Vulnerability and Adaptation to Drought Hazards in Mopani District Municipality, South Africa: Towards Disaster Risk Reduction

By

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DECLARATION

I, **Ndamulelo Nembilwi**, hereby declare that the dissertation for Masters Degree in Environmental Sciences at University of Venda submitted by me has not been submitted previously for a degree at this or any other Institution. It is my work in design and execution and all reference materials contained therein have been duly acknowledged.

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Ndamulelo Nembilwi **Date**

DEDICATION

To my parents,

Maanda Thomas Nembilwi

Alilali Rosinah Nembilwi

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ABSTRACT

South Africa was badly affected by the recent 2015/16 severe drought. Water levels in dams declined drastically resulting in decimation of livestock herds and widespread crop failure. Mopani District Municipality is comprised of many agricultural activities that contribute to the economy and social development of the country. The study evaluated the nature of the drought hazard - its impacts, vulnerability and adaptation strategies employed by rural communities of Mopani District. The study used a mixed method approach with both quantitative and qualitative datasets. The district was divided into two distinct climatic areas, the eastern lowveld which includes the Greater-Giyani, Ba-Phalaborwa and Maruleng Local Municipalities and the western highveld which includes Greater- Tzaneen and Greater- Letaba Local Municipalities. Questionnaires were administered among community members whilst key informant interviews were conducted among relevant government and municipal officials. Anomalies in long term climate data were analysed to determine the frequency and intensity of drought in the district. Drought characterisation was done using a Standardised Precipitation and Evapotranspiration Index whilst vegetation anomaly maps, maize yields and dam level data were used to analyse the impacts of drought across the district. Levels of vulnerability to drought were determined using the Household Vulnerability Index. Spatially distinct patterns of drought conditions across the district were remarkable with wet conditions on the western highveld along the escarpment and harsh dry conditions towards the eastern lowveld. It was found that nearly half the time there is some form of drought or another in the district which may be linked to the remote El Nino phenomenon. Community vulnerabilities have a direct impact on human welfare and different strategies are employed to adapt to drought hazards both at community and district levels. The study showed a link between drought hazard extent and vulnerability. Community members are adapting using conservation agriculture, selling fire-wood, accessing boreholes and rearing chickens, amongst other means to survive in these harsh climatic conditions. Local government intervention strategies include supply of seeds and fertilisers, selling fodder at a cheaper price and supplying water using trucks. The findings of this study contribute to disaster risk reduction efforts in Mopani District Municipality.

Key Words: Drought Trends, Vulnerability, Adaptation, Climatic Change, Hazard.

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List of Acronyms

ARC:	Agricultural Research Council
CBAW:	Community Based Asset Weighting System
CMI:	Crop Moisture Index
CRU:	Climate Research Unit
EVI:	Enhanced Vegetation Index
ENSO:	El Nino Southern Oscillation
ETO:	Reference Evapotranspiration
FAO:	Food and Agriculture and Organisation
FANRPAN:	Food, Agriculture and Natural Resource Policy Analysis Network
GPCC:	Global Precipitation Climatology Centre
GDP:	Gross Domestic Product
IFPRI:	International Food Policy Research Institute
IPCC:	Intergovernmental Panel on Climate Change
ITCZ:	Inter Tropical Convergence Zone
KNMI:	Royal Netherlands Meteorological Institute
LP DAAC:	Land Processes Distributed Active Archive Centre
NCAR:	National Centre for Atmospheric Research
NCEP:	National Centres for Environmental Prediction
NDI:	NOAA Drought Index
NDMC:	National Disaster Management Centre
NDVI:	Normalised Difference Vegetation Index
NGO:	Non-Governmental Organisation
NOAA:	National Oceanic and Atmospheric Administration
MDDMC:	Mopani District Disaster Management Centre
MODIS:	Moderate Resolution Imaging Spectroradiometer
PDSI:	Palmer Drought Severity Index
PET:	Potential Evapotranspiration
SADC:	South African Development Community
SAWS:	South African Weather Service
SAVI:	Soil Adjacent Vegetation Index
SPEI:	Standardised Precipitation and Evapotranspiration Index
SPI:	Standardised Precipitation Index
SPSS:	Statistical Package for the Social Sciences
STATSSA:	Statistics South Africa

SWSI:	Surface Water Supply Index
UNISDR:	United Nations International Strategy for Disaster Reduction
VEP:	Vulnerability as Expected Poverty
VER:	Vulnerability as Uninsured Exposure to Risk
VEU:	Vulnerability as Low Expected Utility
WMO:	World Meteorological Organisation
WRSI:	Water Requirement Satisfaction Index

Chapter 1: Introduction and Background

1.1 Introduction

Drought is a normal recurring aspect of climate variability experienced globally (Abraham, 2006). However, according to Koppen Classification, Limpopo Province is classified as mainly semi-arid, making it vulnerable to drought hazards (M'marete, 2003). In a country with an annual average rainfall of 450 mm, which is below the global annual rainfall of 860 mm, any disturbance in rainfall patterns can bring profound impacts on communities' livelihood and environment (Benhin, 2008). Rainfall distribution in Limpopo Province is characterised by high spatial variability (Maponya, 2013). In 1991/92 the region encountered one of worst droughts which affected most smallholder famers' income in negative ways and increased the food import rates (Mpandeli and Maponya, 2013).

The province has been declared drought-prone, thus facing the challenges of drought from time to time (Mpandeli, *et al.*, 2015). The challenges faced in terms of water supply and grazing land production affect the agricultural activities in general, and particularly the smallholder farmers. This is due to high vulnerability and low adaptive capacity (Maponya, 2013). There are profound impacts of drought on crop and livestock production across Limpopo Province. Water supply in mining, irrigation activities and domestic use is also affected (Mpandeli, *et al*., 2015).

Mopani District Municipality is comprised of distinct climatic conditions that vary spatially from the wet western highveld to the drier eastern lowveld. The region was severely affected by the tropical cyclone Dando in 2012, which caused floods that claimed lives and loss in tourism and agriculture industries (Chikoore *et al*, 2015; Fitchett *et al*, 2016). This was followed by a continental low in 2013. The 2015/16 El Nino drought season has become the hottest drought period on record, accounting for significant damage on livelihoods and economic development (Baudoin *et al*, 2017; Richman and Leslie, 2018).

Drought forms part of the natural disasters which are influenced by human activities in the 21st century. As a result, the need to manage disasters has gained attention from different stakeholders globally. The disaster management cycle is a centre of discussion in many natural disaster cases. Crucial to this study is how to prevent hazards from becoming disasters and hence adaptation strategies should play a key role in any disaster-risk reduction effort. The present study focusses on meteorological, hydrological and agricultural droughts.

The intrinsic nature of drought has made understanding, monitoring and adaptation to drought hazards difficult. In addition, identifying drought conditions is more difficult than other natural hazards, as it usually occurs due to many factors which become apparent only after a long-period of no precipitation (Moran-Tejeda *et al.*, 2013). The difficulties are also experienced while determining the drought onset, extent and fate.

The task of characterising natural hazards may be easier when dealing with other natural hazards, such as floods, which are restricted to small regions and well-defined temporal intervals (Wilhite and Svoboda, 2000). Drought affects wide areas over prolonged periods, making it difficult to locate in time and space. As a result, most of the actions taken to mitigate the negative impacts of drought can only be taken during the response and recovery stages of the disaster management cycle. Thus, the effects of drought can only be alleviated once the phenomenon has occurred (Wilhite and Svoboda, 2000).

Adaptation remains the most valued option for research and assessment in responding to harsh climatic conditions. It aims to find the best strategies to reduce the vulnerability and impaired damage from climate change (Kane and Shogren, 2000). Disruption of social cohesion affects the adaption capacity of every society (Adger *et al*., 2003). The use of traditional approaches (indigenous knowledge) remains one of the most successful attempts to conquer climate change threats in many societies (Ribot, 2002). Vulnerability level has a direct impact on adaptation capacity, the more vulnerable societies are less adaptive and vice versa.

Specialists in various fields perceive the need for mitigation and adaption to drought differently. Some emphasize the development of policies to mitigate and adapt to drought hazards; others advocate for effective communication of the mitigation and adaptation information on climate change, yet a few specialists find the development of insurance policy to be the best alternative to adapt to climate change (Panda, 2017). Some studies also highlight the feasibility of using media to publish the climate information, to attenuate the associated risks (e.g. Kasperson, 1996; Crona *et al*., 2016).

1.2 Problem Analysis and Motivation

The increase in the global temperatures is attributed to both anthropogenic and natural sources (Flato *et al*, 2013). The impacts of drought are believed to be more severe in developing countries than the developed countries (Gbetibouo and Hassan, 2005). South Africa is facing a notable change in the climatic conditions that affect numerous socio-economic sectors. Maponya (2013) found that Limpopo Province is among the areas badly affected by drought in the recent past, where dams were only 50% full as compared to the

84% capacity in the late 1980s. This could mean that the intensity of drought incidents has escalated notably.

Several drought hazards have been experienced across the country for many years, with some causing minimal damage, while some cause extreme damage, which even cripples economic development. These negative impacts are also prominent in agricultural production; biodiversity and social welfare. The Mopani District Municipality is not exempted as it has experienced drought events of varying degrees over time. The impacts also vary spatially across the district.

There are ongoing concerns about climate change, projected increases in frequency, intensity and duration of droughts and resulting impacts in food, water and energy. This has also induced concerns about drought preparedness and appropriate drought management policies in most nations (Sivakumar *et al*, 2011). Most studies addressing future adaptation measures are normative and based on forecast of future climate change. These studies document the extent of drought effects on a larger scale, rather than small local scales, such as Mopani District Municipality (Smit and Pilifosova, 2003).

There is a need to integrate approaches in drought management from international and national stages for drought planners and policy makers to make more informed decisions (Abraham, 2006). Mopani District Municipality was listed as one of the areas that were greatly affected by the 2015-2016 drought spell in Limpopo Province (NDMC, 2017). The water levels in dams faced extreme decline, which resulted in the loss of many livestock' and crops (NDMC, 2015). To enhance reduction of the likely adverse impacts, adaptation at all levels is required, especially at local levels such as Mopani District Municipality of the developing world (Vincent and Cull, 2010).

There is no single set of adaptive measures that can be regarded as appropriate globally. Thus, because adaptation differ with respect to the affected systems, who undertakes them, the climatic incidents together with their forms, timing and the associated impacts (Smit and Pilifosova, 2003). In the agricultural sector, adaptation to climate incidents is complex, multidimensional and involves a multi-scale process that takes many forms (Bryan *et al*, 2009). In Mopani District Municipality, there is a need to integrate different strategies employed to adapt to drought hazards both at the community and district levels, to improve the disaster risk reduction efforts.

The outcomes from drought impact and extent assessment can be used to guide a developing strategic framework for mitigation and adaptation to drought hazards that will help reduce the future risk of drought impact. This will also enable the district to estimate the costs aligned with climatic condition hazard in question (Abraham, 2006). The impacts of drought are not the same across different agro-ecological regions of South Africa. This is due to initial spatial variance in climate change conditions (Gbetibouo and Hassan, 2005). As such, it is crucial that conditions of all agro-ecological regions are documented.

Budgeting for drought impacts as part of the response to drought impact has always been a challenge. However, drought hazard area maps can help decision-makers to distribute the funds accordingly. Several studies have revealed the intrinsic nature of drought, coupled with the immense impact it has. However, few studies have investigated these on local and regional scales (Wilhite *et al*, 2007).

There is anecdotal evidence that climate change will account for about 1.5% decline in the Gross Domestic Product (GDP) of South Africa by 2050. Mopani District Municipality is comprised of many agricultural activities that contribute to social development and the GDP of our country (Benhin 2008). This makes farming in this area crucial, and as such the impacts of drought should be mitigated and effective ways must be implemented to adapt to these hazards.

Adaptation remains an important policy response option globally, as such there is a great need to develop and assess the existing adaptation initiatives to better manage climate change (Smit and Pilifosova, 2003). However, policies must be monitored, to ensure that they meet public acceptable standards, are economic viable and environmentally friendly (Tol *et al*. 1996). In recent years, climate change scientists are more focused on developing adaptation measures but the access to resources remains the main challenge to adaptation (Grothmann and Patt, 2005).

1.3 Research Questions

- What are the characteristics of drought hazards in Mopani District Municipality in the recent past, from 1980-2016?
- Have the nature of drought impacts on rural communities changed in Mopani District Municipality?
- Does the household's vulnerability level to drought hazards differ across Mopani District Municipality?
- How are the rural communities adapting to drought hazards in Mopani District Municipality?

1.4 Aim and Objectives
1.4.1 Aim

To establish and map the characteristics of drought hazards, analyse vulnerability levels and adaptation strategies in Mopani District Municipality to contribute towards disaster risk reduction.

1.4.2 Specific Research Objectives

- Determine the frequency, intensity and spatial extent of the drought hazards in Mopani District during the recent past, from 1980-2016.
- Map the impacts and assess vulnerability of historical drought hazards on rural communities in Mopani District Municipality.
- Evaluate the adaptation strategies employed by rural communities in Mopani District Municipality.
- Develop recommendations for disaster risk reduction

1.5 The Study Area

The study was conducted across communities in Mopani District Municipality, Limpopo Province of South Africa. The district is located about 70 km from the capital city Polokwane in the north-eastern part of the Limpopo Province, with total a population of 1 092 507 and 296320 households with unemployment rate of 39.4% (STATSSA, 2012). It is comprised of the five local municipalities: Greater Letaba; Greater-Tzaneen; Greater-Giyani; Ba-Phalaborwa and Maruleng Local Municipality as shown in Figure 1.1. The decision to focus on all five local municipalities was guided by the distinct climatic conditions across the district. It is a subtropical region with warm temperature all year round (Fitchett *et al*, 2016), receiving 500 mm annual rainfall between October and March. The greater portion (81%) of Mopani District Municipality is made up of rural communities under subsistence livelihood, 14% reside in the urban area and about 5% reside in the farms (STATSSA, 2012).

The district is rich in arable land, which allows for extensive farming, from crop to livestock. Horticulture is highly notable in the area, with fruit production that is taken to international markets. The eastern lowveld of Mopani District Municipality forms part of the Kruger National Park conservation hub (Fitchett *et al,* 2016). Agriculture and tourism are the main economic activities in the district, with a tourism sector that is based on nature, it covers game farms, national park and nature reserves (Myer, and De Crom, 2013).

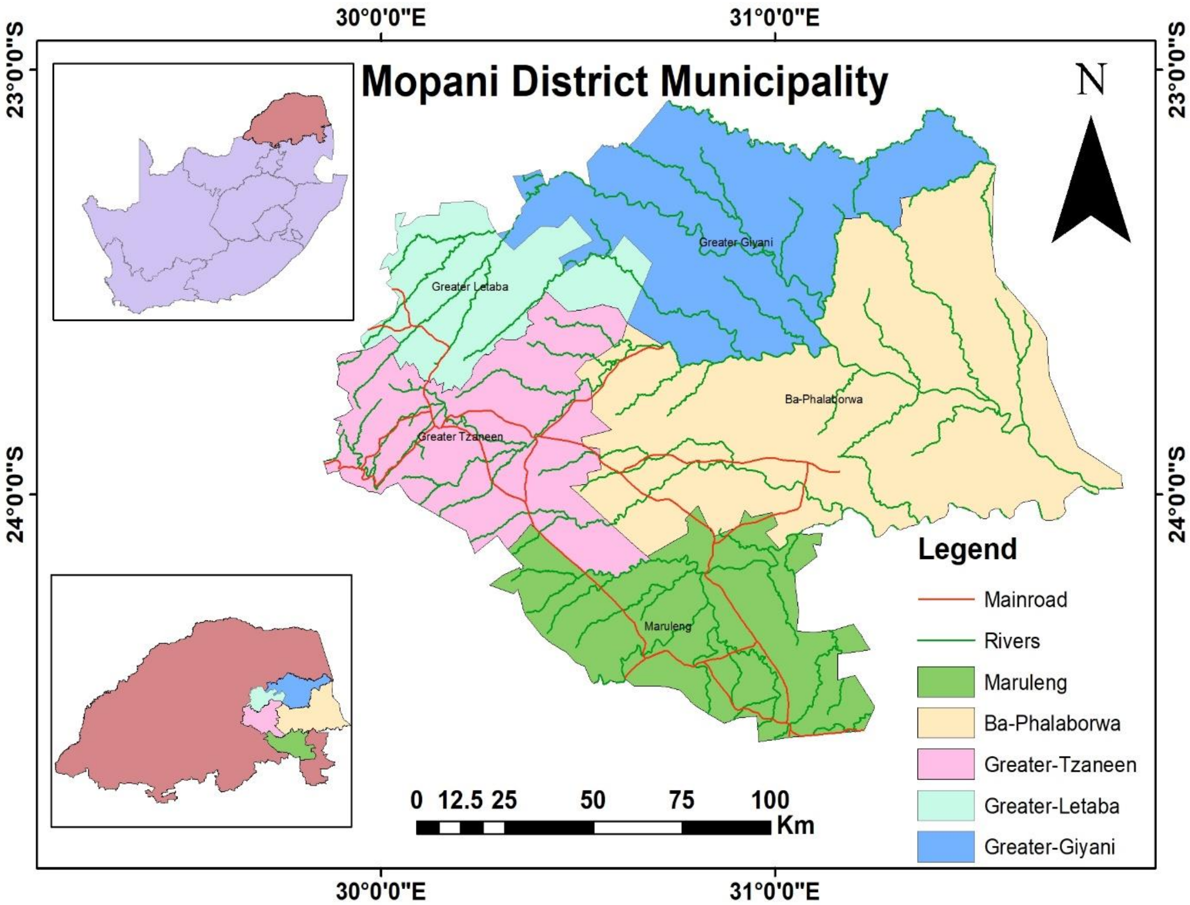

Figure 1. 1 Map showing the location of Mopani District Municipality, Limpopo, South Africa

Mopani District Municipality experience spatially distinct climatic conditions which are influenced by the extensive topographic variation (Figure 1.2) with mountain ranges from as low as 436 m above sea level in the eastern lowveld and above 811 m towards the western highveld region of the district. The soil conditions across the district also varies, with some parts being composed of sandy non-moisture retaining soil. The land uses (Figure 1.3) in the region are influenced by climatic conditions, topography, soil type and accessibility. Mopani District Municipality is classified into residential area, and vegetation (cultivated land, water demanding logging plantation and woodland) which are dominant towards the western highveld and grassland which absorb less water on the eastern lowveld. There are also patches of bare soil and water bodies across the district, some of the major dams in the district include Nsami Dam, Dap Naude Dam, Middle Letaba Dam and Tzaneen Dam.

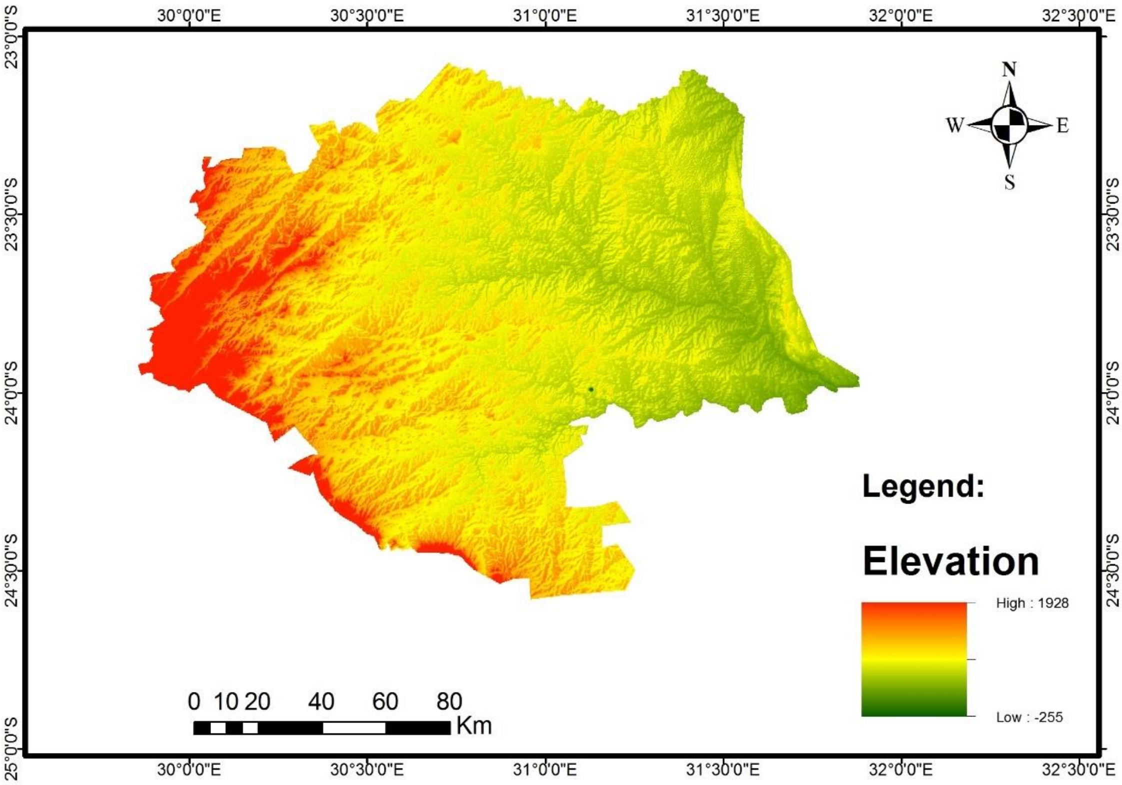

Figure 1. 2 Mopani District Municipality digital elevation

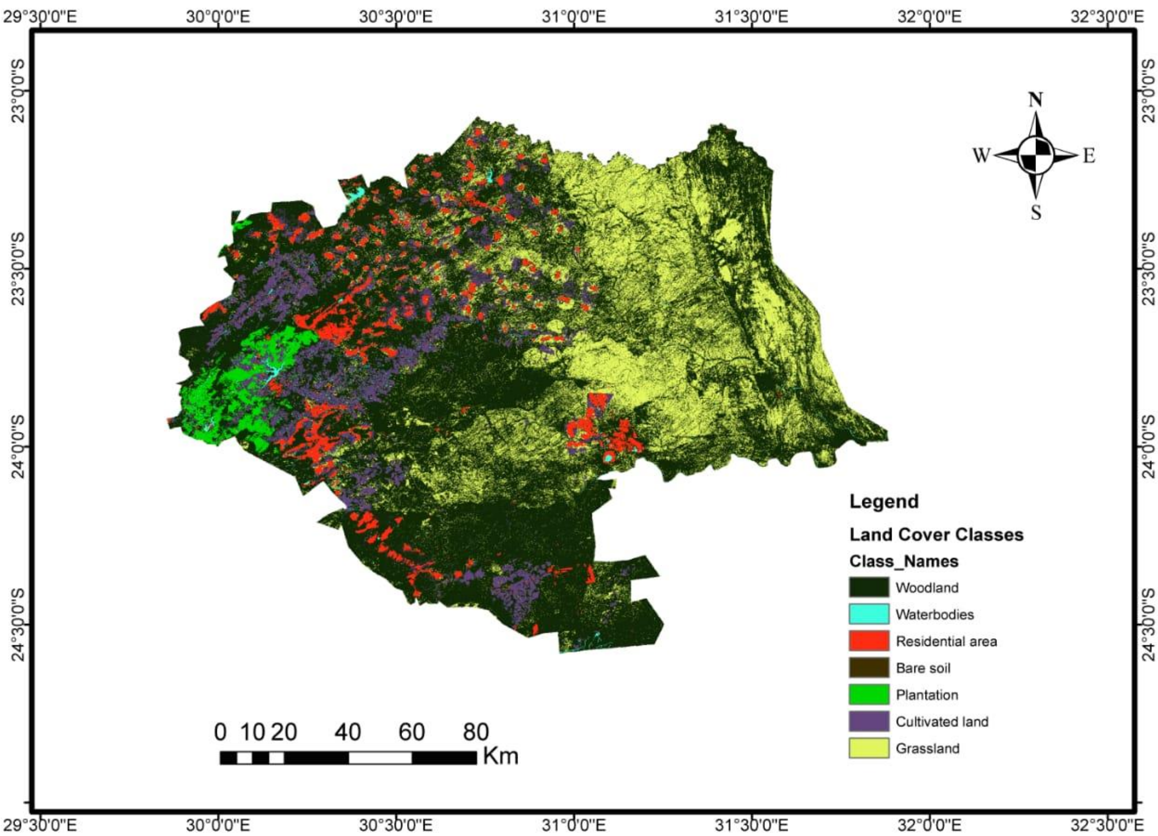

Figure 1. 3 Mopani District Municipality land use classes

Under consideration of the different climatic conditions discovered during the reconnaissance survey, the study was then demarcated into two climatic distinct regions; namely, eastern lowveld and western highveld, as outlined in Table 1.1.

Table 1. 1 Study area demarcations under Mopani District Municipality

Local Municipality	**Demarcation**	**Latitude (S)**	**Longitude (E)**
Greater-Letaba and Greater Tzaneen	Western highveld	-23° 1' 0'' -- -24° 6' 0''	30° 7' 0'' -- 31° 9' 0''
Maruleng, Ba-Phalaborwa and Greater-Giyani	Eastern lowveld	-23° 1' 0'' -- -24° 6' 0''	29° 9' 0'' -- 30° 6' 0''

1.6 Dissertation Structure

Chapter 1 introduced the background to this study, defined some of the key concepts and outlined the purpose. The relationship between vulnerability and adaptation is also explained. The main research questions, aim and objectives are established. The study area selection was also outlined. Global standing in terms of discipline focus in remedying the impacts of drought across the globe were clearly articulated. It was revealed that most researchers are now prioritising adaptation as the best way to deal with climate change. The need to mitigate and adapt to climate change has not only prompted decision-makers in South Africa to implement it as part of policy-making but also in other countries globally. African countries still face great challenge in adapting to drought hazards due to lack of resources. The existing water challenges in most parts of South Africa will be amplified by changing climate.

Chapter 2 details the literature review, with explanations of some of the key terms that guide this study, such as climate change, drought hazards, vulnerability and adaptation. It also outlines drought classification, climate variability and change, the disaster management cycle, and the difference between a disaster and hazard. The concepts, vulnerability and adaptation are reviewed from various scales. The selection of Standardised Precipitation Evapotranspiration Index (SPEI) amongst other many drought indices was justified. And approaches to assess vulnerability were evaluated.

Chapter 3 presents the type of methods used to collect and analyse the data required to attain the objectives of this study. The computation of SPEI using Hargreaves approach is shown in detail. The methods used in the sampling of participants for questionnaires completion among community members are also covered. The five livelihood indicators guiding the Household Vulnerability Index (HVI) are introduced and explained. The setting of household vulnerability variables was outlined in detail.

Results presentation and discussion were split into two chapters; the first one is Chapter 4, which provides details about drought characterisation in Mopani District Municipality. It begins with an outline of general overview of climatic conditions in terms of rainfall and temperature across the district and follows up with a detailed analysis on drought conditions. The drought frequency, intensity and extent are also outlined.

Impacts, household vulnerability to drought hazards and adaptation capacity are detailed in chapter 5. The impact of droughts hazard across the district are shown using the Normalised Vegetation Index (NDVI). The extent of vulnerability per five sustainable livelihood indicators was detailed. The adaptation measures by community members are revealed with the aid of local government authorities.

Chapter 6 concludes the study and makes recommendations. All the chapters end with a summary that outlines the major terms and key findings. However, a detailed account of the findings from this study is presented at the end, together with conclusions and recommendations for disaster reduction indices and future studies.

