Inter-seasonal and intra-seasonal rainfall variability in the North West Province South Africa

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Declaration

I, Keneilwe Phora (Student No:23146818), declare that this dissertation for MSc. in Geography at North West University has not been previously submitted by me for a degree at this University or any other institutions, and that all the references have been fully acknowledged.

Signed..Date...............................

Keneilwe Phora

Signed ....Date................................

Supervisor: Prof. T.A. Kabanda

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Abstract

The present study analysed inter-seasonal and intra-seasonal rainfall variability in the North West Province (NWP) South Africa. The observed rainfall data was obtained from South African Weather Service (SAWS) and Agricultural Research Council (ARC).The data used in the analysis covers a period of 31 rainfall seasons (1984 to 2015). The methodology used in the study to analyse rainfall variability was rainfall time series analysis while the rainfall trends were analysed using Man Kendall trend analysis and the Sens slope.

Before evaluating rainfall variability in the province, NWP was classified into two homogeneous rainfall regimes using Cluster Analysis (CA). Cluster one (C1) covers central and southern stations while Cluster two (C2) covers the north-eastern stations in the province. The rainfall time series of the clusters show that C1 is increasing in aridity while in C2 the rainfall is showing an increase pattern. Mann Kendal trend test and Sens' slope estimator were used to study variability and trends in NWP rainfall. Trend analysis results of North West Province 1984-2015 seasonal rainfall indicated a general decrease in the province rainfall overtime. Four stations registered a statistically significant rainfall trend of which only one showed a negative rainfall trend. 9 out of 15 rainfall stations in C1 reported negative rainfall trend, while C2 is gradually becoming wetter with 82% of the stations showing a positive rainfall trend. In the intra-seasonal analysis, statistically significant stations (Delareyville, Taung, Olifantsport and Potchefstroom) were used. The results suggest that rainfall in North West Province shows a strong spatial and temporal variability at Intra-seasonal scale. Tendency towards aridity can be expected due to the delay and frequency of below normal rainfall experienced in NWP. The rainfall in the region can go for about 14 consecutive recording below normal events. While only few above normal rainfall pentads are recorded. However, some limitations (e.g., data length), were encountered in this study.

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Abbreviations and Acronyms

ARC	Agricultural Research Council
BPDGDS	Bojanala Platinum District Growth and Development Strategy
CA	Cluster Analysis
C1	Cluster one
C2	Cluster two
CSP-VA	Climate Support Program - Vulnerability Assessment
DEA	Department of Environmental Affairs
DWS	Department of Water and Sanitation
ENSO	El Nino Southern Oscillation
FAO	Food and Agriculture Organisation
GDP	Gross Domestic Products
IDP	Integrated Development Plan
IFRC	International Federation of Red Cross
IPCC	Inter-governmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zones
NMMD	Ngaka Modiri Molema District Municipality
NWP	North West Province
NWREAD	North West Province department of Rural, Environmental and Agricultural Development
OLR	Outgoing Longwave Radiation
PCA	Principal Component Analysis
PC	Principal Component
SADC	Southern Africa Development Community

SAWS	South African Weather Service
SPI	Standardised Precipitation Index
SWIO	Southwest Indian Ocean
TC	Tropical Cyclone
Var	Variable
WMO	World Meteorological Organisation

CHAPTER ONE

Introduction

1.1 Overview of the study

This study focuses on the inter-seasonal and intra-seasonal rainfall variability of North West Province (NWP), South Africa. Rainfall variability is recognized by the variations in the frequency of above and below normal rainfall in southern Africa (Jury and Mwafulirwa, 2002). Rainfall variability occurs on a global scale, although its impacts vary in each climatic zone and the adaptation is largely site specific (Lema and Majule, 2009). Therefore, it is important to understand what is happening at different spatial scales.

