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Investigating the influence of present and projected climate on the livelihood of small-scale farmers in the uThungulu District Municipality, KwaZulu Natal, South Africa

by

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Submitted in partial fulfillment of the requirement of the degree

MASTER OF SCIENCE, METEOROLOGY

DEPARTMENT OF GEOGRAPHY, GEOINFORMATICS AND METEOROLOGY FACULTY OF NATURAL AND AGRICULTURAL SCIENCES

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January 2019

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Declaration

I Nosipho Ntombani Zwane declare that this dissertation that I am submitting for the MSc degree in Meteorology at the University of Pretoria is my own work and has not been submitted by me for a degree at any tertiary institution. I have used Harvard as the convention for citation and referencing.

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Abstract

Several studies have been conducted globally with regards to climate variability and change. A gap has been identified to link the impact of present and projected climate on the livelihood of small-scale farmers in South Africa. The main objective of this study was to investigate the influence of present and projected climate on the livelihood of small-scale farmers in the uThungulu District Municipality, KwaZulu Natal, South Africa. Mean monthly composite of rainfall and temperature from observation data obtained (1997-2015) from South African Weather Service (SAWS) characterizes uThungulu District Municipality as having two distinct seasons, a wet season from October to March and a dry season from April to September. For temperature a small dispersion with slight positive skewness in dataset was observed. Meanwhile, for rainfall a large dispersion with negative skewness was observed. The community in this region is highly dependent on rain-fed agriculture making the small-scale farmers vulnerable to climate variability and change. A case study on Ntambanana, one of the six local municipalities of uThungulu District Municipality was considered in which analyses of small-scale farmers perceptions of the past and present climate changes in relation to their livelihood was profiled. Most small-scale farmers' households were female headed between the ages of 18-59 years. In the last 10-20 years, small-scale farmers observed a change in crop farming due to changes in rainfall patterns and less harvest due to high temperatures. The results from small-scale farmers' perceptions correlate to the meteorological data in which long-term linear trends show that temperature maximum is increasing at the rate of 0.0298°C/yr and temperature minimum decreasing at a rate of 0.0629°C/yr. On the other hand, long-term linear trends for rainfall also showed a decrease rate of 1.5887mm/yr. From the Rainfall Anomaly Index (RAI) analysis, 11 out of 19 years had below normal average rainfall. Those years with below average rainfall were also characterized by late onset of rainfall and early rainfall cessation. Some of those years were also associated with El Nino phenomenon which brings dry conditions in South Africa. Two CMIP 5 Global Climate Models (GCMs) were considered for climate projections and those were GFD and Nor. These models were selected because they simulated proximity results to observations. Downscaling based on Quantile Mapping (QM) using three tests (PTF, SSPLINL and QUANT) showed that the SSPLINL and QUANT were better methods to employ when conducting impact studies using GCMs. Changes in projected hydrological processes were also investigated, results showed that uThungulu will have less drought events meanwhile the severity, magnitude and duration will be higher. The study concluded three things (1) uThungulu District Municipality has experienced substantial inter-annual variations in the past and present climate, (2) small-scale farmers

perception of climate corroborate meteorological variables analyzed (3) uThungulu District is prone to extreme climate events and projected climate change and extreme events will result in the livelihood of poor communities such as Ntambanana to be more vulnerable because of limited coping mechanism and resources.

Preface

Amongst the scientific community, there is an ongoing research interest about climate change in general. The earth system science community, through a number of studies understands that climate change is expected to affect means and variability of several climate variables, where-in rainfall and temperature are key variables in the climate system directly affected by global warming, with consequences for food security, health issues and water resources. Future climate projections show not only changes in mean climate of the earth system but also changes in extreme weather and climate events. For this reason, it was appropriate to investigate the influence of present and projected climate on the livelihood of small-scale farmers in the uThungulu District Municipality, KwaZulu Natal, South Africa. uThungulu District Municipality is largely rural with low infrastructural and technological development, thus vulnerable to changing climate. **Chapter one** outlines the study rational and study objectives.

Chapter two captures the literature review on understanding the weather and climate of South Africa, KZN in particular, and systems that affect weather and climate in order to understand the work that is already done under climate change and the impacts thereof. **Chapter three** investigates the variability of temperature and rainfall in uThungulu District Municipality, KZN. **Chapter four** shows a comparative analysis of small-scale farmers' perception and the past and present climate for livelihood analysis. **Chapter five** deals with the impact of climate change on hydrological processes in uThungulu District Municipality. Lastly **Chapter six** provide general conclusions, recommendations and future work.

Acknowledgement

I would like to express my utmost gratitude to the following people for making this work a success.

- Dr. Joel Botai for giving me the opportunity to work with him, for his invaluable input and support during this project. I am thankful for his constant availability, guidance, assistance, sharing his profound expertise particularly with R coding and analysis and patience throughout the project.
- Dr. Casper Madakadze for his guidance and allowing me to work with him on the FAO project which aimed to reduced risks on crop production, raise awareness of climate change to small-scale farmers and extension workers.
- The financial support of the European Union (EU) through contribution agreement DCI-Food/2012/304-807 for the FAO led project *'Supporting smallholder farmers in southern Africa to better manage climate-related risks to crop production and post-harvest handling'* OSRO/RAF/220/EC. I am thankful for the opportunity of being one of the MSc students sponsored by the project.
- Thank you to South African Weather Service for financial support and providing an environment for me to conduct my studies, computational facilities, for their data and for providing financial support.
- Thank you to Water Research Commission funded project (K5/2309) for also providing funds and computational facilities. This also made completion of my MSc a success.
- In conclusion, I give all the Glory to the Lord and a big thank you to my family for constant love, encouragement and support throughout everything.

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List of Abbreviations

AWS: Automated Weather Stations

Can: CanESM2

CDI: Cumulative Departure Index

CMIP 5: Coupled Model Inter-comparison Project

CNR: CNRM-CM5

CO_2: Carbon Dioxide

CSAG: Climate System Analysis Group

DAFF: Department of Agriculture Fisheries and Forestry

DEA: Department of Environmental Affairs

DWAF: Department of Water Affairs

FAO: Food and Agriculture Organisation

GCMs: Global Climate Models

GFD: GFDL-ESM2M

GHG: Greenhouse gases

IPCC: Inter-governmental Panel of Climate Change

KS: Kolmogorov-Sminov

KZN: KwaZulu Natal

LTAs: Long term Adaptation Scenarios

MAP: Mean Annual Precipitation

MAT: Mean Annual Temperature

MK: Mann-Kendall

Nor: NorESM1-M

PTF: Parametric Transformation

QM: Quantile Mapping

QUANT: Non-Parametric Empirical Quantile

RAI: Rainfall Anomaly Index

RCP: Representative Concentration Pathway

RMSE: Root Mean Square Error

SANBI: South African National Biodiversity Institution

SAWS: South African Weather Service

SSPLINN: Smoothing Spline

SST: Sea Surface Temperatures

UCT: University of Cape Town

WWF: World Wide Fund for Nature

CHAPTER ONE: Background information

1.1. Introduction

Scientific research demonstrated that climate change is global challenge facing humans and their socio-economic activities, health, livelihood and food security (Adisa et al., 2017). In 2008 the Department of Science and Technology launched its ten-year innovation plan for South Africa under the theme *innovation towards a knowledge economy 2008-2018*. This plan identified five grand challenge areas that required major research to bring social, economic, political, scientific and technological benefits. This study addresses two of the grand challenges at a local scale, namely: 1) science and technology for global change with a focus on climate change, and 2) human and social benefits. This study contributes to both the scientific and social science knowledge and community by highlighting the impact of climate change on the livelihood of small-scale farmers and the farmers' perceptions of climate change in association with observed temperature and rainfall trends.

Climate change could destruct the growth of economy and other aspect of human and natural wellbeing. Although it is a global challenge, developing countries are the most exposed to climate change and their need for adaptation is higher. According to Elum et al. (2017), Africa's agricultural production will be greatly affected by climate change. The agricultural sector is a source of livelihood for many people particularly in poor rural communities. South Africa has been identified as one country in Africa highly vulnerable to the impacts of climate change, as a result will need supportive policies and frameworks to enhance climate change adaptation processes, particularly for farmers (Elum et al., 2017).

Farming activities rely on favourable climate conditions. Nile and Muller (2016) suggested that, in general, farmers have a long-term perspective on climate in their areas because of its direct impact on their livelihood. To date, little research have been conducted on present and projected climate on the livelihood of small-scale farmers in rural areas. This study will fill the gap on how perceptions of climate change may differ from actual changes and how these discrepancies may impact climate policies and frameworks.

1.2. Problem Statement

Climate projections indicate that Africa is likely to experience significant climatic changes, mainly extreme flooding/drying and warming conditions (IPCC 5th Assessment Report). Climate change models also predicted that the impact of climate change would be greater in regions across Africa, however one of the challenges on climate models and scenarios is that they are somehow complicated by uncertainties with changes in rainfall (Ayanlade et al., 2017).

Most models predicted a drying southern Africa, these results premise that climate change is projected to worsen water related and crop production challenges in KwaZulu-Natal (KZN) Province, South Africa. uThungulu District Municipality in KZN has the third highest population in the province and the region is highly dominated by small-scale farming. Understanding the impact of present and project climate on the livelihood of small-scale farmers is significant for implementing mitigation and adaptation strategies.

Rural farmers are susceptible to climate change, particularly because of compounding challenges of poverty, high dependence on rain-fed agriculture and poor infrastructural and technological development. This research will provide answers to research questions that have a wide application in sectors such as water management, agriculture, disaster risk reduction and human settlement planning. The quantification of the impact of present and projected climate on the livelihood of small-scale farmers will enable the drawing of robust messages to guide response strategies for the community in uThungulu District Municipality for their sustainability.

1.3. Study Rationale

The study is motivated by the fact that internationally, there is growing recognition of the potential implications of present climate variability and projected climate change on agriculture and food security. Amongst the countries in the world, South Africa is identified as a region that is already facing more frequent and more intense drought and flood events, reduction in water availability, higher inter-annual rainfall variability and increasing surface evapotranspiration (Schulze *et al*., 2014). It is therefore appropriate to conduct a study assessing the influence of climate variability and change on the livelihood of small-scale farmers on a municipality spatial scale. The uThungulu District Municipality has been identified as an area where communities are

at risk and are prone to be faced with difficult decisions to make on a daily basis in order to make informed and weather smart decisions for sustainable operational, tactical and strategic purposes.

In the KZN Province where communities are already facing risks related to current climate variability, climate change is projected to worsen agricultural related challenges. Previous studies (Long-Term Adaptation scenarios, Report No.7) suggested that the KZN Province is likely to experience stream flow trends that are opposite to the rest of the country. This means that the KZN Province is likely to be at risk from more extreme flood events due to a projected increase in intensity and frequency of rainfall, while the rest of the country is projected to experience drier conditions. Increased flooding might have significant impact on farming practices. In addition, standing water in a wetter and warmer environment might have a negative impact on human, livestock and crops health. Changes in climate variability and climate might lead to small-scale farmers being more susceptible and vulnerable. Aligned with previous research, there is a need for assessment and validation using the latest community engagement techniques and regional scale climate models. The proposed study will offer answers to research questions that have wide applications in sectors such as agriculture, health, water management, disaster risk reduction and human settlements. The study will quantify uncertainties associated with the study objectives in order to convey a message that can guide farmers in the uThungulu District Municipality.

1.4. Study Objectives

The main objective of this study was to investigate the influence of present and projected climate on the livelihood of small-scale farmers in the uThungulu District Municipality, KwaZulu Natal, South Africa. To achieve the main objective, the following sub-objectives were considered:

Objective 1: To study the variability of temperature and rainfall in uThungulu District Municipality

Objective 2: To evaluate small-scale famers' perceptions to past and present climate and its impact on livelihoods

Objective 3: To investigate the impact of climate change on hydrological processes in uThungulu District Municipality using bias corrected GCMs

CHAPTER TWO: Literature review

2.1 General atmospheric circulation of the Southern Hemisphere

The natural interaction of the atmosphere and the ocean due to the rotation of the earth results in the Rossby waves also known as the planetary waves that propagate eastwards in the atmosphere along the subtropical jet. Carried by the subtropical jet are short waves with ridges and troughs that are important for weather and climate of southern Africa. The circulation in the Southern Hemisphere is dominated by semi-permanent subtropical anticyclones over the Atlantic Ocean and the Indian Ocean, and the circumpolar trough over the Southern Ocean (Tyson and Preston-Whyte, 1998).

Along the tropical southern Africa, rainfall variability in summer may be affected by the Walker circulation (Viswambharan and Mohanakumar, 2014). Under neutral conditions (Figure 1), the Walker circulation is such that there is convergence near the surface over South America, divergence over South Atlantic Ocean and convergence along the south-eastern Africa near the Congo basin. The convergence over the Congo basin leads to uplift of moisture and thus rainfall in Southern Africa. Also regarded as a source of moisture for South African rainfall in summer, is the western Indian Ocean (Tyson and Preston-Whyte, 1998).

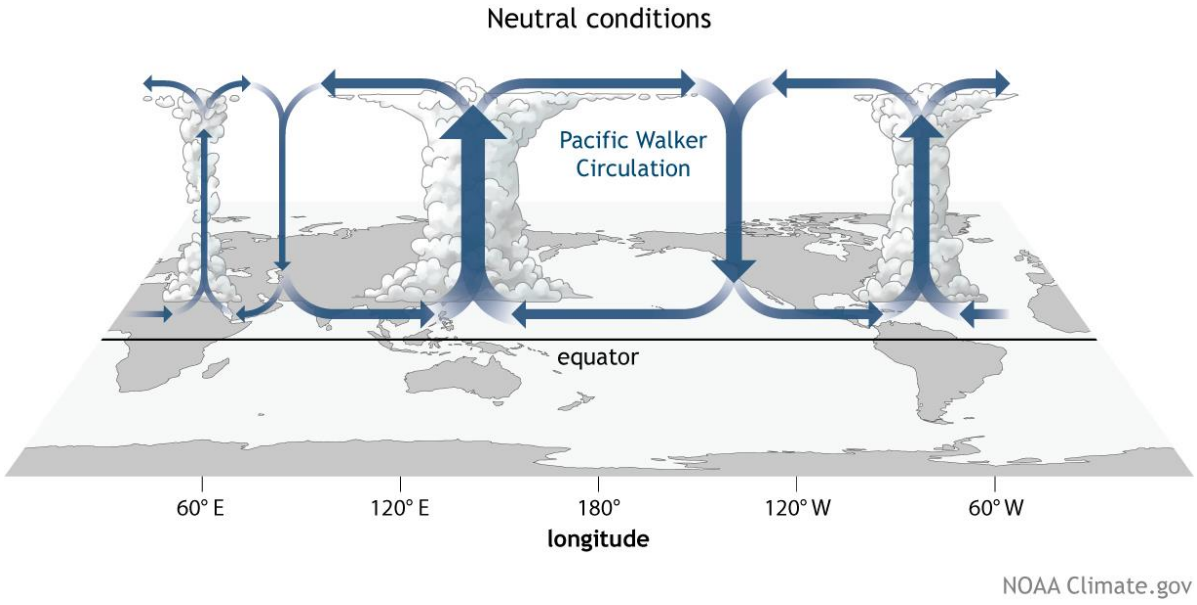


Figure 1: General atmospheric circulation of the Southern Hemisphere under neutral conditions: SOURCE [NOAA Climate.gov]

2.2 The annual cycle in Southern Africa

In southern Africa along the western side the climate is influenced by the Atlantic Ocean in connection with the variability in the Inter Tropical Convergence Zone (ITCZ), the South Atlantic anticyclone and mid-latitude westerlies. This is in contrast to the annual cycle in the ITCZ position in the eastern side which is far less pronounced (Reason et al., 2006). Southern Africa has two distinct seasons, a wet season from November to March and a dry season from April to September (Botai et al., 2016). The wet season occurs when the ITCZ moves south, bringing rainfall, while the dry season occurs when the ITCZ moves northwards (Figure 2) (Reason et al., 2006).

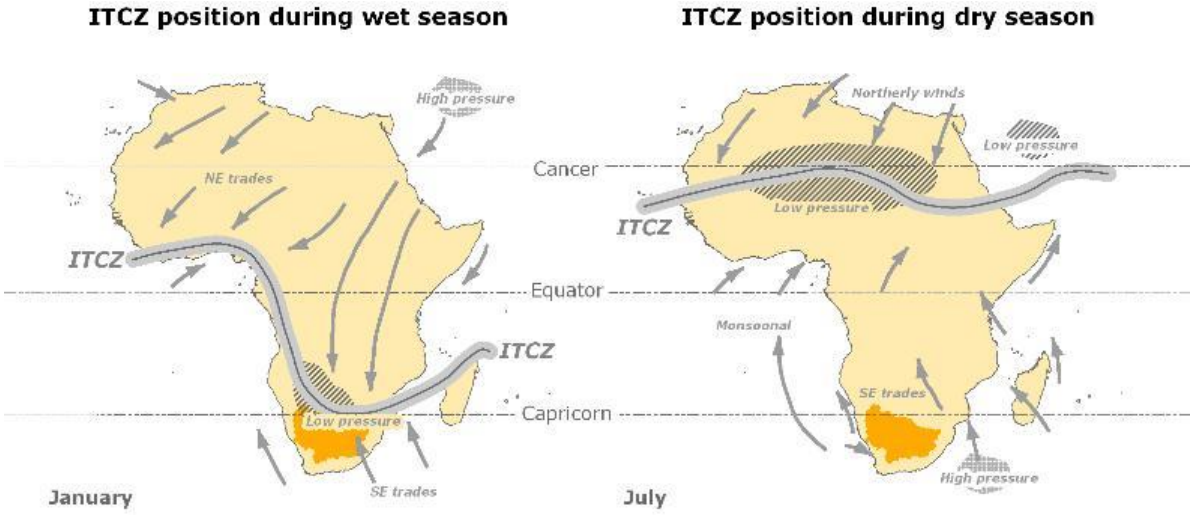


Figure 2: The position of the ITCZ during wet and dry season in South Africa: SOURCE [Reason et al., (2006)]

According to Reason et al. (2006), the ITCZ in its austral summer position is produced by low level confluence of three primary airstreams, namely, north-westerly flow from the tropical south-east Atlantic, the north easterly monsoon winds from tropical western Indian ocean and the south easterly flow from the south west Indian ocean.

In May, the ITCZ is further south. During this time warm SSTs are evident in Gulf of Guinea. From July to August the ITCZ moves more poleward to about 8°-10°N over the Atlantic and more northward over the West Africa. This results in a remarkable cooling in the central and eastern equatorial Atlantic as the cold tongue develops. Between August and November, the tropical eastern Atlantic warms up both north and south of the equator resulting in the ITCZ migrating

southwards towards the equator. In February, the ITCZ is at it southern-most position over land across Madagascar, central Mozambique and south-eastern Zambia in south-eastern Africa (Reason et al., 2006).

2.3 Climatic regions in South Africa

2.3.1 South African climate regions according to Köppen-Geiger Climate Classification System

The development of the Köppen-Geiger climate classification system dates back from 1900 (Mastrodimenico et al., 2000). The main aim was to compare climates from different areas around the world. Due to this fact, it is vital to start any discussion about climate at this point. According to Peel et al (2007), climate in southern Africa ranges from tropical to arid to temperate. Köppen classification is based on five vegetation groups because plants are indicators for many climatic elements (Engelbrecht, 2016). The five vegetation groups of Köppen distinguish between plants of equatorial zone (**A**), the arid zone (**B**), the warm temperate zone (**C**), the snow zone (**D**), and the polar zone (**E**). Demonstrated in **Table 1** is the Köppen-Geiger climate classification system (Kottek et al., 2006)

The Agulhas system around southern Africa forms a key component of the global ocean circulation (Beal et al., 2011) bringing in warm sea breeze. As a result, the biome in the east coast of Mozambique is tropical savannah. Also small pocket of tropical savannah are found over the eastern Angola and western Zambia. Countries which are regarded to have an arid climate are South Africa, Namibia, Botswana, Zimbabwe, Mozambique and some parts of Angola. The arid climate in these countries is due to the rain shadow formed by the mountains on the east coast. The arid is divided into steppe with hot temperatures and a hot desert.

Since 1960 observed surface air temperature have shown an increase in warming trend reaching +0.03°C/year while the trends in rainfall are less clear, with large spatial and temporal variability (Jury, 2012). Southern Africa (SA), south of 15°S is a semi-arid region mainly experiencing great amounts of rainfall in austral summer between November and February (Crétat et al., 2012). Rainfall in southern Africa is experienced as the result of changes in solar insolation and north-south displacement of the Hadley cell. Zonal system circulation also plays a key role such that in summer, easterly winds draw moisture from the Indian Ocean and warm Agulhas Current, while in winter, westerly winds bring dry air from the Atlantic Ocean and cool Benguela Current. The

interannual climate variability is modulated by the ENSO amongst other factors (Reason et al., 2006, Jury, 2012).

Table 1: Köppen-Geiger classification system climate: SOURCE [Kottek et al., 2006]

Type	Description	Criterion
A	**Equatorial climates**	$T_{min} \geq +18°C$
Af	Equatorial rain forest, fully humid	$P_{min} \geq 60mm$
Am	Equatorial monsoon	$P_{ann} \geq 25\ (100\text{-}P_{min})$
As	Equatorial savannah with dry summer	$P_{min} < 60mm$ in summer
Aw	Equatorial savanna with dry winter	$P_{min} < 60mm$ in winter
B	**Arid climates**	$P_{ann} < 10\ P_{th}$
Bs	Steppe climate	$P_{ann} > 5\ p_{th}$
Bw	Desert climate	$P_{ann} \leq 5\ P_{th}$
C	**Warm temperate climates**	$-3°C < T_{min} < +18°C$
Cs	Warm temperate climate with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3P_{smin}$ and $P_{smin} < 40mm$
Cw	Warm temperate climate with dry winter	$p_{wmin} < P_{smin}$ and $P_{smax} > 10P_{wmin}$
Cf	Warm temperate climate, fully humid	neither Cs nor Cw
D	**Snow Climates**	$T_{min} \leq -3°C$
Ds	Snow climates with dry summer	$P_{smin} < P_{wmin}$, $P_{wmax} > 3P_{smin}$ and $P_{smin} < 40mm$
Dw	Snow climates with dry winter	$P_{wmin} < P_{smin}$ and $P_{smax} > 10P_{wmin}$
Df	Snow climate, fully humid	Neither Ds nor Dw
E	**Polar climates**	$T_{max} < 10°C$
ET	Tundra climate	$0°C \leq T_{max} < +10°C$
EF	Frost climate	$Tmax < 0°C$

2.3.2 South African climate regions according to Rouault et al (2003)

A study by Rouault et al (2003) divided South Africa into eight climatic regions through the data from South African Weather Service (SAWS) which divided South Africa into ninety-three rainfall districts. The climatic regions were determined based on cluster analysis of South African rainfall.

Demonstrated in F**igure 3** is the location of the eight climatic regions. **Table 2** gives the names of the eight regions while **Figure 4** shows the mean annual cycle. From these it is clearly indicated which regions in South Africa receives summer rainfall and those receive winter rainfall. Most of South Africa receives summer rainfall with an exception of region 2 (Western Cape). Rainfall in the interior and northern region of South Africa is due to convective thunderstorm driven by tropical-extra tropical interaction and associated cloud bands (Reason et al., 2006). Over the south coast, rainfall is received throughout the year. A bimodal rainfall pattern is evident over the eastern parts of tropical southern Africa, largely attributed to the seasonal migration of the ITCZ (Reason et al., 2005).