Chapter 2: Literature Review

2.1 Introduction

Drought is the deficiency of precipitation relative to what is normally received over a season or in the long term (Hayes *et al*, 2011). Drought can also be defined as a period of dry conditions, with rainfall that is below normal average (Cavatassi *et al*., 2011). Recurring drought hazards with varying magnitudes, affect communities in various ways. Vulnerability levels and adaptive capacity remain a question of resource availability in most communities across Africa (Grothmann and Patt, 2005).

Drought is an aspect of climate variability that cannot be totally eradicated from the earth's climate system, its frequency and extent will change under the changing climate. However, communities are bound to find ways to live with these devastating conditions and try to prevent drought hazards from becoming disasters. Drought hazard management must incorporate more information on pre-hazard planning and mitigation, to reduce vulnerability (Mileti, 1999). This chapter reviews the literature from around the globe, downscaling it to Mopani District Municipality on drought hazards characterisation, impacts, vulnerability and adaptation, in line with the objectives of this study.

2.2 Climate Variability and Change

Climate change refers to a change in regional or global climatic conditions which has been underway naturally since the formation of planet Earth. However, human interventions have seemed to speed up the process notably since the inception of industrial revolution (Change, 2013). Climate change is highly induced by the global warming attributed to greenhouse gas emissions from anthropogenic sources (Wang, 2005). The extreme weather events such as drought and floods are becoming more frequent and intense with ongoing climate change (Li *et al*., 2019). The increase in the frequency of drought hazards has triggered many countries across the globe to prioritise adaptation and mitigation to drought hazards and have it listed on their climate change policies (Biesbroek *et al*., 2010).

Climate change is regarded as one of the greatest threats to planet Earth in the 21st century. By the end of the 21st century there is a possible temperature increase by 4-6 °C in the subtropics and 3-5°C probable increase over the tropics (Engelbrecht *et al*., 2015). The heat wave and high fire danger days will also rise. The evapotranspiration rates of water from vegetations, exposed soils and open water bodies such as dams and rivers will escalate resulting in reduced soil moisture for agricultural activities and water for domestic and industrial use.

Rainfall condition in South Africa is unevenly distributed, and the associated crop production also varies. In addition, a study conducted by Kruger and Shongwe (2004) from 26 weather stations across South Africa has revealed that the number of cold days is declining, with an increase in the number of warm days. The humid eastern part receives 1000 mm and the dry western part receives just 100 mm or less annually (Benhin, 2008).

2.3 Drought Classification

With respect to precipitation, temperature and variability of interest, drought is classically characterised as hydrological; meteorological; socio-economic and agricultural as outlined by Van Lanen *et al*., (2018). Meteorological drought occurs when there is a water shortage, resulting from an imbalance between precipitation and evapotranspiration. Hydrological drought becomes intense when the river flow is lower than normal or when water levels in aquifers decrease.

Agricultural drought persists when the soil moisture content is very low to meet the plants minimum growth water requirements (Chen *et al*., 2009). Socio-economic drought is a circumstance where production and consumption of goods are affected by lack of water in human socio-economic and natural systems. All the types of drought begin when there is a precipitation deficit and they are somehow interrelated, as shown in Figure 2.1

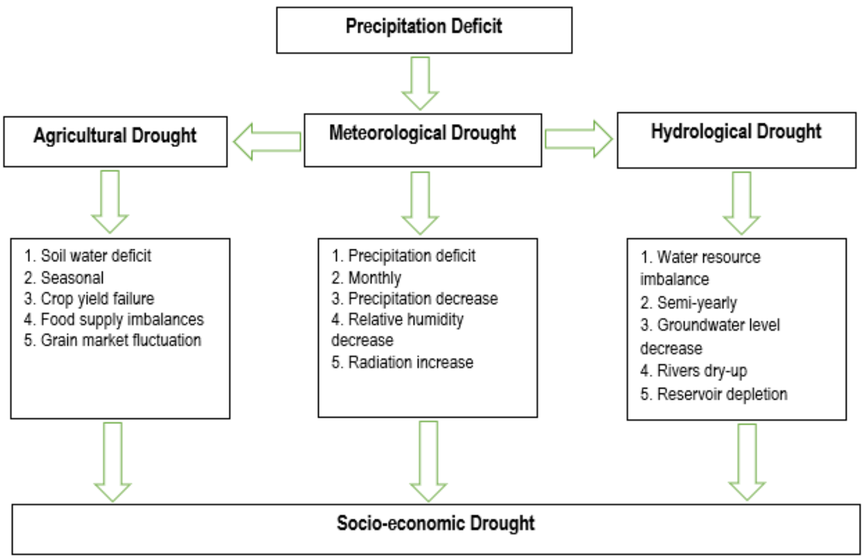

Figure 2. 1 Drought transfer system and interactions (Source; Liu et al., 2015)

2.3.1 Meteorological drought

Meteorological drought results from negative deviation of rainfall from the annual mean. It is mainly expressed through intensity and the duration of the dry period. This has always been a common indicator of drought conditions (Wilhelmi and Wilhite, 2002). Characterising meteorological drought is very simple using the Standardised Precipitation Index (SPI) which has been used in several studies and found to be effective (e.g. Zarch, *et al*., 2015; Chineka, 2016; Liu *et al.,* 2018).

The development of meteorological drought also influences or triggers other forms of droughts, making it much common and frequent than the other three droughts (Wilhite, 2006). This makes its monitoring crucial, as it will help in early warning, before other droughts develop. One of the properties of meteorological drought which is important for drought characterisation is the areal extent (Nalbantis and Tsakiris, 2009).

2.3.2 Hydrological drought

Characterising droughts is based on determining their onset, duration, frequency and areal extent, with respect to hydrological drought, the Palmer Hydrological Drought Index (PHDI) and Surface Water Supply Index (SWSI) in use are computationally intensive and data demanding. This makes characterisation of hydrological drought difficult (Nalbantis and Tsakiris, 2009). Globally, communities are faced with challenges of water availability daily. This is mainly caused by deterioration of water quality, increase in water demand and climate variability and change (Veldkamp *et*. al, 2015). In such cases hydrological drought assessment would play an important role in water management.

Hydrological drought is described as a period of intense decrease in the availability of water in all its forms within the hydrological cycle. The forms of water can be stream flow, groundwater, lake and reservoir. However, stream flow stands out to be the most important variable from the viewpoint of quantity of water expressing surface water resources and it has been used in many studies. The existence of hydrological drought can be depicted easily from the stream flow deficit relative to normal conditions of the flow (Nalbantis and Tsakiris, 2009).

2.3.3 Agricultural drought

Agricultural drought exists after a prolonged period of depleted soil moisture which brings hostile impacts on crops and livestock (Tian, *et al*, 2018). This condition prevails after a season of low rainfall, high evapotranspiration and repeated heat waves (Quiring, 2009). It is mainly concerned about water shortages in crops resulting from a reduction in water supply from precipitation. The increased temperature is responsible for intense transpiration that takes place on plants, affecting their physiological growth and leaving them dry to death (Liu *et al*., 2015).

There are several drought indexes used for agricultural drought monitoring, including the Palmer Drought Severity Index; Crop Moisture Index or Soil Moisture Index; Standardised Precipitation Index and Surface Water Supply Index (Narasimhan and Srinivasan, 2005). Satellite remote sensing is widely used in agriculture drought monitoring as it captures accurate spatial and temporal data on a large scale. This is achieved through the integration of data on soil properties, topography, crop growth, precipitation and land surface temperature (Liu *et al*., 2015).

Although precipitation makes a major contribution to the development of agricultural drought, land surface temperature, soil properties, evapotranspiration and physiological properties of the crop also play a significant role (Liu *et al*., 2015). Agricultural drought incite shortage in agricultural produce which affect many sectors of production (McNally *et al*., 2015).

2.3.4 Socio-economic drought

These are conditions whereby water supply cannot satisfy the demand, leading to societal, economic and environmental impacts (Mehran *et al*., 2015). Socio-economic drought tends to receive less attention, as compared to meteorological, hydrological and agricultural droughts (Arab *et al*, 2010). However, there are expectations that studying socio-economic drought will grow in importance as the population continues to grow in a changing climate. This is due to an increase in population, elevated climate change, agricultural and industrial growth which cause more stress on water supply (Mehran *et al.*, 2015; Loucks, 2015). Assessing socioeconomic drought requires a consideration of all sectors that involve water usage. This means that it should not only be limited to water for human consumption, but also for natural environment and industrial use (Mehran *et al*, 2015).

2.4 Causes of Drought

Drought formation cannot be articulated to a single source. The root cause of drought is reduced or no precipitation for an extended period, with high evapotranspiration rates (Namias, 1991; Tallaksen and van Lanen, 2004). Factors responsible for drought formation can be grouped under sea surface temperature anomalies and atmospheric circulations.

2.4.1 Sea surface temperature

Sea surface temperature changes over the equatorial Pacific Ocean are associated with El Nino Southern Oscillation (ENSO) events. Drought incidents in southern Africa are somewhat linked to these ENSO patterns. During an ENSO period, the region experiences a dry summer and a wet summer during the La Nina events. However, other researche argue that drought incidents over southern Africa cannot only be linked to the ENSO circulations; rather atmospheric circulations over the Indian Ocean and South Atlantic also play a role (Clay *et al*., 2003).

During the 1997/98 El Nino season, the impacts on southern Africa were different, there was not much of rainfall deficit (Manatsa *et al*., 2017). There is growing interest on El Nino Modoki phenomenon which is characterised by flanked cool sea surface temperature in both east and west side of the Pacific Ocean. El Nino Modoki is different from the usual El Nino event in terms of spatio-temporal characteristics and teleconnections patterns (Ashok *et al*., 2007). El Nino occurs at least once in ten years, when there is abnormal heating of the sea surface waters at the central and eastern tropical Pacific Ocean, triggering extreme droughts (Baudion, 2017).

Southern Africa usually experience most extreme drought seasons under mature phase of ENSO when there is warmer than normal sea surface temperatures in the eastern equatorial Pacific Ocean (Rouault and Richard., 2005). The extreme drought experienced over southern Africa in 1981/82 and 1991/92 were linked to the ENSO events (Rouault and Richard, 2003). After the disturbance in the Walker cells, the effects of El Nino cause a displacement of major rain bearing systems towards the Indian Ocean (Lindesay, *et al*, 1998). The anticyclonic circulation becomes dominant. Seasonal rainfall over southern Africa can be predicted using the ENSO phenomena, however there are some uncertainties (Sheffield and Wood, 2008).

2.4.2 Atmospheric circulation

In southern Africa drought events are also articulated to periods of large-scale anticyclones and high persistence of the mid-tropospheric Botswana High, which intensifies during late summer and induce widespread subsidence (Reason, 2016; Chikoore, 2016). Subsidence results from condensational heating of the Botswana High (Lenters and Cook, 1997). The high-pressure dominants suppress convection and inhibit vertical cloud development, which will affect the normal precipitation distribution (Folger and Cody, 2014). Thus, the main rain-bearing system such as the north-west cloud band, is displaced from the subcontinent to locate over the warm Indian Ocean (Mulenga *et al*., 2003).

The Inter-Tropical Convergence Zone (ITCZ) also experiences equatorward displacement, which results in dry summers (Cook *et al*., 2004). If an anticyclone persists for an extended period, it triggers a retreat of the ITCZ from Zambezi valley towards the Congo basin and weaken the Angola low which is important for modulation of moisture convergence over southern Africa (Mulenga, 1998; Chikoore, 2016).

2.5 Impacts of Drought

The United States Federal Emergency Management Agency (1995) described drought as the world's most damaging and depressing natural disaster. Drought events are associated with damages that can account to billions of dollars in global damage, affecting a larger number of communities than other climate related hazards (Wilhite, 2000). Some studies have also shown that impacts of drought are difficult to quantify but they can generally be described as the negative consequences on the environment, society and economy (e.g. Knutson *et al*, 1998; Medellin-Azuara *et al*., 2016; Ziolkowska, 2016; Kala, 2017).

The impacts of drought accumulate slowly over time. This makes drought a slow-onset disaster (Dubrovsky *et al*., 2009). In most cases, the impacts of drought are not considered in discussions about drought monitoring tools. However, understanding drought impacts is crucial for decision-making and effective drought mitigation and preparedness. Determining impacts also provides guidelines on understanding vulnerabilities, which is vital for developing drought-mitigation strategies (Hayes *et al*, 2011).

Extreme climate events such as drought are more unpredictable and abnormal, causing terrestrial ecosystems instability (Liu *et al*., 2015). Most of the studies on drought focus on impacts of climate change on maize crop production only. Drought impacts can be direct or indirect and they are grouped into socio-economic and environmental impacts.

Most countries in southern Africa depend on rain-fed agriculture for socio-economic benefits. However, the deficiency in seasonal or annual precipitation brought by drought may result in food insecurity, economic inflation, power outages and agricultural losses (Boken *et al*., 2005). The local communities and GDP of South Africa has been badly affected by drought. Recurring drought events bring a set-back on development as the country must deal with these immense impacts from time to time (Baudoin, *et al*., 2017). For example, the number of farm labours had to be reduced due to decreased agricultural production in most farms. Community members also had to pay increased prices on maize meal (Agri SA, 2016).

Under normal climatic conditions, South Africa exports approximately 1 million ton of food to Zimbabwe, Lesotho and Botswana. However, the recent shortage of grain during the 2014/15 and 2015/16 drought season has resulted in high import rates of crops, which has affected food security in South Africa and in these neighbouring countries (Baudoin *et al*., 2017). Cape Town and Johannesburg also imposed water restrictions to save water during year 2017 following the impacts of drought on water resources (Agri SA, 2016). Meteorological drought has impacts on groundwater that may persists for months to years (Tallaksen and van Lanen, 2004).

Drought is expected to bring profound disturbances on ecosystem functioning. The biodiversity of many regions is already affected negatively by drought. The affected ecosystems respond to the impacts of drought in various physiological and morphological ways. Ecosystems which do not usually experience drought are much likely to be affected in a negative manner (Loucks, *et al*, 2006). Drought can also promote the deterioration of rangelands into bare soil.

The drought seasons are accompanied by high temperatures which cause stress on human health across the globe, more especially in the urban areas. Human body fails to maintain thermal balance due to high ambient temperatures, that affects body's thermoregulatory system negatively (Kovats, and Hajat, 2008). Those living with compromised health conditions are at high risk. Respiratory infections, cerebrovascular, cardiovascular, fatigue and heat stroke are some of the common physical disorders that may occur due to extended exposure to high temperatures (Kilbourne, 1997; Azongo, *et al*., 2012). Once the ambient air temperature rises above 38°C the body begins to experience fatigue and if it goes beyond 40.6°C, heat stroke is much likely to occur (Baiden, *et al*., 2006).

2.6 Drought Monitoring Indices

Drought monitoring indices have changed over centuries, with new advancements from time to time. Over the centuries the development of different indices has been aimed at remedying the limitations of others and measuring the intensity of drought at different scales (Dubrovsky *et al*., 2009).

Drought indices bring together different hydrological and meteorological parameters, such as rainfall, temperature, soil moisture, evapotranspiration, stream flow and humidity (Narasimhan and Srinivasan, 2005). Through this information, drought onset, spatio-temporal extent, impacts and termination can be determined (Nkemdirim and Weber, 1999). Government departments, private institutions and businesses can use this information to make informed decisions (Quiring and Papakryiakou, 2003). Decision-makers can then plan for drought assistance in due course should there be a need to import food or aid in monetary terms.

There are many drought indices, with each having specific data input requirements and distinct capabilities, depending on the type of drought in question and the climatic region affected. Among the commonly used drought indices is the famous Palmer Drought Severity Index (PDSI), Moisture Anomaly Index (Z-index) (Palmer, 1965), NOAA Drought Index (NDI) (Strommen *et al*., 1980), the Standardised Anomaly Index (Katz and Glantz, 1986), Standardised Precipitation Index (SPI) (McKee, 1993), Water Requirement Satisfactory

Index (WRSI) (FAO, 1986), Crop Moisture Index (CMI) (Palmer, 1968) and Normalised Difference Vegetation Index (NDVI) (Kogan, 1995).

2.6.1 Palmer Drought Severity Index

Over the years, Palmer Drought Severity Index (PDSI) has been widely applied. It considers precipitation, moisture supply, runoff and Evaporation Demand (ET). Despite its success and dominance for such a long period, it has been criticized for its ineffectiveness in some climatic regions (Yu, *et al.*, 2014). It was initially developed to operate in dry sub-humid and semi-arid regions of the United States, as such, it may not produce accurate results in some areas (Palmer, 1965). The PDSI has unspecified, built-in time scale and autoregressive characteristics. The index values can be influenced by conditions of up to four previous years (Guttman, 1998).

When the self-calibrated PDSI was introduced, it was aimed at correcting some of these limitations. The self-calibrated PDSI resolved several deficiencies, thus it strongly influenced the calibration period; spatial comparability limitation and subjectivities in relating drought conditions to the index values (Yu, *et al*., 2014). The values of PDSI range from -10 (very dry) to +10 (very wet).

2.6.2 Crop Moisture Index

The Crop Moisture Index (CMI) was developed also by Palmer (1968) as a complement to PDSI. CMI measures the degree to which the moisture requirements of the plants are met, focusing on the short-term moisture changes. The input data is the total precipitation, mean temperature and CMI of the previous week calculated on a weekly time scale. Moisture content can vary drastically from week to week, but the current state of the agricultural drought in that area can be established using the CMI (Patel, *et al*., 2012).

2.6.3 Water Requirement Satisfaction Index

The Water Requirement Satisfaction Index (WRSI) was developed by the Food and Agriculture Organisation (FAO) in 1979. It is used to establish the relationship between the available soil moisture and crop's moisture demand using station data. However, with continued improvements, the WRSI can also make use of the remotely sensed data in regions that are data sparse. It requires less data and it is easy to operate. The required data is the evapotranspiration, crop coefficients (Kc), precipitation and soil water holding capacity (Senay and Verdin, 2003).

Determining soil moisture can help in forecasting and early warning of natural disasters, such as drought, fire and floods (McNally *et al*., 2015). It can also be used to understand the reduction in crop production and water use efficiency (Jayasree *et al*., 2008). The demand by the crops is to meet the physiological growth needs, and it varies with according to the crop. The WRSI is measured from the first ploughing date of the season to the current day, and it has been used across the world to monitor agricultural drought and in crop production forecasting (Senay *et al*, 2012; Jayasree *et al*., 2008).

2.6.4 Standardised Precipitation Index

The Standardised Precipitation Index (SPI) was developed to quantify the precipitation deficit for multiple time scales (McKee *et al*., 1993). It also gained wide acceptance due to its multi-scale characteristic and simplicity to calculate. It requires little data, with only precipitation as the input data providing a handy and quick approach to drought analysis (Umran Komuscu, 1999).

The introduction of SPI was aimed at correcting some of the uncertainties offered by self-calibrated PDSI. However, in turn it lost popularity as it neglects some of the crucial aspects of drought; namely: temperature, soil moisture and evapotranspiration. Nonetheless, with SPI drought intensity, magnitude and duration can be identified (Heim, 2002). An added advantage is that SPI can operate in different climatic regions, with values ranging from -3 very dry to +3 very wet (Rouault and Richard, 2005). This study employs the Standardised Precipitation and Evapotranspiration Index (SPEI), which is described in detail in Chapter 3.

2.7 Vulnerability to Drought in South Africa

Vulnerability refers to a population's characteristics that affect their level of exposure and capacity to anticipate or recover from a hazard or a disaster (Blaikie *et al*., 2014). It is a way of conceptualising what may happen to a community under prevailing living conditions, should any risk, hazard or disaster occur (Cannon *et al*., 2003). The vulnerability of ecosystems, food security and sustainable development to drought depends on exposure and the ability of the impacted system to adapt (Smit and Pilifosova, 2003).

The capacity to adapt always differ notably among regions, countries and socio-economic groups. Regions which are more vulnerable are those with less adaptive capacity and those which are highly exposed. Poor information and skills, poor infrastructure, unstable or weak institutions, limited economic resources and low level of technology, remain the reasons behind low adaptive capacity and high exposure in most countries (Smit and Pilifosova, 2003).

The impacts of climate change continue to be felt globally, more especially in Africa. In Sub-Saharan Africa temperatures are expected to be greater than the global rates, with a decline in rainfall received annually (Intergovernmental Panel for Climate Change (IPCC), 2009). A United Nations International Strategy for Disaster Reduction (UNISDR) report (2004) states that most of the adverse impacts of climate change in Africa are caused by political instability, poverty and the incompetency of the responsible institutions. As such, it is important to have continuous research to mitigate these impacts. The vulnerability of communities increases as the pressure on water and other natural resources escalate. The scientific community is faced with challenges of finding more timely and comprehensive assessments of the impacts due to increased vulnerability to drought (Wilhite *et al*., 2007). Government could also contribute through outreach programs that teach communities how to best utilize the limited resources to survive during drought conditions.

2.8 The Concept of Drought Adaptation in southern Africa

Adaptation to climate change is the process through which communities reduce the adverse impacts of climate change on human welfare to take advantage of the opportunities that their climatic environment offers (Burton, *et al*., 1978). It requires adjustments in ecological, socio-economic systems responding to the prevailing or up-coming climatic stimuli. It calls for change in practice, processes and structures, to reduce the possible impacts and effects (Smit and Pilifosova, 2003).

For centuries, nations, communities and individuals have been faced with a natural demand to find ways to adapt and mitigate the impacts of climate change and variability (Tyson, *et al*., 2002). The probabilities of adapting to climate change and its variability are highly linked to vulnerability and ability to withstand livelihood stress (Few, 2003). There are many factors that determine the high vulnerability levels of developing countries. These include high reliance on natural resources, low adaptive capacity, low per capita GDP and limited capacity to adapt financially and institutionally (Desanker and Magadza, 2001).

Most farmers in southern Africa are becoming more vigilant about the area becoming drier and a notable change in rainfall timing and drought frequency (Nhemachena and Hassan, 2007). This is most prominent in African countries where there is a high decline in agriculture revenues, with an increase in temperature (Kurukulasuriya *et al*., 2006). Most countries in Africa are faced with an increased risk of hunger due to a decrease in production prompted by climate change (Parry, *et al*., 1999).

Research, observation and climate modelling programs in South Africa are probably the most advanced on the African continent (Ziervogel *et al.*, 2014). Despite all efforts from various institutions to combat climate change impacts, science evidence has revealed that South Africa will continue to warm at a rate that is probably beyond the estimated 1.5°C per decade, as observed in the 21st century (Engelbrecht *et al.*, 2015).

Most agricultural activities in South Africa and across the African continent will be negatively affected by this alarming climate change, as they rely on rain-fed agriculture. Considering that agriculture production is the main source of income and livelihoods for households in most African rural communities, it is important to prioritise adaptation to climate change in the agricultural sector (Bryan, *et al*., 2009).

The adaptive capacity depends on the vulnerability of the affected region (Few, 2003). The elevated level of vulnerability in most African countries and low adaptive capacity are linked to poverty and high reliance on natural resources (Meilink *et al.*, 2000). However, over time, most societies in Sub-tropical Africa continues to deal with climate change events such as drought in a progressive manner (Washington *et al*., 2005).

When a country reaches a stage where it can enhance its adaptive capacity, vulnerability is reduced, promoting sustainable development. The success of possible adaptation strategies highly depends on the flexibility of the strategies and the potential of the proposed strategies to alleviate the cost of disaster, either physically or financially (Smith and Lenhart, 1996).

Many countries around the world are also trying to introduce national drought mitigation strategies. However, it is important for the developed drought monitoring system to be comprehensive in the ability to provide improved early warnings about the drought onset. It should also be capable to determine drought severity and its spatial extent. This information will then be given to decision-makers and help reduce or avoid the impacts of drought (Hayes *et al*., 2011). In the process of improving the early warning systems, it is important that nations document the cost of these investments in terms of economic, social and environmental losses. This should be done with the plan to justify future investments in drought mitigation and adaptation (Wilhite *et al*., 2007). Advancement in early warning system help reduce community vulnerability and enhance adaptation.

2.9 Measuring Vulnerability

Vulnerability can be measured through numerous approaches. However, indicator approach, economic approach and Household Vulnerability Index (HVI) are the common approaches used to measure vulnerability (Nkondze, *et al*., 2013). The indicator approach was developed on the basis of a range of indicators, selected through expert judgement and linking with previous disaster events. While executing these selections, indicators accounting for the highest portion of vulnerability are selected. After the selection process, the selected indicators can be applied in local, national or global scales (IFPRI, 2009).

Indicator approaches make it possible to monitor trends and explore the conceptual frameworks. However, it is subjective in nature when selecting supporting indicators and their relative weights, and this has limited its use. This was also due to accessibility of data at various scales and the difficulty to legitimize the different metrics used (Luers, 2005).

On the other hand, the econometric approach makes use of socio-economic surveys to analyse the level of vulnerability. The econometric approach considers shocks such as health conditions, economic, climatic, and legal shocks (Hoddinott and Quisumbing, 2003). Assessment is done through Vulnerability as Expected Poverty (VEP); Vulnerability as Low Expected Utility (VEU) and Vulnerability as Uninsured Exposure to Risk (VER). All three assessments measure the welfare lost due to external and internal shocks (Hoddinott and Quisumbing, 2010). They only differ in terms of the timing of shocks under consideration, with VEP and VEU being based on the measurement of forecasted probability of household ability to thrive under persisting or previous shocks and VER being based on actual results other than forecasts. Thus, the assessment of thriving after the shock has occurred (Nkondze, *et al*., 2013).

The HVI was developed by the Food, Agriculture and Natural Resources Analysis Network (FANRPAN) to measure household vulnerability. This approach was selected to measure vulnerability in this study, and it is discussed in detail in chapter 3.

2.10 Natural Hazards and Disasters

In this context a hazard is an extreme event that occurs naturally and causes harm to humans, threatening life, health and the environment. Hazardous events differ in intensity, frequency, speed of onset and spatial dispersion. Natural hazards can be climatological, hydrological or geologic (NDMC, 2015). A disaster occurs on a bigger scale; thus, an extended period of hazard with immense impacts results in a disaster. A disaster refers to the actual occurrence of a threat, depending on preparedness and vulnerability. There is a clear distinction between the risk of a hazard and the reality of a disaster (Cioccio and Michael, 2007).

A disaster is a higher disruption of the functioning of a society which causes human or environmental losses, exceeding the ability of the affected society to cope. Understanding the impacts dynamics of a risk and analysis of a personal vulnerability to any hazard makes it possible to manage the complex variables and probabilities that might form part of the disaster. Thus, it enables one to limit and avoid some of the likely impacts of any disaster (Chapman, 1994).

An IPCC (2007) report revealed that disaster risk entails the likelihood over a specified period of immense changes on the casual functioning of a society. This is due to the hazardous physical events interacting with vulnerable social conditions. It may lead to immense environmental, human, economic and property damage that may require external support for subsequent recovery.

2.11 Disaster Management Cycle

A disaster management cycle involves complex continuous processes that begin before the disaster and continue after the disaster has occurred with the aim to avoid or reduce the impacts of natural hazards such as drought (Poser and Dransch, 2010). It is a non-linear cycle of planning mitigation response and recovery (Petersen *et al*., 2017). Disaster mitigation entails all the measures that can be done to minimise the adverse impacts of a disaster. This can be done structurally or in non-structural means. Mitigation measures can be applied either to affected communities or to the threat. A fire break that stops further spread of fire is a structural mitigation measure, whereas communication of information about an upcoming disaster is a non-structural mitigation measure. Figure 2.2 shows the stages employed in a disaster management cycle.

