Rainy season characteristics with reference to maize production for the Luvuvhu River Catchment, Limpopo Province, South Africa

by

Fhulufhelo Phillis Tshililo

Submitted in fulfillment of the academic requirements of

Master of Science in Agriculture

in Agrometeorology
Soil-Plant-Atmosphere-Continuum Research Unit
School of Agricultural, Earth and Environmental Sciences
College of Agriculture, Engineering and Science
University of KwaZulu-Natal
Pietermaritzburg
South Africa

August 2017

PREFACE

The research contained in this dissertation was completed by the candidate while based in the Discipline of Agrometeorology, School of Agricultural, Earth and Environmental Sciences of the College of Agriculture, Engineering, and Science, University of KwaZulu-Natal, Pietermaritzburg, South Africa. The research was financially supported by Agricultural Research Council and Water Research Commission (Project no: K5/2403//4).

The contents of this work have not been submitted in any form to another university and, except where the work of others is acknowledged in the text, the results reported are due to investigations by the candidate.

Professor MJ Savage (Supervisor)

Signed: ……………………..

Date: …………………………

Dr ME Moeletsi (Co-supervisor)

Signed: ……………………..

Date: …………………………

DECLARATION 1: PLAGIARISM

I, Fhulufhelo Phillis Tshililo, declare that:

(i) the research reported in this dissertation, except where otherwise indicated or acknowledged, is my original work;

(ii) this dissertation has not been submitted in full or in part for any degree or examination to any other university;

(iii) this dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons;

(iv) this dissertation does not contain other persons' writing unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

a) their words have been re-written but the general information attributed to them has been referenced;

b) where their exact words have been used, their writing has been placed inside quotation marks, and referenced;

(v) where I have used material for which publications followed, I have indicated in detail my role in the work;

(vi) this dissertation is primarily a collection of material, prepared by myself, published as journal articles or presented as a poster and oral presentations at conferences. In some cases, additional material has been included;

(vii) this dissertation does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the References sections.

Signed: ……………………………

Date: …………………………….

DECLARATION 2: PUBLICATIONS

My role in each paper and presentation is indicated. The * indicates the corresponding author. The paper presented was based on the current project.

Chapter 4

1. Tshililo, F.P*., Savage, M.J., Moeletsi, M.E., 2016. Investigating rainy season characteristics with reference to maize production at the Luvuvhu River Catchment of South Africa. Paper presentation at the 17th WaterNet/WARFSA/GWP-SA Symposium 2016. 26 October 2016. Gaborone, Botswana. The paper was presented by Tshililo FP.

Signed:…………………………..

Date: ……………………………..

ABSTRACT

In arid and semi-arid regions, crop yields are mainly dependent on the amount and spatio-temporal distribution of rainfall. For most smallholder farmers in rural areas of southern Africa, rainfall is a critical input to agricultural production of most staple crops such as maize. To effectively plan for agricultural development, it is of utmost importance that the spatial distribution and temporal variation of rainfall is understood as it govern the type of farming systems that can be practiced in any region. Therefore, a detailed understanding of rainfall is necessary before any farming activities can commence. The study investigated rainy season characteristics with reference to maize production in the Luvuvhu River Catchment. Rainy season characteristics assessed included aridity index, onset, cessation, length of the season, false onset, dry spells, seasonal rainfall, number of rainy days and monthly rainfall. Historical daily rainfall and minimum and maximum air temperature data (1923-2015) were obtained from the Agricultural Research Council. Twelve meteorological stations that were evenly distributed and represented different climatic regions within the catchment were chosen.

An aridity index for different areas of the catchment was calculated using the United Nations Environment Programme equation. Evapotranspiration was calculated using the Hargreaves and Samani equation. Annual rainfall was calculated by summing daily rainfall from 1st January to 31st December. The Instat+ v 3.36 statistical programme was utilized to calculate onset, cessation, and length of the season, the number of rainy days, dry spells, seasonal rainfall and monthly rainfall. The Statistica software was used to generate descriptive statistics as well as to calculate probability of exceedance and non-exceedance for the rainy season characteristics. The Anderson-Darling goodness of fit test was performed to determine the distribution model that best represents the data. The resultant probabilities of exceedance were then computed from the distribution models that best fit the data. A non-parametric Spearman rank correlation coefficient test was used to analyze data for trends in rainy season characteristics as well as monthly rainfall.

The results from the study showed that monthly rainfall at the Luvuvhu River Catchment during the rainy season varies temporally and spatially. In the high rainfall areas of the catchment, the rainy season commences early from the third week of October and ends the first week of April the following year. For dry areas of the catchment, the rainy season commences in the second week of November and ends early in the third week of February. The results further show a decrease in length of the rainy season, the number of rainy days, and seasonal rainfall further away from wet to dry areas of the catchment. There was no significant change on the onset of the rainy season on the catchment for the past 27-90 years. There is a high risk of both short and medium dry spells at most stations during the month of October, with, Folovhodwe, Phafuri and Sigonde being at highest risk. Farmers are therefore advised to use the first onset for land preparation and plant after the second onset in November and December to avoid the high risk of dry spells and false onset in October and November, depending on the location at the catchment. Folovhodwe, Mampakuil, Phafuri and Sigonde have a mean length of rainy season of less than 120 days and seasonal rainfall of less than 500 mm per rainy season. Hence, these areas are not suitable for rain-fed maize in the current climate. However, they are suitable for the production of other crops which may be sold in order to purchase maize. The most favourable sites for maize production within the catchment are Entabeni, Levubu, Lwamondo, Thathe, Tshiombo, and Vreemedeling. Therefore, production should be maximized at these areas so that there is sufficient maize for the whole catchment.

In dry years, stations situated in the low-lying areas in the north-eastern and eastern parts of the catchments receive less rainfall which does not permit planting of maize. In normal and wet years, rainfall is sufficient for the production of various crops. However, in semi-arid areas of the catchment, plans should be made for supplementary water due to high evapotranspiration rates in order to maximize maize production. Stations in the middle/south western parts of the catchment can receive significant rainfall in both dry, normal and wet years. Trend analysis for long-term rainfall data did not show any significant changes in monthly rainfall except for Lwamondo and Levubu where an increasing trend is notable in January rainfall. In December, the rainfall trend was significant at Entabeni, Folovhodwe and Lwamondo. An increase in rainfall is notable at Lwamondo and a decrease in rainfall at Entabeni and Folovhodwe.

Keywords: *Cessation, dry spells, length of the rainy season, onset, rainy days, and seasonal rainfall.*

ACKNOWLEDGEMENTS

I would like to acknowledge the following people and organizations for their support and assistance with this dissertation:

Professor Michael J Savage for supervision and guidance. Your advice really helped in completing the dissertation and will also be useful in future;

Dr. Mokhele E Moeletsi, Agricultural Research Council Institute for Soil Climate and Water (ISCW), for mentorship, advice, and editing the dissertation;

Dr. Mitsuru Tsubo (ISCW), for editing the dissertation;

Agroclimatology staff at ARC-ISCW for support;

Agricultural Research Council Postgraduate Development Programme for funding my studies at the university;

Water Research Commission (Project no: K5/2403//4) for funding the project;

My parents for their everlasting love, encouragement and continuous support during the duration of the study;

My friends for their love and support.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table **Page**

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Rationale for the research

Most socio-economic activities in Africa including South Africa, especially agriculture, depend on climate and specifically rainfall (FAO, 2004). A study in South Africa by Kruger (2006) investigating trends in annual precipitation showed a significant decrease in the northern parts of Limpopo, the southern part of Mpumalanga, north-eastern Free State and western KwaZulu-Natal for period 1910-2004. There have also been changes in monthly rainfall over the past years (Hewitson et al., 2005). Climate variability and change have a direct impact on the productivity of many socio-economic activities (Obasi, 2005). The agricultural sector will be the most affected sector by climate change in South Africa due to its reliance on climate variables such as air temperature and rainfall (Benhin, 2006). The reliance of farmers on rainfall, which varies annually, makes them vulnerable to rainfall variability (Vogel and O' Brien, 2003). Rainfall variability poses a threat to farmers' livelihoods and agricultural production (Ambrosino et al., 2014) as food production in Africa is one of the most vulnerable sectors due to extensive reliance on rain-fed crop production. High intra-and inter-seasonal climate variability, recurrent droughts, and floods that affect both crops and livestock, and persistent poverty that limits the capacity to adapt to climate change also contribute to making Africa vulnerable (Boko et al., 2007). Across the globe, rain-fed agriculture is practiced in 80 % of the agricultural areas. In sub-Saharan Africa, 93 % of the cultivated land is rain-fed. Therefore, rain-fed agriculture plays a significant role in food security (Chikodzi et al., 2012) as water is said to be the limiting factor in agricultural production in South Africa (Maponya, 2011). It has been projected that by 2020, 75-250 million people will be exposed to increased water scarcity and production from rain-fed agriculture could decrease by 50 % (IPCC, 2007).

Regardless of the increase in fertilizer use and improvement in planting technologies, the climate within the growing period still plays a significant role in agricultural production (Ayoade, 2004). Other factors affecting crop production include soil properties and farm management practices (Munodowafa, 2011). However, fertilizer application is critically dependent on rainfall, making rainfall the most important factor affecting crop production as water availability is essential in sustaining crop productivity in rain-fed agriculture (Munodowafa, 2011). Even if drought tolerant cultivars are planted, water will not be available to crops when there is no water in the soil as variations in rainfall from season to season affects soil water availability to crops which then poses crop production risks (Harvest Choice, 2010). Irrigation is said to be an important approach to deal with the current climatic conditions in semi-arid areas as rain-fed agriculture is still dominant in most developing countries (Tilahun, 2006). Rainfall variability and patterns of extremely high or low rainfall are very important for agriculture as well as to the economy of those depending on rain-fed agriculture (Igwenagu, 2015).

Rainy season is defined as that period when a significant amount of rainfall occurs and can vary from place to place (Smith et al., 2008). Rainy season characteristics of importance to agriculture are onset, cessation, and length of the growing season, rainfall amount and the probability of dry spell occurrence during the growing season (Hassan and Stern, 1988). Delayed onset of the rainy season, especially in semi-arid regions of southern Africa, extends the growing period of summer crops into winter (Mubvuma, 2013). However, planting after a false early onset may result in crop failure which leads to expensive re-planting (Ayoade, 2004). Information regarding the onset of rainy season assists farmers with the preparation of land, seeds, manpower and equipment (Omotosho et al., 2000).

Another important feature of the rainy season is the cessation of the season; if cessation occurs early, the crops might experience low cob development resulting in poor harvest (Stern and Coe, 1984). Information on the cessation of rainy season also helps in assessing the possible length of the rain-fed cropping season and provides information on possible information on optimal harvesting and storage of crops (Hachigonta et al., 2008). Heavy rainfall at the end of the rainy season can cause crops to spoil or prevent ripening and harvesting (Stern and Coe, 1984). Yield may be significantly affected by late onset or early cessation of the season as well as damaging dry spells during the season (Ati et al., 2002; Mugalavai et al., 2008). Farmer’s main concerns are for rainfall to be consistent throughout the season so there is guaranteed sufficient soil water at planting and that those conditions are maintained throughout the season (Walter, 1967). If farmers are given information on the seasonal distribution of rainfall, they can choose to plant either more drought-tolerant crops or long maturing varieties (Tadross et al., 2003).

Maize is the largest locally produced crop (Ambrosino et al., 2014) and is the primary staple food in South Africa accounting for around 70 % of caloric human intake (Martin et al., 2000;

Akpalu et al., 2003). Maize is grown extensively under rain-fed conditions in southeastern Africa including South Africa (Akpalu et al., 2003). An analysis of maize production in the last two decades indicated that maize production has either stagnated or declined even though the harvested area has increased (Kandji et al., 2006). Maize can adapt to harsh conditions but high air temperatures and low rainfall could have a serious effect on yield (Akpalu et al., 2003) as rainfall is the most significant driver of maize production. Climate change will not only have negative impacts in South Africa but also southern Africa as a whole since South Africa is the major source of food for the region (Benhin, 2006). South Africa produces 50 % of the total output of maize in southern Africa. Therefore, a decrease in maize yield could increase food insecurity in the region (Akpalu et al., 2003). Information regarding rainfall probabilities and the rainy season is necessary for the design of water supply, supplemental irrigation schemes and for the evaluation of alternative cropping systems under different scenarios, i.e. dry, normal and wet years (Hossain and Anam, 2012).

1.2 Aim

The main aim of this study was to investigate rainy season characteristics with reference to rain-fed maize production in the Luvuvhu River Catchment of Limpopo Province of South Africa using historical data. The rainy season characteristics investigated include onset, cessation length of the rainy season, a number of rainy days, monthly and total seasonal rainfall.

1.3 Objectives

- To investigate the rainy season characteristics using daily historical rainfall data. Changes in the rainy season characteristics such as onset, cessation, length of the season, number of rainy days with reference to rain-fed maize production.
- Characterisation of monthly rainfall during rainy season (October to April) to determine monthly rainfall statistics, trends and probable monthly rainfall amounts under different rainfall scenarios such as dry, normal and wet year with reference to rain-fed maize production.

1.4 Outline of the dissertation

Chapter 1 provides an introduction to the study, detailing the importance of rain-fed agriculture and the effects of the rainy season characteristics on agriculture.

Chapter 2 focuses on the literature review. It focuses on maize production including its importance, planting dates, climatic requirements as well as factors affecting growth at different growth stages. Rainfall variability with the main focus on ENSO and its implication of rainy season characteristics was also reviewed. It also considered different meteorological disasters that occur during the rainy season. Lastly, the chapter reviews climate change as well as its impacts on maize production.

Chapter 3 focuses on the materials and methods used in the study, giving details on the study area, data and how it was analysed. The software and equations used in analysing the data are also explained as well.

Chapter 4 gives the results of the study.

Chapter 5 is the last chapter of the dissertation and includes the conclusion and recommendations of the study as well as further research that can be conducted in the study area to improve maize yield.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Growing season variability is an important indicator of climate change. This is caused by the relationship between climate and growing season characteristics such as onset and cessation (Linderholm et al., 2008). The onset and cessation of rains seems as if they have shifted and will shift even further from their normal calendar dates (ICSU, 2008; Hansen et al., 2012). IPCC (2013) reported that rainfall characteristics such as onset, duration of the rainy season, frequency of dry spells, and rainfall intensity have changed over the years in southern Africa It is expected that the changes will have an impact on crop production especially maize.

2.2 Maize

2.2.1 Importance of maize in the world

Maize (Z*ea mays*) is the most important cereal worldwide with the largest global production (Fischer et al., 2014). Maize is believed to have originated from central Mexico 7000 years ago and is currently being produced in 100 million ha from 125 developed countries (Ranum et al., 2014). Seventy percent of maize produced in developing countries is produced by low and lower middle-income countries (Thornton and Crane, 2012). It is the most important source of food nutrition for millions of people in developing continents such as Africa and Latin America (Smale and Jayne, 2003; IITA, 2009; Fischer at al., 2014). Maize is amongst three most widely grown grain crops in 75 % of these developing countries (Thornton and Crane, 2012). Together with rice and wheat, maize provides at least 32 % in food calories to more than 4.5 billion people in 94 developing countries (Thornton and Crane, 2012). At the continental level, the largest producers of maize are North America (41 %), Asia (28 %), Europe (10 %), South America (10 %) and sub-Saharan Africa (6 %) (Fischer et al., 2014). At the country level, the largest maize producers are USA (38 %), China (20 %), Brazil (7 %) and Mexico (3 %) (Fischer et al., 2014). Although the production of maize in sub-Saharan Africa is low when compared to other countries, maize plays a significant role in food security in eastern and southern Africa and is consumed by 50 % of the population, but it is less important in western and middle Africa as it is mainly used for animal feed (Fischer et al., 2014).

2.2.2 Maize in South Africa

In South Africa, maize constitutes about 70 % of grain production and covers 60 % of the cropping area (Akpalu et al., 2008). Maize is the largest locally produced grain crop in South Africa and is the largest source of carbohydrates in the southern Africa region (DAFF, 2008). Annually, South Africa produces approximately 8 million tons of maize grain on 3.1 million ha with half being white maize for human consumption (du Plesis, 2003). Maize is produced all over South Africa with 84 % of maize produced in the Free State, Mpumalanga, and Northwest (DAFF, 2011). Commercial farmers produce 98 % of maize while the remaining 2 % is produced by small-scale farmers (DAFF, 2011). White maize is generally produced in the western part of the country while yellow maize is produced in the eastern part (DAFF, 2008). Two-thirds of maize in Africa is produced in eastern and southern Africa with South Africa being the largest producer (Nafziger, 2010).

2.2.3 Planting dates

Planting dates of maize are determined by rainfall patterns and weather conditions (Baloyi, 2012). Maize in South Africa is usually planted in November and December and harvested from late May to August. However, depending on the rainfall patterns, maize can be planted as early as October and late in January (Baloyi, 2012). Since South Africa has different climate regions, different planting dates have been suggested for western and eastern maize producing areas (DAFF, 2008). Maize is planted from October to the first week of November in the cooler eastern producing areas (DAFF, 2008). In drier, western producing areas maize is planted from the last two weeks of November to mid-December. From the last week of October to mid-November maize can be planted in the central regions of South Africa (DAFF, 2008).

2.2.4 Factors affecting maize growth

2.2.4.1 Air temperature

Maize is regarded as a warm-weather crop (Whitmore, 2000) which is not suitable in areas where mean daily air temperature can be less than 19 ^{o}C (du Plesis, 2003). Early maturing maize cultivars can reach maturity in 80 to 110 days when mean daily temperature exceeds 19 ^{o}C (Whitmore, 2000). Maize is sensitive to frost occurrence at all stages as it can damage maize growth and thus, it should be grown during a frost-free period and in areas that are less vulnerable to frost (du Plesis, 2003). The optimum air temperature required for successful maize crop growth are 18 to 32 ºC (du Plesis, 2003). Air temperatures directly affect photosynthesis, respiration, transpiration of crop, absorption of water and nutrients (Akbar et al., 2008). The rate of these processes is said to increase with an increase in temperature. Air temperatures above 35 ºC have detrimental effects on maize growth (du Plesis, 2003). Air temperatures less than 10 ºC slows down growth and development (Belfield and Brown, 2008). Ideal temperature for flowering is between 19 to 25 ºC. For germination, the optimum temperatures are 12 ºC or greater (Baloyi, 2012). Optimum flowering occurs when the temperatures range from 19 to 25 ºC. Tasselling occurs best when air temperatures are between 21 and 30 ºC (Belfield and Brown, 2008). High-temperature exceeding 30 ºC causes stagnated growth, wilting, top firing, tassel blask, silking decay, desiccation, pollen abortion, poor seed set which eventually results in yield loss (Akbar et al., 2008).

2.2.4.2 Rainfall

Rainfall is the most important factor affecting crop production especially in dry land farming areas where rainfall is the only source of water for crop production (Ramos, 2001). The quantity of rainfall received at any place over a period of time gives a general picture of its efficiency to meet crop water needs (Weerasinghe, 1989). In semi-arid regions, the yield parameters depend on the amount and temporal distribution of rainfall (Munodowafa, 2011). Maize can be grown under rain-fed or irrigation conditions (Nafziger, 2010). Water is said to be the most yield-limiting factor in maize production. Although maize crop is water-efficient, in order to produce high yields a considerable amount of rainfall is required (Belfield and Brown, 2008). Maize can grow and yields with as little as 300 mm of rainfall per annum (Belfield and Brown, 2008), however, 500 to 700 mm of rainfall is required for adequate soil water annually (DAFF, 2008). Under rain-fed which is the most common cropping system, available plant water is supplied by seasonal rainfall and stored in the soil and thus, maize flourish when planted on soils with high water holding capacity (Nafziger, 2010). The growth of the maize plant is controlled by low and high levels of water as sufficient soil water improves nutrients uptake (Tidsale et al., 1990). When plant available water is low, nutrient availability is limited as low water levels retard the processes that are involved in nutrient uptake such as diffusion. On the other hand, excessive amounts of water results in lack of oxygen which restrict respiration and ion absorption. If maize is subjected to a short drought, it can recover after good rains (Whitmore, 2000). Mid-season drought is more damaging than drought occurrence at the start or end of the season. If drought occurs at the beginning of the season, a farmer might re-plant but if drought occurs in the middle of the season it might be late for the farmer to replant and yield just decreases or total crop failure occurs (Boken et al., 2005).

2.2.4.3 Planting dates

Planting date including all the other factors such as erratic seasonal rainfall and rainfall variability continuously affect maize yield (Kgasago, 2006). Mid-summer drought occurs in Mid-December to mid-January in most part of South Africa hence, the occurrence of mid-summer drought plays an important parts in selecting planting dates (Kgasago, 2006). The farmer has to make sure that the growth stage of maize sensitive to heat and water stresses do not coincide with the mid-summer drought (ARC-GCI, 1999).

An experiment in East Africa showed that planting maize early during the rainy season or even before the rainy season begins produces a higher yield of maize compared to planting later. Maize planted on the 4th of March at Kakamega in Kenya produced 9632 kg ha^{-1} whereas the maize that was planted in April produced 1972kg ha^{-1} (Turner, 1966). A two month delay in planting after the rainy season had commenced caused a reduction in maize yield from 4390 to 2598kg ha^{-1}. At the beginning of the rainy season soil has a flush of nitrogen therefore maize planted early stands a good chance of benefiting from improved supply of nitrogen. Maize planted late receives low rainfall during the most important stage in maize (tasselling to maturity) when compared to maize planted early. Low yield of maize that was planted late was caused by water stress that was experienced during grain forming (Turner, 1966).

2.3 Rainy season characteristics

2.3.1 Onset and cessation

The onset of the rainy season is defined as a time a region receives an accumulated amount of rainfall sufficient for the growing of crops and it is not the first day of rains (Oruonye et al., 2016). Cessation refers to the termination of effective rainfall and does not necessarily mean the last day of rainfall (Oruonye et al., 2016). The onset of the rainy season is the most critical rainy season characteristic as it indicates the start of the growing season and planting date for farmers (Mubvuma, 2013). Early onset of rainfall has been found to be the main cause of longer duration of the rainy season, therefore causing high season rainfall in Free State (Moeletsi and

Walker, 2011). Tadross et al. (2007) noted that onset of the rainfall for the growing season has been occurring late in most parts of the southern African countries. A study prepared by Mubvuma (2013) looking at the rainy season trends for period 1971-2001 in the semi-arid regions of Zimbabwe revealed that the onset of the rainy season has shifted from late October to late November. Chikodzi et al. (2011) showed that over the years the rainy season has been commencing late and ending early and is characterised by increased incidents of mid-season drought. A delay in the onset of rains causes a short growing season and an early onset leads to a longer growing season (Sivakumar, 1988; Mupangwa et al., 2011). A study conducted in Kano region in Nigeria showed that growing season is starting late and ending early, therefore causing a short growing season (Sawa et al., 2014). However, studies by Raes et al. (2004), Mugalavai et al. (2008) and Mupangwa et al. (2011) reported no changes on the onset of the rainy season in western Kenya and Zimbabwe.

2.3.2 Length of growing season period

Growing season is defined as a period in a year in which the rainfall is suitable for crop production and it varies spatially, temporarily and also with crop type (Odekunle, 2003). The length of growing season information is a determinant of crop/cultivar that can be planted in the region (Mavi, 1986). Mapungwa et al. (2011) concluded that the length of the growing season does not have an effect on the amount of rainfall but it can a have an effect on the number of wet days or rainfall events. The average length of the growing season in southern African countries such as Malawi and Zambia was found to be between 90-120 days (Tadross et al., 2007). The longest period of the growing season was found to be 224 days in Matops in Zimbabwe while the shortest was 38 days in Filabusi and Beitbridge in Zimbabwe in the study conducted by Mapungwa et al. (2011). Adamgbe and Ujoh (2013) found 267 days to be the longest duration of the growing season in Ghoko in Nigeria and the shortest length of the rainy season was 146 days in 1983. Mubvuma (2013) noted that the length of the growing season increased when the onset of the rainy season commenced early. For example, the study revealed that the year with the longest growing season of 150 days had an early onset at the end of September while the shortest period of 77 days had a later onset on the 1st of December (Mubvuma, 2013).

Studies conducted by Sikavumar (1988) and Chiduza (1995) also confirmed that there is a strong correlation between onset and the length of the growing season. A study conducted in

Masvingo Province in Zimbabwe by Mubvuma (2013) showed that the length of the growing season has shifted from 120 days to 100 days in Zimbabwe which is not suitable for maize production.

2.3.3 Dry spells

Dry spells are defined as a sequence of dry days bracketed by wet days on both sides (Kumar and Rao, 2005). Dry spell analysis assists in calculating the probability of intra-seasonal drought (Cook et al., 2004). Dry spells result from poor rainfall distribution (Woltering, 2005). Crops do well with consistently spread rains than with heavy rainfall interrupted by long periods of dry spells (Usman and Reason, 2004). A study in Limpopo province revealed that there had been an increase in dry spell frequencies from December to February for 1979-2002 (Reason et al., 2005). A study by Simba et al. (2012) indicated that there is an increase in the length of dry spells with time in Masivingo Province in Zimbabwe. It has been projected that there will be a significant reduction in the number of dry spells for 2014-2070 and 2071-2100 periods for Africa (Bougalia and Sushama, 2013). The results imply that dry spells will occur over a long period and will increase in magnitude for 2041-2070 (Bougalia and Sushama, 2013). A study in the Rushinga District of Zimbabwe by Nyakudya and Stroosnijder (2011) showed that dry spells of more than 20 days occurred in dry to above normal years and not during wet years. A dry season is characterised by a high number of dry spells (Mupangwa et al., 2011). A study by Mzezewa et al. (2010) revealed that there was a high probability of having a 3-day dry spell than 10 and 21-days dry spells at Thohoyandou in the Limpopo Province.

2.3.4 Wet spells

Wet spells are defined as a sequence of rainy days bracketed by dry days on both sides (Kumar and Rao, 2005). A study conducted by Hudson and Jones (2002) revealed that there had been a decrease in the number of wet days per year in southern Africa. Late onset of the rainy season causes a decrease in the number of wet days while an early onset causes a longer growing season (Mupangwa et al., 2011). Frequent and intense wet spells can cause floods, which can lead to crop failure (Reason et al., 2005). Wet seasons were found to be characterised by a high number of wet spells (Mupangwa et al., 2011). A study by Cook et al. (2004) showed that during dry summers there was a decrease in the number of intense wet spells of more than 5 mm per day.

2.3.5 Relationship between rainy season characteristics and maize yield

Perfect timing of the planting dates is one of the key factors which affect crop production in rain-fed agriculture (Raes et al., 2004). A study conducted by Adagmbe and Ujoh (2013) in Nigeria showed that there is a strong relationship between rainy season characteristics and maize yield. A strong correlation was obtained between rainy days (0.747), annual (0.599) and maize yield. Ifabiyi and Omoyosoye (2011) also found a strong correlation between rainy days and maize yield in Nigeria. This means that the higher the number of rainy days the higher the maize yield per hectare (Adagmbe and Ujoh, 2013). Adagmbe and Ujoh (2013) showed a strong relationship between annual rainfall and maize production in Nigeria. This means that annual rainy days and rainfall amount of rainfall has the greatest effect on maize yield (Ifabiyi and Omoyosoye, 2011). However, a study by van Oosterhout (1996) revealed that years with the highest rainfall amount did not have the highest maize yield.

Studies by Stanton and Cammack (1953) indicated that if crops are planted early, the yields will be higher. Low rainfall results in low maize yield (Adagmbe and Ujoh, 2013), but high rainfall does not necessarily cause high yield especially in areas with high rainfall (Usman and Reason, 2004). Poor crop production in semi-arid areas is caused by unreliable rainfall and worsened by high runoff and evaporation (Hensley et al., 2000). A study conducted in southern Africa revealed that there is an increase in mean dry spell length that has caused a decrease in rainy day frequency in Zambia, Malawi and Zimbabwe during the growing season (Tadross et al., 2007). A study by Banziger and Diallo (2001) revealed that there is a relationship between rainfall and average maize yield in eastern and southern Africa, with an increase in rainfall causing an increase in maize production and a decrease in rainfall causing a decrease in maize yield.