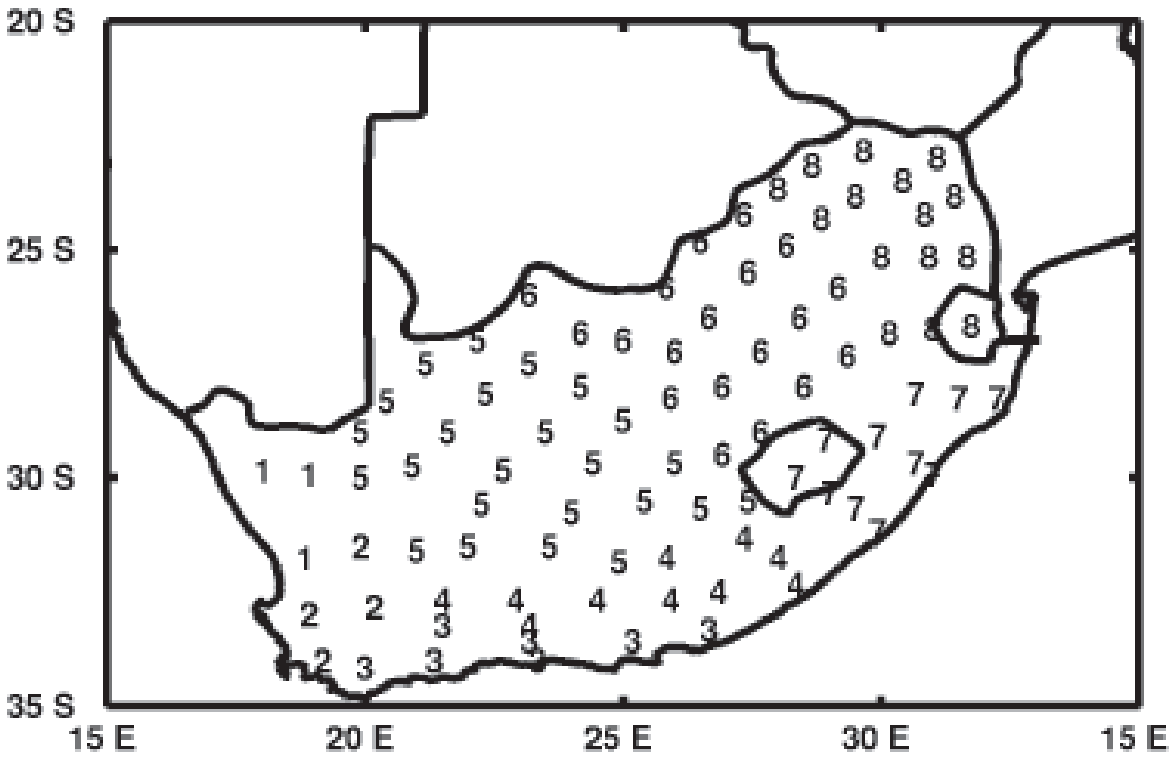


Figure 3: Location of 8 climatic regions in South Africa: SOURCE [Rouault et al., 2003]

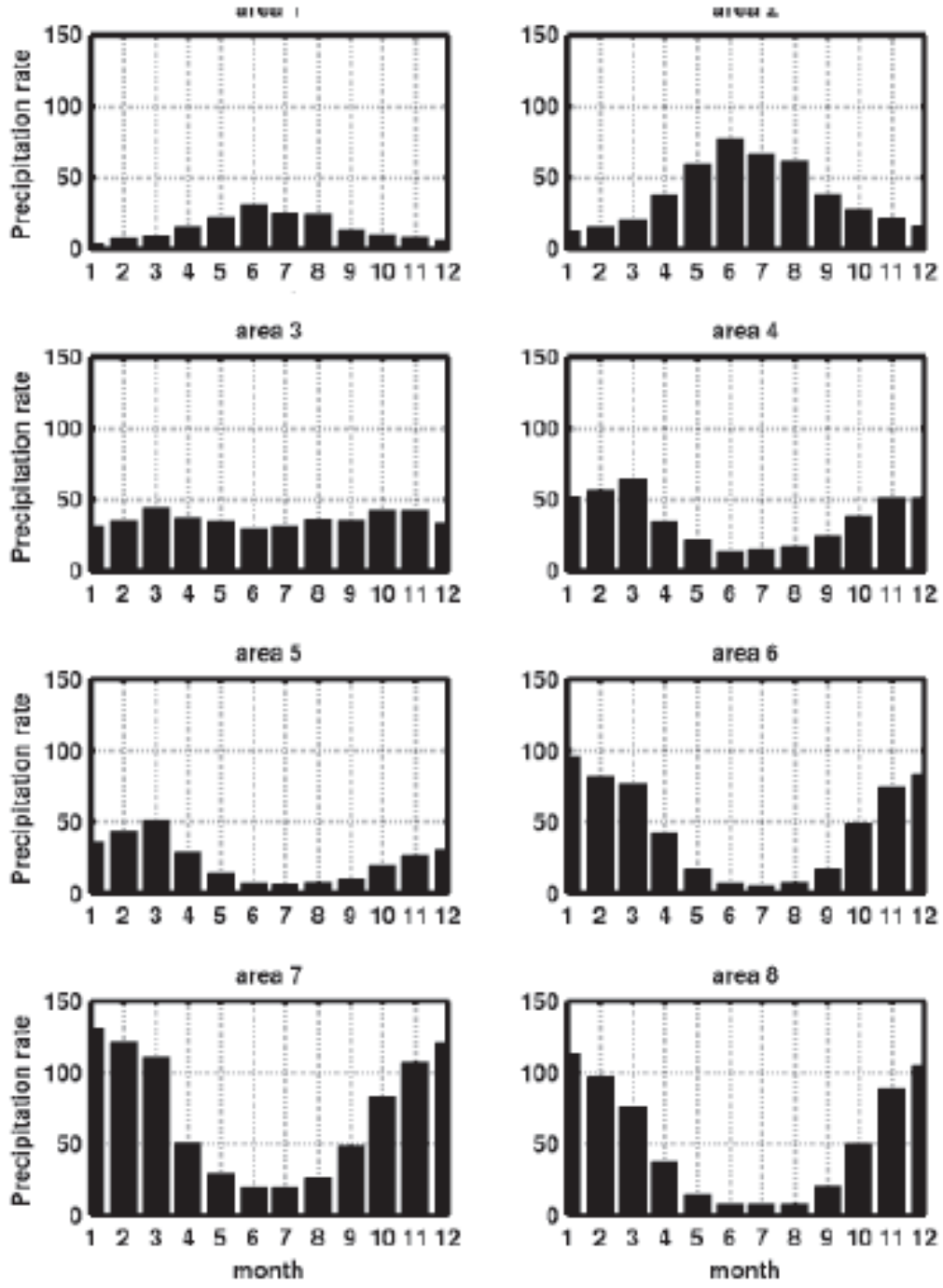


Figure 4: Mean annual cycle of eight climatic regions in South Africa: SOURCE [Rouault et al., 2003]

Table 2: The eight climatic areas defined by the South African Weather Service

Number	Name
1	North-Western Cape
2	South-Western Cape
3	South Coast
4	Southern Interior
5	Western Interior
6	Central Interior
7	KwaZulu Natal
8	North-Eastern Interior

2.3.3 Drivers of climatic conditions in South Africa

2.3.3.1 Cut off lows

Most heavy rainfall in South Africa is connected with cut off lows. According to Mason et al. (1997), numerous severe floods over much of South Africa such as in September 1987 and March 1988 resulted from cut off lows. Frequently cut off lows form in combination with anticyclones to the south of the subcontinent and give an onshore flow from the Agulhas Current to the eastern escarpment. Along the south east coast, anticyclones can deliver a large proportion of rainfall particularly when the onshore flow is strengthened by low pressure inland (Mason et al., 1997). Singleton and Reason (2007), investigated the inter-annual variability of cut off lows over subtropical southern Africa. It was suggested that there may be a link between annual frequency of cut off lows and La Nina years. Demonstrated from the results was that of the seven mature episodes of La Nina years investigated, five of these years were connected with significant increase in occurrences of cut off lows.

It was realized from the study by Singleton and Reason (2007) that cut off lows can be categorized into three types depending on the nature of the jet streak that led to their formation. These types are namely ‘polar’, ‘subtropical’ and ‘polar vortex’. The polar-type cut off lows are created as a result of equatorward extensions of polar jet and are likely situated poleward of the jet. Subtropical cut off lows are most likely formed by equatorward extension of a subtropical jet or where a split in zonal polar jet causes a weak equatorward branch. The polar vortex cut off low

forms from an extension of the polar vortex itself and tends not to be advected away from the main polar vortex (Singleton and Reason 2007).

Furthermore, Singleton and Reason (2006) modelled a cut off low event which occurred in August 2002. The cut off low was characterized by anomalously high precipitation over the Eastern Cape of South Africa. The simulation showed that a meso-low located 200km over the open ocean tracked in a north-westerly in the direction of the east coast of South Africa. This resulted in convective cells occurring over the warm Agulhas current at a low level jet impacting the Eastern Cape Coast. Intensified rainfall occurred over the coastal region where this warm moist air impacted the topography.

2.3.3.2 Cold fronts and Tropical cyclones

The SAWS Report (2016) documented and gave a warning on a late winter extreme system which developed in South Africa, affecting mostly the southern and eastern parts of South Africa. This system was due to the cold front in connection to the upper air trough from the ocean region of the south west of the country on the23 July and developed to cut off low on the 24 July. Evident from the eastern part of the country was a ridging high pressure, introducing cold moist condition to the east as the cut off low pressure developed further. The cold front followed, this is a transition zone where a cold air mass is replacing a warmer air mass. The cold front propagates from west to east. The air behind the cold front is colder and drier. As the cold front passed through, temperatures dropped significantly resulting in very cold weather with rainfall.

According to SAWS, tropical cyclones' season in South Africa is fromNovember to April. Only those moving into the Mozambique Channel influence South Africa's weather. When this is experienced in South Africa dry weather dominates over the interior because of subsiding air surrounding the tropical cyclone. Only a few move in over or close enough to the land to cause destruction, and then usually north of the 25°S latitude. In such cases, the Northern Province, Mpumalanga and KwaZulu-Natal may experience destructive winds and the risk of flooding. Significant tropical cyclones that had such an effect on South Africa were Domoina which occurred in January 1984, Imboa in February 1984 and more recently Eline in February 2000.

2.3.4 El Nino Southern Oscillation (ENSO)

2.3.4.1 Brief History

El Nino has been documented since the 1500s. It is an oceanic process along the coasts of Northern Peru and Ecuador. The term El Nino was initially used to describe the annual appearance of warm waters around Christmas time. The period of warm water appearance was inconsistent, in some years warm water appeared earlier and lasted longer. This resulted to the term being used to describe periods of anomalous warming in the coast (Taylor, 1998).

In the 1800s, Sir Gilbert Walker and colleagues started to describe large scale pressure oscillations. They established the Southern Oscillation which was a global scale pressure that was linked with rainfall anomalies in many areas of the tropics such as India, Australia and South America (Taylor, 1998). The Southern Oscillation global pressure was used as the basis for seasonal rainfall prediction (DeVries et al., 1997). In the late 1960s scientists (Bjerknes, 1969) realized that El Nino and the Southern Oscillation can put of a single climate phenomenon and coined the term El Nino Southern Oscillation (ENSO) (DeVries et al., 1997).

2.3.4.2 Impact of ENSO variability on Southern African climate

The impact of ENSO is largely felt in southern Africa during the summer peak rainfall months December to March (Mason and Jury, 1997; Reason, 2001). In this period the tropical atmosphere circulation is usually dominant over most of the subcontinent and rainfall has reached maturity. The tropical air penetrates southward and the convergence zone usually reaches 20°S in austral summer. Mason (2001) stated that when El Nino occurs, the convergence is frequently weakened and shifted to east and north leading to dry conditions dominating over much of Southern Africa.

In southern Africa the ENSO events occur partly because of changes in sea surface temperatures (SSTs) in the tropical Indian Ocean. The upsurge heat fluxes over the tropical Indian Ocean intensify the *in situ* atmospheric instability resulting to a weaker pressure gradient onto the subcontinent. Moreover, the influence of ENSO events in southern Africa occurs through Southern Hemisphere standing waves. When warm events occur, a northward shift of westerlies and a weakening of amplitude of waves occur. The westerlies over southern Africa bring less moisture from the Indian Ocean thus dry conditions prevail (Mason, 2001).

2.3.4.3 Dry summers that occurred during ENSO years and non-ENSO years in South Africa

A study by Mulenga et al (2003) in the northeast South Africa using NCEP/NCAR Reanalysis data documented dry summers that occurred in ENSO and non-ENSO years. In South Africa El Nino is associated with dry conditions. The circulation is such that there is an offshore shift of ascending branch of the Walker circulation to be over the western Indian Ocean rather than over the tropical Southern Africa (Mulenga et al., 2003). Results from an idealized model (Cook, 2000) suggested that some droughts occurring in South Africa could possibly be associated to ENSO driven by warm SST over the Pacific Ocean through atmospheric teleconnection that propagate Rossby like features.

Non-ENSO driest summers since 1949 were those that occurred in 1951/52, 1967/68 and 1981/82 (Mulenga et al., 2003, Reason et al., 2005). For non-ENSO drought a common feature includes an increase in mid-latitude circulation in South Africa and an increase in advection of cool dry air from the south Atlantic to the county. According to Mulenga (2003), the circulation during the 1981/82 non-ENSO drought was dominated by positive pressure anomalies and anticyclonic conditions over Southern Africa which reflected moisture flux with cool dry south Atlantic air over western South Africa and a weakening onshore flow of moisture from the southwestern Indian Ocean. Another study by Reason et al (2005) also examined non-ENSO summer drought 2003/4 over the Limpopo region, the results demonstrated that the October-December 2003 drought was associated with major mid-latitude circulation anomalies that resulted in an increase (decrease) in the advection of cool, dry (warm, moist) south east Atlantic (south West Indian) ocean air masses over South Africa.

2.4 Impact of climate change

2.4.1 Impact of climate change in South Africa

Africa is mostly susceptible to future climate change (Conway et al., 2011) and South Africa is cited as one of the most extreme examples because it lies within an arid to semi-arid climatic region (Reason et al., 2005). Numerous studies have revealed atmospheric concentrations of greenhouse gases (GHG) are increasing due to human activities, particularly since pre-industrial times (Stocker et al., 2013). Most scientists agree that climate change is inevitable even if the developed countries would put more effort to mitigate the GHG emissions. Poor and developing countries such as South Africa, which rely on agricultural production, are likely to be most vulnerable to climate change and climate vulnerability (Bryan et al., 2009).

The increase in atmospheric concentration of CO_2 and other GHG has had an influence on global temperature and are predicted to cause further warming in the near future (Hartman et al., 2013). One consequence of increased temperatures will be an intensification of the hydrological cycle at the global scale (New, 2002) which will result to distinct impact on hydrological systems and river flow. Although global climate model predictions of future precipitation differ, predictions of future temperatures are more uniform, especially for the next few decades.

Over southern Africa, the projected impacts of climate change are not uniform. Different places are faced with different effects of climate change, and this trend is projected to continue into the future. Other parts of southern Africa will have less rain and more wind while others will have more rain, and overall it will be hotter and more humid everywhere (IPCC 4th assessment report, 2007). According to the African Climate Policy Centre (2011) report, the western parts of South Africa are likely to become drier whilst the eastern parts will become wetter. The availability of a large ensemble of Global Climate Models (GCMs) at a higher spatial resolution CMIP 5 (Taylor et al., 2012) gives an opportunity to validate previous findings on impact of climate change in South Africa.

The impact of anticipated climate change in South Africa are similar to those being experienced around the world which include warming temperatures day and night all year round, changes in rainfall timing and quantities, changes in seasons, increases climate variability (e.g. floods, drought and heat waves), higher sea-level and increasing frequency and intensity of extreme weather events (CSAG, University of Cape Town). These primary impacts lead to secondary

impacts such as crop failure which leads to loss of food security especially for rural people, and increase in many types of human and animal disease such as cholera and malaria, whilst damage in infrastructure like roads and telecommunications facilities can be expected from flooding, leading to social economic losses.

2.4.2 Climate change impact in the agricultural sector

The foundation of developing economy is agriculture. South Africa requires a healthy agricultural industry in order to contribute to the country's gross domestic product, ensure food security and create more job opportunities. The sustainability of agriculture depends on farming methods and practices and profitable yields and well-being of farmers (Gbetibouo and Ringler, 2009). South Africa can be divided into distinct farming regions. The distinct regions hold specific farming activities ranging from intensive crop production in winter rainfall and high summer rainfall to cattle in bushveld and sheep farming in arid areas (World Wide Fund for nature report). This is because South Africa receives rainfall with high spatio-temporal variability (Ratna et al., 2012).

According to Statistics SA (2009), about 20% of the country's soil is suitable for production of rain-fed crops. Only 3% is considered truly fertile while about 69% is suitable for grazing and livestock farming in South Africa. Each year the population of South Africa is growing by almost 2%, resulting in a population of 82 million by the year 2035 (Annexure C: Western Cape Agricultural Systems Summary). This means there will be more demand of resources and food production.

South Africa is a water scarce country and receives less than 500 mm of rainfall annually (Mabhaudhi et al., 2018). The decline in rainfall has led to decline in farms (Agri SA's status report on the current drought crisis, 2016). The remaining farms survive through increased irrigation, fuel fertiliser, mechanisation and genetically modified seed inputs. Thus, it is essential for farmers to adapt to climate changes. Commercial farmers suffer bigger financial losses due to increased temperatures and decreased rainfall while small scale farmers are more vulnerable because they have fewer resources to survive the same conditions (Agri SA's status report on the current drought crisis, 2016).

2.4.3 Climate change impact in the hydrological sector

South Africa is a water limited country with water quality problems linked to population growth and issues of social and economic development (New, 2002). Less than 9% of annual rainfall ends up in rivers, and only about 5% recharges ground water (Climate Change Adaptation Summary Report, 2018). On top of that rainfall and river flow are irregular and unevenly distributed in space leaving only 12% of the land area generating 50% of stream flow (Schulze, 2005 and Schulze 2008). The main users of surface water are agricultural irrigation, domestic, industrial, mining and power generation. This shows that water is the most valuable resource in South Africa and to the economy (South African National Biodiversity Institute)

Projections in a study by Hewitson and Crane (2006) showed that the eastern South Africa is mostly likely to become wetter under SREASA2 scenario which implies more flood events. Climate change predictions are that rainfall will be more infrequent but more intense. This will result in decline of the country's arable land and increase agricultural unpredictability. The effective method of increasing food productivity is to irrigate which implies a huge amount of water usage. It is projected that climate change will affect water supplies in South Africa. Fresh water systems such as rivers will be impacted mainly by increasing variability in rainfall. Ground water and surface water will decrease while increased evaporation from the ground will increase saltiness in the soils resulting in reduction in plant growth. It is said (DWAF, 2012) that by mid-century about 50 million people in South Africa may experience water shortages. Some of these factors are due to rising sea-level which causes salinisation of ground water and estuaries, leaving less fresh water for humans and agriculture.

2.5 Impact of climate change on the livelihood of small-scale farmers in KwaZulu Natal (KZN) Province

The KZN region is an area of great importance as far as the economy of the country is concerned and the livelihood of people is dependent on subsistence agriculture. KZN is characterized by summer rainfall and includes a large proportion of agriculturally productive land. Many studies have been conducted for the KZN region mainly from a biophysical and impact perspective (e.g. Tyson et al., 2002, Schulze, 2005) and also studies with regards to ecological and adaptation topics (e.g. Schulze et al., 2010a, Schulze, 2005). This study hopes to tackle challenges that are faced by small scale farmers in KZN and how climate change impacts their livelihood.

The IPCC 4th assessment report (2007) alerts that the warming of the global climate system is unequivocal due to GHG emission. Global temperatures are estimated to rise between 1.8°C and 4°C during the period of 2090-2099 above reference observed period of 1980-1999. By looking at farmers perception, even though perception is not the same as reality it helps to address socio economic challenges and to recommend plausible adaptation strategies that will match farmers experience and adaptive capacity (Kusakari et al., 2014).

Livelihood is predominantly defined through the lens of income. According to Chambers and Conway (1992), “livelihood comprises the capabilities, assets and activities for the means of living”. Livelihood is only sustainable if it can cope and recover from stress (e.g. climate change), maintain or enhance its capabilities or assets and give sustainable livelihood opportunities for the next generation (Kusakari et al., 2014).

It is a known fact that small-scale farmers are faced with challenging circumstances and that agriculture is one of the few livelihood options available to them. According to Mabhaudhi et al (2018), the drought that occurred in 2015/2016 was the worst to be experienced in southern Africa. That event showed the sensitivity of small-scale farmers to extreme events. Small-scale farmers may notice changing climate trends, particularly the increasing unpredictability of rainfall and decreasing amount of rainfall and increasing drought frequency and severity. However, all this does not help them to have sustainable production. While current approaches to climate change adaptation have had positive responses, suggestions in studies like (Mabhaudhi et al 2018) of promoting indigenous crop species in KZN may ensure food nutrition and food security.

2.6 Research gaps and Justification of the Study

According to Nhamo et al (2019), southern Africa is vulnerable to drought because of its dependence on climate sensitive sectors such as agriculture and hydro-energy. Weather extreme events are worsened by poor levels of preparedness and low adaptive capacity. Since evidence of climate change and its impacts continue to emerge, KwaZulu-Natal is found to be most vulnerable as the communities depend on natural resources.

According to the department of agriculture and environmental affairs report (2013), KwaZulu-Natal has been subjected to extreme weather events at regular intervals over the last 100 to 150 years. Measuring the persistence of these events is therefore vital. Previous studies (Hewitson et al., 2005; Schulze, 2005) suggested warming trend in KwaZulu-Natal that was consistent with the global climate change, and a wetting trend. This study hopes to give an update to the previous studies by 1) measuring the variability of past and present climate changes in uThungulu District Municipality, 2) analyse the small-scale farmers' perception of past and present climate and lastly 3) empirically link the influence of present and projected climate on the livelihood of small-scale farmers in uThungulu District Municipality.

It is said in a study by Nhamo et al (2019), that the Southern African Development Community (which is comprised by 15 southern African countries) was exposed to an intense drought in 2014-2016. In the year 2015/2016 rain season the situation was worsened by the strongest ENSO episodes on record. The impacts of the drought were severe, resulting in more than 40 million people becoming food insecure. According to Nhamo et al (2019), the 2015/16 drought was severe resulting to 643 000 livestock deaths due to lack of pasture and water. There was also 10 % decrease in maize production compared to previous year. Whilst weather extremes are foreseeable, being ready for their occurrence and being able to manage them determines their impact and whether they become disasters.

CHAPTER THREE: The variability of temperature and rainfall in the uThungulu District Municipality, KZN

3.1. Abstract

This study investigated the variability of temperature and rainfall in uThungulu District Municipality using observed data obtained from South African Weather Service (SAWS) for period of 1997-2015. It was discovered that uThungulu District Municipality is characterized by warm temperatures between 18°C to 20°C. Variability was observed across all seven stations and the dataset showed a small dispersion with middle cluttered bimodal distribution and slight positive skewness, indicating slight increase in temperature. The stations showed a large dispersion and a negative skewness for the rainfall, illustrating a decrease in rainfall in uThungulu District Municipality. Most of the rainfall is received in summer between October to March. Similarly, long-term anomalies showed inter-annual variability for both temperature and rainfall. Trend analysis was conducted using basic descriptive statistics (MK test). It was discovered that between 1997-2015 rainfall has decreased at a rate of 1.5887 mm/yr, while temperatures depicted a positive trend. The conclusion drawn from this study is that monitoring the variability of weather and climate in KwaZulu-Natal (KZN) should continue especially since KZN is prone to extreme temperature and rainfall events.

3.2. Introduction

In Africa, fluctuating climate is governed by the interactions of the ocean and the continent. Since 1960 observed surface air temperatures have shown an increasingly warming trend reaching +0.03°C/year while the trends in rainfall are less clear, with large spatial and temporal variability (Jury, 2012). According to New et al. (2006), the Intergovernmental Panel on Climate Change (IPCC) second report highlighted the lack of information on trends and variability in daily climate and climate extreme. The increase in temperature due to the increase in the atmospheric concentration of greenhouse gases is now undeniable. For years studies of global climate change using observation data for temperature and rainfall only focused on changes in mean values and there were few studies of climate extremes (Shrestha et al., 2017).

Recently due to the prominence of climate change, the research on past climate trends has progressed profoundly, particularly for temperature and rainfall (Shrestha et al., 2017). The temperature and rainfall trends are of interest to a number of socio-economic sectors such as

agriculture, health, water and natural resource management (Kruger and Nxumalo, 2017). In the IPCC 2nd Assessment report (1995), it was indicated that limited studies on observed historical trends in climate extremes were available. Temperature and rainfall are the two most important variables to investigate particularly for countries where the economy is highly depended on rain-fed agriculture (Asfaw et al., 2018). Rainfall trends and variability are mostly mentioned factors in explaining numerous socio-economic problems such as food insecurity. According to Asfaw et al. (2018), agricultural calendars in most parts of Africa are tied to the timing of local rainfall. Therefore, investigating the spatio-temporal dynamics of temperature and rainfall is important to provide inputs to policy makers (Asfaw et al., 2018).

Southern Africa south of 15°S is a semi-arid region mainly experiencing great amounts of rainfall in austral summer between November and February (Crétat et al., 2012), except for regions in the southwestern South Africa and along the south coast. uThungulu District Municipality, located on the eastern side of the country in KwaZulu Natal is characterized by high temperature and bimodal nature of rainfall (Reason *et al*., 2005). Rainfall is one of the weather parameters that varies a lot on spatial and temporal basis, impacting on agriculture (Moeletsi and Walker, 2012).

In a highly agrarian community where the livelihood of the population is depended on rain-fed agriculture like in uThungulu District Municipality, analysis of rainfall and temperature patterns is also vital to cope with impact on crop yield, animal breeding and ecosystem management. The characterization of the intra and inter-annual spatio-temporal of these meteorological variables in the context of climate change is paramount in assessing climate induced changes and in suggesting feasible adaptation strategies and agricultural practices (Asfaw et al., 2018).

A number of studies emerged at a regional scale for different countries. However, there has been little work at local scale. In this chapter the objective was to study the variability of temperature and rainfall at a local scale in uThungulu District Municipality, KwaZulu-Natal (KZN) Province, South Africa. This is because KZN has a wide spread extreme event such as heatwaves, cold fronts, drought and flood.

3.3. Study Area

uThungulu District Municipality is located in the north-eastern region of the KZN province. It includes areas from KwaGingindlovu in the south to the uMfolozi River in the north, and inland to Nkandla. The district is home to six local municipalities namely: uMhlathuze, Ntambanana, uMlalazi, Mthonjaneni, Nkandla and uMfolozi (**Figure. 5**). The district has very diverse climatic conditions due to the topography. Warm climate is experienced throughout the year, with very mild winters with an average temperature of 14.5°C and hot, humid summers with an average temperature of 28.4°C. The mean annual rainfall, which is highly seasonal, is approximately 550 mm/year. The temperate climate and warm seas off the coastline make this district an ideal location for the development of agricultural projects and tourism facilities. The major land uses in uThungulu District Municipality are commercial and subsistence agriculture. For commercial agriculture, the main crop is sugarcane, grown largely in the lower-lying coastal belt. The horticultural crops comprise citrus, subtropical fruits and vegetables. Subsistence agriculture is associated with the majority of the tribal areas which are considered to be under-developed and characterized by high levels of poverty (uThungulu District Municipality, IDP, 2012/13-2016/17).

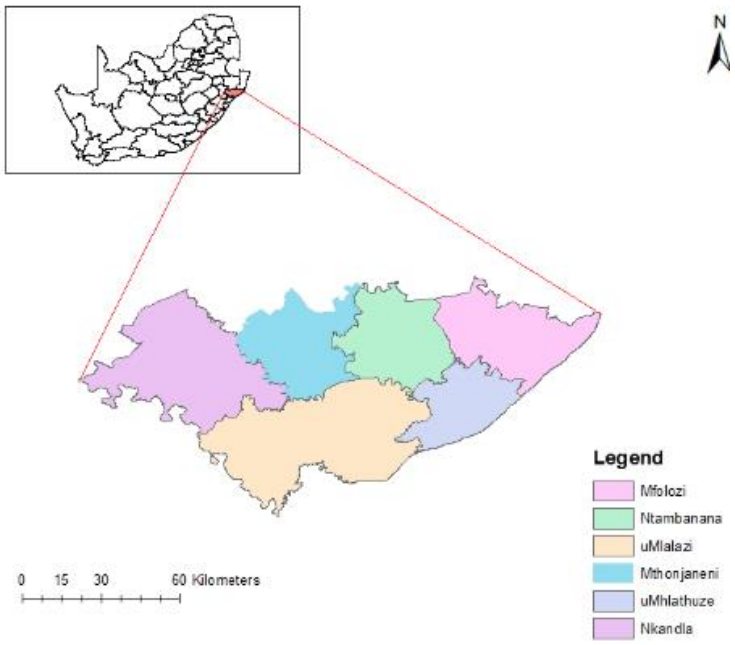


Figure 5: uThungulu District Municipality and its six local municipalities

3.4. Observations from SAWS Automated Weather Stations

The dataset used as a proxy for observation is from seven Automated Weather Stations (AWS) obtained from the South African Weather Service (SAWS) around the uThungulu District Municipality (**Figure 6**). The meteorological variables of interest were daily rainfall, and minimum and maximum temperature for the period 1997-2015. This period was chosen because of availability of complete dataset. **Table 3** shows seven AWS from SAWS that were considered and the number of daily records and missing records for minimum and maximum temperature and rainfall. For quality control, where there were missing values for temperature, a mean value for each month was taken to replace the missing value while a median value for each month was taken to replace missing value for rainfall. Observation data provides the current state of the atmosphere and/or ocean at the specific points in time and space. The names of the stations considered in this study were Babanango, Greytown, Ladysmith, Mandini, Mtunzini, Riverview and Ulundi. Only one station had the poor quality of data for both temperature minimum and maximum and that was Ladysmith, indicated by 72% of missing data. On the other hand, Babanago also had poor data quality for rainfall indicated by 73% of missing data records

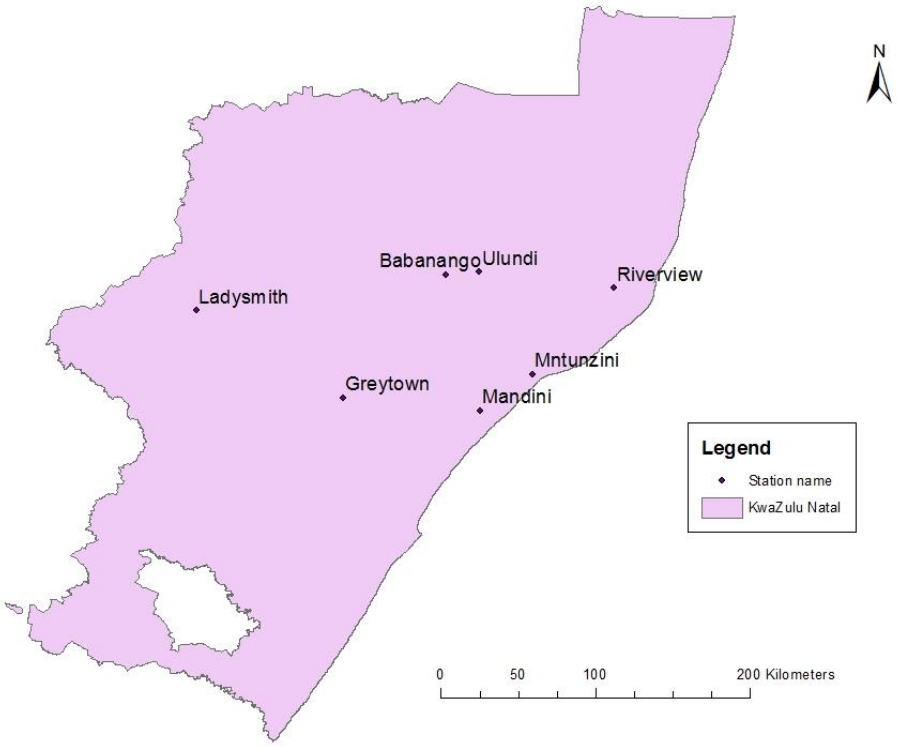


Figure 6: Seven weather stations obtained from the South African Weather Service

Table 3: The South African Weather Service Stations AWS in Operation in uThungulu District Municipality

Station	Latitude	Longitude	Start to End Date	Number of Daily Records	% Number of Missing Records		
					Tmax*	Tmin*	Pr*
Babanango	-28.3644	31.2065	1997 to 2015	6933	57%	56%	73%
Greytown	-29.0832	30.6034	1997 to 2015	6927	5%	6%	10%
Ladysmith	-28.5755	29.7503	1997 to 2015	6865	72%	72%	36%
Mandini	-29.1582	31.4023	1997 to 2015	6893	32%	32%	17%
Mtunzini	-28.9474	31.7079	1997 to 2015	6881	10%	47%	34%
Riverview	-28.4440	32.1821	1997 to 2014	6393	61%	53%	41%
Ulundi	-28.3500	31.4000	1997 to 2015	6791	41%	41%	47%

**Where Tmax= Temperature maximum*

Tmin= Temperature minimum

Pr= Precipitation

3.5. Downscaled Model data from six CMIP 5 GCMs

Daily rainfall, temperature minimum and temperature maximum data from six CMIP 5 Global Climate Models (GCMs) was downloaded from http://esgf-data.dkrz.de for the historical period 1976-2005 and projected 2071-2100. GCMs comprise mathematical formulations of the process that consist of the climate system (such as atmosphere, biosphere, ocean and cryosphere). Climate models are used to make climate projections and the knowledge acquired can contribute to policy and decisions regarding climate change. **Table 4** shows the list of GCMs used in this study, their contribution centre and the resolution.