Firstly, the study investigate the inter-seasonal rainfall variability of NWP by analysing the characteristics and trends of seasonal rainfall in order to quantify the nature and the extent of the changes in rainfall patterns over the study area. Rainfall variability is characterised by the type, amount, frequency, intensity and duration of the rain (Al-Houri, 2014). Secondly, this study investigate rainfall variability at intra-seasonal scale. In this section, rainfall characteristics are at a shorter time scale by analysing in-seasonal fluctuations.

South Africa and most parts of southern Africa is experiencing water scarcity (Boko et al., 2007). According to Walmsley et al., 1999, South Africa’s water resources are very limited and almost fully utilized. The rainfall trends in South Africa indicate a significant decrease in the number of rainy days, reduced rainfall months and an increase in dry spell durations across the country (Phora, 2016; DEA, 2013b). These resulted in a marginal reduction in seasonal rainfall. The rainfall trend in South Africa displays a decreasing trend in the east, severe decline in the western part of the country (Davies, 2010; Zengeni et al., 2016). Poor rainfall experienced in the country has resulted in increasingly frequent droughts (Unganai and Kogan, 1998; Richards et al., 2001; Rouault and Richards, 2003; Kabanda, 2004).

In South Africa and most developing countries, rainfall variability makes it challenging for farmers to adapt better to sustainable farming practices (Tadross et al., 2005), making the farming sector vulnerable to rainfall variability impacts. North West Province economy is based on water-dependent sectors such as agriculture, tourism and mining (NWREAD, 2015a). Therefore, rainfall variability may have detrimental effects on the society.

Due to the decrease in NWP rainfall (NWREAD, 2014; Phora, 2016), water scarcity has become problematic in North West Province (NWP) (NWREAD, 2014) and it is intensified by the drought vulnerability in the area (Times Live, 15 June 2016; SAWS, 20 May 2016). Understanding the rainfall variability of NWP is critical to establish appropriate monitoring techniques for future rainfall trends and changes in the variability. A broad analysis of rainfall at different time scales such as, inter-annual, inter-seasonal and intra-seasonal is essential for rainfall dependent sectors (Al-Houri, 2014).

1.2 Problem statement

Water is one of the most vital requirements for social and economic development (Al-Houri et al., 2014). The primary channel through which rainfall variability is affecting NWP and South Africa is through water availability and water becomes a crucial lens through which to study rainfall variability (NWREAD, 2015b). The scarcity of water in North West Province is increased by the climate state of the area such as the semi-aridity and rainfall variability in the region.

In NWP, and in most parts of southern Africa, rainfall has become incoherent, adversely affecting social-economic activities that include agriculture, forestry, tourism management and water resource management in most parts of southern Africa and threatening food security in the region (NWREAD, 2014). NWP is vulnerable to rainfall variability because its economy is driven by rainfall dependent sectors. Knowledge of long-term rainfall variability is important for land use and water resource managers in semi-arid regions. A contribution to the understanding of rainfall variability at inter-seasonal and intra-seasonal scales is of great importance. Therefore, this study intends to examine rainfall variability of North West Province at these timescales.

1.3 Aims and Objective

The core aim of this research is to evaluate inter-seasonal and intra-seasonal rainfall variability in the North West Province from 1984 to 2015. The following specific objectives are developed to achieve the aim.

1. To determine various rainfall regimes (homogeneous rainfall regions) of North West Province.
2. To examine the inter-seasonal rainfall time series and trends.
3. To analyse intra-seasonal rainfall variability.

1.4 Description of the study area

North West Province (the study area) Figure1.1, covers an area of approximately 102881km^2 with altitude ranging from 1000-2000 metres above sea level (Masigo and Matshego, 2005). NWP is made up of four district municipalities: Ngaka Modiri Molema district municipality is found in the central part of the province, Dr Ruth Segomotsi Mompati district municipality in the west, Bojanala Platinum District Municipality in the north-eastern of NWP and Dr Kenneth Kaunda district municipality in the southeast (NWREAD, 2014).

