and development due to irrigation as well as the mulching effect.

### 12.4.4. Sustainable use of seasonal forecast information

The research realized increased variation in seasonal forecast information from multiple forecasts for both rainfall and temperatures. There is a positive correlation between rainfall and crop yield (Drastig et al., 2016). Seasonal forecast variation therefore leads to crop yield variability. It is therefore challenging to make specific recommendations based on each specific seasonal forecast. Despite the variation in seasonal forecast, assessment of seasonal forecast can be conducted at a holistic level. Comparing parameters of seasonal forecast rainfall with historical rainfall extremes provides a measure of the seasonal forecast's relative to historical rainfall. Seasonal forecast information can also be used with short term weather forecasts, which are relatively accurate. Seasonal forecasts provide information of the general seasonal trends, which enhances determination of holistic farm management decisions, such as choice of crop. The study has shown that there are holistic farm management decisions which consistently lead to higher yields despite variation in forecast. Despite differences in forecast accuracy strategies containing organic ground cover such as maize mulch, long seasoned varieties, increased fertility and irrigation consistently led to higher productivity across different farmers' categories and location. Use of short-term weather forecast during the cropping season also enables farm management decisions such irrigation frequency and quantity. Farm operations such as fertilizer application are sensitive to in-season weather, hence short-term weather forecasts can also be used to determine timing of fertilizer application.

Seasonal forecast information can also be used with indigenous knowledge (IK). IK is very diverse and is most found amongst old-black African farmers. IK can be used to determine immediate or seasonal state of the weather. IK uses the behaviour and dynamics of natural and bio-physical phenomenon such as insects, animals, rivers, vegetation, trees, etc. to determine weather. Certain specific changes in the behaviour and dynamics has been found to be correlated with the occurrence of specific weather patterns. For instance, presence of locusts, mopane worms, etc. usually correspond with very dry seasons. The presence and specific behaviour of swallows is associated with immediate rainfall. Increase in the frequency of the birth of female animals such as cows or even humans, is a sign of an incoming high rainfall season. IK can therefore compliment the uncertainties associated with seasonal forecast information.

## 12.5. Conclusion

The research highlighted the potential feasibility of integrating seasonal forecast information and crop models to make farm management decisions under Southern African small-scale farming conditions. The research however realized notable crop yield forecast variation across all crops, farmer types and locations due to increased forecast variability. The crop yield forecasts from Limpopo are potential more reliable compared to Eastern Cape as the forecasts are within range of measured historical weather. Greater crop yields can be realized with early seeding in the Eastern Cape, whereas sowing mid-season leads to greater yields in Limpopo.

There is notable variation in the potential recommendations for farm management decision making amongst farmers. Research can lead to (1) uniform recommendations, leading to no specific farm management decision (9%). (2) Forecast type specific management decision making (40%). and (3) consistent performance of certain specific farm management decisions (51%). Farm management decision making is relatively easier when management decisions are uniform regardless of climate variation. On the contrary farm management decision making is challenging when the recommendations are uniform as well as when they are climate dependent. Most of these farm management decisions that led to higher yields contained organic ground cover, long seasoned varieties, fertilization and irrigation. The ability of farmers to use the all the strategies varies, hence farmers can select which components of the strategies that lead to high yields, correspond to their bio-physical and socio-economic conditions. Resource endowed, and literate farmers can utilize strategies such as irrigation. Farmers that are unable to utilize such resource demanding strategies can also utilize strategies organic amendments such as mulch. Integrating seasonal forecast information and crop model can therefore be utilized as a tool to evaluate different management strategies prior to commencement of the cropping season. To improve effectiveness, seasonal forecasts can be used with short term weather forecasts which are also relatively accurate or with indigenous knowledge.

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# CHAPTER 13. CONCLUSIONS

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## 13.1. Volume 1 – SEASONAL FORECASTS AND SMALLHOLDERS

### 13.1.1. Evaluation of benefits through engagements

It is to be noted that at this stage the information produced and presented was not acted upon, and this is purposefully that we did not encourage this before understanding the limits of the information we present. Despite a few communication challenges, such as languages, the format of the workshop gave enough flexibility to gather small groups and dedicate sufficient time (beside the presentation) to seat with stakeholders and interact directly, hence allowing to better explain, respond, understand the indicators presented. At the end of the day, all stakeholders understanding of the information presented was very satisfactory, and this resulted in valuable discussions around the local validity and usefulness of those indicators.

The reception was always overwhelming positive, both for the specific indicators presented as well as for the approach in general. Two assessment aspects can be highlighted. Firstly, how the information produced relate to their individual local and community knowledge. There were obviously discrepancies here and there, most being expected due to the nature of the information (e.g. prediction, scale aggregation). This was explained and understood, and stakeholders could relate to the information in a way that made it useful to receive, discuss and act upon pending timeously reception. Secondly, how useful/applicable was the information. Only few concrete actions were identified in response to the discussed information. This is mostly due to the need of recurrent and timeously communication, for instance rainfall-crop indicator before planting, and dryness indicators before the peak of the growing season. Yet all qualified the work presented to be valuable to them, encouraging for more, highlighting regularity and timing of the dissemination as critical.

The project team is confident they have developed a coherent context for the development of a relevant set of climate-crop indicators, tailored to the farming communities and their extension services. The major challenge towards future efficient implementation is likely linked to the regularity, continuity and timing of the information production and dissemination.

### 13.1.2. Feedbacks: Enablers and barriers

Context and experiences

Throughout the project, and the various themes and approaches tested and developed, various enablers and barriers were faced. As rigorous as we make this process we acknowledge the complexity and local dependency of the following observations. We ground these observations in our experience through and beyond the project, and present it in a way that intent to highlight wider and more generic issues. In this volume, we built on the "month to season forecast" integration to crop models and related engagements in the Eastern Cape and Limpopo Province. We record and highlight here enablers and barriers faced in the development of the climate-crop integrated assessment and its dissemination to various stakeholders. It is intentional that we do not separate challenges from enablers, but make an effort to reveal challenges and enabling characteristic of the many interconnected project elements. This is designed to be fed back to relevant institutions and communities, in order to encourage experts to take those into consideration for future advancements.

### Data availability and access

The availability and mostly access, of climate and agricultural data remain, in practice, a major challenge. In South Africa, we believe through experience beyond the project that the data exist, with sufficient spatial resolution and of appropriate quality. Yet amongst partners producing climate data and seasonal forecasts in South Africa, the Climate System Analysis Group (CSAG-UCT) stopped producing seasonal forecasts regularly on the basis of skill, user assimilation and communication challenges; while project leaders and the South African Weather Service (SAWS) which continues to produce such data set, struggled to find the appropriate binding and basis to share those data on a regular basis. With regard to the CSIR, the movement of project partners, out and later to the CSIR, compromised original plans, but later resulted in re-design and completion of seamless forecast aspects of the project, mostly in KwaZulu-Natal.

The Eastern Cape and Limpopo Province study sites were purposefully selected on the basis of previous community and agricultural engagements. The project thus did not feel major challenges with regard to existence and access to the required agricultural and crop data. It is however likely that future efforts in this direction, and particularly the up scaling to provincial or national levels, will likely face challenges in terms of existence and access to sufficient agricultural data necessary to calibrate and validate crop models. It is likely that the agricultural data access will be inconsistent in space, possibly in time and likely in the nature of the systems characterised (e.g. commercial vs. subsistence, or cereal vs. underrepresented crops).

For climate and agricultural data, a reinforced partnership (including mutually beneficial agreements) between data producer and next-user would help enormously, which contractual partnership is hardly achievable within such project time frame. Also we would encourage the research designer/donors in South Africa (such as the Water Research Commission) to facilitate where possible, and encourage their partners to continue seeking such agreements, even beyond the scope of an active project and which would serve as basis for future collaborations.

Although only partly used in this project (e.g. soil moisture mapping in Eastern Cape). we recognise the spatial and temporal strength of remote sensing data, which resolution (space and time) continuously increases, and which access becomes easier, including number of sources offering free access. This existing data, now providing duration long enough to explore long term concepts, should be considered in any step taken toward scaling up of a similar work, and possibly as well in the use of numerical tools such a crop models in areas with few field data, such as it is the case in rural areas of South Africa.

### Climate-crop integration

Research integrating seasonal forecasts and crop models involves multiple assumptions from both crops and seasonal forecasts. GCMs predicting weather do not account for all the factors affecting climate, hence the forecast is a product including large uncertainties. Similarly, crop models do not account for all factors leading to crop yield. Hence combining seasonal forecasts and crop models compounds the uncertainty in the outputs. The processing of large number of seasonal forecasts and large combination of simulations allows for some exploration of this uncertainty. It requires the use of appropriate computing tool, ranging from crop model, to computing languages, or parallelised computation (Vol. 1 Chapter 5).

Although emanating from a different set of skill, the project driven engagements with Eastern Cape and Limpopo Province university partners, local extension services and farming communities, played a major role in addressing technical choices toward a satisfactory integration of climate with crop models. Stakeholders ranged from junior and senior academics within the university, some already familiar with some or all concepts of the project, through to the farming communities, some with secondary education and enormous field experience. Community engagement was done through workshops, focus group discussions, household surveys, etc. This involved exchanging information on climate change and variability communicating with farmers and government agricultural extension workers. Although it was relatively easier to mobilise farmers and extension officers in Limpopo compared to the Eastern Cape, the community engagement was a clear enabling tool in the production of relevance. The interest, capacity to understand and critic, as well as the willing participation toward improvement of all participant, often lead to guiding the technical choices and processes.