Table 4: Description of six CMIP 5 GCMs:

Model Name	Contributing Institute	Resolution	Forcings
CanESM2	Canadian Centre for Climate Modelling and Analysis, Canada	2.8°x2.8°	Greenhouse Gases, Ozone, Snow Albedo, Solar Irradiance, Volcanic, Black Carbon, Organic Carbon and Land Use
NorESM1-M	Norwegian Earth System Model, Norway	1.8°x2.5°	Greenhouse Gases, Ozone, Sulphate Aerosol, Solar Irradiance, Volcanic, Black Carbon and Organic Carbon
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory, United State of America	2.0°x2.5°	Greenhouse Gases, Ozone, Sulphate Aerosol, Solar Irradiance, Volcanic, Black Carbon, Organic Carbon, Land Use, Sea Salt, Mineral Dust and Dust
BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University, China	2.8°x2.2°	Greenhouse Gases, Ozone, Sulphate Aerosol, Solar Irradiance
CNRM-CM5	Centre National de Recherches Météorologiques- Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique, France	1.4°x1.4°	Greenhouse Gases, Sulphate Aerosol, Solar Irradiance, Volcanic, Black Carbon and Organic Carbon
MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	1.9°x1.9°	Greenhouse Gases, Sulphate Aerosol, Solar Irradiance, Volcanic, Black Carbon and Organic Carbon

SOURCE:[*https://www.climatechangeinaustralia.gov.au/en/climate-projections/about/modelling-choices-and-methodology/list-models/*]

3.6. Methodology

3.6.1. Data Management and Analysis Flow chart

The observation data obtained from the SAWS AWS was used for time-series analyses which included linear trends and statistical properties. On the other hand, the observation data was used to bias correct the CMIP 5 GCMs and thereafter form gridded data for uThungulu District Municipality. The gridded data was used to investigate projected changes in weather/climate extremes. Furthermore, a survey together with weather and climate analysis was investigated to find out the impact of climate change on the livelihood of small-scale farmers in uThungulu District Municipality (see flow chart **Figure 7**).

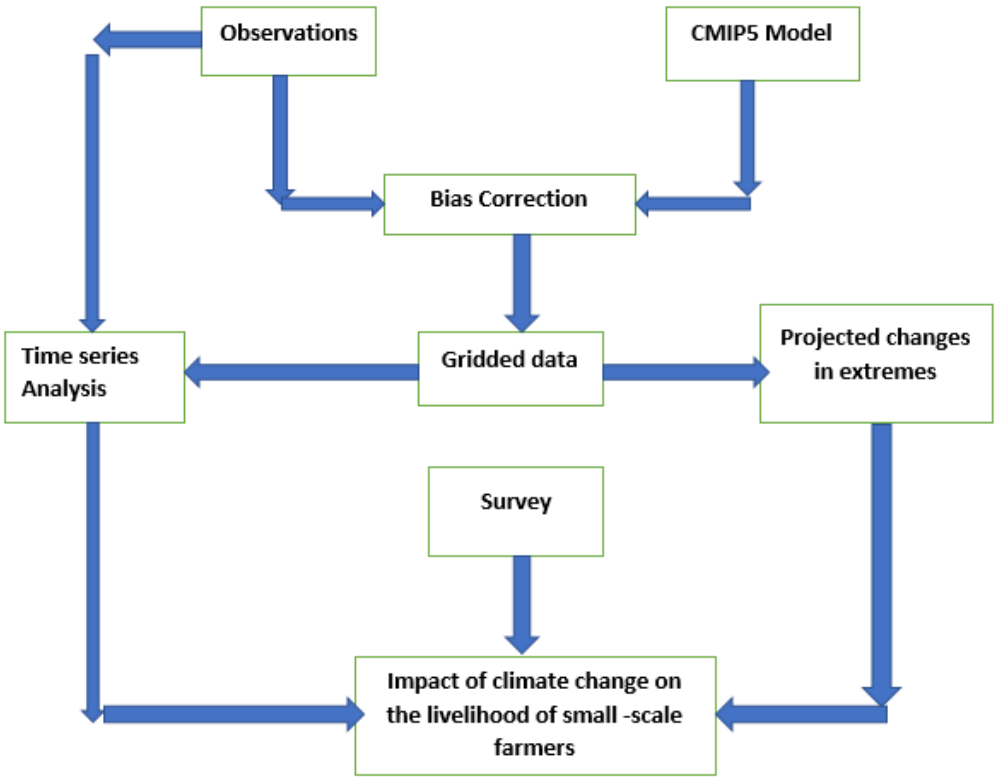


Figure 7: Data Analysis Flow Chart

3.6.2. Linear Trend and Statistical Properties

The Mean Annual Temperature (MAT) and Mean Annual Precipitation (MAP) indices from all seven stations were considered to understand the environmental status of uThungulu District Municipality. MAT helps to determine the suitability of a location for agricultural activities. On the other hand, MAP provides the characterization of long-term quantities of water available in the location for hydrological and agricultural purposes. The Prewhitening nonlinear trend analysis was employed for trend analysis in uThungulu District Municipality. The Mann-Kendall (MK) test has been used globally to detect trends in meteorological time series. The primary purpose of MK is to statistically assess if there is a monotonic increasing or decreasing trend of the variables over time, but the trend may or may not be linear. The MK test does not require the fitted regression line to be normally distributed (parametric). The following assumptions underlie the MK test; (1) when no trend is present, the data obtained over time are independent and identically distributed, (2) the data obtained over time are representative of true conditions and (3) the sample collection, handling and measurement methods provide unbiased and representative observations of the underlying populations over time (Gilbert, 1987). Significant trends were those with estimated p-value < 0.05

3.7. Results

3.7.1. Analysis of Temperature and Rainfall Variability in uThungulu District Municipality

3.7.1.1. Temperature and Rainfall Variability

Figure 8 show the variability in temperature and rainfall for stations in uThungulu District Municipality. uThungulu District Municipality is characterized by warm temperatures between 18°C to 22°C. For temperature all seven stations are variable the dataset exhibits a small dispersion with middle cluttered bimodal distribution and slight positive skewness. The slight positive skewness in the box plot, illustrate a slight increase in temperature across the seven stations in uThungulu District Municipality. Also shown in the mean monthly temperature graph (Appendix A) where warm temperatures of above 20°C are experienced in austral summer months (October-March) and low temperature of below 20°C are experienced in winter months June and July.

For rainfall, most of the stations had the large dispersion with downward negative skewness except for stations in Mtunzini and Riverview. The negative skewness shows a decrease in rainfall across uThungulu District Municipality. The region also receives most of its rainfall in October to March (shown in Appendix A). uThungulu District Municipality is also characterized by bimodal peak in rainfall occurring prominently during the transition season of autumn (March) and beginning of early summer (October). The highest record in rainfall was in January with a value of 219 mm. These temperature and rainfall results are in agreement with the studies by Rouault et al (2003) which characterized the eight climatic regions of South Africa.

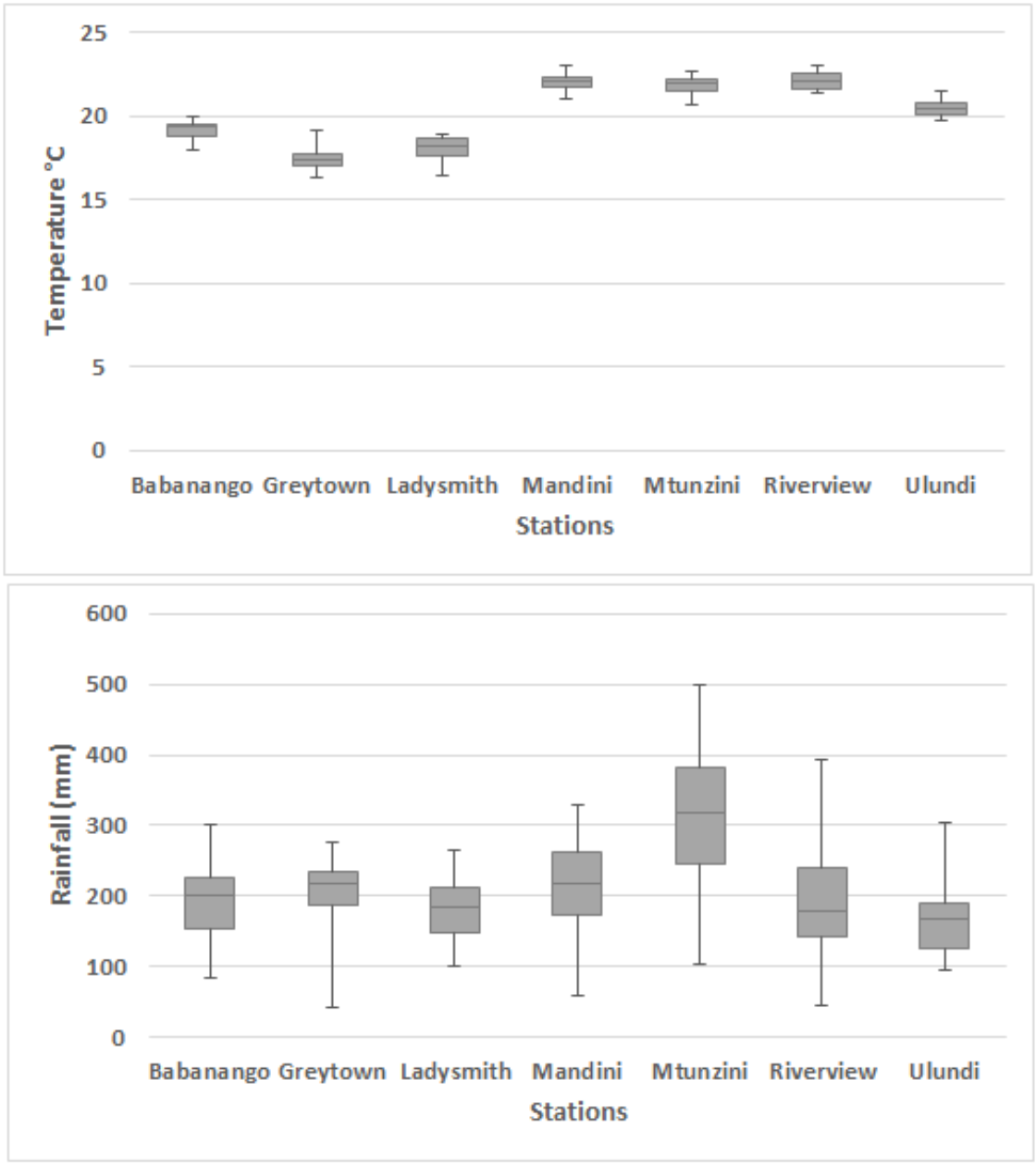


Figure 8*:* Mean Monthly Composite for Temperature (A) and Rainfall (B) across uThungulu District Municipality

3.7.2 Long Term Variability Analyses

3.7.2.1. Temperature and Rainfall Anomalies

Time series of standardized anomalies in annual temperature and rainfall spatially averaged over uThungulu District Municipality are depicted in **Figure 9** and **Figure 10** respectively. Positive anomalies indicate that the total temperature or rainfall recoded for that year was above the mean value calculated for the entire period of 1997 to 2015 and negative anomalies indicate that the total temperature or rainfall recorded for that year is below the mean value calculated for the same period.

The long-term anomalies for temperature showed inter-annual variability, nine out of eighteen years had above normal temperature which indicated that those years were characterized by high temperatures and only four years (2000, 2009, 2011 and 2013) had below normal temperatures. For rainfall anomalies, wet years occurred in 2000, 2006, and 2012 meanwhile the driest years with below normal rainfall occurred in 2003, 2014, and 2015. From the rainfall plot the year 2015 was the driest year for the entire period, in the year 2015 South Africa experienced the worst drought since 1982 as a result of El Nino. When El Nino occurs, the convergence is frequently weakened and shifted to east and north leading to dry conditions dominating over much of Southern Africa.

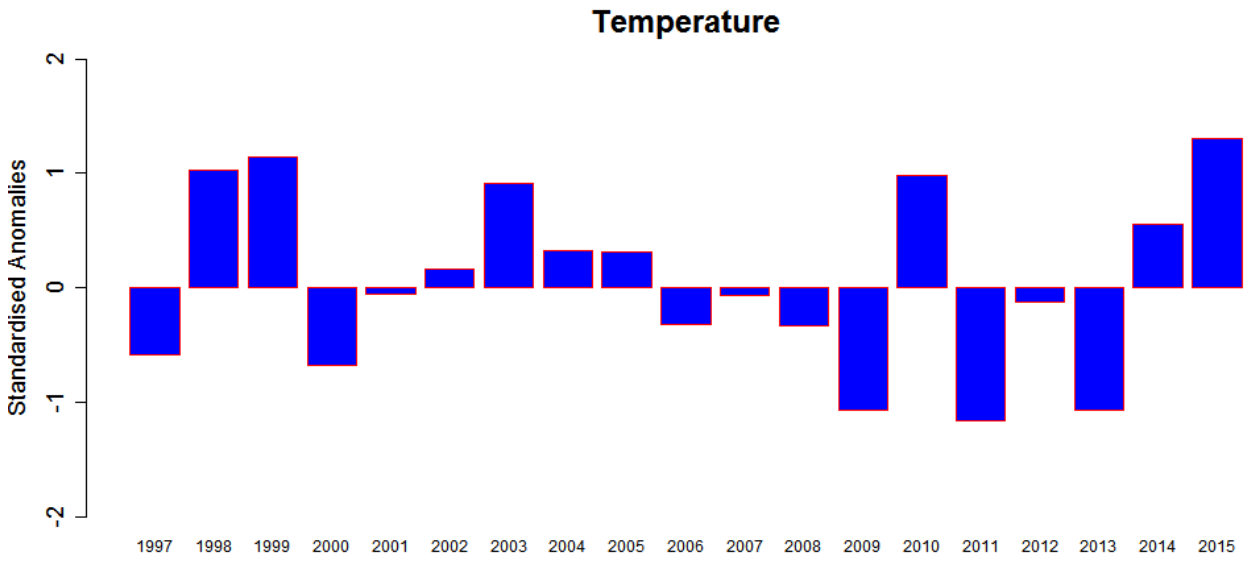


Figure 9: Temperature Anomalies in uThungulu District Municipality (1997-2015)

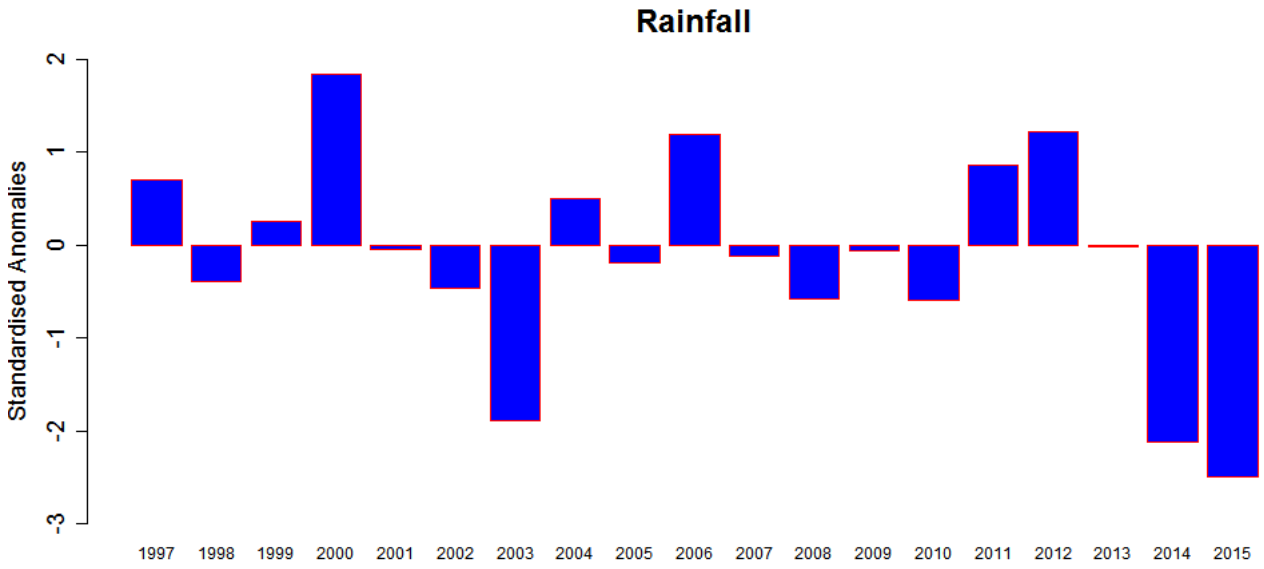


Figure 10: Rainfall Anomalies in uThungulu District Municipality (1997-2015)

3.7.2.2. Temperature and Rainfall Trend Analysis

The Prewhitening nonlinear trend analysis was employed in uThungulu District Municipality. Basic descriptive statistics for rainfall in **Table 5** show that the seven stations in uThungulu District Municipality were variable. The long-term annual variation (**see Figure 11**) of rainfall during 1997-2015 show a decrease in rainfall at a rate of 1.5887 mm/yr. A minimum rainfall of 94.22 mm was observed at Ulundi, showing that Ulundi is the driest region of uThungulu District Municipality. During 1997-2015, Mtunzini region was the wettest with maximum rainfall of 498.25 mm. Results from the MK test demonstrate that the majority of the stations depicted a negative trend with only one station, Riverview, with a positive trend (see **Figure 12**). The trends for all the stations were insignificant with p-values > 0.05 (**Table 5**).

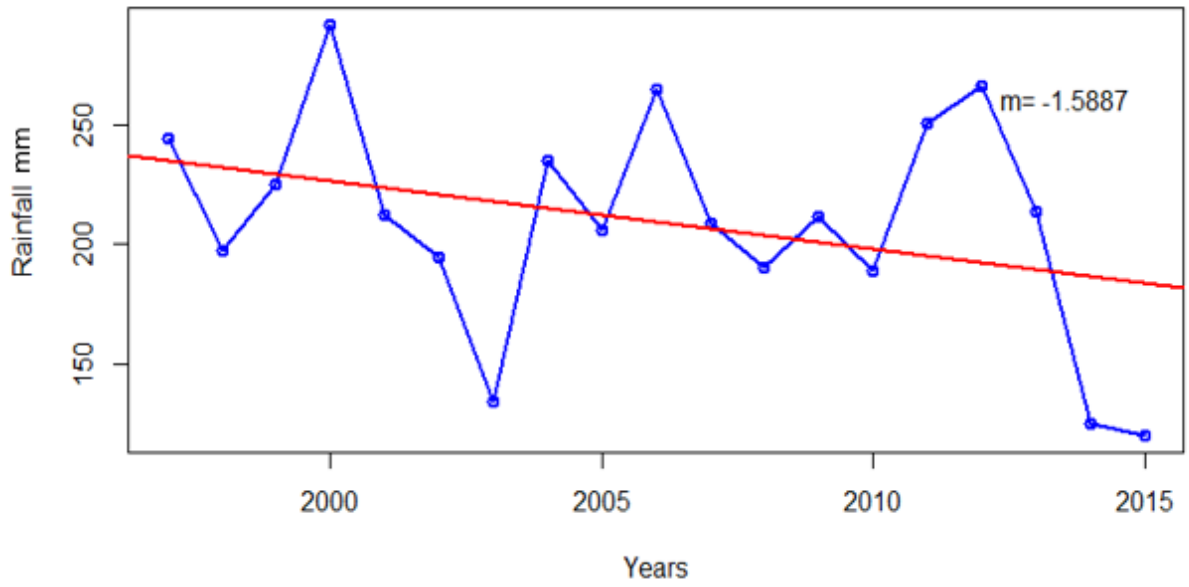


Figure 11: Annual Rainfall Variation (1997-2015) in uThungulu District Municipality

Table 5: Basic statistics and MK trend analysis of rainfall in uThungulu District Municipality (1997-2015)

STATION	Min	Max	Mean	SD	CV (%)	MK test (Trend)	P value
BABANANGO	120.74	300.19	197	0.4898	0.2486	**-0.281**	0.1116
GREYTOWN	140.77	277.15	212	0.3513	0.1657	**-0.0719**	0.7049
LADYSMITH	101.22	264.73	185	0.4563	0.2466	**-0.0588**	0.7619
MANDINI	119.40	328.63	218	0.5766	0.2644	**-0.0216**	0.2255
MTUNZINI	163.57	498.25	323	1.0162	0.3146	**-0.1680**	0.3633
RIVERVIEW	107.29	394.45	198	0.7307	0.3690	0.1240	0.4954
ULUNDI	94.22	304.11	168	0.5414	0.3222	**-0.0458**	0.8202

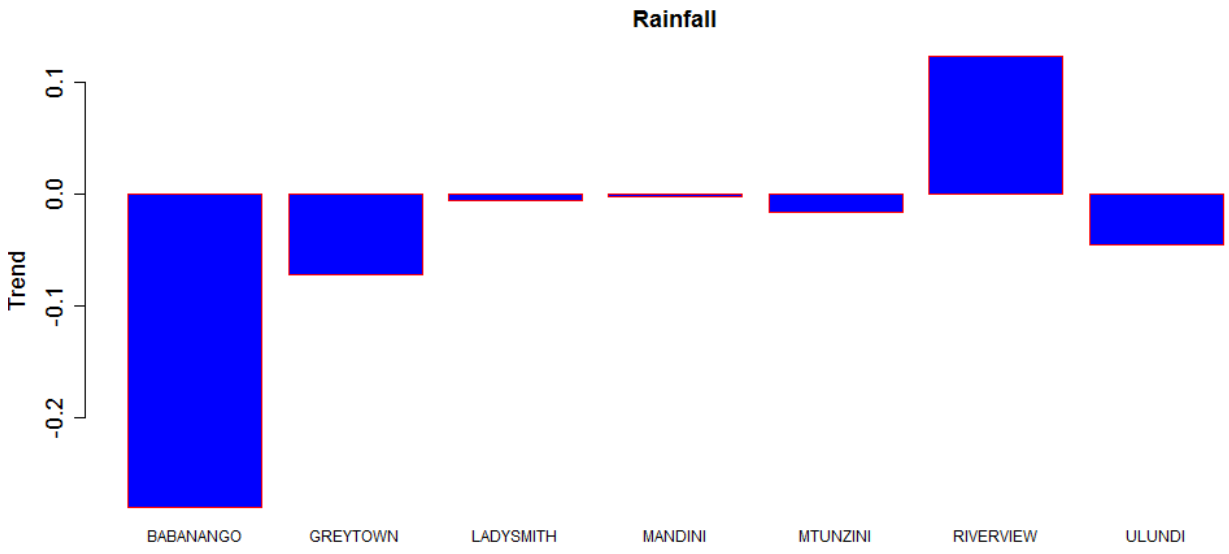


Figure 12: Rainfall trends for seven stations in uThungulu District Municipality

For temperature statistical analysis in **Table 6** uThungulu District Municipality is warm, the maximum temperature peak at 27°C in three stations (Mandini, Mtunzini and Riverview). Six out of seven stations depicted negative trend for temperature minimum (**Figure 13**) of which the trend was significant in four stations, namely: Babanango, Greytown Mandini and Riverview. The analyses for temperature maximum demonstrated largely positive trend. The trend was largely significant for temperature maximum with four station having p-value of less than 0.05 **(Table 6)**.