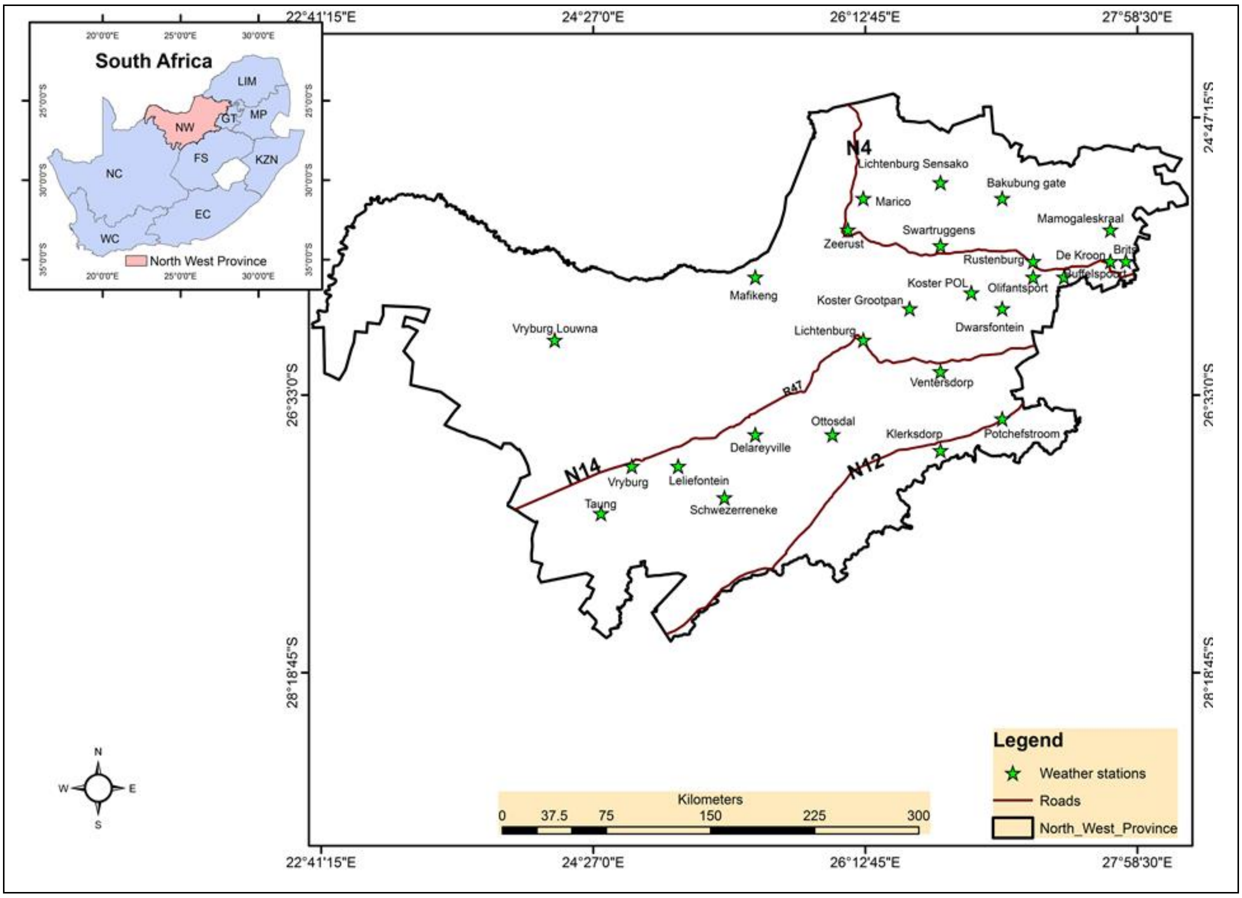


Figure 1.1: Study area: The location of study area and spatial distribution of rainfall stations

1.4.1 Climate

North West Province lies within the arid to semi-arid Kalahari region. It extends from Pretoria-Johannesburg in the east to the Botswana border in the north (Anim et al., 2008). The province's landscape is arid in the western parts where it forms south-western border with the Northern Cape (Anim et al., 2008). The eastern part of NWP is wetter than the western part, where dry, semi-desert conditions prevail (Walmsley and Walmsley, 2002).