2.4 Rainfall variability

2.4.1 El Niño-Southern Oscillation (ENSO)

ENSO is one the most significant causes of climate variability on a yearly basis in southern Africa including South Africa (Nicholson and Selato, 2000; Sheffield and Wood, 2011). ENSO is a naturally occurring global phenomenon which is caused by interactions between ocean and atmosphere in the tropical-subtropical pacific to Indian Ocean (Tyson and Preston-Whyte, 2000). ENSO is characterized by three phases which are El Niño (warm phase), La Niña (cold phase) and the neutral phase (Diaz and Markgraf, 2000; Tyson and Preston-Whyte, 2000). El Niño refers to a large-scale warming of the equatorial eastern and central Pacific Ocean caused by disruption of the ocean-atmosphere system (Figure 2.1) (FAO, 2004). El Niño events last for a period of 12 to 18 months and re-occur irregularly at an interval of two to seven years (Babkina, 2003). La Niña refers to abnormally cold temperatures in the south equatorial Pacific Ocean (FAO, 2004). During La Niña major rainfall producing systems are located over southern Africa and results in above-normal rainfall (Figure 2.2) (Tyson and Preston-Whyte, 2000). During an El Niño, major rainfall producing systems are displaced from the interior to the oceans (Cook, 2000; Tyson and Preston-Whyte, 2000) and therefore result in warm and below normal rainfall in southern Africa (Figure 2.2) (Jury, 2001). During an El Niño, southern Africa is marked by widespread drought conditions (Cook, 2000; Jury and Lyons, 1994).

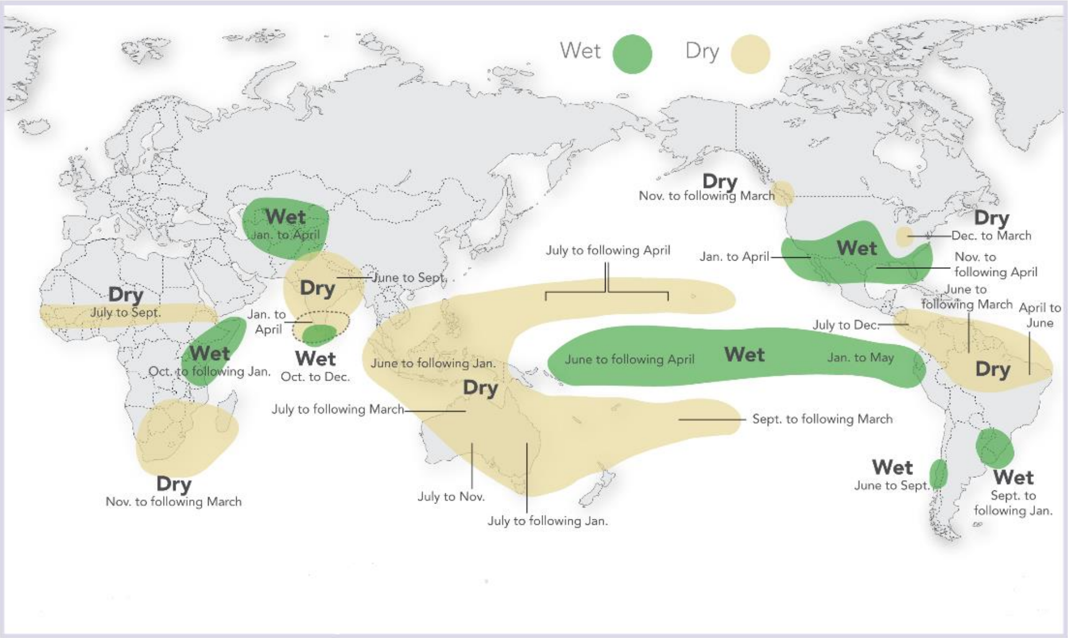


Figure 2.1 Rainfall condition around the world during El Niño event (Source: www.iricolumbia.edu)

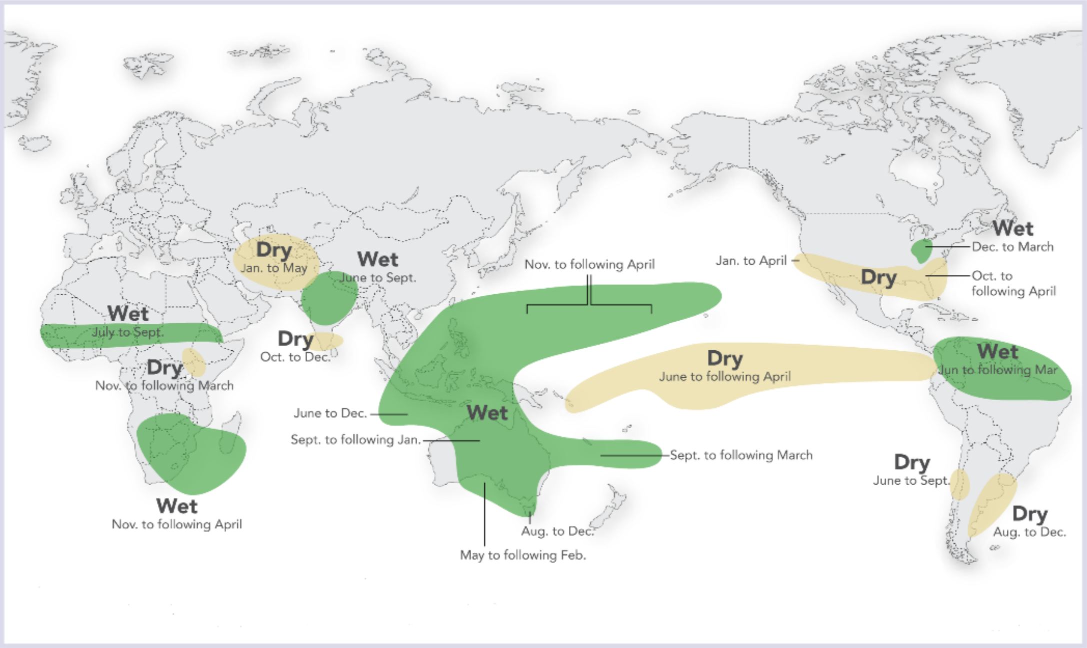


Figure 2.2 Rainfall conditions during La Niña event (Source: www.iricolumbia.edu)

2.4.2 ENSO and rainy season characteristics

South Africa is one of the regions in southern Africa for which rainfall is influenced by ENSO (Reason and Mulenga, 1999; Lindesay et al., 1986; Nicholson and Selato, 2000; Tsubo and Walker, 2007). Different studies such as those done by Lindesay et al. (1986) have shown a relationship between rainfall and ENSO events in eastern and southern Africa. Climatic records in Africa showed that severe droughts that have occurred in certain parts of continents are interrelated to ENSO events (Tadross et al., 2007). El Niño results in decreased rainfall and droughts during summer season (Figure 2.1) (Reason and Jagadheesha, 2005). A decrease in rainfall causes negative impacts on crop production. During the El Niño years, there is a delay in the onset of the rainy season and low seasonal rainfall (Tadross et al., 2003; Moeletsi et al., 2011). A study by Hachigonta and Reason (2006) showed that during El Niño years there was an increase in dry spell frequencies in southern Zambia. La Niña years are characterized by above-normal seasonal rainfall, early onset, and flooding (Figure 2.2) (Tyson and Preston-Whyte, 2000). Low rainfall during El Niño years is caused by a short growing season period (Phillips et al., 1998). A study by Phillips et al. (1998) in Zimbabwe showed that there is a possibility of experiencing short season drought in January during La Niña and El Niño events when compared to neutral years.

2.4.3 Relationship between ENSO and maize yields

A study by Tsubo and Walker (2007) revealed that there is a connection between ENSO and summer rainfall in the Free State province. The results from their study further showed that there is a low risk of planting maize during La Niña years while there is a high risk during El Niño years. The rainfall that occurs during El Niño events is not suitable for crop production. A study by Moeletsi et al. (2011) in the Free State revealed that during El Niño events the length of the growing season tends to be shorter and causes a decrease in total seasonal rainfall. During La Niña events, there is a longer growing season period which results in high seasonal rainfall (Phillips et al., 1998; Nicholson et al., 2000). Results from a study by Moeletsi et al. (2011) in Free States also showed a low production of maize during these El Niño events of 1972/73, 1982/83, 1983/84, 1991/92, and 1994/95. The maize production was reduced from 3 to 1.5 million tons. The above yields imply that during El Niño events the production is 50 % less than the mean in Free State. Moeletsi et al. (2011) concluded that during El Niño years there is low production while during La Niña there is high production of maize. If dry spells occur during the pollination period it can lead to few kernel developing which results in low maize yields (Phillips et al., 1998). Planting early helps in shifting pollination period to December before January dry spells occur. The study by Philips et al. (1998) also showed that simulated maize yield during El Niño events resulted in low maize yields. Planting maize early during both ENSO events (El Niño and La Niña) increases maize yield when compared to neutral years (Phillips et al., 1998).

2.5 Meteorological disasters

Natural disasters are defined as “serious disruptions of the functioning of the society, causing widespread human, material or environmental losses which exceed the capacity of the affected society to cope using only its own resources” (Sivakumar, 2005). Hydro-meteorological disasters include landslides/avalanches, drought/famine, extreme temperatures and heat waves, floods, hurricanes, forest/scrub-fires, wind storms and insect infestations. From 1993-2002 there has been a rising trend in natural disasters (Sivakumar, 2005). For the period 2003-2013, natural disasters and hazards in developing countries affected more than 1.9 billion people and caused damage amounting to USD 494 billion (FAO, 2015). Twenty-two percent of the economic damage and loss caused by climate-related disasters such as floods, drought, and tropical storms is in the agricultural sector (FAO, 2015). Increases in the level of dependency on agriculture, especially rain-fed agriculture, make southern Africa at risk of experiencing climate-related disasters such as floods and drought (Bola et al., 2013).

2.5.1 Drought

Drought is a recurring phenomenon in southern African agricultural climate (Vogel, 1994). Unganai (1994) indicated that it is becoming unusual for drought not to occur somewhere in southern Africa every year. Drought is defined as the period in which there is low/insufficient amount of water in rivers, lakes, reservoirs, soil water and groundwater (Sheffield and Wood, 2011). Drought is classified into four types namely, meteorological, hydrological, and agricultural/soil water and socio-economic (Figure 2.3) (Whitmore, 2000; Boken, 2005). A meteorological drought occurs when seasonal or annual rainfall is lower than the long-term average (Boken, 1995; Whitmore, 2000). Hydrological drought occurs when meteorological drought is prolonged and leads to a decrease in the supply of surface and ground water (Wilhite and Glantz, 1985; Sheffield and Wood, 2011). Agricultural drought occurs when there is a deficit in soil water caused by meteorological and hydrological drought. A socioeconomic drought is a combination of the meteorological, hydrological and agricultural drought which leads to undesirable social and economic impacts (Wilhite and Glantz, 1985; Sheffield and Wood, 2011; Sen, 2015).

2.5.1.1 Causes of drought

Drought is mainly caused by high rainfall variability in South Africa and occurs as a result of below normal rainfall (FAO, 2004). Drought may also be caused by anthropogenic factors such as over-pumping of ground water, diverting rivers and farming intensively in agricultural lands (Sheffield and Wood, 2011). There is a strong relationship between ENSO events and precipitation in areas that are affected by ENSO events. ENSO accounts for 50 % of rainfall variability in eastern and southern Africa (Ogallo, 1994). During an El Niño which is the high phase of ENSO, large parts of southern Africa experience drier than normal conditions. A study by Rasmussen (1987) revealed that from 1875 to 1978 there were 24 ENSO events, 17 events were linked to 10 % decrease in rainfall.

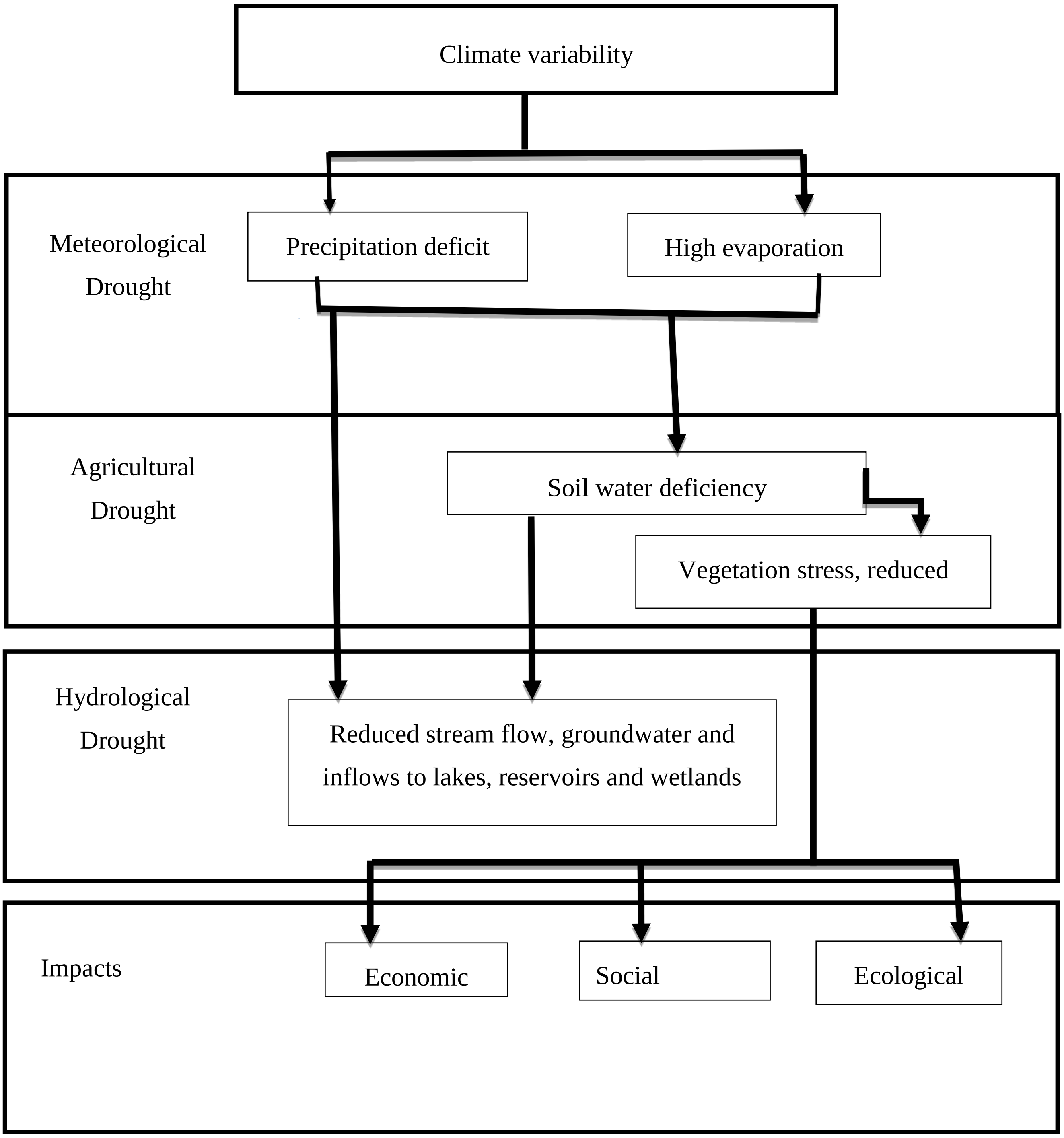


Figure 2.3 Different types of droughts and their connections and impacts (Source: Sheffield and Wood, 2011)

2.5.1.2 Impacts of drought

Drought has both primary and secondary impacts. Primary impacts/physical impacts include a decrease in agricultural production, hydroelectric power generation, water for domestic use (FAO, 2004). Secondary impacts affect the growth domestic product (GDP) which might lead to a decrease in industrial output and then cause an increased inflation rate and retrenchments at workplaces (Vogel et al., 1999). Agriculture is the most affected sector by drought. Twenty-two percent of agricultural debt after the 1992 drought was caused by drought impacts (Vogel, 1994). Impacts of droughts are indicated in Table 2.1.

2.5.2 Floods

Floods are defined as an overflow that comes from a river or other body of water and causes or threatens damage (Chapman, 1994; Smith, 2004), in other words, any relatively high streamflow overtopping the natural or artificial banks in any reach of a stream (Smith, 2004). Floods are regarded as the most common natural disasters in both developed and developing countries (Smith, 1999). Floods are mainly caused by excessive rainfall. Other causes of floods include ice melt, ice jam, landslides, dam failures, storms, and tsunamis (Figure 2.4) (Smith, 2004). Floods can cause damage to life, livelihoods and environment (van Zyl, 2006). From 1980-2010 there have been 77 flood events in South Africa with Eastern Cape, KwaZulu-Natal, North West and Limpopo province being the most vulnerable provinces to flooding (Zuma et al., 2012). The probability of flooding occurring in any given year in South Africa is 83.3 % (Zuma et al., 2012). Floods are part of the earth natural hydrologic cycle and can occur anywhere in the world anytime. Of all types of disasters, floods are the most damaging and demanding of all types of natural disasters (Smith, 2001). Floods can be described according to the water source origin, geography of receiving area, cause and the speed of onset (Smith, 2004). There are different types of floods, namely flash, river, coastal and urban (Figure 2.4).

Table 2.1 Primary and secondary impacts of droughts (Source: Vogel et al., 1999)

Primary impacts	**Secondary impacts**
SOCIAL	
Disrupted distribution of water resources	Migration, resettlement, conflicts between water users
Increased quest for water	Increased conflicts between water users
Marginal lands become unsustainable	Poverty, unemployment
Reduced grazing quality and crop yields	Overstocking; reduced quality of living
Employment lay-offs	Reduced or no income
Increased food insecurity	Malnutrition and famine; civil strife and conflict
Increased pollutant concentrations	Public health risks
Inequitable drought relief	Social unrest, distrust
Increased forest and range fires	Increased threat to human and animal life
Increased urbanization	Social pressure reduced safety
ENVIRONMENTAL	
Increased damage to natural habitats	Loss of biodiversity
Reduced forest, crop, and rangeland productivity	Reduced income and food shortages
Reduced water levels	Lower accessibility to water
Reduced cloud cover	Plant scorching
Increased daytime temperature	Increased fire hazard
Increased evapotranspiration	Crop withering and dying
More dust and sandstorms	Increased soil erosion; increased air pollution
Decreased soil productivity	Desertification and soil degradation (topsoil erosion)
Decreased water resources	Lack of water for feeding and drinking
Reduced water quality	More waterborne diseases
ECONOMIC	
Reduced business with retailers	Increased prices for farming commodities
Food and energy shortages	Drastic price increases; expensive imports/substitutes
Loss of crops for food and income	Increased expense of buying food, loss of income
Reduction of livestock quality	Sale of livestock at reduced market price
Water scarcity	Increased transport costs
Loss of jobs, income, and property	Deepening poverty; increased unemployment
Less income from tourism and recreation	Increased capital shortfall
Forced financial loans	Increased debt; increased credit risk for financial institutions

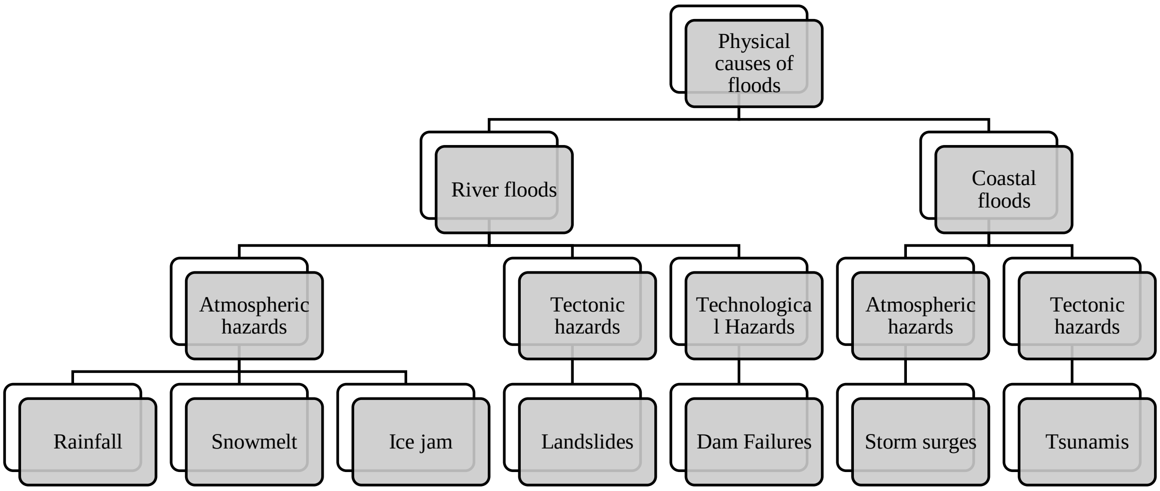


Figure 2.4 The physical causes of floods in relation to other environmental hazards (Source: Smith, 2004)

2.5.2.1 Impacts of flooding

Flooding and its impacts continue to threaten most parts of the developed and developing world, and is viewed as the most frequent and catastrophic disaster that affects human settlements, infrastructures and farming in the flood prone areas (Nelson, 2004). The impacts of flooding vary temporally, spatially, economically, culturally and politically (Johnson, 2003). Impact severity depends on many factors such as physical setting, uses and socio economic status (Johnson, 2003). However, flooding often has significant, damaging effects on agricultural production. The impacts of flooding can either be classified as direct or indirect (Gommes and Negre, 1992). Directs impacts of flooding are those that affect property, income of individual, enterprises and the public sector e.g., loss of life and crops due to flooding (Gommes and Negre, 1992). Indirect impacts of flooding take long and are more widespread geographically and economically, they result from decreased income, environmental degradation and other factors (Gommes and Negre, 1992). The impacts of flooding differ depending on the time of occurrence. Floods can either occur during the growing season or non-growing period (Johnson, 2003). The impacts of flooding during the growing and non-growing period are shown in Table 2.2.

Table 2.2 The impacts of floods during the growing and non-growing period (Source: Johnson, 2003)

Non-growing seasons	**Growing seasons**
Loss of top soil	Waterlogging of crops
Loss of soil nutrient	Lodging of standing crops
Soil compaction	Loss of soil nutrient
Soil erosion	Loss of soil pasture use
Deposition of undesirable materials	Soil erosion
Permanent damage to perennial crops, trees, livestock, buildings and machinery	Greater susceptibility to diseases and insects
Displacement of persons	Interruptions to tillage, planting, crop management and harvesting
Breakage of levees and other retention structures	Permanent damage to perennial crops, trees,livestock, buildings and machinery
Anaerobic processes	Soil temperature reduction and/or retardation
Permanent cessation of farming in floodplains	Necessity of installation of expensive drainage systems
Permanent diversion /realignment of rivers, streams and other bodies of water and settlements	Loss of livestock and/or habitat
Loss of livestock and/or habitat	Grain spoilage, in field and off-site
	Transportation interruptions
	Feedback effect, enhancing precipitation due to large, free-water evaporative surfaces

2.6 Climate change

Africa is regarded as the most vulnerable continent and sensitive to the impacts and risk of climate change and climate variability due to low adaptive capacity (IPCC, 2013). Near-surface temperature in Africa has increased by 0.5 to 2 ºC in the past 100 years (IPCC, 2013).Unlike temperature, precipitation projections are uncertain and exhibit higher spatial and seasonal dependence (Niang et al., 2014). However, it has been projected that southern Africa will experience a decrease in annual precipitation in the mid-21st century (IPCC, 2013). Food production systems in Africa relies on rain-fed crop production, therefore making it the world's most vulnerable to high intra- and inter-seasonal climate variability, recurrent droughts and floods (Book et al., 2007). Intergovernmental Panel on Climate Change (IPCC), (2013) reported that the impact of climate variability and change is at present being felt.

IPCC (2007) projected that agricultural yield would be reduced by 50 % in 2020 while crop net revenue will decrease by 90 % in 2100. Small-scale farmers are the ones that will be affected the most as they lack adaptation means (IPCC, 2013). In Africa agriculture is the main source of livelihood for those residing in rural areas as it provides 60 % of the employment opportunities in Africa and contributes 30 % towards gross domestic product (GDP) (Nhemachena and Hassan, 2007). A study conducted by Benhin et al. (2010) has shown that a decrease in rainfall and an increase in temperatures will have a negative effect on both subsistence and commercial farmers in South Africa. Subsistence farmers are expected to have 151 % loss of net revenue while commercial farmers will have a loss of 111 % by 2080 resulting in significant net loses. The commercial farmers are more likely to have a loss of R694 billion by 2080 as a result of climate change (Benhin et al., 2010). Crop farmers are the ones vulnerable to climate change compared to mixed farmers and livestock farmers (Benhin et al., 2010).

CHAPTER 3: MATERIALS AND METHODS

3.1 Study area

The study was conducted for the Luvuvhu River Catchment (LRC) in the Limpopo Province over the north-eastern part of South Africa. It is located between the latitudes 22°17'33.57" S and 23°17'57.31"S and longitude 29°49'46.16" E and 31°23'32.02" E (Figure 3.1) (Singo et al., 2012). The Luvuvhu River Catchment and Letaba form the Luvuvhu/Letaba water management areas. The Luvuvhu/Letaba water management area is one of the 18 water management areas (WMA) that are recognized by the Department of Water Affairs (Jewitt and Garratt, 2004). The catchment covers an area of 5941 km² and is located on a plateau of about 199 to 1588 m above sea level. The catchment drains into the Limpopo River at the border of Mozambique and Zimbabwe (Singo et al., 2012). Agriculture (vegetables, citrus, and a variety of subtropical fruits such as bananas, avocadoes) is the main pillar of the economy at the catchment (Masupha et al., 2015). There is a large percentage of people practicing subsistence agriculture and residing in informal residential areas as than 50 % of the area of the catchment used for subsistence farming (Jewitt and Garratt, 2006) (Table 3.1). This means that people engage in crop, livestock production and other activities mainly for own consumption.

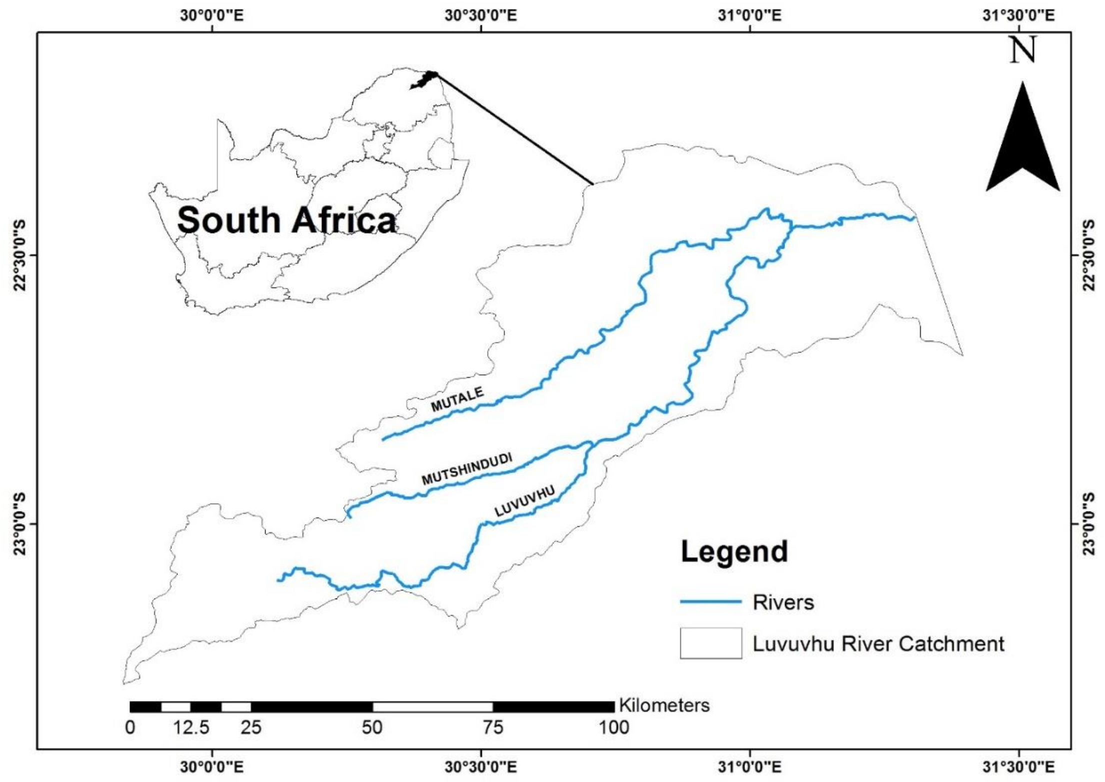


Figure 3.1 Location of the study area

Table 3.1 Land uses at the Luvuvhu River Catchment (Source: Jewitt and Garratt, 2006)

Land use	**Area (%)**
Commercial forestry	4
Subsistence agriculture and grazing	50
Cultivated land (including irrigated lands representing 3%)	13
Protected game reserves areas	30
Urban areas	3

The climate of Luvuvhu River Catchment varies spatially and temporally and is mostly classified as a semi-arid and subtropical catchment (Warburton, 2012). The catchment experiences wet summers from October to April (Singo et al., 2011) and receives peak rainfall in January and February (Dlamini, 2013). Rainfall in the catchment is influenced by topography with high rainfall and low evapotranspiration occurring over the Soutpansberg mountain range and lowest rainfall and high evapotranspiration in the arid areas along the east of the catchment next to Kruger National Park (Jewitt and Garratt, 2004) (Figures 3.2 and 3.3). The catchment receives rainfall of about 450 mm per annum in the low-lying areas (north and eastern part)

(Figure 3.3) and 2300 mm at Entambeni in the Soutpansberg mountain (south-western and northwestern part) (Dlamini, 2013). The mean annual precipitation is 608 mm while the mean annual air temperatures are 17 ^{o}C in mountainous areas and 24 ^{o}C near Kruger National Park (Singo et al., 2011; Warburton, 2012).