### Indigenous knowledge

In the Limpopo province, A. *Hlaiseka* et al. studied the use of indigenous knowledge to forecast rainfall for adaptation of *Vigna subterranea* production practices (Vol. 1 Section 9.2). The study shed light on how smallholder farmers in selected villages convert local knowledge into rainfall forecasts. Through dissemination or presentations, the importance of rainfall forecasts in *V. subterranea* production has been better understood. The identification and collection of the data revealed a major challenges, including interviews under hot temperature conditions, language issues (e.g. some of the native terminologies related to rainfall forecasts could not be translated well into English terms). recording of some rainfall signs, which could not be visualised or pictured at the time.

The involvement of local experts from academia, to extension offices, to farming communities, once again proved a critical enabler. The developed network facilitated the identification of key informants, and following a snowball sampling technique allowed to mobilize participants in the study. The process was supported and encouraged by the large community of stakeholder, and the project partner involved felt the appropriate guidance, support and skills, leading to the successful development of their own capacity and completion of the study. It is also important to the team at large and particularly the young academics supported in Limpopo (and Eastern Cape) that this topical engagement and network started through the project, continues to develop and benefit all parties at local scale.

The Eastern Cape Indigenous Knowledge efforts within the project, were conducted in four villages in Raymond Mhlaba Municipality (Vol. 1 Section 9.1). Raymond Mhlaba Local Municipality was selected as the study area because farming is one of the main activities that communities rely on, with a majority of people being engaged in subsistence farming. Many of the small scale farmers in the study area rely on Indigenous Knowledge (IK). Participants were purposively selected and their details obtained from the Raymond Mhlaba farmers Association. Questionnaires were used to collect information on the indicators farmers observe for weather forecasting. The questionnaire contained three sections and combined structured and semi-structured questions. Open ended questions were included to allow participants to give detailed information. The topics covered in the questionnaires included the indicators farmers used and their meanings. Participants ages ranged from 22 to 84, including elderly often holding most of the indigenous knowledgeable and with vast experience in using indigenous knowledge forecasting indicators.

While the research involving Indigenous Knowledge starts with the identification of the knowledge holders, and in most cases, IK holders were the elderly, accessing to those knowledge holders proved the largest challenge. As it could be expected no single knowledge holder can express a list of indigenous knowledge representing the range of communities, the range of crops, or the range of affected conditions. Seeking a complete picture of IK thus required to go into deep rural areas, identify elderly farmers who were well informed in IKS practices, and repeating the process. This effort was helped through the project driven community engagement workshops held in 2016, 2017 and 2018, in Alice, Eastern Cape and in Ha-Lambani, Limpopo. It allowed to access various representative of various local communities and ease the identification and access to IK holders. When we contacted farmers to set appointments for interviews, they could remember us from the previous community engagement workshops and were willing to let us visit their farms.

### Remote sensing

In this report (Vol. 1 Chapter 8). M. Chari et al. propose a framework relating soil moisture and adaptive capacity in rural farming communities near Alice in Eastern Cape. From this premise they continue into mapping of soil moisture patterns and mapping of adaptive capacities of communities in Raymond Mhlaba Local Municipality in the Eastern Cape using geospatial techniques. Geospatial services are not yet fully embraced by farming communities especially in Eastern Cape Province. Technically, remote sensing data comes with caveat, such as irregularity of record (e.g. cloud obstruction). and big data set management to master. Later through the approach, when communicating the source, process and outputs of the approach, language barriers made difficult to grasp the full extent of the approach by local stakeholder during the community engagement workshops (e.g. how to translate “satellite” in Xhosa?). Government agricultural extension officers enhanced the transfer of scientific information to the farmers. Farming communities embraced the information which they qualified of very useful, although it was their first time to hear of remote sensing use in farming. Extension officers also agreed that remote sensing provides an economic option to produce information such as soil moisture which is valuable for farming communities.

Remote sensing also offer unique potential for up scaling, in terms of spatial availability, and relatively easy and cost effective (sometime free) access. Remote sensing data use is becoming a standard in research and in numerous derived applications. The necessary skills to handle such data set are slowly being expended, and much so within academia and the younger generation of scholar. We believe that in the near future, particularly with the development of the next generation of farmers, extension officers, and agricultural experts, remote sensing will be commonly used in complement of experimental farms and field-based data. The combination of field-based data grounded in expertise and local relevance, in combination with off ground data collection systems, will certainly facilitate the scaling up of numerical-based approach such as the use of crop model, seasonal forecast or the integration of one and the other. While such tools will remain partial representation of complex systems, their power of building tailored information for decision making could then be unlocked to places where field-based data is scarce, such as number of rural areas in South Africa.

### Heterogeneous systems

One of the primary reason why high level solutions do not take root into farming communities is the lack of high and relevant resolution of those options. This, in part at least, is the consequence of the high heterogeneity of community farming, with farmers having very different set of skills and knowledge (e.g. some with primary education and others with a university degree). different level of reliance on their production often linked to their capacity to cope and adapt, or different household members characteristic affecting the availability of labour. This heterogeneity can be characterised when studying specific communities, and this project with one common ambition of better preparing farming communities to climate variability, clearly advanced different options, at least at the level of community relevance. This was feasible following the specific characterisation of those communities, for instance via typologies (Vol. 1 Chapters 6 and 7).

These efforts can hardly be performed at larger scale (provincial or national). or at least not with the same resolution. This would certainly become a major challenge of a scaling up exercise. However through this project experience, we observed that the numerical combination of seasonal forecast and crop models are well fitting the high level low resolution, emanating from considerations for accuracy (e.g. model are partial). for uncertainty (e.g. embedded in seasonal forecasts) or simply scope of rural often unrepresented agricultural systems (e.g. Bambara nuts). These approaches are the most efficient and relevant at those scale, which can be easily scaled up. On the other hand, this effort must come in parallel with efforts characterising the heterogeneity of community farming practices, in order to 1) better guide the high level low resolution effort and most importantly 2) tailor those suggestion to a level of details and relevance, only achievable at local scale and which should facilitate adoption.

Engagement and communication

Engagement with the various stakeholders, as we brought forward above, is an enabling activity, necessary during the design and the execution of such a project. It is particularly crucial to tailor and communicate the message resulting from larger numerical approaches, into suggestions to farming communities that make sense, and susceptible to make a difference. Despite clear and undeniable value, those engagements come with their share of challenges.

Communication with farmers is often impaired by language barriers. While all farmers were speaking Xhosa with good basis of English in Eastern Cape, the farmers gathered in Limpopo Province were speaking 3 different languages, often not including English. The project strategy with that regards was to rely strongly on local universities (UFH in Eastern Cape and UniVen in Limpopo). as well as extension officers. Although it took different forms in those two locations, the workshop organised through the project were all successful and well received by the stakeholders. This success definitely was the result of the involvement of local students/interns with both a good understanding of the project research and the local language(s). the wide involvement of the extension officers (all speaking English and local languages) taking in some extent an intermediary role for the interpretation from and to farmers, as well as the more continuous engagement beyond the workshop between local students, academics, and local extension officers and farming communities. Although these diverse stakeholders (e.g. academics from other institutions, local academics, students from other institutions, local students, local agricultural extension officers, and farming communities) make the organisation and logistic more complex, this also allows for better communication with the various types of actors involved.

A student attracted later to the project, interrogated the communication of seasonal forecasting information specifically to rural small scale farmers in developing countries. The challenge is on assessing the potentials, means and methods to communicate climate change information to empower small-scale farmers in the Eastern Cape, Province, South Africa (Vol. 1 Chapter 11). Language barriers makes it difficult to communicate scientific information to people who do not know science. Unavailability of equal resources make it difficult to test the different communication tools. Through community engagement workshops we managed to communicate with small scale farmers how to use seasonal forecast information. During the engagement workshops local agricultural extension officials translated the presentations made into to local language to the farmers. The small-scale farmers welcomed the new information.

### 13.1.3. A worthwhile effort

Knowledge contribution

With a clear research ambition to leverage seasonal forecast information for the benefit of smallholder farmers in South Africa, and to do so using numerical tools such as crop models, the project positively contributed to a number of advances in knowledge.

The scientific process started with grounding the research within two farming communities in Limpopo and Eastern Cape. The local partners and their network, as well as the direct engagement of the project team with the community lead to better understanding of the community dynamics and aspirations. This local specific knowledge is related to two communities presented in Chapter 2 and Chapter 3 of this volume, and emphasise the heterogeneity of these communities, in terms of conditions and aspirations, as well as in terms of integration, acceptance and use of seasonal forecast information (see for instance Vol. 1 Chapters 6 and 7). This baseline is necessary to any scientific progress, so to clearly define a baseline, toward the building of a process that can be scaled up within a variable environment, such as is the South African agricultural production scene.

From this necessary understanding, the scientific process came to explore, understand, assimilate accessible numerical data and tools towards building approaches that ingest and digest seasonal forecast information, in order to reveal the most relevant possible information with decision potential, as well as facilitate its reception, understanding and use by farming communities. This would be the approach/methodological knowledge contribution of this project, mostly arising from the crops models' use (Chapter 4) with available seasonal forecasts (Chapter 5) and leading to the definition of (full or subset of) preferred crop management, per farm types, and with consistent response under varying seasonal forecasts (Chapter 12).

As a result of a multi-partner project, partners who have varying skills and interests, the knowledge contribution did not stop here. Significant contributions were made in terms of Indigenous Knowledge in both Limpopo and Eastern Cape, specifically in terms of agricultural decision making, and seasonal time scale, which adequately fit within this project objectives (Chapter 9). In some extent these advances connect with the numerical approach from a reception and a localisation perspective. The former relates to the relation of seasonal forecast with indigenous indicators and consequently the better understanding and assimilation of this information. The latter relates to the potential to ground a possible recommendation into a very specific and very local context either by translation or by further use of indigenous indicators. Such perspective, when/if applicable only improve acceptance and use of seasonal information.