North West Province falls under the arid climatic zone in South Africa and experiences temperatures ranging from 31°C in summer to 3°C in winter (Anim et al., 2008). Most of the rainfall in the province occurs within summer months between October and March (Kruger et al., 2012). The province is regarded as a water-stressed region because it receives an average rainfall of <500 mm per year, which is extremely variable in time and space (Speelman et al., 2008).

The scarcity of water and the spatial variability of rainfall are likely to have a severe impact on the water resources and agricultural production in the province. The impact of rainfall variability poses a threat to the economy of the province. Poor rainfall in the province will result in recurrent droughts and increased aridity in the area.

1.4.2 Socio-economic activities

The main economic sectors in the province are agriculture and mining. These sectors play a major role in the economy of South Africa, acting as a primary source of employment. Most of these economic sectors are located in southern and the eastern region while the central region is mostly dominated by game and livestock farming (NWREAD, 2014). In the province, the agricultural sector produces 13% of provincial gross domestic product (GDP) and 18% of labour forces (NWREAD, 2015a) while at least 22% of commercial maize in South Africa produced in NWP. The mining sector contributes 34% of the provincial GDP and 21% of employment in the province (NWREAD, 2015a).

Based on the main economic sectors in NWP per district municipality, Bojanala Platinum District Municipality has been recognised as the economic growth engine of the province and contributes the vast majority of total production output and employment opportunities within the province (BPDGDS, 2005). The dominant land uses in the district are agriculture, mining, conservation, industrial, commercial, recreational and residential areas (Middleton, 2013). The mining sector plays an important part in the district, because it is the primary source of employment and has led to many developments (IDP, 2012). Just like Bojanala Platinum District Municipality, Dr Kenneth Kaunda District Municipality economy is based on agriculture and mining, with a number of the mines in the district linked to the Witwatersrand reefs (NWREAD, 2014).

In Ngaka Modiri Molema district municipality (NMMD), service industries account for 44% of the economy. Agriculture contributes 5.2% to the economy of this municipality, and mining 2% (NMMD, 2016). Dr Ruth Segomotsi Mompati District Municipality economy is mainly based on game farming and extensive commercial livestock such as cattle or beef (NWREAD, 2014).

1.5 Summary

This chapter provides an overview of the study. It also details the problem statement and highlights the importance of the dissertation in North West Province. Rainfall variability has the potential to impact on the socio economic sectors in NWP. The scarcity of water in North West Province is increased by the climate state of the area such as the semi-aridity and rainfall variability in the region. Hence, the primary channel through which rainfall variability is affecting NWP is through water availability, making water become a crucial lens through which to study rainfall variability.

The main aim of the study is to evaluate rainfall variability of NWP at different time scales. Knowledge of rainfall variability at different time scales is important for understanding the climate of a specific area and helping in the future projection for adaptation and mitigation measures. The study objectives include delineating NWP rainfall into homogeneous regimes, examining the NWP rainfall time series to understand the behaviour and pattern of rainfall in the province. Rainfall trends in NWP are analysed and intra-seasonal rainfall time series characteristics are evaluated.

The dissertation is divided into seven chapters made into five categories: Introduction to the dissertation and description of the study area (Chapter 1). Literature review on rainfall variability and the modulating factors associated with rainfall (Chapter 2). Description of data and methods (Chapter 3). Data analysis and results (Chapter 4, 5 and 6); chapter 4 is focused of classifying NWP into homogenous rainfall regime. Chapter 5 focuses on the analysis of inter-seasonal rainfall variability of NWP and chapter 6 is the analysis of intra-seasonal rainfall variability of NWP. Summary and conclusion are in chapter 7.

CHAPTER TWO

Literature review

2.1 Introduction

This chapter presents a comprehensive literature review on rainfall variability focusing on rainfall changes from a global to a national scale. The chapter also highlights the impact of rainfall variability on different sectors that are highly vulnerable to rainfall variability.