3.2 Data acquisition

There are a number of datasets required in assessing the implication of rainy season characteristics on maize production. Data used in the study are explained in the sections that follow.

3.2.1 Daily rainfall and air temperature data

Daily rainfall and air temperature data were obtained from Agricultural Research Council databank. Only stations with data for a period of more than 25 years were chosen. The stations used in the study are shown in Table 3.2 and Figure 3.4. Stations used were spatially distributed across the catchment and were a representative of different climatic conditions within the catchment. Data were arranged using July to June calendar corresponding to the agricultural year.

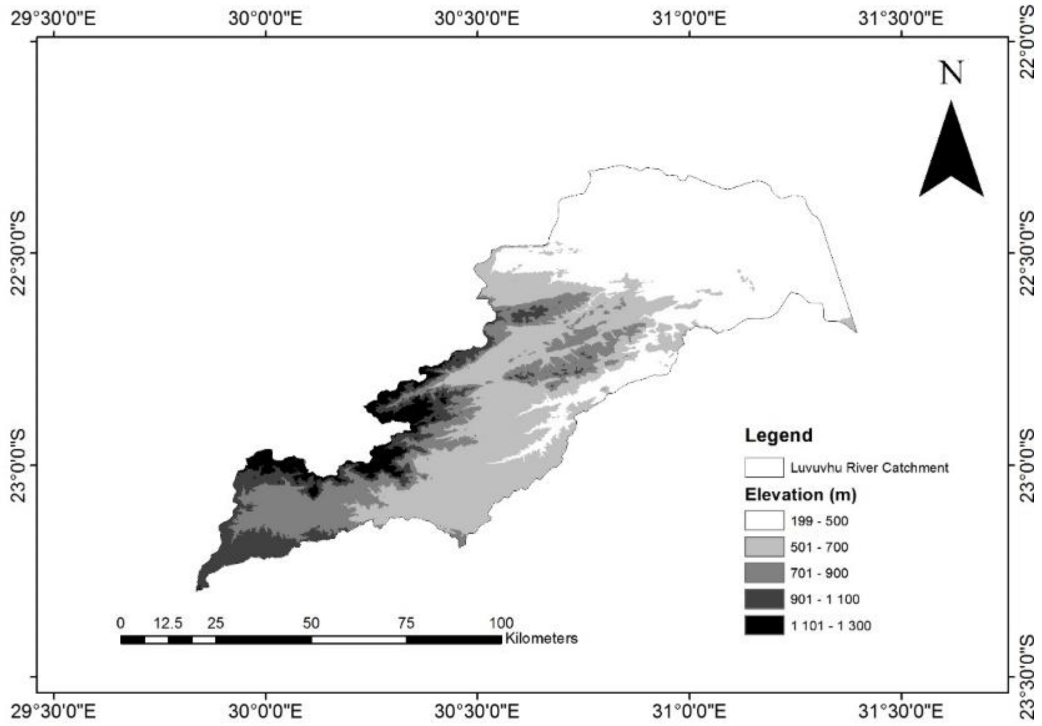


Figure 3.2 Elevation at the Luvuvhu River Catchment

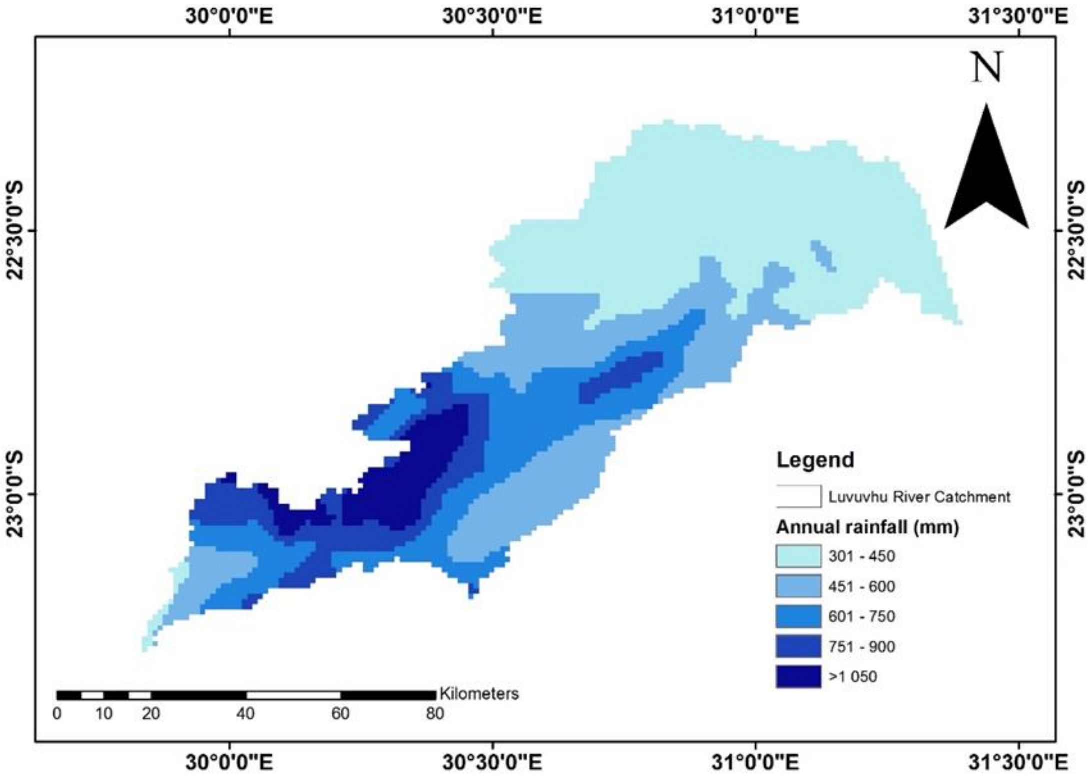


Figure 3.3 Annual rainfall at the Luvuvhu River Catchment

Table 3.2 Geographic information of meteorological stations used in the analysis

Station	Latitude (º)	Longitude (º)	Elevation (m)	Data period
Elim	-23.17	30.05	808	1945-2004
Entabeni	-23.00	30.27	1376	1923-2012
Folovhodwe	-22.53	30.48	610	1954-2004
Levubu	-23.04	30.15	877	1986-2015
Lwamondo	-23.04	30.37	650	1978-2015
Mampakuil	-23.17	29.00	945	1945-2004
Phafuri	-22.42	31.22	201	1970-2004
Phunda Maria	-22.68	31.02	462	1945-2004
Sigonde	-22.40	30.71	416	1983-2015
Thathe	-22.88	30.32	1250	1963-2004
Tshiombo	-22.80	30.48	650	1983-2009
Vreemedeling	-22.96	30.01	1421	1945-2004

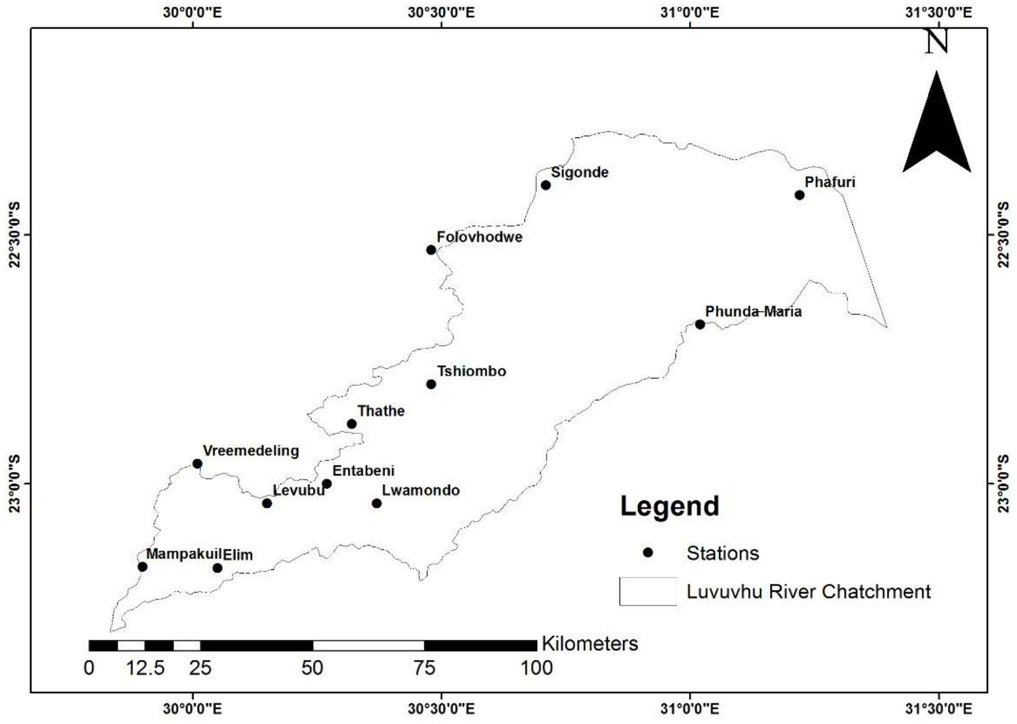


Figure 3.4 Location of meteorological stations within the Luvuvhu River Catchment

3.2.2 Data Patching

All station had missing daily rainfall values for some days. Missing daily rainfall values was estimated using the ARC standalone patching program that makes use of the Inverse Distance Weighting (IDW) method described by Chen and Lui (2012) and Shabalala and Moeletsi (2015). The equations for IDW are given below:

$$R_p \;=\; \sum_{i=1}^{N} w_i\, R_i \tag{3.1}$$

$$w_i \;=\; \frac{d_i^{-\alpha}}{\sum_{i=1}^{N} d_i^{-\alpha}} \tag{3.2}$$

where R_p is the missing rainfall data (mm), R_i is the rainfall of known rainfall stations (mm) , N is a number of rainfall stations, W_i is the weighing of each rainfall station, d_i is the distance from each rainfall station to the unknown site, α is the power and control parameter (Chen and Liu, 2012). Stations within a radius of 50 km and less were used to estimate missing rainfall data. A minimum of five neighbouring stations were used to patch missing daily rainfall values.

3.3 Determination of rainy season characteristics

3.3.1 Dry and rainy days

Meteorologically, a rainy day is defined as any day with total cumulative rainfall of at least 0.85 mm accumulated in one day (Mupangwa et al., 2011). Definitions of the rainy season characteristics in relation to any application are region specific (Ambrosino et al., 2014). A study by Woltering (2005) showed that the Mzinyathini catchment in Zimbabwe experienced a pan evaporation of 4 to 8 mm per day. Hence, a rainfall of 0.85 mm might not have a significant influence on the crop growth. Different authors use different thresholds for dry and rainy days, e.g., Tadross et al. (2007) used a threshold of 2 mm while Mupangwa et al. (2011) used 5 mm and Reason et al. (2005) used 1 mm. This study adopted a threshold of 5 mm. Therefore, dry and rainy days were defined as follows:

- Dry day: any day with a total rainfall of less than 5 mm.
- Rainy day: any day with a total rainfall of 5 mm or more.

3.3.2 Onset, cessation and the length of the rainy season

Onset, cessation, and length of the rainy season are regarded as the most important indices affecting maize production (Tadross et al., 2007). These indices are the ones that should influence the choice of cultivars. The study defined onset as the first day after the 1st October when the accumulated rainfall in 10 days is at least 25 mm (Tadross et al., 2007). The definition used for defining the onset was for farmers and hence no criteria was introduced to account for false onset. Ambrosino et al. (2014) argued that the criteria for avoiding false onset such as one used by Reason et al. (2005), Moeletsi and Walker (2011), Mupangwa et al. (2011), Tongwane and Moeletsi (2014) and Masupha et al. (2015) are useful for retrospective analysis only and of no use to farmers as farmers plant after the first significant rainfall irrespective of what might occur in the following days. Not all farmers plant after the first rainfall for a number of reasons such as unavailability of tractors, manpower, and inputs (Masupha et al., 2015) and oversaturated soil which makes it difficult for the tractor to plough. Therefore three onset dates were generated for each station. The second onset was calculated 7 days after the first onset, while the third onset was calculated 7 days after the second onset. Cessation was defined as three consecutive decades (10 day periods) of less than 20 mm each occurring after 1st February (Tadross et al., 2007). The length of the rainy season was calculated by subtracting the first onset date from the cessation date.

3.3.3 False onset

In order to calculate the risk of the first onset date being a false onset, a further criterion was introduced to account for a false onset. Thus the second definition of onset was defined as the first day after which 25 mm or more of rainfall accumulates in 10 days and in the following 20 days 20 mm of rainfall is accumulated. Twenty millimeters of rainfall in the next 20 days guarantees that the maize has enough soil water to sustain crop growth in the first 30 days (Moeletsi and Walker, 2011). Results obtained using the two definitions were then compared. The study assumed that planting would have failed if in the following 20 days the amount of rainfall was less than 20 mm for that year. For example, if results generated by the two definitions are different, then planting would have failed in that particular year. The percentage of failure was determined for all stations within the catchment.

3.3.4 Dry spells

The Instat^{+} V 3.36 statistical programme was used to calculate the length of dry spells in October, November, December, and January. Dry spells were classified into three categories namely short (> 7 days), medium (> 14 days) and long (> 21 days). The risk of a short, medium and long dry spell occurring in October, November, December and January was calculated using the Instat $^+$ V 3.36 statistical programme.

3.3.5 Monthly rainfall

Rainfall data analysis is dependent on its distribution pattern (Sharma and Singh, 2010). The most commonly used probability distributions include normal, lognormal, gamma, Weibull, and Gumbell. Probability distributions are widely used in understanding the rainfall pattern and computation of probabilities as it is thought that rainfall events follow a particular type of distribution (Abdullah and Al-Mazroui, 1998).

A goodness of fit test based on the Anderson-Darling at 0.05 level of significance was used to determine the best probabilistic distribution model that fit the monthly rainfall data. The Anderson-Darling Statistics (A^2) is given by:

$$A^2 \;= -n \frac{1}{n} \sum_{i=1}^{n} (2i-1).\left[lnF(X_i\ ) + ln\big(1 - F(X_{n-i+1})\big)\right] \qquad (3.3)$$

$i = 1, 2, 3 \ldots\ldots n$

where n is the sample size, F is cumulative distribution function of probability distribution and X_i is the ordered observations (Stephens, 1974).

The Anderson-Darling statistic measures how well the data follow a particular distribution. The corresponding p-value was used to test whether the data come from a chosen distribution. If the p-value is less than 0.05, the null hypothesis that the data comes from that distribution is rejected (Mzezewa et al., 2010). The p-value with the greatest magnitude was considered to be the best fit. Monthly rainfall data were fitted into four probability distributions, namely normal (N), lognormal (LN), weibull (W) and generalized extreme value (GEV) (Table 3.3).

Table 3.3 Probability distribution models used in the study (Source: Mzezewa et al., 2010)

Distributions	Probability density function	Parameter description
Normal	$F(x) = n(x;\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-0.5\left(\frac{x-\mu}{\sigma}\right)^2\right]$ $-\infty \leq x \leq \infty$	μ = mean of population σ = standard deviation of the population x
Lognormal	$Y = \frac{1}{\sigma_y\sqrt{2}\pi} \exp\left[0.5\left(\frac{y-\mu}{\sigma}\right)^2\right]$ $0 \leq x \leq \infty$	$Y = ln\, x$ σ_y = is the standard deviation of lnx μ = is the mean of $ln\, x$
Weibull	$F(x) = \frac{\propto}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1} \exp\left(-\left[\frac{x}{\beta}\right]^{\alpha}\right)$ for $0 \leq x \leq \infty$	α = is the scale parameter β = is the shape parameter of the distribution
Generalised extreme value	$\mathrm{F}(x;\mu,\sigma,\varepsilon) = \exp\left\{-\left[1+\varepsilon\left(\frac{x-\mu}{\sigma}\right)^{\frac{-1}{\varepsilon}}\right]\right\}$	ε = extreme value shape parameter μ = location parameter σ = scale parameter

3.3.6 Aridity index

Agro-climatic zonation for the catchment was calculated using UNEP (1992) aridity index (AI) equation represented by:

$$AI = \frac{P}{ET_o} \tag{3.4}$$

where P is the mean annual rainfall and ET_o is the mean annual evapotranspiration. According to UNEP classification AI < 0.05 represents a hyper-arid zone, 0.05 to 0.20 represents arid zone, 0.20 to 0.50 represents semiarid zone, 0.50 to 0.65 is a sub-humid zone and greater than 0.65 represents a humid zone.

Mean annual rainfall was calculated from daily rainfall data. Daily ET_o was calculated using the Hargreaves and Samani (1982) equation given by:

$$ET_o = 0.0135\,(KT)(R_a)(TD)^{0.5}(TC + 17.8) \tag{3.5}$$

where $TD = T_{max} - T_{min}$ (^oC) is the decimal air temperature range, TC is the average daily temperature (^oC) and R_a is the extra-terrestrial radiation (mm/day) and KT is empirical coefficient. Hargreaves (1994) recommended using $KT = 0.162$ for "interior" regions and $KT = 0.19$ for coastal regions. Although the Hargreaves and Samani (1982) method may overestimate (Sheffield et al., 2012), the equation has been successfully used in some locations for estimating ET_o where sufficient data were not available to use other methods (Orang et al., 1995).

3.4. Data analysis

3.4.1 Statistical analysis

Using the definitions of rainy season characteristics, Instat$^+$ V 3.36 was used to analyze daily rainfall data for onset, cessation, and length of the rainy season, false onset, total seasonal rainfall, monthly rainfall and a number of rainy days. Years in which onset of rains occurred after the 31st January were regarded as years in which rainfall did not meet the onset criterion and therefore they were not included in the analysis. Descriptive statistics such as mean, coefficient of variation (CV), standard deviation (STD), skewness coefficient (C_s) and kurtosis coefficient (C_k) were calculated for monthly rainfall data from October to April using Statistica Software.

3.4.2 Probabilities of exceedance and non-exceedance

Probabilities of non-exceedance for onset, length of the season, the number of rainy days, seasonal rainfall and monthly rainfall were calculated using Statistica statistical software. For onset 20, 50 and 80 % were used to indicate early, normal and late onset of the rainy season respectively. Cessation of the rainy season was represented by probability of exceedance, with 80, 50, and 20 % indicating early, normal and late cessation of the rainy season. Twenty percent (20 %) probability of non-exceedance was used as an indicator for short season, while 50 and 80 % were used to represent normal season and a long season in that order. For seasonal rainfall, the probabilities of non-exceedance were used to represent the dry, normal and rainy seasons. Monthly probabilities of non-exceedance at 20, 50, and 80 % were determined and represented wet years, normal years and dry years respectively. The return period (T) is the period expressed in a number of years in which the monthly rainfall observation is expected to return. It is calculated according to the following equation:

$$T = \frac{1}{P} \tag{3.6}$$

where P is exceedance probability (i.e. the probability that a given monthly rainfall is equaled or exceeded).

3.4.3 Trends

Spearman's rank correlation coefficient test was conducted to detect trends in rainy season characteristics over the years. The Spearman rank correlation coefficient is a non-parametric test used for evaluating the relationship between two independent variables (Gauthier, 2001). It is similar to the Pearson Product Moment. The only difference is that the Spearman test operates on the ranks of data rather than raw data (Gauthier, 2001). The reason why the Spearman rank was used is that it is a non-parametric technique unaffected by the distribution of the data. The Spearman rank correlation was calculated using the following equation:

$$r_s = 1 - \frac{6\sum d_i^2}{n^3 - n} \tag{3.7}$$

where d_i is the difference between ranks for each x_i, y_i data pair and n is the number of data pairs. The value of r_s can be any value between -1 and 1. When the value of r_s is equal to 1, the data pairs have a perfect positive correlation ($d_i = 0$) and when it is -1 there is a perfect negative correlation (Gauthier, 2001). A negative value indicates a decreasing trend and a positive value an increasing trend. For this study r_s values will be interpreted as follows:

- 0.0 to 0.2 very weak
- 0.2 to 0.4 weak
- 0.4 to 0.6 moderate
- 0.4 to 0.8 strong
- 0.9 to 1.0 very strong

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Onset of the rainy season

4.1.1 Early, normal and late onset dates

Generated three onset dates at 20, 50 and 80 % probability of non-exceedance are shown in Table 4.1. The first significant rainfall for the rainy season was observed to occur early in the first week of October at Entabeni, Levubu, and Lwamondo and later in the second week of December at Elim, Folovhodwe, Phafuri and Sigonde (Table 4.1). At 20 % probability of non-exceedance, onset can be expected from the first week of October to the third week of November depending on the location within the catchment. At 50 % probability of non-exceedance, onset can be expected to occur from the second week of October at Entabeni, Levubu and Thathe to the second week of November at Folovhodwe. Late first onset corresponding to 80 % probability of non-exceedance can be expected from the last week of October to the second week of December (Table 4.1).

Due to unavailability of tractors, shortage of seeds, personal reasons and for variation purposes, farmers might not plant immediately after the first rains of the season, indicating that these farmers will delay a few more days before they plant. Hence, the second onset was calculated. The second rains at 20, 50 and 80 % probability of non-exceedance of the season can be expected from the third week of October to the last week of December depending on the location (Table 4.1). At 20 % probability of non-exceedance, second onset occurs from the third week of October to the second week of November. At 50 % probability of non-exceedance, second rains for the season can be expected from the last week of October to the first week of December. Late onset can be expected from the second week of November to the last week of December.

The third onset of rains for the season can be expected from the last week of October to the third week of January depending on the location. In one out of five years, the third onset can be expected from the last week of October to the first week of December at the catchment. In one out of two years, the third rains for the season can be expected from the second week of November to the last week of December. In four out of five years, third rains of the season can be expected from the last week of December to the second week of January.

Table 4.1 Early (20 %) probability of non-exceedance, normal (50 %) and late (80 %) onset dates for 12 meteorological stations at the Luvuvhu River Catchment

	First onset				**Second onset**				**Third onset**			
Stations	**Early**	**Normal**	**Late**	**STD (days)**	**Early**	**Normal**	**Late**	**STD (days)**	**Early**	**Normal**	**Late**	**STD (days)**
Elim	11/10	19/11	09/12	16	29/10	15/11	01/12	16	13/11	02/12	15/12	12
Entabeni	06/10	13/10	22/10	11	18/10	30/10	12/11	12	03/11	13/11	26/11	11
Folovhodwe	18/11	11/11	09/12	21	08/11	05/12	28/12	16	01/12	28/12	18/01	13
Levubu	06/10	13/10	24/10	11	19/10	28/10	14/11	11	31/10	11/11	27/11	10
Lwamondo	06/10	19/10	09/11	18	19/10	11/11	28/11	16	31/10	22/11	12/12	15
Mampakuil	16/10	03/11	21/11	16	06/11	24/11	14/12	14	24/11	10/12	28/12	12
Phafuri	13/10	04/11	08/12	21	12/11	03/12	01/01	18	29/11	25/12	17/01	13
Phunda Maria	19/10	03/11	25/11	16	11/11	24/11	18/12	12	28/11	20/12	15/01	14
Sigonde	20/11	14/11	07/12	18	07/11	03/12	08/12	17	28/11	13/12	16/01	13
Thathe	08/10	15/10	30/10	17	20/10	04/11	16/11	14	02/11	15/11	03/01	14
Tshiombo	12/10	24/10	04/11	15	16/10	11/11	25/11	14	13/11	27/11	19/12	11
Vreemedeling	12/10	21/10	09/11	13	03/11	17/11	02/12	13	18/11	03/12	19/12	12

The results from this study show that stations situated in high rainfall regions area experiences onset earlier compared to those situated in the dry low-lying areas of the catchment. This was also demonstrated in a study by Sithole (2010) where an early onset occurred in wet areas and late in dry areas in Zimbabwe, implying that onset of the rainy season is influenced by rainfall distribution which is influenced by topography. For example, an early onset occurs at Entabeni which is situated along the Soutpansburg mountain range receiving more than 1735 mm of annual rainfall. Late onset occurs at Folovhodwe, Phafuri and Sigonde situated in the dry low-lying areas of the catchment receiving less 500 mm of annual rainfall. These results are also consistent with the results from Aviad et al. (2004) and Mupangwa et al. (2012) which indicated that onset of the rainy season commences later as aridity increases. Onset dates varied by between 3 and 6 weeks depending on the location within the catchment.

It has been demonstrated that planting on the date corresponding to 20 % probability of non-exceedance has a high probability of a false onset, as there might not be enough rainfall to sustain maize until vegetative stages and might lead to crop failure (Moeletsi et al., 2012). Farmers are advised not to plant on dates corresponding to 20 % probability of non-exceedance. Raes et al. (2004) stated that planting later in the season on dates corresponding to 80 % probability of non-exceedance reduced the risk of crop failure and shortened the season but early maturing varieties are recommended as late planting shortens the season and crops might not reach maturity if late varieties are planted. However, farmers who intend to sell their maize for high profit can plant on this date, provided they have alternative sources of water such as rainwater harvesting technologies and irrigation systems (Moeletsi and Walker, 2012). Farmers can obtain high profits before maize is more readily available and decreases once it is more readily available in the markets (Raes et al., 2004). Onset varied by nearly a month between wet and dry areas of the catchment, demonstrating farmers in wet areas plant maize a month earlier than farmers in arid areas of the catchment. A study by Masupha et al. (2015) investigating probabilities of dry spells indicated that when planting is done after the second and third onset, there is a low probability of medium and dry spells in the Luvuvhu River Catchment. Farmers are therefore advised to plant following the second onset of rains and use the first onset for planning purposes, gathering of tools, seeds, and manpower.

4.1.2 Trends

Spearman rank correlation coefficient test results indicated that there was no significant change in all three onset dates at the Luvuvhu River Catchment except for Phafuri. Therefore, the onset of the rainy season has not changed over the years in most areas of the catchment (Table 4.2). Increasing trend is also notable at Phafuri ($r_s = 0.34$) for the third onset, indicating that for this area, onset of rains has shifted forward by a few days (Figure 4.2). Therefore, the onset of the rainy season has not changed over the years (Table 4.2). Although not significant statistically, there is a decreasing trend notable at Sigonde ($r_s = -0.29$) for the second onset. This indicates that over the years second rains of the season have been occurring earlier than before and therefore lengthening the rainy season.