This project also contributed to the highly relevant challenges of acceptance and use. This was addressed through the lens of Ecological Intensification (EI). with particular attention to the farm typology (Chapter 7). We discuss the particular potential of EI for small scale low input farmers, rigorously frame the strength or weakness of EI in that context, which directly feeds into acceptance and use of novel information/techniques (Chapter 10).
The communication of the science process and products always had a predominant role, and the project attracted scientific interrogation towards better communication of specifically seasonal forecast information to rural communities (Chapter 11).

Finally, a noticeable remote sensing effort was successfully lead, focusing on soil moisture and adaptive capacity mapping ambitions. The contribution builds on the significance of soil moisture as a decision parameter for farming communities and demonstrated the potential to use this approach with climate or seasonal forecast information (Chapter 8). Beside the knowledge contribution, this effort also points to a promising direction in the face of the field data scarcity often encountered in rural South Africa, many African countries and the developing world. Where numerical tools are very efficient and offer great accuracy where ground data is plentiful, these qualities are rightfully questionable where field data is scarce.

A number of studies, supported by this one, suggested that the increased access and resolution of off-ground data sources could at least in part facilitate the use of data demanding approach, even where field data is scarce.

All the good work and knowledge contributions only briefly highlighted above, are accompanied by many limitations and constraints that keep challenging such effort in terms of adoption, operationalization and scaling up amongst others. As the skill of seasonal forecast is varying in space and in time, as the decision maker (farming communities) are exercising in varying conditions and with varying priorities and uncertainties, nuances and reservations must necessarily come as part of the information. We recognise the importance of this complexity, and we are confident that this project contribution to knowledge is measurable and of direct value to future efforts directed to the empowerment of rural farming communities in South Africa.

### Capacity building

Supervision was planned from the project design, and the foreseen numbers were achieved overall. Although not all completed to this day, the project included with full or partial support the capacity building of 1 Hons, 3 Masters and 5 PhDs (Appendix I). These young researchers have taken an integral part of this project, and this involvement reflects through their co-authoring of one or more Chapters of this reports, often presenting a piece of knowledge also disseminated through journal/conference scientific publication (Appendix II).
Involved students were also offered the opportunity to network within the varying project partners' institution, mostly through the opportunity to present their work and build relevant networks. This extended participation proved of great value for all project member involved, and particularly for the skill and network development of our young student and project partners.

Although institutional capacity building is not as easily measured, the number of partners involved in this project, which is clearly offering sometime erratic but defining interactions with some, and often numerous and frequent interactions with others, is definitely improving inter-institutions connectivity and consequently future opportunity for collaboration. The project and its relevance to a wide range of colleagues within or connected to project partners' institution, was a basis for internal seminar, symposium, and measure of institutional involvement in research and its applications. Those characteristics undoubtedly serve positively the building of institutional capacity.

Finally this project explicitly relied on recurrent engagements with farming communities. This exercise is a demonstration of the project and its partner's ambitions to do research for impact. Although this remains a challenging exercise for number of academics, its proved benefits for application and development, makes it a necessary exercise of research for impact. This effort undeniably results in capacity building of farming communities (in Limpopo and Eastern Cape). as well as academic communities encouraged to the exercise.

Societal impact

This volume of the project did not intend to improve seasonal forecast, but intended to leverage the information already existing in a manner that increase its relevance and use by farming communities. The knowledge contribution of the project is clearly and directly impacting the research sphere internationally, regionally, nationally and most importantly locally, with a direct observable effect on the University-Extension interactions at local levels. This most immediate short term impact, will hopefully continue beyond the time frame of the project and lead to improved student development and continuation of efforts with measurable effect on the farming communities.

Individuals, institutions and community capacity building is participating to indirect societal impacts, mostly through the improved knowledge and better access to information, allowing to revisit advises and decision made by extension officer and farming communities.

All aspects contribute to defining and exploiting the role of water in agriculture, better exploiting available tools and information to drive the development of water-efficient production technologies, decision-support models and information systems, consequently playing a role in meeting the needs our South African farming communities, and in this section particularly small scale farms. This project ambitions directly aligns with SDG 1 (No poverty) and SDG 2 (Zero Hunger) through the improvement of management of crop in the face of climate variability.

## 13.2. OVERALL PROJECT CONCLUSIONS

### 13.2.1. A worthwhile effort

From planning to the design and execution of this project, a long path was walked, which we believe was a worthwhile process. We started with a challenging research proposal, with measurable societal impact potential. This report argues the steps taken, demonstrates the knowledge contribution made, and emphasises the need for dedicated engagements. The project led to measurable scientific outcomes and youth driven capacity building, former and latter accumulating to a successful project, grounding a new vision to improve the integration, acceptance and educated use of seasonal forecast information by smallholder farmers.

With a clear research ambition to leverage seasonal forecast information for the benefit of smallholder farmers in South Africa, and to do so using numerical tools such as crop models, the project positively contributed to a number of advances in knowledge.

- Local relevance and heterogeneity of conditions.
- Optimal crop decision, per farm types, and across seasonal forecasts.
- Indigenous relevance for reception and assimilation of numerical information.
- Acceptance and Use, and Communication imperatives.
- Remote sensing, and unlocking the potential of numerical tools where ground data is scarce.
- Empowerment of rural farming communities.

This project is recognising water and agricultural systems, as complex systems evolving at the centre of various communities (e.g. academics or farmers). dealing with information of varying skills and relevance (e.g. skills of seasonal forecast or relevance of time scale). which must be communicated iteratively and faces communications challenges (e.g. language, concepts such as uncertainty, trust). While importance and provision must be made for the inclusion of some extent of all these aspects, we believe the improvement of the part we deal with in this report, is taking a measurable role in the development of better managed agricultural systems, particularly under global (e.g. population increase, climate change) and national (e.g. wealth and food share, economic development) challenges.

This project demonstrated the value of using numerical tools, purposefully for the benefit of smallholder farming communities, with the imperative involvement of rural university and extension offices. This process, although clearly still facing challenges for operationalization and scaling up, used the right ingredient of such future development. Amongst the multitude of ways this work can be taken forward, it seems evident that the success of national scale operationalization of this sort of approach must explicitly develop and involve the local university-extension link, which in terms will most likely be the owner of the combined numerical skills and local heterogeneity relevance.

Despite a number of technological challenges that were encountered in the development of agrohydrological forecasts for commercial sugarcane production, the efforts in this activity showed some promise. The capacity that has been developed in this pursuit (through development and application of relevant tools, etc.) has been valuable, and should be maintained going forward to address the challenge of increasing climate variability.

### 13.2.2. Enablers and barriers

We do not expect to be exhaustive on the listing of challenging and enabling characteristic of such a large effort. The following table describe the major topics, which had to be formally addressed in the application of seasonal forecasts to smallholder farmers. Some were foreseen (e.g. language during workshops). some were not and were included in the project (e.g. Indigenous Knowledge). some known or not are not part of this project but would arise from a continuation, for instance aiming at the up scaling of such an approach.

Engagement likely is the element that has make this project well received with communities, and it is our hope that the network built through this project including local universities, extension officers and farming communities, will find the sufficient support to continue engaging and thus maintaining an active network which over time (longer than a project time frame) will benefit the good two way communication that is needed to slowly adapt agricultural systems to global challenges.

**Table 13-1 Summary of enablers and barriers**

| | Challenging characteristics | Recommended enabling characteristics |
|---|---|---|
| Data | •At station scale, access inconsistent through time<br>•At larger scale, consistency in space, and systems representation | •Facilitation of renewable agreements<br>•Remote sensing for scaling up and unlocking numerical tool |
| Climate-crop integration | •Multiple technical choices with related consequences<br>•Embedded assumptions, uncertainty and hypothesis | •Hardware capacity held within institution<br>•Technical skills (climate and crop) |
| Indigenous knowledge | •Identification of knowledge holder<br>•relevant/sufficient representation of IK | •Group gathering/workshop offering preliminary contacts<br>•The researcher goes to the farmers |
| Remote sensing | •Technical skills required<br>•Specific communication challenges | •Available and easy access<br>•Large space and time coverage<br>•Potential to unlock numerical approach where field data is scarce |
| Heterogeneous systems | •Local relevance, acceptance<br>•High range of "systems" | •Local characterisation<br>•Building of local relevance<br>•High level low resolution AND ground level high resolution, each in their own sphere (approach, actors, etc.) |
| Engagement and Communication | •Language<br>•Various stakeholder types<br>•Relevance<br>•Network | •Involvement of local universities and their academics and their students<br>•Attracting full range of stakeholders (typically extension offices in between universities and farmers) |

### 13.2.3. Lessons and recommendations

The heterogeneity highlighted in this project is once again emphasized through the different audiences, decision makers, systems and consequently the responses to climatic factors. As much as better understanding, communication and integration of forecast information is useful for any decision maker, the capacity to produce such information and communicate it at a very rapid time rate is still technically very difficult, mostly due the large uncertainty involved, as well as the technical operationalization of the process, leading to low reliability of its execution on a regular basis. While the weather forecasts on (very) short time horizon remain accurate, its process through modelling tool does not provide large added value to smallholder farmers, while it requires large computation demand, and appropriate interpretation to facilitate its efficient communication and integration in the decision process. Although this remains a very interesting and promising research avenue for the future, the ambition to progress towards operationalization through better use of forecast information into the decision-making of agricultural practices, must account for the added value of the information produced, against its cost and reliability of production. At this time, operationalizing very short term climate-crop information is very demanding while its benefits for the farming communities are limited compared to the value of the original weather forecast. On the other hand operationalizing crop-based seasonal forecasts information, while being comparatively demanding to produce, offers measurable improvements of the use of seasonal forecast as well as sufficient time to produce it, communicate it, and hopefully integrate it to agricultural decisions.