The negative trend depicted for temperature minimum, can be interpreted that the temperature minimum in uThungulu District Municipality is decreasing, meanwhile the positive trend for temperature maximum show an increase in temperature maximum. The opposing temperatures therefore create a spectrum of extremes; thus, it can be concluded that uThungulu District Municipality is susceptible to extreme events

Table 6: Basic statistic and MK trend analysis of temperature minimum and maximum in uThungulu District Municipality (1997-2015)

STATION	Min °C	Max °C	Mean °C	SD	CV (%)	MK test (Trend Tmax)	P value	MK test (Trend Tmin)	P value
BABANANGO	12.92	25.50	19.20	0.5130	2.6718	**0.3590**	0.0408	**-0.4409**	0.0401
GREYTOWN	10.89	23.97	17.40	0.6127	3.5212	**0.0458**	0.0202	**-1.2067**	0.0305
LADYSMITH	10.69	25.38	18.00	0.7128	3.9600	-0.2160	0.0225	1.2837	0.1532
MANDINI	16.60	27.39	20.00	0.5531	2.7655	**0.2160**	0.0225	**-0.9623**	0.0419
MTUNZINI	16.24	27.44	21.80	0.5795	2.6582	**0.0196**	0.0396	**-0.8321**	0.3512
RIVERVIEW	16.81	27.41	25.10	0.5141	2.0482	**0.4250**	0.1530	**-1.0350**	0.0211
ULUNDI	14.34	26.68	20.50	0.4315	2.1048	**0.1500**	0.4047	**-0.1012**	0.1281

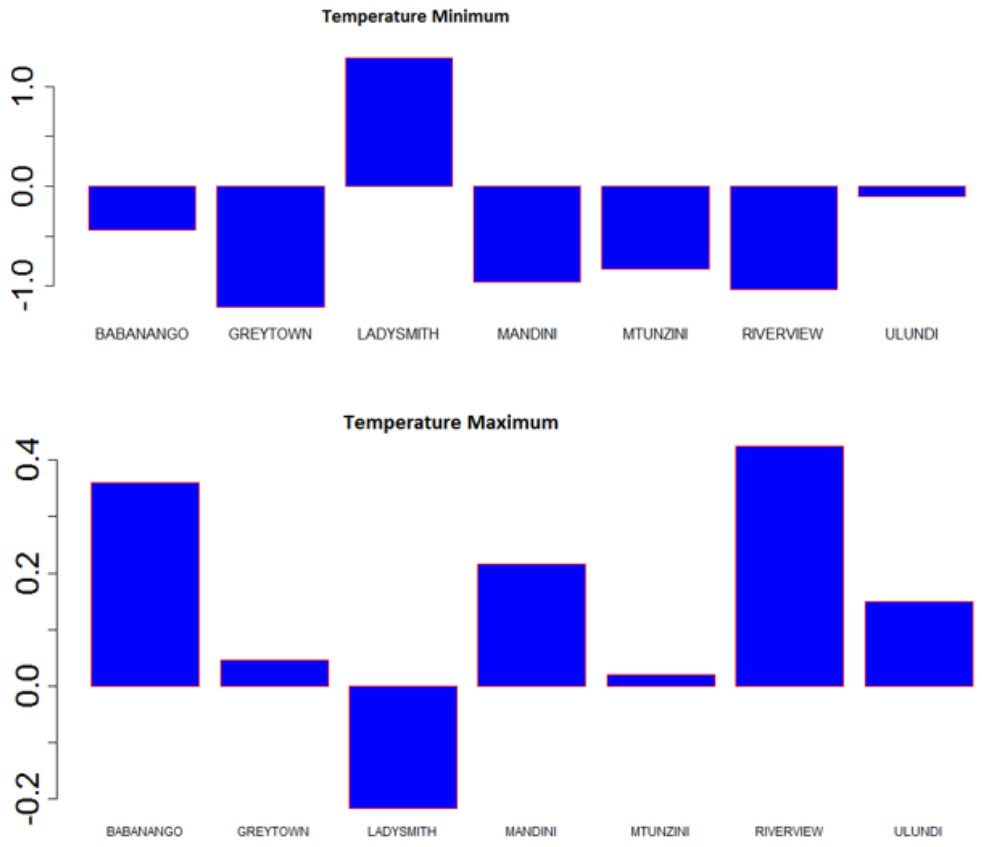


Figure 13: Minimum and Maximum Temperature trends for seven stations in uThungulu District Municipality

3.8. Conclusion

uThungulu District Municipality is characterized by inter-annual variations, with changes in rainfall and temperature. The results showed that the region is highly susceptible to extreme events. This was shown by spectrum observed between minimum and maximum temperature. Results showed a decreasing trend in minimum temperature and an increasing trend in maximum temperature. During the study period rainfall has been decreasing at a rate of 1.5887 mm/yr with about 90% of the stations having a negative trend. The results demonstrated that uThungulu District Municipality has been drying in 1997-2015.

CHAPTER FOUR: Analyses of small-scale farmers' perceptions of the past and present climate changes in relation to their livelihood

4.1. Abstract

Most studies have demonstrated that climate change is a global challenge facing humans and their socio-economic activities, health, livelihood and food security. In this chapter, data was collected using survey together with meteorological parameters measured at the South African Weather Service (SAWS). The survey was subjected to the reliability and validity test using the Statistical Package for the Social Sciences (SPSS). This study investigates small-scale farmers' perception of past and present climate, and the impacts thereof to their livelihood. An ethnographic analysis together with Rainfall Anomaly Index (RAI) and Cumulative Departure Index (CDI) were used to compare farmers' perceptions in Ntambanana local Municipality, KwaZulu-Natal. The aim of the analyses was to determine if the South African Weather Service (SAWS) meteorological records (Temperature minimum, Temperature maximum and Rainfall) from 1997-2015 corroborate farmers observations. The results obtained illustrate that small-scale farmers surveyed had observed changes in climate in the last 10-20 years. The farmers' perceptions on climate change and variability mirrors the climatic trend analysis. Moreover, analysis of RAI showed that 9 out of 19 years experienced below normal rainfall and these years are also characterized by late onset rainfall and early cessation. On the other hand, analysis of CDI demonstrated changes in the length of the growing season. This study highlighted that the livelihood of small-scale famers was under threat as a result of climate change and variability and little access to information also hinders their adaptive capability.

4.2. Introduction

A livelihood is defined as the activities, the assets and the access that jointly determine the living gained by an individual or household (Krantz, 2001). According to Davis et al (2010 a, b), about 90% of rural households are involved in farming activities. In Africa, a total of about 70% household income is from farming activities, while in Asia and America approximately 50% of the household income is from farming activities (Davis et al 2010 a, b).

The inequalities in the society have led to rich and poor people (Meiring et al., 2018). In order to address the issue of poverty and lack of basic needs and its eradication, the Brundtland Commission on Environment and Development introduced a concept of sustainable livelihood (Krantz, 2001). In a classic 1992 paper by Chambers and Conway, sustainable rural livelihood was defined as "*the ability of the livelihood to cope with and recover from stress and shocks, maintain or enhance its capability and assets, and provide continual livelihoods opportunities for the next generation; and which contributes net benefits to other livelihood at the local and global level and in the short and long term*". The sustainable livelihood gives a holistic and integrative approach with the capacity to understand and analyze the complexity of rural development.

According to Krantz (2001), rural livelihood is a complex structure comprising of mostly agriculture, with some of the population diversifying into non-farming activities in order to get sustainable livelihood and better income for their households. Several studies (Ellis 2000, Fabusoro *et a*l. 2010) have listed livelihood determinants as gender, unintended birth into a predisposed livelihood, inherited livelihood, spontaneous livelihood and lastly education and migration.

According to Mubvuma (2013), extreme conditions associated with changes in temperature, rainfall, water availability and shortening of the length of growing season have major implications for sustainable development. The link between climate and growing parameters (onset and cessation rain) makes growing season variability an important indicator of climate such that rainfall onset determines the starting of the growing period and date of planting for farmers. If rainfall is delayed, especially in semi-arid southern African regions, the date of planting will be delayed leading to growing period extending to winter season with lower temperatures affecting the crops. On the other hand, early rainfall withdrawals also have an effect of cutting short the growing period of crops, leading to crops failing to reach their physiological maturity stage (Mubvuma, 2013).

According to Ayanlade *et al* (2017), successful understanding of climate change is not only limited to the values of climate parameters. It also includes variability and associated extreme events and the understanding of these by local farmers who are being affected. Incorporating farmers understanding and communicating scientific findings to farmers is very useful in implementing and monitoring strategies which would improve the crop yield.

Indicated by Ayanlade *et al* (2017), farmers cope with the climate change based on their perception of changing climate. Looking at the climate change literature, it is evident that more attention has been paid on climate change system modelling, climate change impacts, adaptation and risk assessment, while relatively little attention has been given to the perceptions and options for adaptation of those experiencing climate changes (i.e. farmers). In the case of small-scale farmers, what is ostensible is the gap between scientist's analysis of global climate change and its impact of the agricultural sector at the international level, awareness and the concern for the problem at local levels particularly for rural farmers (Ayanlade *et al*., 2017). Therefore, the is a need to conduct a study to examine farmers perception and understanding of extreme weather events, their significant impacts on crop and livestock production and their strategies for adaptation and coping under climate change.

The communities of Ntambanana Local Municipality, particularly small-scale farmers are likely to be vulnerable to climate change because their livelihood is dependent on rain-fed agriculture and the area is largely rural with low infrastructural and technological development. It is therefore significant to conduct a study that will map the gap between scientist analysis of global climate change and rural farmers' awareness and how climate change has impacted their livelihoods. In this chapter the objective is to evaluate small-scale farmer's perception to past and present climate and its impact on livelihoods.

4.3. Materials and Methodology

Data collected via survey (questionnaires) from farmers in Ntambanana Local Municipality was subjected to reliability and validity tests. These tests help to eliminate the bias in the results. Validity is the amount of systematic or built-in errors in questionnaire. While the reliability is an extent to which a questionnaire procedure produces the same results on repeated trials (Bolarinwa, 2018). The validity and reliability tests in the questionnaire of this study follows methodology of Deniz and Alsaffar (2013). **Figure 14** shows the possible combinations of validity and reliability. The questions in the questionnaire were open ended format, meaning that the questions allowed the community of Ntambanana local municipality to voice their feelings and notions freely. This type of questionnaire was considered because it provides real perceptions and tend to draw accurate feedback and suggestions from respondents. A research hypothesis was developed from the research objective "small-scale farmers' perceptions of the past and present climate changes in relation to their livelihood". A total of 143 farmers were surveyed. The survey had a total of 12 sections and only 6 sections were analyzed which were relevant to address small-scale farmers' perceptions of the past and present climate changes in relation to their livelihood.

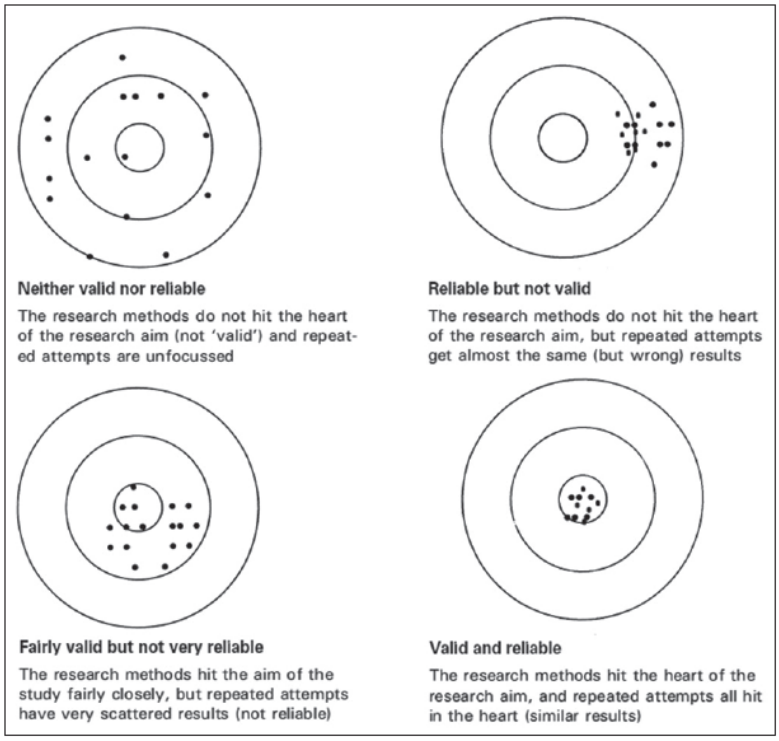


Figure 14: Graphical representation of possible combinations of validity and reliability [SOURCE: Bolarinwa, 2018]

The data collected from the questionnaire was used together with the meteorological data from the South African Weather Service to assess small-scale farmers' perceptions of historical trends from meteorological data. The meteorological data were mainly used to evaluate the inter-annual and decadal trends. The meteorological data and data from the survey were used as descriptive statistics to show farmers' perception, adaptive capacity and how climate change impacted their livelihood. The Cumulative Departure Index (CDI) and Rainfall Anomaly Index (RAI) analysis (Ayanlade *et al*., 2017, Hein *et al*, 2019) were used to analyze annual and seasonal rainfall variability respectively. Furthermore CDI and RAI were both used to assess the trend of rainfall onset and cessation, length of rainy days and intensity. CDI was calculated using the equation below (Ayanlade *et al*., 2017, Hein *et al*, 2019).

$$CDI = \frac{(R_a - R_m)}{SD} \qquad (1)$$

Where CDI is the cumulative departure index, Ra is the actual rainfall for the growing season months (developed from daily rainfall data), Rm is the mean rainfall and SD is the standard deviation of the total length of the period of study (1997-2015). The positive and negative RAI was calculated using the following equations (Ayanlade *et al*., 2017).

$$RAI = +3\left(\frac{RF - M_{RF}}{M_{H10} - M_{RF}}\right) \qquad (2)$$

$$RAI = -3\left(\frac{RF - M_{RF}}{M_{L10} - M_{RF}}\right) \qquad (3)$$

Where RAI is the rainfall anomaly index, *RF* is the rainfall for the year in question, M_{RF} is the mean actual annual rainfall for the total length period and M_{H10} and M_{L10} are the mean of 10 highest and lowest values of rainfall for the period respectively.

4.4. Analyses of Questionnaire Responses

4.4.1. Reliability and Validity

The validity and the reliability of the survey questionnaire administered to the small-scale farmers participated was tested using the Statistical Package for the Social Sciences (SPSS). The validity expresses the degree to which a measurement measure what it purports to measure. Two measurements of validity were considered, namely: 1) Face validity and 2) Construct validity. Reliability measures the degree to which the results obtained by a measurement and procedure can be replicated. A most used measure of reliability is internal consistency, measured by Cronbach's alpha. This applies to the consistency among the variables in a summated scale (Bolarinwa, 2018; Deniz and Alsaffar, 2013). From the questionnaire the reliability and validity was tested on the following sections:-

1. Section 3A and Section 3B -Income, assets and livelihood sources
2. Section 4 -Household coping strategies
3. Section 6 -Access to information and use of indigenous knowledge systems
4. Section 10 -Farmers perception on long-term climatic and environmental changes
5. Section 11 -Perceived farm level adaptation strategies among smallholder farmers

1) Measure of Reliability and Results

The internal consistency of the knowledge scale and of the attitude scale were calculated using the Cronbach's alpha which is an index of consistency and the mean inter-item correlation. The Cronbach's alpha should be around 0.8 to 0.9, however anything above 0.7 is considered acceptable. The inter-item correlation analyses the strength and the direction of the relationship between all possible pairs of questionnaire items. When consistent we should expect moderate to strong positive correlation between all the items.

Table 7 show the reliability results for all the sections that were considered from the questionnaire. In section 3A there were 12 items to answer. Only 24 responses were valid and a total of 117 responses were excluded. The calculated Cronbach's alpha was 0.850 which is acceptable, meaning that the responses in this section were reliable.

For section 3B, more improvement of the results compared to section 3A is observed. A total of 88 responses were excluded and only 53 responses were valid. The Cronbach's alpha as 0.847 which is acceptable. This section had strong internal consistent with strong positive inter-item correlation and all values were above minimum acceptable value of 0.3 across the questions (see **Table 8**).

More reliability is observed in section 4, a total of 89 responses were valid and 52 responses were excluded. The Cronbach alpha was acceptable with value of 0.823. The responses had internal consistency seen with positive inter item correlation (not shown) and had above acceptable minimum value of 0.3 across questions

When analysing section 6, the total number of participants has increased to 143, with only 14 valid responses and 129 responses were excluded from the analysis. Section 6 had a total of 48 items to answer. The calculated Cronbach's alpha for this section was 0.793 which is acceptable and shows that the people were reliable in answering the questions. The internal consistency was moderately positive correlation between all items with 9 questions having negative correlation to the rests.

In section 10, only 52 responses were valid and 91 were excluded. A total number of participants were 143. The Cronbach alpha was 0.397 which is not acceptable; participants were not reliable in answering the questions. For the inter-item correlation, it was shown to be negative across all questions and had minimum value of less than 0.3 which is not acceptable.

Observed in section 11 was Similar to the previous section. Section 11 had an unacceptable Cronbach alpha of 0.638 from the total of 17 items to answer from. A total of 72 responses were valid with 71 cases excluded. The participants were not reliable in answering the questions. The inter-item correlation was also negatively correlated across the questions with minimum value of less than 0.3 which not acceptable.

Table 7: Reliability Results

	Case Processing Summary		Reliability Statistics	
	Number of Items	Percentage (%)	Cronbach's Alpha	Number of Items
Section 3A				
Validity	24	17.0	0.850	12
Excluded	117	83.0		
Total	141	100.0		
Section 3B				
Validity	53	37.6	0.847	6
Excluded	88	62.4		
Total	141	100.0		
Section 4				
Validity	89	63.1	0.823	14
Excluded	52	36.9		
Total	141	100.0		
Section 6				
Validity	14	9.8	0.793	48
Excluded	129	90.2		
Total	143	100.0		
Section 10				
Validity	52	36.4	0.397	24
Excluded	91	63.6		
Total	143	100.0		
Section 10				
Validity	72	50.3	0.638	17
Excluded	71	49.7		
Total	143	100.0		

Table 8: Inter-Item Correlation Matrix

	Income Source most 2yrs ago	Income Source most 10yrs ago	Income Source second 2yrs ago	Income Source second 10yrs ago	Income Source third 2yrs ago	Income Source third 10yrs ago
Income Source most 2yrs ago	1.000	0.301	0.699	0.389	0.443	0.366
Income Source most 10yrs ago	0.301	1.000	0.424	0.617	0.393	0.609
Income Source second 2yrs ago	0.699	0.424	1.000	0.340	0.667	0.382
Income Source second 10yrs ago	0.389	0.617	0.340	1.000	0.317	0.742
Income Source third 2yrs ago	0.443	0.393	0.667	0.317	1.000	0.516
Income Source third 10yrs ago	0.366	0.609	0.382	0.742	0.516	1.000

Conclusion

The reliability tests in all six sections showed that only two sections were not reliable in the questionnaire and four sections participants responded reliably. In the two sections where participants did not response reliably the inter-item correlation was also found to be negative and to be below the accepted minimum value of 0.3. Therefore, this questionnaire had internal consistency and similar questions could be given to a different group to repeat the exercise.

2) Measure of Validity

2.1. Face Validity

The face validity involves the expert looking at the questions in the questionnaire and agreeing that the questions are a valid measure of the concept that is being measured just on the 'face of it' (Bolanirwa, 2018). Given that the questionnaire was evaluated by the principal investigators, the face validity is therefore inherently assumed. The questions in this study were able to profile small-scale farmers and the risk that they are subjected to due to climate change in Ntambanana local municipality. Although most of the questions were long, the following subjects were covered in the questionnaire:-

- Demographics and Marital status
- Employment and Household status
- Livelihood sources
- Land use
- Indigenous knowledge and usage
- Crop and Livestock production
- Small-scale farmer's perception on climate
- Observed changes due to climate change
- Household copying strategies

2.2. Construct Validity

The construct validity concerns whether the questions are representatives of the domains they are supposed to measure (Kline, 2011). According to (Bolarinwa, 2018 and Deniz and Alsaffar 2013), construct validity measures the traits or theoretical construct that is intended to measure. In livelihood analysis of rural communities, the demographics play an important part in understanding diversity and typology of the community. Also, vital for livelihood analysis is the social relations such as the gender, class difference, age and marital status. These govern the distribution of income, work relations, pattern and lastly consumption (Pienaar and Traub, 2015).

The present study profiled small-scale farmers in Ntambanana local Municipality using questionnaires. **Table 9** presents the demographic characteristics of the household. Clearly illustrated is that the majority of the heads of the households were female farmers (60.3%). Only 39.7% households were male headers. The average farmer's age was at the range of 18-59 years. About 70% of the farmers had no formal education, while 30% of the farmers only had primary education. The majority of farmers were not formally employed and they were married with a single spouse and a total of 62.4 % depended on farming as source of income and livelihood.

The household demographic in the Ntambanana local municipality has emerging farmers of about 3.1% who sell their produce and smallholder farmers 62.4% who rely on their produce for consumption. Also important for livelihood analysis and diversification is the household income. A total of 5% households depended on non-farming labour for income, 18.4% were elders and depended on grants, while 5.3% households depended on formal employment and 5.8% household relied on businesses and self-employment for income.

Since farming is the main source of livelihood in Ntambanana local municipality, it is vital to consider the dry and wet seasons to regulate livelihood. The wet season being dominant for farm activities and dry season being dominant for non-farming labour. In spring farmers anticipate the coming of the first rains. According to (Moeletsi and Walker, 2012), the onset of rainfall is important for farmers. Earlier onset allow them to plough land and plant earlier, while late onset can decrease crop yield due to plant stages being aligned with months of lower rainfall.

Table 9: Summary of the demographic and farming characteristics

Variable	Responded percentage
Sex of the household head	
Male	39.7
Female	60.3
Household age category	
0-5 years	0
6-11 years	0
12-17 years	12.9
19-59 years	80.1
Over 60 years	7
Level of education	
Married (with single spouse)	46.5
Married (polygamous)	7.1
Divorced	4
Single/Never Married	36.4
Other	6
Livelihood sources	**Percentage**
Farming	62.4
Non-farming labour	5
Pension	18.4
Formal employment	5.3
Self-employed	5.8
Petty trade	3.1
Other	27%

4.4.2. Small-scale farmer's perception on long term climate and environmental changes

The null and alternative hypothesis for this section were postulated as follows: -

Null hypothesis H_0: The perceptions of small-scale farmers on long-term climate and environmental changes corroborate results observed from analyses of South African Weather Service (SAWS) meteorological data (1997-2015).

Alternative hypothesis H_1: The perceptions of small-scale farmers on long-term climate and environmental changes contradict results observed from analyses of SAWS meteorological data (1997-2015).

The farmer's perception on long term climate and environmental changes was tabulated in **Table 10**. 78.8% of small-scale farmers in Ntambanana local Municipality had access to the information about climate in general. Information on seasonal forecast was available to only 66.7% of small-scale farmers and about 68.9% of small scale farmers had information on daily forecast. From the questionnaires, it was noted that most of the information that small-scale farmers had was from the indigenous knowledge communicated to them by the traditional leaders and community leaders. A total of 87.6% had access to information on agronomic and post-harvest information and 70.5% had access to information on animal production and health information.

Small scale farmers had an opportunity to label their crop production constrains. Pest and diseases were leading the crop production constrains, followed by temperature and rainfall, soil fertility and lack of knowledge. About 59.8% farmers thought the mean temperature had increased over the last 10-20 years, meanwhile 58.5% of farmers thought mean rainfall decreased. Small scale farmers also observed environmental changes in the last 10-20 years such as veld fired to have increased. From the responses of small-scale farmers, a majority (33%) indicated that they have noticed a change in crop farming and this change was due to changed rainfall patterns, 18% indicated less harvest due to high temperatures and 9% observed changed growth patterns. Other factors were also noted but rainfall and temperature were the highest cause of changes in crop farming.

To verify the farmers' perceptions, we also plotted daily observation data across uThungulu District Municipality for a period of 1997-2015 for the growing period from October to March. It is clear that uThungulu District Municipality have experienced substantial daily

variations. Daily linear trends show that temperature maximum is increasing at a rate of 0.0007°C/day (**Figure 15**), meanwhile daily linear trends for temperature minimum (**Figure 16**) show a decrease at a rate of -0.002°C/yr. The results clearly demonstrate that uThungulu District municipality is susceptible to extreme events due to the marginal difference between temperature minimum and temperature maximum. Small scale farmer's perception and observations in the last 10-20 years with regards to temperature was indeed verified with meteorological data and they agree with each other.

On the other hand daily rainfall observations from SAWS were plotted in **Figure 17**. A decrease in rainfall at the rate of 0.0059mm/day was evident. It is not obvious to determine the significance of the rainfall trend. However, in section **4.2.2.2** it was shown that the rainfall trend in uThungulu District was mostly negative which implied decreased in rainfall over the years.

The results observed climatic and environmental changes in the last 10-20 years by the farmers are consistent to the results from the observation data from SAWS automated weather station from 1997-2015. From these results the null hypothesis is accurate, and we can reject the alternative hypothesis. The change in climate is due to an increase in average temperatures because of the greenhouse gas build up in the atmosphere since pre-industrial times. Our warming planet earth is facing many challenges (like floods, drought, heat waves and decreasing biodiversity) due to the global warming. With the change in climate, the livelihood of people is at stake.