2.2 Rainfall variability

The world is experiencing a high variability in climate parameters such as temperature and precipitation (Singh and Kumar, 2015). Rainfall variability has impacted every part of the world differently. However, the vulnerability of each area is determined by their adaptive capacity (Singh and Kumar, 2015). In Africa, due to the inability to adapt to climate variability, the continent is regarded as the most vulnerable (Dennis and Dennis, 2012). The vulnerability of variations in rainfall is intensified by its reliance on rainfall-dependent sectors.

2.2.1 Rainfall variability over Africa

Climate across the African continent is controlled by oceanic and land interactions that produces a variation of climates from humid tropics and arid Sahara that can impact economic development through water resources and agriculture (Christensen et al., 2007; Jury, 2013). The prevailing patterns of rainfall and seasonality in Africa are associated with the mid-latitude westerlies and the Inter Tropical Convergence Zone (ITCZ) (Nicholson, 2000). The complexity in the African climate results in considerable rainfall variations across the sub-regions (Mendelsohn et al., 2000). The continent is mostly arid to semi-arid with the exception of parts in the central and western regions which are very humid (Mendelsohn et al., 2000).

In the Sahel multi-decadal rainfall variability prevails (Jury, 2013). The rainfall variability of the regions shows low to high-frequency variation dominated by timescales of seven years or greater (Nicholson, 2000). L'hote et al., 2002 study using the annual rainfall time series for the Sahel over 31 years (1970 to 2000) showed that the region was dominated by drier seasons and only three observed wetter seasons. Spinoni et al., 2014 study also showed a progressive decline in average annual rainfall occurring in some parts of West Africa as well as observed decrease in the average annual rainfall each decade. According to Le Barbé et al., 2002 most of the rainfall deficit in West Africa between 1971 and 1990 was due to the decrease in the amount and frequency rainfall events. Intern Africa east, the rainfall patterns shows an increase in the northern sector while a decline in rainfall is experienced over the southern regions (Schreck and Semazzi, 2004). Due to the pronounced variation in the eastern Africa rainfall trend, it is projected that the region will experience wetter climate with more intense wet seasons (Daron, 2014).

Inter-annual rainfall variability has increased in southern Africa since the 1970s although the long-term precipitation trends are weak (Jury, 2013). The variability observed in the post-1970 period results from rainfall irregularities that lead to recurrent droughts events reported over the years (Richards et al., 2001). The regions rainfall variability comprises erratic and unpredictable seasonal rainfall that makes farming vulnerable across most part of the region (FAO, 2004). IPCC, 2007, report indicates that below-normal rainfall years are becoming more frequent in southern Africa. This results from a decreasing number of' rainy days in the region (Christensen et al., 2007). Although many studies have suggested a decrease in southern African rainfall; New et al., 2006, reported an increase in wet day precipitation and heavy precipitation running through parts of southern Africa (Botswana, Zimbabwe, Mozambique and southern Namibia) which suggests an expected increase in the region's rainfall intensity. While IPCC, 2014 also reported a significant increase in heavy rainfall events is expected in different parts of the region. Tadross et al., 2005 study reported expected changes in the seasonality and extreme weather events.

The trends in rainfall variability in the Sahel and southern Africa are roughly parallel, having both experienced dry and wet periods in the same years and a trend towards increasingly dry conditions (L'hote et al., 2002). While the eastern Africa region rainfall trends are not the same with the western and southern Africa, the rainfall in east Africa is expected to increase while other regions expect a decrease in rainfall (Schreck and Semazzi, 2004). In East Africa the most prominent time scale of variability varies between cycles of 2.3, 3.5 and 5 to 6 years (Nicholson, 2000).