Figure 2. 2 Disaster Management Cycle (Poser and Dransch, 2010).

One key aspect of the disaster management cycle is preparedness, wherein populations take precautionary measures for an upcoming disastrous event. The level of preparedness determines the extent of impaired impacts. Being prepared for a disaster helps reduce risk through advanced measures that ensure effective response. Preparations can involve temporary evacuation of populations from the area in danger and reservation of food or water in huge storage areas for use during the disaster (Paton, 2003).

Through preparedness all the stakeholders involved in disaster risk reduction can organise and provide relief strategies to impacts of an upcoming or occurring disaster. When structuring a preparedness plan, it is always important to consider the seasonal threats, such as heavy rainfall, severe winds and veld fires. Plans on how the information about the emergency will be distributed to communities of varied sizes and in areas of varying accessibility must also be in place (Allan, 2006).

After the occurrence of a disaster, communities and disaster management authorities are expected to respond. The response can either be positive or negative. In responding to a disaster, the assistance offered focuses most on the basic needs. Responses to drought can either be reactive or proactive (Smithers and Smit, 1997). Depending on economic capacity, the response can be immediate or after some time, following the response there is always a need to recover. Adaptive response is classified according to timing with respect to the climatic stress, duration, form of response and effect on the affected population (Smit and Skinner, 2002).

Disaster recovery entails reconstruction of the damaged infrastructure and rehabilitation of the altered areas. The decisions taken at this stage aim to restore the livelihoods, services and the natural environment. If all the anticipated measures are effectively applied, the likelihood of the disaster in future is reduced. This will be due to increased resistance which will prevent the hazards from becoming disasters (NDMC, 2015). A better understanding of the stages entailed in disaster management cycle would help reduce vulnerability and induce adaptation.

2.12 Conceptual Framework

The conceptual framework (Figure 2.3) shows the key concepts that guide this study and how they interact. Drought hazard covers the potential of the hazard in question becoming a disaster. This is the potential or probability of drought event to cause loss of life and property, deterioration of livelihoods, service provision and environmental resources. Drought hazard is a dangerous event that poses a threat to coping, depending on vulnerability and adaptive capacity (Twigg, 2015).

Vulnerability shows the extent of susceptibility of a society to a hazard. It varies with respect to exposure and coping abilities. Coping abilities encompass mitigation and adaptation (Downing and Bakker, 2000). Societal vulnerability depends on several factors, such as economy, technology and infrastructure development. The nature of society and environment are the supreme determinants.

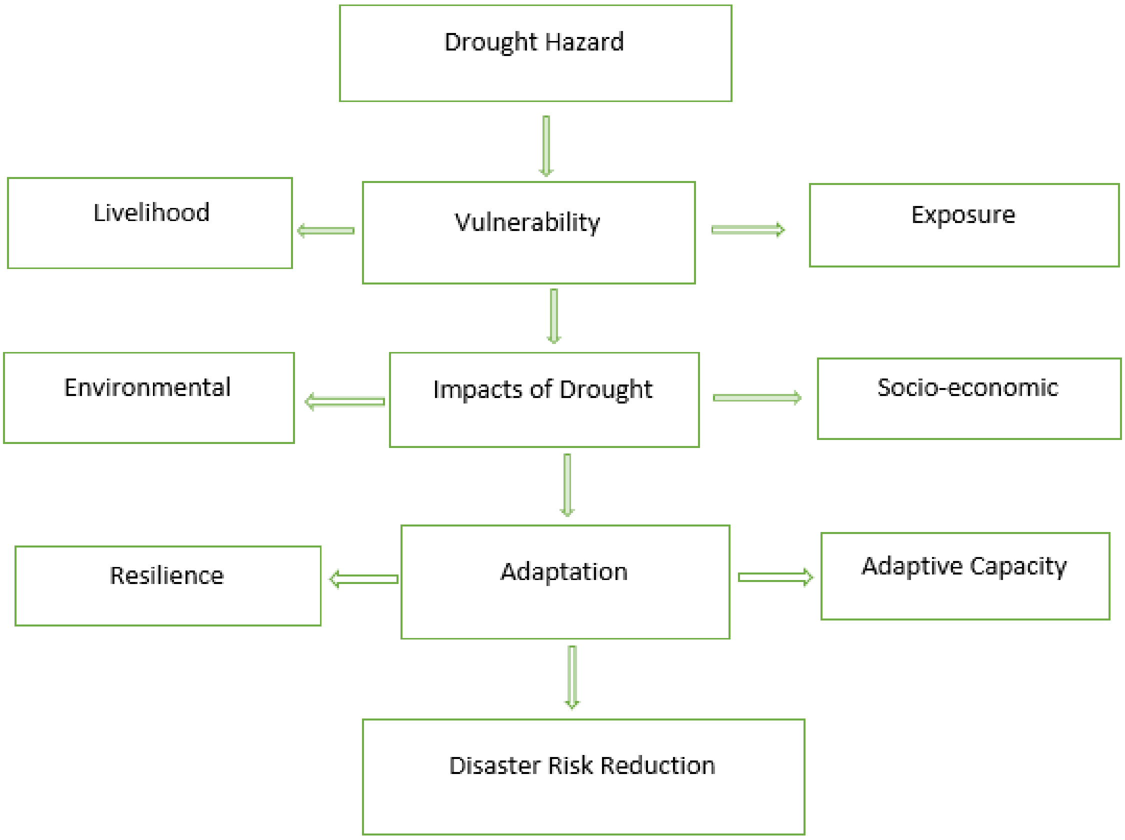

Figure 2. 3 Conceptual Framework

The extent of vulnerability changes over time within a society, with new developments in policies, technology, societal behaviours and change in the nature of the incident hazard (Wihite, 2000). The most vulnerable groups are those that face difficulties in recovering their livelihoods after the occurrence of a disaster. Furthermore, if any subsequent hazardous event occurs, they are most likely to be adversely affected (Blaikie *et al*., 2014).

Adaptation has four main components: stress characteristics; system characteristics (cultural, economic, political, institutional and biophysical environment); multiple scale and adaptive responses (Bryan *et al*., 2000). There are uncertainties as to whether the best move is to prioritise short-term adaptation or long-term adaptation in terms of farming. Adaptation involves a continuous stream of activities and actions that inform decisions about all aspects of life and reflect social norms and processes (Bryan *et al*., 2000).

The adaptive capacity entails a combination of strength, attributes and available resources for individuals, community and society that can be used to reduce or moderate the adverse impacts of a hazard. The extent of exposure remains the main contributor in adaptive capacity. The term exposure covers environmental services, economic development, livelihoods and infrastructure that can potentially be affected. It accounts for all the aspects that are at risk within a system (Twigg, 2015). Coping with drought occurs when a population reach a stage where they can effectively deal with the challenges brought by drought conditions.

The concept of disaster risk reduction involves many stakeholders. In general, it covers the efforts to reduce the disaster risk which can be systematic to analyse and manage the casual factors of disasters (Wannous and Velasquez, 2017). These efforts can lead to a reduction in exposure to the hazards, reduced vulnerability, advancement in land and environmental management and improvement in the preparedness efforts. Disaster risk reduction efforts account from policy goals and objectives, together with the strategic and instrumental measures to improve resilience (IPCC, 2007).

2.13 Summary

This chapter covered some of the comprehensive literature from numerous studies on the concept of drought characterisation, impacts, vulnerability and adaptation. The conditions of climate change and variability across the globe were articulated. The interlinked stages of disaster management cycle were also explored. In addition, drought hazard types, causes and likely impacts were revealed. It was also revealed that there are number of drought indices which can be used to characterise drought. SPEI was selected as the most suitable drought index for this study. The different approaches for measuring household vulnerability were also explained and HVI was found suitable to use in this study.

Chapter 3: Research Methodology

3.1 Introduction

Research methodology aims to outline all the logical steps followed in data collection and analysis in answering the research questions. It is a systematic and scientific way of resolving the research problems (Dawson, 2002). This chapter presents the methods used to collect the data to meet the objectives set out in Chapter 1. The methods used in data collection were both primary and secondary. The research design, sampling routes and methods of analysis are also discussed and justified.

3.2 Research Design

The study used the mixed methods approach. Morse and Niehaus (2009), define the mixed method approach as a process where one or more approaches are used to supplement the other method to collect the intended data. Over the years this approach has been used in a number of studies (e.g. Morse, 1991; Creswell and Tashakkori, 2007; Tashakkori and Creswell, 2007; Bergman, 2008; Andrew and Halcomb, 2009). Incorporation of methods should include at least one quantitative and one qualitative method. This is done to attain information that cannot be retrieved with the use of just one approach (Kumar, 2019).

The process of deciding whether to use qualitative or quantitative or both approaches should be guided by the research questions and intended outcomes, and not by the researcher's personal preferences (Marshall, 1996). The "How much?" or "How many?" questions are better answered by quantitative approach while the "How?", "What?" or "Why?" questions are better covered through qualitative approach (McCusker and Gunaydin, 2015).

Both qualitative and quantitative methods were integrated into a single study, generating a more comprehensive understanding of the phenomenon under study and expanding the scope of the research (Watkins and Gioia, 2015). This enables a robust engagement with various stakeholders, to gather more extensive data, increasing the validity and reliability of the collected data (Babbie and Mouton, 2001; Brekke, 2012).

Qualitative research is flexible and open-ended, allowing addition of new knowledge (Munyai, 2015). The use of qualitative approach is usually aimed at revealing an in-depth understanding of the matter under discussion while the use of quantitative approach aims at achieving generalised understanding of the matter (Marshall, 1996). Under this notion, qualitative approaches emphasize saturation, aimed at sampling until no new substantive information is acquired and quantitative approaches ensure that the gathered information is a true representation of the sampled population (Palinkas, *et al.*, 2015).

Quantitative methods are designed to capture numbers whereas qualitative methods record words (Creswell and Tashakkori, 2007; McCusker and Gunaydin, 2015). This gives qualitative approach an advantage for capturing the essential subjective nature of social interactions (Silverman, 2006). The qualitative approach aims to get better understanding about the phenomenon of interest based on respondents', personal experience and attitude (McCusker and Gunaydin, 2015). One of the links between the them is that they are both concerned with people's actions and views (Brannen, 2005).

3.3 Methods of Data Collection

The data collection process serves as a crucial aspect of research project, as the collected data contributes to better understanding of the theoretical framework (Bernard, 2002). There is no form of analysis that can make up for improperly collected data; a sound judgement then becomes crucial when deciding on the manner of gathering data and sources of data (Tongco, 2007). Depending on the intended output, different data collection methods were employed in this study, including primary and secondary data collection methods.

Primary data was gathered using household questionnaires and key informant interviews, while secondary data such as water dam level data was obtained from the Department of Water and Sanitation in Tzaneen Local Municipality. Maize yield data was obtained from the Department of Agriculture, Forestry and Fisheries and vegetation data from the Moderate Resolution Imaging Spectroradiometer (MODIS). The Royal Netherlands Meteorological Institute (KNMI) Climate Explorer Tool was used to obtain the mean monthly Global Precipitation Climatology Centre (GPCC) data from National Centres for Environmental Prediction (NCEP)/ National Centre for Atmospheric Research (NCAR) and mean maximum and minimum temperature data from University of East Anglia's Climate Research Unit (CRU). The selected resolutions (1° x 1° for rainfall data and 0.5° x 0.5° for temperature data) were kept constant for both the eastern lowveld and western highveld demarcations of the study area.

3.3.1 Primary Data

3.3.1.1 Household Questionnaires

A set of questionnaires were distributed to the sampled community members per local municipality. The first part of the questionnaire (Section A) captured the demographic information of the respondents, followed by community-based asset weighting (Section B). The five sections on household vulnerability ranged from section C to G. To assess the extent of vulnerability, the Sustainable Livelihoods' five indicators of vulnerability were used; namely, financial status, social status, human capabilities, natural assets and physical assets.

These indicators were explored, and respondents' conditions were revealed in relation to each. The indicators were adopted from FANRPAN (2011) study, which explores Household Vulnerability Index (HVI). The last set of questions under section H assessed the household adaptation strategies. The questionnaires used both closed and open-ended questions (Appendix A) to allow respondents to give additional information about drought hazards in their respective communities. The study comprised of 121 households, with 26 households from Greater-Giyani; 24 households from Greater-Letaba; 10 households from Maruleng, 16 households from Ba-Phalaborwa and 45 households from Greater-Tzaneen Local Municipality. The respondents were selected from the five local municipalities to obtain detailed information about the livelihood conditions across the district.

3.3.1.2. Key Informant Interviews

Key informants from the Mopani District Municipality Disaster Management Centre and local Department of Agriculture personnel were interviewed using an unstructured face to face set of questions (Appendix B) which allowed for addition of information. The interview explored the views of responsible personnel in dealing with drought hazards, with the aim of understanding the gaps in administration efforts. These interviews covered the perceptions on the relationship between climate change and agriculture production and household's livelihood. The level of vulnerability and extent of drought impacts from the leadership perspectives were also revealed. The key informants also gave detailed information about the adaptation strategies in place. Ten key informants were purposively selected, five were from the Mopani District Disaster Management Centre (MDDMC), and five local Department of Agriculture with representation from each local municipality.

3.3.2 Secondary Data

3.3.2.1 Rainfall Data

Rainfall is important for renewal of the global energy and water cycle, precise information about precipitation reaching the land surface is crucial for freshwater assessment and drought risk reduction management (Schneider, *et al*., 2008; Baudoin, *et al*., 2017). The GPCC monthly rainfall data for Mopani District Municipality was obtained from the NCEP/NCAR through internet-based KNMI Climate Explorer tool (https://climexp.knmi.nl/start.cgi). GPCC was established in 1978 by National Meteorological Service of Germany following a request by the World Meteorological Organisation (WMO) (Rudolf and Schneider, 2005). GPCC is expected to perform monthly precipitation analysis across the globe from approximately 67 200 land surface rain gauge stations. It provides data in different resolutions, ranging from 0.25° x 0.25°, 0.5° x 0.5°, 1° x 1° and 2.5° x 2.5° (Schneider, *et al*., 2008).

The retrieved monthly GPCC rainfall data was taken at the resolution of 1° x 1° (~100 km) for both the western highveld and eastern lowveld. The resolution was selected based on the size of the study area demarcations being too small to display any data on 0.25° x 0.25° and 0.5° x 0.5° resolutions, and this made 1° x 1° the finest resolution available for this study. GPCC data was selected to avoid uncertainties brought by gaps in observed station data. GPCC is continuous over space and time, and obtainable at even higher spatial resolution. The gathered data covered the period from 1980-2016. This was done to ensure effective analyses of climatic trends over these years. Guttman, (1998) also conferred that a minimum of 20 to 30 years is effective for climate pattern analysis. Rainfall station data from South African Weather Service and Agricultural Research Council was also analysed to validate the satellite data.

3.3.2.2 Temperature Data

Global warming continues to threaten basic livelihood survival; therefore, it is crucial to be informed and updated on regular basis about temperature changes, in order to improve climate models and plan in terms of agriculture production and supply of water for the future (Kruger and Shongwe, 2004). The monthly records of minimum and maximum temperature were obtained from University of East Anglia's Climate Research Unit (CRU) through the internet-based KNMI Climate Explorer tool (https://climexp.knmi.nl/start.cgi). They were taken at a resolution of 0.5° x 0.5° (~100 km) for both the eastern lowveld and western highveld of Mopani District Municipality. CRU data was selected to avoid gaps associated with meteorological station data sets. These temperature records were used to determine the potential evapotranspiration of this region from 1980-2016. Through temperature records the impact of global warming on drought severity were also be determined. Temperature station data from SAWS and ARC were also analysed to validate the satellite data.

3.3.2.3 Dam Level Data

Hydrological data can be correlated to the prevalence of drought conditions (Narasimhan and Srinivasan, 2005). When the temperatures are high, water evaporation rates are expected to rise. Water demand will also escalate, resulting in a decline in water supply capacity. The data dam levels around Mopani District Municipality was obtained from the Department of Water and Sanitation at Greater-Tzaneen from 1980-2016. The provided data had gaps, and the human effect on water control measures was considered.

3.3.2.4 Normalised Difference Vegetation Index

The use of vegetation indices from the spectral reflectance of the remotely sensed data in the near infrared and visible band have been used in several applications for years. This application was done to monitor the vegetation health condition; vegetation cover mapping and ecosystem change detection (Chen, *et al*., 2009). Vegetation indices can also be used to assess the relationship between climate change and terrestrial conditions, such as drought, evapotranspiration and heat waves (Estel, *et al*., 2015).

MODIS data was obtained from the United States Geological Survey's Land Processes Distributed Active Archive Centre (LP DAAC) website (http://lpdaac.usgs.gov). MODIS vegetation indices have been used widely and they provide reliable spatial and temporal information which allows for terrestrial vegetation condition analysis over a large area (Estel, *et al*., 2015). It is comprised of seven spectral bands specifically designed for land application with spatial resolution ranging from 250 m to 1 km (Justice *et al.,* 1997; Zhang *et al*., 2003). It allows for intra and inter seasonal comparison of the collected data through frequent repeat cycles over one area (Ray *et al*., 2015). The available MODIS data records only starts in year 2000 and the selected resolution for this study is 250 m.

Although there are many vegetation indices, such as the Soil Adjacent Vegetation Index (SAVI) and Enhanced Vegetation Index (EVI), most studies make use of the NDVI for vegetation monitoring (Ray *et al*., 2015). Advancement in technology has greatly improved the capabilities of NDVI to operate on different spatial and temporal scales (Tucker *et al*., 2005). The NDVI can be calculated as follows:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Where,

NIR = near infrared

RED = red spectral reflectance

The NDVI scale of measurement ranges from -1.0 and +1.0. For this study, the NDVI was used to determine the impacts of drought hazards on vegetation over time in the five local municipalities. Vegetation reflection reveals the health condition of the vegetation. The green colour represents a healthy vegetation, while the red colour resembles vegetation that is struggling. Flourishing vegetation is directly associated with the availability of soil moisture. In dry conditions soil moisture is greatly reduced and in wet conditions there is an abundance of moisture. Where there is abundant moisture, more plants will grow reflecting greener colour and places with deprived soil moisture, will have less plant growth. MODIS NDVI was used to assess the impacts of drought seasons across Mopani District Municipality between year 2000 and 2016.

3.3.2.5 Maize Yield Data

Unpredictable and unreliable rainfall conditions in the semiarid regions contribute to low crop production as sensitive crops such as maize require consistent moisture supply throughout their life cycle (Hansen *et al.*, 2004). The impacts of ENSO persist during the late summer coinciding with critical growth stage of maize (Sheffield *et al*., 2008). The impacts of drought on agriculture were analysed through the maize yield data obtained from the Department of Agriculture, Forestry and Fisheries (DAFF, 2017). The assessed data represent both commercial and subsistence farmers with access to irrigation systems in times of drought conditions and those relying on rainfed agriculture. The subsistence farmers are highly affected than the commercial farmers. The acquired data was from 1986 to 2015.

3.4 Sampling Methods

Sampling methods are employed to maximize efficiency and validity of the collected data (Morse and Niehaus, 2009). In this study systematic random and purposive sampling approaches were used. Systematic random sampling method was used among households (community members), while purposive sampling was used for municipal officials to select the respondents.

3.4.1 Systematic sampling

In systematic sampling, the selection of the first sample is done randomly, and subsequent samples are selected by a uniform interval. Every K^{th} item is selected after being determined by dividing the number of items in the sampling frame by the desired number of the sample size (Acharya, et al., 2013). Based on the random start and the interval, some challenges might be encountered while using systematic sampling on periodic populations. However, there are suggested alternatives to get around this challenge such as a centred systematic where the starting point is at the centre of first block of *k* population units rather than being randomly selected (Iachan, 1982). Systematic sampling was chosen as it is cost-efficient, easy to use, and to verify (Palinkas, *et al*., 2015). To select households in each local municipality, a list of all households was obtained from each local municipality authority. The respondents were drawn using systematic random sampling in each municipality and given the questionnaires.

3.4.2 Purposive sampling

Purposive sampling is a non-probability type of sampling wherein the samples are selected out of convenience (Acharya, *et al*., 2013). It is applicable under both quantitative and qualitative research approaches (Tongco, 2007). Samples are chosen based on the qualities they possess in relation to the matter under discussion and there is no limit on the number of participants (Palinkas, *et al*., 2015; Tongco, 2007). However, after conducting a series of purposive samples under different sample sizes, Seidler (1974) postulated that at least five informants are required to make the data reliable.

The selected individuals or groups should have knowledge and good understanding of the phenomenon of interest, should be willing and available to communicate that information effectively (Cresswell and Plano-Clark, 2011; Bernard, 2002). Purposive sampling was chosen as it is straight forward and there is no need to sample population, making it suitable in selection of key informants. The sampled key informants were representatives from each local municipality, from MDDMC and Department of Agriculture.

3.4.3 Household sampling frame

The target population was from Mopani District Municipality in the Limpopo Province. The reason for using the whole district was guided by reconnaissance findings, which showed that the district faces challenges of varying degrees in terms of frequency, intensity, impacts, vulnerability and adaptation strategies to drought hazards. A list of all the households in Mopani District Municipality was used to draw the desired sample. The household sample size was calculated using Tara Yohane formula as follows:

$$n = \frac{N}{1 + N(e)^2}$$

Where *n* represents the sample size;

N represents the population size and

e represents the level of precision.

The selected sampling precision (*e*) is 9% due to large number of households under study.

Mopani District Municipality had a total number of 296320 households (STATSSA, 2011); the sampling unit was based on households and the sample size was determined as follows:

$$n = \frac{296320}{1 + 296320(0.09)^2}$$

$$= \frac{296320}{1+296320\times0.0081}$$

$$= \frac{296320}{2401.192}$$

$$= 123$$

The household sub-sample size was then assigned in each local municipality as follows:

Table 3. 1 Households Sampling

Local Municipality	Number of households	Percentage (%)	Calculations (% x n)	Number of Households
Greater-Giyani	63548	21.4	21.4%× 123	26
Greater-Letaba	58261	19.6	19.6% × 123	24
Maruleng	24470	8.2	8.2% × 123	10
Ba-Phalaborwa	41115	13.8	13.8% × 123	16
Greater-Tzaneen	108926	36.7	36.7% × 123	45
Total:	**296320**	**100**		**121**

The calculations in Table 3.1 show that a total of 121 households formed part of this study, with 26 households from Greater-Giyani; 24 households from Greater-Letaba; 10 households from Maruleng, 16 households from Ba-Phalaborwa and 45 households from Greater-Tzaneen Local Municipality.

3.5 Ethical Considerations

All ethical-related issues in respect to the study were taken into consideration. Permission application letter was sent to the district and the study was granted permission. The relevant stakeholders were informed before data collection commenced, which included the Municipal Managers, MDDMC managers and leaders of the participating villages in each of the five local municipalities Participation by the respondents was voluntary and their names and responses were kept confidential. The respondents were fully informed about the nature of the study and its purpose. The ethical clearance certificate was obtained from the University of Venda Higher Degrees Committee (Appendix D).

3.6 Data Presentation and Analysis

Several techniques and methods were used to analyse and present the data. Descriptive statistics such as percentage, frequencies and cross tabulation in SPSS and Microsoft Excel

2016 were used to present the response from key-informant interviews and household questionnaires in pie charts and graphs. The analysis methods include the Standardised Precipitation Evapotranspiration SPEI), Household Vulnerability Index (HVI), anomalies analysis, time-series and contrast analysis.

3.6.1 Standardised Precipitation Evapotranspiration Index

Standardised Precipitation Evapotranspiration (SPEI) is derived from the Standardized Precipitation Index (SPI). It is used to describe the nature and characteristics of drought; thus onset, duration and magnitude of drought. To achieve this, the relative dryness of the area is considered through the amount of precipitation received in a specific period. It also considers the amount of evapotranspiration in that area. SPEI was developed as a multi-scalar drought index, with similar capabilities as the SPI, but it also considers the crucial aspect of drought severity determinism, which is the evapotranspiration demand by the atmosphere (Beguria *et al*., 2014).

Potential Evapotranspiration (*PET*), which is sometimes called the Reference Evapotranspiration (*ETO*), represents the evapotranspiration of a well-watered hypothetical reference crop under specified conditions. It depicts the evaporative demand of the atmosphere irrespective of the crop type, development and management practices. It is only affected by the climatic parameters. This makes it possible for the potential evapotranspiration calculated at different regions under different seasons to be comparable (Allen, *et al*., 1998).

A study conducted by Vicente-Serrano *et al*. (2012), found that SPEI correlates better with other anomalies in various hydrological, environmental and agricultural variables than SPI. To calculate SPEI, the algorithm developed by Vicente-Serrano *et al*. (2010) was used through the R package SPEI version 1.7 which was developed by Bergueria and Vicente-Serrano (2014).

The R package SPEI has three provisions to calculate the potential evapotranspiration, i.e. Hargreaves, Thornthwaite, Penman-Monteith method (Vincente-Serrano *et al*., 2015). For the purpose of this study, the Hargreaves approach of calculating the potential evapotranspiration, based on geographic coordinates of the weather station, minimum and maximum air temperature and extra-terrestrial radiation, was adopted. The approach was adopted due to its suitability in large-scale studies with gaps in some climatic data such as wind speed, relative humidity and vapour pressure (Trambauer *et al*, 2014).

Furthermore, this approach is less sensitive to errors from climatic data inputs (Hargreaves and Samani, 1985). In this study, SPEI was used to determine the frequency and intensity of drought hazards across Mopani District Municipality from 1980-2016. It was selected as unlike SPI, it considers temperature and other climatic factors, and not just precipitation only. This makes it to have a strongest correlation with El Nino Southern Oscillation (ENSO) than SPI (Meque and Abiodun, 2014; Manatsa *et al*, 2017). SPEI can also detect the impacts of drought on water resources under any climatic conditions across the world (Vicente-Serrano *et al*., 2012).

SPEI formulation according to Hargreaves Method.