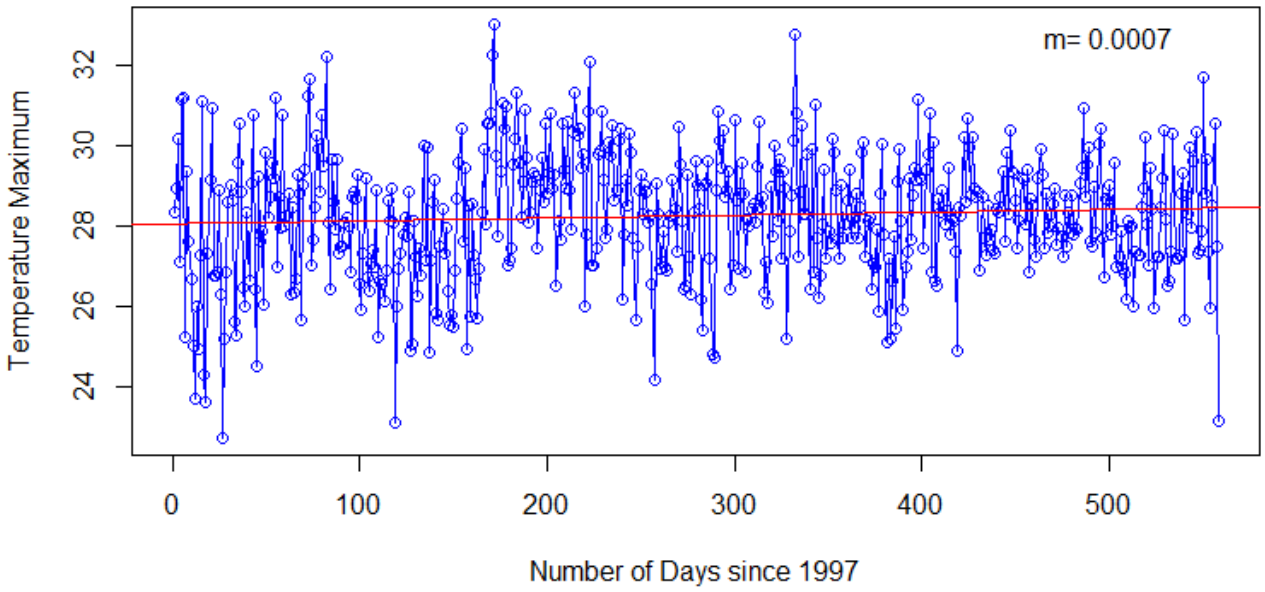


Figure 15: Trend in daily temperature maximum in the uThungulu District Municipality (1997-2015)

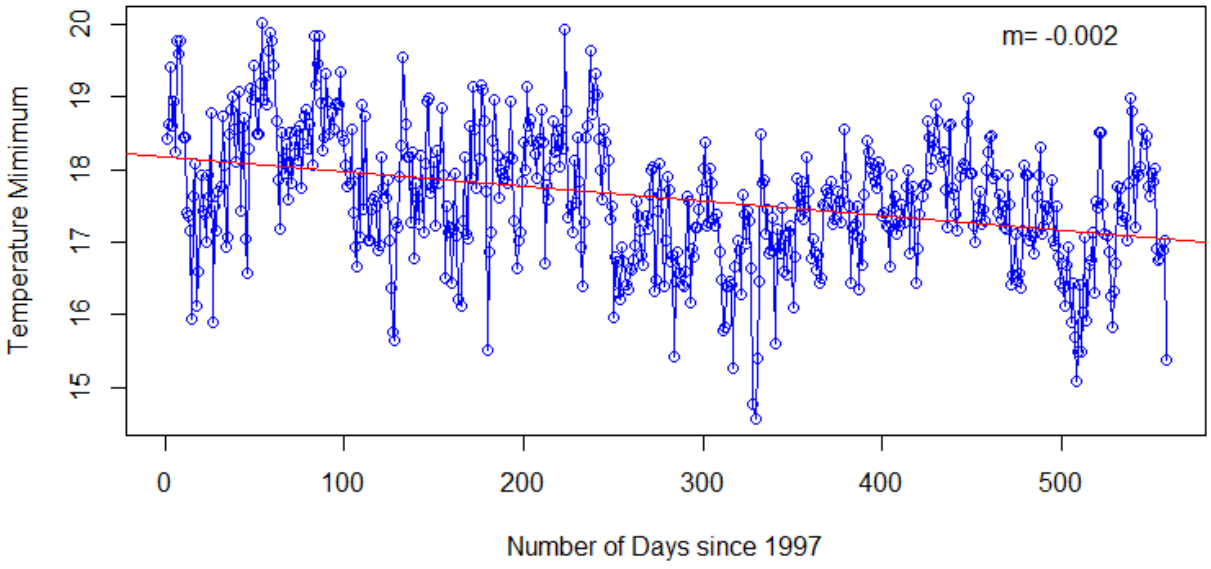


Figure 16: Trend in daily temperature minimum in the uThungulu District Municipality (1997-2015)

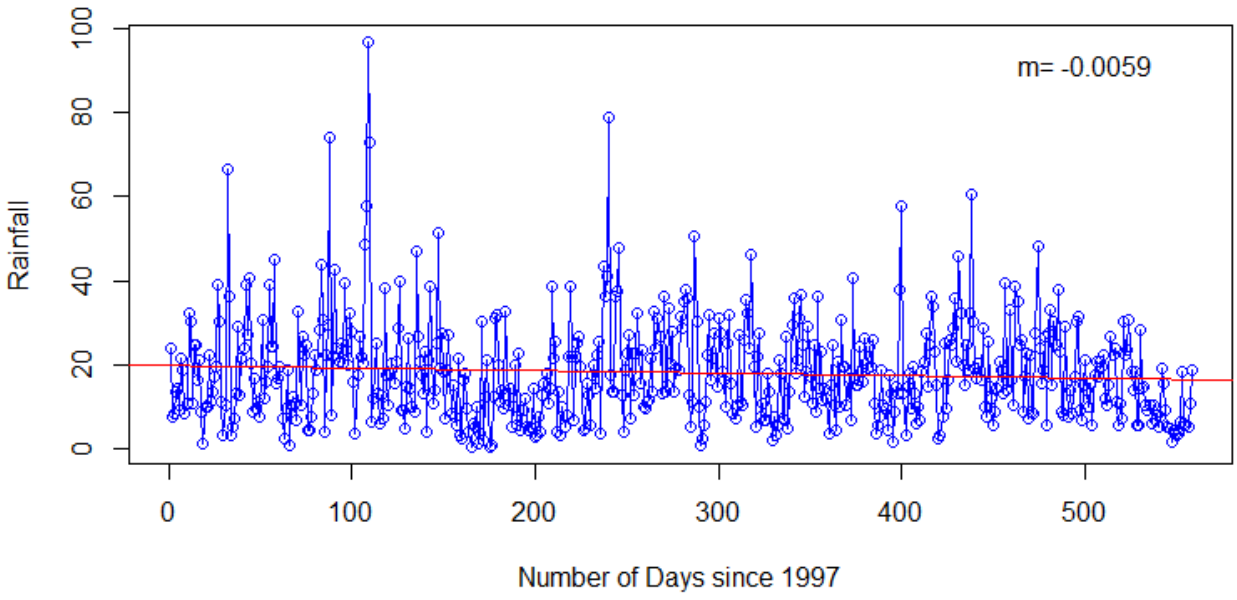


Figure 17: Trend in daily rainfall in the uThungulu District Municipality (1997-2015)

Table 10: Farmers perception on long term climatic and environmental changes

Variable	Farmer's Perception		
Access to information and use of indigenous knowledge	Access	No access	
Agronomic and post-harvest information	87.6%	12.4%	
Animal production and health information	70.5%	29.5%	
Climatic/ weather in general	78.8%	21.2%	
Seasonal forecast	66.7%	33.3%	
Daily or 3 day forecast	68.9%	31.1%	
Crop production constrains	**Percentage**		
Rainfall	15.7		
Temperature	16.6		
Pest and diseases	35.4		
Soil fertility	10.3		
Lack of knowledge	6.2		
Other	15.8		
Climatic and environmental changes over last 10-20 years	**Increase**	**Decrease**	**Other**
Mean temperature	59.8%	26.8%	13.4%
Mean rainfall	36.4%	58.5%	5.1%
Veld fires	54.1%	35.3%	10.6%
Changes in crop farming in the last 10-20 years (yes/no)	**Percentage**		
No	42%		
Yes	58%		
Observed cause of change			
Increased weeds and pests	11%		
Changed rainfall patterns	33%		
Less harvest due to high temperatures	18%		
Observed changed growth patterns	9%		
Risky farming	2%		
Other	27%		

4.4.3. Analysis of Rainfall Anomaly Index (RAI)

A plot of RAI (**Figure 18**) was used to further investigate the variation of rainy years in Ntambanana Local municipality. Clearly demonstrated from **Figure 18** is that 9 out of 19 years experienced below normal rainfall. These results imply that the years with lower than normal rainfall are also characterised by late onset rainfall and early cessation (Ayanlade *at al*., 2017). These years can also be associated with ENSO phenomenon as seen in **Table 11**. Such as years (2003 and 2015) characterized by El Nino and years (2000 and 2006) characterised by La Nina. In South Africa, El Nino is associated with dry conditions and La Nina is associated with wet conditions. During El Nino, The circulation is such that there is an offshore shift of ascending branch of the walker circulation to be over the western Indian Ocean rather than over the tropical Southern Africa (Mulenga et al., 2003).

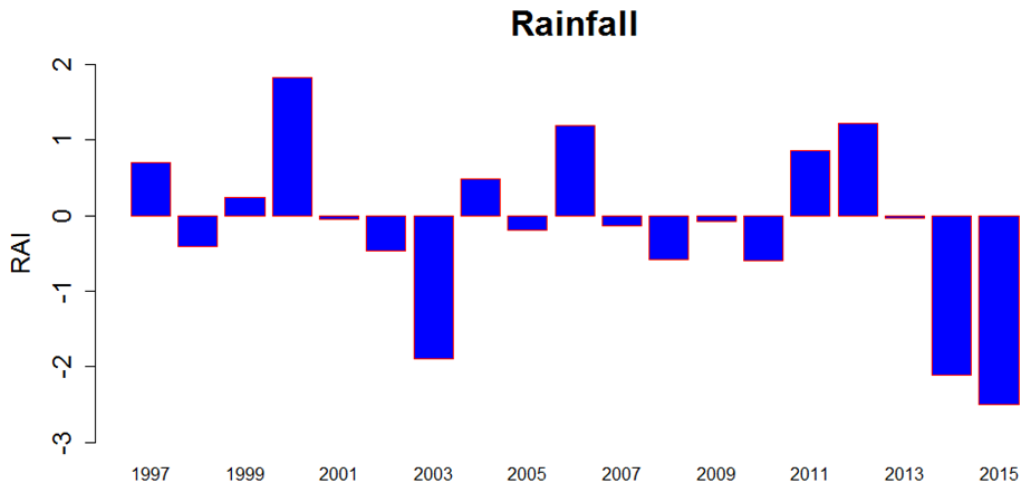


Figure 18: Rainfall Anomaly Index

Table 11: Summary of ENSO years: SOURCE [NOAA Climate.gov]

El Nino				La Nina		
Weak	**Moderate**	**Strong**	**Very Strong**	**Weak**	**Moderate**	**Strong**
1952-53	1951-52	1957-58	1982-83	1954-55	1955-56	1973-74
1953-54	1963-64	1965-66	1997-98	1964-65	1970-71	1975-76
1958-59	1968-69	1972-73	**2015-16**	1971-72	1995-96	1988-89
1969-70	1986-87	1987-88		1974-75	2011-12	1998-99
1976-77	1994-95	1991-92		1983-84		**1999-00**
1977-78	**2002-03**			1984-85		2007-08
1979-80	2009-10			**2000-01**		2010-11
2004-05				**2005-06**		
2006-07				2008-09		
2014-15				2016-17		

4.4.4. Analysis of Cumulative Departure Index (CDI)

The farmer's perceptions from **Table 10** were also compared and tested by CDI during growing season. Small-scale farmers indicated that changes in crop farming was due to changed growth patterns. A graph of CDI (**Figure 19**) demonstrate changes in the length of the growing season. In this region the early growing season is generally in October-November-December (OND) and the late growing season is in January-February-March (JFM).

From **Figure 19** the early growing season is illustrated as being dominated by below normal rainfall relative to the late growing season which is illustrated to receive normal rains. With these results, it is clear that the fluctuation of rainfall anomalies will determine the growth pattern of small-scale farmers, forcing them to start planning in JFM due to abundance of rainfall. Similar changes in the start of the rain season have been reported by Mubvuma (2013) and Tadross *et al* (2009) and this gives some degree of reliability in the results. The above results also confirms the farmers perception that the early and late growing season rainfall are oscillating for late onset of rainfall and reduced early growing season of rainfall between 1997-2015.

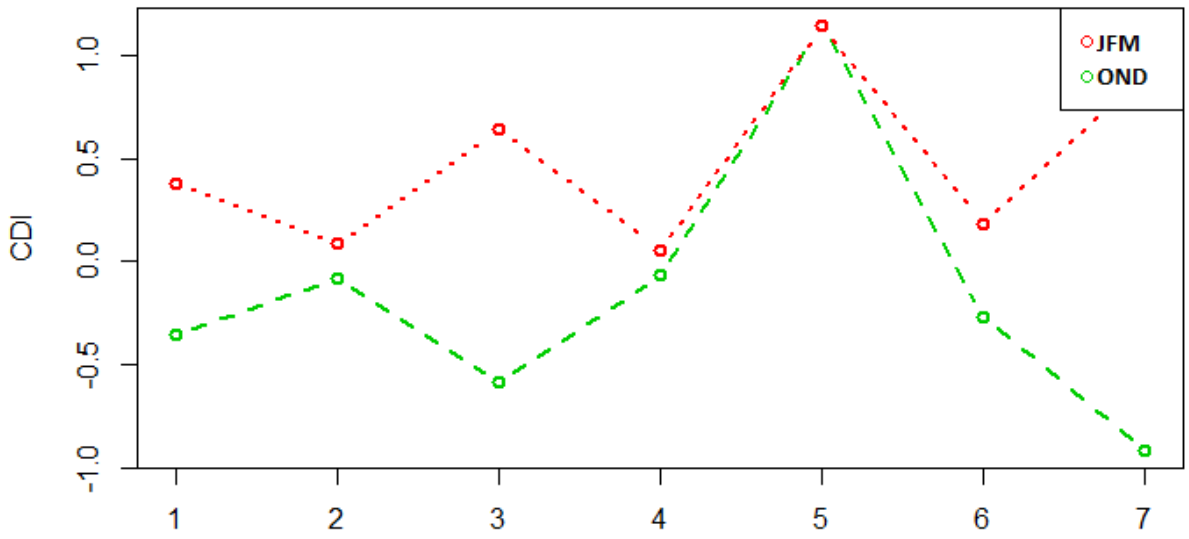


Figure 19: Length of early and late growing season

4.4.5. Investigating livelihood resilience of Ntambanana small scale farmers under changing climate

Understanding the response of farmers to past climatic change is a necessary step to informing how to support current and future adaptation (Wiid and Ziervogel, 2012). It is clear that the livelihood of small-scale farmers is under threat due to climate change. According to Tanner et al (2014), climate change is not only an environmental problem that can be solely address in scientific ways. There are a number of systems that are linked to climate change which include politics. It is therefore important to investigate livelihood resilience of poor communities such as Ntambanana.

The change in climate has led to a huge number of households in Ntambanana to be unable to access food for their families. **Table 12** and **Table 13** demonstrate the farmer's livelihood sources and household coping strategies respectively. In Ntambanana, the main source of livelihood is subsistence farming and selling of cereal, root crops and receiving pension. Most of the households (66%) skip days without eating or harvest immature crops. The impact of changing climate fall disproportionately on the livelihood systems of the poor citizens, undermining their capacity to build sustainable livelihoods and increasing their vulnerability (Tanner et al, 2014).

Climate impacts vary depending on a number of factors such as biophysical factors, including latitude longitude and closeness to the coast (Wiid and Ziervogel, 2012). It was clearly demonstrated that the farmers are mostly sensitive to extreme climate conditions. Since Ntambanana is characterised by subsistence food production and economic poverty, it is favourable for this region to be sensitive to the impacts of climate change.

Adaptation is the core component of any policy response to climate change. Without building adaptation, climate change is detrimental to the agricultural sector, while building adaptation measures, vulnerability can be reduced. There is a clear need of a change from a top-down approach on climate change and agriculture wherein adaptation relies on climate change scenarios and estimate impacts through scenario analysis to a bottom-up approach which considers socio-economic and policy producer's perception and elements of decision making

Table 12: Income and Livelihood sources

	Percentage
Sale of cereal and pulses (maize, rice, sorghum)	28%
Sale of root crops (cassava, potato)	14%
Employed for farm work	6%
Self employed	6%
Pension	18%
Other	28%

Table 13: Household Coping Strategies

	Response		
Were there any days in the past 12 months that household was faced with difficulties in accessing food	Yes (70%)		No (30%)
	Code	**Frequency**	**Percentage**
Skip days without eating	4	4	66
Limit portion size	1	7	16
Borrow food from relatives/friends	2	7	33
Harvest immature crops	4	7	66
Reduce adult consumption so children can eat	3	6	50
Rely on casual labour for food	1	6	16

Code: Never=1 Seldom=2 Sometimes=3 Often=4 Daily=5

4.5. Conclusion

This chapter illustrated both qualitative and quantitative methods to investigate the small scale farmer's perception with the past and present climate and also analysed the livelihood resilience of small scale farmers in Ntambanana local Municipality. From compering the meteorological data from 1997-2015 and answers from the questionnaire the Null hypothesis **H_0:** which stated that the perceptions of small-scale farmers on long-term climate and environmental changes corroborate results observed from analyses of South African Weather Service (SAWS) meteorological data (1997-2015) was assumed to be accurate.

Furthermore, analysis from the RAI demonstrated that over the years the study area has experienced below normal rainfall which were characterized by late onset rainfall and early cessation. On the other hand, analysis from CDI showed the changes in crop farming due to changed growth patterns. It was clear that the livelihood of small-scale farmers is under threat with changes in rainfall pattern and agricultural practices were forced to change. Many families depending on agriculture are surviving below the poverty line due to climate change. This study highlighted the need to always involve the famers on policy developments because they are the most affected by climate change.

CHAPTER FIVE: Impact of Climate Change on hydrological processes in uThungulu District Municipality

5.1. Abstract

This chapter investigates the impact of climate change on hydrological processes in uThungulu District Municipality. Two CMIP 5 GCMs (GFD and Nor) were considered and statistically downscaled to seven stations in uThungulu District Municipality. Bias corrections was applied to the GCMs to correct systematic errors. This study employed the quantile mapping (QM) bias correction method using parametric transformations (**PTF**), QM using smoothing spline (**SSPLINL**) and lastly QM using non-parametric empirical quantiles (**QUANT**). Results showed that downscaling based on quantile mapping using SSPLINL and QUANT produce robust results of close mean biases between simulation and observations. The Kolmogorov-Sminov (KS) test was used to measure the distance between observations and simulations for rainfall, temperature minimum and maximum. In order to investigate the projected changes in hydrological processes in uThungulu District Municipality an area average of three catchments responsible for water resources in the area were considered, namely: Mfolozi, Mhlatuze and Thukela. The main impact hydrological model used was ACRU to simulate streamflow for historical period (1985-2089) and future period (2070-2089) for RCP 8.5. Results showed that uThungulu District Municipality is characterized by high streamflow in summer (December-April). Furthermore, it was found out that drought events are projected to be less in future, however the duration, severity and magnitude maybe higher. Moreover, Results from the baseflow statistics and elasticity between streamflow and rainfall showed an increase in baseflow in future and every 10% of change in rainfall may result in approximately 9% of change in streamflow.

5.2. Introduction

When conducting impact studies using GCMs, it is significant to do bias correction in order to get the true reflection of the data. Simulations by models often show a distinct systematic deviation from the true observed climate. According to Maraun (2013), the simplest methods correct the long term climatological mean bias between simulations and observations. Quantile mapping even attempts to remove quantile-dependent biases. This study assessed the performance of quantile mapping using three tests (PTF, SSPLINL and QUANT) for rainfall, temperature minimum and maximum. Seven stations from uThungulu District Municipality were used as observations from 1997-2015

A Taylor Diagram was plotted in **Figure 20** in order to investigate how models correspond to the observation data of uThungulu District Municipality using three main comparative assessment statistics, namely: standard deviation, correlation and root mean square error (RMSE). Clearly illustrated in this plot is how realistically each model reproduces observation. GFD and Nor best represent observation as they have high correlation and low RMSE. CAN and CNR are shown to also have relatively good representation of observations. BNU has slightly high RMSE and correlation while MPI is the worst model to reproduce observation, having highest RMSE. This process allows us to pick the model that best represent observation in order to do further analysis. In this case, the chosen model will be both GFD and Nor with a training period of model history from 1985-2005 and future timescale from 2071-2100.

The proposed study will apply a similar approach as Schulze (2012), where output from five CMIP 3 GCMs were downscaled to station level and interpolated to 5838 Quinary catchment in South Africa including Lesotho and Swaziland. This study will however use the selected models from the new generation of CMIP 5 (GDF and Nor). The interpolated model climate data is used to drive the Agricultural Catchments Research Unit (ACRU) agro-hydrological model to assess projected hydrological responses to future climate change. This study will investigate the likely changes in streamflow and extreme events in Mfolozi, Mhlathuze and Thukela catchments in uThungulu District Municipality.

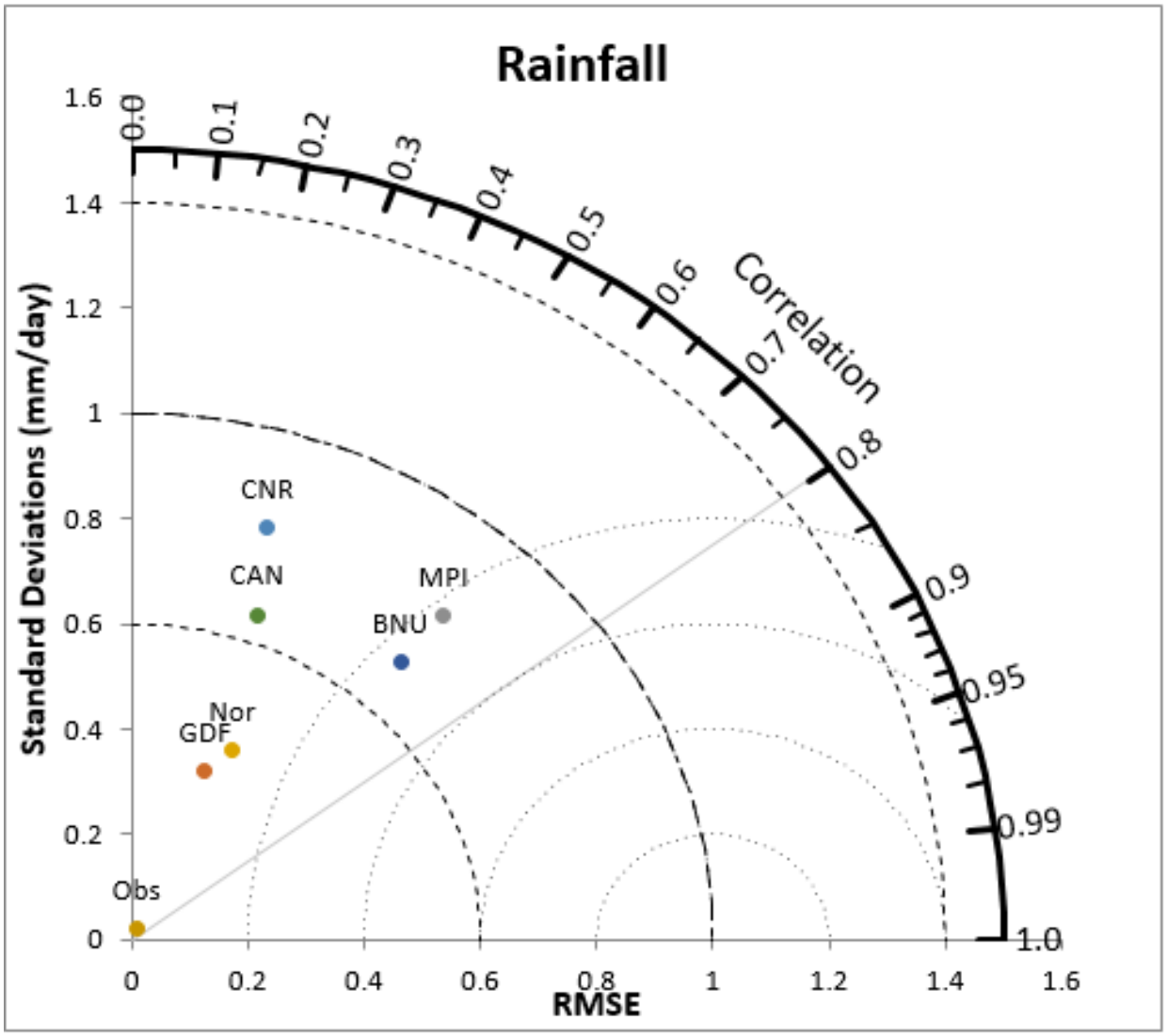


Figure 20: Taylor Diagram of six GCMs and Observations

5.3. Materials and Method

5.3.1. Applying bias correction to downscaled GCMs to correct systematic errors

A Taylor diagram for rainfall was used to investigate if the models used in this study corresponded to the observation data of the uThungulu District Municipality. The main comparative assessment statistic techniques used were standard deviation, correlation and root mean square error (RMSE). According to Taylor (2005), the Taylor diagram characterizes the statistical relationship between two fields (i.e. model and observation). The diagram does not give information about overall biases but only characterizes the *centered* pattern error. The following equation is the reason that each point in the two dimensional space can be represented by three different statistics.

$$\mathbf{E'^2 = \sigma_f^2 + \sigma_r^2 - 2\sigma_f\sigma_r R} \qquad \mathbf{(4)}$$

Where R is the correlation coefficient between observation and model, E' is the *centered* RMS differences between the fields and σ_f^2 and σ_r^2 are the variances of the model and observation fields respectively. The construction of the Taylor diagram with the correlation given by the cosine of the azimuthal angle is based on equation (4) above and the law of cosines $c^2 = a^2 + b^2 - 2abcos\text{ø}$

Information from the GCMs have been used widely as the source of constructing climate change scenarios and examining climate change impacts. However, GCMs come at a very coarse resolution which then requires statistical or dynamical downscaling in order to generate a finer resolution. The output from downscaling is often associated with systematic errors or biases. Statistical bias correction algorithms have been used to 'correct' these systematic errors or biases. This then results in model simulated outputs more representative of observations (Hawkins et al., 2013). Bias correction of climate model projections is essential in order to properly assess the impacts of climate change on human and environmental resources (Matthew et al., 2016). Numerous bias correction methods have been reviewed and compared and Quantile Mapping (QM) was found to outclass other methods (**Table 15**) (Matthew et al., 2016). This study employed the quantile mapping (QM) bias correction method using parametric transformations (**PTF**), QM using smoothing spline (**SSPLINL**) and lastly QM using non-parametric empirical quantiles (**QUANT**). The GCMs were downscaled to each of the seven stations in uThungulu District Municipality.

5.3.2. Using GCMs to project changes in hydrological processes in uThungulu District Municipality

Climate change is projected to worsen water-related challenges in KZN province. Previous studies painted an optimistic picture suggesting that catchments in KZN are likely to experience flow trends opposite to what is projected over the rest of the country, meaning that they are likely to be flooded (Schulze et al., 2005).

GCMs (in **Table 4**) were used to assess projected changes in hydrological processes in uThungulu District Municipality. Three main catchments responsible for water supply in uThungulu District Municipality were considered and those were Mfolozi, Mhlathuze and Thukela. As the first step, before climate model projections can be used, it is vital to verify historical simulations against observations. The models were selected based on their ability to simulate observations. If the model performs well in reflecting observed climate in its simulation, there is a high chance that it will also perform well in generating climate projections. Bias corrected GCM data was used to assess projected changes in hydrological processes in uThungulu District Municipality.

The main impact model used in South Africa for agro-hydrological studies is the Agricultural Catchment Research Unit (ACRU). This model requires inputs of inter alia, near surface temperature, rainfall and potential evaporation to simulate several hydrological variables (Schulze et al., 2005). The climate data used in this study included daily temperature maximum and minimum and rainfall simulated by CMIP 5 GCMs of both GFD and Nor forced by the Representative Concentration Pathway (RCP) 8.5 for the future (2070-2090) projections with historical baseline of 1985-2004.

RCPs are greenhouse gas (GHG) concentration pathways which describes four different climate futures (SAWS 2017, Climate Change Atlas). RCPs have been defined with respect to the contribution of atmospheric radiative forcing in year 2100. Shown in **Figure 21** is the graph of the four RCPs labelled by the radiative forcing values in the year 2100 (RCP 2.6, RCP4.5, RCP 6 and RCP 8.5). RCP 2.6 is well known as the ‘aggressive mitigation scenario’ where the value of GHG concentration will be at +2.6W/m^2. RCP 4.5 and RCP 6 are the ‘intermediate scenarios’ where the value of GHG concentration in the atmosphere will be 4.5W/m^2 and 6W/m^2 respectively. Lastly, is the RCP 8.5 which is the ‘business as usual’ scenario, in this scenario there will be 8.5W/m^2 concentration of GHG in the atmosphere by the year 2100.