This recommendation obviously must be considered in the light of the user of the information. Likely commercial farmers with extensive access to numerical tools and internet, will be much likely willing and capable of receiving short-term processed information. On the other hand farming communities with limited access to such tools and information on a regular basis, are more likely to prefer seasonal time scale information, through the extension offices, and consequently better communicated, interpreted, understood and most likely to be integrated. While production of useful information, desired information, must be continued, there is no doubt that local stakeholder must be involved, including academics in local University, extension services, as well as farming communities in order to make this information relevant and useful but also to allow for local interpretation, communication and use. As much as the process can be run remotely, and the heavy computation should benefit from high computation capacities at national, governmental and/or educational institutions, the communication, the interpretation and as much expertise as possible must lie within local Universities, local government institutions, and ultimately support and encourage the extension offices in their communication with the farming communities.

The work in the KwaZulu-Natal case study revealed that there is promise for the application of forecast information at a range of time scales, including short-term horizons tailored for commercial agricultural sector, usually with greater access and interest for computationally intensive forecast information and tools. For sugarcane production for instance, forecasts relating to water supply and demand were of the greater interest, since there is already an operational crop forecasting system in place. Improved water management (relating to, for example, irrigation and dam operations) has the potential to improve crop production and profitability. Recommendations going forward include expanding the seasonal forecasts of water supply to other seasons (beyond autumn) and the application of simulation modelling in this pursuit (in parallel with statistical modelling). Interest in seasonal forecasts of water supply extend beyond the sugar industry, with interest being expressed from other catchment' water managers. Work conducted in this project to develop shorter (7-day) forecasts of crop water requirements will complement work from another WRC project (K5/2819). the latter being focused on producing this information in a smartphone app for the fruit industry. As recommended in a smallholder context, the application of remote sensing information in modelling would also benefit agrohydrological forecasting in the commercial agriculture context, as demonstrated by other services (e.g. FruitLook).

From a technical perspective numerous ways exists to progress forward. We are confident that the combination of forecasts and water/crop modelling tools offer a tailored perspective on forecast information that allows for specific agricultural decisions. Following this numerical direction, we believe the use of remote sensing data and particularly the value thereof in areas where there is limited field data, is promising. The explicit use of indigenous knowledge could further benefit forecasting studies through an improved description of local systems, as well as to communicate changes and recommendations related to climate/agricultural systems.

# APPENDIX:

## APPENDIX I: CAPACITY BUILDING REPORT

### A I.1. Individuals

#### A I.1.1. Students

**Table 0-1 Completed or continuing students**

| # | Student name and Surname | Gender | Race | Degree | University | Country of Origin |
|---|---|---|---|---|---|---|
| H1 | Luleka Dlamini | Female | Black | Hons | University of Cape Town | South Africa |
| M2 | Luleka Dlamini | Female | Black | MSc | University of Cape Town | South Africa |
| M3 | Amukelani E. Hlaiseka | Female | Black | MRDV | University of Venda | South Africa |
| M4 | Khululwa N. Xoxo | Female | Black | MSc | University of Fort Hare | South Africa |
| P5 | Martin M. Chari | Male | Black | PhD | University of Fort Hare | Zimbabwe |
| P6 | Siyabusa Mkuhlani | Male | Black | PhD | University of Cape Town | Zimbabwe |
| P7 | Feroza Morris | Female | Black | PhD | University of KwaZulu-Natal | South Africa |
| P8 | Farirai Rusere | Male | Black | PhD | University of Cape Town | Zimbabwe |
| P9 | Tineyi Pindura | Male | Black | PhD | University of Fort Hare | Zimbabwe |

**Table 0-2 Discontinued students**

| # | Student name and Surname | Gender | Race | Degree | University | Country of Origin |
|---|---|---|---|---|---|---|
| M | Tshimangadzo Mutheiwana | Male | Black | MSc | University of Venda | South Africa |
| M | Mlungisi Shabalala | Male | Black | MSc | University of KwaZulu-Natal | South Africa |

#### A I.1.2. Research summary topics

Honours Students

| Miss Luleka Dlamini | |
|---|---|
| Degree | Honours |
| First registration | 2017 |
| Expected graduation | 2018 (completed) |
| Institution | University of Cape Town |
| Supervisor(s) | Dr Olivier Crespo |
| Title | The impact of droughts on sugarcane yields in Pongola, KwaZulu-Natal |
| Abstract | Drought is one of the important constraints to sugarcane yields in South Africa. Previous research has mainly focused on either the impact of temperature, rainfall or drought (which is the combination of rainfall and temperature) on yields at spatial scale, however, the temporal scale at which these variables have a significant impact on yields has not been explored, particularly in KZN. This study investigates the impact of droughts, |

| Miss Luleka Dlamini | |
|---|---|
| | temperature and rainfall on sugarcane yields at three, six, nine and twelve month's temporal scales, in Pongola from 1996 to 2015. Standardised Precipitation Evapotranspiration Index (SPEI). a drought index that is based on water balance, was used to analyse drought periods in Pongola. The study also used time series analysis to observe the variation in yields over the years. Principal Component Analysis was then used to identify the relationship and variance within each climatic dataset at different temporal scales. Lastly, correlation analysis was used to quantify the relationship between sugarcane yields and the climate variables at different temporal scales.<br>The results demonstrate that Pongola has experienced moderate and severe drought conditions as well as wet conditions. The droughts occurred when the temperature was above normal conditions while rainfall was below normal conditions. These climatic conditions vary mostly between summer and winter, which corresponds to the first three phases of a 12-month sugarcane life cycle. As a result, sugarcane yields were found to be decreasing over the years. Overall, there was a low correlation between yields and the climatic variables. When correlating yield with SPEI, a negative relationship was found. Similarly, a negative correlation between yields and rainfall was obtained. However, a positive correlation was observed between temperature and yields. Based on these findings, it was first concluded that the combination of high temperature and low rainfall at the late stages of the growing season (03 and 06-months scales) may have a positive impact on sugarcane yields. Secondly, relatively high temperatures are required throughout the sugarcane lifecycle for optimal yields. Lastly, high rainfall may lead to waterlogging, especially in the first three phases of the crop development as Pongola receives most it rains during that period. Thus, when heavy rainfall is expected during these stages of the sugarcane, farmers in Pongola should make sure that they do not over-irrigate to avoid water logging as it may reduce the yields. |
| New skills | Improved my writing and presentation skills |
| Individual outputs | ● 3 presentations (oral and poster presentations)<br>I presented (poster presentation) my research at the South African Space Agency (2017) student workshop and the South African Society for Atmospheric Science conference (2018) and I won the best poster presentation prize. I also did an oral presentation at my department colloquium, where I won the best honours presentation. |

## Master students

| Ms Amukelani E. Hlaiseka | |
|---|---|
| Degree | Masters in Rural Development |
| First registration | 2016 |
| Expected graduation | 2018 |
| Institution | University of Venda |
| Supervisor(s) | Prof J. Francis and Mrs M.A. Mathaulula |
| Title | Indigenous Approaches To Forecasting Rainfall For Adaptation Of Bambara Nuts (*Vigna Subterranea*) Production Practices In Selected Villages Of Vhembe District |

| Ms Amukelani E. Hlaiseka | |
|---|---|
| Research Summary | Increasingly, people are relying on both print and electronic media for climate information that meteorologists observe and update regularly. Despite these advances and adoption of western science, some smallholder crop farmers continue to rely on indigenous techniques to forecast the nature of forthcoming seasons and adapt agricultural activities to climate variability. This study originated from the realisation that non-conventional crops such as Bambara nuts (*Vigna subterranea)* are becoming increasingly important in addressing food insecurity and nutrition in the smallholder farming sector. Despite this emerging trend, it is not clear how climate variability influences the crop's productivity. Nor are the indigenous approaches that farmers use to forecast rainfall and disseminate knowledge on this phenomenon clear. Thus, the current study was carried out to identify and document indigenous approaches that smallholder farmers use to forecast rainfall, temperature and adaptation practices relating to Bambara nuts (*Vigna subterranea*).<br><br>The study was conducted in the villages of Xigalo and Ha-Lambani, both located in the Vhembe district. These villages were chosen to represent the Va-Tsonga and Vha-Venda communities with a considerable *V. subterranea* produced by smallholder farmers. Xigalo is located in Collins Chabane local municipality while Ha-Lambani is under Thulamela local municipality. The two areas are 71.5 km apart, with Xigalo situated in a lower lying area compared to Ha-Lambani village. Respondents were selected using a snowball sampling technique. Smallholder farmers and community elderly were selected through references from key informants and agricultural extension officers. Triangulation of participatory methods and techniques was used to collect qualitative data from respondents. These included key informant interviews, learning circles, photovoice, one-on-one interviews, and narrative inquiry.<br><br>The results show that *V. subterranea* is customarily planted during the summer season, after early rainfall. Early rainfall is known locally to decompose dried corn stalks. Prior the ploughing period, rainfall is predicted based on observations of multiple indicators, such as human behaviour, plant phenology, animal phenology, bird phenology and insect phenology. The meanings derived from the indicators are locally based due to differences in culture and traditional beliefs. These traditional beliefs justify planting times and the conservation of *V. subterranea*. The revealed results contribute significantly to the field of rural development by enabling the development of policy interventions for the integration of seasonal forecasting techniques into the adaptation to *V. subterranea* production. Paying attention to the subsisting role of indigenous approaches in the crop's productivity will help to understand how scientific methods can be infused to promote *V. subterranea* production. |
| New skills | Skills acquired through participation in the project (Studies, scientific workshops, community engagements, etc.)<br>Project management, report writing, PowerPoint Presentations, public speaking, Questionnaire administration, facilitation of focus group discussions, Qualitative analysis Software programme ATLAS.ti, knowledge of local protocols in community engagements |
| Individual outputs | ● Thesis is yet to be submitted in November 2018<br>● 3 oral presentations done at workshops<br>● 2 articles in preparation |