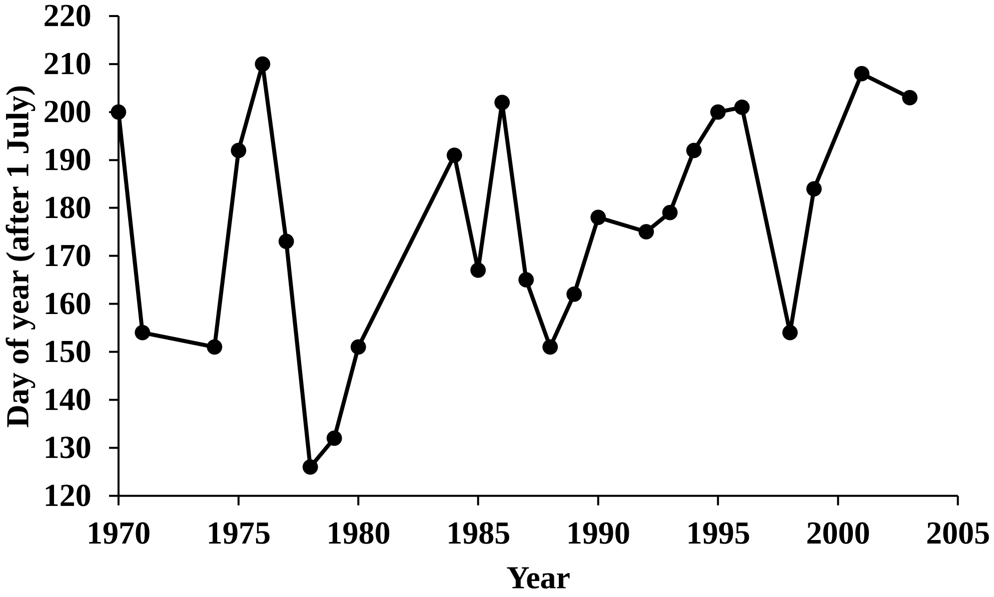


Figure 4.1 Temporal variation in the third onset dates at Phafuri

Table 4.2 Spearman rank correlation coefficient test results for first, second and third onsets within the Luvuvhu River Catchment

Stations	**First onset**			**Second onset**			**Third onset**		
Spearman rank	**t-stat**	**P-value**	r_s	**t-stat**	**P-value**	r_s	**t-stat**	**P-value**	r_s
Elim	-0.64	0.52	-0.08	-1.03	0.30	-0.13	0.05	0.95	0.00
Entabeni	0.25	0.79	0.02	1.07	0.28	0.11	0.75	0.45	0.08
Folovhodwe	-1.4	1.60	-0.18	-0.69	0.49	-0.10	0.40	0.68	0.07
Levubu	1.12	0.26	0.19	0.95	0.34	0.16	-0.08	0.93	-0.01
Lwamondo	1.17	0.24	0.19	1.22	0.22	0.20	1.09	0.28	0.18
Mampakuil	-0.13	0.89	0.01	0.55	0.57	0.07	1.17	0.24	0.16
Phafuri	-0.20	0.84	-0.03	0.96	0.34	0.18	1.77	0.08	0.34**
Phunda Maria	-1.7	0.08	-0.23	0.05	0.95	0.00	0.56	0.57	0.08
Sigonde	-0.88	0.38	-0.16	-1.08	0.28	-0.29	-0.05	0.95	-0.01
Thathe	1.13	0.26	0.18	0.23	0.81	0.03	0.93	0.35	0.15
Tshiombo	0.59	0.55	0.11	1.00	0.32	0.19	0.30	0.76	0.06
Vreemedeling	-0.59	0.55	-0.07	-0.18	0.85	-0.02	-0.12	0.90	-0.01

*Significant at 5 %, ** significant at 10 %

4.1.3 False onset

The number of years with false onset are shown in Table 4.3 and Appendix 1-12. The number of years with false onset increases as one moves from stations situated in high rainfall areas to arid areas (Table 4.3). Levubu had 0 % risk of false onset occurrence, therefore maize planted at Levubu is less prone to shortages of soil water. Phafuri had the highest number of years with false onset while Entabeni had relatively low chances (4 %) (Table 4.3). For years analysed, planting failed in four out of 90 years at Entabeni and a farmer can only wait for seven days before planting was possible after the first onset. At Phafuri planting failed in 18 of out 34 years. Therefore, the risk of false onset is estimated to be 55 % and the area has a high risk of crop failure if planting is done after the first onset. For other years in which planting would have failed farmers had to wait between 33-71 days for successful planting. At Sigonde, Lwamondo, and Tshiombo farmers had to wait about 29-64 days before successful planting implying high vulnerability at these places.

During the 1970/71 rainy season, farmers would have waited for seven days before they could have re-planted if they had planted after the first onset. If farmers had planted in those years with false onset, it would have resulted in total crop failure and needed expensive re-planting. Therefore, farmers at Phafuri and Sigonde are advised not to plant after the first onset as there is a high risk of crop failure. However, if farmers at these areas want to plant after the first onset they should explore other options such as rainwater harvesting so that during dry spells they have water for plants.

4.2 Cessation of the rainy season

4.2.1 Early, normal and late cessation

Calculated early, normal and late cessation dates are presented in Table 4.4. Cessation of the rainy season can be expected from the first week of February to the first week of May depending on the location at the catchment (Table 4.4). At the 80 % level of probability of exceedance, cessation can be expected in or after the first week of February at Phafuri, Sigonde, Phunda Maria, and Folovhodwe and Mampakuil. Early cessation of rains can subject the maize to high risk of water stress as maize planted might not reach maturity (Moeletsi and Walker, 2012) especially if rains end in the first week of February. When considering a 120-day maize crop, if it was planted in November, by the first week of February it would not have reached maturity, indicating that in four out of five year's maize will not reach maturity if late maturing varieties are planted.

Table 4.3 Number of years with false onset at stations within the Luvuvhu River Catchment

Stations	No of years with false onset	No of years analysed	Percentage (%)
Entabeni	4	90	4
Levubu	0	34	0
Lwamondo	9	38	23
Tshiombo	7	27	26
Phafuri	18	34	55
Sigonde	10	32	31
Mampakuil	15	59	25
Elim	16	59	27
Thathe	5	40	13
Phunda Maria	20	59	34
Folovhodwe	19	59	32
Vreemedeling	20	59	28

Normal cessation of rainy season can be expected after the third week of February at Folovhodwe, Phunda Maria, Sigonde, Mampakuil and Phafuri to the 2nd week of April at Entabeni (Table 4.4). At Levubu cessation can be expected after the first week of April. Late cessation (20th percentile) is likely to occur after the last week of February at Folovhodwe and the first week of May at Entabeni and Levubu. The probability of crops experiencing water stress due to early cessation is said to be lower when the season ends on the dates corresponding to 20 % probability of exceedance (Moeletsi and Walker, 2011). Therefore in one out of five years, crops will have a low probability of experiencing water stress due to early cessation of rains. At 80, 50 and 20 % probability of exceedance, cessation of the season is delayed by between 20 to 50 days when comparing dry and wet areas of the catchment, as wet areas of the catchment receive last rains of the season later than the dry areas. Cessation of the rainy season indicates high variability on a yearly basis when compared to onset. Studies of rainy season characteristics in the Free State showed high variability for the onset as compared to cessation of rain (Moeletsi and Walker, 2012). Standard deviation is highest at Entabeni (33) followed by Levubu (31), Thathe (29), Lwamondo (28), Tshiombo (28), Elim (27), Vreemedeling (26), Phunda Maria (22), Mampakuil (21), Phafuri (20), Folovhodwe (19) and lowest for Sigonde (17) (Table 4.4). The standard deviation is higher in wet areas than in dry areas of the catchment, indicating that cessation can easily be predicted more accurately in dry areas than in wet areas of the catchment.

Table 4.4 Early (80 %) probability of exceedance, normal (50 %) and late (20 %) cessation dates and standard deviation (STD) for 12 meteorological stations at the Luvuvhu River Catchment.

Station	**Early**	**Normal**	**Late**	**STD (days)**
Entabeni	06/03	08/04	03/05	33
Levubu	26/02	01/04	02/05	31
Lwamondo	11/02	16/03	15/04	28
Tshiombo	07/02	02/02	30/03	28
Phafuri	01/02	18/02	07/03	20
Sigonde	01/02	21/02	11/03	17
Mampakuil	03/02	24/02	12/03	21
Elim	17/02	06/03	02/04	27
Thathe	28/02	23/03	16/04	29
Phunda Maria	01/02	20/02	16/03	22
Folovhodwe	01/02	17/02	28/02	19
Vreemedeling	20/02	11/03	07/04	26

4.2.2 Trends

The Spearman rank correlation coefficient test at the 5 % and 10 % level of significance revealed that there was no significant trend in cessation dates at any stations of the catchment except for Entabeni and Tshiombo (Table 4.5). At Entabeni a weak decreasing trend (r_s = -0.24) is evident, indicating that over the years the rainy season has been ending earlier by a few days, therefore decreasing the length of the rainy season (Figure 4.2). At Tshiombo an increasing trend (r_s = 0.36) is notable at Tshiombo, implying that over the years the rainy season has been ending later.

Table 4.5 Spearman rank correlation coefficient test results for the cessation of the rainy season for the various stations within the catchment.

Station	**t-stat**	**P-value**	r_s
Elim	0.45	0.64	0.06
Entabeni	-2.34	0.02	-0.24*
Folovhodwe	0.25	0.79	0.03
Levubu	1.40	0.16	0.24
Lwamondo	0.11	0.91	0.01
Mampakuil	-0.56	0.57	-0.07
Phafuri	-0.44	0.65	-0.07
Phunda Maria	0.67	0.50	0.08
Sigonde	0.51	0.60	0.09
Thathe	0.13	0.89	-0.02
Tshiombo	1.95	0.06	0.36**
Vreemedeling	0.87	0.38	0.11

* Significant at 5%; **significant at 10%

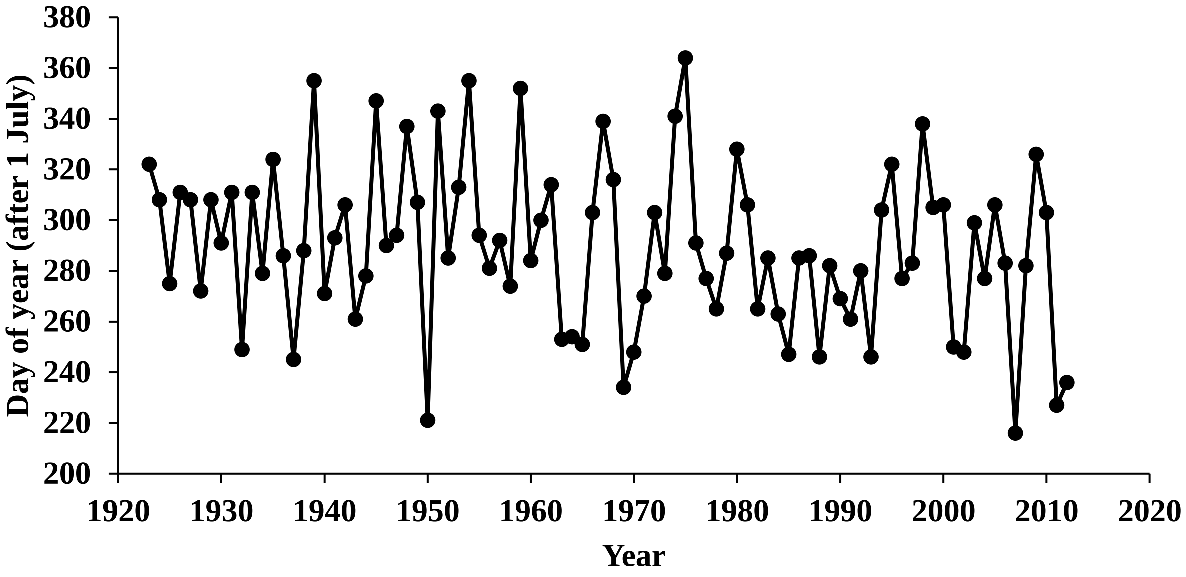


Figure 4.2 Temporal variation in the cessation of the rainy season at Entabeni

4.3 Length of the rainy season

4.3.1 Short, normal and long rainy season

At 20, 50 and 80 % probability of non-exceedance, the length of the rainy season ranges from 67 days at Folovhodwe to 203 days at Entabeni (Table 4.6). In one out of five years, the length of the rainy season ranges from 67 days at Folovhodwe to 149 days at Entabeni. Maize generally requires an average of 120 days depending on the cultivar from planting until harvesting (Hachigonta et al., 2008). Five out of twelve stations had a length of rainy season less than 120 days. Medium maturing maize should not be planted during the years of drought as the maize will suffer from a shortage of water due to early cessation of rains. Therefore, farmers are advised not to plant maize unless they have an alternative source of water to supplement the maize crop until it reaches full maturity. In normal years (50th percentile), all areas of the catchment will have a rainy season greater than 120 days except for Phafuri, Sigonde, Phunda Maria, Folovhodwe, and Mampakuil. Wet areas of the catchment experience a longer rainy season than the dry areas.

At Thathe, Levubu and Entabeni, farmers can plant from early to late maturating varieties depending on the date of planting while farmers at Folovhodwe, Phafuri, Mampakuil, and Sigonde are advised to only plant early maturing varieties. At Lwamondo, Tshiombo and Elim, Vreemedeling farmers should plant very early, medium, and late maturing maize varieties. At

Sigonde, Folovhodwe, Phafuri, and Phunda Maria, the length of the rainy season differs by more than 70 days when comparing these stations to Entabeni which has a long rainy season. The length of the rainy season at the Luvuvhu River Catchment deviates by more than 25 days at all stations, indicating high variability.

Table 4.6 Short (20 % probability of non-exceedance), normal (50 %) and long (80 %) length of the rainy season and standard deviation (STD)

Stations	Short	Normal	Long	STD (days)
Elim	112	135	169	34
Entabeni	149	177	203	35
Folovhodwe	67	92	132	38
Levubu	133	163	200	32
Lwamondo	114	146	175	37
Mampakuil	89	113	140	31
Phafuri	72	103	136	38
Phunda Maria	82	108	143	26
Sigonde	77	104	125	31
Thathe	127	153	186	38
Tshiombo	102	131	168	34
Vreemedeling	114	139	169	32

4.3.2 Trends

The Spearman rank correlation coefficient test at 5 % level of significance showed that the relationship between time and duration of the rainy season was not significant at all stations except for Thathe, Entabeni and Phunda Maria (Table 4.7). At Thathe and Entabeni there is a weak decreasing trend, meaning the rainy season has been slowly shortening over the years (Figure 4.3 and 4.4). This implies that instead of long maturing varieties, farmers might have to switch to early and medium maturing maize varieties. Phunda Maria shows decreasing trend in length of the rainy season but significant at 10 % level. Very early maturing varieties or no planting would occur in future due to decreasing trend.

Table 4.7 Spearman rank correlation coefficient test results for the duration of the rainy season

Station	**t-stat**	**P-value**	r_s
Elim	10.16	0.24	0.15
Entabeni	-2.20	0.02	-0.22*
Folovhodwe	1.36	0.17	0.18
Levubu	0.80	0.42	0.14
Lwamondo	-0.47	0.63	-0.07
Mampakuil	-0.67	0.50	-0.08
Phafuri	-0.06	0.94	-0.00
Phunda Maria	1.82	0.07	0.23**
Sigonde	1.15	0.25	0.22
Thathe	-2.19	0.03	-0.33*
Tshiombo	0.78	0.13	0.15
Vreemedeling	0.90	0.37	0.11

*****Significant at 5%; **significant at 10%

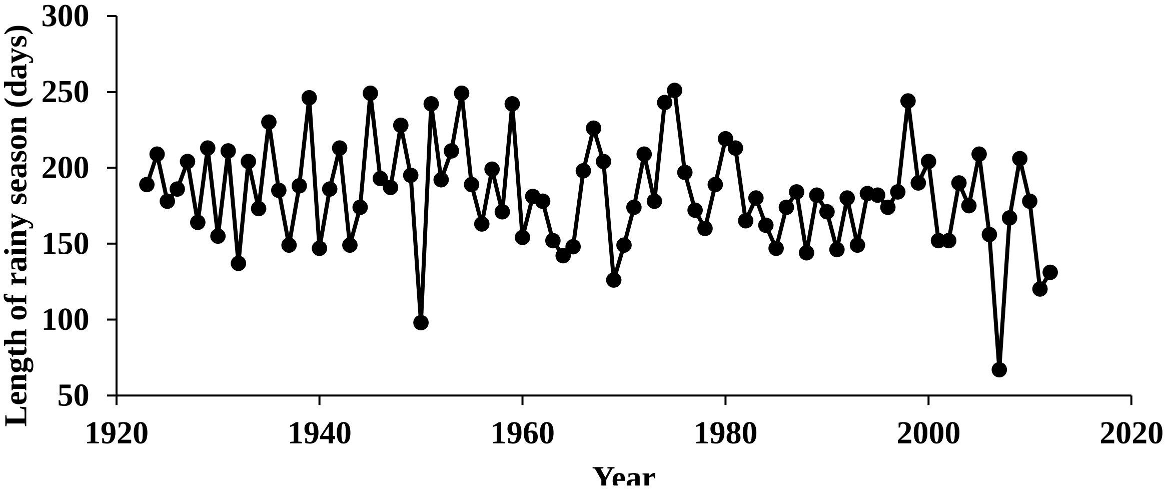


Figure 4.3 Temporal variation in the length of the rainy season at Entabeni

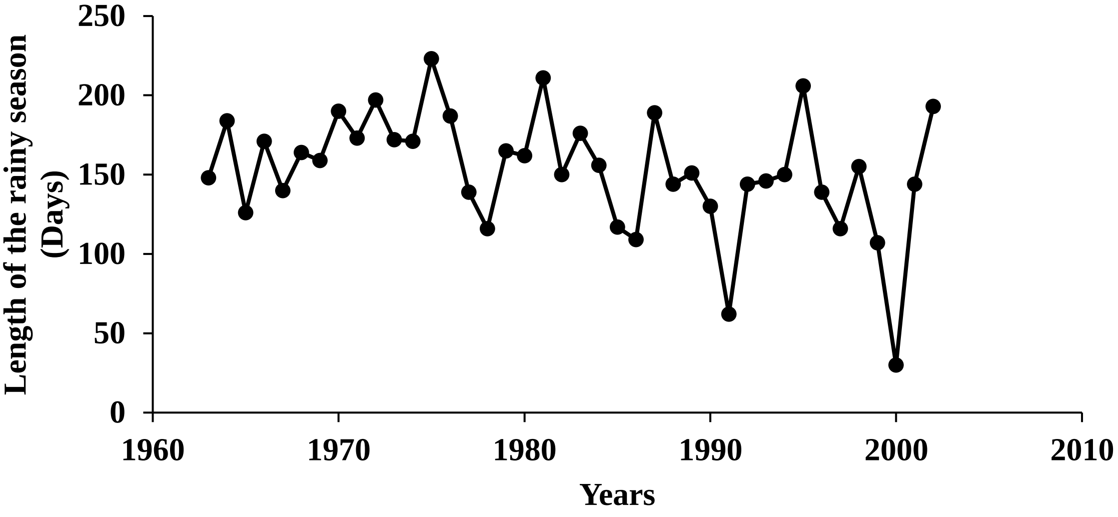


Figure 4.4 Temporal variation in the length of the rainy season at Thathe

4.4 Dry spells during rainy season

4.4.1 October

There is a high probability of short dry spells compared to medium and high dry spells at the catchment. All stations had high probability (> 90 %) of short dry spells, with Mampakuil, Sigonde, Phafuri, Folovhodwe, Phunda Maria, Lwamondo, Vreemedeling and Elim having 100 % probability of short-term dry spells (Table 4.8). The results indicate that for the stations mentioned, every year there is a probability of dry spells longer than 7 days but less than 14 days in October. All stations had more than a 50 % probability of medium dry spells except for Entabeni, Thathe and Levubu. For the years analyzed, Levubu had the lowest probability at 9 % of long dry spells while Sigonde had the highest probability at 65 % (Table 4.8). For stations receiving high rainfall amounts, there is a low probability of dry spells when compared to stations situated in dry areas. The results from this study show that planting in October might subject maize to both short and medium dry spells which might lead to crop failure especially at Sigonde, Phafuri, Folovhodwe, Mampakuil, Vreemedeling, Tshiombo, Elim and Phunda Maria (Table 4.8).

Table 4.8 Probability of dry spells (%) in October for more than the indicated number of dry days

Stations	**> 7**	**> 14**	**> 21**
Elim	100	67	21
Entabeni	90	38	11
Folovhodwe	100	88	41
Levubu	94	32	9
Lwamondo	100	74	35
Mampakuil	100	88	41
Phafuri	100	76	45
Phunda Maria	100	86	43
Sigonde	100	88	65
Thathe	98	41	12
Tshiombo	96	59	30
Vreemedeling	100	70	31

4.4.2 November

Mampakuil and Phafuri had 100 % probability of short dry spells in November while Entabeni and Levubu had 74 % (Table 4.9). Other stations had more than 80 % probability of short dry spells. Entabeni had the lowest probability of medium dry spells while Mampakuil, Sigonde, Phafuri, Folovhodwe, Phunda Maria and Tshiombo had more than 50 %. Levubu had 0 % probability of long dry spells. All stations had a low probability (< 30 %) of long dry spells except for Sigonde and Folovhodwe. Farmers are therefore advised to plant during November at all stations except for Folovhodwe, Phunda Maria, Sigonde, Mampakuil, and Tshiombo as there is still a high probability of medium dry spells. If planting is to be done in these areas, there should be water to supplement rainwater.

Table 4.9 Probability of dry spells (%) in November for more than indicated number of dry days

Stations	**>7**	**>14**	**>21**
Elim	98	41	17
Entabeni	74	15	1
Folovhodwe	95	68	31
Levubu	74	26	0
Lwamondo	91	35	12
Mampakuil	100	51	17
Phafuri	100	53	26
Phunda Maria	92	54	24
Sigonde	97	68	35
Thathe	83	39	17
Tshiombo	96	56	26
Vreemedeling	97	40	11

4.4.3 December

All stations had more than an 80 % probability of short dry spells in December except for Entabeni which had 61 % (Table 4.10). Entabeni had the lowest probability of medium dry spells. Mampakuil, Sigonde, Folovhodwe and Phafuri had more than 50 % probability of medium dry spells. Entabeni had 0 % probability of long dry spells. The risk of long dry spells for all stations was less than 30 %. If maize is planted late October to November, it flowers between December and February (Hachigonta et al., 2008). Water shortages during flowering due to long dry spells compromises the final yield.

Table 4.10 Probability of dry spells (%) in December for a more than indicated number of dry days

Station	**>7**	**>14**	**>21**
Elim	91	34	8
Entabeni	61	10	0
Folovhodwe	95	69	40
Levubu	82	18	6
Lwamondo	83	35	9
Mampakuil	93	59	12
Phafuri	97	53	26
Phunda Maria	97	44	20
Sigonde	97	52	26
Thathe	85	37	17
Tshiombo	93	41	0
Vreemedeling	92	27	7

4.4.4 January

All stations had high probability of short dry spells in January, with Sigonde having 100 % (Table 4.11). Levubu had a low risk of the medium dry spell while Phafuri, Folovhodwe, Phunda Maria, and Sigonde had a high risk (> 50 %). All stations had less than 25 % probability of long dry spells in January. Entabeni had the lowest probability of long dry spells (2.2 %). Similar to the results of this study, a study by Mzezewa et al. (2010) showed that the probability of having dry spells increases with a decrease in the duration of dry spells. For example, there is a high probability of experiencing a 7-day dry spell than 21-day spells (Table 4.11).

Table 4.11 Probability of dry spells (%) in January for more than the indicated number of dry days

Station	**>7**	**>14**	**>21**
Elim	84	41	15
Entabeni	65	55	2
Folovhodwe	98	68	31
Levubu	85	12	3
Lwamondo	85	29	12
Mampakuil	88	42	22
Phafuri	94	65	21
Phunda Maria	91	58	17
Sigonde	100	63	16
Thathe	71	27	17
Tshiombo	93	33	11
Vreemedeling	81	30	8

4.5 Monthly rainfall during the rainy season

4.5.1 Descriptive statistics

Tables 4.12 and 4.13 show descriptive statistics for monthly rainfall from October to April for twelve (12) stations located within the Luvuvhu River Catchment. In October, rainfall at the catchment ranges from 20 mm at Sigonde to 98 mm at Thathe. For November and December, all the stations had greater than 50 mm of rainfall. The Luvuvhu River catchment receives peak rainfall in January and February with all stations receiving more than 100 mm of rainfall except for Mampakuil, Folovhodwe, and Sigonde (Figure 4.5). In March, rainfall ranges from 39 mm at Sigonde to 180 mm at Levubu. The results of this study show high rainfall variability of monthly rainfall on a yearly basis with a coefficient of variation and standard deviation ranging from 52 to 131 % and 20 mm to 231 mm respectively. As a result, it is difficult to predict monthly rainfall totals within the catchment from historical data due to high variability in monthly rainfall.