The first step was to determine the potential evapotranspiration, using Hargreaves and Samani (1985) approach as follows:

$$ETO = 0.0023 \times Ra \times TD^{0.5}\ (Tm + 17.8) \qquad (3.1)$$

Where:

ETO = Daily reference evapotranspiration

TD = Difference between maximum and minimum temperatures

Tm = Average monthly temperature

Ra = The water equivalent of the extra-terrestrial radiation in mm/day:

$$Ra = \frac{1440}{\pi}(G_{sc}.d_r)[\Psi s \sin(\varphi)\sin(\delta) + \cos(\delta)\sin(\Psi_s)] \qquad (3.2)$$

Where:

G_{sc} = Solar constant of 0.0820 MJ/m^2/min

d_r = Inverse relative distance from earth to the sun, given by:

$d_r = 1 + 0.033 \cos\left[\frac{2\pi(JD)}{365}\right]$

JD = Julian day of the year

Ψ_s = Sunset hour angle (rad)

δ = Solar declination (rad), given by: $0.409 \sin\left(2\pi.\frac{JD}{365} - 1.3\right)$

φ = Latitude of the location

To convert $MJ/m^2/d$ to mm/d, multiply $MJ/m^2/d$ value by 2.43

This was followed by determining the climatic water balance (D), which is the difference between precipitation (P) and potential evapotranspiration (ETO)

$$D = P - ETO \qquad (3.3)$$

Where:

$D =$ Climatic water balance

$P =$ Precipitation

$ETO =$ Potential evapotranspiration

After that, probability density function $f(x)$ of log-logistic distribution, developed by Vicente-Serrano et al. (2015), was used. The log-logistic probability function was fitted to data series of D in which the logarithm follows a logistic distribution. The equation is as follows:

$$F(x) = \frac{\beta}{\alpha}\left(\frac{x-y}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-y}{\alpha}\right)^{\beta}\right]^{-2} \qquad (3.4)$$

With $y \leq x < \infty,\ \alpha < 0,\ \beta < 0 \ and \ y < 0$

Where:

$\alpha =$ Scale parameter

$\beta =$ Shape parameter

$y =$ Location parameter

Classical approximation by Abramowitz and Stegun (1965) was then used to transform function $F(x)$ to a normal variable as follows:

$$z = U - \frac{c_0 + c_1 U + C_2 U^2}{1 + d_1 U + d_2 U^2 + d_3 U^3} \qquad (3.5)$$

Where:

$U = \sqrt{2\ In\ ((H(x)}$ for $0 < H\ (x) \leq 0.5$ with $H(x) = 1 - G(x)$ as the probability of exceeding the determination value D. The constants are given as follows:

$c_0 = 2.515517$

$c_1 = 0.802853$

$c_2 = 0.010328$

$d_1 = 1.432788$

$d_2 = 0.189269$

$d_3 = 0.001308$

The resulting Z value will be the SPEI values. These values range from - 2 (extremely dry) to + 2 (extremely wet) as indicated in Table 3.2:

Table 3. 2 SPEI Classical Table (Source: Vicente-Serrano et al., 2012)

Categories	SPEI values
No drought	>0
Mild drought	0 to -0.99
Moderate drought	-1.0 to -1.49
Severe drought	-1.5 to -1.99
Extreme drought	≤ -2.0

SPEI calculations are based on the original SPI calculation procedure. To calculate the SPI, input data is the monthly or weekly precipitation data only. However, SPEI uses the difference between monthly or weekly precipitation and potential evapotranspiration (*PET*) data. From this, a climatic water balance can be determined at different time scales. This approach was selected for this study as it also considers an important aspect of drought; namely: evapotranspiration.

3.6.2 Household Vulnerability Index

Household Vulnerability Index (HVI) is a statistical tool developed by FANRPAN for measuring the internal and external vulnerability introduced by shocks. The vulnerability of different households differs from place to place. Distinct ecological and social conditions of those affected also have an impact on their vulnerability (Nkondze, *et al*., 2013).

HVI is equipped to measure the vulnerability of households and communities to hazards such as poverty; HIV and AIDS and extreme weather events like drought (Sibanda *et al*., 2008). To assess the extent of vulnerability among households, this study adopted the five Sustainable Livelihoods five indicators of vulnerability, namely; Financial Status, Social Status, Human Capabilities, Physical Assets and Natural Assets. The dimensions covered under each of the five sustainable livelihood indicators are shown in Table 3.3 as adopted from FANRPAN, (2011).

Table 3. 3 Five sustainable livelihood indicators (Source: FANRPAN, 2011).

Natural Assets	**Physical Assets**	**Human Assets**	**Financial Assets**	**Social Assets**
Land	Livestock	Farm Labour	Salary	Community Support
Soil	Equipment	Dependents	Savings	Social Welfare Support
Water		Gender Composition	Pension Funds	Access to Information
				Extended Families

Validation of the selected indicators was done through the Community-Based Asset Weighting System (CBAW), to allow community members to choose dimensions that contribute the most to their vulnerability, as shown in Section B of Appendix A. Under CBAW, a scale of 5 was used, where 1 represents mild impact, 2 moderate impact, 3 medium impact, 4 severe impact and 5 extreme impact. CBAW results were then used to assign weight to the indicators, as shown in Table 3.4.

Table 3. 4 Community-Based Asset Weighting Results

Indicator	**Assigned Weight**
Financial Resource	21
Physical Resources	22
Social Assets	19
Human Resource	17
Natural Resource	22

Data from 121 household questionnaires was captured and used to produce an HVI variable table (Appendix C). Each variable was assigned a score at a range between 0 and 1, where 0 means no impact and 1 means full impact. After setting boundaries for each variable, a transformation which was variable-dependent was done. In a well-defined variable case, no impact was given a 0 score and 1 for full impact. However, in the cases of Yes or No responses, subjective assigning of scores was done based on the direction of variable impact. In cases where a variable had more than one response option, the scores were split and 0 meant no impact, 0.25 slight impact, 0.5 typical impact, 0.75 minor impact and 1 for full impact. These multiple response cases were transformed using the formula: $V = \left(\frac{X}{Y}\right)$

Where

V = Value

X = Actual value

Y= Maximum value

All these dimensions under the five sustainable livelihood indicators were weighed to produce household vulnerability ($Vhhi$). Statistical Package for the Social Sciences (SPSS), version 25 was used to analyse vulnerability through data review, cross-tabulation and Chi-square. The calculations were formulated as follows:

$$Vhhi = \sum_{j=1}^{m} \mathrm{Xwj} \; / \sum_{j=1}^{m} \mathrm{wj}$$

Where
j = Dimension of impact
m = Specific dimensions of impact
w = Corresponding weighted vulnerability
Vhhi = Sum of the weighted vulnerabilities across all dimensions

After calculating household vulnerability, it is classified into following levels: Coping Level with Low Vulnerability Household (CLH), Acute Level with Moderate Vulnerability Household (ALH) or Emergency Level with High Vulnerability Household (ELH) with respect to the extent of the coping levels (Sibanda *et al*., 2008). The HVI values were adjusted from FANRPAN (2011) to match the outcomes from this study.

Table 3. 5 HVI classical values (Source: Sibanda et al., 2008).

Category	**HVI Value**
Low Vulnerability (Level 1)	0 – 10
Moderate Vulnerability (Level 2)	11 – 20
High Vulnerability (Level 3)	21 – 30

3. 6.3 Time Series Analysis

Over the years climatic research has gained attention globally, with some of its key focus areas being on understanding and forecasting of changes in regional climatic conditions. To achieve this goal, the application of time-series analysis plays a crucial role (Bucur and Haria, 2012). A time-series refers to the serially correlated data recorded sequentially over time. Time series analysis aims to depict trends patterns and construct models that will justify and predict the relationship between phenomena under discussion. In this study the phenomena were temperature and rainfall data. Thus, it tries to visualise and understand past data in order to predict anticipated future changes (Burtiev, et al., 2013).

Most time-series analyses feature trends, cyclical, seasonal variations and random functions which can either be modelled mathematically, using the functions of time, or estimated using non-parametric smoothing approaches (Dettling, 2008). A trend is comprised of a fixed long-term tendency, a cyclical is characterised by long irregular oscillations, with a period longer than one year and a seasonal component is comprised of periodic oscillations occurring under a period of less than a year (Burtiey, 2013). This relationship can be expressed as follows:

$$Y_t = T_t + S_t + C_t + R_t$$

Where Y_t = Time series

T_t = Trend

S_t = Seasonal

C_t = Cyclical

R_t = Random or systematic fluctuations

This study used time-series analysis to analysis the seasonal trends in temperature and rainfall records, from 1980 to 2016, across Mopani District Municipality.

3.6.4 Anomalies Analysis

Anomalies analysis tries to depict the patterns that do not conform to a well-defined notion of normal behaviour in a data. The non-conforming patterns are referred to as anomalies, outliers, shocks, exceptions, discordant observation or deviations. A normal distribution must be established first and then anomalies can be detected. However, there are some challenges, as defining a normal distribution is not that easy and classification of a normal distribution and an outlier might not be accurate (Chandola *et al*., 2009)

There are three different categories of anomalies; namely: point, collective and contextual anomalies. Point anomalies occur when an individual data record is anomalous to the entire record, collective anomalies are related records which are exceptional in respect to the entire data set while contextual anomalies are data records which deviate from a specified context (Chandola *et al*., 2009). In this study anomalies analysis was used to depict the abnormal trends in rainfall and temperature data over the past years from 1980-2016.

3.6.5 Composite Analysis

Composite analysis, which is sometimes referred to as "selective climatology", is used to analyse pattern similarities on various time scales, which can be daily, monthly or seasonally (Chikoore, 2016). It depicts prominent characteristics of drought; historical repeating patterns can also be identified better in group than with one event (Mulenga, 1998; Mulenga, *et al*., 2003). Composite analysis has been used in many studies over time (e.g. Jury and Levey, 1997; Mwafulirwa, 1999; Manatsa *et al*., 2011). In this study drought events, which occurred between 1980 and 2016 in Mopani District Municipality were included in composite of temperature and rainfall anomalies. For a better composite analysis, the focus was on the rainy season which range from December to March in this semi-arid region.

3.7 Summary

This chapter introduced and justified the methods used to collect and analyse the data. It was revealed that both primary and secondary types of data were used. The primary data came from questionnaires and key-informant interviews, while secondary data was the rainfall, temperature, dam level data, maize yield and vegetation data. Systematic sampling was used to sample community members while purposive sampling was used on key-informants. The methods of analysis used were anomalies, time-series, composite analysis, SPEI and HVI.

Chapter 4: The Occurrence of Drought in Mopani District Municipality

4.1 Introduction

This chapter presents drought characterisation in Mopani District Municipality using the Standardised Precipitation and Evapotranspiration Index (SPEI). The influence of remote phenomena on the occurrence of drought in the study area is also explored. Limpopo Province is one of the regions highly affected by drought impacts in South Africa. In this chapter, the Mopani District Municipality is categorised into two climatic distinct regions - the eastern lowveld region comprising Ba-Phalaborwa, Greater-Giyani, Maruleng Local Municipalities and a portion of the Kruger National Park, while the western highveld region is made up of Greater-Tzaneen and Greater-Letaba Local Municipalities.

4.2 Rainfall

Being in the subtropics, rainfall in South Africa is highly variable and unreliable on a variety of spatial and temporal scales. The eastern side of the country receives high rainfall which may be attributed to the presence of the warm Agulhas current and the onshore moisture from the south-western Indian Ocean. The west part is desert-dry due to a combination of the cold Benguela Current in the south Atlantic Ocean and offshore prevailing winds. The seasonal distribution of rainfall is also significant, as 10% of the country receives an annual rainfall of more than 750 mm. The interior region receives summer rainfall while the south western parts receive Mediterranean type of rainfall distribution in winter (Benhin, 2008).

Limpopo Province is also subjected to distinct climatic conditions influenced by mountain ranges and the northeastern escarpment across the province (Figure 4.1). The dominant rain bearing system in Mopani District Municipality is the moist air from the Indian Ocean coupled with tropical cyclones and tropical storms which lands occasionally (Chikoore *et al*., 2015). Much of the Limpopo Province receive mean annual rainfall amounts between 400 and 700 mm with lower rainfall in the northern lowveld near Musina (Figure 4.1). The presence of the northeastern escarpment (south-north) and the west-east Soutpansberg Mountain range is clearly discernible through the very high rainfalls (exceeding 1000 mm annually) recorded in those regions.

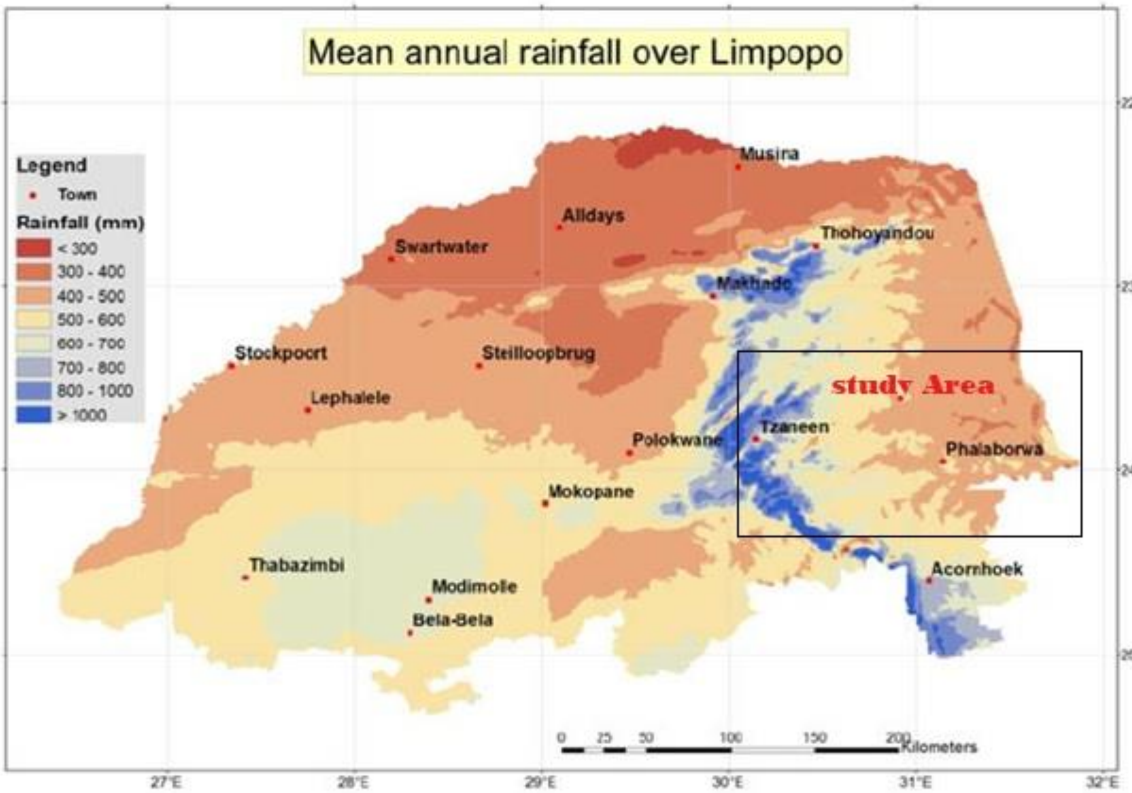

Figure 4. 1 Mean Annual Rainfall over Limpopo Province (Source: ARC-ISCW, 2014)

Under normal climatic conditions, the rainy season in Mopani District Municipality starts in October and ends in March with a peak between December and February (Figure 4.2). These results correspond to the findings by Mzezewa *et al*., (2010) where it was revealed that more than 80% of the rainfall in Limpopo Province is received between October and March. Fitchett *et al*., (2016) determined that the district receives an annual total rainfall of 500 mm between October and March whilst Tyson *et al*., (1986) found similar summer rainfall pattern over the interior parts of South Africa.

The western highveld of the district receives more rainfall than the drier eastern lowveld. January is the wettest month in the western highveld, receiving a mean rainfall of 136 mm while on the eastern lowveld December receives a mean of 98 mm, making it the wettest month on the eastern lowveld (Figure 4.2). The dry season prevails from April to September with June and August being the driest months on the western highveld with a mean rainfall of 9.0 mm and 5.1 mm received during the driest month (June) of the eastern lowveld. The spatial monthly rainfall distribution varies by 38 mm between the western highveld and eastern lowveld of the district. It was found that the northeastern interior of South Africa has the biggest difference between summer and winter rainfall (Rouault and Richard, 2003).

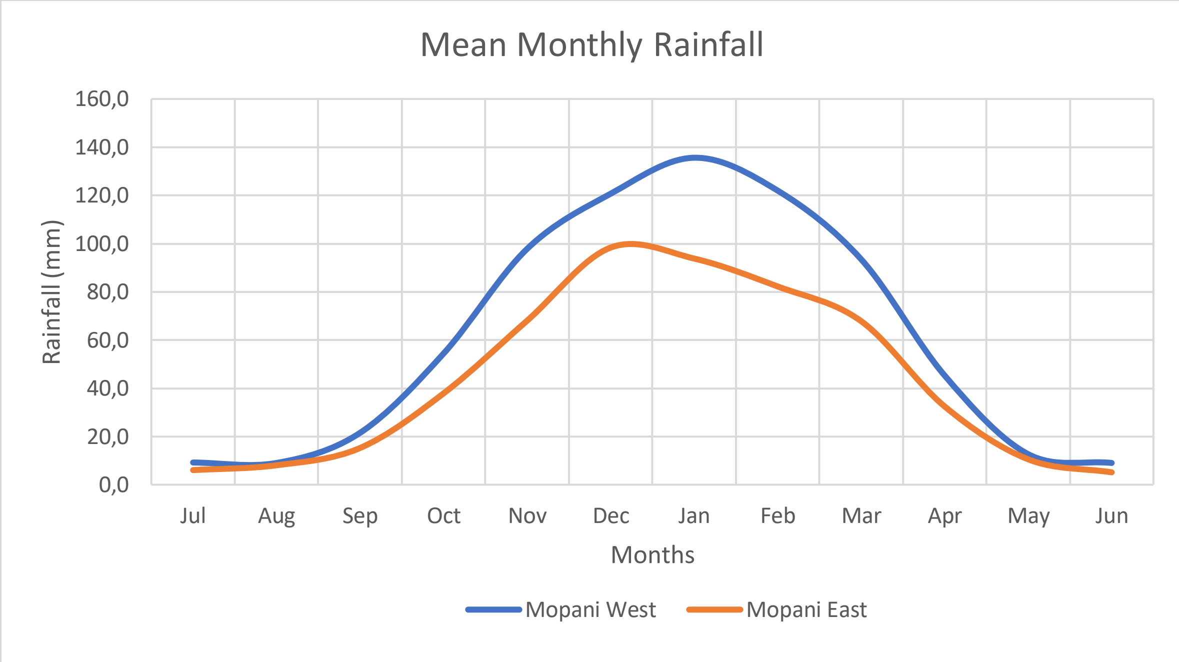

Figure 4. 2 Mean monthly rainfall for Mopani Western highveld and Eastern lowveld

The inter-annual rainfall distribution over Mopani District Municipality has also varied significantly over time (Figure 4.3). Throughout the years the eastern lowveld continues to receive less rainfall, while the western highveld receives more rainfall. The year 2000 experienced highest rainfall record of more than 600 mm on the western highveld and 450 mm on the dry eastern lowveld. About 25% of the rainfall received during year 2000 resulted from tropical cyclone Eline (Reason and Keibel, 2004). This confirms the findings by Ziervogel *et al*., (2014); Chikoore *et al.,* (2015) which showed that tropical cyclones are associated with severe rainfall events and flooding in Limpopo. Eline was found to be the longest-lived tropical cyclone which made the year 2000 the wettest year on record in southern Africa since 1976 (Reason and Keibel, 2004).

The tropical cyclone impacts are also intense with some of the major events which occurred in year 1996 and 2012. Davis, (2010) urged that climate change is projected to cause reduced mean annual precipitation and inclined temperatures with more frequent flash floods. During year 2012 from 17-19 January tropical cyclone Dando which developed in the south western Indian Ocean resulted in flooding that caused major damage to livestock and crops (Chikoore *et al*, 2015). Many parts of Limpopo lowveld received rainfall which was above 500 mm over a 24-hour period (Fitchett *et al*., 2016). The infrastructure was damaged, communities lost their property and roads were washed away (Mpandeli *et al*., 2015).

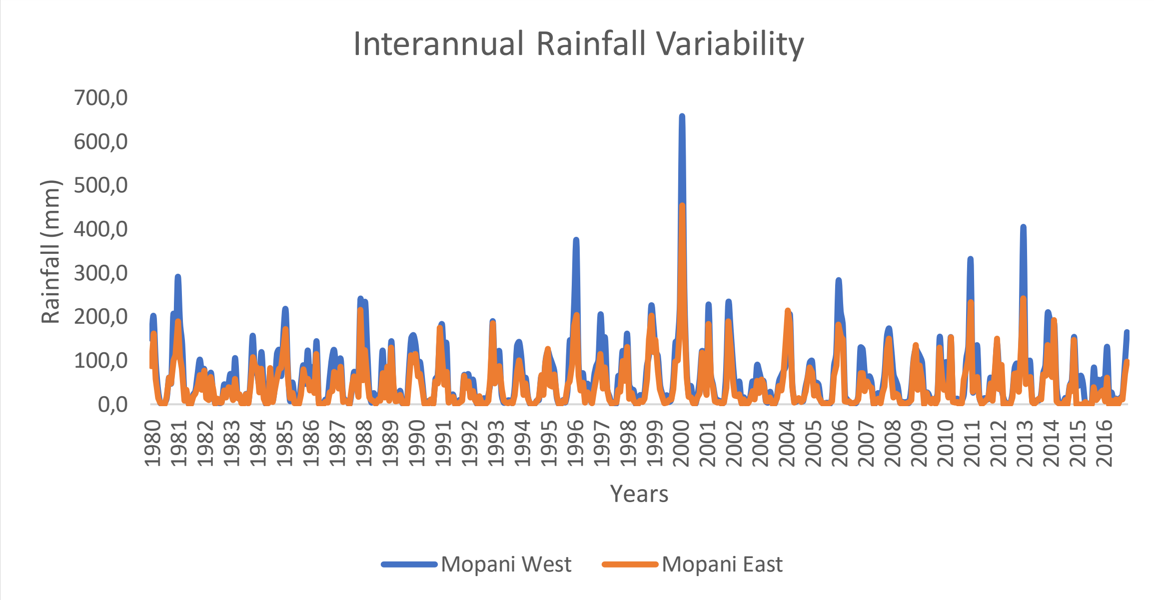

Figure 4. 3 Interannual rainfall variability for Mopani highveld west and lowveld east

4.3 Temperature

The mean annual maximum temperature for Mopani District Municipality also exhibits temporal and spatial differences. The eastern lowveld is much warmer with a mean monthly maximum temperature of 33.1°C experienced during January whilst the western highveld is cooler, with a mean maximum temperature of 29.9°C between January and February months (Figure 4.4). The highest temperatures are experienced throughout the summer months, which are normally expected to be hot in any semi-arid region. Fitchett *et al*., (2016) also found that Mopani District Municipality normally experience warm temperatures all year-round. There is a non-linear relationship between temperature and rainfall, which shows a decrease in rainfall with the increasing temperature. Meadows (2006), predicted that future increases in temperature over southern Africa will bring a decrease in precipitation and more severe and frequent droughts. The years with highest temperature are 1982, 1992, 2012 and 2015 in the eastern lowveld (Figure 4.5) which may correspond to drought seasons.

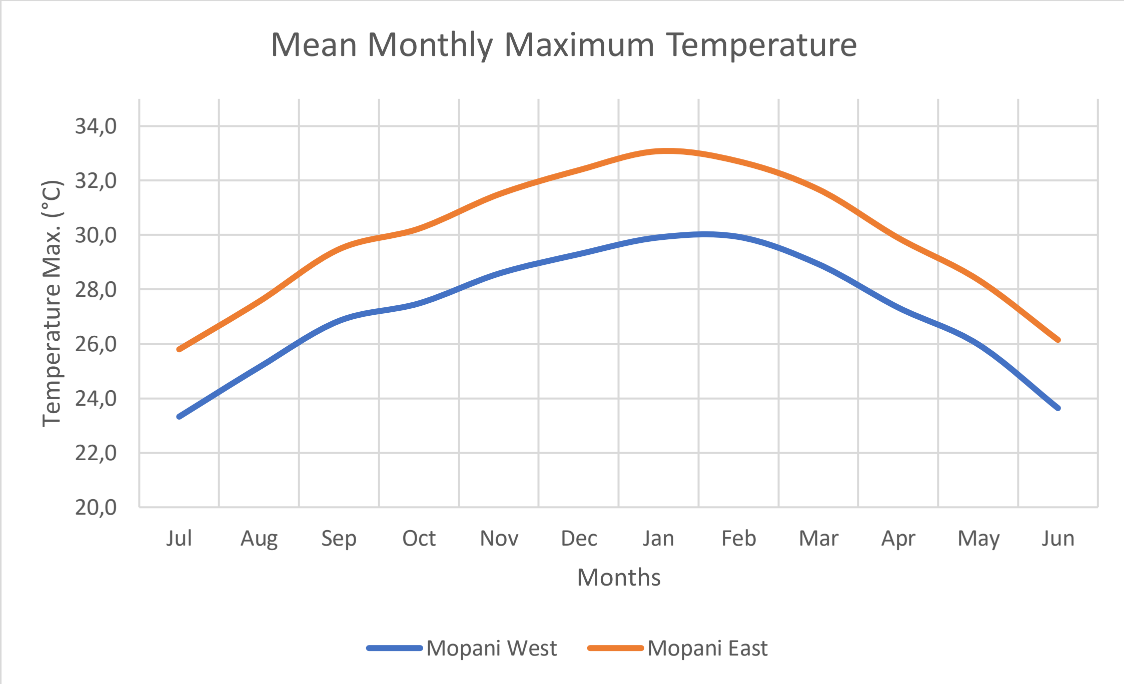

Figure 4. 4 Annual cycle of maximum temperature for Mopani highveld west and lowveld east

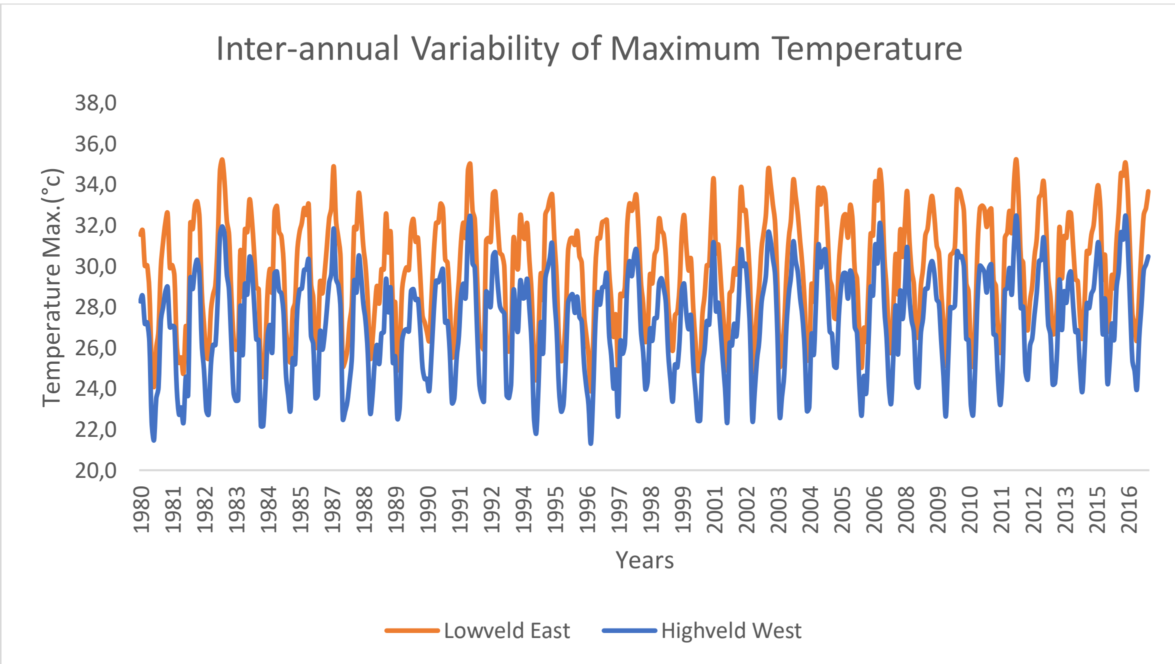

Figure 4. 5 Inter-annual variability of maximum temperature for Mopani lowveld east and highveld west

4.4 Correlation of Drought Conditions with El Nino

The occurrence of drought in Limpopo Province is related to a remote phenomenon resulting from fluctuations of sea-surface temperatures (SSTs) in the eastern equatorial Pacific Ocean. The El Nino phenomenon affects patterns of surface air temperatures, pressure, winds and rainfall across much of the tropics and subtropics (Chikoore, 2016). In Limpopo, rainfall is negatively correlated (R=-0.541) such that periods of El Nino are often seasons of drought (Figure 4.6). Most of the droughts in Mopani identified using the SPEI have occurred during El Nino. Conversely, La Nina tends to favor higher rainfalls (Reason *et al*, 2000) which may lead to flooding in the lowveld through landfalls of tropical cyclones from the southwest Indian Ocean. The effect on El Nino on seasonal rainfall in Limpopo may be evolving and compounding due to rapidly rising surface air temperatures which are themselves also influenced by El Nino.