In order to investigate the projected changes on the hydrological processes in uThungulu District Municipality, we considered the estimation of rainfall elasticity of streamflow in the three main catchments (Mfolozi, Mhlathuze and Thukela) area averaged. According to Chiew (2006), the rainfall elasticity of streamflow is defined as the proportional change in mean annual streamflow divided by the proportional change in mean annual rainfall (see equation 1). This means that elasticity of 2 indicates that a 1% change in rainfall results in a 2% change in streamflow.

$$\varepsilon p = \text{median}\left(\frac{Q_t - \overline{Q}}{P_t - P}\,\frac{\overline{P}}{\overline{Q}}\right) \qquad (1)$$

$\overline{P}$ and $\overline{Q}$ are the mean annual rainfall and streamflow respectively. To estimate the εp a value $\left(\frac{Q_t - \overline{Q}}{P_t - P}\,\frac{\overline{P}}{\overline{Q}}\right)$ is calculated for each pair of P_t and Q_t in annual time series. Furthermore, we compared the baseflow statistics using the R package FlowScreen (for daily streamflow trend a) of historical and future streamflow in order to see the changes in hydrological processes in uThungulu District Municipality.

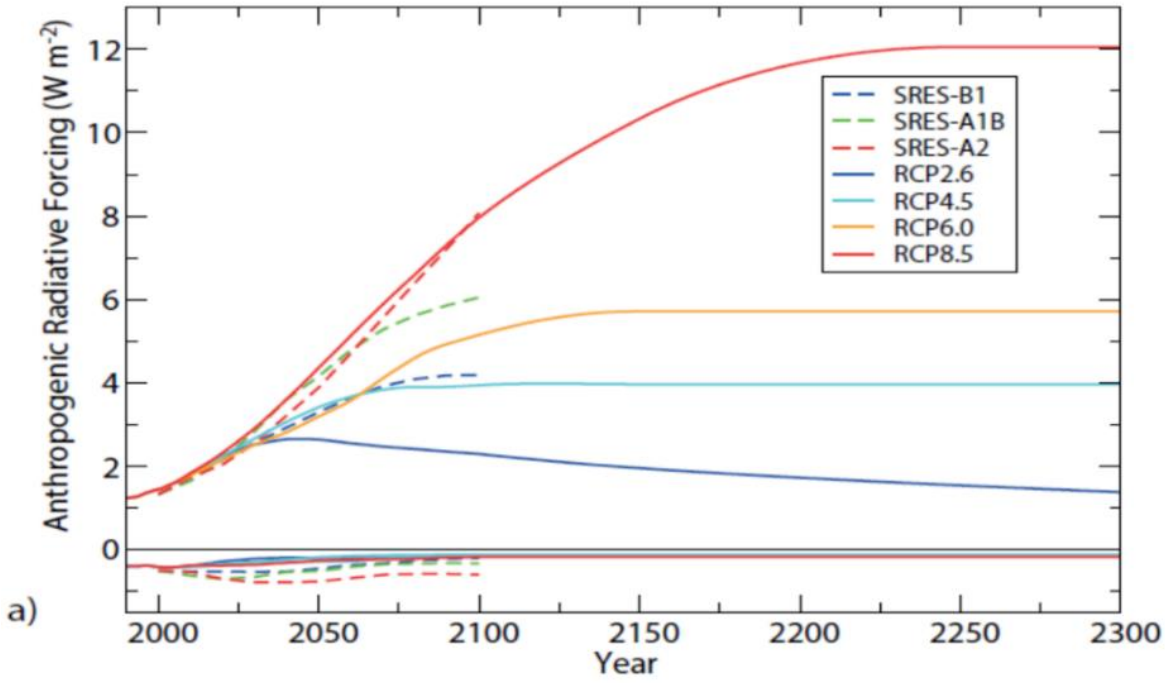


Figure 21: Representative Concentration Pathways: SOURCE [IPCC AR5]

5.4. Results and Discussion

5.4.1. Bias Corrections Application and Statistical Downscaling Results

Figure 22-27 show results from GFD model while **Figure 28-33** show results from Nor model. From the two models, it is evident that the downscaling based on quantile mapping using SSPLINL and QUANT produce robust results of close mean biases between simulation and observations. This was shown by a near straight line with only two outliers. The Kolmogorov-Sminov (KS) test is used to quantify the uncertainty due to downscaling of GCMs with the observations. This is done by measuring the distance between simulation and observation. This distance is called KS-statistic and is often associated with the p-value which determines the significance of the results obtained. **Table 14** to **Table 15** show a summary results of downscaling from seven stations in uThungulu District Municipality and across the two CMIP5 models (GFD and Nor) for rainfall, minimum and maximum temperature. The statistically downscaled tables largely show temperature minimum to have the largest KS-statistic; and p-values largely statistically insignificant with value of zero or less than zero.

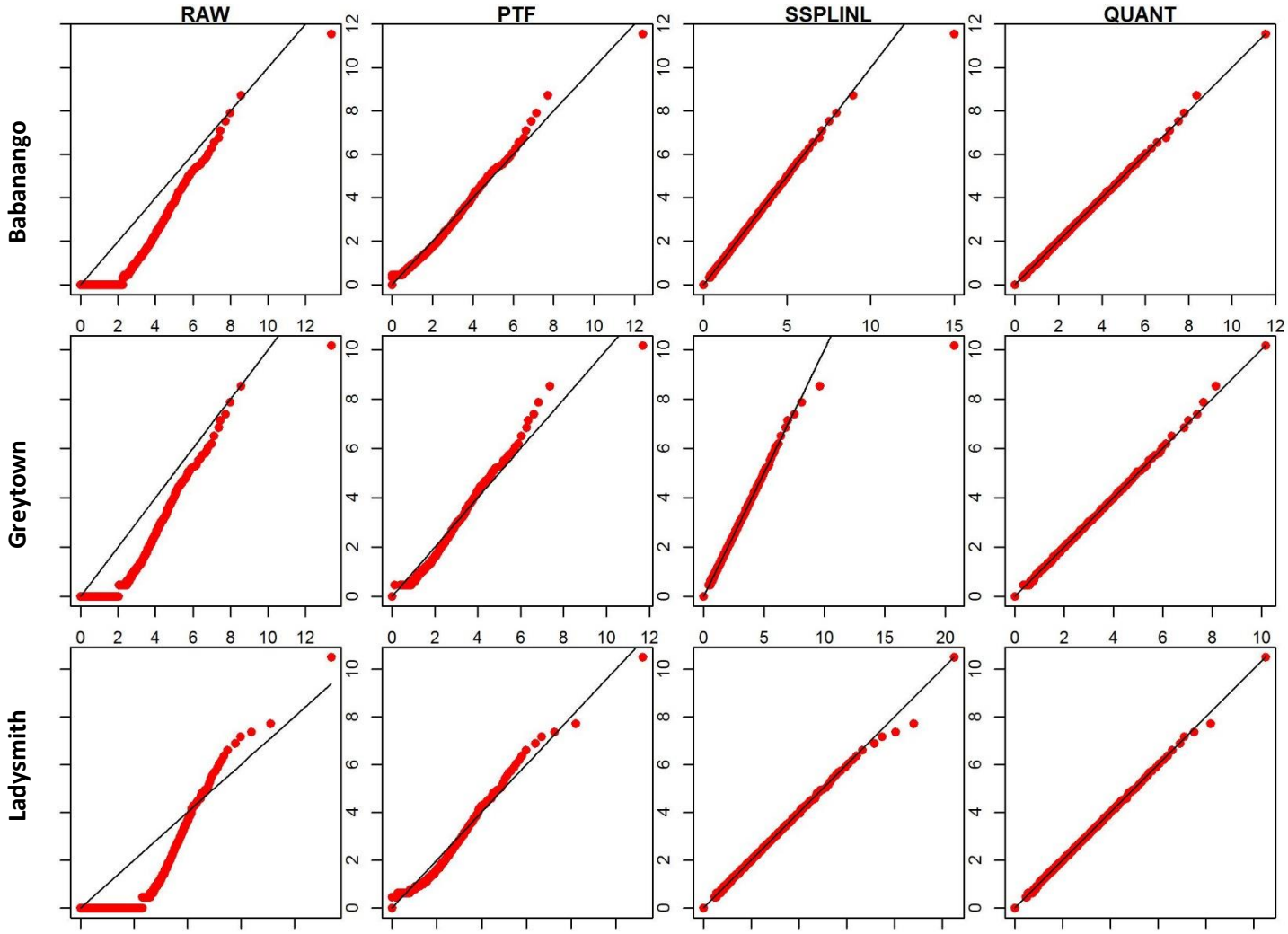


Figure 22: Statistical downscaling results of observed daily rainfall data for 1997-2015 derived from GFD model based on QM

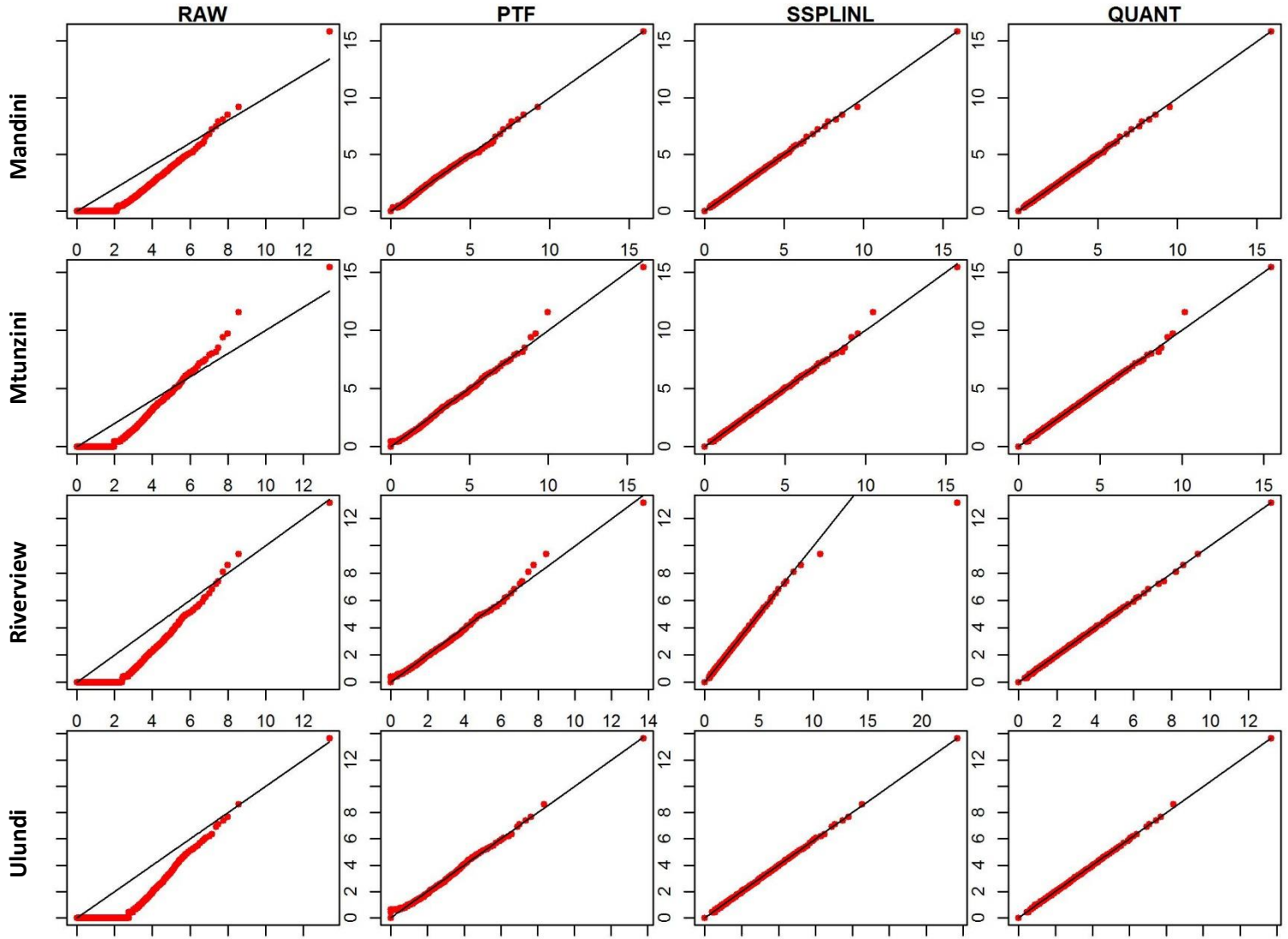


Figure 23: Statistical downscaling results of observed daily rainfall data for 1997-2015 derived from GFD model based on QM

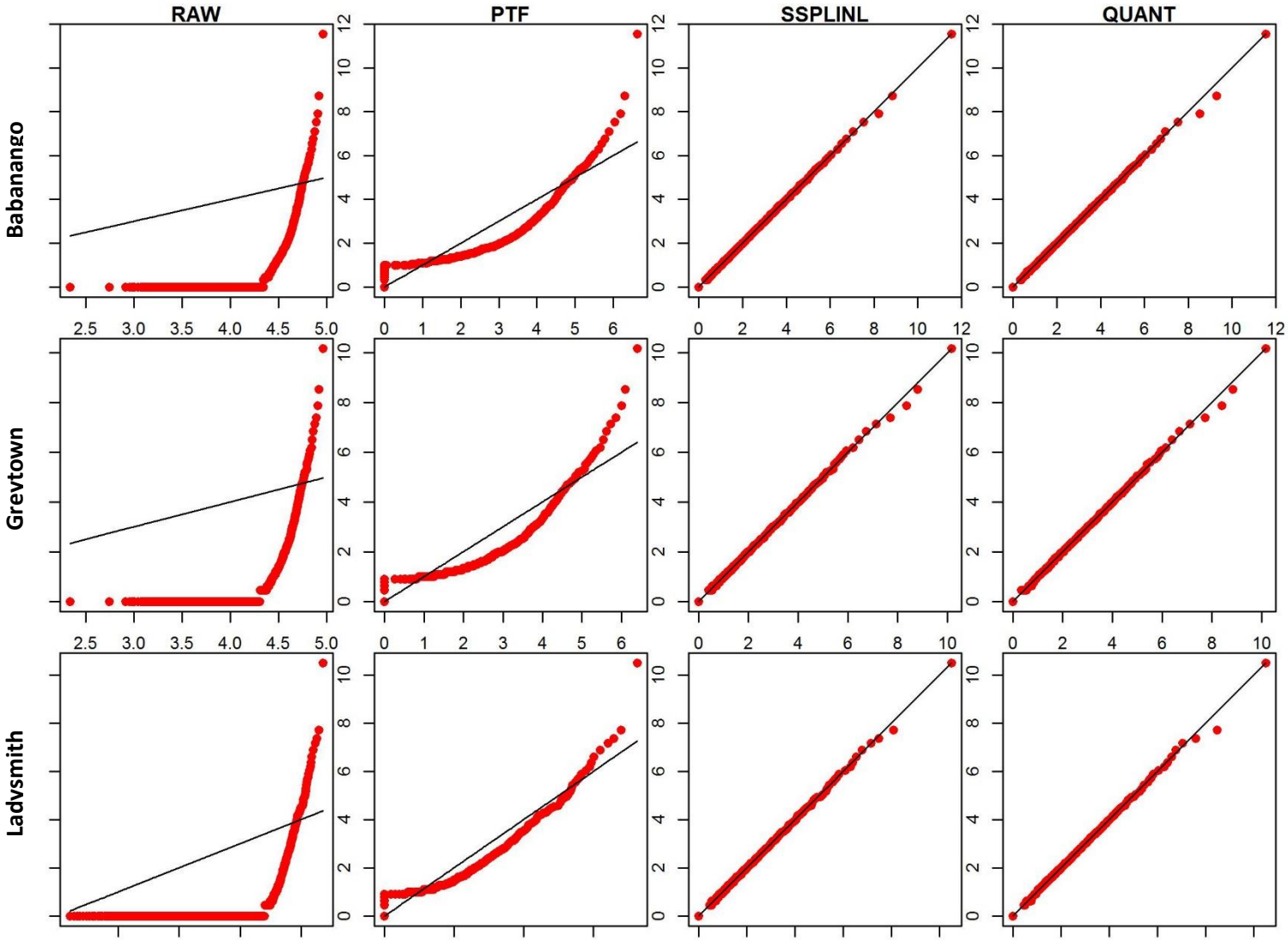


Figure 24: Statistical downscaling results of observed daily temperature minimum data for 1997-2015 derived from GFD model based on QM

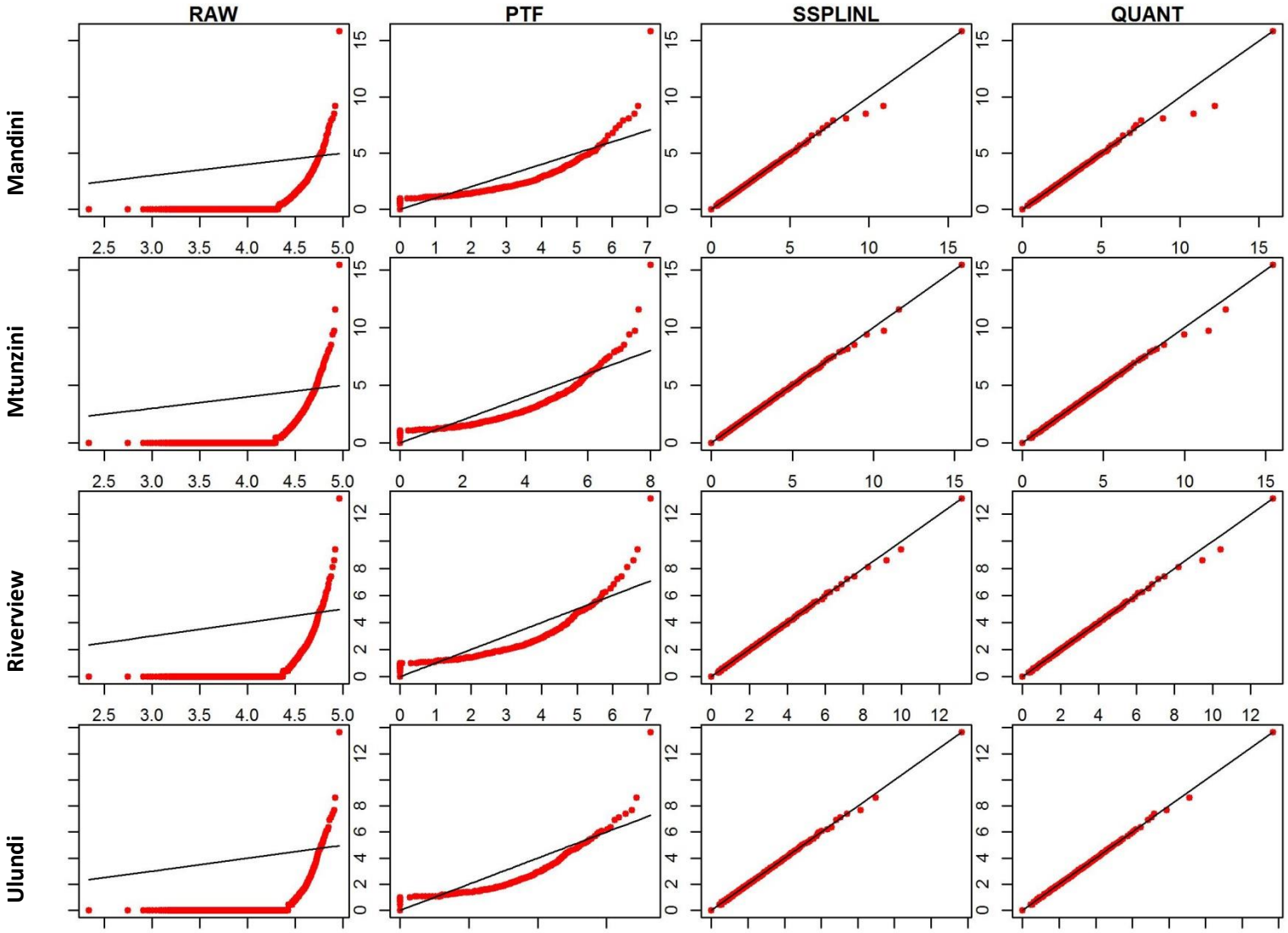


Figure 25: Statistical downscaling results of observed daily temperature minimum data for 1997-2015 derived from GFD model based on QM

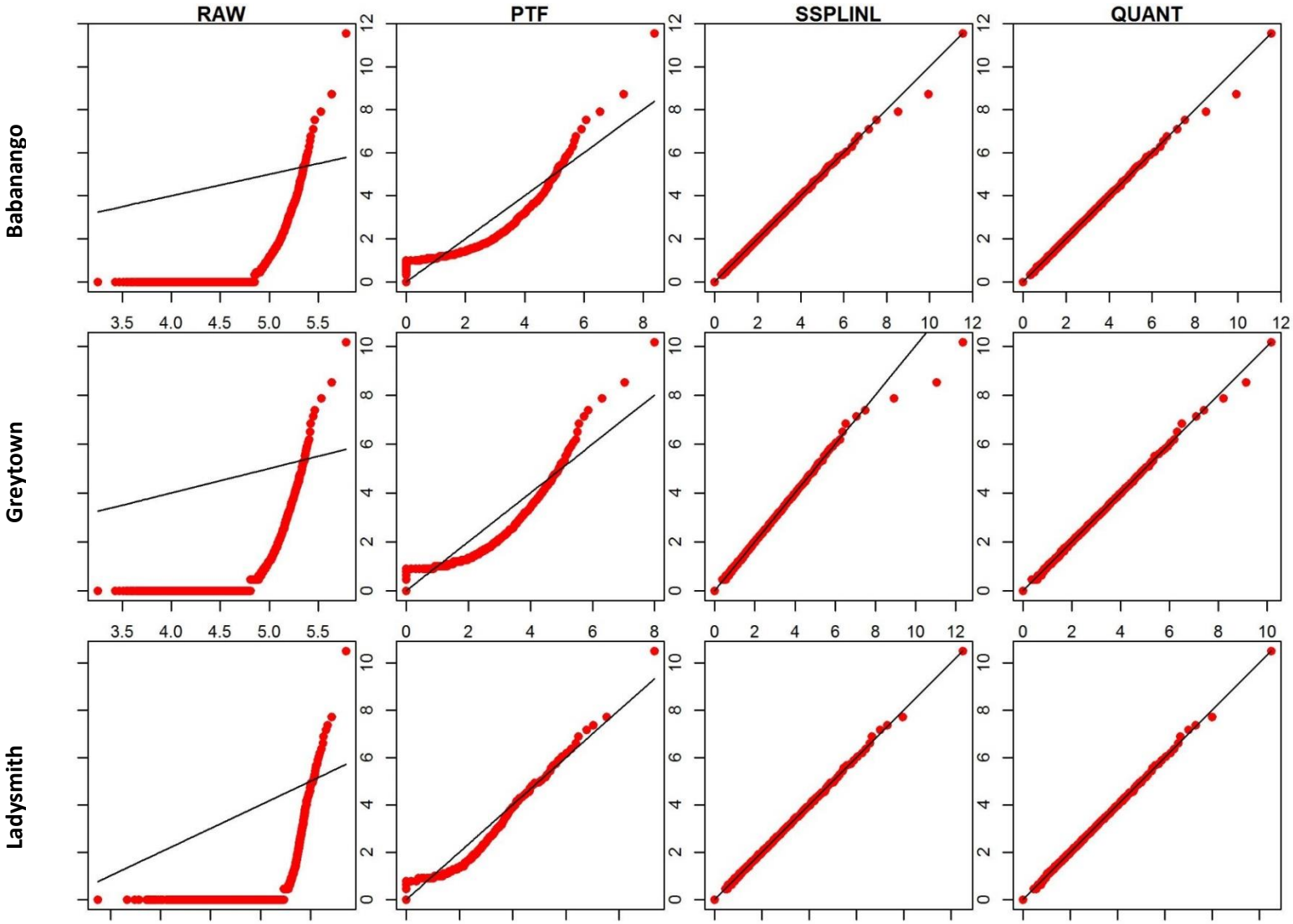


Figure 26: Statistical downscaling results of observed daily temperature maximum data for 1997-2015 derived from GFD model based on QM

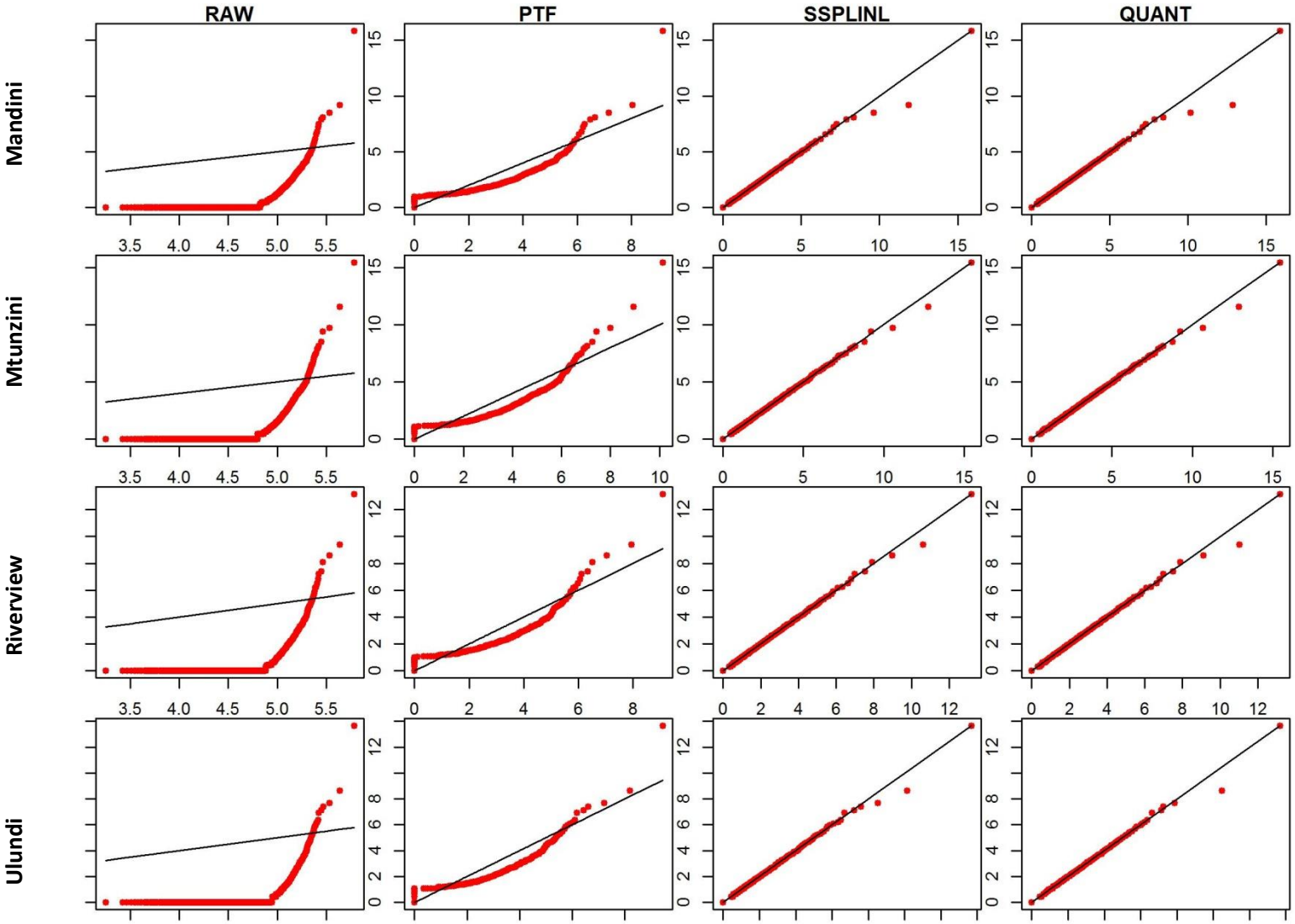


Figure 27: Statistical downscaling results of observed daily temperature maximum data for 1997-2015 derived from GFD model based on QM