Table 4.12 Descriptive statistics for monthly rainfall from October to January

	October					**November**					**December**					**January**				
	Mean (mm)	**STD (mm)**	**CV (%)**	**C_s**	**C_k**	**Mean (mm)**	**STD (mm)**	**CV (%)**	**C_s**	**C_k**	**Mean (mm)**	**STD (mm)**	**CV (%)**	**C_s**	**C_k**	**Mean (mm)**	**STD (mm)**	**CV (%)**	**C_s**	**C_k**
Elim	49	34	69	0.7	0.06	77	45	58	0.4	-0.6	108	64	59	0.81	-0.21	148	121	82	1.6	3.7
Entabeni	100	71	71	1.3	2.17	166	91	55	0.9	0.9	249	142	57	1.03	0.79	341	197	57	0.85	0.34
Folovhodwe	28	29	106	1.38	4.26	45	54	119	2.45	7.58	58	60	103	1.57	2.55	60	79	119	2.53	7.79
Levubu	82	64	86	0.57	-0.39	146	81	55	1.49	3.53	196	100	52	0.62	0.3	262	231	88	1.82	2.3
Lwamondo	74	60	81	1.38	1.79	112	81	73	0.7	-0.26	119	66	55	1.3	2.45	167	161	93	2.9	11
Mampakuil	32	26	84	1.73	3.57	62	40	64	0.76	-0.23	77	43	56	0.64	0.19	98	81	83	0.99	0.3
Phafuri	28	27	95	1.1	0.77	59	51	87	0.95	0.2	66	53	81	1.05	0.86	102	100	98	1.63	3.07
Phunda Maria	33	30	93	1.84	4.26	70	51	73	0.8	0.09	90	61	67	0.88	0.27	103	103	100	2.36	7.17
Sigonde	20	20	101	0.91	-0.37	55	49	89	0.99	0.26	73	53	73	1.26	1.49	92	112	121	2.95	11.29
Thathe	74	53	71	1.81	4.94	110	74	67	0.61	-0.15	162	125	77	1.92	1.14	213	186	87	2.21	7.85
Tshiombo	57	42	74	1.38	2	121	84	69	0.57	-0.08	140	85	60	0.82	-0.25	183	145	79	1.27	1.55
Vreemedeling	49	34	69	1.08	1.22	89	55	62	0.89	0.01	118	62	52	0.6	-0.86	161	140	87	2.47	9.45

Table 4.13 Descriptive statistics for monthly rainfall from February to April

	February					**March**					**April**				
Stations	**Mean (mm)**	**STD (mm)**	**CV (%)**	**Cs**	**Ck**	**Mean (mm)**	**STD (mm)**	**CV (%)**	**Cs**	**Ck**	**Mean (mm)**	**STD (mm)**	**CV (%)**	**Cs**	**Ck**
Elim	152	164	107	4.3	25.5	90	97	108	3.5	15.8	44	74	106	2.9	13.4
Entabeni	344	288	84	2.1	7.7	253	206	82	1.9	5.2	107	71	71	1.34	2.17
Folovhodwe	72	71	98	1.46	2.82	42	56	131	2.01	4.04	24	32	133	2.38	7.79
Levubu	223	281	126	3.5	15.8	174	64	86	1.64	2.7	74	64	86	1.64	2.75
Lwamondo	123	156	127	5.27	30.2	97	67	69	1.48	2.1	57	59	104	2.22	5.78
Mampakuil	97	124	128	3.82	16.61	61	53	86	1.44	1.81	27	31	114	1.63	2.99
Phafuri	100	107	107	1.92	4.83	51	50	97	1.47	2.84	18	29	161	3.26	13.61
Phunda Maria	104	102	98	1.79	4.25	54	65	119	2.46	8.42	27	31	111	1.88	4.07
Sigonde	79	103	121	3.34	14.45	39	34	89	0.82	-0.42	21	30	142	1.69	1.56
Thathe	251	253	101	1.94	4.26	143	136	95	1.59	2.34	77	126	164	5.1	29.48
Tshiombo	192	221	115	2.49	7.3	153	146	95	2.09	5.23	38	37	97	2.15	6.89
Vreemedeling	163	162	99	3.96	2.95	100	74	74	1.36	2.26	42	39	93	1.26	1.49

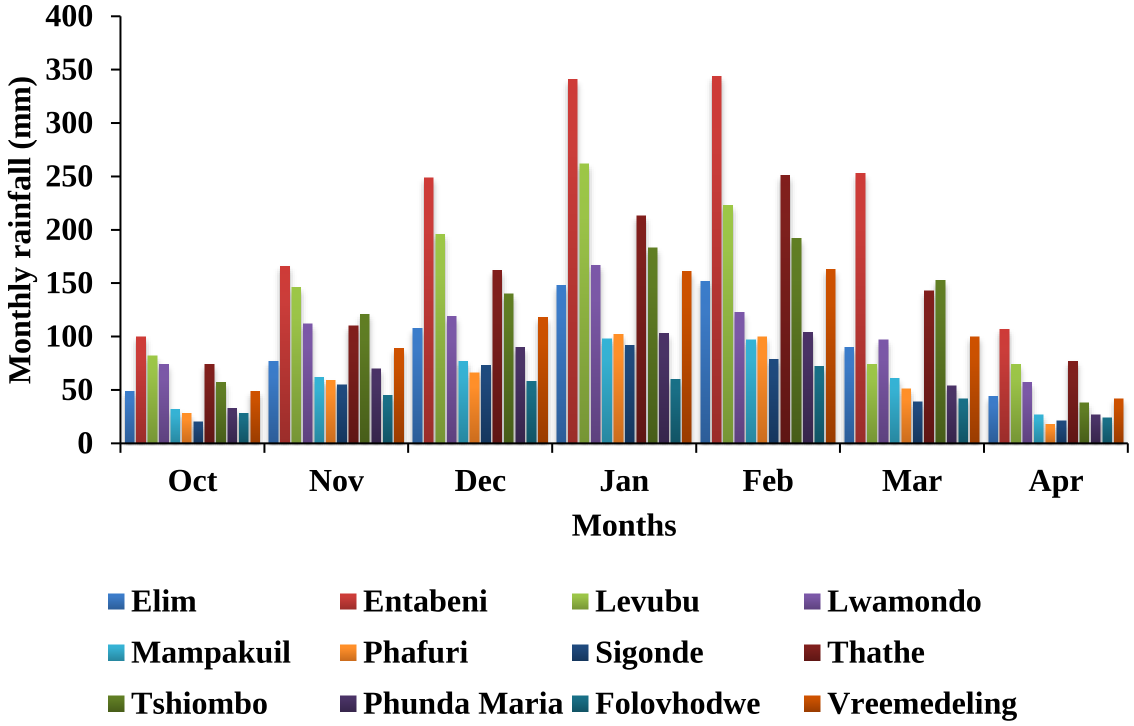


Figure 4.5 Monthly rainfall from October to April at the catchment

4.5.2 Probable monthly rainfall from October to April

The goodness of fit values for monthly rainfall data for twelve selected meteorological stations are given in Table 4.14. The most important and widely used probability distribution in rainfall analysis is a normal distribution (Kwatu and Duke, 2007). Normal distribution mostly fits annual rainfall and river flow (Tilahun, 2007). However, there have been cases where rainfall data is not normally distributed (Savage and Iwig, 1985). Stephens (1974) showed that rainfall is not necessarily normally distributed with the exception only in wet regions, emphasizing the importance of always fitting data according to different probability distributions such as lognormal, gamma, Weibull, and Gumbell to determine the best fit. Monthly rainfall data for January was observed to follow Generalised Extreme Value at all stations except for Tshiombo, Phafuri, Phunda Maria, and Lwamondo. When looking at February rainfall data, the number of stations which follows this corresponding probability distribution is as follows: generalized extreme value (7), lognormal (2), Weibull (1) and normal distribution (1). Most of the monthly rainfall data fit the GEV (Table 4.14).

Table 4.14 Anderson-Darling goodness of fit test results

	Jan			Feb			March			April			Oct			Nov			Dec		
	Prob	**AD stats**	**AD P-value**	**Prob**	**AD stats**	**AD P-value**	**Prob**	**AD stats**	**AD P-value**	**Prob**	**AD stats**	**AD P-value**	**Prob**	**AD stats**	**AD P-value**	**Prob**	**AD stats**	**AD P-value**	**Prob**	**AD stats**	**AD P-value**
Elim	GEV	0.49	0.75	GEV	0.29	0.94	GEV	0.24	0.97	GEV	0.57	0.67	GEV	0.40	0.84	GEV	0.35	0.89	GEV	0.36	0.88
Entabeni	GEV	0.25	0.96	GEV	0.52	0.72	W	0.33	0.90	GEV	0.33	0.90	GEV	0.26	0.96	GEV	0.20	0.98	GEV	0.25	0.96
Folovhodwe	GEV	0.64	0.60	GEV	1.12	0.29	N	4.9	0.00	N	3.04	0.025	GEV	1.18	0.27	GEV	0.61	0.63	GEV	0.47	0.77
Levubu	GEV	0.28	0.94	LN	0.39	0.85	GEV	0.20	0.98	GEV	0.28	0.94	GEV	0.36	0.87	GEV	0.60	0.63	GEV	0.30	0.93
Lwamondo	LN	0.35	0.89	GEV	0.61	0.62	LN	0.25	0.96	W	0.34	0.89	W	0.21	0.98	W	0.49	0.75	GEV	0.24	0.97
Mampakuil	GEV	0.33	0.88	GEV	0.35	0.88	GEV	0.16	0.99	N	2.97	0.028	GEV	0.27	0.95	W	0.33	0.91	GEV	0.19	0.99
Phafuri	W	0.16	0.99	GEV	0.41	0.83	GEV	0.53	0.70	N	3.6	0.024	GEV	0.65	0.59	GEV	0.33	0.90	GEV	0.36	0.87
Phunda Maria	W	0.34	0.89	W	0.31	0.92	GEV	0.54	0.69	GEV	1.14	0.287	GEV	0.26	0.96	GEV	0.41	0.82	W	0.38	0.56
Sigonde	GEV	0.18	0.99	N	2.83	0.03	GEV	0.43	0.81	GEV	2.03	0.088	GEV	0.73	0.53	GEV	0.42	0.82	GEV	0.12	0.99
Thathe	GEV	0.19	0.99	GEV	0.18	0.99	GEV	0.34	0.90	GEV	0.59	0.65	GEV	0.38	0.86	GEV	0.18	0.99	GEV	0.38	0.86
Tshiombo	W	0.24	0.97	LN	0.28	0.94	GEV	0.14	0.99	GEV	0.41	0.83	GEV	0.16	0.99	LN	0.46	0.78	GEV	0.35	0.89
Vreemedeling	GEV	0.33	0.90	GEV	0.49	0.74	W	0.25	0.96	GEV	0.59	0.65	W	0.27	0.95	LN	0.29	0.94	W	0.14	0.99

4.5.2.1 October

Calculated probability of non-exceedance at 20, 50 and 80 % for monthly rainfall totals from October to April are shown in Table 4.15. At 20 % probability of non-exceedance, Sigonde, Phafuri, and Folovhodwe receive less than 5 mm of rainfall. This implies that in one out of five years there will be no rainfall in October and therefore no planting would occur. Low or zero amounts of rainfall shortens the rainy season by a month at these areas. At 50 % probability which is considered normal in seven out of nine stations, total monthly rainfall for October will be greater than 25 mm. In wet years (80 %) all stations receive more than 25 mm of rainfall. This means that in four out of five years, planting can begin in October at the catchment at all stations.

4.5.2.2 November

In dry years, rainfall in November ranges from 10 mm at Sigonde and Folovhodwe to 95 mm at Entabeni. All stations receive more than 25 mm of rainfall expect for Sigonde, Folovhodwe, Phafuri, and Phunda Maria. This means that in one out of five seasons farmers at Sigonde and Phafuri would not plant in November as the rainfall would not be sufficient for the planting season to commence, as a result shortening the season by two months. In normal years, rainfall ranging from 29 mm for Folovhodwe to 153 mm for Entabeni can be expected. Planting can commence for the low-lying areas of the catchment such as Sigonde and Phafuri that would not have planted in October due to low rainfall. In four out of five years, rainfall of above 100 mm should be expected in all areas except for Sigonde and Folovhodwe (Table 4.15). This implies that in wet years there would be sufficient rain to sustain maize planted in October and November in all areas.

4.5.2.3 December

At 20 % probability of non-exceedance (dry years), total rainfall in December ranges from 11 mm at Folovhodwe to 128 mm at Entabeni. Entabeni (128 mm) has the highest rainfall followed by Thathe (62 mm), Tshiombo and Lwamondo (63 mm), Elim (42 mm), Mampakuil (42 mm), Sigonde (28 mm), Phafuri (23 mm) and Folovhodwe with the lowest rainfall of 11 mm (Table 4.15). In normal years rainfall ranges from 38 mm at Folovhodwe to 222 mm at Entabeni. In one out of two years, rainfall above 40 mm for the catchment can be expected.

4.5.2.4 January

In dry years, rainfall in January ranges from 12 mm at Folovhodwe to 166 mm at Entabeni (Table 4.15). All stations can expect rainfall greater than 25 mm in one out of five seasons except for Folovhodwe, Phafuri and Sigonde. However, only seven out of nine stations had rainfall total greater than 50 mm. For a 50 % probability, rainfall ranges from 58 mm at Sigonde to 189 mm at Levubu. In wet years, monthly rainfall total of greater than 200 mm can be expected in six out of nine stations (Table 4.15). Rainfall received in wet years might lead to waterlogging or flooding of crops for areas such as Entabeni, Levubu and Thathe.

4.5.2.5 February

In dry years (20 % probability of non-exceedance), rainfall ranges from 11 mm for Sigonde to 105 mm for Entabeni (Table 4.15). Sigonde and Phafuri received less than 20 mm of rainfall. In normal years, rainfall ranges from 48 mm for Sigonde mm to 166 mm for Thathe. This means that in one out of two years there is a 50:50 chances of receiving more than 50 mm of rainfall in 6 out of 9 stations at the catchment. At 80 % probability, rainfall ranges from 121 mm for Mampakuil to 548 mm for Entabeni. High rainfall at Thathe, Entabeni, and Sigonde might lead to flooding of crops in one out of five seasons.

4.5.2.6 March

In dry years (20 % probability of non-exceedance), rainfall ranges from less than 10 mm for Sigonde, Folovhodwe, Phunda Maria and Phafuri to more than 50 mm for Entabeni, Levubu, Thathe and Tshiombo (Table 4.15). A 120-day maturing cultivar planted in October would have reached maturity. However, for maize planted late in December or early January, the lack of rainfall might lead to a shortage of water during the sensitive growth stage which might lead to low yield or total crop failure. In normal years, rainfall received at the catchment varies from 25 mm for Folovhodwe to 189 mm for Entabeni. Areas of the catchments such as Levubu, Thathe and Entabeni still receive sufficient rainfall to sustain maize even if planted late in December. However, for Sigonde, Phunda Maria and Folovhodwe, if planting is to be done in late December there should be plans for an alternative source of water as there is not enough rainfall to sustain maize growth. This means that in one of two seasons, plans should be made to provide water for maize planted in December and January as rainfall in March would not be sufficient to sustain maize growth. At 80 % probability (wet years), rainfall ranges from 80 mm for Sigonde to 363 mm for Entabeni.

4.5.2.7 April

At 20 % probability of non-exceedance five out of twelve stations will receive no rainfall in April (Table 4.15). This implies that in one out of five years, maize planted in January might not reach maturity as there will be insufficient rainfall to sustain maize until maturity. In dry years farmers are therefore advised not to plant maize in January as there will not be rainfall to sustain it until the end of the plant growing cycle. More than 20 mm of rainfall in April can be expected in one of two years in eight out of twelve stations, implying that for those farmers who planted in January, maize will have sufficient water to sustain it. However, for the remaining four stations, maize might wilt due to a shortage of water. When considering a 120-day maturing maize cultivar crop, if planting is done in October and November, rainfall in April is not beneficial to the crop as it would have reached maturity. However, for maize planted in January, April rainfall might still be needed to sustain maize.

4.5.3 Trend analysis

Table 4.16 shows monthly rainfall trends analysis results from October to April for selected stations within the Luvuvhu River Catchment. No significant trend was noted at the catchment in October and November (Table 4.16). This implies that there have been no changes in monthly rainfall for the catchment. Based on a 5 % level of significance, results from a Spearman correlation coefficient test showed a significant relationship between rainfall received in December and time at Lwamondo, Entabeni, and Folovhodwe (Figure 4.6). At Lwamondo, rainfall in December has increased over the years, therefore leading to more water being available for maize in December. For Folovhodwe and Entabeni, decreased rainfall has been experienced over the years, these conditions are not favourable for Folovhodwe as water might not be sufficient for maize production and might subject maize to water shortages.

Table 4.15 Probability of non-exceedance (20, 50, and 80 %) for monthly rainfall totals from October to April

Months	**October**			**November**			**December**			**January**			**February**			**March**			**April**		
Non-Exceedance probability (%)	**20**	**50**	**80**	**20**	**50**	**80**	**20**	**50**	**80**	**20**	**50**	**80**	**20**	**50**	**80**	**20**	**50**	**80**	**20**	**50**	**80**
Return period (years)	**5**	**2**	**1.25**	**5**	**2**	**1.25**	**5**	**2**	**1.25**	**5**	**2**	**1.25**	**5**	**2**	**1.25**	**5**	**2**	**1.25**	**5**	**2**	**1.25**
Elim	14	45	81	35	71	120	54	95	175	54	112	245	53	112	246	30	69	121	10	36	69
Entabeni	50	77	143	95	153	232	128	222	231	166	297	513	105	263	548	104	189	363	34	82	168
Folovhodwe	3	21	44	10	29	62	11	38	103	12	41	110	15	50	124	0	25	69	0	15	39
Levubu	37	73	145	91	135	179	112	192	282	106	189	385	63	159	334	64	132	307	32	54	126
Lwamondo	24	61	123	35	82	186	63	104	158	63	129	222	57	103	137	46	79	136	11	48	81
Mampakuil	11	27	42	28	51	103	42	76	107	27	78	172	30	67	121	20	48	94	0	16	49
Phafuri	1.76	19	55	12	45	104	23	45	106	22	69	185	15	74	154	7	40	87	0.16	6	32
Phunda Maria	10	24	47	23	56	109	33	88	120	26	80	146	17	85	163	9	32	85	2	20	43
Sigonde	1.5	12	41	10	48	99	28	62	116	20	58	139	11	48	128	6	32	80	0.4	8	36
Thathe	34	68	99	48	100	175	64	131	244	73	170	336	65	160	405	51	92	244	21	43	102
Tshiombo	22	45	92	41	103	219	63	123	233	55	170	259	43	98	292	50	108	221	50	108	221
Vreemedeling	20	46	70	42	77	135	62	108	172	63	119	237	70	110	239	36	81	158	10	28	72

Table 4.16 Spearman correlation coefficient test results for monthly rainfall from October to April

Months	**October**			**November**			**December**			**January**			**February**			**March**			**April**		
Statistics	**t-stat**	**p-value**	r_s	**t-stat**	**p-value**	r_s	**t-stat**	**p-value**	r_s	**t-stat**	**p-value**	r_s	**t-stat**	**p-value**	r_s	**t-stat**	**p-value**	r_s	**t-stat**	**p-value**	r_s
Elim	1.03	0.31	0.13	0.70	0.48	0.09	0.03	0.96	-0.00	-1.25	0.21	- 0.01	-0.50	0.61	-0.06	-0.11	0.91	-0.01	- 1.36	0.178	-0.17
Entabeni	-0.87	0.38	-0.09	-0.34	0.72	-0.03	-2.42	0.01	-0.24*	-1.26	0.20	-0.13	-1.36	0.17	-0.14	-2.19	0.03	-0.22*	**-1.54**	**0.12**	**-0.16**
Folovhodwe	1.28	0.20	0.16	-0.33	0.74	-0.04	-1.95	0.05	-0.24*	-1.85	0.06	-0.23**	-0.29	0.77	0.03	-0.41	0.68	-0.05	-2.75	0.007	-0.33*
Levubu	0.10	0.91	0.01	0.63	0.52	0.11	0.11	0.90	0.02	2.55	0.00	0.43*	-0.16	0.86	-0.031	1.57	0.12	0.28	0.86	0.39	0.16
Lwamondo	-1.15	0.25	-0.19	0.96	0.33	0.16	2.37	0.02	0.37*	2.24	0.03	0.35*	-0.00	0.99	-0.007	0.60	0.54	0.10	0.89	0.37	0.14
Mampakuil	0.72	0.47	0.09	0.36	0.71	0.04	-0.45	0.64	-0.06	-1.33	0.18	-0.17	-0.43	0.66	-0.05	0.51	0.60	0.06	-2.59	0.01	-0.32*
Phafuri	-0.04	0.96	-0.00	-1.15	0.25	-0.19	-1.12	0.26	-0.19	1.17	0.24	0.20	-0.73	0.46	-0.12	-0.09	0.92	-0.017	-0.67	0.50	0.11
Phunda Maria	1.38	0.17	0.17	0.72	0.47	0.09	-1.21	0.22	-0.15	0.32	0.74	0.04	-0.24	0.80	-0.03	0.03	0.97	0.00	-1.24	0.21	-0.16
Sigonde	-0.66	0.50	-0.11	0.52	0.60	0.09	0.68	0.49	0.12	0.99	0.32	0.17	1.22	0.22	0.21	-0.29	0.76	-0.05	0.91	0.36	0.16
Thathe	0.29	0.81	0.08	-0.06	0.52	-0.10	-0.06	0.52	-0.09	0.10	0.91	0.01	-0.68	0.49	-0.10	-0.41	0.68	-0.06	-1.39	0.17	-0.21
Tshiombo	-0.66	0.51	-0.13	1.12	0.27	0.21	0.61	0.54	0.12	1.94	0.06	0.36**	0.17	0.86	0.35	1.79	0.08	0.33**	0.48	0.62	0.09
Vreemedeling	1.4	0.16	0.18	-0.42	0.66	-0.05	-1.34	0.18	-0.17	-1.19	0.23	-0.15	0.27	0.78	0.03	1.34	0.18	0.17	-0.87	0.38	-0.11

*Significant at 5 % **significant at 10 %

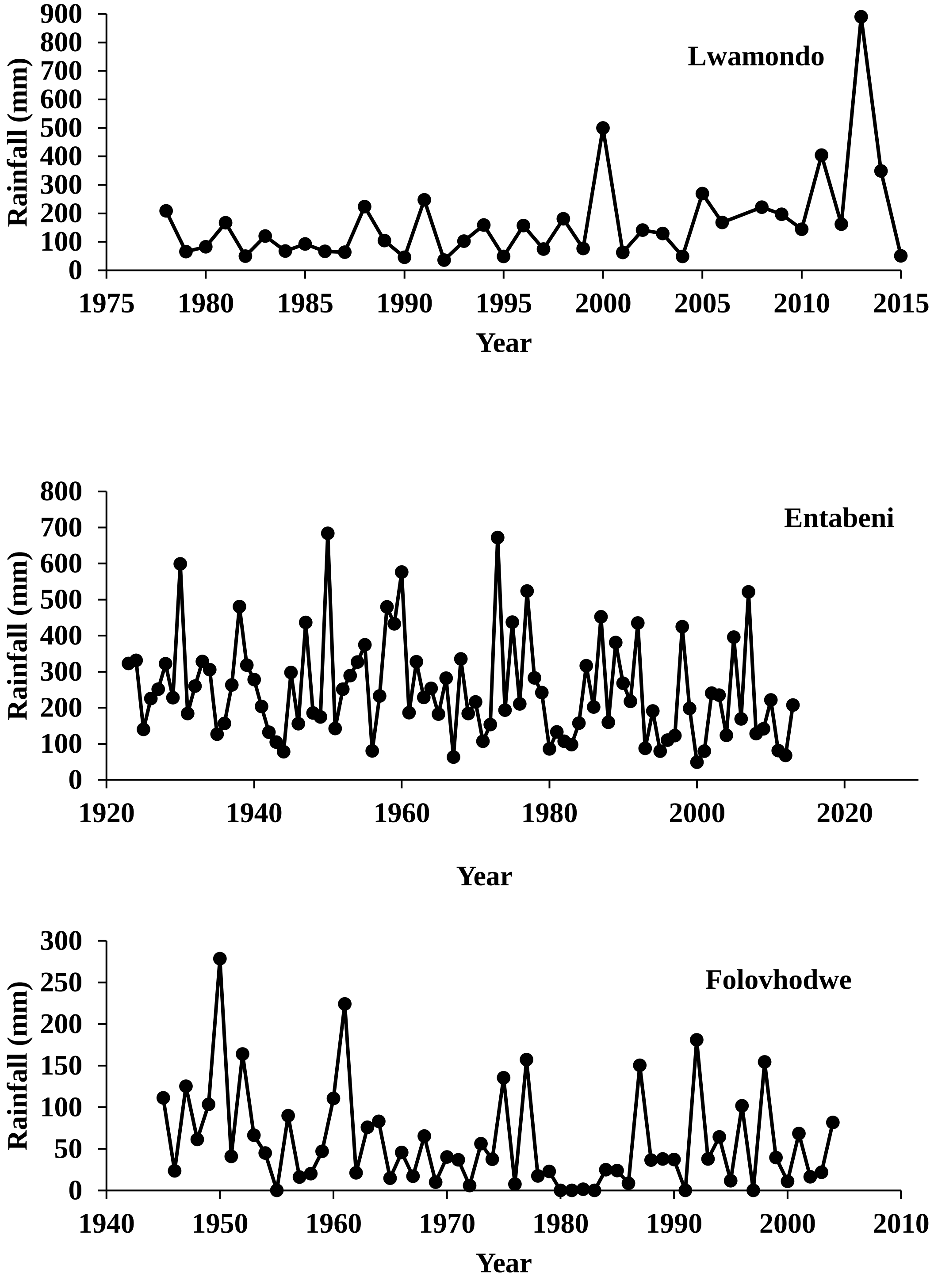
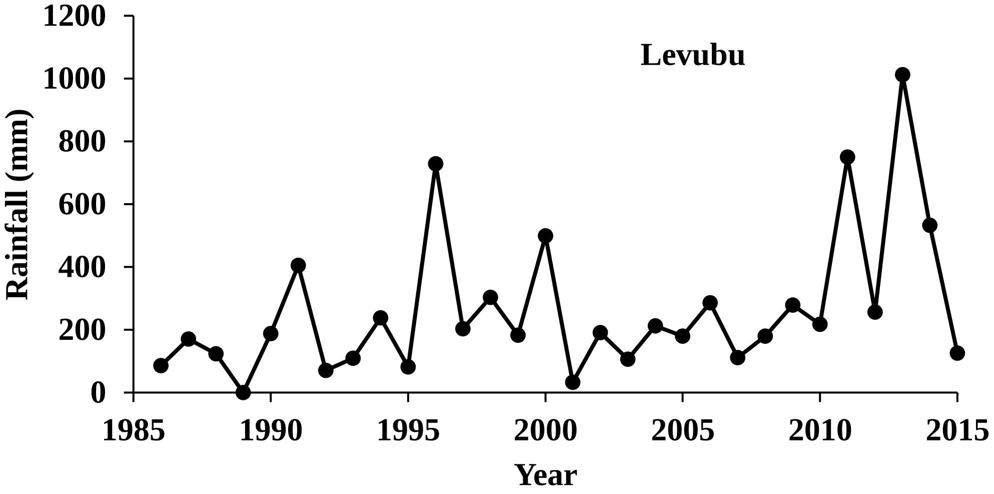


Figure 4.6 Temporal variations in December rainfall for Lwamondo, Entabeni, and Folovhodwe

In January, there was no significant trend for the catchment except for Levubu and Lwamondo where an increase in rainfall is notable (Table 4.16). Although not significant, there is also a weak increasing trend for Tshiombo. This implies that rainfall for these three areas has slightly increased over the years and there is sufficient rainfall to sustain maize during sensitive growth stages such as early vegetative, flowering or grain filling if maize was planted in October, November and December (Figure 4.7).



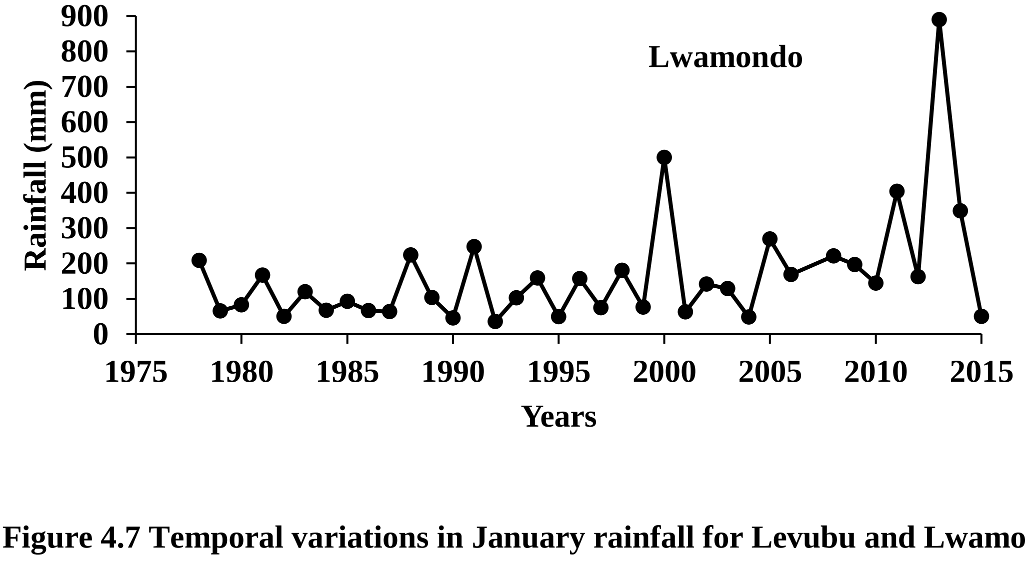


Figure 4.7 Temporal variations in January rainfall for Levubu and Lwamondo

In February, there was no significant change in rainfall over the years for all areas of the catchment (Table 4.16). Even though the trend is not significant, there is a weak increasing trend prominent at Tshiombo (Table 4.16). This implies that the areas have experienced more rainfall over the years making it less prone to dry spells. For all areas of the catchment, there was no significant trend in March rainfall over the years. Although not significant, there is a weak increasing trend evident at Levubu and Tshiombo. This means that over the years the amount of rainfall received in Levubu and Tshiombo has slightly increased. The increase in rainfall might be beneficial for maize planted in November and December. A strong significant decreasing trend is evident at Folovhodwe and Mampakuil in April rainfall (Figure 4.8). This means that these areas over the years have experienced reduced rainfall in April.