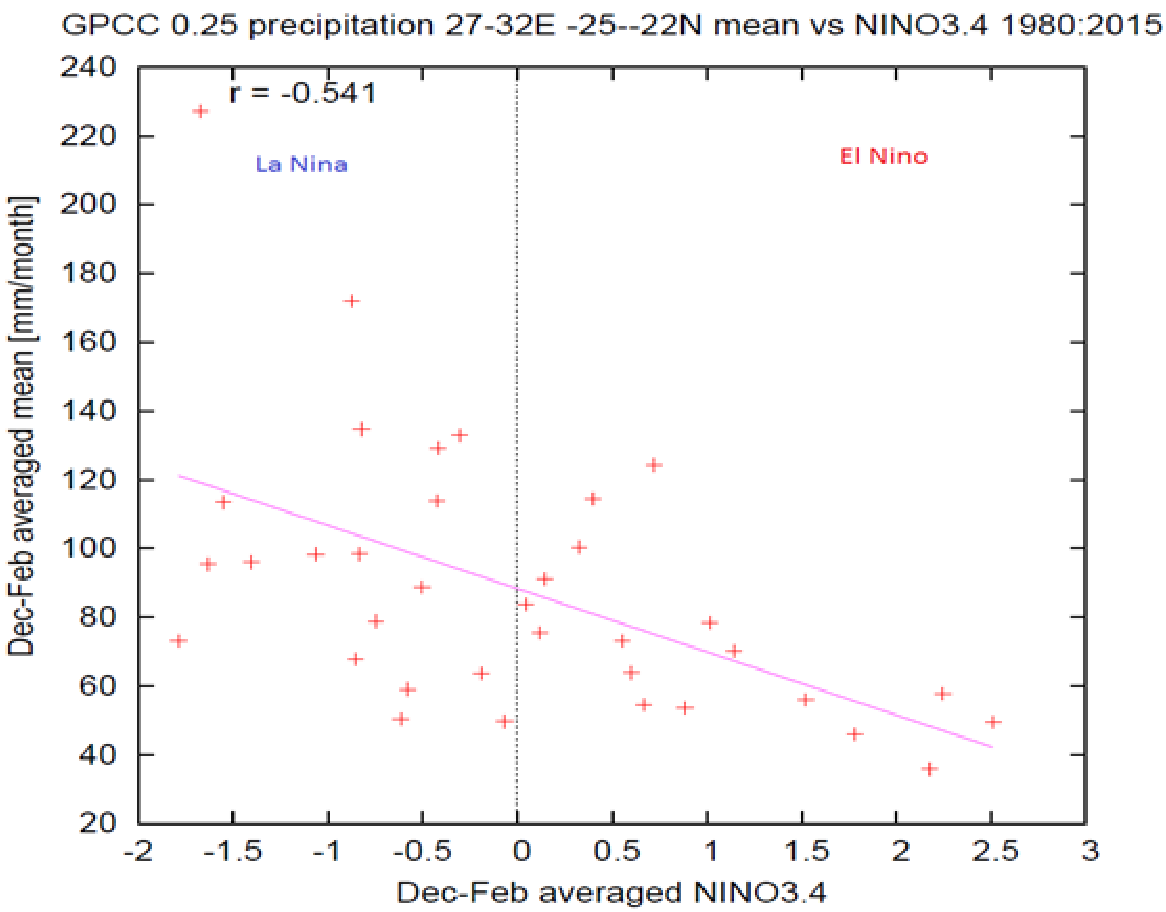

Figure 4. 6 Scatter plot showing the relationship between summer NINO 3.4 sea temperature anomalies and summer mean precipitation over Limpopo Province, South Africa. The correlation is significant at 95% confidence interval

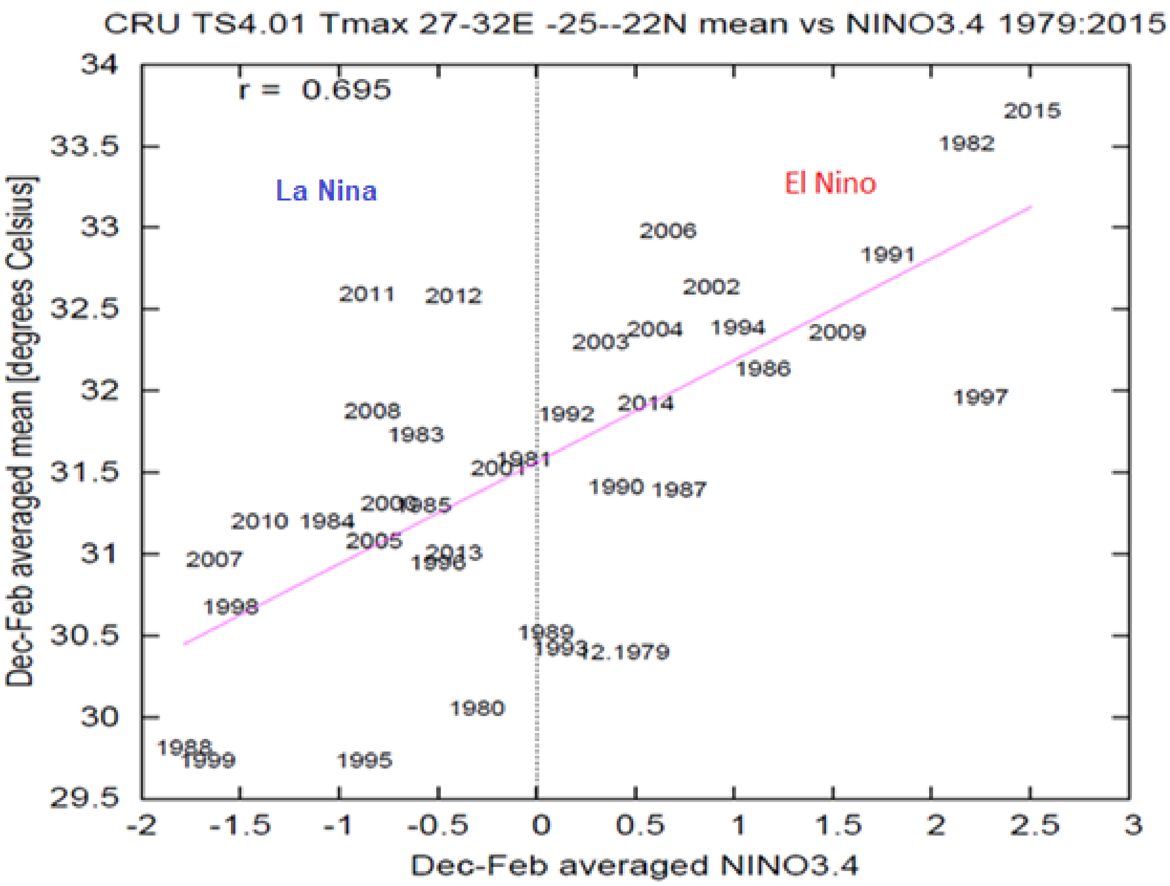

Figure 4. 7 Scatter plot showing the relationship between summer NINO 3.4 sea temperature anomalies and summer mean temperatures over Limpopo Province, South Africa. The correlation is significant at 95% confidence interval.

The correlation between El Nino and maximum air temperature has a stronger positive relationship (R=0.695) than the correlation between El Nino and precipitation (Figure 4.7). From these relationships it can deduced that El Nino is more likely to bring hottest conditions (or heat waves) in Mopani District Municipality. In the 2015/16 drought season the region experienced the worst drought in history, with the highest mean temperature record of above 33°C. A study by Lyon (2009) found a strong link between the occurrence of drought and heat waves in southern Africa. La Nina events tend to be cooler air temperatures, perhaps due to frequent cloudiness and higher rainfall during that time.

4.5 Drought Characterisation using SPEI

To characterise the nature of drought conditions across Mopani District Municipality, the SPEI index, which ran through the R-studio, was used. It was calculated from 1980 to 2016 for a period of 1 (SPEI 1), 3 (SPEI 3), 6 (SPEI 6) and 12 (SPEI 12) months of the year.

However, for drought classification and frequency determination, SPEI 6 was used as it was recommended to be suitable for describing a rainy season by Rouault and Richard (2003).

Figure 4.8 (D) and Figure 4.9 (D) show SPEI 1 for one month in both the western highveld and eastern lowveld, respectively. It shows a general trend of inter-changing dry and wet periods from one month to another. The predominant dry period starts from May to October and the wet period starts from November to April, which is similar to a normal dry winter season and wet summer season experienced in semi-arid region (Mpandeli, *et al*., 2015). The moisture differences from one month to another are not much, implicating the limitations of one-month SPEI interval in both the eastern lowveld and western highveld.

Figure 4.8 (C) and Figure 4.9 (C) show SPEI 3 with moisture deficits over a 3-month time scale, representing mid-season moisture conditions (Rouault and Richard, 2003). The 3-month time scale is suitable for monitoring soil moisture or rainfall conditions during the growing season (Rouault and Richard, 2003). The dry period is much dominant in the first half of the study duration. Figure 4.8 (B) and Figure 4.9 (B) show SPEI 6 with ongoing fluctuation from wet to dry seasons, dry seasons are dominant. The time scale ranges between October and March, and April to September from 1980-2016. The notable drought seasons were in the following years: 1980/81, 1982/83, 1983/84, 1986/87, 1991/92, 1993/94, 1997/98, 2002/03, 2004/05, 2007/08, 2011/12, 2014/15, 2015/16 as shown in Table 4.1. The period from 1980-1995 was characterized by declining rainfall due to frequent droughts (Chikoore, 2016).

One of the droughts that affected the district occurred in 1991/92 which was a severe drought on the west and moderate on the eastern lowveld. LDA (2011), described 1991/92 drought as the worst drought in South Africa and some parts of the South African Development Community (SADC). Although this was recorded as the worst drought across many regions in South Africa since 1922, based on the outcomes from SPEI 6, in Mopani District Municipality it was not extreme. The elderly indicated that during 1991/92 drought they lost livestock due to water and fodder shortages. Mpandeli *et al*., (2015) found that the 1991/92 drought season brought a major set-back on farming, small-holder farmers lost their livestock and crops dried out and food import rates increased.

Table 4. 1 Drought Events Classification under SPEI 6 in Mopani District Municipality and their Categories

Drought Event	Category	
	Western Highveld	**Eastern Lowveld**
1980/81	Moderate	Mild
1982/83	Severe	Moderate
1983/84	Mild	Moderate
1986/87	Mild	Moderate
1991/92	Severe	Moderate
1993/94	Moderate	Moderate
1997/98	Severe	Mild
2002/03	Severe	Severe
2004/05	Extreme	Mild
2007/08	Moderate	Extreme
2011/12	Extreme	Moderate
2014/15	Moderate	Extreme
2015/16	Severe	Extreme

In 1993/94 both sides of the district experienced moderate drought, 1997/98 was a severe drought on the western highveld while it was a mild drought on eastern lowveld. The season 2002/2003 came with severe drought conditions for the entire district. The 2004/5 season had the first extreme drought of this study in the western highveld, in the following season (2007/8), extreme drought was experienced in the eastern lowveld. About 23 years later after the 1991/92 drought season, South Africa experienced the worst drought ever in 2015/16 season (Baudion, 2017). This was recorded as a prolonged drought season as the rising temperatures coupled from 2014/2015 drought season which was moderate on the western highveld and extreme on the eastern lowveld. The 2015/16 drought was extreme in the eastern lowveld and severe in the western highveld of Mopani District Municipality. Figure 4.6 (A) and Figure 4.7 (A) shows 12 months (SPEI 12) period which is suitable to describe the long-term drought conditions (Rouault and Richard, 2003).

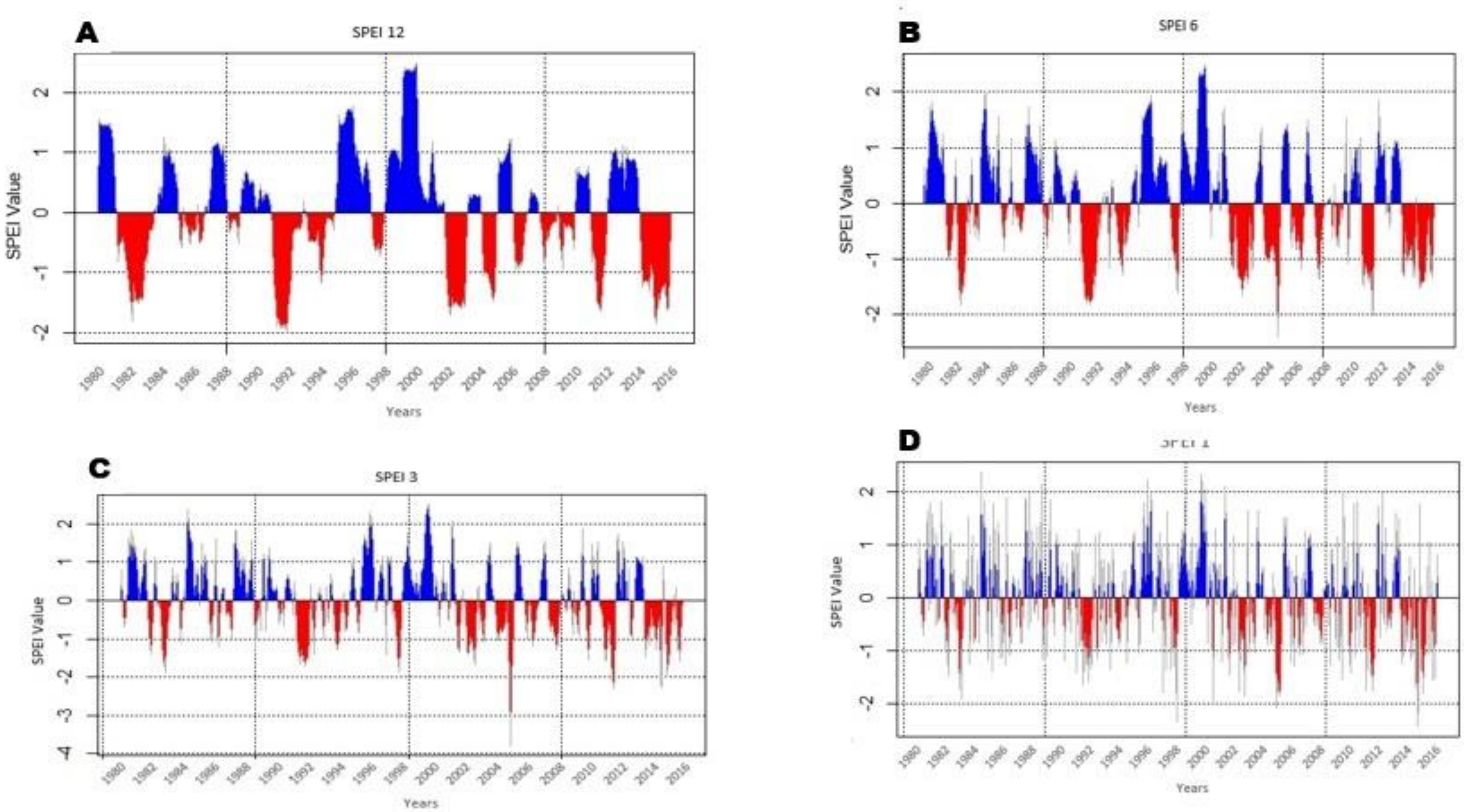

Figure 4. 8 Mopani District Municipality western highveld SPEI (A: SPEI 12, B: SPEI 6, C: SPEI 3, D: SPEI 1)

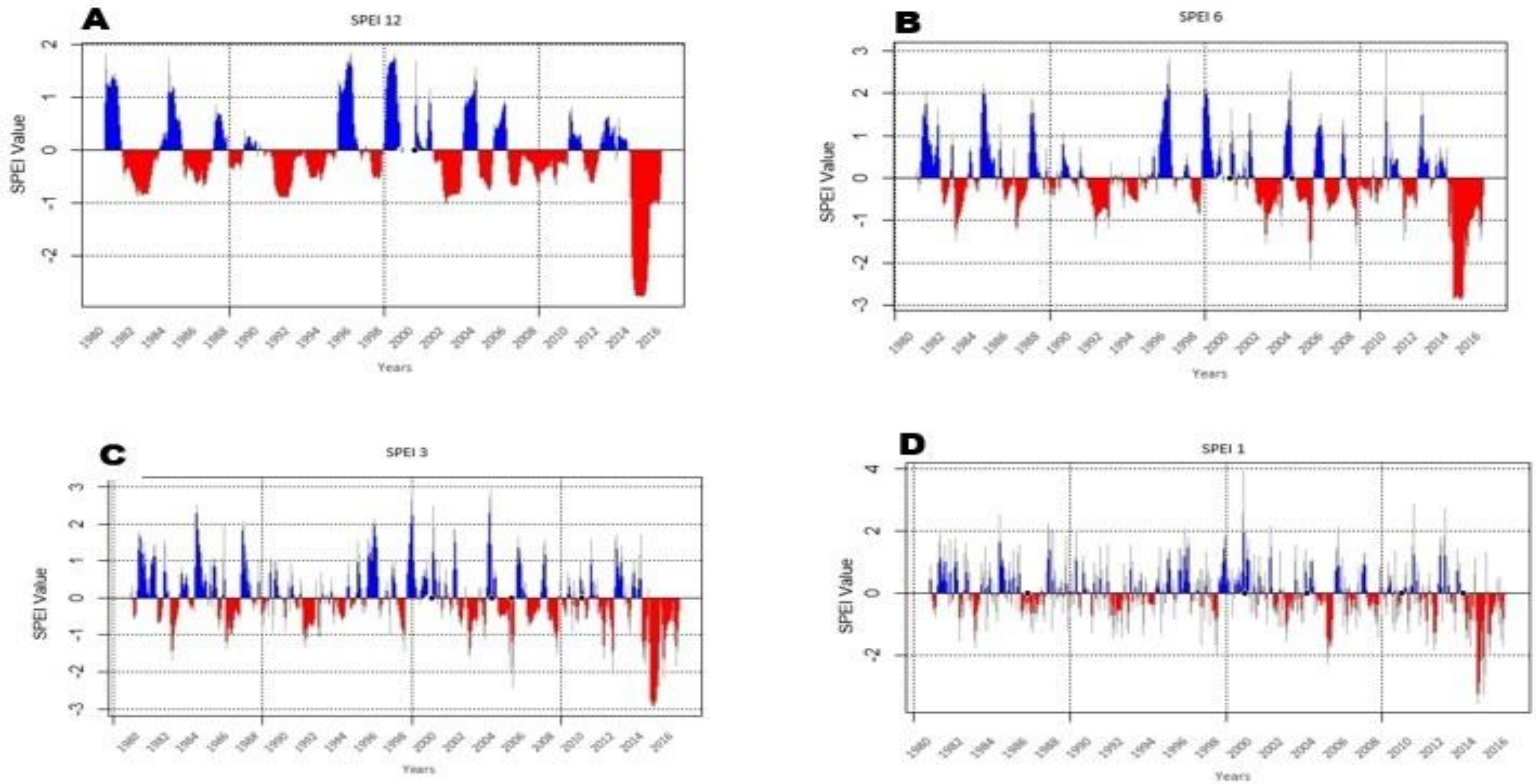

Figure 4. 9 Mopani District Municipality eastern lowveld SPEI (A: SPEI 12, B: SPEI 6, C: SPEI 3, D: SPEI

4.6 Drought Frequency in Mopani District Municipality

Since the 1970s climate incidents such as drought have increased in frequency and intensity (Liu *et al*., 2016). Furthermore, with advancements in earth system calibration models, Dai, (2011) concurred that drought incidents across the globe will continue to rise in the 21st century. This brings concerns to livelihoods as FAO (2011), found that recurrent droughts incidents were linked to famine and high mortality rates in Somalia. In this study drought frequency was determined by calculating the total number of droughts per category within a 37-year period of study using SPEI 6. Results show that Mopani District Municipality experiences drought of similar frequency on the eastern lowveld and western highveld (Table 4.2). The number of seasons with no drought (wet) account for 50.91 % on western highveld and 50.80% on the eastern lowveld. Mild (30,52%) and moderate (13.90%) drought seasons are most frequent on the eastern lowveld. The severe (4,57%) and extreme (0,46%) droughts are much more common on the western highveld. This distribution further reveals that the number of drought seasons is almost equal to the number of rainy seasons. It can be said that nearly half the time, there is some form of drought occurring in Mopani District. Although the western highveld was described as the cool and wet portion of the district, it proved to be the one experiencing more severe and extreme droughts. Chikoore, (2016) found that persistently moist regions are the most likely to be adversely affected by drought whereas the dry regions suffer less impacts as they are mostly dry already.

Table 4. 2 Drought frequency in western highveld and eastern lowveld of Mopani District Municipality

Level	Category	Occurrence Frequency (%)	
		Western highveld	Eastern lowveld
> 0	No drought	50,91	50,80
0 to -0.99	Mild drought	30,37	30,52
-1.0 to -1.99	Moderate drought	13,70	13,90
-1.5 to 1.99	Severe drought	4,57	4,56
≤ -2.0	Extreme drought	0,46	0,23

4.7 Spatial Extent and Intensity of Drought

Determining drought onset and when it ends has always been difficult as it is a slow developing phenomenon. However, identifying and tracking the critical parameters and indicators of drought have helped to determine the onset, spatial extent, frequency and duration of drought events (Rahmat, *et al*., 2015). These critical parameters include evapotranspiration, soil moisture, precipitation, stream flows, groundwater levels and reservoir storage (Ray *et al*., 2015). Spatial extent of drought was determined using precipitation anomalies through NCEP.

The general trend over the years shows an increase in magnitude from the eastern lowveld towards the western highveld. The western highveld, which is normally wet, shows more decline in precipitation due to drought, as compared to the forever dry eastern lowveld. Thus, the western highveld is highly impacted by drought as compared to the eastern lowveld. The spatial extent of drought is analysed for three droughts seasons of significance, 1991/92, 1997/98 and 2015/16. It is shown that whilst the drought signal tends to be cantered over Zimbabwe and Mozambique nearly all the time, the Mopani District is also particularly affected. The 1991/92 and 2015/16 rainfall anomalies are comparable (Figures 4.10 and 4.12). Whilst most of South Africa did not experience the widely expected severe drought of 1997/98, Mopani District did experience this drought (Figure 4.11).

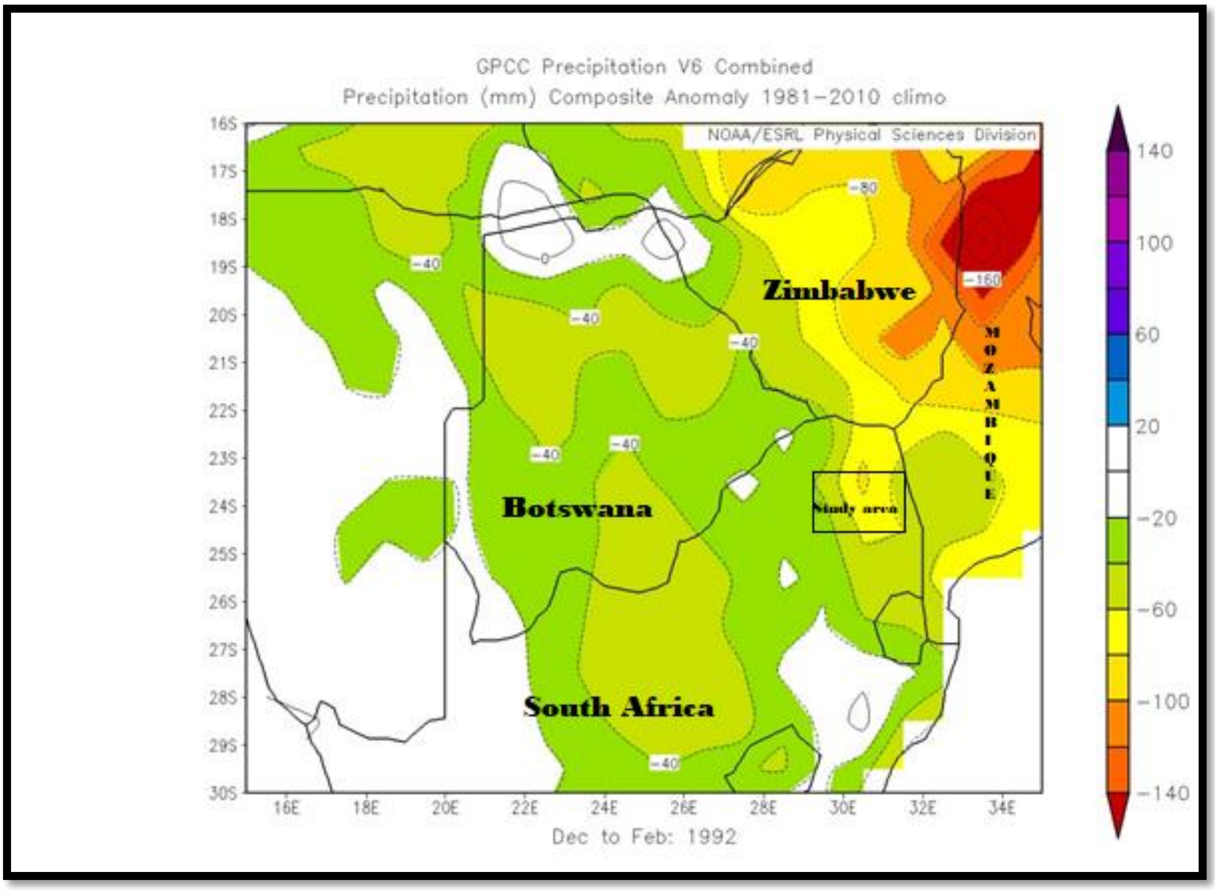

Figure 4. 10 Precipitation anomalies in 1991/1992 in Mopani District Municipality