| Miss Khululwa N. Xoxo | |
|---|---|
| Degree | MSc |
| First registration | 2016 |
| Expected graduation | 2019 |
| Institution | University of Fort Hare |
| Supervisor(s) | Dr. L. Zhou and Dr. S. Mazinyo |
| Title | Application of Indigenous Knowledge and Scientific Seasonal Forecasts for Climate Risk Management: A Case Study of Raymond Mhlaba Local Municipality, Eastern Cape Province, South Africa |
| Progress Report | Agriculture is said to be one of the most weather-dependent of human activities (Qian et. al, 2014). This makes smallholder farmers rely more on rainfall hence the need for a more reliable climate and weather forecasts. Reliable weather and climate forecasts can assist farmers with the selection of appropriate tillage systems, crop varieties and planting dates (Kalanda-Joshua, Ngongondo, Chipeta, & Mpembeka, 2011).In the past years, research has focused on the importance of indigenous knowledge as part of a solution to climate change (Johnson, 1992). Rural communities in the past have relied on indigenous knowledge for their daily survival and adaptation to the landscapes around them. Traditionally, farmers have also relied on indigenous knowledge to understand weather and climatic patterns (Kalanda-Joshua et al., 2011).<br><br>A lot of research has been done on scientific forecasting alone to determine climatic trends. Studies have found that there has been lack of communication of forecasts, especially to smallholder farmers. In some cases the accuracy of these forecasts have been questioned (Codjoe, Owusu, & Burkett, 2014). It is because of this gap that this study integrates indigenous knowledge with scientific seasonal forecasts at a local level.<br><br>Aim<br>This study seeks to apply indigenous knowledge (IK) and scientific forecasts to reduce exposure of small scale farmers to climate risks. The objectives of the study are (1) document existing indigenous knowledge indicators that are used to predict weather and climate in Raymond Mhlaba Municipality; (2) understand farmers perceptions on climate change and variability and link it to empirical evidence; (3) to link IK indicators with Scientific Seasonal Forecasts. The research expects to get and record the various IK indicators that farmers use in the Raymond Mhlaba Municipality.<br><br>To date my research proposal has been defended and approved by department, it was submitted to higher degrees committee. Currently, household questionnaires are being drafted in preparation for the submission on the ethical clearance application to be received in May. Background, historical literature review has been conducted and the work has presented at regional conferences and are currently being developed into a peer reviewed publication. I am now waiting to commence data collection and write the thesis and peer reviewed articles. |
| New skills | Integration of seasonal forecast and crop models in climate risk management. |
| Individual outputs | ● 1 Oral paper presentation at a Conference;<br>● 1 journal publication being authored<br>● Abstract accepted for conference presentation in December 2018 |

| Miss Luleka Dlamini | |
|---|---|
| Degree | Masters |
| First registration | 2018 |
| Expected graduation | 2019 |
| Institution | University of Cape Town |
| Supervisor(s) | Dr Olivier Crespo |
| Title | Improving the performance of Crop Models by using Remote Sensing data |
| Progress Report | This study aims to integrate remote sensing data with a crop model to improve crop yield simulations. Thus, igniting an interest to access and use crop models, particularly in rural areas where field data is limited. This study will build on the previous extensive work that has been done to calibrate the mechanical DSSAT model to monitor and model maize growth and yield in Free State. Remotely sensed soil moisture have been selected as the data that will be used to improve DSSAT model crop yield simulation. To achieve the second objective of the study, recalibration method has been identified from literature as an appropriate strategy to integrate crop model with remote sensing data. Currently, I am working on recalibrating the model with soil moisture. After each n-step recalibration attempts, maize yield will be obtained to assess the improvements. Early in 2018, the research manuscripts will be submitted to various publications based on the acquired results. |
| New skills | Crop modelling, Python |
| Individual outputs | ● Abstract submitted to the Combined Congress Conference |

## Doctoral students

| Miss Feroza Morris | |
|---|---|
| Degree | PhD |
| First registration | 2016 |
| Expected graduation | 2019 |
| Institution | University of KwaZulu-Natal |
| Supervisor(s) | Dr M Toucher, Prof R Schulze |
| Title | Short to long range hydrological forecasting in the Mhlathuze catchment |
| Progress Report | The project will focus on forecasting streamflow of the Mhlathuze River and the level of the Goedertrouw Dam across different time ranges. These forecasts are needed for decisions regarding water allocation and to support industry forecasts of sugarcane yield. Research will focus on the process of generating hydrological forecasts including downscaling of weather/climate forecasts, model initialization, evaluation of forecast output and the reduction of errors and uncertainty. The potential for forecasts to improve decision-making will also be explored by assessing the adoption of alternative management strategies using a simulation approach. |
| New skills | Generating hydrological forecasts |
| Individual outputs | ● 1 Oral presentation at a local conference<br>● Oral presentation at an international conference<br>● Abstract accepted for oral presentation at an upcoming international conference<br>● 3 Papers In Preparation |

| | |
|---|---|
| Mr Martin M. Chari | |
| Degree | PhD |
| First registration | 2016 |
| Expected graduation | 2019 |
| Institution | University of Fort Hare |
| Supervisor(s) | Prof. H. Hamandawana, Dr. L. Zhou |
| Title | Enhancing adaptive capacities of farmers to climate-induced rainfall variability by modelling soil moisture patterns in Raymond Mhlaba Local Municipality, Eastern Cape Province, South Africa |
| Progress Report | The study aimed to enhance adaptive capacities of farmers to climate-induced rainfall variability by producing reliable soil moisture maps to support water management and agricultural practice, particularly during dry seasons. The study area is the Raymond Mhlaba Local Municipality, in the Eastern Cape which is one of South Africa's provinces ranked as being extremely vulnerable to the adverse effects of climate-induced rainfall variabilities due to limited adaptive capacities. The study also reflects a Geographical Information Systems (GIS) approach to identify resource-poor communities with limited abilities to cope with the adverse effects of climate change. The designed methodology identified 14 villages with low adaptive capacities from a total of 180 villages in the study area. The methodology is of general applicability in guiding public policy interventions aimed at reaching, protecting and uplifting socio-economically disadvantaged populations in both rural and urban settings. The methodology has been presented at a local conference and developed into a paper which has been published in an international journal. To date, 4 courses and 8 workshops involving work related to the research have been attended. Chapter write-up for the thesis is currently being undertaken and constructing of more publications from the research. |
| New skills | Disaster risk management; Climate risk management; Climate change and adaptation; Integration of seasonal forecast and crop models in climate risk management; Project management; Data management using R and Python programming; Writing articles for publication |
| Individual outputs | ● 1 oral paper presentation at a conference<br>● 1 article published in an international journal<br>● 1 article published in a national newsletter<br>● Abstract accepted for conference presentation in December 2018 |

| Mr Siyabusa Mkuhlani | |
|---|---|
| Degree | PhD |
| First registration | 2016 |
| Expected graduation | 2019 |
| Institution | University of Cape Town |
| Supervisor(s) | Dr. O. Crespo |
| Title | Integration of seasonal forecasts and crop models to enable climate variability management amongst small-scale farmers in South Africa? |
| Progress Report | The study aimed to integrate seasonal forecast information and crop models to increased smallholder farmers' preparedness to climate variability using climate variability management strategies. The research was based on Lambani and Nkonkobe communities in Limpopo and the Eastern Cape provinces respectively in South Africa. The first objective of the study 'assessment of the current socio-economic perceptions to historical and future climate and document the current climate variability management strategies used by farmers of different typologies and agro-ecologies in South Africa' was been completed. This has led to the development of farmer categories and assessment of the perceptions, strategies and challenges in managing climate variability amongst smallholder farmers in South Africa. The work has been developed into a manuscript and has been presented at 3 local and regional conferences in South Africa. Calibrating of crop models based on the different crops and crop types cultivated by different farmer categories in South Africa has been completed. The calibrated crop model has been integrated with seasonal forecast information for 'comparison of cropping systems' productivity exposed to seasonal forecasts under climate variability management strategies amongst different farmer typologies and agro-ecologies'. The study then assessed the feasibility, practicability, potential challenges and economic impacts of adopting the current and research recommended climate variability management strategies among the different farmer typologies and agro-ecologies of South Africa. *A* PhD Thesis and 2 manuscripts for publication are currently being developed from the research study |
| New skills | Advanced application of crop models<br>Data management using packages such as R, Python, etc.<br>Experience in community engagement |
| Individual outputs | ● 3 Oral paper presentations at 3 local and regional conferences<br>● 2 manuscripts submitted for peer review |

| Mr Farirai Rusere | |
|---|---|
| Degree | PhD |
| First registration | 2016 |
| Expected graduation | 2019 |
| Institution | University of Cape Town |
| Supervisor(s) | Dr. O. Crespo |
| Title | Assessing the value of ecological intensification of improving smallholder farmers food security and livelihoods in a changing world |
| Progress Report | The study aims to assess the potential of ecological intensification of agriculture to improve crop and livestock production and biodiversity conservation in marginal areas in southern Africa in the face of climate change and variability. The research is being carried out in Lambani, a village in Vhembe district, South Africa. The first objective of the study, evaluating the current crop and livestock systems in Lambani, has led to the development of farmer typologies, assessment of constraints and challenges in their farming systems amongst smallholder farmers in South Africa and perceptions on potential solutions and key ecosystem services needed their context and farm types to improve food security and livelihoods. The work has been developed into two manuscript and has been presented at two local conference.<br>Currently I am working on quantifying the potential trade offs and synergies to guide in farm system design of potential ecological intensification strategies in different farm types in smallholder agriculture. Currently, the research is focussing on designing cropping systems using DSSAT and Cool Farm Tool to deliver ecological intensification for the different farm types, and assess its potential, practicability, environmental and economic impacts on different farm types and households in Amathole and Ha Lambani, South Africa. |
| New skills | During the course of the year I managed to attend two writing retreat workshops to sharpen my scientific writing skills organised by the African climate Development Initiative (ACDI) and the University of Cape Town, Postgraduate studies directorate<br>I managed to attend a summer school at the University of Sao Paulo, Brazil on Advanced Science on Climate Change<br>Advanced application of crop models<br>Greenhouse gas quantification approaches |
| Individual outputs | • 3 oral presentations at 3 international conferences<br>• 1 poster presentation at 1 international conference<br>• 1 oral presentation at a local conference<br>• 2 publications currently under review<br>• 2 publications currently being authored |