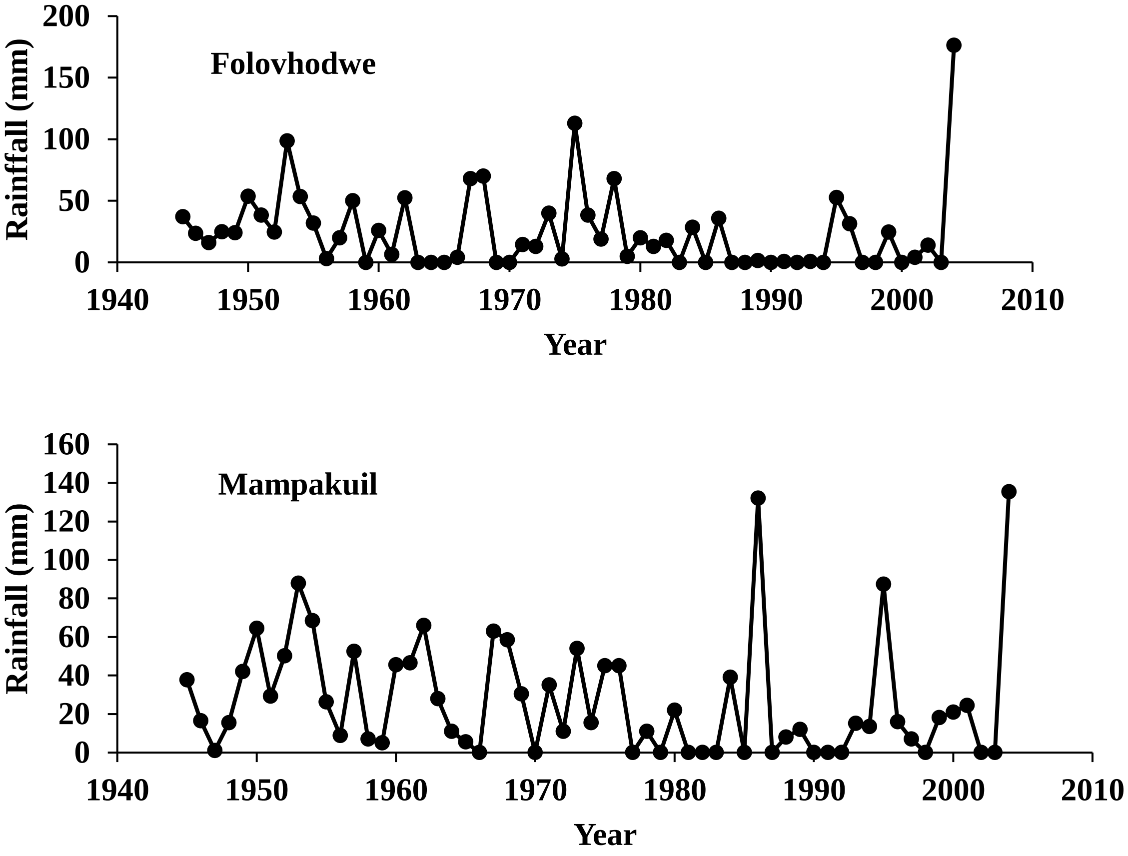


Figure 4.8 Temporal variations for April rainfall for Folovhodwe and Mampakuil

4.6 Seasonal rainfall

4.6.1 Dry, normal and wet seasons

Seasonal rainfall ranges from182 mm to 1973 mm depending on the location at the catchment. Seasonal rainfall shows high variability spatially and temporally (Table 4.17). In the dry season, seasonal rainfall ranges from 182 mm for Folovhodwe to 1079 mm for Entabeni. In normal years it ranges from 268 mm for Folovhodwe to 1476 mm for Entabeni. When above normal rainfall is received (80 % probability of non-exceedance), total rainfall from October to April received is more than 500 mm of seasonal rainfall and production of maize should be maximized by planting more areas than normal and using high yielding cultivars. In dry seasons, only five out of twelve stations receive more than 500 mm of rainfall while in normal years the number increases to seven.

A study by Moeletsi and Walker (2011) showed that areas receiving less than 400 mm of rainfall in dry years are vulnerable to soil water deficits, therefore in one out of five seasons, rainfall for Sigonde, Phafuri, Folovhodwe, and Mampakuil might not be enough for rain-fed maize production, resulting in low production as maize requires between 500 to 800 mm per season. For this reason, planting rainfed maize in these regions might be risky as water requirements might not be met and crop failure might occur. The results from this study further show high seasonal rainfall variability across all stations at the catchment, with a standard deviation ranging from 198 mm for Folovhodwe to 559 mm for Entabeni (Table 4.17).

Alternatively, farmers in areas receiving less than 500 mm of rainfall can plant other summer crops which require less water such as sorghum, millet, soybean and beans (Brouwer and Heibloem, 1986) (Table 4.18). Farmers can then market those crops and use proceeds to purchase maize. But farmers who decide to plant maize as it is their only staple food, should explore other options such as rainwater harvesting technologies. These options can assist in supplementing food production, during a long period of dry spells, and lengthening the rainy season.

4.6.2 Trends

Test of significance at 5 % level of significance, revealed that there was no significant change in seasonal rainfall over the time for most stations expect for Lwamondo, Levubu, and Entabeni (Table 4.19). At Lwamondo (r_s = 0.36) and Levubu (r_s = 0.37), a weak increasing trend is evident, implying an increase in seasonal rainfall over the years. Therefore more water will be available for maize at these areas. For Entabeni there is a decreasing trend (*rs* = -0.21), meaning over the years seasonal rainfall has been decreasing (Figure 4.9).

Table 4.17 Dry (20 % probability of non-exceedance), normal (50 %), wet (80 %) rainy seasonal rainfall (mm) and standard deviation (STD)

Station	**Dry**	**Normal**	**Wet**	**Standard deviation**
Elim	406	600	876	284
Entabeni	1079	1476	1973	559
Folovhodwe	182	268	514	198
Levubu	787	1032	1535	489
Lwamondo	500	680	898	351
Mampakuil	279	439	592	198
Phafuri	270	369	661	229
Phunda Maria	308	429	767	236
Sigonde	252	357	528	196
Thathe	662	950	1343	523
Tshiombo	574	841	1150	422
Vreemedeling	499	690	895	274

Table 4.18 Water requirements for different crops (Source: Brouwer and Heibloem, 1986)

Crop	Crop water need (mm/total growing period)
Beans	300-500
Citrus	900-1200
Cotton	700-1300
Groundnuts	500-700
Maize	500-800
Sorghum/millet	450-700
Soybean	450-700
Sunflower	600-1000

Table 4.19 Spearman rank correlation coefficient test results for the seasonal rainfall

Station	t-stat	P-value	r_s
Elim	-0.45	0.65	-0.06
Entabeni	-2.09	0.03	-0.21*
Folovhodwe	-0.98	0.33	-0.12
Levubu	2.27	0.02	0.37*
Lwamondo	2.32	0.02	0.36*
Mampakuil	-1.06	0.29	-0.13
Phafuri	-0.50	0.62	-0.08
Phunda Maria	0.82	0.41	0.11
Sigonde	0.85	0.40	0.15
Thathe	-1.77	0.08	-0.27**
Tshiombo	1.88	0.07	0.35**
Vreemedeling	-0.42	0.67	-0.05

*Significant at 5 %, ** significant at 10 %

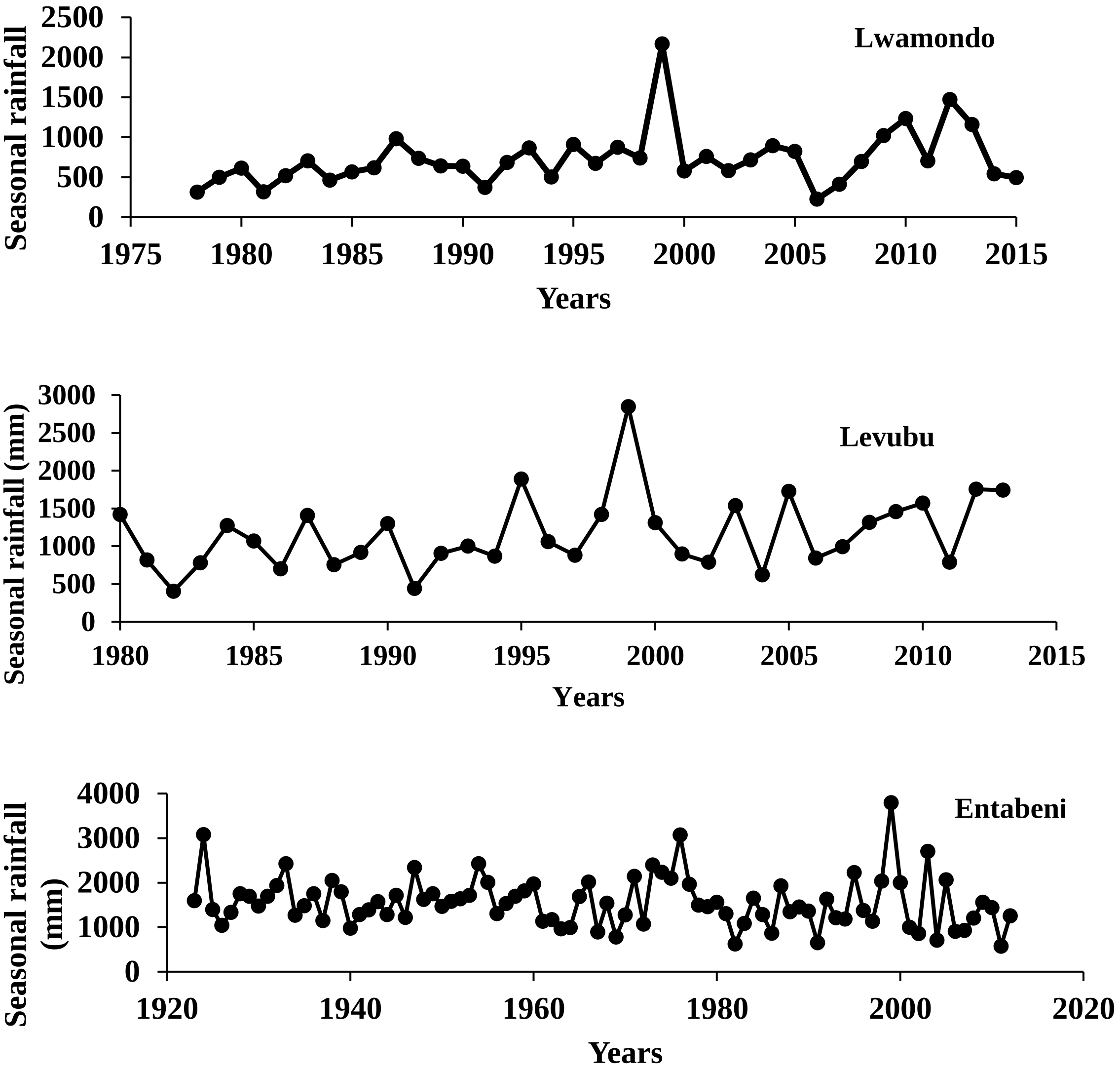


Figure 4.9 Temporal variation in seasonal rainfall at Levubu, Lwamondo and Entabeni

4.7 Number of rainy days with 5 mm or more of rainfall

4.7.1 Low, normal and high number of rainy days

A number of rainy days at 20, 50, and 80 % probabilities of non-exceedance are shown in Table 4.20. The number of rainy days per season ranges from nine days for Folovhodwe to 67 days for Entabeni. In one out of five years, the number of rainy days ranges from 9 to 74 days depending on the location. At 50 % probability of non-exceedance, the number of rainy days will range from 14 to 56 days. The number of rainy days between 24 and 67 days can be expected at 80 % percent probability of non-exceedance. The lowest number of rainy days ever recorded at the station for the years analyzed was 4 days recorded for Phafuri in 1991/92. During 1991/92 there was a drought which affected 80 % of southern Africa, hence the low number of rainy days for Phafuri (Vogel et al., 2000). During the same drought, Entabeni, which normally receives high rainfall, had experienced a number of rainy days 50 % less than the average. This indicates that drought affects dry and wet areas of the catchment differently, and dry areas suffer the most. The highest number of rainy days per season was 86 days observed for Entabeni in the 1924/25 season. The results show high values of standard deviation at all stations, indicating that the number of rainy days is unpredictable for all stations.

Table 4.20 Low (20 % probability of non-exceedance), normal (50 %) and high (80 %) number of rainy days with more than 5 mm of rainfall and standard deviation (STD) at the catchment

Station	**Low**	**Normal**	**High**	**STD (days)**
Elim	21	30	42	34
Entabeni	47	56	67	24
Levubu	35	45	58	27
Lwamondo	24	36	42	30
Mampakuil	17	22	31	34
Phafuri	13	20	24	36
Phunda Maria	16	22	34	36
Sigonde	10	17	22	40
Thathe	26	38	52	34
Tshiombo	25	33	41	28
Folovhodwe	9	14	24	56
Vreemedeling	25	32	42	28

4.7.2 Trends

Based on the 5 % and 10 % level of significance, the Spearman rank correlation coefficient test indicated that there was a significant relationship between the number of rainy days and time for Entabeni, Vreemedeling and Lwamondo (Table 4.21). For Entabeni and Vreemedeling, the number of rainy days indicates a decreasing trend over the years (Figure 4.10) while for Levubu the number of rainy days had been increasing over the years. A study by Hudson and Jones (2002) revealed that there had been a decrease in the number of rainy days per year in southern Africa. Cook et al. (2004) also showed that during summer there was a decrease in the number of rainy days of more than 5 mm per day. On the other hand, this study indicated that there is a weak increase in the number of rainy days of more than 5 mm for Levubu.

Table 4.21 Spearman rank correlation coefficient test results for the seasonal rainfall

Station	**t-stat**	**P-value**	r_s
Elim	-1.56	0.12	-0.203
Entabeni	-2.09	0.038	-0.21*
Folovhodwe	-1.69	0.09	-0.21**
Levubu	1.97	0.05	0.33**
Lwamondo	0.47	0.63	0.07
Mampakuil	-0.79	0.42	-0.10
Phafuri	-1.61	0.11	-0.27
Phunda Maria	-0.41	0.67	-0.055
Sigonde	0.29	0.76	0.05
Thathe	-1.78	0.08	-0.27**
Tshiombo	1.47	0.15	0.28
Vreemedeling	-2.44	0.01	-0.30*

*Significant at 5 % ** significant at 10 %

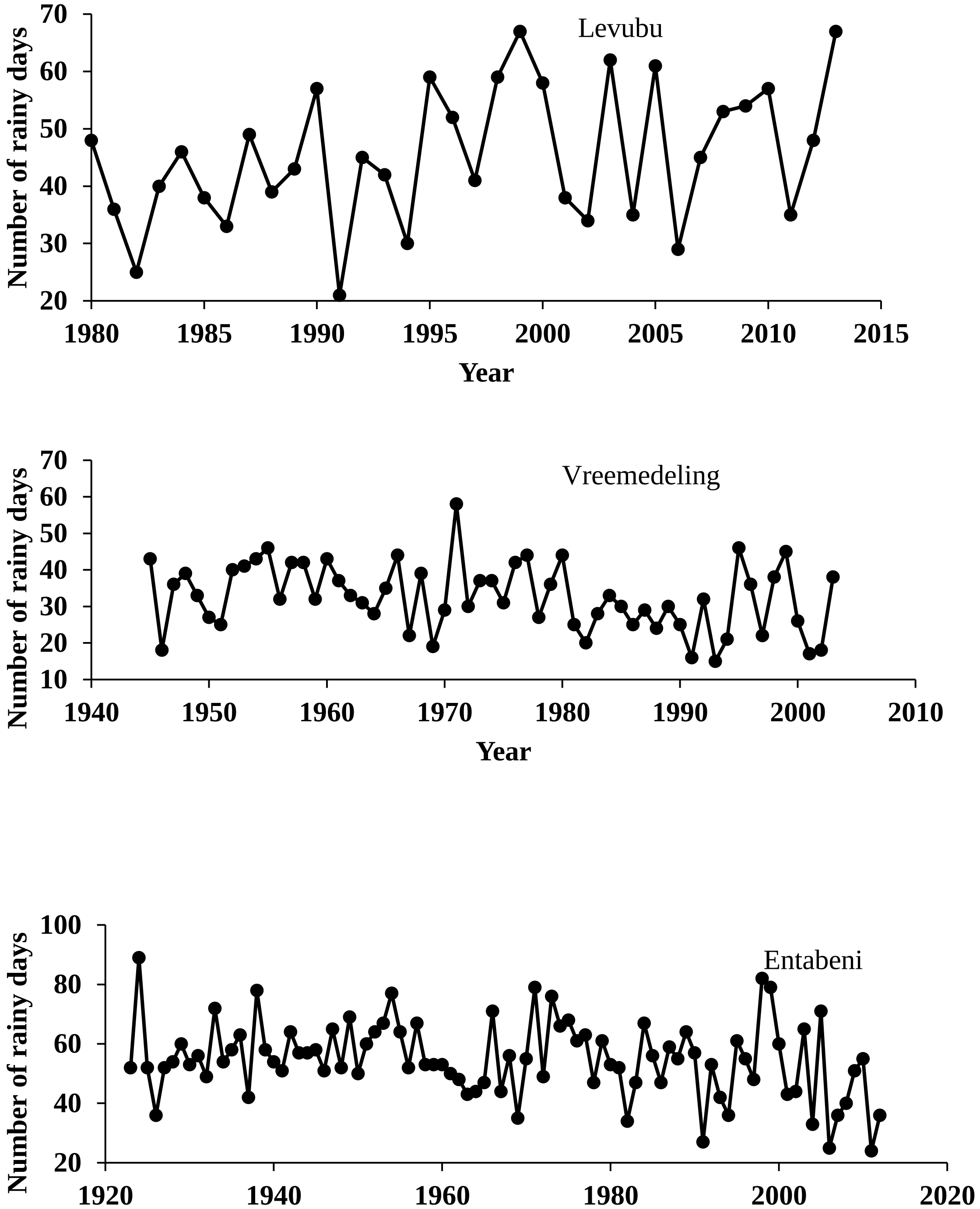


Figure 4.10 Temporal variation for the number of rainy days for Levubu, Vreemedeling, and Entabeni

4.8 Number of rainy days with 10 and 20 mm

4.8.1 Low, normal and high number of rainy days

Table 4.22 shows probable number of days with cumulative rainfall above 10 and 20 mm at 20, 50 and 80 % probability of non-exceedance. At 20 % probability of non-exceedance eight out of twelve stations can expect cumulative daily rainfall exceeding 10 mm in more than ten days. This indicates that in one out of five seasons, four stations will receive rainfall exceeding 10 mm for less than 10 days. In one in two years more than 10 days will have cumulative rainfall exceeding 10 mm except Folovhodwe. The number of days with total cumulative rainfall exceeding 20 mm ranges from two for Folovhodwe to 29 mm for Entabeni.

Table 4.22 Low (20 % probability of non-exceedance), normal (50 %) and high (80 %) number of days with cumulative rainfall exceeding 10 and 20 mm and standard deviation (STD)

	10 mm				**20 mm**			
Stations	**20**	**50**	**80**	**STD (days)**	**20**	**50**	**80**	**STD (days)**
Elim	12	19	26	7	6	10	13	4
Entabeni	31	28	47	11	15	22	29	8
Folovhodwe	6	9	15	6	2	4	7	3
Levubu	22	30	38	9	11	16	23	6
Lwamondo	15	22	29	8	6	8	13	5
Mampakuil	10	14	19	5	4	6	9	3
Phafuri	7	11	16		3	6	11	4
Phunda Maria	8	14	19	6	4	7	11	4
Sigonde	6	10	14	5	3	5	7	3
Thathe	18	26	36	10	10	14	19	7
Tshiombo	15	22	27	7	7	12	16	6
Vreemedeling	14	20	27	7	9	13	20	6

4.8.2 Trends

At the 5 % level of significance, the Spearman correlation coefficient test results showed statistically significant trends for Entabeni, Levubu and Lwamondo for number of days with cumulative rainfall exceeding 10 and 20 mm. For Levubu and Lwamondo the results show an increasing trend in number of days with rainfall exceeding 10 and 20 mm (Figure 4.11). For Entabeni, a decreasing trend is noticeable for all thresholds, indicating a decline in the number of days with cumulative rainfall of more than 10 mm and 20 mm (Figure 4.12). These findings are similar with results from Love et al. (2008) which showed a decrease in number of days with a total cumulative rainfall exceeding 10, 20 and 30 mm over the years in southern Zimbabwe.

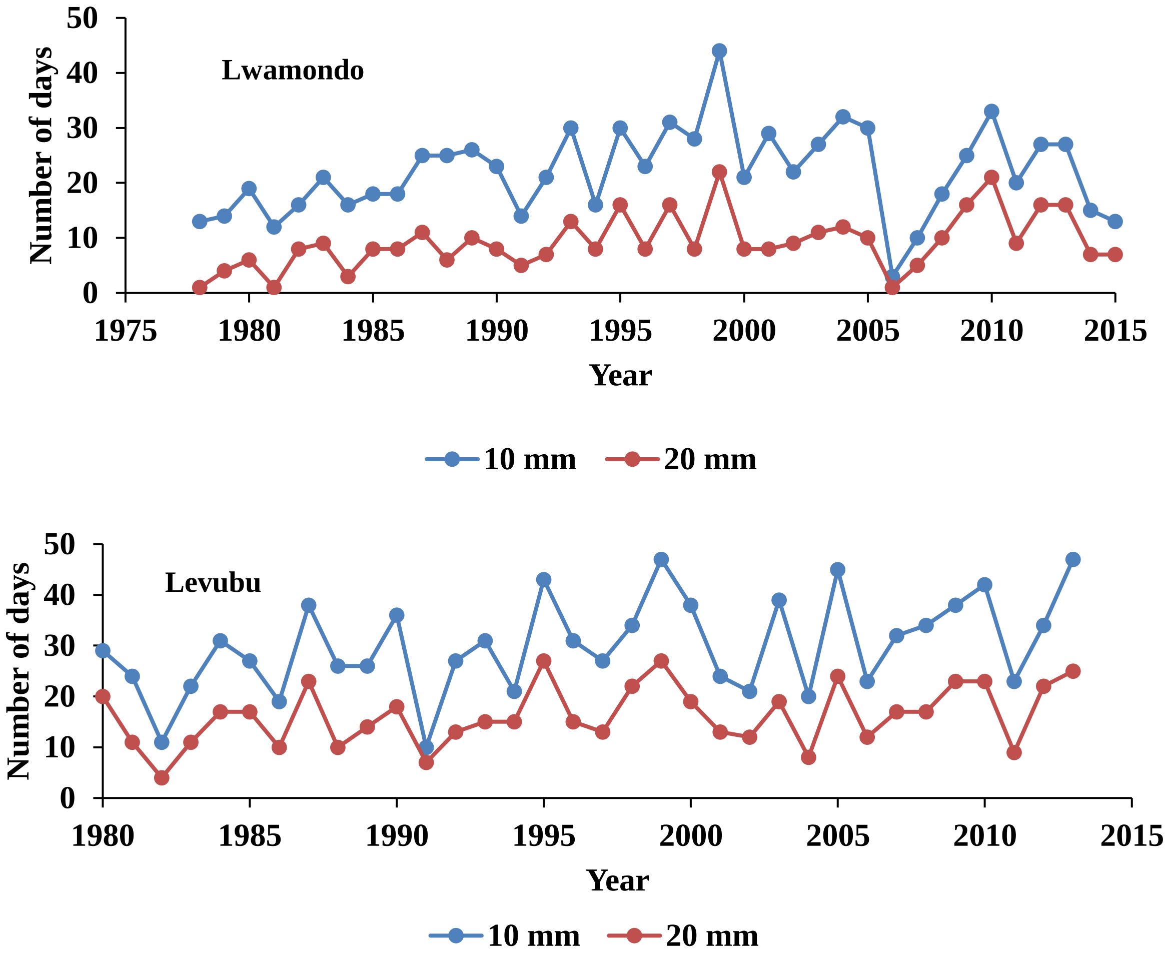


Figure 4.11 Temporal variations in the number of rainy days with cumulative rainfall of above 10 and 20 mm for Lwamondo and Levubu

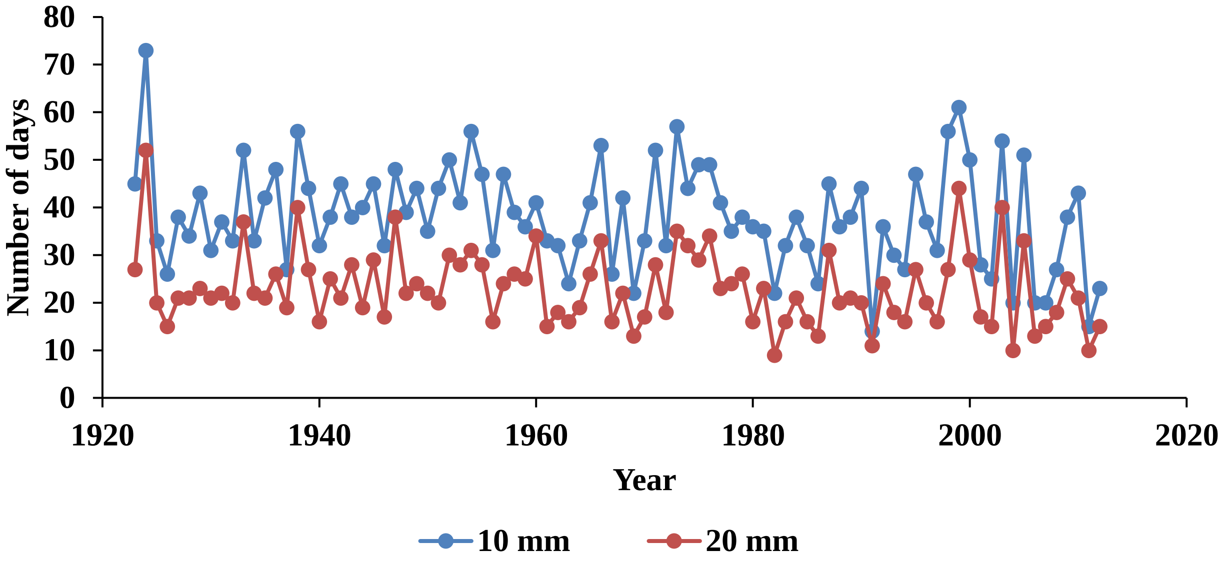


Figure 4.12 Temporal variations in number of rainy days with cumulative rainfall exceeding 10 and 20 mm at Entabeni

4.9 Relationship between rainy season characteristics

Multiple regression analysis tests were conducted between onset and cessation, onset and length of the season, onset and seasonal rainfall, onset and the number of rainy days, the number of rainy days, the number of rainy days and seasonal rainfall (Table 4.23). Regression analysis revealed that the relationship between onset and cessation of the rainy season was not significant at the 5 % level of confidence for all stations (Table 4.23). Hence, the start of the rainy season for Luvuvhu River Catchment does not influence the cessation of the rainy season. There is a strong significant relationship between onset and length of the rainy season at all stations except for Levubu. This is consistent with results by Sivakumar (1988) and Mupangwa et al. (2012) which showed a strong relationship between onset and length of the rainy season wherein earlier onset leads to a longer season while delayed onset leads to a shorter season. Therefore, it is of extreme importance for farmers to plant maize cultivars depending on the time of onset e.g., if the onset of the rainy season occurs earlier, farmers can plant medium to late maturing varieties and if onset is delayed, farmers can plant very early maturing varieties.