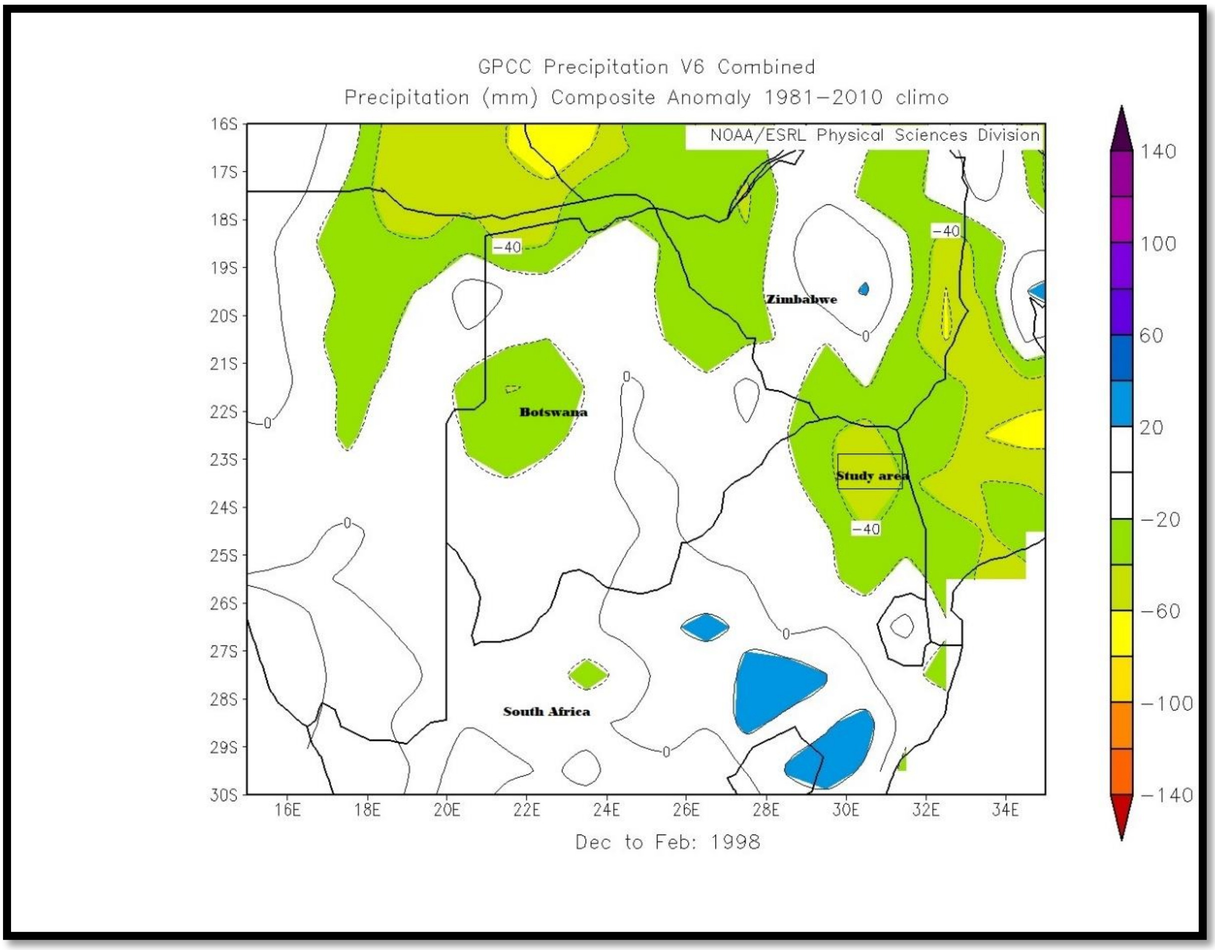

Figure 4. 11 Precipitation anomalies in 1997/1998 in Mopani District Municipality

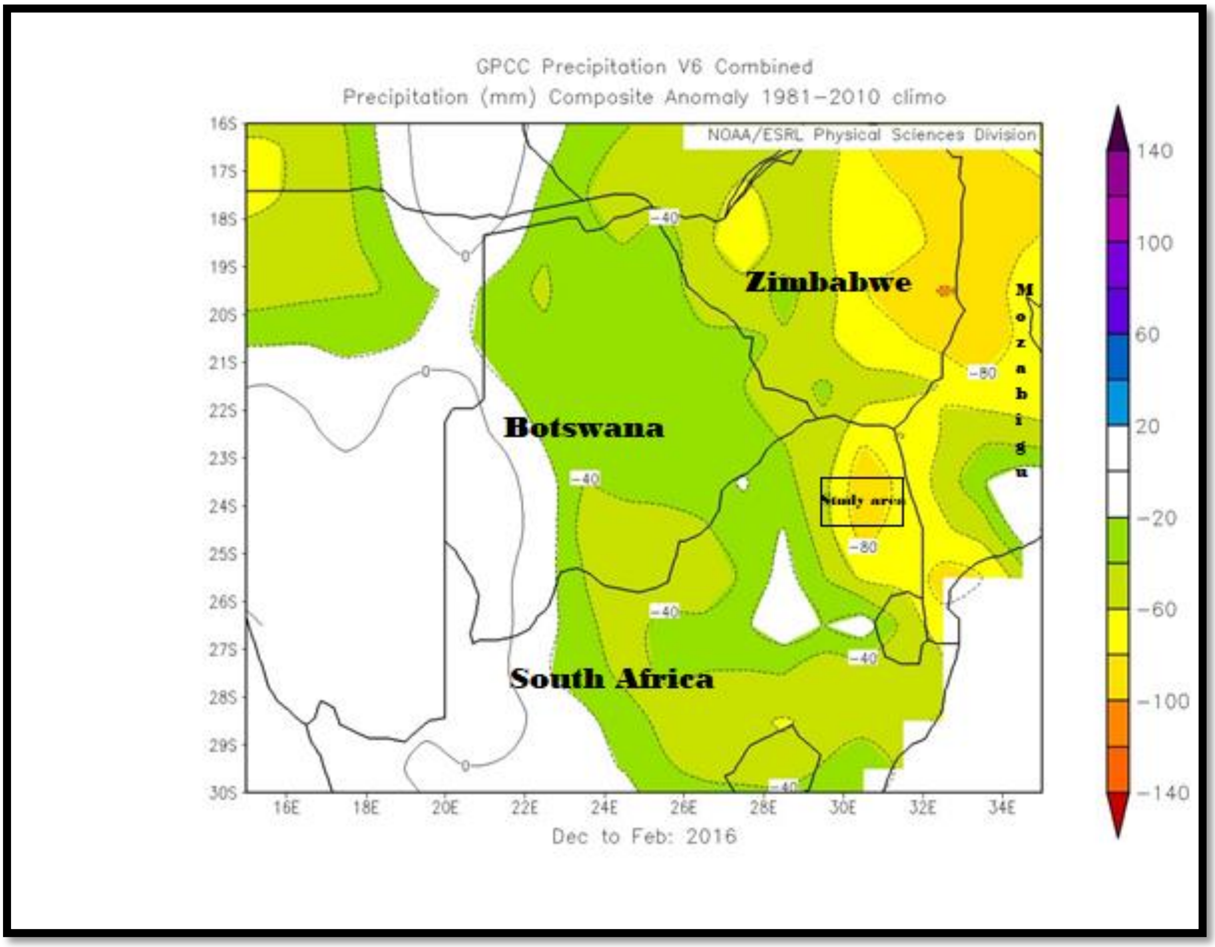

Figure 4. 12 Precipitation anomalies in 2015/2016 in Mopani District Municipality

4.8 Summary

This chapter presents the climatic conditions in Mopani District Municipality. At first it revealed the precipitation and temperature conditions for the past 37 years, followed by the drought conditions. There is a notable change of seasonal drought from the eastern lowveld towards the western highveld of the district. The western highveld received high rainfall under cool temperature while the eastern lowveld was hotter with low rainfall records. The drought frequency favours more mild and moderate droughts on eastern lowveld; however, a new trend of effects is shown where the severe and extreme droughts seem to dominate the forever cool and moist western highveld. It was revealed that El Nino events have a direct linear relationship with high temperatures in semi-arid regions such as Mopani District Municipality.

Chapter 5: Drought Impacts, Household Vulnerability and Adaptation in Mopani District Municipality

5.1 Introduction

This chapter presents and analyses the findings regarding the impacts of drought hazards, household vulnerability and adaptation strategies in Mopani District Municipality. Developing countries still face high levels of vulnerability, as they highly rely on natural resources, and have limited capacity to adapt financially and institutional (Desanker and Magadza, 2001). Drought hazard detection, monitoring and impact assessment have been enhanced through the availability of long-term satellite data (Kogan, 2001). Questionnaires and key informant interviews were used to gather information on household vulnerability and adaptation strategies. The impacts of drought hazards are analysed using contrast analysis through the Normalised Difference Vegetation Index to outline spatial variations.

5.2 Impacts of Drought in Mopani District Municipality

The future impacts of climate change on water resources remain inconclusive. Furthermore, many scientists have been suggesting the likely increase in frequency and intensity of extreme climate events, such as drought, which might continue to threaten water resources (IPCC, 2007). Concurrently, a UNISDR (2004) report attributes the adverse impacts of climate change to political instability, poverty and incompetency of the responsible institutions. This makes understanding of drought impacts crucial for effective decision making in disaster risk reduction efforts (Hayes, *et al*., 2011). The impacts of drought were assessed using the vegetation data, dam level data and maize yield data.

5.2.1 Vegetation

Satellite estimates using different sensors provide a more detailed spatial extent information on vegetation stress caused by drought hazard. The NDVI made use of the MODIS data to determine the impacts of drought on vegetation. A healthy vegetation will show typically high absorption at the red region due to high chlorophyll content and high reflection at near infrared region due to leaf internal structure (Ray *et al*., 2015). There is a relationship that exists between rainfall and vegetation which can be presented and analysed to depict spatial-temporal variations (Mpandeli *et al*., 2015). Based on data availability, the following drought seasons were selected and analysed: 2002/2003, 2007/2008, 2014/2015 and 2015/2016. The analysis was run from December of the previous year to March of the following year since that is when a normal rainy season would prevail in this region.

Throughout the years there is a general trend which shows dominance of vegetation (dense forest) on the western highveld and low vegetation cover (grassland) on the eastern lowveld (Figure 5.1). The greener portion dominance towards the west shows that rainfall was high in the western highveld across the study period and low on the eastern lowveld. Reduced vegetation cover will have impact on grazing fodder and affect livestock negatively (Mpandeli *et al*., 2015). The 2015/16 period shows high loss in vegetation cover across the district which resemble dry conditions in terms of moisture and can also be linked to high evapotranspiration which normally occurs during drought years.

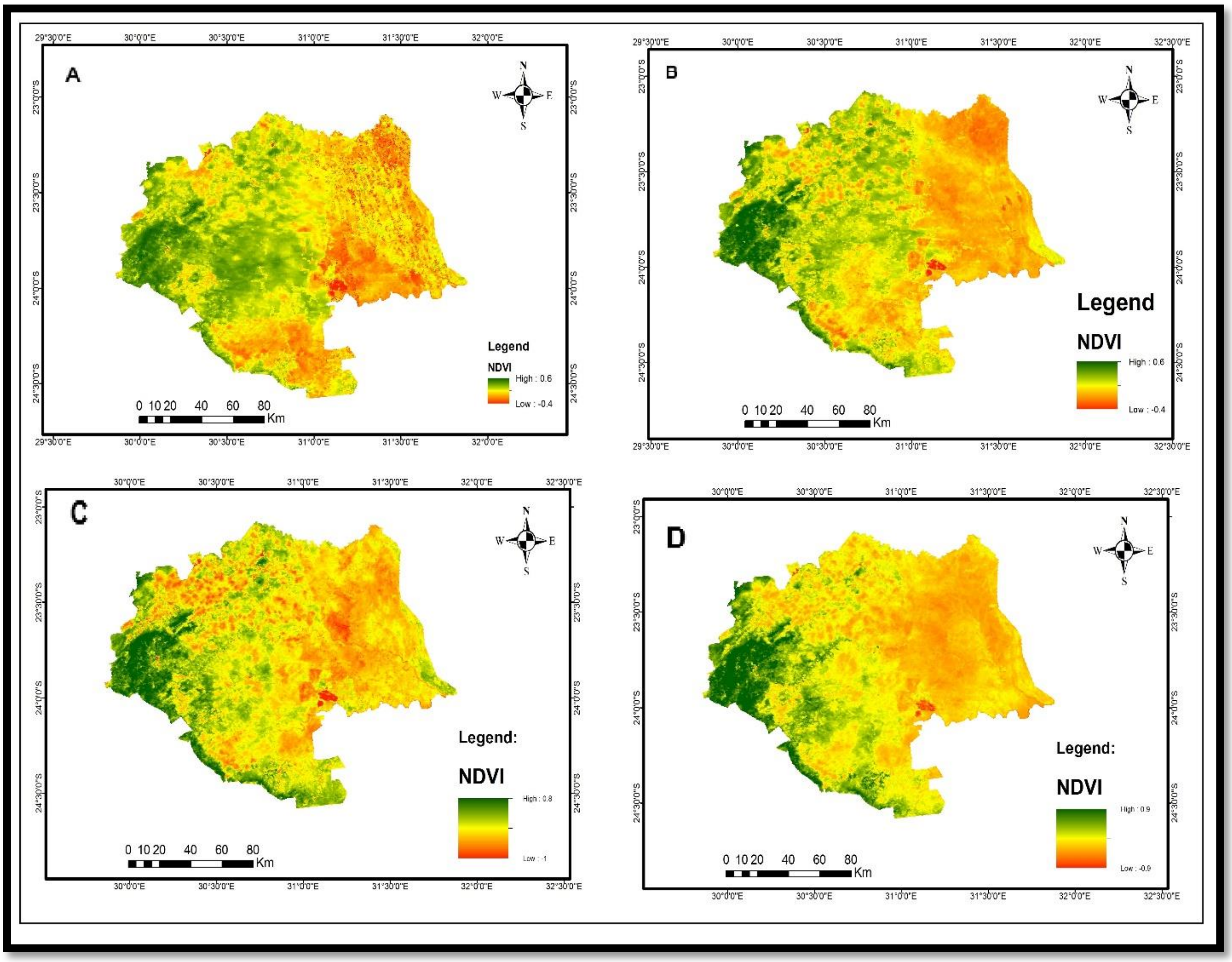

Figure 5. 1 NDVI across Mopani District Municipality (A: 2003, B: 2008, C: 2015, D:2016)

5.2.2 Water Supply

In most parts of the world, community members face water scarcity and availability challenges as a result of deteriorating water quality, improper water infrastructure, variability and change in climate and increased population which in turn increase water demand (Veldkamp *et al*., 2015).

One of the reasons societies experience intense impacts from drought incidents is because they only plan for normal or above-normal water supply conditions and avoid situations where there could be natural variability of climate. The challenges of surviving in a profound decrease water supply that might extend for several seasons or even to years are also not considered. Other factors which might affect drought planning include increasing population, urbanisation and land degradation (Wilhite *et al*., 2007). All these should be considered in drought pre-planning.

In Mopani District Municipality, three dams were selected based on availability of data. The study period was intended to be from 1980-2016, however, some of the dams had data gaps as shown in Figure 5.2. The considered dam includes Tzaneen Dam, Dap Naude Dam and Nsami Dam. The human input (dam valve control) in terms of water supply controls which might influence dam levels was considered. Dams have been subjected to drastic changes in water levels due to numerous factors with drought included. Tzaneen Dam had the highest record of just above 60% full during year 2000, which could be attributed to Tropical Cyclone Eline. In 1995 the dam recorded its lowest level of 2.5% full during the December month. This support Maponya (2013) findings which revealed that Limpopo Province is among worst regions affected by drought in recent past (1980-2016) which resulted in drastic decline in dam levels to 50% full as compared to 84% full in 1980s.

DapNaude dam shows consistent low dam levels whereas Nsami dam shows sharp fluctuations over the years. Nevertheless, the declining trends in water levels are not only happening in Mopani District Municipality, Mosase *et al*., (2019) coincided that there is high pressure from increased economic and social demand which affect global water resources negatively.

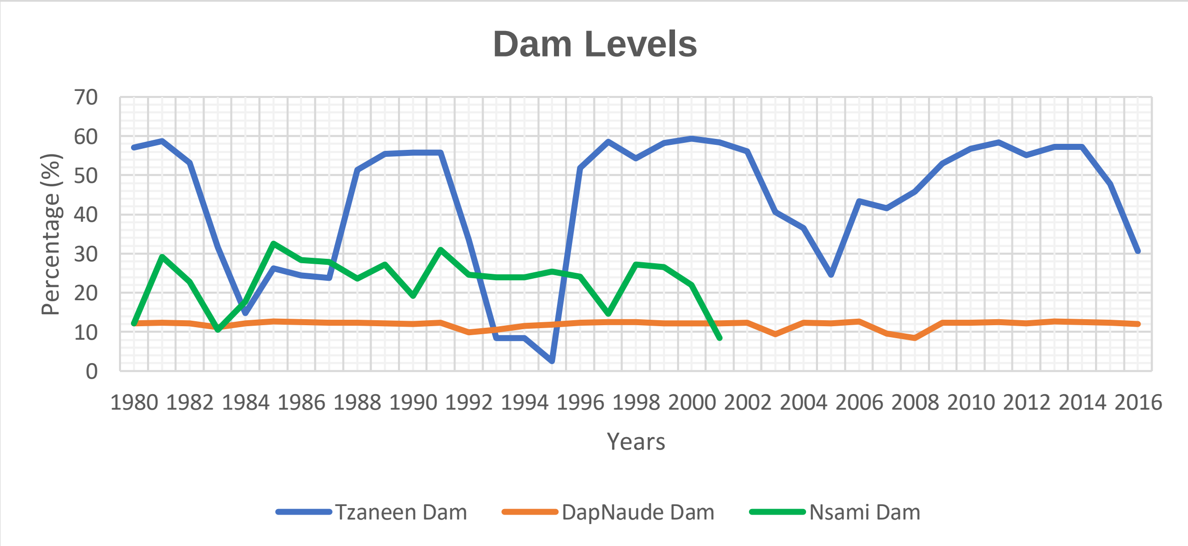

Figure 5. 2 Dam Levels around Mopani District Municipality

5.2.3 Maize Yield in South Africa

The prominent producers of maize in South Africa are found in Mpumalanga, North West, Free State and Kwa-Zulu Natal Province. Figure 5.3 shows the maize production in South Africa from 2010 to 2016, a major drop in maize yield was experienced in year 2016 which resulted in high import rates which surpassed the usually high export rates of maize (BFAP, 2016). This was induced by the 2015/16 drought season which brought changes in most areas, in terms of the growing period, most farmers planted their maize only in January and not within the normal October to November period (BFAP, 2016).

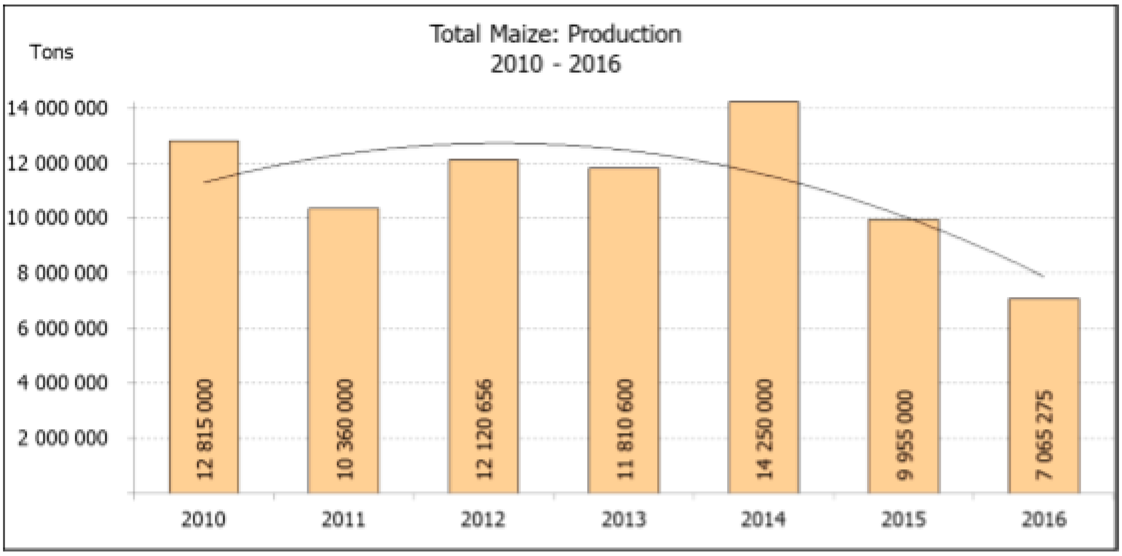

Figure 5. 3 Maize production in South Africa from 2010 to 2016 (Source: DAFF, 2016)

Limpopo Province is one of the main provinces supplying maize for national consumption and international exports. The maize yield is comprised of production from commercial and subsistence farmers. The general trend of yield shows (Figure 5.4) improvement in overall production, however this does not necessarily reflect that there are no negative implications brought by drought on maize yield. A sharp decline in production experienced in year 1991, 1994, 2005, 2010 and 2015 (Figure 5.6) could be linked to some of the drought events that affected this region. It is important to note that such recorded yields reflect major commercial markets which are feasible only for commercial farmers. This increasing trend could be articulated to the use of boreholes as means of water supply by commercial farmers during drought seasons or an increase in cultivated area. Commercial farmers are also able to afford fertilisers and the drought resistant seeds which perform better under harsh climatic conditions. Commercial farmers also have better access to seasonal forecasting information which play a crucial role in drought preparation. Meanwhile the subsistence farmers across Mopani District Municipality are struggling due to drought and their production has declined drastically, some of them are even forced to abandon their rain-dependent farm lands. This corresponds to Kurukulasuriya *et al*., (2006) findings which revealed that agricultural revenue has shown a high decline across many African countries, due to increased temperature.

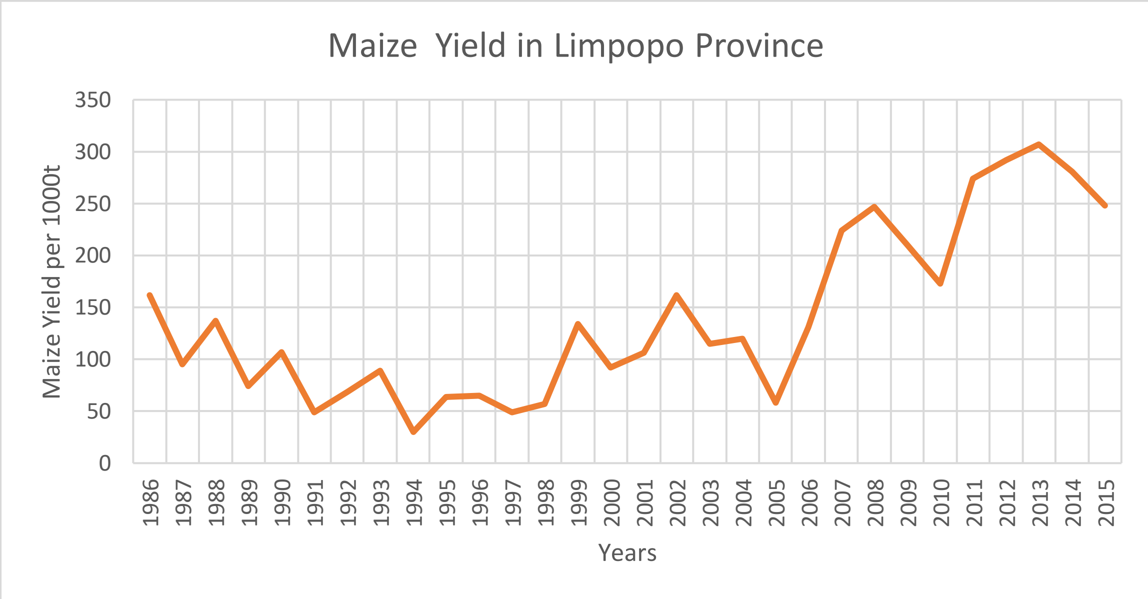

Figure 5. 4 Maize yield in Limpopo Province (Source: DAFF, 2016)

The fluctuations in maize yield bring concern to community's livelihood as they affect the maize meal market. It was reported that in 2001 maize prices had an alarming increase in only five months (Austin, 2009).

5.3 Demographic Factors

The study comprised of 121 households from Mopani District Municipality, with 45 from Greater-Giyani Local municipality, 10 from Maruleng Local Municipality, 16 from Ba-Phalaborwa Local Municipality, 24 from Greater-Letaba Local Municipality and 26 from the Greater-Giyani Local Municipality. Ten key informants also formed part of this study, five were from the MDDMC and five from local Department of Agriculture. All respondents were Africans, from Tsonga, Sotho and Venda groups.

5.3.1 Gender and Age

The study comprised of respondents from several age groups of both genders. The gender proportions were of 54.5% female and 45.5% male. The age groups were dominated by elderly people who are believed sources of indigenous knowledge in terms of drought adaptation. This knowledge was accumulated over decades of experiencing drought. The youth and middle age groups were only fairly represented across all five-local municipality (Figure 5.5). The age group between 21-30 had 3.3%, 31-40 had 17.4%, 41-50 had 27.3% while ≥ 50 had 52.1%.

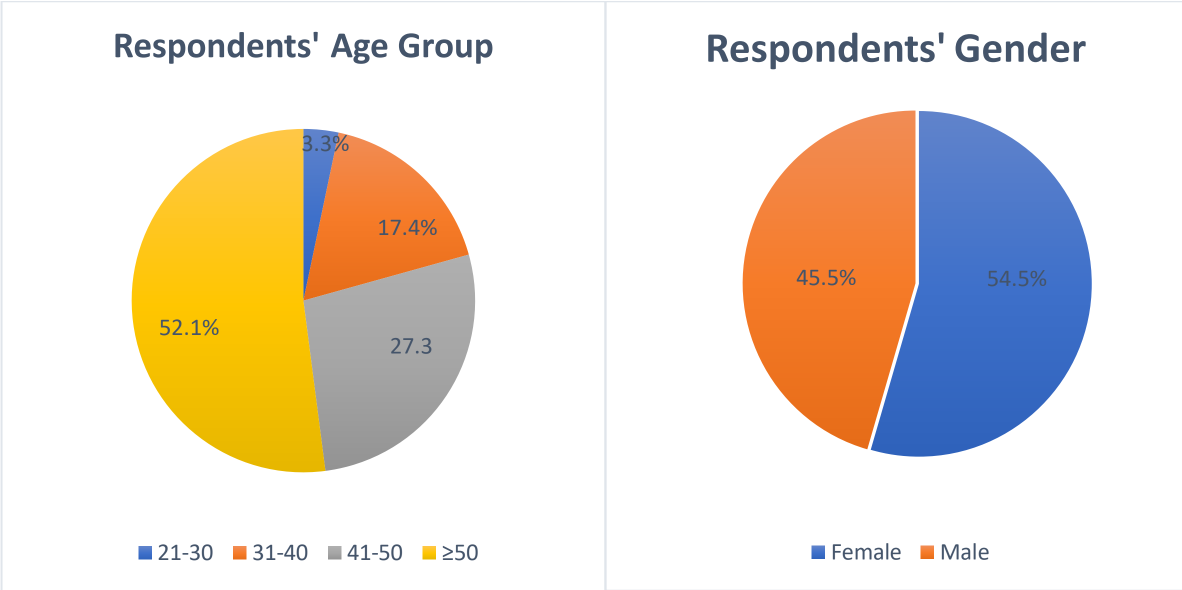

Figure 5. 5 Respondents' Age and Gender in Mopani District Municipality

5.3.2 Marital Status and Level of Education

The respondent’s marital status was dominated by married couples who made up 52.1% of the population, followed by single respondents who made up 38%. The proportion of windowed respondents contributed 6.6% and the least were separated/divorced who made up 3.3% (Figure 5.6). The education level of the respondents was fairly distributed across the district with 37.2% having no formal education, 24.8% having primary school education, 26.4% secondary school education and only 11.6% having attained tertiary education.