| Mr Pindura Tineyi Herbert | |
|---|---|
| Degree | PhD |
| First registration | 2017 |
| Expected graduation | 2019 |
| Institution | University of Fort Hare |
| Supervisor(s) | Prof. W. Nel, Dr. L. Zhou |
| Title | Advocating the importance of communicating seasonal forecasting to rural scale farmers in the developing countries |
| Progress Report | The paper is centered on exploring existing processes for knowledge dissemination and sharing seasonal forecast information for small-scale farming systems to help improve farm production in the face of extreme weather events. The paper will also identify potential constraints to the dissemination of scientific information, and concludes with some recommendations on approaches, methods and tools to communicate seasonal forecasts information to all stakeholders involved. |
| New skills | Advanced communication skills<br>Data management using packages such as Vensim , R<br>Experience in community engagement |
| Individual outputs | ● 1 Poster presentations at 1 local conferences<br>● 1 manuscripts submitted for peer review |

Interns and other students involvement

It is to be acknowledged that number of intern/students, otherwise not directly involved in the project, were involved at various stages of the research, particularly so for the organisation and execution of the workshops. We particularly would like to thank them for their voluntary and willing involvement in farmer's engagements, which translated in very practical support such as translation, minuting and recording of those engagements.

### A I.1.3. Workshop/Training attended

1. Using climate information for adaptation and policy development. *Climate System Analysis Group (CSAG).* July 2016, University of Cape Town, South Africa
2. Integrated use of seasonal forecasts for community preparedness to climate variability. *Water Research Commission (WRC) stakeholder engagement workshop*, University of Fort Hare, 17-18 October 2016, Alice, South Africa
3. Review of Eastern Cape Provincial Climate Change Response Strategy, *1st Department of Environmental Affairs (DEA) workshop*, Premier Hotel, 15 November 2016, East London, South Africa.
4. Review support of Eastern Cape Provincial Climate Change Response Strategies and Development of Action Plans, *2nd Department of Environmental Affairs (DEA) workshop*, Premier Hotel, 09 March 2017, East London, South Africa.
5. WRC101 workshop, *Water Research Commission (WRC) workshop,* 24 May 2017, East London, South Africa.
6. Adaptation for Extreme Events. *The Adaptation Network*, 29-31 May 2017, Rhodes University, Grahamstown, South Africa.
7. Linking disaster risk reduction (DRR) and climate change adaptation (CCA) to reduce social vulnerability and build resilience (Think tank). Rhodes University, 30-31 May 2017, Grahamstown, South Africa.

8. Essentials for R programming. *African Doctoral Academy (ADA).* 08-12 January 2018, Stellenbosch University, Cape Town, South Africa.
9. Writing and publishing. *African Doctoral Academy (ADA).* 09-13 July 2018, Stellenbosch University, Cape Town, South Africa.
10. Adaptation Futures. *5th International Climate Change Adaptation Conference,* 18-21 June 2018, Cape Town International Convention Centre, Cape Town, South Africa.
11. South African Society for Atmospheric Science. *34th Annual* Conference, 20-21 September 2018, La Montagne, Balito, KwaZulu-Natal, South Africa.
12. Adaptation Futures Master Class. 5th International Climate Change Adaptation Conference, 22 June 2018, South African National Biodiversity Institute (SANBI). Cape Town, South Africa.
13. School on Advanced Science on Climate Change. 1-17 July 2017, University of Sao Paulo, Brazil.

## A I.2. Institutions

### Table 0-3 Project partner's institutions

| Institution Name | Nature of Development |
|---|---|
| University of Fort Hare | Enhance capacity building through expert training of postgraduate students and increased knowledge base for scientists.<br>Extension agents training workshops were organized on a quarterly basis as part of information dissemination.<br>2 students are enrolled (1PhD and 1 MSc). The student projects consist of soil moisture and adaptive capacity mapping for the PhD and application of indigenous knowledge for the MSc. |
| University of Venda | Most staff and students at the University are well-trained in quantitative methods of research. Given the sensitive nature and need for deeper understanding of systems, processes and other dimensions of climate change, it will crucial to mount workshops in which both students and staff are trained to use qualitative software. Furthermore, basic training in climate change will be needed at community level and even the university so that there is better understanding of the phenomenon and the need to effectively counter its effects. |
| University of Cape Town | As lead of a multi-partner research, the execution of this project supported institutional development in numerous fields, including,<br>● Project management resource and skill, through the participation to computing capacity and participation to project management skill training<br>● Research support and development, through the continuation and the further exploration of internationally relevant research topics: climate and crop modelling expertise, towards better use of short time scale climate-crop integrated expertise developments.<br>It also included the full or partial sponsorship of 1 Hons, 1 MSc, and 2 PhD students. |
| Council for Scientific and Industrial Research | Hydrological forecasting based on a physical-conceptual hydrological model (ACRU) is a new area of research at the CSIR, and thus the work in this regard represents a significant form of capacity building for the institution. An important aspect of this work is the coupling of ACRU with Delft-FEWS, which is vital to facilitate the data-intensive nature of forecasting with a physical-conceptual model (specifically with respect to managing model inputs, outputs and the carrying over of conditions from one forecast run to the next). This will also benefit the development of long term climate change projections of water availability, considering the ever-increasing ensemble of GCM projections that are becoming available. |
| University of KwaZulu-Natal | Learning the Delft-FEWS system (coupled to ACRU) built capacity in the Centre for Water Resource Research to develop hydrological forecasts. It also has the potential to be used in water accounting research conducted in the Centre. |
| Agricultural Research Council | Capacity to apply the AquaCrop model was developed in the project. |
| DWA | Improved water management in agricultural environments |
| DAFF | Improved monitoring and planning associated with regional crop production and drought. Extension services equipped with additional/improved forecast information for farmer advisories. |

### A I.2.1. Agricultural experts at local institutions

The project team, beyond the individuals directly involved in the project, interacted at various and regular occasions with same institution colleagues, and external non-academic institutions. This was typically the case during the annual engagements with local students, junior and a few senior academic colleagues, as well as extension officers and other agricultural department officials.

This interaction, although remaining annually, proved to be an amazing place of ideas and knowledge exchange, which take part in the individual source of information, and participate to their institutional activities. Typically this can be ingested by lecturers through lectures to students, or by extension officers through training to farmers.

## A I.3. Communities

### A I.3.1. Lambani, Limpopo

Through a participatory action research that builds on existing (indigenous knowledge and practices). the project will examine common climate change adaptation practices using appreciative inquiry. In addition, the project will mobilize a broad range of stakeholders, including churches, schools, and leadership institutions such as Ward Committee, Civic Associations, Traditional Leaders, Water Users Associations, NGOs & CBOs and support agencies to strengthen existing systems. Also, special attention will be placed on research that leads to better understanding of climate change-related information/knowledge dissemination systems. Overall, the aim is to build sufficient capacity within the communities to manage local systems. Unemployed graduates and matric graduates with interest in this type of work will be recruited and trained in participatory community-based research skills. They will then serve as local level paraprofessionals. All this will be in line with the Institute for Rural Development thrust spearheaded under the banner of 'Taking the University to its rightful owners' grassroots communities.

A smallholder farmer workshop was held in October 2017, with about 55 people participating. Among these were farmers, local extension workers and postgraduate students plus staff from the Universities of Venda, Fort Hare and Cape Town. In addition, a one-day scientific workshop on integrated use of seasonal forecast for community preparedness to climate variability was held the same month. Twenty-eight academic staff, agricultural extension personnel and students from the Universities of Venda, Fort Hare and Cape Town participated. In both workshops, it was resolved that the research team would package weather forecasting information from ongoing research activities and share with extension personnel. Thus, since then quarterly newsletters have been shared with the extension staff and feedback regularly received. This is ongoing. It is imperative to point out that the interface with the Limpopo Department of Agriculture and Rural Development (LDARD) as a result of implementation of this project culminated in the Institute for Rural Development teaming up with the LDARD to submit to the IDRC a joint proposal for funding focusing on climate variability and change and its impact on livestock in the Limpopo valley.

### A I.3.2. Alice, Eastern Cape

Alice study area in the Eastern Cape focused on working in synergy with the community water and agricultural user groups on the best management and adaptation strategies possible. This was meant to influence quick adoption of technologies through practice and extended knowledge. This was achieved through workshops and community meetings, on the possible adaptation and mitigation strategies possible. It was also envisaged that the study influenced policy adoption beginning with the local community-based policy makers such as the chiefs, district water and agricultural officers, etc.

A workshop was conducted on 6th September 2017 at the local Alice community hall in Alice town. The objectives were to:

- Meet with the local community water and agricultural user groups in order to establish best management and adaptation strategies possible in their region/study area.
- Re-train extension workers and farmers on how to utilize seasonal forecast information.
- Create a communication platform between scientists and agricultural extension workers for communicating seasonal forecast information.