Table 4.23 Multiple regression analysis results between rainy season characteristics

Stations	**Onset and cessation**		**Onset and length of the rainy season**		**Onset and seasonal rainfall**		**Onset and number of rainy days**		**Number of rainy days and length**		**Number of rainy days and seasonal rainfall**	
	R^2	P-value	R^2	P-value	R^2	P-value	R^2	P-value	R^2	P-value	R^2	P-value
Elim	0.01	0.4	0.41	0.00	0.07	0.04	0.14	0.00	0.33	0.00	0.59	0.00
Entabeni	0.00	0.90	0.11	0.00	0.01	0.31	0.09	0.00	0.27	0.00	0.64	0.00
Folovhodwe	0.06	0.06	0.75	0.00	0.03	0.19	0.14	0.28	0.11	0.01	0.79	0.00
Levubu	0.01	0.52	0.06	0.15	0.12	0.43	0.02	0.38	0.24	0.00	0.74	0.00
Lwamondo	0.01	0.50	0.4	0.00	0.03	0.28	0.08	0.07	0.21	0.00	0.62	0.00
Mampakuil	0.01	0.39	0.53	0.00	0.00	0.87	0.00	0.89	0.12	0.00	0.67	0.00
Phafuri	0.07	0.12	0.75	0.00	0.18	0.01	0.20	0.00	0.40	0.00	0.51	0.00
Phunda Maria	0.05	0.04	0.62	0.00	0.05	0.04	0.03	0.08	0.26	0.00	0.80	0.00
Sigonde	0.00	0.79	0.68	0.00	0.13	0.04	0.11	0.06	0.30	0.00	0.64	0.00
Thathe	0.00	0.99	0.22	0.00	0.00	0.77	0.15	0.01	0.24	0.00	0.43	0.00
Tshiombo	0.00	0.64	0.33	0.00	0.02	0.42	0.06	0.15	0.48	0.00	0.72	0.00
Vreemedeling	0.00	0.30	0.33	1.07	0.00	0.24	0.00	0.39	0.21	0.00	0.58	0.00

The relationship between onset and seasonal rainfall was significant for Phafuri and Elim, indicating that early onset leads to high seasonal rainfall while delayed onset leads to a low rainfall. Farmers are therefore advised to plant drought-resistant varieties when onset is delayed. For the relationship between onset and number of rainy days at the 5 % level of the significance, it was not significant at most stations except for Entabeni, Elim, Phafuri, and Thathe, where there was a weak correlation. Early onset leads to a high number of rainy days while delayed onset is characterized by a low number of rainy days. There is a significant relationship between the number of rainy days and seasonal rainfall for all stations. This study revealed that wet seasons are characterized by a high number of rainy days while a dry season has a low number of rainy days. Similar results were obtained by Mupangwa et al. (2012). A significant relationship between the number of rainy days and length of the rainy season exists at all stations of the catchment, indicating that a long season is characterized by a greater number of rainy days than a short season. At the 5 % level of significance, there is a strong correlation between the number of rainy days and seasonal rainfall, with a low number of rainy days leading to low seasonal rainfall and a high number of rainfall days causing high seasonal rainfall.

4.10 Aridity index and implications for crop production

Mean annual rainfall and evapotranspiration, as well as aridity index for selected stations within the Luvuvhu River catchment are shown in Table 4.24. Resultant agro-climatic zones based on UNEP (1992) are also included. Average annual rainfall in the catchment ranges from 356 mm for Folovhodwe to 1735 mm for Entabeni. Annual evapotranspiration ranges from 1450 mm for Levubu to 1804 mm for Elim. Comparable to results by Mzezewa et al. (2010), ET_0 is higher than the rainfall meaning that rainfall is not effective within the catchment. A study by Jolota and Prihar (1990) showed that 50 to 70 % of annual rainfall evaporates to the atmosphere without any benefit to crop production. As a result, necessary steps such as dry planting, conservation agriculture, intercropping, wind breaks, agroforestry and mulching are required to utilize rainfall effectively and reduce evapotranspiration from the soil surface (Rockstrom et al., 2003) (Table 4.25).

Aridity index values show that Entabeni is a humid zone, Levubu, Lwamondo, Tshiombo and Thathe are sub-humid zones, while Sigonde, Elim, Phunda Maria, Mampakuil and Phafuri are semi-arid zones and lastly Folovhodwe is an arid zone. In arid zones, crop water requirements frequently exceed total rainfall received and as a result no rain-fed agriculture can be practiced without plans for alternative sources of water (Wani et al., 2003). Rainfall is not the only limiting factor in agricultural production in semi-arid and dry sub-humid zones, but extreme rainfall variability coupled with high rainfall intensity, few rainfall events, and poor spatial and temporal rainfall distribution also play a crucial role (Rockstrom et al., 2003). Dry spells are said to occur almost every season in semi-arid and sub-humid zones (Wani et al., 2003). As a result, irrigation is said to be crucial for good and reliable harvests as semi-arid areas carry a high risk of unreliable rainfall which might lead to crop failure (Brouwer and Heibloem, 1986).

Table 4.24 Agro-climatic zones of the 12 selected stations at the Luvuvhu River Catchment

Station	Annual precipitation (mm)	Annual evapotranspiration (mm)	Aridity index (AI)	Zones
Elim	732	1804	0.40	Semi-arid
Entabeni	1735			Humid *
Folovhodwe	356			Arid *
Levubu	1356	1450	0.93	Sub-humid
Lwamondo	865	1580	0.54	Sub-humid
Mampakuil	497			Semi-arid *
Phafuri	464	1789	0.25	Semi-arid
Phunda Maria	526			Semi-arid*
Sigonde	421	1750	0.24	Semi-arid
Thathe	1172			Sub-humid *
Tshiombo	986	1558	0.63	Sub-humid
Vreemedeling	801			Sub-humid *

Brouwer and Heibloem (1986) climate classification

Farmers at the semi-arid and sub-humid areas of the Luvuvhu River Catchment are advised to adapt rainwater management strategies in order to improve their yield (Table 4.25). Rainwater management strategies include external water harvesting systems, in-situ water harvesting systems, evaporation management and integrated soil and crop management. These strategies help to improve yields and water productivity (Rockstrom et al., 2003). For example, at Patancheru in India, sorghum/pigeon pea intercropping yield increased from 1.1 t ha^{-1} with normal practices to 5.1 t ha^{-1} with improved rainwater management practices indicating that rainwater management strategies indeed do improve yield (Rockstrom et al., 2003).

Table 4.25 Rainwater management strategies used in improving rain-fed yields (Source: Rockstrom et al., 2003)

Rain water management strategy	**Methods**	**Purpose**	**Management options**
Increase plant water availability	Ex-situ water harvesting systems	Mitigate dry spells, protect springs, recharge groundwater, enable off-season irrigation, permit multiple uses of water	Surface micro-dams ,subsurface tanks, farm, farm ponds, percolation dams/tanks diversion and recharging structures
	In-situ water harvesting systems	Concentrate rainfall through run-off to cropped area or other use Maximise rainfall infiltration	Bunds, ridges ,broad-beds and furrows, micro-basins, run-off strips Terracing, contour cultivation , conservation agriculture, dead furrows , staggered trenches
	Evaporative management	Reduce non-productive evaporation	Dry planting (early), mulching, conservation agriculture, intercropping, wind breaks, agroforestry, early plant vigour, vegetative bunds, and optimum crop geometry.
Increase plant water uptake capacity	Integrated soil and crop management	Increase proportion of water balance flowing as productive transpiration	Improved crop varieties, soil fertility, optimum crop rotation, pest control, organic matter.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

5.1 Conclusions

The study investigated rainy season characteristics (onset, cessation, the length of the rainy season, dry spells, number of rainy days per season, monthly rainfall and seasonal rainfall). Twelve meteorological stations were selected based on the location and length of the data set. Stations chosen were representative of different rainfall regions within the catchment. The Luvuvhu River Catchment is divided into different agro-climatic zones with different rainfall characteristics. It has arid (Folovhodwe), semi-arid (Sigonde, Phafuri), sub-humid (Lwamondo, Levubu, Elim, Tshiombo, and Thathe) with Entabeni being humid. There is a high rainfall variability across the catchment during rainy season months with high rainfall occurring in January and February. Rainy season characteristics are influenced by spatial rainfall distribution as wet areas of the catchment experience early onset, late cessation, high seasonal rainfall, and a high number of rainy days, low chance of false onset and low chance of dry spells. Dry areas are characterized by late onset, early cessation, short season, low seasonal rainfall, a low number of rainy days and high chance of dry spells. Therefore farmers at wet areas of the catchment are advised to plant both long, medium and early maturing varieties, whereas farmers in the dry areas of the catchment should plant early maturing varieties.

Available maize varieties should be improved to suit different climates, i.e. very early maturing (90-120 days) and requiring less water. Compared to wet areas of the catchment, dry areas have a high probability of crop failure if planting is undertaken after the first onset due to a high number of dry spells. Furthermore, all areas had a high probability of both short and medium dry spells in October. With Sigonde, Phafuri, Tshiombo and Folovhodwe still having a high probability of dry spells in November, planting is not advised for these areas in November but in December. Therefore, farmers should use the first onset for land preparation and planting following the second onset in November and December as there are fewer dry spells depending on the location. However, if planting is undertaken after the first onset, it should be supplemented with irrigation or rain-harvested water to avoid the negative effects of long dry spells on maize growth.

In dry years, semi-arid areas of the catchment experience a short season as sufficient rainfall only occurs in December and then starts to decrease again in January, implying that in four out of five years there would not be any planting of maize as there would not be sufficient rainfall for farmers to begin planting and sustain the crop through its growing season. For sub-humid and humid areas of the catchment such as Levubu, Thathe and Entabeni, rainfall is sufficient for all years to permit maize production (dry, normal and wet years). However, farmers are advised to plant drought tolerant cultivars and crops in years with below normal rainfall but planting can commence as early as October. In wet years, planting can begin as early as October for all areas of the catchment. In wet years, farmers should plant more areas so that they can store maize for dry years, meaning farmers should also invest in proper storage facilities for maize. Production of maize for areas that are favourable such as Entabeni, Levubu, Lwamondo, Thathe, Tshiombo and Vreemedeling, should be maximized so that there is sufficient maize to supply all areas of the catchment. Proper storage facilities for maize should be built to store surplus in high rainfall seasons. Areas such as Folovhodwe, Phafuri, Phunda Maria, and Sigonde do not meet maize production requirements in the current climate. On the other hand, they meet production requirements of other crops such as cowpeas, sorghum, and dry beans which can be marketed in place of maize.

But if farmers still decide to plant maize, they should invest in rainwater harvesting technologies, proper irrigation systems and reduce plant population density. For farms located next to rivers, farmers can purchase generators to pump water during irregular rains and long periods of dry spells. Regression analysis indicated that there was no relationship between onset and cessation of the rainy season for the catchment. However, there is a strong relationship between onset and length of the season, indicating that early onset leads to a longer season. Farmers would be advised to explore different rainwater management strategies, especially those for semi-arid areas if they want to grow maize and have a consistent harvest, as rain-fed agriculture would not yield good results if they are not planting drought-tolerant cultivars requiring less water.

5.2 Findings

- The catchment is divided into different agro-climatic zones with the northeastern and eastern parts of the catchment being arid and semi-arid. The southwestern parts of the catchment are sub-humid and humid. The low-lying areas in the southwestern parts of the catchment are semi-arid, and therefore, different agricultural management strategies should be applied.

- Rainfall from October to April indicates high variability on a yearly basis with coefficient of variation ranging from 52 % to 131 %.
- Peak rainfall in the catchment is experienced in January and February.
- Rainy season characteristics of the catchment are influenced by rainfall distribution and topography. Therefore, early onset in October occurs in areas situated in mountainous areas receiving more than 700 mm of annual rainfall such as Entabeni, Levubu, Thathe, Lwamondo, Vreemedeling, and Tshiombo, while onset occurs later in November in the low-lying areas of the catchment which receive less than 500 mm of annual rainfall such as Sigonde, Phafuri, Phunda Maria, Folovhodwe, and Mampakuil.
- Wet areas of the catchment experience earlier onset than other areas from mid-October and late cessation from Mid-March to early April, therefore leading to a longer rainy season than the remainder of the catchment.
- Dry areas (north and north-eastern) of the catchment, with less than 600 mm of annual rainfall, experience onset later in November and early cessation in February, therefore making the season shorter than that for wet areas (south western parts).
- There is a delay in receiving the first rainfall of the season by nearly a month compared to wet areas (Entabeni, Levubu and Thathe) for dry areas (Folovhodwe, Mampakuil, Phafuri, Phunda Maria and Sigonde) of the catchment.
- There is a high probability of crop failure if planting is done following the first onset for dry areas of the catchment (Folovhodwe, Mampakuil, Phunda Maria, Phafuri and Sigonde).
- Seasonal rainfall ranges from 315 mm for Folovhodwe to more than 1500 mm for Entabeni.
- Areas favourable to maize production at the catchment are Entabeni, Lwamondo, Levubu, Thathe, Tshiombo and Vreemedeling.
- Areas not suitable for maize production are Folovhodwe, Mampakuil, Phafuri, Phunda Maria and Sigonde. Other crops such as sorghum, beans, and cow peas should be considered.

- For dry years (20 % percentile), rainfall is not sufficient to permit planting for the following areas Folovhodwe, Mampakuil, Phafuri, Phunda Maria and Sigonde.
- For Entabeni, Levubu, Lwamondo, Thathe and Vreemedeling, planting can start in October in dry years. However, less rainfall is received and therefore drought- tolerant cultivars should be planted.
- For wet years (80 % percentile), the season starts in October and ends in April in all areas of the catchments.
- No changes in the onset of the rainy season for the catchment were noted for period 1923-2015.
- Changes were noted in cessation, the length of the season, the number of rainy days, monthly rainfall and seasonal rainfall for the catchment.

5.3 Recommendations

- Information on rainy season characteristics of different areas should be communicated to extension services officer and farmers during workshops.
- Farmers are advised to use seasonal forecasts as a guide in planning for the oncoming season.
- In early onset years, late maturing varieties should be planted and in years with late onset, early-maturing and drought-tolerant maturities should be planted.
- For areas not meeting rain-fed maize production requirements, other crops requiring less rainfall such as sorghum, beans, and cowpeas should be planted and can be traded in place of maize.
- Production of maize should be maximized at favourable areas of the catchment by increasing planting areas and using high yielding cultivars, therefore communities' storage facilities should be built to store surplus maize.
- The currently available cultivars should be improved to adapt to various climates at the catchment.
- Farmers should be made aware of different rainwater management strategies used to improve rain-fed agricultural yield in other parts of the world.

- A list of all available cultivars and where to obtain them in the catchment should be compiled with all the information from rainfall requirements, days to reach maturity, temperature, suitable areas, and soil types should be circulated to farmers.
- The first onset rains should be used for planning only, as planting can result in crop failure due to long periods of dry spells in October and November, depending on the location.
- Available cultivars should be upgraded to suit different climates.

5.4 Further research

Future research at the catchment should investigate the following:

- The availability and accessibility of drought-tolerant and early-maturing maize cultivars for the smallholder farmers in rural areas.
- The introduction of other crops requiring less rainfall such as sorghum, millet, cow peas and beans as well as their economic value for areas not meeting rain-fed maize production requirements.
- The introduction of water-management strategies for semi-arid and sub-humid regions of the catchment to increase maize yield.
- Crop suitability taking into account all production requirements of the crops including soil, water, air temperature, solar radiation, and pH.

REFERENCES

Abdullah, M.A., AL-Mazoui, M.A., 1998. A climatological study of the southwestern region of Saudi Arabia. I. Rainfall analysis. Clim. Res. 9, 213-223.

Adamge, M.E., Ujoh, F., 2013. Effect of variability in rainfall characterisation on maize yield in Gboko, Nigeria. J. Environ. Prot. 4,881-887.

Agricultural Research Council (ARC), 2014. Agroclimatology Database, 600 Belvedere, Pretoria, 0083, South Africa.

Akbar, M., Saleem, M., Azhar, F.M., Ashraf, M.Y., Ahmed, R., 2008. Combining ability analysis in maize under normal and high-temperature conditions. J. Agric. Res. 64, 27-38.

Akpalu, W., Hassan, W.R., Ringler, C., 2009. Climate Variability and Maize in South Africa: Results from GME and MELE Methods. IFPRI Discussion Paper No. 843, Washington.

Ambrosino, C., Chandler, R.E., Todd, M.C., 2014. Rainfall-derived growing season characteristics for agricultural impacts assessment in South Africa. Theor. Appl. Climatol. 115, 411-426.

ARC-GCI, 1999. Maize information guide. Agricultural Research Council Institute of Grain Crops, Potchefstroom, South Africa.

Ati, O.F., Stigter, C.J., Oladipo, E.O., 2002. A comparison of methods used to determine the onset of growing season in Northern Nigeria. J. Climatol. 22, 731-742.

Aviad, Y., Kutiel, H., Lavee, H., 2004. Analysis of beginning, end, and length of the rainy season along with a Mediterranean arid climate transect for geomorphic purposes. J. Arid. Environ. 59, 189-204.

Ayoade, J.O., 2004. Introduction to climatology for the tropics, 2nd ed. Spectrum Books Limited, Ibadan.

Babkina, A.M., 2003. El Niño. Overview and bibliography. Nova Science Publishers Inc, New York.

Baloyi, T.C., 2012. Evaluation of selected industrially manufactured biological amendments for maize production. PhD Thesis, University of the Free State, Bloemfontein, South Africa.

Banziger, M., Diallo A.O., 2001. Progress in developing drought and stress tolerant maize cultivars in eastern and southern Africa. Seventh Eastern and Southern Africa Regional Maize Conference, 11-15 February, 189-194.

Belfield, S., Brown, C., 2008. Field crop manual: A guide to upland production in Cambodia, ACIAR Project. The State of New South Wales, Wales.

Benhin, J. K. A., 2006. Climate change and South African agriculture: Impacts and adaptation options. Discussion Paper 21. Special Series on Climate Change and Agriculture in Africa. Pretoria: Centre for Environmental Economics and Policy in Africa, University of Pretoria, South Africa.

Benhin, J., Mutoko, M., Ritho, C., Mbatia, O., 2010. Analysis of economic efficiency in smallholder maize production in Northwestern Kenya. E. Afr. Agr. Forestr. J. 74 (1&2), 139-147.

Boken, V.K., Cracknell, A.P., Heathcote, R., 2005. Monitoring and predicting agricultural drought: A global study, Oxford University Press, New York.

Boko, M., Niang, I., Vogel, C., Githeko, A., Medang, M., Osman-Elasha, B., Tabo, R., Yand, P., 2007. Africa, in: Parry, M.L., Canziani, O.F., Palutikof, J., van der Linden, P.J., Hanson, C.E. (Eds), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge (UK), pp. 433-467.

Bola, G., Mabiza, C., Goldin, J., Kujinga, K., Nhapi, I., Makurira, H., Mashauri, D., 2014. Coping with droughts and floods: A case study of Kanyemba, Mbire District, Zimbabwe. Phys. Chem. Earth. 67-69, 180-186.

Bouagila, B., Sushama, L., 2013. On the current and future dry spell characteristics over Africa. Atmosphere. 4, 272-298.

Brouwer, C., Heibloem, M., 1986. Irrigation Water Management: Irrigation water needs. FAO, Training manual no. 3, Rome, Italy.

Chapman, G., 1994. Earthquakes and natural hazards: What is floods? Geohazards factsheet, Geoscience. Australia.http://www.ga.gov.au/urban/factsheet/flood (accessed 16 November 2016).

Chen, F., Liu, C., 2012. Estimation of the spatial rainfall distribution using inverse distance weighting (IDW) in the middle of Taiwan. Paddy. Water. Environ. 10, 209-222.

Chiduza, C., 1995. Analysis of rainfall data and their implication on crop production: A case of Northern Sebungwe. Zimbabwe. J. Agric. Res. 33 (2), 175-189.

Chikodzi, D., Simba, F.M., Murwendo, T., 2012. Perceptions, Vulnerability and adaptation to climate change and variability in Masivingo Province. Greener. J. Polit. Sci. 2 (5), 156-165.

Cook, C., Reason, C.J.C., Hewitson, B.C., 2004. Wet and dry spells within particularly wet and dry summers in the South African summer rainfall region. Climate. Res. 26, 17-31.

Cook, K.H., 2000. The South Indian Convergence Zone and interannual rainfall variability over southern Africa. J. Clim. 13, 3789-3804.

Department of Agriculture, Forestry and Fisheries (DAFF), 2008. Maize. Directorate Plant Production. Pretoria.

Department of Agriculture, Forestry and Fisheries (DAFF), 2011. Pocket guide to South Africa 2011/12. Pretoria

Diaz, H.F., Markgraf, V., (Eds) 2000. El Niño and the southern oscillation. Multiscale variability and global and regional impacts. Cambridge University Press. Cambridge, pp. 496.

Dlamini, L., 2013. Modelling of standardised precipitation index using remote sensing for improved drought monitoring. MSc dissertation, University of Witwatersrand, South Africa.

du Plessis, J., 2003. Maize production. Directorate of Agricultural Information Services. Department of Agriculture South Africa.

Fischer, T., Bgerlee, D., Edmeades, G., 2014. Crop yield and global food security: will yield increase continue to feed the world ?. Australian Centre for International Agricultural Research, Canberra, Australia, pp. 634.

Food Agricultural Organisation (FAO), 2004. Drought impact mitigation and prevention in the Limpopo river basin. A situation analysis. Land and water discussion paper 4. Food and Agriculture Organisation of United Nations, Rome, Italy.

Food Agricultural Organisation (FAO), 2005. The impact of natural hazards and disasters on agriculture and food security and nutrition. A call for action to build resilient livelihoods. http://www.fao.org/3/a-i4434e (Accessed 10 June 2016).

Gauthier, T.D., 2001. Detecting trends using spearman's rank correlation coefficient. Environ. Forensics. 2, 359-362.

Gommes, R., Negre, T., 1992. The role of Agrometeorology in the alleviation of natural disaster. Agrometeorology series working paper No. 1, FAO, Rome, Italy.

Hachigonta, S., Reason, C.J.C., Tadross, M., 2008. An analysis of onset date and rainy Season duration over Zambia. Theor. Appl. Climatol. 91, 229–243.

Hansen, J., Sato, M., Ruedy, R., 2012. Increasing climate extremes and the new dice. http://www.columbia.Edu/jeh1mailings/2012/20120811 (accessed 10 January 2016).

Hargreaves, G. H., 1994. Simplified coefficients for estimating monthly solar radiation in North America and Europe. Departmental Paper, Dept. of Biol. And Irrig. Engrg, Utah State University, Logan, Utah.

Hargreaves, G.H., Samani, Z.A., 1982. Estimating potential evapotranspiration. J. Irrig. Drain. Div.108 (3), 225-230.

Harvest Choice, 2010. Rainfall variability and crop yield potential .International Food Policy Research Institute, University of Minnesota, Washington. http://harvestchoice.org/node/2240. (Accessed 10 June 2016).

Hassan, M.N., Stern, R.D., 1988. A simple method for analysing daily rainfall data: a case study for Kota Bharu. Pertanika. 11, 101-106.

Hensley, M., Anderson, J.J., Botha, J.J., van Staden, P.P., 2000. Optimising rainfall use efficiency for developing farmers with limited access to irrigation water. WRC Report No. 878/1/00. Water Research Commission, Pretoria.

Hewitson, B.C., Tadross, M., Jack, C., 2005. Historical precipitation trends over southern Africa: a climatology perspective, in: Schulze, R.E. (Ed.), Climate change and water resources in southern Africa: studies on scenarios, impacts, vulnerabilities and adaptation. Water Research Commission, South Africa, pp. 319-324

Hossain, M.M., Anam, S., 2012. Identifying the dependency pattern of daily Dhaka station using Markov Chain and Logistic regression model. Agric. Sci. 3 (3), 385-391.

Hudson, D.A., Jones, R.G., 2002. Simulation of present-day and future climate over southern Africa using HadAMZH. Hadley. Cent. Tech. Note. 39. Met off. Hadley Cent, Exeter, U.K., pp. 42.

Ifabiyi, I.P., Omoyosoye, O., 2011. Rainfall characteristics and maize yield in Kwara state,Nigeria. Ind. J. Fund. Appl. Life. Sci. 1 (3), 60-65.

Igwenagu, C.M., 2015. Trends analysis of rainfall pattern in Enugu state Nigeria. European J. Stat. Probabil. 3 (3), 12-18.

Intergovernmental Panel on Climate Change (IPCC), 2007. Climate change 2007 synthesis report. Contribution of working Groups I, II and III to the forth assessment report of the Intergovernmental Panel on Climate Change, in: Pachauri, R.K., Reisinger, A. (Eds.), IPCC, Geneva, Switzerland.

Intergovernmental Panel on Climate Change (IPCC), 2013.Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, in: Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley P.M. (Eds.), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1535 doi: 10.1017/CBO9781107415324.

International Council for Science (ISCU), 2008. Global environmental change including climate change and adaptation in sub-Saharan Africa, Science Plan, ICSU Regional Office for Africa.

International Institute of Tropical Agriculture (IITA), 2009. Research for development: Cereals and Legume systems, Ibadan, Nigeria.

International Research Institute for Climate and Society (IRICS), 2016. El Niño telecommunications. Http://iri.columbia.edu/wp-content/uploads/2016/05/El Niño-Rainfall.pdf (accessed 13 October 2016)

International Research Institute for Climate and Society (IRICS), 2016. La Niña telecommunications. Http://iri.columbia.edu/wp-content/uploads/2016/05/La Niña-Rainfall.pdf (accessed 13 October 2016)

Jalota, S.K., Prihar, S.S., 1990. Bare soil evaporation in relation to tillage. Adv. Soil. Sci.12, 187-216.

Jewitt, G.P., Garratt, J.A., 2004. Hydrological modeling in the Luvuvhu River Catchment. CAMP technical report, University of KwaZulu-Natal, South Africa.

Johnson, G., 2003. Assessing the impacts of extreme weather and climate events on agriculture with particular reference to flooding and heavy rainfall, in: Agrometeorology related to extreme events. Technical note no. 201.943. World Meteorological organisation, Geneva, pp.73-106.

Jury, M.R., 2002.Economic impacts of climate variability in South Africa and development of resources prediction models. J. Appl. Meteor. 41, 46-55.

Jury, M.R., Lyons, W., 1994. Contrasting synoptic weather events over Southern Africa in the dry summer of 1983. S. Afr. Geogr. J. 76 (1), 6-10.

Kandji, S.T., Verchot, L., Mockensen, J., 2006. Climate change and variability in southern Africa: Impact and adaptation in the agricultural sector. ICRAF/UNEP, Nairobi, 36.

Kgasago, H., 2006. Effect of planting date and densities on yield components of short and ultra-short growth period maize (*Zea Mays L*). MSc Dissertation, University of Pretoria, South Africa.

Kruger, A.C., 2006. Observed trends in daily precipitation indices in South Africa: 1910-2004. Int. J. Climatol. 26, 2275-2285.

Kumar, K.K., Rao, T.V.R., 2005. Dry and wet spells at Campina Grande-PB. Rev. Brasil. Meteorol. 20, 71-74.

Kwatu, X.S., Duke, O., 2007. Characterisation and frequency analysis of one day annual maximum rainfall of Accra, Ghana. ARPN. Eng. Appl. Sci. 2 (5), 27-31.

Linderholm, H.W., Walther A., Chen, D., 2008.Twentieth-century trends in the thermal growing season in the Greater Baltic Area. Climate Change. 87, 405-419.

Lindesay, J.A., Harrison, M.S.J., Haffner, M.P., 1986. The Southern Oscillation and South African rainfall. S. Afr. J. Sci. 82, 196–197.

Love, D., Uhlenbrook, S., Twomlow, S. and van der Zaag, P., 2008. Changing rainfall and discharge patterns in the northern Limpopo Basin, Zimbabwe. European Geophysical Union General Assembly, April 2008, Austria.

Makuvaro, V., Walker, S., Munodawafa, A., Masere, T.V., Murewi, C., Chagonda, I., 2014. An overview of current agronomic practices of smallholder farmers in semi-arid central and western Zimbabwe. Afr. J. Agric. Res. 9 (31), 2710-2720.

Maponya, P., 2010. Climate change and agricultural production in Limpopo Province, South Africa: Impact and adaptation options. PhD Thesis, University of Pretoria, South Africa.

Martin, R.V., Washington, R., Downing, T.E., 2000. Seasonal maize forecasting for South Africa and Zimbabwe derived from an agro-climatological model. J. Appl. Meteor. 39, 1473-1479.

Masupha, E.T., Moeletsi, M.E., Tsubo, M., 2015. Dry spells with reference to the maize crop in the Luvuvhu River Catchment of South Africa. Phys. Chem. Earth. 92, 99-111.

Mavi, H.S., 1986. Introduction to Agroclimatology. Mohan Primlani, New Deihi.

Moeletsi, M.E., Walker, S., 2012. Rainy season characteristics of the Free State Province of South Africa. Water SA 38 (5), 775-782.

Moeletsi, M.E., Walker, S., Landman, W.A., 2011. ENSO and implications on rainfall characteristics with reference to maize production in the Free State Province of South Africa. Phys. Chem. Earth. 36, 715-726.