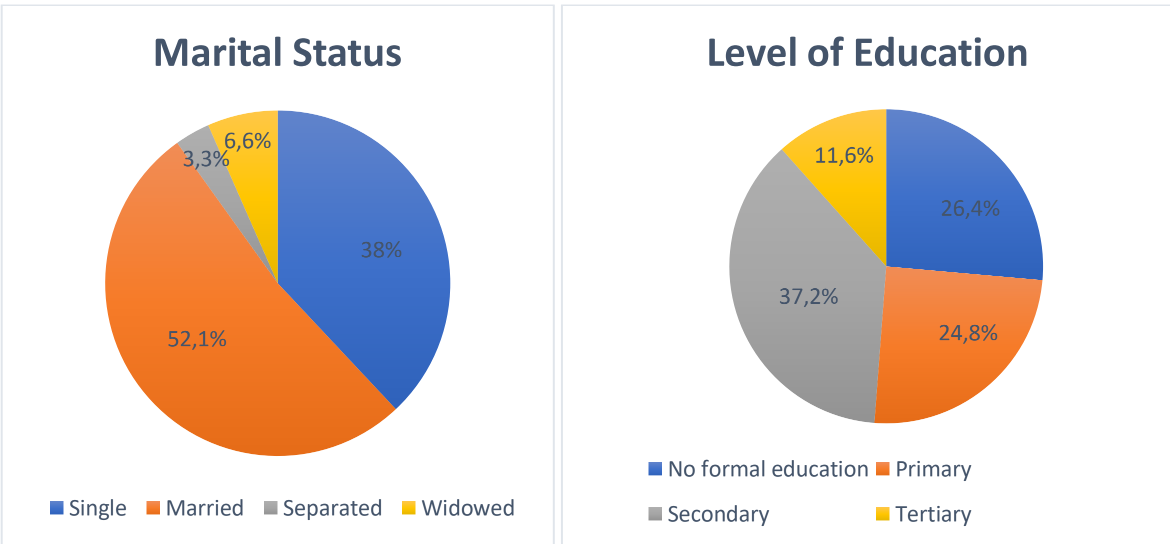

Figure 5. 6 Marital Status and Level of Education of respondents in Mopani District Municipality

5.4 Contribution of Demographic Factors to Drought Vulnerability

The cross-tabulation between HVI and gender, age, marital status, level of education and employment status was done to establish the contribution of these factors to drought vulnerability across Mopani District Municipality as shown in Table 5.1. The correlation between demographic factors and drought vulnerability was assessed using the chi square. The chi square test for gender and household vulnerability showed the following values: x^2 = 4.185, df = 2 and p-value = 0.123. This means that there is no statistical significance between the two variables.

Age also proved to have no statistical significance, with the following values: x^2 = 10.587, df=6 and p-value = 0.102. However, the correlation between marital status and HVI shows a statistical significance with values: x^2 = 15.672, df = 6 and p-value = 0.016. The level of education also had no statistical significance to HVI with these values: x^2 = 7.167, df = 6 and p-value = 0.306. The employment status of the respondents also had no statistical significance to HVI, the values were: x^2 = 5.501, df = 6 and p-value = 0.481.

Table 5. 1 Cross-tabulation of demographic factors' contribution on drought vulnerability significant at p =0.05

	Chi-square	**df***	***p*-value**
Gender	4.185[a]	2	0.123
Age	10.587[a]	6	0.102
Marital status	15.672[a]	6	0.016
Level of education	7.167[a]	6	0.306
Employment status	5.501[a]	6	0.481

5.5 Exposure to drought hazard

The household vulnerability was measured using the five sustainable livelihood indicators developed by FANRPAN. These are, physical assets, human resources, financial resources, natural resources and social assets. The vulnerability of households was determined after their responses were weighed across these sustainable livelihood indicators as shown in Appendix C.

5.5.1 Physical assets

Physical assets were assessed using the possessed assets and the distance travelled to the nearest service centre and agricultural market. The considered possessed physical assets were land, livestock, tractor, car, electricity/solar/generator, television/radio/phone and a house. These were selected under consideration that they have an impact on coping during drought conditions.

Ownership of physical assets was spread across several assets, with some of the households owning more than two and some having nothing at all. About 31% of the households had access to power, which was either from electricity, generator or solar power. The district is well known for its wildlife ranges, even livestock herds were substantial, with about 92 households owning either cattle (34), goats (21), sheep (3), poultry (23), pigs (9) or donkeys (2). The dominant livestock were cattle, followed by poultry, goats, pigs and lastly donkeys.

About 14% of the respondents had land ownership where they mainly practised crop farming, including maize, potatoes, sorghum, cabbage, spinach, onions, chillies and tomatoes. However, some (3%) of the households had abandoned their farm lands and were renting them out as crop farming is no longer feasible due to the harsh climatic conditions. This makes their coping difficult as they depend on subsistence farming. Ownership of a tractor would make farming easier, but most (99.1%) of the households could not afford to buy tractors. Only one household had a tractor and others had to hire it. Owning a car would also ease life, more especially for those practicing subsistence farming. But only 6% of the households across the district owned a car.

Access to information that comes with owning a television/radio/phone is crucial in order to be well informed about upcoming drought hazards. The study revealed that 18% of the households were equipped in this regard. Having your own house is crucial for survival, and 76% of the respondents had their own houses while others (24%) were renting, which required them to spend even more on rent, leaving them with little for subsistence during drought conditions.

Proximity to a service centre also plays a crucial role in the provision of basic services that enable survival, even in harsh climatic conditions. These service centres include medical clinic, home affairs and shopping centres. About 50% of the households had to travel about 11-20 km; 32.2% travelled 1-10 km, 13.2% travelled <1 km and 4.1% had to travel for more than 31 km to the nearest service centre. The agricultural market is highly crucial for the produced crops and livestock herds, about 80.2% of the produce where bought in the local markets of less than 1 km and only 19.8% was being transported to markets which were far-off than 100 km in Pretoria, Johannesburg and Mpumalanga. Household vulnerability in terms of physical assets is shown in Figure 5.7, with 3 households at level 1; 55 households at level 2 and 63 households in level 3 of the vulnerability levels.

Figure 5. 7 Physical assets HVI for Mopani District Municipality

5.5.2 Human resources

Human resources play a crucial role in the daily coping of communities. The study scrutinised the size of households together with the number of dependants. Farm labour force and members of the family, with either disability or terminal illness, are found to be a limiting factor for coping and were also considered.

Availability of resources for household to cope with harsh climatic conditions is dependent on the household size. The largest household size had 11 people, the smallest had only one person and on average household had five members. The highest number of households' dependants was 10, the lowest was zero and the average is 4. A household without any dependant stands a better chance of coping because of reduced expenditure.

Considering household size, about 88.5% of the respondents declared that they had enough farm labour force. Nonetheless, 11.5% of the respondents reported that their farm labour force was insufficient, and they would hire people for help. The capacity of a household to sustain itself without outsourcing farm labour force boosts the agricultural produce, as they would not have to spend more on labour. Disability or terminal illness makes people less productive, more especially on physical work such as farming. Households with disabled or terminally ill respondents constitutes only 12.8% while 87.2% were medically fit. Household vulnerability in terms of human resource is shown in Figure 5.8, with 58 households under level 1, about 52 households in level 2 and 11 households in level 3.

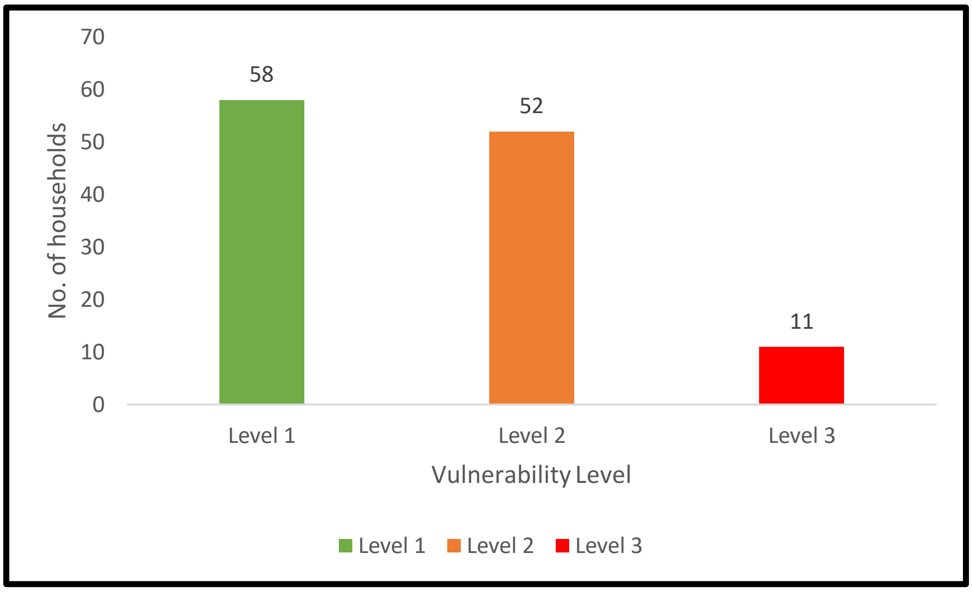

Figure 5. 8 Human Resource HVI for Mopani District Municipality

5.5.3 Financial resources

With the national food poverty line of R 547,00 (STATSSA, 2018), the financial standings of respondents determine their adaptive capacity in times of drought hazards. The financial resources which were examined include employment status, household monthly income, agricultural produce income, alternative sources of income rather than agriculture, access to financial assets and sources of financial support during the drought conditions.

In terms of employment status, about 35.8% of the respondents were pensioners/retired, 32.5% were employed, 24.2% were facing unemployment and only 7.5% were self-employed individuals. The overall household monthly income plays a crucial role in coping during drought conditions. The incomes were classified based on reconnaissance study that revealed the overall financial standing across the district. About 29% of the households received a monthly income of less than R1000,00. De Cocke, *et al*., (2013) also found that more than 20% of households in Mopani District Municipality receive monthly income less than R500,00 which makes coping difficult during drought conditions. On the other hand 44.6% of the households had a monthly income of between R1001,00 and R5000,00.

Households receiving moderate monthly income between R5001,00 and R10 000,00 accounted for 11.6%; households between R10001,00 and R15 000,00 constituted 5.0%. Only 9.9% of the households received over R15 001.00 monthly income which is ideal for coping. Limited economic resources remain part of the reasons behind low adaptive capacity and high exposure in most communities (Smit and Pilifosova, 2003)

Farmers and community members in Mopani District Municipality rely heavily on rain-fed agriculture, with farming practices that take place from the backyard gardens to extensive farm lands. Furthermore, a study conducted by Benhin (2008) shows that rainfall in most parts of South Africa is unpredictable and unreliable. Across the district, about 79% of the respondents are somehow involved in farming activities. However, only 43% of them were dependent on agricultural activities to feed their families. Some (57%) their household income generation had nothing to do with faming. These are households where there is no agricultural land (e.g. Namakgale B in Ba-Phalaborwa Local Municipality), employed in other sectors or they have decided to abandon farming as the land is no longer productive under reduced or no rainfall conditions.

Out of those making a living without directly relying on agriculture, 55% are employed in various institutions as house workers, cashiers, police officials, educators and petrol attendance just to name few. About 17% sell fire wood, 2% sell mud bricks, and 17% were street vendors selling various products such as snacks and vegetables. The remaining 10% involved in other activities, such as money lending as a means of income, others rely on children's and old age social grants. Women are the ones mainly involved in selling of mudbricks, firewood and being street vendors.

Financial assets such as social schemes, savings, charity/NGOs, loans/credits would help sufficiently to survive harsh drought conditions. The study shows that 36% of the households did not have access to any of these, with 64% having access to either one, two or even more of these financial assets. Just below half, 45% of the households received financial support during times of drought from extended family members. Assistance from government came in the second place, with 32%, charity/social schemes/NGOs contributed 22% and the remaining 1% got help from private institutions. Household vulnerability in relation to financial resources (Figure 5.9), had 7 households on level 1, 31 households on level 2 and 83 households under level 3, making financial resource the most vulnerable indicator of these community members.

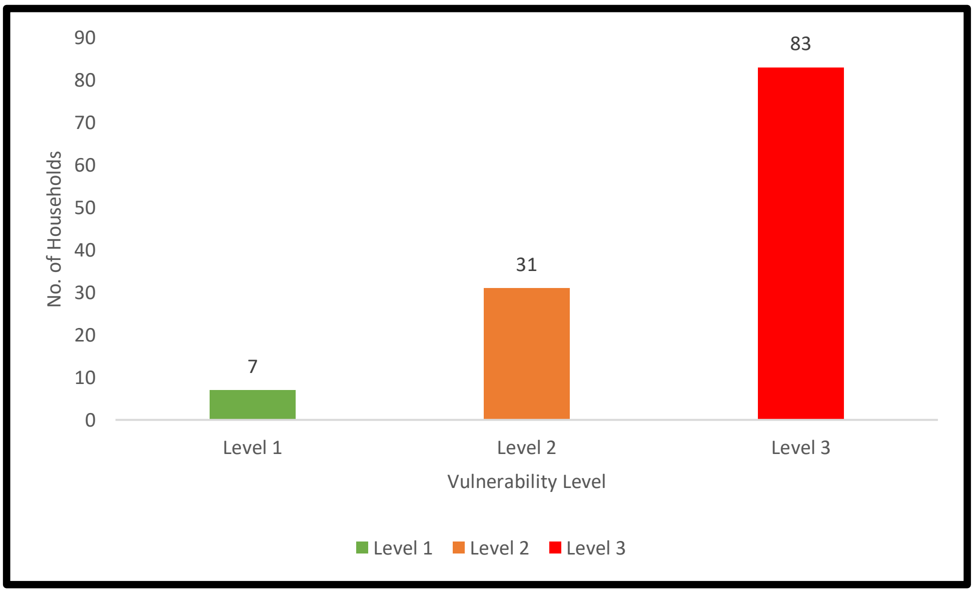

Figure 5. 9 Financial resource HVI for Mopani District Municipality

5.5.4 Natural assets

Although there are ongoing investments on the development of adaptation strategies, access to resources remains the main challenge (Grothmann and Patt, 2005). Natural assets which were examined include possession of arable farm land and its soil condition, size of that arable land, sources of water for agriculture use, distance travelled to fetch water for domestic use and accessibility to these natural resources.

Fertile arable land is a key requirement for guaranteed agricultural produce. Those who have fertile arable land are much likely to have higher production and have a better chance to survive harsh climatic conditions, such as drought. About 65% of the respondents had arable land and 83% of the possessed land was fertile. Much of this land was in the Greater-Letaba and Greater-Tzaneen Local Municipalities. A larger piece of land would ideally mean that the produce could be more if other external factors were favourable.

Water supply is a challenge in most of the communities across Mopani District Municipality daily, and dry drought conditions just make it worse. This challenge originates from poor infrastructure development and abandoned water supply projects. Figure 5.10 shows an example of abandoned water supply project in Tzaneen Local Municipality, where about 20 water tanks with capacity of 10 000 ℓ each have been left erected for no use for over years. In the same municipality, Figure 5.11 shows a dysfunctional borehole which has not been working since 2003 after a experiencing a pump problem. Community members had to travel over an hour to fetch water. Furthermore, Veldkamp *et al*., (2015) found that an increase in water demand as the population grow under a changing climate has resulted in daily challenges around water access.

Figure 5. 10 An abandoned water supply project in Greater-Tzaneen Local Municipality

Figure 5. 11 Dysfunctional borehole in Greater-Tzaneen Local Municipality

About 40% of the respondents had to travel for more than 1 km to fetch water for household use. This included some streets without water in Mokgolobotho village at Tzaneen Local Municipality, Oaks village in Maruleng, Ga-Makhushane village in Ba-Phalaborwa and Gawula village in Greater-Giyani Local Municipality. Due to cultural norms women and children are the ones entrusted with the responsibility to fetching water for household use. Wilhite *et al*., (2007) found that vulnerability of community members increases as the pressure on water and other natural resources increase. In Mogapeng village of Tzaneen Local Municipality, some streets can go for about a month without receiving any water.

However, about 8.5% of the households can afford to drill boreholes in their yards and install tanks for water storage. Community members without boreholes sometimes had to buy water from borehole owners for prices ranging from R1-R3 per 25 ℓ. Ground water plays a crucial role in water supply for most rural communities, where it is accessible. The only challenge is that most of the major ground water aquifers in South Africa are less utilised due to high salinity (Mukheibir and Sparks, 2003). The natural assets indicator categorises 17 households under level 1, 47 households under level 2 and 57 households under level 3 of the household vulnerability index (Figure 5.12)

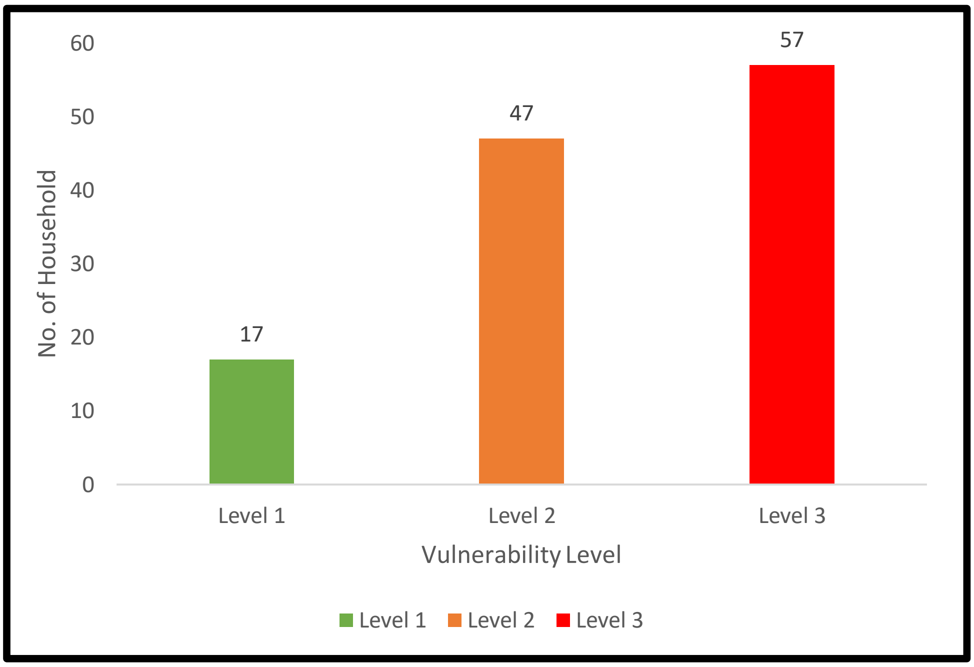

Figure 5. 12 Natural Assets HVI for Mopani District Municipality

5.5.5 Social assets

Social support from extended families and fellow community members was considered as one of the aspects that contributes to household vulnerability. Under social assets, the source of social support, social scheme membership, source of information about upcoming drought hazards, extended family support and access to social service facilities were examined.

Adger *et al*., (2003) found that disruption of social cohesion affects the adaptation capacity of every society. Therefore, being a member of a social scheme serves as a starting point for guaranteed social support which is crucial during times of drought. About 26.4% of households are members of social schemes, while 73.6% are not affiliated to any social scheme. Kasperson (1996), asserted that feasibility in media use to publish climate change information would help attenuate the associated impacts. In Mopani District Municipality, most respondents (97.5%) have reduced vulnerability as they had access to information relating to climate change and associated conditions, such as drought. This information was accessed either through the radio, television, social media, newspapers and government communiques, and they were able to make informed decisions about upcoming drought events. Mpandeli et al., (2015) also found that high rainfall variability in the region has triggered most farmers to rely on seasonal forecasts to plan their growing season. Only 2.5% of the respondents said they were not informed about the upcoming drought events.

Financial support of the extended family members in times of need results in increased household expenditure. About 34.6 % of the respondents indicated that they always supported extended families in times of need, this supports the findings by Mpandeli et al., (2015) which found that some families survived through help from extended families during year 2000 when it was flooding.

The availability of social service facilities, such as health care, public schools and public transport, helped reduce the vulnerability of households during drought hazards. All the respondents indicated that they had full access to all these social service facilities. Under social assets 97 households are level 1, about 22 households in level 2 and 2 households in level 3 (Figure 5.13).

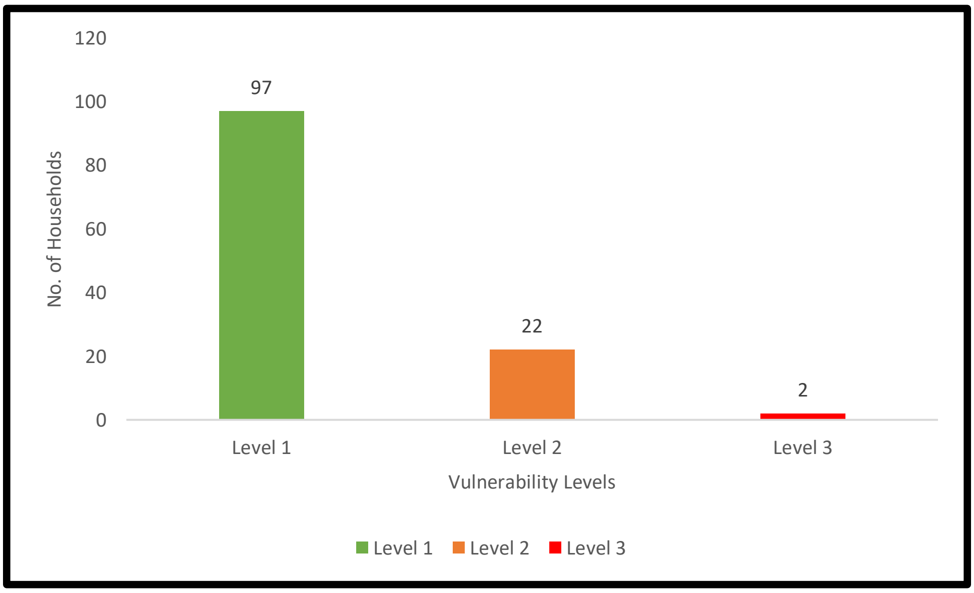

Figure 5. 13 Social Assets HVI for Mopani District Municipality

5.6 Extent of drought vulnerability in Mopani District Municipality

The Household Vulnerability Index was used to measure vulnerability levels across Mopani District Municipality through the five sustainable livelihood indicators (financial assets, physical assets, social assets, human resource and natural assets). The threshold used was 0 -10 for coping level households (CLH) of low vulnerability, 11- 20 for acute level households (ALH) with moderate vulnerability and 21-30 for emergency level households (ELH) with high vulnerability.

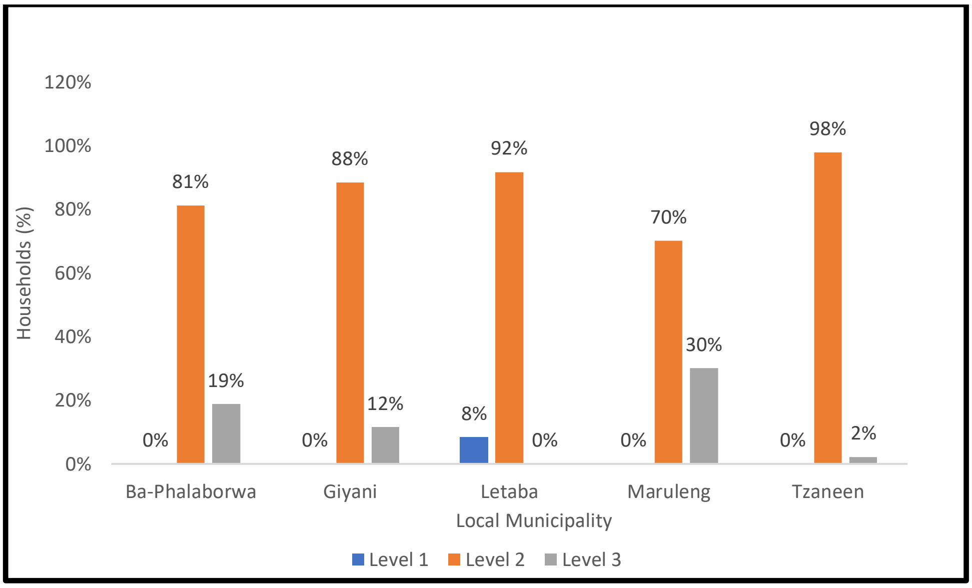

Figure 5. 14 HVI per Local Municipality in Mopani District Municipality

In Ba-phalaborwa Local Municipality, none of the households were on coping level (Figure 5.14), 81% of the households were facing moderate vulnerability at acute level and 19% of the households are faced with high levels of vulnerability on emergency level. Vulnerability levels in Greater-Giyani Local Municipality had no household on coping level, 88% on acute level and 12% of the households were on emergency level. In Greater-Letaba Local Municipality, 8% of the households were on coping level, 92% were faced with moderate vulnerability and none of the households were on emergency level. Maruleng Local Municipality had no households with a low level of vulnerability, 70% had a moderate level and 30% had a high vulnerability. The Greater-Tzaneen Local Municipality also had no households with a low-level vulnerability; 98% of the households had moderate vulnerability and 2% were faced with a high level of vulnerability to drought hazards.

5.7 Household Adaptation to drought in Mopani District Municipality

Adaptation strategies employed across households in the district differ. Adger *et al*., (2003); Mpandeli *et al*., (2015), found that the distinct strategies employed for drought adaptation can either be reactive or impulsive. In some instance the questionnaires administered across the district in the five local municipalities revealed some similarities in adaptation strategies taken by community members. The success of possible adaptation strategies depends mainly on their flexibility and potential to alleviate the cost of disaster, either physically or financially (Smith and Lenhart, 1996).

About 79% of the households are involved in farming activities, livestock farming, crop farming, or mixed farming. Most (83%) of the households involved in farming had been practicing subsistence farming since birth. However, 18 households were forced to abandon their farmlands due to extreme dry conditions. Five of them were in Tzaneen, three in Maruleng, three in the Greater Giyani, four in Ba-Phalaborwa and three in Greater Letaba Local Municipality. About 52% of the households had a means to adapt to these extreme conditions, with most (86%) of the respondents preferring to use indigenous routes to survive, while others (14%) were using modern technologies (farming machinery). Ribot (2002) also found that the use of traditional approaches (indigenous knowledge) remains one of the most successful attempts to conquer climate change threats in many societies.

Increases in temperatures had called for a change in farming practices for community members to survive. Some of these changes included changing from livestock to crop farming or vice versa. This was since some community members argued that the loss endured from livestock farming was better than that of crop farming. The argument was that during harsh drought conditions those with livestock could simply sell some of it at a low price, in order to be able to buy fodder and out-source water where possible. Mpandeli *et al*., (2015) also found that across other districts in Limpopo Province, livestock farmers resorted to destocking during times of uncertain climatic conditions. Adger *et al.*, (2002) also found coinciding results in Zimbabwe, where farmers sold their livestock to reimburse for reduced income associated with low harvest during dry periods.

Two households in Maruleng Local Municipality stated that they preferred growing ground nuts, *habanero* and *serrano* chillies as they thrived better in harsh drought conditions. Five respondents, two from Greater-Giyani and three from Tzaneen Local Municipality had switched to drought-tolerant maize seeds (FNK 2778 and GKC 2147 hybrids) with short growing periods. Mphandeli *et al*., (2015) also recommends a change in farming practice to ploughing drought resistance crops that grows fast as one of the best approaches to adapt to drought hazards.

The same has been done in livestock farming in Maruleng and Ba-Phalaborwa Local Municipalities, where ten community members had the “Nguni” cows which are believed to be drought tolerant, thus, three households from former and seven from latter municipality. Although Panda (2016), recommends taking out an insurance policy, as the best alternative to deal with climate change, none of the respondents had any form of drought insurance. This was either due to limited access to such information or financial constraints.

Water conservation has also become a priority, where farmers try to ensure that they save the little water they have. This has called for the improvement in irrigation system, where most (83%) farmers are opting for drip irrigation under minimal tillage, as it is water efficient. Patt and Gwata, (2002); Hansen *et al.,* (2004), also concurred that the zero-tillage approach helps conserve soil moisture. Figure 5.15 shows one approach to try and save water through irrigation with an artificial watering can.