The workshop objectives were successfully accomplished and these are milestone in promoting policy adoption beginning with the local community-based policy makers such as the chiefs, district water and agricultural officers, etc. It was agreed that seasonal forecast information be communicated to agricultural extension workers within the municipality through electronic mail (email) in the form of a quarterly newsletter. The first newsletter was distributed in November 2017. The quarterly-newsletter also has a section for feedback in order to know how the seasonal forecasts information is of use to them.

The final community engagement workshop was held on the 6th of September 2018 at RVSC lab at University of Fort Hare in Alice town. The purpose of the workshop was to assess progress on the;
(1) application of the integrated ‘seasonal forecast and crop model’ tool amongst farmers.
(2) integration of seasonal forecast information with indigenous knowledge.
(3) dissemination of the knowledge after the life-span of the project.
The workshop objectives were also successfully accomplished. About 40 farmers attended the workshop an actively participated in the workshop deliberations.

### A I.3.3. Mhlathuze catchment, KwaZulu-Natal

The KwaZulu-Natal case study was focused on the Mhlatuze catchment and involved the application of weather and climate forecasts to develop tailored agricultural forecast products, in consultation with stakeholders. In contrast to the other case studies, the Mhlatuze case study focused more on commercial agriculture. Hence the community in this case is a broader group consisting of industry stakeholders and water managers. A specific capacity that is expected to be built includes the ability to forecast water availability in the catchment, primarily the level of the Goedertrouw Dam. This capacity is not likely to be built amongst water managers in the course of the project, but if it can be over time it will offer the potential for improved decision-making. For the sugar industry, improved seasonal forecasts of the dam level will offer the potential to improve their operational crop yield forecasts for the area.

# APPENDIX II: PROJECT OUTPUTS

| | Planned beyond | Submitted | Accepted | Predictable Total |
|---|---|---|---|---|
| Conferences | 1 | 3 | 16 | 20 |
| Papers | 4 | 3 | 3 | 10 |
| Thesis | 5 | 2 | 1 | 8 |
| Popular article | 1 | 0 | 1 | 2 |
| Blog Newsletter | 1 | 0 | 1 | 2 |
| Engagement | 0 | 0 | 6 | 6 |

## A II.1. Papers

1. Chari MM, Hamandawana H, Zhou L. 2018. Using geostatistical techniques to map adaptive capacities of resource-poor communities to climate change: A case study of Nkonkobe Local Municipality, Eastern Cape Province, South Africa. *International Journal of Climate Change Strategies and Management, Vol. 10 Issue: 5, pp.670-688,* https://doi.org/10.1108/IJCCSM-03-2017-0071

2. Mkuhlani, S., Crespo, O., Rusere, F., Zhou, L., Francis, J. Classification of small-scale farmers for improved climate variability management in South Africa; Journal of Agroecology and Sustainable Food Systems 2018, 1-23: https://doi.org/10.1080/21683565.2018.1537325

3. Rusere, F., Crespo, O. A review on the potential of ecological intensification to improve food production systems in smallholder agriculture in sub Saharan Africa. Agriculture and Food security. Submitted.

4. Rusere, F., Mkuhlani, S., Crespo, O. Dicks L.V. Developing pathways to improve smallholder agricultural productivity through ecological intensification technologies in semi-arid Limpopo, South Africa. African Journal of Science, Technology, Innovation and Development. Submitted

## A II.2. Conferences/Symposiums

1. Chari MM, Hamandawana H, Zhou L. 2018. Mapping satellite soil moisture for improving farmer preparedness to climate variability: A case study of Raymond Mhlaba Municipality, South Africa. *4th Department of Science & Technology (DST) Global Change Conference*, Bolivia lodge, 03-06 December 2018, Polokwane, South Africa.

2. Dlamini L., Crespo O., 2018. The impact of drought on sugarcane yields in Pongola, KwaZulu-Natal. Poster presentation at the 34th Annual Conference of South African Society for Atmospheric Science, Ballito, Durban, South Africa, 20-21 September 2018.

3. Mkuhlani S., Crespo O., Zhou L., Joseph F., 2018, Integrating seasonal forecast information and crop models for enhancing decision making amongst small-scale farmers of South Africa, South African Society for Atmospheric Sciences, La Montagne, Ballito, Durban, South Africa, 20-21 September, 2018

4. Rusere, F., Dicks, L.V., Mkuhlani, S., Crespo, O. 2018. A participatory approach for exploring options for ecological intensification to improve food security and agricultural sustainability: A perspective of South African smallholder agriculture. World symposium on climate and Biodiversity, 3-5 April, Manchester, UK.

5. Rusere F., Dicks, L.V., Mkuhlani, S., Crespo, O., 2018. Footprint smallholder farm types to identify low carbon agricultural practices in semi-arid Limpopo, South Africa. Cool farm alliance meeting 18-20 April, Robinson College, University of Cambridge, Cambridge, UK

6. Dlamini L., Crespo O., 2017. The impact of drought on sugarcane yields in Pongola, KwaZulu-Natal. Poster presentation at the 1st South African National Space Agency student workshop, Hermanus, 2-6 October 2017.

7. Dlamini L., Crespo O., 2017. The impact of drought on sugarcane yields in Pongola, KwaZulu-Natal. Oral presentation Department of Environmental and Geographical Science Colloquium, Cape Town, 13 October 2017.

8. Morris, F., Toucher, M., Lumsden, T. and Schulze, R., 2017. Use of medium range rainfall and temperature forecasts for agrohydrological forecasting using the ACRU agrohydrological model. IAHS 2017 Scientific Assembly, 10-14 July, Port Elizabeth, RSA.

9. Rusere F., Mkuhlani S., Crespo O., 2017. An expert-based farm typology for targeting ecological intensification to improve food security in smallholder farmers: A case of Limpopo, South Africa. Oral presentation at the 3rd Annual Conference on Climate Change & Development for early career researcher & students, University of Cape Town, South Africa, 6 March 2017.

10. Mkuhlani S., Rusere F., Crespo O., 2017. Use of farm typology approach for effective rainfall variability management in Alice and Lambani, South Africa. Oral presentation at the 3rd Annual Conference on Climate Change & Development for early career researcher & students, University of Cape Town, South Africa, 6 March 2017.

11. Mkuhlani S., Rusere F., Crespo O., 2017. Use of farm typology approach for effective rainfall variability management in Alice and Lambani, South Africa. Oral presentation at the combined congress, 23-26 January 2017, Klein-Kariba, Bela Bela, Limpopo, South Africa.

12. Rusere F., Crespo O., 2017. A review on the potential of ecological intensification to improve food production systems in smallholder agriculture in Southern Africa. Oral presentation at the combined congress, 23-26 January 2017, Klein Kariba, Bela Bela Limpopo, South Africa.

13. Xoxo K.N., Mazinyo S., Zhou L., 2016. Integrating indigenous knowledge with scientific seasonal forecasts for small scale farmers: A review. Oral presentation at the 3rd Global Change conference, Durban, South Africa, 5-8 December 2016.

14. Chari MM, Hamandawana H, Zhou L. Assessing and mapping the adaptive capacity of resource-poor households to changing climate: A case study of Nkonkobe Local Municipality, Eastern Cape Province, South Africa. *3rd Department of Science & Technology (DST) Global Change Conference*, Southern Sun Elangeni & Maharani Hotel, 5-8 December 2016, Durban, South Africa.

15. Mkuhlani S., Rusere F., Crespo O., 2016. Use of farm typology approach for effective rainfall variability management in Alice and Lambani, South Africa. Oral presentation at the 3rd National Conference on Global Change 2016, Southern Sun Elangeni & Maharani Hotels, 5-8 December 2016, Durban, South Africa.

16. Crespo O., Lumsden T., Landman W., 2016. Can crop forecasts improve food production preparedness to seasonal climate shocks? Oral presentation at the SANCID Symposium, Goudini Spa, Worcester, 11-13 October 2016.

### A II.3. Popular articles

1. Dlamini, L. 2018. Engaging with local South Africa smallholder farming communities: a necessary effort for improving community preparedness to climate variability. *Water Wheel vol. 17 issue 4 (2002) pp: 39-41 Published by Water Research Commission. http://hdl.handle.net/10520/EJC-10290fb485*

### A II.4. Blogs/Newsletters

1. Chari M.M., Hamandawana H., Zhou L. 2018. Technique to map adaptive capacities of communities to climate change. *Adaptation Network, May 2018 Newsletter,* Available online: http://www.adaptationnetwork.org.za/2018/05/technique-map-adaptive-capacities-communities-climate-change/

### AII.5. Dissertation/theses

1. Luleka Dlamini: Improving the performance of Crop Models by using Remote Sensing data; Masters Thesis: Environmental and Geographical Science Department; University of Cape Town; December 2019

2. Farirai Rusere; Assessing the value of ecological intensification of improving smallholder farmers food security and livelihoods in a changing world; Environmental and Geographical Science Department; University of Cape Town; December 2019

3. Martin M. Chari; Enhancing adaptive capacities of farmers to climate-induced rainfall variabilities by modelling of soil moisture patterns in Raymond Mhlaba Local Municipality, Eastern Cape Province, South Africa; PhD Thesis; University of Fort Hare; October 2019

4. Morris Feroza; Use of weather and climate forecasts for agrohydrological purposes. PhD Thesis; University of KwaZulu-Natal, April, 2019

5. Siyabusa Mkuhlani; Integration of seasonal forecast information and crop models to enhance climate variability management strategies; PhD Thesis; Environmental and Geographical Science Department; University of Cape Town; December 2018

6. Khululwa N. Xoxo; Application of Indigenous Knowledge and Scientific Seasonal Forecasts for Climate Risk Management: A Case Study of Raymond Mhlaba Local Municipality, Eastern Cape Province, South Africa; Masters Thesis; University of Fort Hare; December 2018