Mubvuma, M.T., 2013 Climate change: Matching growing season length with maize crop varietal life cycles in semi-arid regions of Zimbabwe. Greener. J. Agri. Sci. 3 (12), 809-816.

Mulgavai, E.M., Kipkorir, E.C., Raes, D., Rao, M.S., 2008. Analysis of rainfall onset, cessation and length of growing season for western Kenya. Agr. Forest. Meteorol. 148, 1123-1135.

Munodawofa, A., 2012. The effect of rainfall characterisation and tillage on sheet erosion and maize grain yield in semi-arid conditions of granitic sandy soils of Zimbabwe. Applied and Environmental Sciences 1-8.

Mupangwa, W., Walker, S., Twomlow S., 2011. Start, end and dry spells of the growing season in semi-arid southern, Zimbabwe. J. Arid. Environ. 75, 1097-1104.

Mzezewa, J., Misi, T., Van Rensburg, L.D., 2010. Characterisation of rainfall at semi-arid ecotope in the Limpopo Province (South Africa) and its implications for sustainable crop production. Water SA 36, 19-26.

Nafziger, E.D., 2010. Growth and production of maize: Mechanised cultivation. Soil, plant and crop production, Urbana.1, 331-363.

Nhemachena, C., 2008. Agriculture and future climate dynamics in Africa: Impacts and adaptation options. PhD Thesis. Department of Agricultural Economics, Extension and rural development. University of Pretoria, Pretoria, South Africa.

Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J., Urquhart, P., 2014: Africa, in: Barros, V.R., Field, C.B., Dokken, D.J, Mastrandrea, M.D., Mach, K.J., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1199-1265.

Nicholson, S.E., Selato, J.C., 2000. The influence of La Niña on African rainfall. Int. J. Climatol. 20, 1761-1776.

Nyakudya, I.W., Stroosnijder, L., 2011. Water management options based on rainfall analysis for rainfed maize (Zea Mays L) Production in Rushinga District Zimbabwe. Agr. Water. Manag. 98, 1649-1659.

Obasi, G.O.P., 2005. The impacts of ENSO in Africa. In: Climate change and Africa. Cambridge University Press, UK, pp. 218-230.

Odekunle, T.O., 2004. Rainfall and the length of the growing in Nigeria. Int. J. Climatol. 24,467-479

Ogallo, L.J., 1994. Interannual variability of the East African monsoon wind systems and their impact on East African climate. WMO/TD 619, 99–104.

Omotosho, J.B., Balogun, A.A., Ogunjobi, K., 2000. Predicting monthly and seasonal rainfall, onset and cessation of the rainy season in West Africa using only surface data. Int. J. Climatol. 20, 865-888.

Orang, M.N., Grismer, M.E., Ashktorab, H., 1995. New equations to estimate evapotranspiration in Delta. California Agriculture, May-June, Californian, United States.

Oruonye, E.D., Ahmed, Y.M., Gambo, M.N., Tukura, E., 2016.Effects of rain variability on maize yield in Gassol LGA, Turaba State, Nigeria. J. Agr. Biotechnol. 1(1), 1-8.

Phllips, J.G., Cane M.A., Rosenzwei G.C., 1998. ENSO seasonal rainfall patterns and simulated maize yield variability in Zimbabwe. Agric. Forest. Meteorol. 90, 39-50.

Raes, D., Sithole, A., Makaru, A., Millford, J., 2004. Evaluation of first planting dates recommended by criteria currently used in Zimbabwe. Agric. Forest. Meteorol. 125, 177-185.

Ramos, M.C., 2001. Rainfall distribution patterns and their change over time in Mediterranean area. Theor. Appl. Climatol. 69,163-170.

Ranum, P., Pena-Rosas, J.P., Garcia-Casal, M.N., 2014. Global maize production, utilization and consumption. Ann. N.Y. Acad. Sci. 1312, 105-112.

Rasmussen, E.M., 1987. Global climate change and variability: effects of drought and desertification in Africa, in: Grants, M.H. (Ed), Drought and Hunger in Africa: Denying famine a future. Cambridge University Press, Cambridge.

Reason, C.J.C., Hachigonta, S., Phaladi, R.F., 2005. Interannual variability in rainy season characteristics over the Limpopo region of southern Africa. Int. J. Climatol. 25, 1835-1853.

Reason, C.J.C., Jagadeesha, D., 2005. A model investigation of the recent ENSO impacts over Southern Africa. Meteorol. Atmos. Phys. 89,181–205.

Reason, C.J.C., Mulenga, H., 2002. Enso-like decadal variability and South African rainfall and SST anomalies in the South West Indian Ocean. Int. J. Climatol. 19, 1651-1673.

Rockstrom, J., Karlberg, L., Wani, S.P., Barron,J., Hatibu, N., Oweis, T., Bruggeman,A., Farahani, J., Qiang,Z., 2010. Managing water in rain-fed agriculture– The need for paradigm shift. Agr. Water. Manage. 97, 543-550.

Savage, M.J., Iwig, W.C., 1985. A simple transformation for annual district rainfall totals for southern Africa. S. Afr. Sci. 81, 517-521.

Sawa, B.A., Adebayo A.A., Bwala, A.A., 2014. Dynamics of hydrological growing season at Kano as evidence of climate change. Asian. J. Agric. Sci. 6 (2), 75-78.

Sen, Z., 2015. Applied drought, modelling, prediction and mitigation. Elsevier, Amsterdam.

Sene, K., 2013. Flash floods: forecasting and warning. Springer Science, London.

Shababala, Z.P., Moeletsi, M.E., 2015. Rainfall patching program. Agricultural Research Council Institute for Soil Climate and Water, Pretoria, South Africa.

Sharma, M.A., Singh, M.A., 2010. Use of probability distribution in rainfall analysis. New York Sci. J. 3 (9), 40-49.

Sheffield, J., Wood, E.F., 2011. Drought: Past problems and future scenarios. Earthscan, United Kingdom.

Sheffield, J., Woods, E.F., Roderick, M.L., 2012. Little change in global drought over the past 60 years. Nature 491, 435-438.

Simba, F.M., Seyiti, L., Murwendo, T., Mapurisa, B., Chayangira, J., Matete, C., Chrima, J., Mushonjowa, E., Mufandaedza, J., 2012. Analysis of trends dry spells during rainy season for Masvingo airport and Zaka stations in Masvingo Province, Zimbabwe. J. Environ. Res. Develop. 7A (1) 218-228.

Singo, L.R., Kundu, P.M., Odiyo, J.O., Mathivha, F.I., Nkuna, T.R., 2011. Flood frequency analysis of annual maximum stream flows for Luvuvhu River Catchment, Limpopo Province, South Africa, University of Venda.

Sithole, A., 2010. Agroclimatic characterisation of the growing season for improved rain-fed maize productivity in Zimbabwe, in: Masaka, J. (Ed.), Midlands State University J. Sci, Agric. and Tech. 2, 1-11.

Sivakumar, M.V.K., 1988. Predicting rainy season potential from the onset of rains in southern sahelian and Sudanian climatic zones of West Africa. Agr. Forest. Meteorol. 42, 295-305.

Sivakumar, M.V.K., Motha, R.P., Das, H.P., (Eds), 2005. Natural disasters and extreme events in agriculture. Springer-Verlag, Berlin.

Smale, M., Jayne, T.S., 2003. Maize in Eastern and Southern Africa: “Seeds” of success in retrospect. EPTD Discussion paper 97. IFPRI, Washington, D.C.

Smith, G.T., 1999. Floods: Environmental health practitioners/ Emergency Management guide. Department of Human Services. Australia.

Smith, I.N., Wilson, L., Suppiah, R., 2008. Characteristics of the northern Australian rainy season. J. Climate. 21, 4298-4311.

Smith, K., 2001. Environmental hazards: Assessing risk and reducing disaster, 3rd ed. Routledge, London.

Smith, K., 2004. Environmental hazards: Assessing risk and reducing disasters, 4th ed. Routledge, London.

Stanton, W.R., Cammack, R.H., 1953. Resistance to maize rust *Puccinia Polysora.* Nature 172, 505-506.

Stephens, M.A., 1974. EDF statistics of the goodness of fit and some comparisons. J. Am. Stat. Asscoc. 69, 730-737.

Stern, R.D., Coe, R., 1984. A model fitting analysis of daily rainfall data. J. Roy. Stat. Soc. Series A 147 (1), 1-34.

Streck, N.A., Lago, I., Gabriel, L.F., Samboranha, F.K., 2008. Simulating maize phenology as a function of air temperature with linear and nonlinear model. Pesq. Agropec. Bras. Brasillia. 43 (4), 449-455.

Tadross, M., Suarez, P., Lotsch, A., Hachigonta, S., Mdoka, M., Unganai, L., Lucio, F., Kamdonyo, F., Muchinda, M., 2007. Changes in growing-season rainfall characteristics and downscaled scenarios of change over southern Africa: implications for growing maize. Regional expert meeting report, pp.193-204. www.csag.uct.ac.za/~mtadross

Tadross, M.A., Hewiston, B.C., Usman, M.T., 2003. Interannual variability of the onset of the maize growing season over South Africa and Zimbabwe. J. Climate.18, 3356-3372.

Thornton, P., Cramer, L., (Eds.) 2012. Impacts of climate change on the agricultural and aquatic systems and natural resources within the CGIAR’s mandate. CCAFS Working Paper 23. Copenhagen, Denmark.

Tilahun, M, K., 2006. The characterisation of rainfall in the arid and semi-arid regions of Ethiopia. Water SA 32 (3), 429-436.

Tisdale, L.W., Nelson, L., Beaton, J.D., 1990. Soil fertility and fertilizers, 4th ed. Macmillan, Singapore.

Tongwane, M.I., Moeletsi, M.E., 2014. Intra-seasonal rainfall variability during maize growing season in the northern lowlands of Lesotho. Theor. Appl. Climatol. 120, 575-585.

Tsubo, M., Walker, S., 2007. An assessment of productivity of maize grown under water harvesting system in a semi-arid region with special reference to ENSO. J. Arid. Environ. 71, 299-311.

Turner, D.J., 1966. An investigation into the causes of low yield in late planted maize. E. Afr. Agric. Fir. J. 31,249-260.

Tyson, P.D., 1986. Climate change and variability in Southern Africa. Oxford University Press, Cape Town.

Tyson, P.D., Preston-Whyte, R.A., 2000. The weather and climate of Southern Africa. Oxford University Press, Cape Town.

UNEP, 1992. World atlas of desertification. Edward Arnold. London.

Unganai, L.S., 1994. Chronology of droughts in Southern Africa: The impacts and future management options. SACCAR Newsletter. 28, 8-17.

Usman, M.T., Reason, C.J.C., 2004. Dry spell frequencies and their variability over southern Africa. Climate. Res. 26, 199-211.

van Oosterhout, S., 1996. What does in situ conservation mean in the life of small-scale farmer? Examples from Zimbabwe's Communal Areas, in: Sperling, L., Loevinsohn, M. (Eds), Using Diversity: Enhancing and maintaining genetic resources on-farm. IDRC, New Delhi, pp. 35-52.

van Zyl, K., 2006. A study on disaster risk management plan for the South African agricultural sector, AgricSA, Pretoria.

Vogel, C., 1994. (Mis) management of droughts in South Africa: Past, present and future. S. Afri. J. Sci. 90, 4-6.

Vogel, C., Laing, M., Monnik, K., 1999. Impacts of drought in South Africa 1980-94, in: Wilhite, D. (Ed), Hazards and disasters: a series of definitive major works. Routledge Publishers, Oxford, UK.

Vogel, C., Liang, M., Monnik, K., 2000. Drought in South Africa with special reference to the 1980-94 period, in: Wilhite, D.A. (Ed), Drought volume 2A global assessment, Routledge, London, pp. 348-367

Vogel, C., O' Obrien, K., 2003. Climate forecasts in Southern Africa, in: O' Brien, K., Vogel, C. (Eds), Coping with climate variability: the use of seasonal forecasts in southern Africa. Ashgate, Aldershot, pp. 75-96.

Walter, M.W., 1967. Length of the rainy season in Nigeria. Niger. Geogr. J. 10,123-128.

Wani, S. P., Pathak, P., Sreedevi, T.K., Singh, H.P., Singh, P., 2003. Efficient management of rainwater for increased crop productivity and ground water recharge in Asia, in: Kijne, J.N., Barker, R., Molden, D. (Eds), Water productivity in Agriculture: Limits and opportunities for improvement. CABI Publishing and International Water Management Institute. Wallingford, Uk and Colombo.

Warburton, M.L., 2012. Challenges in modelling hydrological response to impacts and interactions of land use and climate change. PhD Thesis, University of KwaZulu-Natal, South Africa.

Weerasinghe, K.D.N., 1989. The rainfall probability analysis of Mapalama and its implication to agricultural production of the area. J. Natn. Sci. Coun. Sri Lanka. 17 (2), 173-186.

Whitmore, J.S., 2000. Drought management on farmland. Kluwer Academic Publishers, Netherlands.

Wilhite, D.A. Glantz, M.H., 2009. Understanding: the drought phenomenon: the role of definitions. J. Water. Int. 10 (3), 111-120.

Woltering, L., 2005. Estimating the influence of on-farm conservation practices on the water balance: Case of the Mzinyathini catchment in Zimbabwe. M.Sc. Thesis. Delft University of Technology, The Netherlands.

Zuma, B.M., Luyt, C.D., Chirenda, T., Tandlich, R., 2012. Flood disaster management in South Africa: Legislative framework and current challenges. International conference on applied life sciences, 10-12 September 2012, Turkey, pp. 127-132.

APPENDIX

Appendix 1-12 show onsets of results obtained using two different onset definitions

Appendix 1 Levubu

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1980	110	110	0
1981	94	94	0
1982	101	101	0
1983	107	107	0
1984	107	107	0
1985	101	101	0
1986	112	112	0
1987	95	95	0
1988	102	102	0
1989	101	101	0
1990	98	98	0
1991	136	136	0
1992	122	122	0
1993	93	93	0
1994	106	106	0
1995	120	120	0
1996	114	114	0
1997	100	100	0
1998	94	94	0
1999	142	142	0
2000	103	103	0
2001	99	99	0
2002	99	99	0
2003	110	110	0
2004	103	103	0
2005	97	97	0
2006	110	110	0
2007	94	94	0
2008	116	116	0
2009	118	118	0
2010	127	127	0
2011	110	110	0
2012	103	103	0
2013	110	110	0

Appendix 2 Lwamondo

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1978	108	157	49
1979	131	131	0
1980	134	134	0
1981	142	142	0
1982	102	102	0
1983	99	99	0
1984	95	95	0
1985	120	149	29
1986	94	94	0
1987	129	129	0
1988	104	104	0
1989	112	112	0
1990	95	95	0
1991	104	141	37
1992	100	100	0
1993	93	93	0
1994	120	176	56
1995	99	99	0
1996	96	96	0
1997	93	93	0
1998	100	100	0
1999	112	150	38
2000	111	111	0
2001	108	108	0
2002	113	157	44
2003	122	122	0
2004	143	143	0
2005	110	110	0
2006	161	161	0
2007	187	9999	
2008	126	126	0
2009	138	138	0
2010	128	128	0
2011	95	95	0
2012	104	104	0
2013	111	143	32
2014	102	138	36
2015	137	137	0

Appendix 3 Tshiombo

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1983	105	105	0
1984	107	107	0
1985	123	159	36
1986	112	150	38
1987	150	150	0
1988	103	103	0
1989	101	101	0
1990	138	138	0
1991	137	137	0
1992	125	125	0
1993	98	146	48
1994	146	146	0
1995	111	175	64
1996	104	136	32
1997	107	107	0
1998	100	100	0
1999	116	116	0
2000	117	117	0
2001	131	131	0
2002	121	171	50
2003	110	110	0
2004	161	199	38
2005	128	128	0
2006	110	110	0
2007	96	96	0
2008	117	117	0
2009	139	139	0

Appendix 4 Sigonde

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1984	124	124	0
1985	123	123	0
1986	176	176	0
1987	147	147	0
1988	103	103	0
1989	149	194	45
1990	159	159	0
1991	136	9999	
1992	164	164	0
1993	146	146	0
1994	178	178	0
1995	194	194	0
1996	104	149	45
1997	134	9999	
1998	105	105	0
1999	112	159	47
2000	141	9999	
2001	131	131	0
2002	9999	9999	0
2003	111	111	0
2004	160	9999	
2005	143	143	0
2006	128	183	55
2007	9999	9999	
2008	93	126	33
2009	142	142	0
2010	128	128	0
2011	144	144	0
2012	109	109	0
2013	113	113	0
2014	165	165	0
2015	137	137	0

9999 onset criteria not met

Appendix 5 Phafuri

Years	**25 mm in 10 days**	**25 mm in 10 days and 25 mm in the next 20 days**	**Difference (days)**
1970	127	134	7
1971	100	100	0
1972	140	9999	
1973	172	9999	
1974	132	132	0
1975	172	172	0
1976	122	210	88
1977	152	152	0
1978	102	102	0
1980	106	106	0
1981	110	143	33
1982	147	9999	
1983	9999	9999	
1984	183	9999	
1985	148	148	0
1986	124	9999	
1987	157	195	38
1988	105	158	53
1989	103	103	0
1990	113	113	0
1991	138	138	0
1992	205	9999	
1993	122	122	0
1994	146	146	0
1995	106	177	71
1995	111	173	62
1996	164	164	0
1997	179	9999	
1998	105	141	36
1999	116	116	0
2000	118	9999	
2001	130	9999	
2002	160	160	0
2003	107	107	0

9999 onset criteria not met

Appendix 6 Elim

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1945	105	105	0
1946	9999	9999	0
1947	141	179	38
1948	110	110	0
1949	140	140	0
1950	158	158	0
1951	103	103	0
1952	110	110	0
1953	126	126	0
1954	146	146	0
1955	117	117	0
1956	120	120	0
1957	95	162	67
1958	155	155	0
1959	135	209	74
1960	116	116	0
1961	128	128	0
1962	138	138	0
1963	105	105	0
1964	114	114	0
1965	160	160	0
1966	171	171	0
1967	136	136	0
1968	120	120	0
1969	153	153	0
1970	101	101	0
1971	99	99	0
1972	94	94	0
1973	108	147	39
1974	133	133	0
1975	170	170	0
1976	123	123	0
1977	172	172	0
1978	107	107	0
1979	111	147	36
1980	142	142	0
1981	144	182	38
1982	104	156	52

Appendix 6 continuation

Years	**25 mm in 10 days**	**25 mm in 10 days and 20 mm in the next 20 days**	**Difference (days)**
1983	130	130	0
1984	121	199	78
1985	121	121	0
1986	116	150	34
1987	144	144	0
1988	102	102	0
1989	138	138	0
1990	98	143	45
1991	135	9999	
1992	125	164	39
1993	128	128	0
1994	142	142	0
1995	142	142	0
1996	148	148	0
1997	99	133	34
1998	128	128	0
1999	111	111	0
2000	116	116	0
2001	128	128	0
2002	154	9999	
2003	110	146	36

9999 onset criteria not met

Appendix 7 Mampakuil

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20days	Difference (days)
1945	107	107	0
1946	186	186	0
1947	142	142	0
1948	110	110	0
1949	139	139	0
1950	154	154	0
1951	102	102	0
1952	109	109	0
1953	103	103	0
1954	128	159	31
1955	110	110	0
1956	119	147	28
1957	94	94	0
1958	113	150	37
1959	111	111	0
1960	133	133	0
1961	121	121	0
1962	133	133	0
1963	103	154	51
1964	113	113	0
1965	127	127	0
1966	106	171	65
1967	114	114	0
1968	120	120	0
1969	110	110	0
1970	100	100	0
1971	98	98	0
1972	93	93	0
1973	104	145	41
1974	132	132	0
1975	170	170	0
1976	93	117	24
1977	107	152	45
1978	110	110	0
1979	105	106	1
1980	111	142	31
1981	145	9999	
1982	158	158	0

Appendix 7 continuation

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20days	Difference (days)
1983	106	106	0
1984	106	106	0
1985	121	121	0
1986	118	146	28
1987	145	145	0
1988	103	9999	
1989	101	101	0
1990	99	148	49
1991	136	136	0
1992	124	124	0
1993	130	130	0
1994	122	122	0
1995	111	111	0
1996	103	103	0
1997	100	105	5
1998	96	96	0
1999	112	117	5
2000	128	128	0
2001	131	131	0
2002	111	111	0
2003	111	111	0

9999 onset criteria not met

Appendix 8 Thathe

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1963	104	104	0
1964	113	113	0
1965	128	128	0
1966	107	108	1
1967	114	114	0
1968	114	114	0
1969	93	93	0
1970	102	102	0
1971	99	99	0
1972	95	129	34
1973	102	102	0
1974	123	123	0
1975	114	114	0
1976	99	99	0
1977	106	147	41
1978	100	100	0
1980	122	122	0
1981	111	115	4
1982	96	96	0
1983	102	102	0
1984	108	108	0
1985	106	106	0
1986	100	100	0
1987	111	111	0
1988	95	95	0
1989	101	101	0
1990	100	100	0
1991	138	138	0
1992	156	156	0
1993	124	124	0
1994	98	98	0
1995	121	121	0
1995	116	116	0
1996	103	103	0
1997	100	100	0
1998	105	105	0
1999	159	9999	
2000	186	186	0
2001	112	112	0
2002	111	111	0

9999 onset criteria not met

Appendix 9 Entabeni

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1923	134	134	0
1924	93	93	0
1925	98	98	0
1926	126	126	0
1927	106	106	0
1928	109	109	0
1929	96	96	0
1930	137	137	0
1931	101	101	0
1932	113	113	0
1933	108	108	0
1934	107	107	0
1935	95	95	0
1936	102	102	0
1937	97	97	0
1938	93	93	0
1939	110	110	0
1940	93	125	32
1941	108	108	0
1942	93	93	0
1943	113	113	0
1944	105	105	0
1945	99	99	0
1946	93	130	37
1947	108	108	0
1948	110	110	0
1949	113	113	0
1950	124	124	0
1951	102	102	0
1952	94	94	0
1953	103	103	0
1954	107	107	0
1955	109	109	0
1956	119	119	0
1957	94	94	0
1958	104	104	0

Appendix 9 continuation

Years	25 mm in 10 days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1959	111	111	0
1960	131	131	0
1961	120	120	0
1962	137	137	0
1963	102	102	0
1964	113	113	0
1965	104	127	23
1966	106	106	0
1967	114	114	0
1968	113	113	0
1969	93	93	0
1970	100	100	0
1971	98	98	0
1972	95	95	0
1973	102	102	0
1974	99	99	0
1975	114	114	0
1976	95	95	0
1977	106	106	0
1978	106	106	0
1979	99	99	0
1980	110	110	0
1981	94	94	0
1982	101	101	0
1983	106	106	0
1984	102	102	0
1985	101	101	0
1986	112	112	0
1987	103	103	0
1988	103	103	0
1989	101	101	0
1990	99	99	0
1991	116	116	0
1992	101	101	0
1993	93	98	5
1994	122	122	0

Appendix 9 continuation

Years	**25 mm in 10 days**	**25 mm in 10 days and 20 mm in the next 20 days**	**Difference (days)**
1995	141	141	0
1996	104	104	0
1997	100	100	0
1998	95	95	0
1999	116	116	0
2000	103	103	0
2001	99	99	0
2002	97	97	0
2003	110	110	0
2004	105	105	0
2005	98	98	0
2006	128	128	0
2007	150	150	0
2008	116	116	0
2009	121	121	0
2010	126	126	0
2011	108	108	0
2012	106	106	0

9999 onset criteria not met

Appendix 10 Folovhodwe

Years	25 mm in ten days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1945	141	141	0
1946	186	9999	
1947	160	160	0
1948	110	110	0
1949	127	127	0
1950	158	158	0
1951	104	104	0
1952	147	147	0
1953	122	122	0
1954	124	175	51
1955	110	9999	
1956	161	161	0
1957	124	186	62
1958	182	182	0
1959	139	9999	
1960	134	134	0
1961	127	127	0
1962	139	9999	
1963	155	155	0
1964	114	115	1
1965	210	210	0
1966	168	172	4
1967	9999	9999	
1968	134	134	0
1969	93	93	0
1970	134	9999	
1971	99	99	0
1972	139	9999	
1973	171	207	36
1974	132	132	0
1975	167	167	0
1976	211	211	0
1977	168	168	0
1978	116	116	0

Appendix 10 continuation

Years	25 mm in ten days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1979	110	110	0
1980	110	110	0
1981	145	9999	
1982	9999	9999	0
1983	134	9999	
1984	134	134	0
1985	123	9999	9
1986	198	9	
1987	104	153	49
1988	103	103	0
1989	113	113	0
1990	158	9999	
1991	9999	9999	0
1992	171	171	0
1993	146	146	0
1994	162	162	0
1994	111	194	83
1996	104	144	40
1997	141	9999	
1998	105	105	0
1999	115	210	95
2000	118	118	0
2001	130	130	0
2002	9999	9999	
2003	110	110	0

9999 onset criteria not met

Appendix 11 Vreemedeling

Years	25 mm in ten days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1945	106	106	0
1946	139	189	50
1947	122	122	0
1948	110	110	0
1949	140	140	0
1950	160	160	0
1951	103	103	0
1952	109	109	0
1953	122	122	0
1954	127	127	0
1955	109	109	0
1956	119	155	36
1957	94	100	6
1958	104	104	0
1959	135	135	0
1960	115	115	0
1961	120	120	0
1962	137	137	0
1963	104	104	0
1964	113	113	0
1965	127	127	0
1966	106	169	63
1967	114	114	0
1968	133	133	0
1969	110	110	0
1970	100	100	0
1971	98	98	0
1972	95	146	51
1973	108	146	38
1974	134	134	0
1975	149	149	0
1976	121	121	0
1977	105	152	47

Appendix 11 continuation

Years	**25 mm in ten days**	**25 mm in 10 days and 20 mm in the next 20 days**	**Difference (days)**
1978	107	107	0
1979	111	111	0
1980	110	142	32
1981	110	179	69
1982	100	9999	
1983	130	130	0
1984	121	121	0
1985	122	160	38
1986	112	112	0
1987	104	151	47
1988	102	102	0
1989	114	114	0
1990	138	138	0
1991	147	147	0
1992	123	123	0
1993	94	123	29
1994	105	105	0
1995	111	111	0
1996	139	139	0
1997	102	180	78
1998	95	95	0
1999	113	117	4
2000	113	113	0
2001	132	132	0
2002	123	164	41
2003	111	144	33

9999 onset criteria not met

Appendix 12 Phunda Maria

Years	25 mm in ten days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1945	134	134	0
1946	181	9999	
1947	180	9999	
1948	111	111	0
1949	129	129	0
1950	155	155	0
1951	117	187	70
1952	147	147	0
1953	125	125	0
1954	128	128	0
1955	106	106	0
1956	155	155	0
1957	120	120	0
1958	103	154	51
1959	134	209	75
1960	134	134	0
1961	152	152	0
1962	139	145	6
1963	156	9999	
1964	113	143	30
1965	162	162	0
1966	168	172	4
1967	155	9999	
1968	133	133	0
1969	101	110	9
1970	127	127	0
1971	99	99	0
1972	95	171	76
1973	107	107	0
1974	132	132	0
1975	136	136	0
1976	122	122	0
1977	111	111	0
1978	111	111	0
1979	132	132	0

Appendix 12 continuation

Years	25 mm in ten days	25 mm in 10 days and 20 mm in the next 20 days	Difference (days)
1980	110	110	0
1981	115	9999	
1982	306	9999	
1983	106	9999	
1984	124	124	0
1985	122	122	0
1986	120	150	30
1987	145	145	0
1988	103	103	0
1989	114	114	0
1990	138	138	0
1991	136	9999	
1992	125	164	39
1993	126	126	0
1994	106	178	72
1995	174	174	0
1996	162	162	0
1997	136	136	0
1998	105	105	0
1999	116	116	0
2000	118	118	0
2001	131	131	0
2002	122	127	5
2003	111	177	66

9999 onset criteria not met