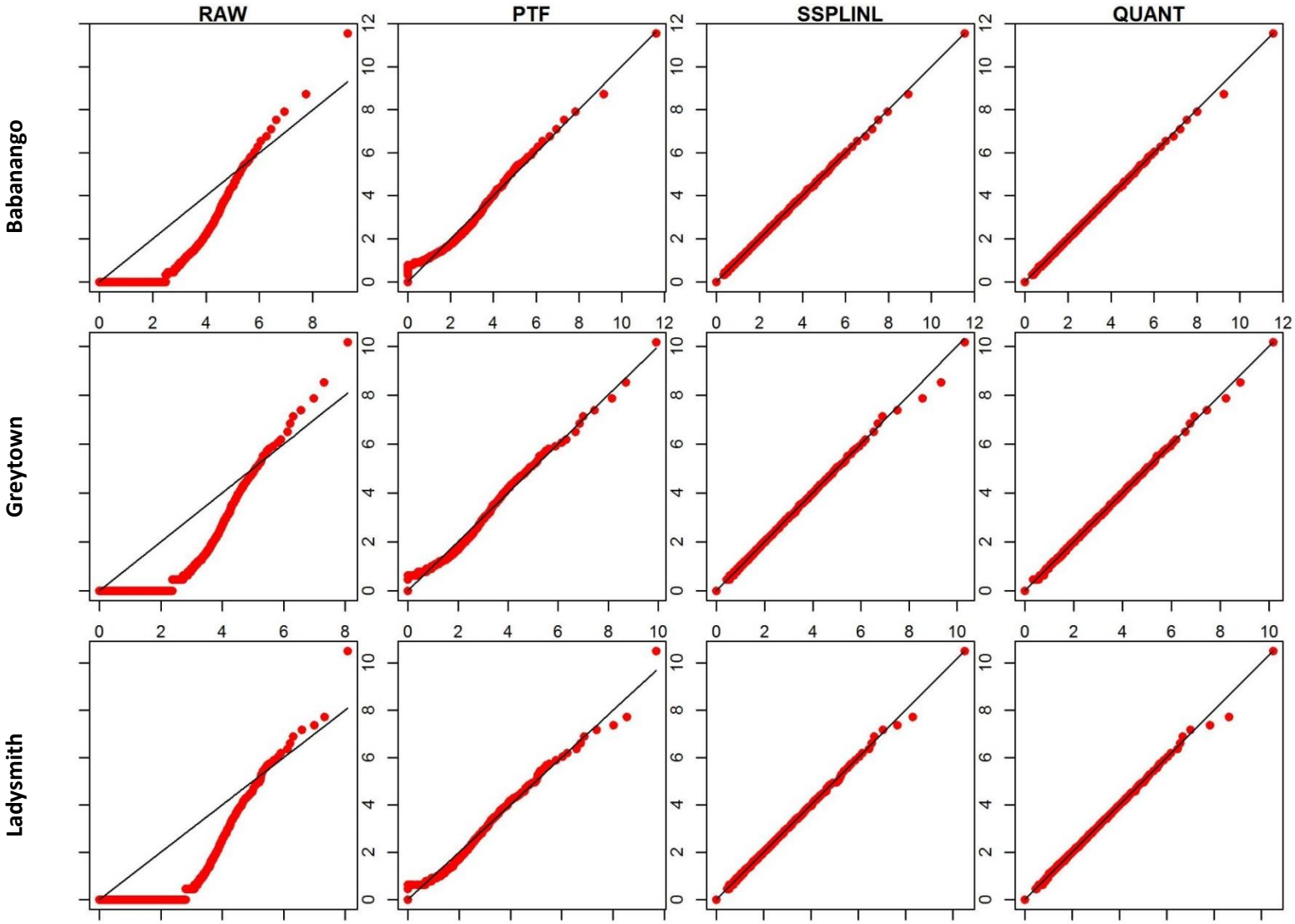


Figure 28: Statistical downscaling results of observed daily rainfall data for 1997-2015 derived from Nor model based on QM

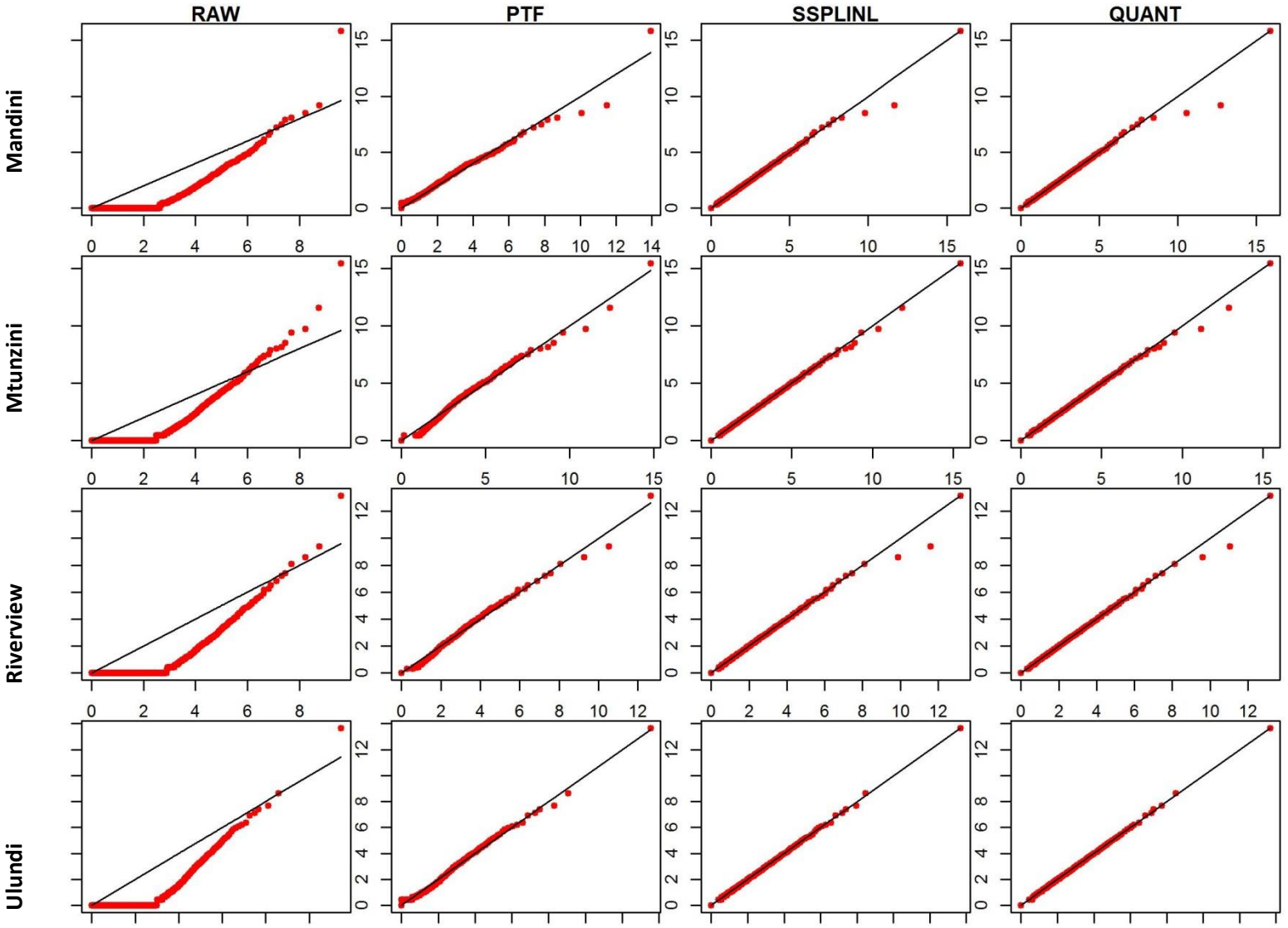


Figure 29: Statistical downscaling results of observed daily rainfall data for 1997-2015 derived from Nor model based on QM

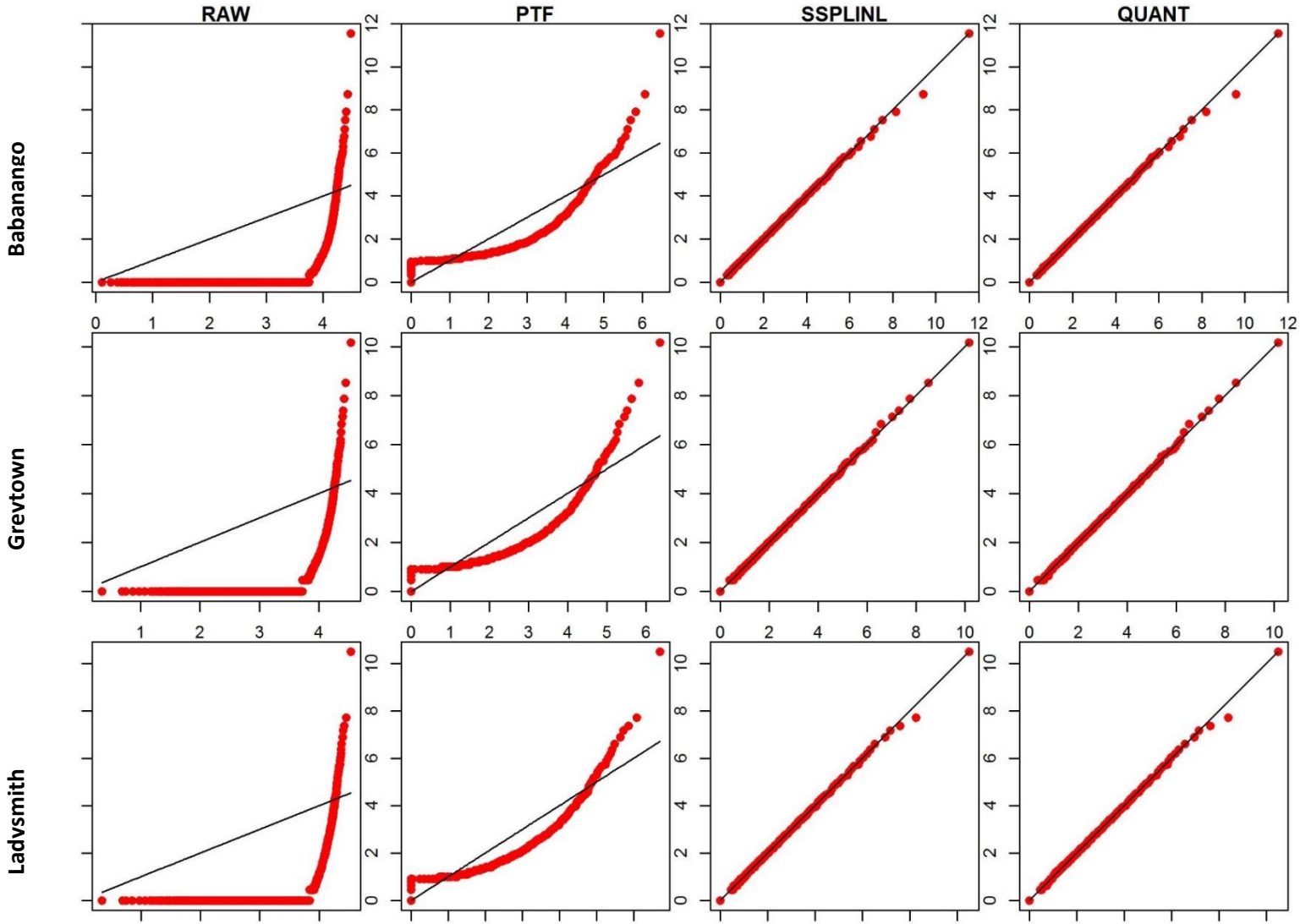


Figure 30: Statistical downscaling results of observed daily temperature minimum data for 1997-2015 derived from Nor model based on QM

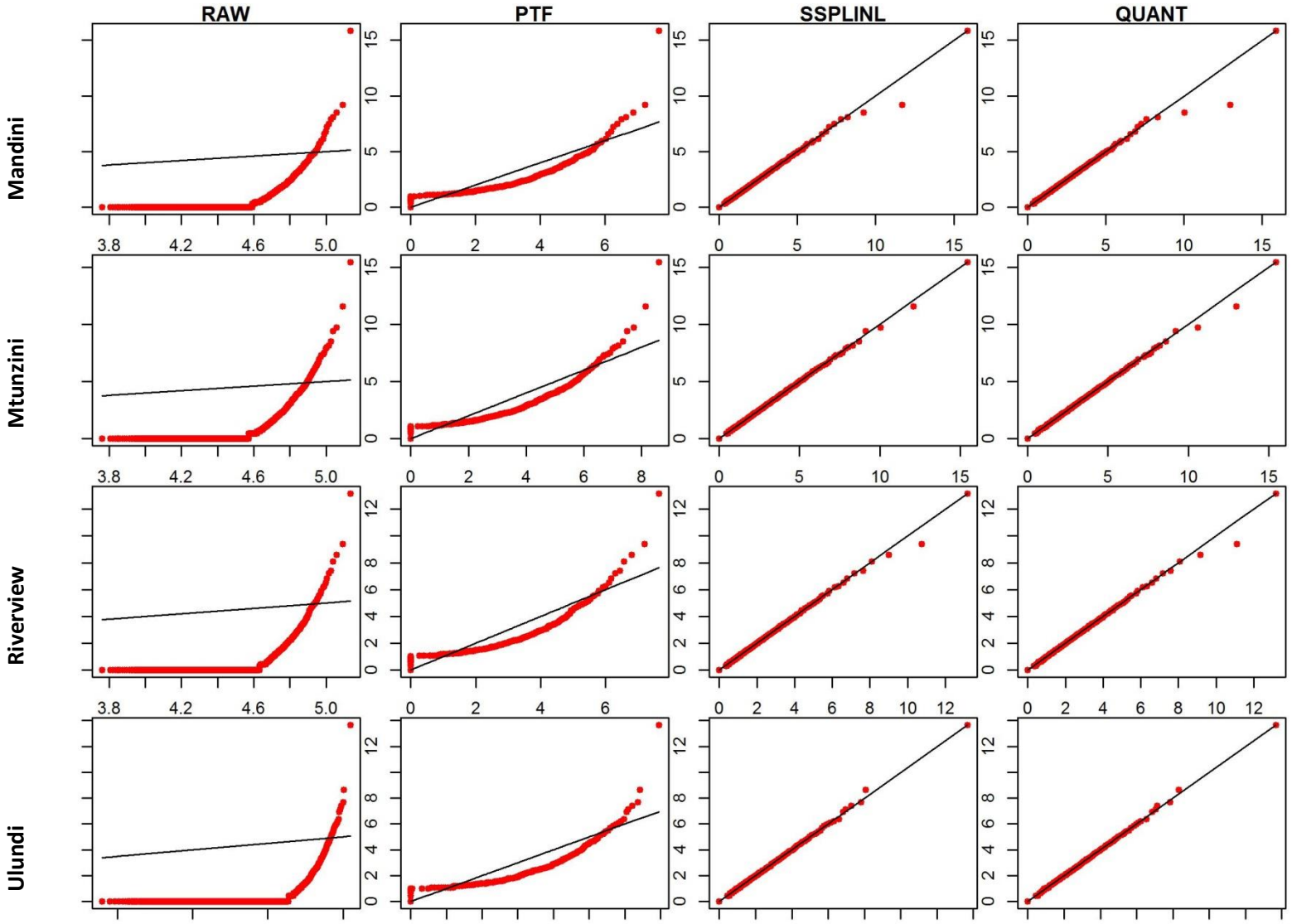


Figure 31: Statistical downscaling results of observed daily temperature minimum data for 1997-2015 derived from Nor model based on QM

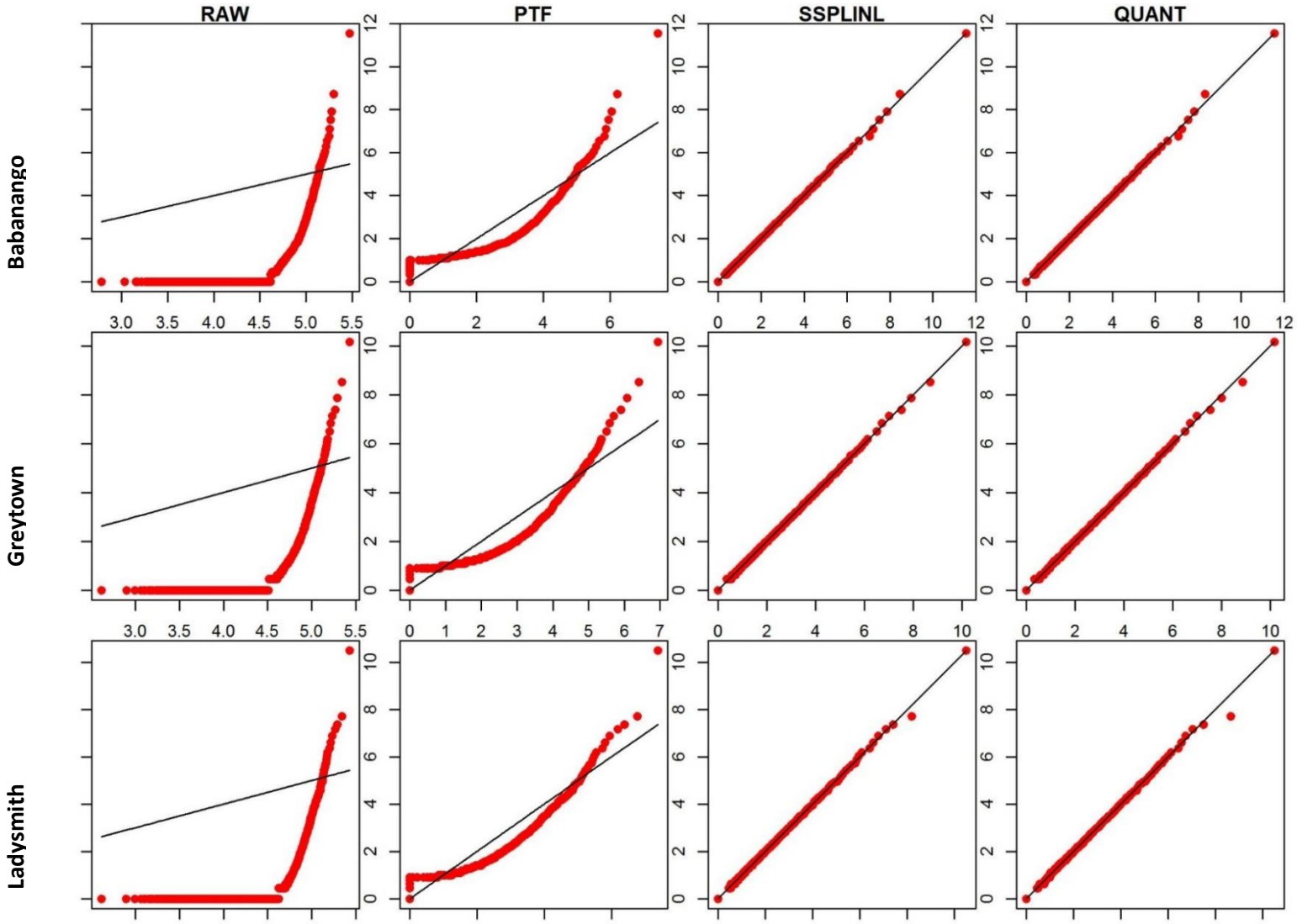


Figure 32: Statistical downscaling results of observed daily temperature maximum data for 1997-2015 derived from Nor model based on QM

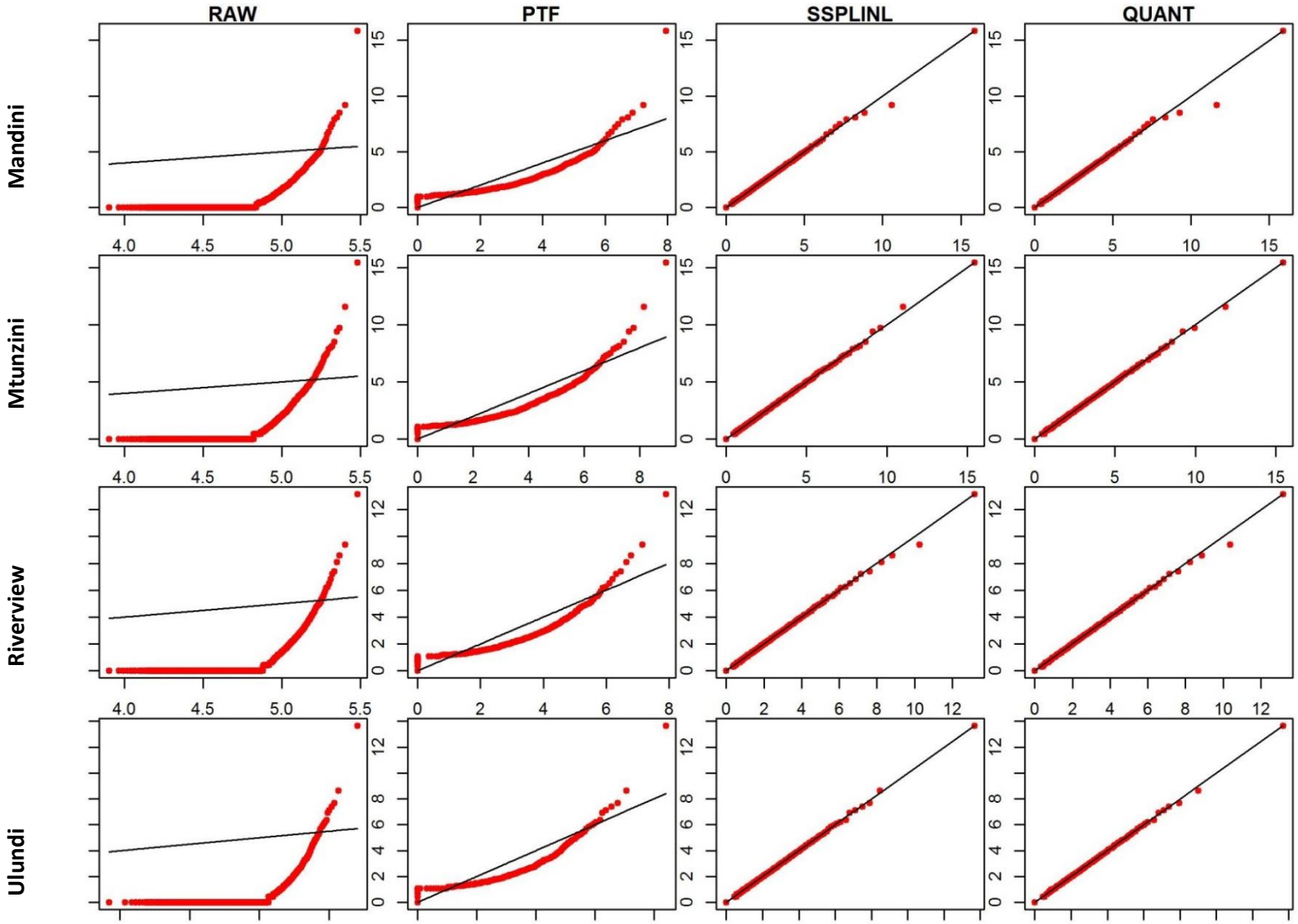


Figure 33: Statistical downscaling results of observed daily temperature maximum data for 1997-2015 derived from Nor model based on QM

Table 14: Summary of statistical downscaling results for rainfall

Station	Latitude	Longitude	Parameters	GFD-Model			Nor-Model		
				PTF	SSPLINL	QUANT	PTF	SSPLINL	QUANT
Babanango	-28.3644	31.2065	p-value	3.01E-13	0.00	0.00	9.36E-7	0.00	0.00
			KS-statistic	0.067	0.079	0.079	0.047	0.079	0.079
Greytown	-29.0832	30.6034	p-value	0.00	0.00	0.00	7.28E-13	0.00	0.00
			KS-statistic	0.136	0.114	0.114	0.066	0.114	0.114
Ladysmith	-28.5755	29.7503	p-value	9.19E-7	4.71E-12	0.00	6.07E-5	4.71E-12	0.00
			KS-statistic	0.047	0.064	0.033	0.040	0.064	0.032
Mandini	-29.1582	31.4023	p-value	0.00	0.00	0.00	2.89E-12	0.00	0.00
			KS-statistic	0.116	0.099	0.099	0.065	0.099	0.099
Mtunzini	-28.9474	31.7079	p-value	0.00	0.00	0.00	0.00	0.00	0.00
			KS-statistic	0.106	0.125	0.123	0.183	0.125	0.123
Riverview	-28.4440	32.1821	p-value	4.24E-5	9.36E-9	3.25E-8	0.00	6.05E-9	3.25E-8
			KS-statistic	0.041	0.054	0.053	0.086	0.055	0.052
Ulundi	-28.3500	31.4000	p-value	5.20E-6	0.32	1	0.05	0.19	1
			KS-statistic	0.044	0.017	0.002	0.024	0.019	0.003

Table 15: Summary of statistical downscaling results for temperature minimum

Station	Latitude	Longitude	Parameters	GFD-Model			Nor-Model		
				PTF	SSPLINL	QUANT	PTF	SSPLINL	QUANT
Babanango	-28.3644	31.2065	p-value	1.55E-15	0.00	0.00	0.00	0.00	0.00
			KS-statistic	0.073	0.093	0.079	0.082	0.092	0.079
Greytown	-29.0832	30.6034	p-value	0.00	0.00	0.00	0.00	0.00	0.00
			KS-statistic	0.090	0.114	0.114	0.089	0.134	0.114
Ladysmith	-28.5755	29.7503	p-value	1.87E-8	4.94E-10	0.00	7.74E-10	6.66E-9	0.00
			KS-statistic	0.053	0.058	0.033	0.058	0.055	0.033
Mandini	-29.1582	31.4023	p-value	0.00	0.00	0.00	0.00	0.00	0.00
			KS-statistic	0.083	0.109	0.099	0.081	0.109	0.099
Mtunzini	-28.9474	31.7079	p-value	0.00	0.00	0.00	0.00	0.00	0.00
			KS-statistic	0.111	0.148	0.123	0.109	0.153	0.123
Riverview	-28.4440	32.1821	p-value	20.8E-11	2.66E-15	3.25E-5	2.04E-11	3.11E-15	3.25E-8
			KS-statistic	0.062	0.072	0.053	0.062	0.072	0.053
Ulundi	-28.3500	31.4000	p-value	0.00	0.00	1	0.00	0.01	1
			KS-statistic	0.080	0.031	0.003	0.079	0.028	0.003

Table 16: Summary of statistical downscaling results for temperature maximum

Station	Latitude	Longitude	Parameters	GFD-Model			Nor-Model		
				PTF	SSPLINL	QUANT	PTF	SSPLINL	QUANT
Babanango	-28.3644	31.2065	p-value	1.51E-14	0.00	0.00	1.11E-16	0.00	0.00
			KS-statistic	0.071	0.092	0.079	0.076	0.092	0.079
Greytown	-29.0832	30.6034	p-value	0.00	0.00	0.00	0.00	0.00	0.00
			KS-statistic	0.091	0.133	0.114	0.092	0.138	0.114
Ladysmith	-28.5755	29.7503	p-value	3.45E-9	4.71E-12	0.00	4.29E-9	3.99E-11	0.00
			KS-statistic	0.056	0.064	0.033	0.055	0.062	0.033
Mandini	-29.1582	31.4023	p-value	0.00	0.00	0.00	0.00	0.00	0.00
			KS-statistic	0.081	0.106	0.099	0.079	0.107	0.099
Mtunzini	-28.9474	31.7079	p-value	0.00	0.00	0.00	0.00	0.00	0.00
			KS-statistic	0.110	0.123	0.123	0.105	0.155	0.123
Riverview	-28.4440	32.1821	p-value	2.61E-10	2.00E-15	3.25E-8	1.25E-10	1.19E-13	3.25E-8
			KS-statistic	0.059	0.073	0.053	0.068	0.068	0.053
Ulundi	-28.3500	31.4000	p-value	0.00	0.00	1	0.00	0.00	1
			KS-statistic	0.087	0.032	0.003	0.032	0.032	0.00

5.4.2. Projected changes in hydrological processes in uThungulu District Municipality

Ensemble of two bias corrected models (GFD and Nor) selected in **Figure 20** from the Tylor diagram was used to force the ACRU model and to simulate streamflow for historical period 1985-2004 and projection period 2070-2089 (RCP8.5). **Figure 34** show the monthly flow distribution for the hydrological calendar for historical and future time-slices respectively in uThungulu District Municipality. Demonstrated in these plots is that uThungulu District Municipality experiences high streamflow discharge in summer particularly from December to April. This is because uThungulu District Municipality is characterized by summer rainfall as demonstrated in chapter 3. When comparing the two graphs it can be seen that the streamflow discharge is likely to increase in summer in future compared to the historical graph, therefore more rain can be expected in the catchment in summer.