7. Amukelani E. Hlaiseka; Indigenous approaches to forecasting rainfall for adaptation of Bambara nuts (*Vigna subterranea*) production practices in selected villages of Vhembe District; Masters Thesis; Institute for Rural Development; University of Venda; November 2018

8. Luleka Dlamini; The impact of drought on sugarcane yields in KwaZulu-Natal, South Africa; Honours Thesis (Atmospheric Science); Environmental and Geographical Science Department; University of Cape Town; October 2017

# APPENDIX III: STAKEHOLDER ENGAGEMENTS

[1]Bhila PF, [1]Lephondo D, [1]Matau MP, [1]Mboweni N, [1]Nemathithi AJ, [1]Nyamukondiwa P, [1]Rabelani R, [1]Hlaiseka A, [2]Xoxo N, [2]Chari M, [3]Mkuhlani S, [3]Rusere F, [2]Pindura T, [2]Zhou L, [1]Francis J and [3]Crespo O

[1] *IRD, University of Venda*
[2] *RVSC, University of Fort Hare*
[3] *CSAG, EGS dept., University of Cape Town*

## A III.1. Workshops for integrated use of seasonal forecasts for community preparedness to climate variability

| 1 | Integrated use of seasonal forecast for community preparedness to climate variability stakeholder engagement workshop |
|---|---|
| date | 17-18 October 2016 |
| venue | University of Fort Hare, Alice, Eastern Cape |
| participants | Day 1: farmers, extension officers, Risk and Vulnerability Science Center (RVSC). UCT delegates<br>Day 2: UFH academics, UFH students, extension officers, Risk and Vulnerability Science Center (RVSC). UCT delegates, UCT delegates |
| objective | Introduction and grounding of the research team with communities and local academics |

| 2 | Workshop for integrated use of seasonal forecasts for community preparedness to climate variability |
|---|---|
| date | 2-3 November 2016 |
| venue | Day 1: Will of God church, Lambani, Limpopo<br>Day 2: Research Conference Centre, university of Venda, Limpopo |
| participants | Day 1: traditional leaders, farmers, extension officers (LDRAD). IRD interns, UNIVEN students, UCT delegates<br>Day 2: UNIVEN academics, UNIVEN students, IRD interns, UCT delegates |
| objective | Introduction and grounding of the research team with communities and local academics |

| 3 | Second Integrated use of seasonal forecast for community preparedness to climate variability stakeholder engagement workshop |
|---|---|
| date | 6-7 September 2017 |
| venue | Day 1: Alice Community Hall, Alice, Eastern Cape<br>Day 2: University of Fort Hare, Alice, Eastern Cape |
| participants | Day 1: farmers, extension officers, Risk and Vulnerability Science Center (RVSC). UCT delegates<br>Day 2: UFH academics, UFH students, Risk and Vulnerability Science Center (RVSC). UCT delegates |
| objective | Preliminary results, benefit assessment, and further ways to improve |

| 4 | Second Integrated use of seasonal forecast for community preparedness to climate variability stakeholder engagement workshop |
|---|---|
| date | 5-6 October 2017 |
| venue | Day 1: Church of the Nazarene, Ha-Lambani, Limpopo<br>Day 2: Research Conference Centre, University of Venda, Limpopo |
| participants | Day 1: traditional leaders, farmers, extension officers (LDRAD). IRD interns, UNIVEN students, UCT delegates<br>Day 2: UNIVEN academics, UNIVEN students, IRD interns, University of fort Hare students, UCT delegates |
| objective | Preliminary results, benefit assessment, and further ways to improve |

| 5 | Third Integrated use of seasonal forecast for community preparedness to climate variability stakeholder engagement workshop |
|---|---|
| date | 05-06 September 2018 |
| venue | Day 1: University of Fort Hare, Alice, Eastern Cape<br>Day 2: University of Fort Hare, Alice, Eastern Cape |
| participants | Day 1: farmers, extension officers, Risk and Vulnerability Science Center (RVSC). UCT delegates<br>Day 2: UFH academics, UFH students, Risk and Vulnerability Science Center (RVSC). UCT delegates |
| objective | Results, benefit assessment, and further ways to improve |

| 6 | Third Integrated use of seasonal forecast for community preparedness to climate variability stakeholder engagement workshop |
|---|---|
| date | 04-05 October 2018 |
| venue | Day 1: Will of God Church in Lambani Village, Limpopo Province<br>Day 2: School of Agriculture Boardroom, University of Venda, Limpopo Province |
| participants | Day 1: farmers, extension officers, Univen students, Institute of Rural Development, UCT delegates, UFH students<br>Day 2: Univen academics, Univen students, UFH students, UCT delegates |
| objective | Results, benefit assessment, and further ways to improve |

## A III.2. Gallery

### 2016, Day 1 with the farmers, Ha-Lambani, Limpopo Province

**2016, Day 2 with the academics, University of Venda**

## 2017, Day 1 with the farmers, Ha-Lambani, Limpopo Province

## 2017, Day 2 with the academics, University of Venda

**2018, Day 1 with the farmers, Ha-Lambani, Limpopo Province**

**2018, Day 2 with the academics, University of Venda**

## 2016, Day 1 with the farmers, Alice, Eastern Cape

**2016, Day 2 with the academics, University of Fort Hare**

## 2017, Day 1 with the farmers, Alice, Eastern Cape

## 2017, Day 2 with the academics, University of Fort Hare

## A III.2. Materials sample

WRC-funded project

Science Engagement

**Integrated use of seasonal forecast for community preparedness to climate variability Stakeholder engagement workshop**

***School of Agriculture Boardroom: 5 October 2018***

### Agenda

This is a Water Research Commission (WRC)-funded project, which the University of Cape Town (UCT) leads. Implementation partners are the Universities of Fort Hare, KwaZulu-Natal and Venda (UNIVEN), Agricultural Research Council, South Africa Weather Services and Council for Scientific and Industrial Research. The project is coming to an end after three years of implementation, which mainly focused on developing a climate-crop integrated assessment tool in support of agricultural decision making at monthly to seasonal scales. Integration of the project's scientific outputs with indigenous knowledge is critical pillar and in this regard, periodic reflection workshops are central to its success. Hence this workshop.

During previous workshops, the scope of the project was introduced (2016) and the potential to integrate seasonal forecasts and crop models highlighted (2017). The aim of the current workshop is to examine the progress made to date. In this respect, the specific objectives are to: (1) assess application of the integrated 'seasonal forecast and crop model' tool amongst farmers; (2) integrate seasonal forecast information with indigenous knowledge; and (3) disseminate the knowledge after completion of the project.

**Programme:**

| Time | Activity | Responsibility |
|---|---|---|
| 09:00 | Arrival, tea and registration | C. Munsaka, UNIVEN |
| 09:05 | Welcome remarks and introductions | J. Francis |
| 09:10 | Overview of the project: Crop modelling and global application | O. Crespo, UCT |
| 09:15 | Use of Indigenous knowledge in Forecasting Rainfall | A.E. Hlaiseka |
| 09:30 | Use of indigenous forecasting with seasonal forecasting with seasonal forecasting information | K.N. Xoxo, UFH |
| 09:45 | Seasonal forecast projections in the Eastern Cape | T. Pindura |
| 10:00 | Developing an integrated model for estimating adaptation cost to climate variability for maize farmers in resettlement areas of Zimbabwe | D. Shoko |
|  | Break/Energiser | All |
| 10:15 | Application of satellite imagery in climate variability management | M. Chari, UFH |

GROUP 1 : Discussion
TOPICS : Usefulness of indigenous knowledge forecasts

This discussion follows
> Use of indigenous forecasting with seasonal forecast information (Khululwa Nangamso Xoxo)
> Seasonal forecast projections in the Eastern Cape (Tineyi Pindura)

GROUP constitution:

| Total | #Male | #Female | #Farmers | #Ext. Officers | #Academics | # <35 | 35<#<65 | # >65 | (other) | (other) | (other) |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  | 1 | 8 | 8 | 1 | 1 | 2 | 7 |  |  |  |  |

| DISCUSSION SUPPORT | Very much | Maybe | likely not |
|---|---|---|---|
| **USEFULNESS: Which activity do you use indigenous knowledge** |  |  |  |
| Planting dates | ✓ |  |  |
| Crop planting material | ✓ |  |  |
| Pest management | ✓ |  |  |
| Soil fertility management | ✓ |  |  |
| Other (Specify) CONTROLLING OF WEEDS | ✓ |  |  |
|  |  |  |  |
| **ACCESS: Sources of weather information** |  |  |  |
| Extension officer |  | ✓ |  |
| online |  | ✓ |  |
| Media (radio/tv/etc) | ✓ |  |  |
| phone/smartphone |  | ✓ |  |
| (where else) |  |  |  |
| (where else) |  |  |  |
|  |  |  |  |
| **APPLICABILITY: IK practices used to adapt to Climate variability** |  |  |  |
| Floods | ✓ |  |  |
| Erratic rainfalls | ✓ |  |  |

|  |  |  |  |
|---|---|---|---|
| Drought | ✓ |  |  |
| Increased pest control incidences | ✓ |  |  |
|  |  |  |  |
|  |  |  |  |
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**List climatic indicators that you use for forecasting**

BIRDS
FLOWERING OF PLANTS
SUN

**Meaning of these indicators**

- BIRDS – FOR RAINING, FOR SEASON (SUMMER)
- FLOWERING OF PLANTS – FOR SEASONING
- SUN – EARLY RISING – SEASON
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Can you recall major events related to climate change/variability since 1990?

– LATE SEASONS eg winter and summer,
– Thunderstorms in winter,
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