Figure 5. 15 An artificial watering can used for irrigation to save water in the Greater-Giyani Local Municipality

To avoid excessive burning of crops during fertiliser application, farmers now mix fertilisers with water and thus fertilise plants while irrigating. The crop growing period has now been reduced, to try and avoid the dry months of the year. Mpandeli *et al*., (2015), also found that smallholder farmers have moved to ploughing crops that mature fast to avoid rainfall uncertainties. One farmer in the Greater-Letaba Local Municipality had a water pumping machine, (Figure 5.16) which made use of diesel to pump water. However, the continuous fluctuations in fuel prices affected his production as he could not afford it at sometimes.

Figure 5. 16 Water pumping machine in Greater-Letaba Local Municipality

He added that he had to stop growing tomatoes and focus on chillies, as the chemicals (insecticides) required for tomatoes to thrive under high temperatures were not financially feasible. Nhemachena and Hassan, (2007) also indicated that most farmers in southern Africa are becoming cautious, as the area is becoming drier with notable changes in rainfall timing. Still in Letaba Local Municipality, another farmer outside Ga-Kgapane shopping centre excavated a pond, (Figure 5.17) to get some water to irrigate his crops (cabbage, chillies, beetroot, green beans and tomatoes).

Figure 5. 17 Water pond in Greater-Letaba Local Municipality

Another approach which helps save water is the “double line” planting system on a raised bed (Figure 5.18) where two planting lines were irrigated at the same time. FANRPAN, (2011) found that in most developing countries, there are challenges when dealing with drought as most forms of interventions are not carefully articulated. Local government interventions in Mopani District Municipality include free supply of seeds and fertilisers, selling fodder at a low price and water supply for household use by trucks. Nhemachena and Hassan (2007) also found that local government supports the agricultural sector after occurrence of a natural disaster such as drought to ensure food security and help sustain jobs of those making a living from agricultural sector.

Figure 5. 18 Double line planting system on a raised bed in Greater-Letaba Local Municipality

5.8 Summary

This chapter assessed the impacts of drought on vegetation, water and maize yield. The western highveld of Mopani District Municipality was found to be the most vegetated side using NDVI, and the inter-seasonal changes on water dam level were shown. The overall trend on maize production shows an increase, but this is not the case for subsistence farmers who are faced with a decline in maize production due to drought. Vulnerability levels of community members across Mopani District Municipality in respect to five sustainable livelihood indicators (physical, human, financial, social and natural) were also outlined. Most households are financial vulnerable, and the Greater Tzaneen Local Municipality was the most vulnerable. These impacts trends incite that the normally wet western side of the district is highly impacted by the drought seasons. The community members promote conservation agriculture as they adapt to changing climate that has caused more frequent droughts.

Chapter 6: Conclusion and Recommendations

6.1 Introduction

This chapter covers discussion of key findings, recommendations and conclusion. The main aim of the study was to establish and map the characteristics of drought hazards, analyse impacts, vulnerability levels and adaptation strategies in Mopani District Municipality to contribute towards disaster risk reduction efforts.

6.2 Discussion of Key Findings

6.2.1 Drought Conditions in Mopani District Municipality

The district is subjected to two distinct climatic conditions, with rainfall that increase from the eastern lowveld towards the western highveld. The spatial mean monthly rainfall distribution varies by 38 mm between the western highveld and eastern lowveld. This complement the findings by Maponya, (2013), that Limpopo Province experience variety in rainfall distribution from one district to another and within the districts. Mopani district is subjected to drought conditions of differing categories, Tabrizi *et al.,* (2010) urged that coping with drought requires a good understanding of drought categories and possible links among them. Over the years, the district has also been affected by few tropical cyclones negatively. This affirms Nash *et al*., (2015) findings that with the continued impacts of climate change in southern Africa, tropical cyclone and tropical storm tracks are expected to shift towards the south making a landfall in southern Mozambique and Limpopo Province (Nash *et al*., 2015).

Drought frequency shows an equal distribution between the eastern lowveld and the western highveld. The number of drought seasons are also equivalent to the number of rainy seasons. The western highveld which is normally wet experience more of severe and extreme droughts, while the eastern lowveld is dominated by mild and moderate drought seasons. This supports the finding by Chikoore, (2016) that the normally wet regions are much likely to be affected by drought incidents compared to the relatively all year dry regions.

Evapotranspiration is crucial for energy balance and precipitation (Oki *et al*., 2006), and as such any change in evapotranspiration will have a high impact on the global hydrologic cycle and energy budget (Cong et al., 2009). Global warming was reported as a contributing factor to the 0.13°C decadal increase in Earth's surface air temperature over the past 50 years (IPCC, 2007). This increasing air temperature would make the air temperature dry and induce high evaporation from open water bodies, which will affect the water resources negatively. Nevertheless, over the past 50 years this has not been the case, pan evaporation has shown a decline in some parts of the world (Cong *et al*., 2009). The possible causes of steady decline in pan evaporation could be due to reduced sunlight with increasing cloud cover; increased humidity resulting from decreased vapor pressure and monsoon changes that cause a decrease in wind speed (Peterson *et al*., 1995; Stanhill and Cohen, 2001; Cohen *et al*., 2002).

6.2.2 Impacts of Drought in Mopani District Municipality

Communities across the district are faced with water access challenges daily, in some villages under Maruleng Local Municipality, the only means of water supply it's through water trucks supplied occasionally. FAO, (2004); Owen, (2013) found that the ongoing interventions through investments in dam construction by Limpopo river basin partner countries (Botswana, South Africa, Zimbabwe and Mozambique) to combat water problems are not yet fruitful. Although drought cannot be the only cause of water problems in the district, it has proven to have notable impact on water access across the district, causing dam levels to decline drastically. This correspond to Mosase *et al*., (2019) findings where it was revealed that water challenges in Limpopo are expected to rise as the population increase under changing climate over time. Maponya (2013) also found that Limpopo Province is among the worst areas affected by drought in the recent past, where dams were only 50% full as compared to the 84% capacity in the late 1980s.

Drought impacts on vegetation force those involved in livestock farming across Mopani District Municipality to sell their livestock at a lower price to get the minimum possible profit. This confirms the findings by Mphandeli (2014) where it was revealed that due to 1991/92 drought hazard famers in Vhembe District Municipality had to sell livestock for as low as R5 per unit. Temperature and rainfall changes across Mopani District Municipality have a direct impact on water resources, this has also proved to be the same in Sekhukhune District municipality from a study conducted by Mpandeli *et al*., (2015). In a district with more than 65% of the households declared food insecure (De Cocke *et al*., 2013), any disturbance in the normal agricultural output might cause a severe setback. Maize is a sensitive crop that require consistence moisture supply, the recurring drought incidents has proved to be impacting maize production negatively.

6.2.3 Drought Vulnerability in Mopani District Municipality

The vulnerability levels differ with respect to the livelihood indicators (financial, human, social, physical and natural) considered, most of the household were reported to be more vulnerable with respect to financial assets. About 29% of the households receive monthly income less than R1000,00 which is not enough for survival under the national poverty line of R547,00 per individual as some of the households are comprised of up to ten dependants. De Cocke *et al*., (2013) concurred through findings that revealed Mopani District Municipality as the poorest district in Limpopo Province after compering the average household incomes. There is a strong relationship between single/divorced respondents and vulnerability. The challenges faced during the drought conditions cannot be exclusively linked to natural causes, some of these are just exacerbated conditions which prevails daily as a results of poor service delivery. This corresponds to Meilink *et al.*, (2000) findings about the elevated level of vulnerability in most African countries and low adaptive capacity which is linked to poverty and high reliance on the natural resource for a living. The community members are forced to find means to adapt to harsh climatic conditions, in this pursuit some have decided to rent out their farm lands to make income.

Accessibility to prominent agricultural markets is not convenient for small scale farmers, subsistence farmers across Mopani District fail to transport their produce to prominent markets due to financial constraints and lack of information on regulating procedures. Downing, (2000) also found that most farmers in South Africa have limited access to markets and technology. The offered assistance by the government has not done much to reduce the household vulnerability, FANRPAN (2011) asserted that institutional initiatives are less effective, and most forms of interventions are not carefully articulated to match the needs of those affected. Jamir *et al*., (2013); Panda, (2017) found agricultural insurance, use of herbicides, insecticides and fertilisers as some of the approaches that help reduce subsistence farmers vulnerability to harsh climatic conditions.

However, due to financial constraints, subsistence farmers across Mopani District Municipality could not afford agricultural insurance, making them more vulnerable to drought. The extent of vulnerability changes over time within a society, with new developments in policies, technology, societal behaviours and change on nature of the incident hazard (Wihite, 2000). Communities have introduced some strategies that promote water efficiency to reduce vulnerability, this entails using grey water for crop irrigation and for household duties of convenient. The most vulnerable groups are those that face difficulties in recovering their livelihoods after the occurrence of a disaster. Furthermore, if any subsequent hazardous event occurs, they are most likely to be adversely affected (Blaikie *et al*., 2014).

Although, farmers try to find ways to maintain agricultural production under drought conditions, they are hindered by financial challenges. Mpandeli *et al*., (2015) conquered that most small-scale farmers are limited by financial constrains as they are not even eligible to get loans for support. Pachauri, (2004) asserted that a decrease in agricultural production influenced by climate change would have tremendous impacts on rural communities' vulnerability and livelihoods. Reduced agricultural production has also forced some households to quit farming. This confirmed a study by Maponya *et al*., (2015) which found that some of the farmers have deserted their farm lands and seek for employment opportunities in different industries.

6.2.4 Adaptation to Drought in Mopani District Municipality

The employed adaptation strategies differ from one household to another in respect to their level of vulnerability. Few, (2003) also found that the adaptive capacity depends on the vulnerability of the affected region. However, the adaptation strategies in place have been used over years, some originate from indigenous knowledge systems, Ribot, (2002) also concurred that traditional approaches remain one of the most successful attempts to conquer climate variability and change threats in many societies. Mpandeli *et al*., (2015) highlighted that even though most of the adaptation strategies are developed to survive under short term conditions, they can also be applied when drought recur. In addition to this Washington *et al*., (2005) urged that over time most societies in Sub-tropical Africa have dealt with climate change events such as drought in a progressive manner. Furthermore, Conway, (2008) found that adaptation strategies used during contemporary conditions facilitate an improved understanding of the likely impacts in the future.

Smallholder farmers across Mopani District are relying on conservation agriculture to try and maximise their production. They are making use of drip irrigation and artificial watering can since they are water efficient. This was being done under double line planting system with minimum tillage using drought tolerant seeds. Drought tolerant "Nguni" cows have become the favourite as they adapt well to drought. Patt and Gwata, (2002) also found that farmers apply direct seeding, adjust fertiliser input, use drought-reliant seeds and conserve soil moisture using zero-tillage system as means of coping with drought seasons. Some of the subsistence farmers had access to information about upcoming climatic conditions which help them prepare for the growing season. Mpandeli *et al*., (2015) also urged that farmers need to have information on future seasonal forecast on time in order to prepare for climatic uncertainties. There are government driven initiatives to assist communities in adapting to harsh climatic conditions through supply of fodder at a cheaper retail price.

6.3 Future Work

This study revealed that over the years there has been a change on drought characteristics from lowveld eastern and western highveld of Mopani District Municipality. Therefore, there is a need to try and understand the rationale behind this shift in future research. The frequency of drought has also changed, with drought becoming more frequent in the recent past. This could be linked to the climate change impacts. However, there is a need for a detailed study that will establish this relationship. The adaptation measures in place across the district are helping community members survive to some extent but there is still a need to develop an integrated framework for adaptation strategies that will combine all the measures in place. An investigation that focuses exclusively on water supply service would help improve the water problems that affect most of the communities daily prior to challenges brought by harsh climatic conditions, such as drought.

6.4 Conclusion

Drought is one of the natural disasters of major concern for Mopani District Municipality, this is mainly because most of the community members rely on rain fed agriculture which tend to be troubled during the drought seasons. The intricate nature of drought makes drought characterisation and management difficult. The study revealed that Mopani District Municipality is faced with spatial distinct climatic conditions, the western highveld is wet whereas the eastern lowveld is dry. The same applies with temperature records across the district. The drought impacts on vegetation are more on the eastern lowveld as compared to the western highveld of the District. The 2015-16 drought spell has replaced the 1991/92 as the worst drought with highest temperature in record across South Africa.

Most rural community are faced with exclusion challenges coupled by poor service delivery. They try make living through subsistence means in various sectors of economy. Their farming practice is highly reliant on rainfall and they cannot afford any means of production beyond that. Introduction of drought stress just exacerbate this struggling situation. Climate change is also expected to worsen the challenges of water accessibility that the district is already faced with due to poor service delivery. Mild and moderate drought conditions have proved to be part of the climate variability in Mopani District Municipality.

Over generations various strategies have been deployed to try and adapt to drought conditions with conservation agriculture as the championing approach that has proved to assist subsistence farmers to attain living production during drought seasons. The vulnerability level has been progressive over decades, however, informed decision making, financial assistance, drought hazard-based insurance, advancements in technology, farmers awareness and advanced access to information can reduce vulnerability much sharply. Improvements in early warning systems would also help communities prepare for drought and reduce vulnerability. The impacts of drought vary across the district and different aspects are also affected differently, the vegetation, water bodies and food production (particularly maize) are adversely affected by drought spells. The exposure to drought hazard accessed through five sustainable livelihood indicators (financial assets, social assets, human resource, physical assets and natural assets) revealed that households are more susceptible to financial resources.

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Appendices

Appendix A: Household Questionnaire for Community Members

Aim: The purpose of this questionnaire is to gather information on vulnerability level of the community members and how they adapt to the drought hazards.

Ethical consideration: The information to be collected from these questionnaires is for academic use only. All participants are assured that the information will be treated as confidential and will not be disclosed anyhow without their consent. Participation is voluntary, and the respondents can withdraw at any time they feel like. Please simply put a cross(x) in appropriate box next to the question and give detailed answer where necessary.

Municipality [ ]

Ward No. [ ]

House No. [ ]

Part 1: Vulnerability to Drought Hazards

Section A: Demographic Information

1.1 Gender

Female	1	
Male	2	

1.2 Age

Under 21	1	
21-30	2	
31-40	3	
41-50	4	
51 and above	5	

1.3 Marital status

Single	1	
Married	2	
Divorced/Separated	3	
Widowed	4	
Other (specify)	5	

1.4 Race

Black/African	1	
White	2	
Indian	3	
Colored	4	
Other (specify)	5	

1.5 Highest level of education

No formal education	1	
Primary	2	
Secondary	3	
Tertiary	4	

Section B: Community-Based Asset Weighting

Indicator		**Weight**
Financial Resource	1	
Physical Resources	2	
Social Assets	3	
Human Resource	4	
Natural Resource	5	

Section C: Financial Resources

2.1 Employment status

Employed	1	
Unemployed	2	
Self-employed	3	
Retired/ Pensioner	4	
Other(specify)	5	

2.2 Condition of employment

Short-term contract	1	
Long-term contract	2	
Permanent	3	
Unemployed	4	

2.3 Household average monthly income

Less than R500	1	
R501- R1000	2	
R1001- R5000	3	
R 5001- R10000	4	
R 10001- R15000	5	
R15001 and Above	6	

2.3.1 How many people are contributing to this average monthly income?

………
………
……

2.4 How much do you make from agricultural production trade monthly**?**

Less than R500	1	
R501- R1000	2	
R1001 – R1500	3	
R1501 - R2000	4	

R2001 – R2500	5	
R2501 – R3000	6	
R3001 and Above	7	

2.5 Other sources of income besides agriculture

Selling Firewood	1	
Mud Bricks Selling	2	
Street Vendor	3	
Employed (name of institution/company)	4	
Others: Specify	5	

2.6 Which financial assets do you have access to?

Social Schemes	1	
Savings	2	
Loans/credit	3	
Charity Organizations/NGOs	4	
None	5	
Others (Specify)	6	

2.7 Where do you get most of your financial support during drought period?

Private Institutions	1	
Charity/Social Scheme	2	
Non-Governmental Organizations	3	
Extended Family	4	
Government	5	
Other (specify)	6	

Section D: Physical Assets

3. 1 Which of the following physical assets do you own?

Land	1	
Livestock	2	
Tractor	3	
Car	4	
Electricity/Solar/Generator	5	
Television/ Radio/Phone	6	
House	7	
Other(specify)	8	

3.2 How big is your livestock herd?

Cattle	Goats	Poultry	Sheep	Pigs	Donkeys	Other(specify)

3.3 How far is the nearest service centre?

Less than 1 km	1	
1 – 10 km	2	
11 - 20 km	3	
21 – 30 km	4	
31 – 40 km	5	
41 – 50 km	6	
51 and above	7	

3.4 How Far Is the Nearest Agriculture Market?

Less than 1 km	1	
1 – 10 km	2	
11 - 20 km	3	
31 – 40 km	4	
41 – 50 km	5	
51- 60 km	6	
61 and Above	7	

Section E: Social Assets

4.1 Where do you get most of the social support during drought period?

Private Institutions	1	
Charity/Social Scheme	2	
Non-Governmental Organizations	3	
Extended Family	4	
Government	5	
Other (specify)	6	

4.2 Are you a member of any social scheme?

Yes	1	
No	2	

4.3 Where do you get information regarding upcoming drought hazards?

Radio	1	
Television	2	
Social Media	3	
News Paper	4	
Government Communiqué	5	
Other (specify)	6	

4.4 Do you support any extended family member financially?

Yes	1	
No	2	
Occasionally	3	

4.5 Which of the following social service facilities do you have access to?

Health Care Clinic	1	
Public Schools	2	
Public Transport	3	
Other (specify)	4	

Section F: Human Resources

5.1 What is the size of your household?

Females	**Males**

5.2 How many dependants do you have?

Females	**Males**

5.3 Do you think you have an enough farm labour force?

Yes	1	
No	2	

5.3.1 Justify your answer for the above question

………

………

………

5.4 Do you have family members with any form of disability or terminal illness?

Yes	1	
No	2	

Section G: Natural Assets

6.1 Which of the following resources do you have access to?

Arable farmland	1	
Minerals	2	

Water	3	
Pastures	4	
Others, (specify):	5	

6.2 How much distance do you travel to fetch water for domestic use?

Less than 1 km	1	
1 – 2 km	2	
3 – 4 km	3	
5 km and Above	4	

6.3 Where do you collect water for agricultural use?

River	1	
Tap Water	2	
Springs	3	
Borehole	4	
Dam	5	
Rainwater Harvesting	6	
Other (specify)	7	

6.4 Do you have arable land?

Yes	1	
No	2	

6.4. 1 How big is your arable land?

....

....

6.5 What is the condition of soil quality?

Very Good	1	
Satisfactory	2	
Infertile	3	

Part 2: Adaptation to Drought Hazards

Section H

7.1 Do you practice any farming?

Yes	1	
No	2	

7.1.1 If Yes, what type of farming?

Crop farming	1	
Live-stock farming	2	
Horticulture	3	
Crop and live-stock farming	4	
Other (specify)	5	

7.2 For how many years have you been practicing farming in this area?

……………………………………………………………………………………………………

……………………………………………………………………………………………………

7.3 Do you have any methods to adapt to drought in place?

Yes	1	
No	2	

7.3.1 If Yes, what is your generic form of drought adaptation plans/strategies?

Indigenous	1	
Modern technology practice	2	
Both	3	
None	4	
Other (specify)	5	

7.3.2. Which of these drought adaptation strategies do you have in place?

Change from livestock to crop	1	

Change from crop to livestock	2	
Change the use of fertilizers and pesticides	3	
Improve the irrigation system	4	
Prioritize water conservation	5	
Shorten growing period	6	
Plant different crop	7	
Other (specify):	8	

7.4 Have you changed your farming practice due to drought hazards?

Yes	1	
No	2	

7.4.1 If Yes, what were those changes?

Change in ploughing time	1	
Change in crop/live-stock type	2	
Change in irrigation method	3	
Change in harvest time	4	
Others (specify)	5	

7.5 Do you have any change on crop/live-stock production as result of drought?

Yes	1	
No	2	

7.5.1 If Yes, what impact does the change have on production?

Increased	1	
Reduced	2	
Steady/In-between	3	

7.6 Do you have a drought insurance plan?

Yes	1	
No	2	

7.6.1 Justify your answer above

....
....
....

7.7 Do you receive any compensation from the government for drought loss?

Yes	1	
No	2	

Appendix B: Key Informant Interviews

Government Officials under Disaster Risk Reduction Unit and Department of Agriculture

Aim: The purpose of these questionnaires is to gather information on how the government officials from Disaster Risk Reduction Unit in Mopani District Municipality and local Department of Agriculture contribute to the pursuit of adapting to drought hazards and reducing vulnerability.

Ethical consideration: The information to be collected from these questionnaires is for academic use only. All participants can be assured that the information will be treated as confidential and will not be disclosed anyhow without their consent. Participation is voluntary, and the respondents can withdraw at any time they feel like. Please simply put a cross(x) in appropriate box next to the question and give detailed answer where necessary.

☐ **District Municipality**

☐ **Local Municipality (Specify)** ______________________

1. How do you understand climate change?
2. Are you aware of any recent drought events that have affected your area?
3. What do you think it is the main contributor to the impacts of drought across this district municipality?
4. Was any drought vulnerability and impacts assessment conducted for Mopani District Municipality in the past 30 years (1987-2016)?

4.1 If Yes, are there any improvements in how they deal with drought over time?

5. What is the government's contribution towards reducing community vulnerability to drought?
6. Does the government provide any compensation for any loss attributed to drought?
7. What areas do you think the government should work on to reduce vulnerability and impacts of drought?
8. Do you consider historical disadvantages and contemporary dimensions of social, economic and political oppression in addressing issues of reducing drought hazard vulnerability in different local communities?

9. How are you addressing the five sustainable livelihood indicators (financial, human, social, physical and natural assets) in your attempt to reduce vulnerability to drought hazards? (check the table below for details)

Natural Assets	**Physical Assets**	**Human Capital Assets**	**Financial Assets**	**Social Assets**
Land	Livestock	Farm Labour	Salary	Community Support
Soil	Equipment	Dependents	Savings	Social Welfare Support
Water		Gender Composition	Pension Funds	Access to Information
				Extended Families

10. What are some of the main challenges when dealing with natural hazards in general?
11. How or on what basis do you allocate funds/resources for drought relief during the drought?
12. How is the relationship between policy makers and communities in communicating climate change information?
13. How effective is your local drought mitigation and adaptation plan?
14. Do you have any drought insurance initiatives in place meant for the communities/small hold farmers?
15. How do you consider the need to reduce drought vulnerability and impacts while planning for new developments?
16. How effective are the strategies for dealing with vulnerability and impacts of drought?
17. Should there be multiple hazards at the same time, are the existing models of reducing vulnerability and impacts of drought capable of dealing with the multiple threats?
18. What are some of the usual challenges in effectively communicating climate change information?
19. What are the long-term plans for combating the drought impacts and vulnerability on local communities in relation to the projected population sizes?

Thank You!!! **Thank You!!!** **Thank You!!!**

APPENDIX C: Household Vulnerability Variables

Dimension & Weight	Variable	Theory	Description of variable	Weight given to variable	Transformation
Physical Resources (22)	Physical assets	More physical assets reduce vulnerability	The number of physical assets	8	0 for 3 or more physical assets, and 1 for no physical asset at all.
	Livestock herd	Big livestock herds enable coping in drought conditions	The size of the livestock herd	6	1 for households without cattle, 0 for households with cattle and other livestock and 0.5 for households with other livestock rather than cattle
	Service centre	Nearest service centre help in reducing vulnerability	Distance travelled to the nearest service centre	4	0 for distance ≤ 10 km, 0.5 for 11-49 km and 1 for ≥50km
	Agriculture market	Closest agriculture market aids in efficient sale reducing vulnerability	Distance travelled to the nearest agricultural market	4	0 for distance ≤ 10 km, 0.5 for 11-49 km and 1 for ≥50km
	Household size	Bigger household size increase vulnerability	The size of the household	4	1= household size >10, 0.5 = 6-10 and 0= <5

Human Resources (17)	Number of dependants	The more the dependents, the more the vulnerable the family becomes.	The number of dependants	2	<4 dependents = 0 and >4 dependants =1
	Farm labour force	Huge+ labour force reduce vulnerability	The household's farm labour force	3	1= household with enough farm labour and zero otherwise
	Disability or terminal illness	Disability or terminal illness increase vulnerability	Members of the family with disability or terminal illness	3	1 =household member with disability or terminal illness
Natural Assets (22)	Resource access	Access to more resources reduces vulnerability	Access to resources	7	1= household without access to resource, access to any 3= 0, any 2 = 0.5, and 1 resource =0.75
	Water for domestic usage	Nearby water resource reduce vulnerability	Distance travelled to collect water for domestic usage	4	Less than 1km =0, 1- 4 km =0.5 and ≥5 km =1
	Water for agriculture usage	Rainfed agriculture is more vulnerable to drought	Sources of water for agricultural usage	3	1 for household relying on rainfall, 0.75 for river and 0 otherwise

	Arable land	Those with arable lands are less vulnerable	Possession of arable land	3	0 for arable land possession and 1 for no land
	Size of arable land	Those with big arable lands are less vulnerable	The size of the arable land in possession	4	≥ 2.4 hectares =0 and ≤ 2.3 =1
	Soil condition	Fertile lands are less vulnerable	The condition of the soil on the possessed arable land	4	0 for very good soil, 0.5 for satisfactory condition and 1 for infertile soil
Social Assets (19)	Social support	Those with more social support are less vulnerable	Sources of social support	4	0.5 for private institution, social scheme and NGO, 0.25 for extended family and 0.75 for government support.
	Social scheme	Members of social schemes are less vulnerable	Social scheme membership	3	0 for households with membership and 1 for those without any membership
	Information access	Those with more access to information about upcoming drought are less vulnerable	Access to information about upcoming drought hazards	4	0 for households with any access to information and 1 for no access

	Extended family	Those supporting extended family members are more vulnerable	Financial support of extended family members	3	1 for extended family support, 0,5 for occasional support and 0 for those who don't support extended family
	Social service facilities	Access to social service facilities reduce vulnerability	Access to basic social service facilities	4	0 for households with access to social facilities and 0 otherwise
Financial Resources (21)	Employment status	Employed individuals are less vulnerable	The status of employment	5	0= employed, 0.5 = self-employed, 0.75 = retired/pensioner and 1= unemployed
	Condition of employment	Permanent employed individuals are less vulnerable	The condition of employment	3	1 = not employed, 0= long-term and permanent employment and 0.5 = short-term contract
	Household average monthly income	High household average income reduce vulnerability	Household monthly average income	5	1 = R500-R1000, 0.5 = R1001-R1000, 0.75 = R5001-R10000 and ≥R100001 = 0
	Monthly agricultural profit	High agriculture profit reduce vulnerability	Agriculture monthly profit	5	1 for ≤ R1000, 0.5 for R10001-R3000 and 0 for ≥R30001
	Other sources of income	Alternative sources of income reduce vulnerability	Alternative sources of income other than agriculture	2	0 for any other source and 1 for those without any source of income

	Financial assets	Access to number of financial assets reduce vulnerability	Access to financial assets	4	0 for one or more source of financial assets and 1 for those without any financial asset
	Financial support	Extended financial support reduce vulnerability	Financial support/relief in drought conditions	2	0.5 for those receiving financial support from private institutions, charity and NGO, 0.25 for extended family support and 0.75 for the government

Appendix D: Ethical Clearance Certificate