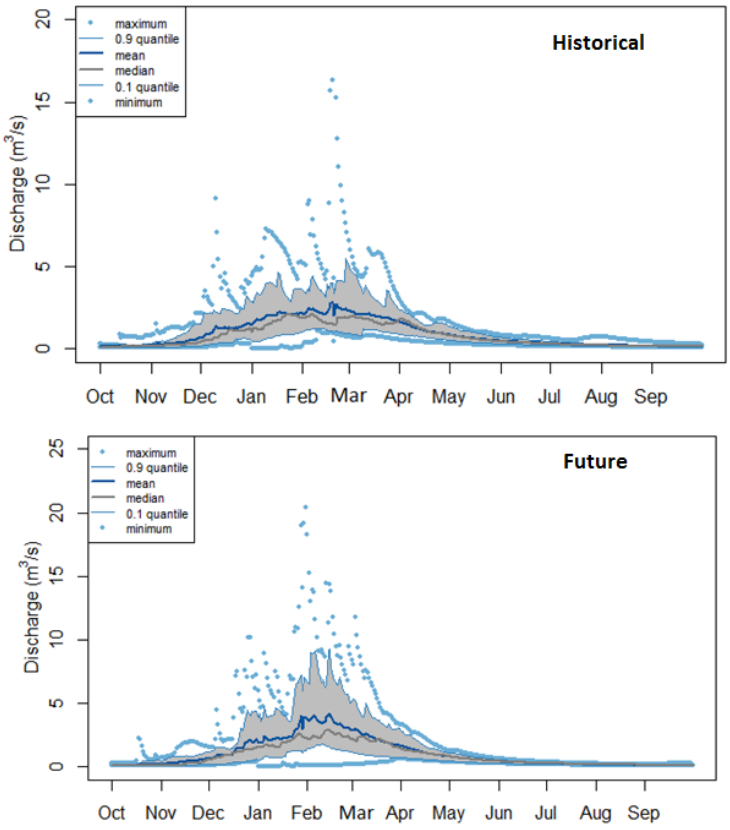


Figure 34: Streamflow Discharge for Historical and Future periods

Figure 35 show results of drought events that occurred in historical and projected period. The graph clearly demonstrates that during the historical time-slice more drought events occurred of a total number of 36 compared projected future droughts, which only shows a total of 24 drought events are projected to occur in future. These results give an indication that uThungulu District Municipality may have less drought events occurrences in future.

Plotted in **Figure 36-38** is a comparison of drought duration, drought severity and drought magnitude in historical and future time periods. It can be seen from **Figure 36** that droughts are likely to be prolonged in future with high values of drought duration compared to historical. Also evident is that droughts are likely to be more severe in future (**Figure 37**). Out of 36 drought occurrences in historical period, only three of those were severe, meanwhile more than five of the events in future were more severe. The measured magnitude of drought is also higher in future compared to historical (**Figure 38**). These results demonstrate that in as much as the drought events may decrease in future, the duration of the drought may increase and the severity and magnitude may also be higher.

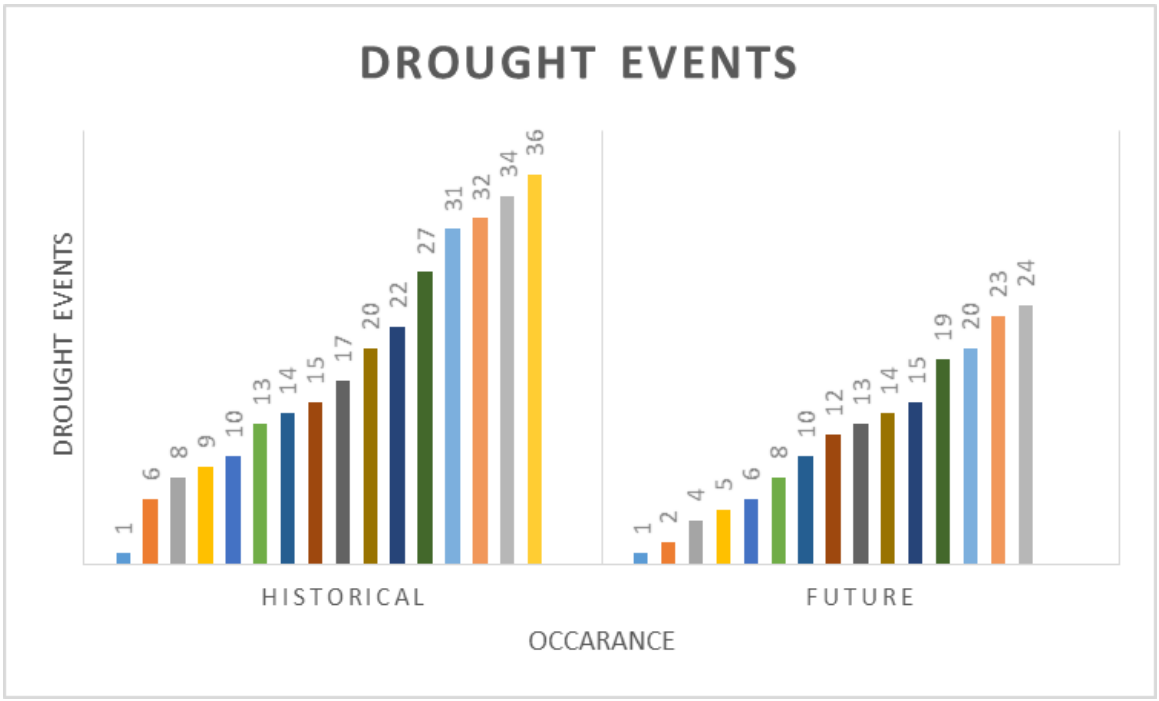


Figure 35: Historical and Future drought events in uThungulu District Municipality

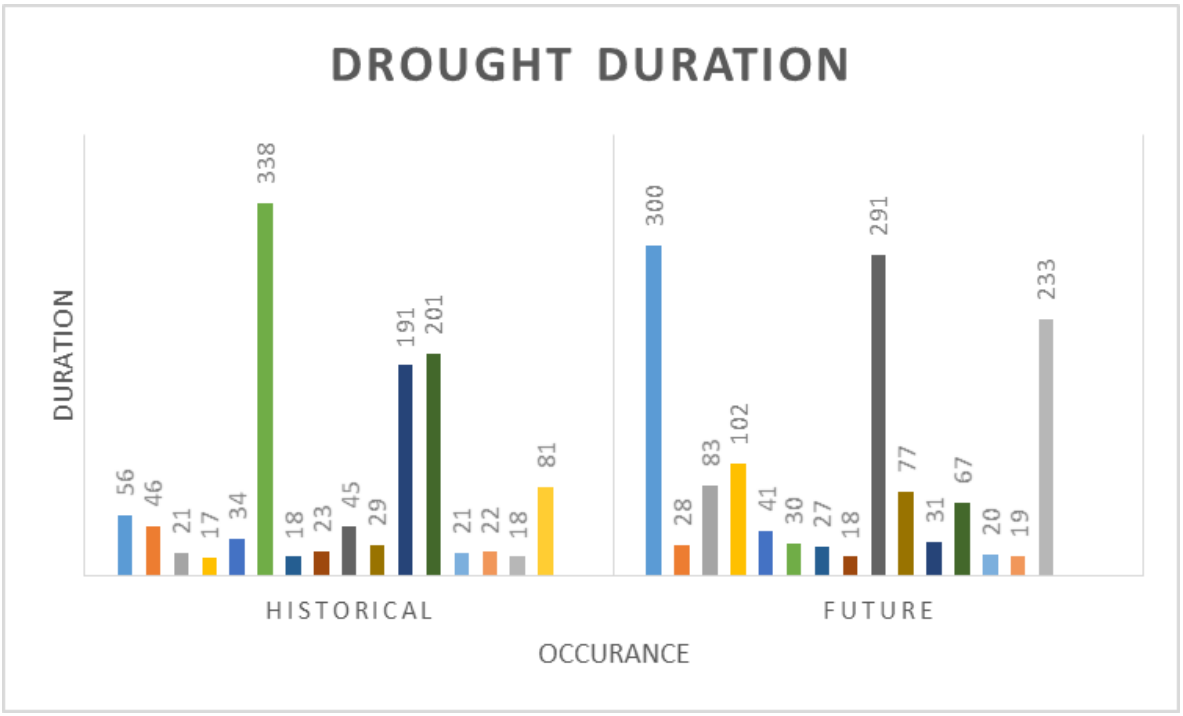


Figure 36: Historical and Future drought duration in uThungulu District Municipality

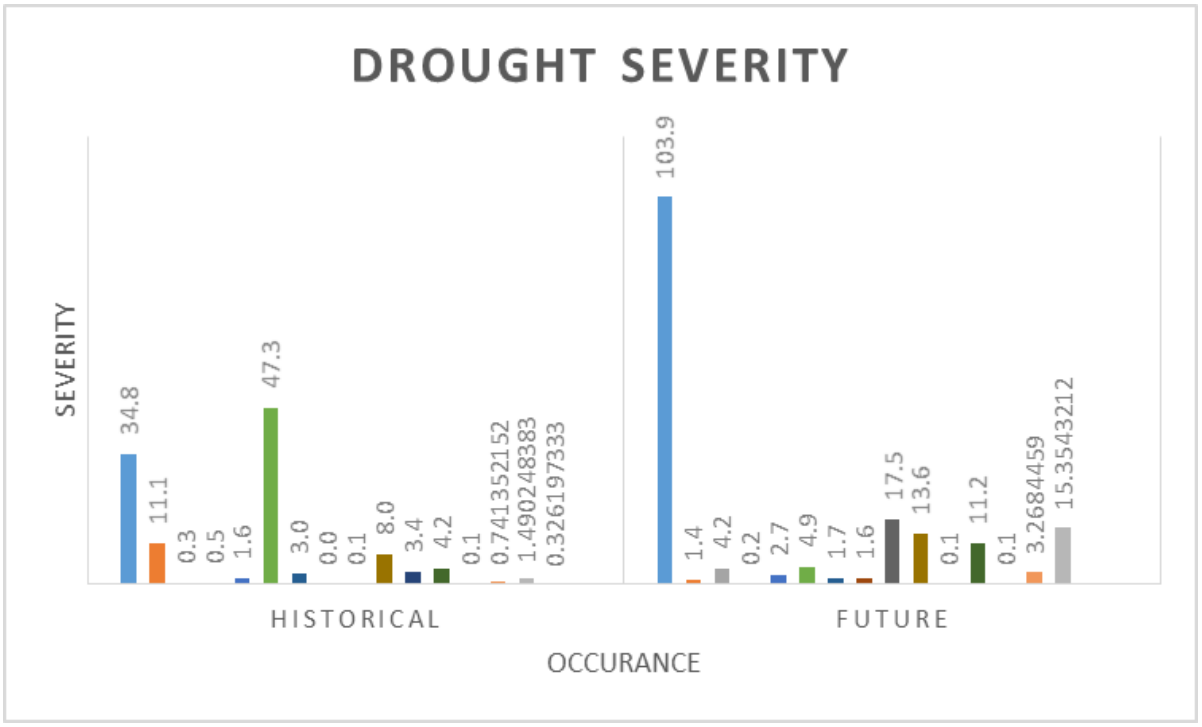


Figure 37: Historical and Future drought severity in uThungulu District Municipality

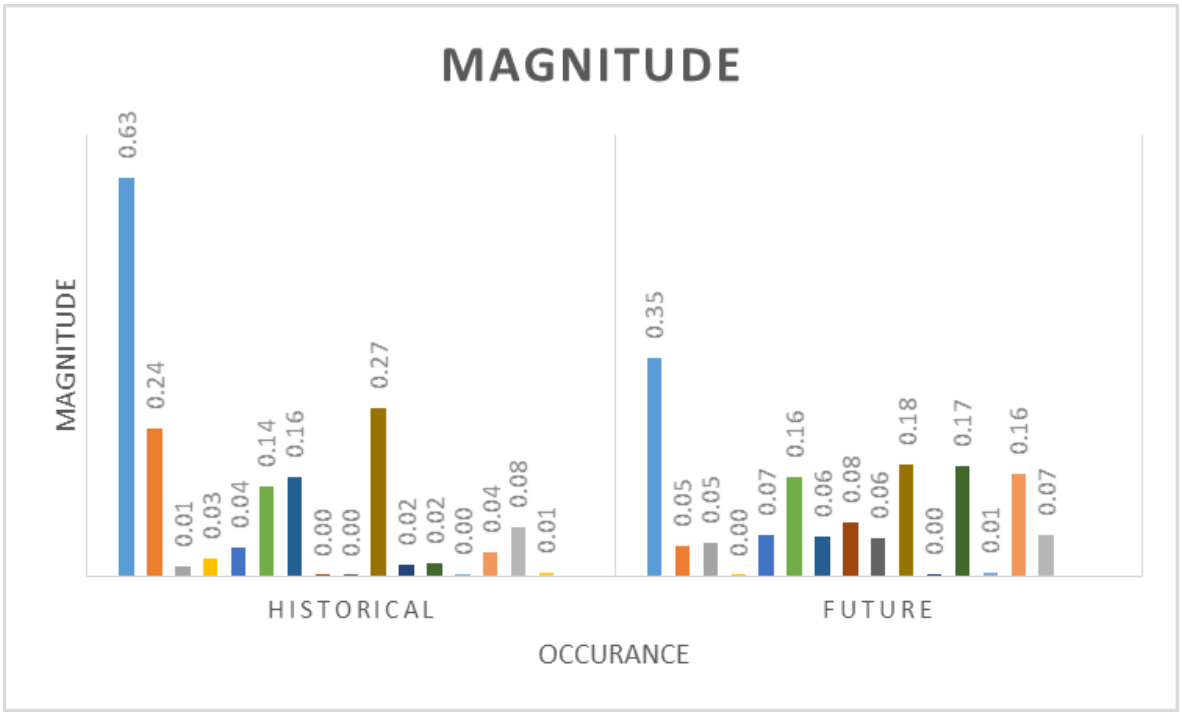


Figure 38: Historical and Future drought magnitude in uThungulu District Municipality

Further results to demonstrate the changes in hydrological processes in uThungulu District Municipality was to investigate elasticity and baseflow statistics between streamflow and rainfall. Shown in **Figure 39** is the baseflow statistics where:-

Mean Q = Mean daily streamflow

MeanBF = Mean daily baseflow

MaxBF = Maximum daily flow

MinBF = Minimum daily flow

BFVol = Baseflow volume

MeanBFI = Mean daily baseflow index

MaxBFI = Maximum daily baseflow index

MinBFI = Minimum daily baseflow index

Baseflow is also known as the drought flow, it is the portion of the streamflow that is sustained between rainfall events. Baseflow plays a significant role in sustaining ecosystems, by providing water when it is needed the most, during dry conditions. Clearly characterized in **Figure 39** is that the baseflow is likely to increase in future in uThungulu District Municipality. This is good news for the agricultural community and small-scale farmers.

Baseflow	Historical	Future
MeanQ	0.906778	1.060236
MeanBF	0.713648	0.818822
MaxBF	2.672476	3.912667
MinBF	0.096331	0.091585
BFVol	0.084279	0.12339
MeanBFI	0.815039	0.816942
MaxBFI	0.989616	0.986452
MinBFI	0.315876	0.259302

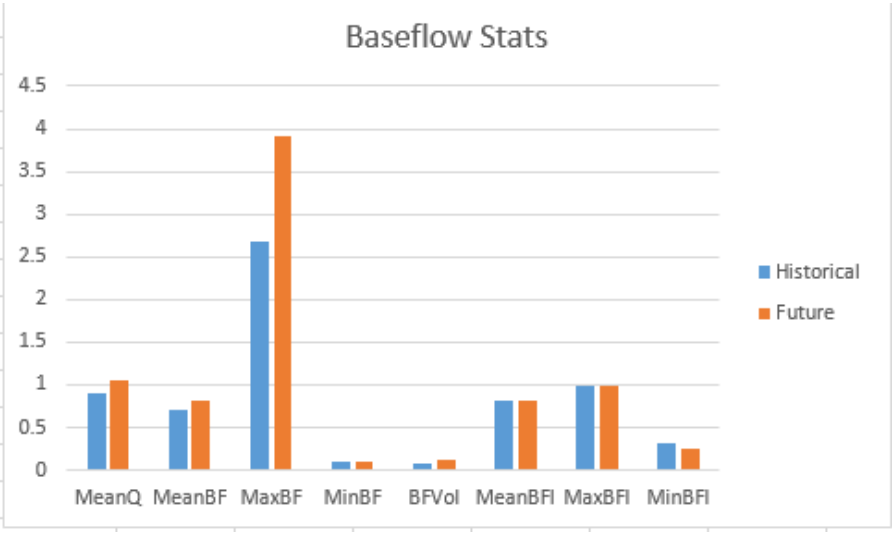


Figure 39: Baseflow statistics

Table 17 show results of streamflow-rainfall relationship and elasticity, the elasticity values were 1.75 and 1.90 for non-hydro years in the historical and future period respectively. This implies that for every 10% change in precipitation the streamflow would change on average 17.5% (Historical) and 19.0% (Future). Similarly for the hydro-years the change in precipitation would result in approximately 9% change in streamflow. The results also show the difference in non-hydro and hydro years in terms of water accumulation. During the non-hydro years also known as the period between January-December, elasticity is over estimated compared to the hydrological year (also known as the continuous 12 month period from October-September). Therefore it is important to consider the hydrological year because it is the period for which hydrological events and variability are evident.

Table 17: Precipitation Elasticity of Streamflow based on Rainfall-Streamflow Relationship

	Historical Elasticity	Future Elasticity	Historical Elasticity %	Future Elasticity %
Non-Hydro years	1.75	1.90	17.5%	19.0%
Hydro years	0.90	0.94	9.0%	9.4%

5.5 Conclusion

This chapter showed the projected changes in hydrological processes in uThungulu District Municipality. It was demonstrated that the area maybe susceptible to a decrease in drought events in future. However, the duration, severity and magnitude may also be higher. On the other hand, the baseflow is projected to increase which is good results for water supply during droughts and it means that the small-scale farmers can be able to use the baseflow as the supplement of water resources. Climate change and variability has been recognized as posing a major threat to the well-being of mankind as its impacts transcend all spheres of society. From the scientific and policy view point, readiness to climate change and variability is often hinged on knowledge about the past climate conditions and using the past to understand the future. It is therefore cultural that scientific community have always used past climatic conditions often recorded (and or observed) to build future climate scenarios. Thus, in this chapter, observations and historical data was used to construct future projections.

CHAPTER SIX: Conclusions, Recommendations and Future work

6.1. Conclusion

This study demonstrated that within the period of 1997-2015, uThungulu District Municipality has been affected by climate change. Temperatures showed a positive warming trend of 0.6°C rate, which is similar to the global temperature change. On the other hand the region has experience drought, clearly indicated by a decreasing trend rate of 1.5887 mm/yr. Through ethnographic analysis together with the analysis of the rainfall anomaly index (RAI) and cumulative departure index (CDI), results showed that the livelihood of small-scale farmers is at risk. Below normal rainfall has been experienced, characterized by late rainfall onset and early rainfall cessation. These changes in rainfall affects the agricultural practices of small-scale farmers and their livelihood. From the responses on the questionnaire, it was also noted that the small-scale farmers' perceptions on climate change and variability mirrors climatic trend analysis conducted using the South African Weather Service meteorological data of the same period. Lastly, projected hydrological processes in uThungulu District Municipality also showed that drought events will be less in future, however the impact of those few events that will occur will be higher as the duration, severity and magnitude will be high. This study has produced results that can be used by policy and decision makers in sectors such as the Department of Agriculture, Department of Water and Sanitation Municipalities and private investors willing to assist small-scale farmers in rural communities.

6.2. Recommendations

The following recommendations were done from this study:

1. For survey analysis, this study recommends that the reliability and validity tests are conducted on the survey responses in order to measure the appropriateness, meaningfulness and usefulness of the research study.
2. The use of a Tylor diagram is recommended in this study for model selection and model evaluation because it shows three model performance statistics simultaneously.
3. The use of GCMs when constructing climate change scenarios requires either statistical or dynamic downscaling to generate finer resolution. Downscaling results in biases on model output. Therefore, this study recommends the use of downscaling based on

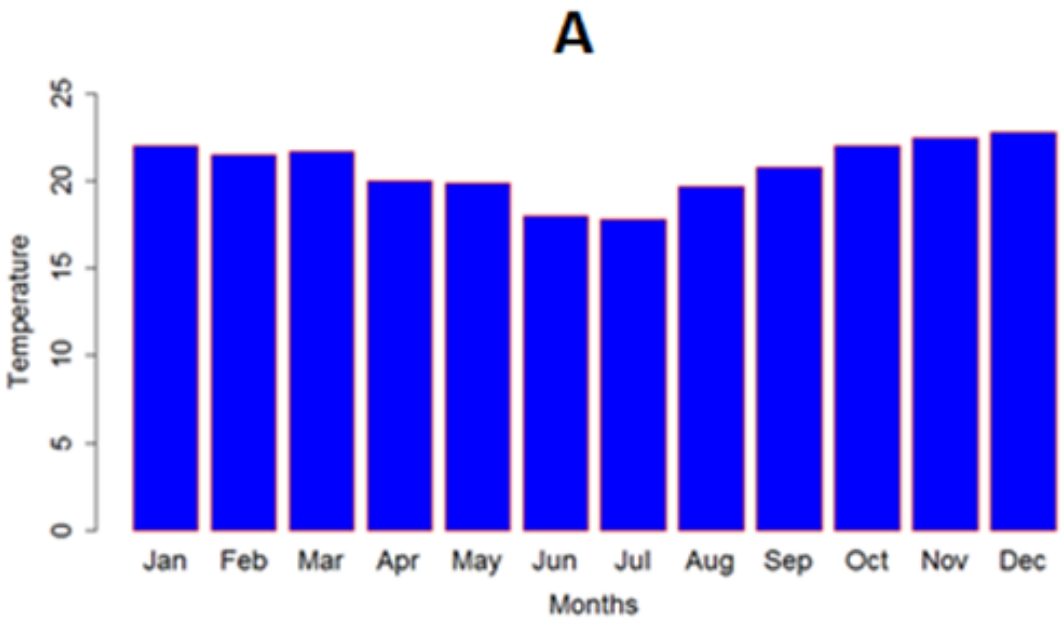
quantile mapping using SSPLINL and QUANT because they produce results of close mean biases between simulation and observations.

4. The results on projected hydrological processes recommends the use of drought early warning systems to assist small-scale farmers on their farming activities and preparation of dry periods.

6.3. Future work

1. Future work will include considering risks associated with extreme weather and climate events and how the impact can be minimized for small-scale farmers' by exploring accessible early warning systems that can be user-friendly to small-scale farmers.
2. The present study showed that there is corroboration between farmers' perceptions and analyzed meteorological data. In future this work will be expanded by assessing and documenting the indigenous knowledge of the farmers related to climate change and strategically provide Tylor-made adaptation measures and coping mechanisms.
3. Lastly, will be to develop a multi-hazard early warning system that will incorporates indigenous knowledge

Appendix A


A
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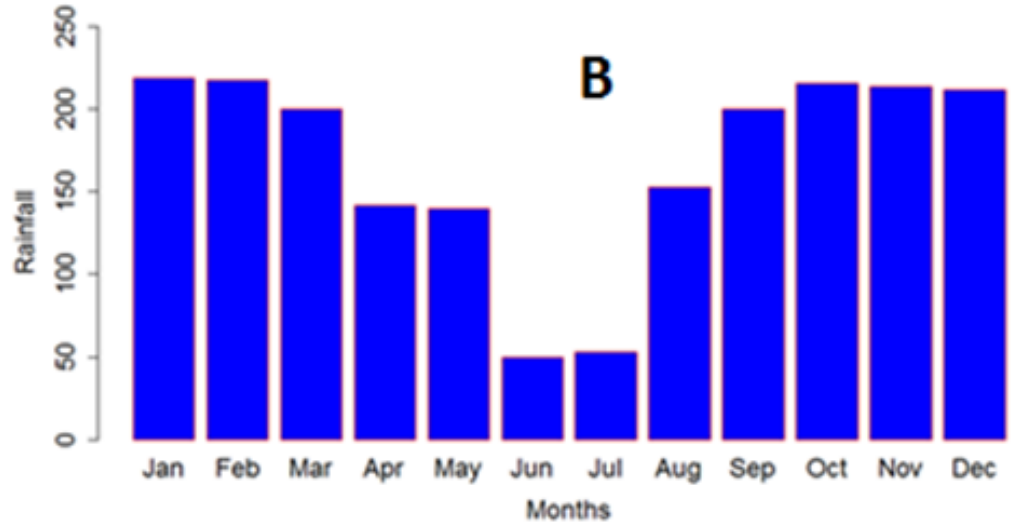
B
Rainfall
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50
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150
200
250
Jan
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Mar
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May
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Dec
Months

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