2.2.2 Regional rainfall variability

Southern Africa lies within an arid or semi-arid climatic region and has limited water resources (Mason and Joubert, 1997). The region is highly vulnerable to rainfall variations due to its dependence on climate-sensitive sectors that are critical to the economy and livelihoods of its inhabitants (Lesolle, 2012). The region is already struggling to cope effectively with the impacts of current rainfall variability and is likely to struggle with adaptation to future changes (Cooper et al., 2008). The dependence of the region on rain-fed agriculture makes it vulnerable to these changes (Cooper et al., 2008). The region and Africa broadly suffer from poor infrastructure and low socio-economic development, and the impact or rainfall variability often resulting in increased vulnerability due to lack of adaptive capicity (Fauchereau et al., 2003).

In the southern Africa Development Communitiy (SADC) region, agriculture, trade in agriculture and tourism play a critical role in the economy and in sustaining rural livelihoods (Lesolle, 2012). These sectors depend on climate variables such as rainfall, making it important to understand the changes in this parameter (Molua, 2002). Rainfall trends in southern Africa are variable but evidence points to an increased seasonal variability, with increasing rainfall extremes across the region (DEA, 2014). A study by Shongwe et al., 2009 showed that the tendency towards the decrease in southern Africa rainfall results from the delayed start and early cessation of the rainfall. While IPCC, 2014, projections show a likely decrease in the average annual rainfall over most parts of the region.

The southern Africa region has experienced a decreasing rainfall trend from the 1950s which has resulted in recurrent drought events affecting the region (IPCC, 2007). Drought in southern Africa has become a recurrent event and over the years it has been studied by Unganai and Kogan 1998; Vicente-Serrano et al., 2012; Rouault and Richards, 2003. Severe widespread and significant drought conditions affected the region in the 1982 and 1991seasons. Severe droughts, which extend for successive years, often results in serious economic, environmental and social concerns (Wilhite, 1997).

The recurrent drought in the region has impacted agriculture, water resources, as well as social economies, industrial and environmental resources (Vogel and

Drummond, 1993; Unganai and Kogan 1998; Rouault and Richards 2003; Kabanda, 2004). The impacts associated with drought are most severe in areas whose economy is least diversified and primarily based in agriculture (FAO, 2004).

Frequent drought events and dry spells experienced in Zimbabwe during the rainfall season, has increased the risk rain-fed cropping failure in the country (Mupangwa et al., 2011). Zimbabwe and most parts of southern Africa, experienced the worst drought during 1991 rainfall season, which resulted in complete failure of crops and loss of livestock (FAO, 2004). The 1991 to 1992 drought in Zimbabwe resulted in an 11% drop in GDP (Vicente-Serrano et al., 2012). Due to this variability, crop production across Zimbabwe has weakened and the environment is more arid, affecting agricultural production (Chatiza et al., 2011).

Due to the observed fluctuation in rainfall, floods have also occurred in the region. The 1984 floods in southern Africa that resulted from tropical cyclone Demoina affected northeastern South Africa, Mozambique and Swaziland (DEA, 2014). While in 2002, north eastern part of South Africa, Zimbabwe and Mozambique was characterised by several damaging extreme rainfall events that were associated with the tropical Cyclone Eline (Dyson, 2009). Severe flooding and high winds resulted in loss of life, livestock and farming land (FAO, 2004). Mozambique was worst affected by tropical cyclone Eline, which killed over 300 people in Mozambique and left millions more people displaced (FAO, 2004; Gericke and du Plessis, 2012). Mozambique regularly experiences both extremes of rainfall variability which results in periods of drought and severe flooding caused by excessive rainfall and cyclones (FAO, 2004).

The most recent drought, recorded in the region is the 2015 season. Across many parts of southern Africa, the 2015 rainfall season was the driest in the last 35 years (FAO, 2016). In South Africa, more than five provinces were affected badly by the drought (News24 2016/01/17). North West Province was hit the hardest with water resources and food production severely affected (Times Live, 2016 15 June). While the most recent wet extreme event to affect the region is Tropical Cyclone (TC) Dineo in February of 2017 (SAWS, 2017). On the 15th February 2017 TC Dineo hit the southern coast of Mozambique bringing along strong winds and torrential rains (IFRC, 2017). The cyclone moved towards South Africa and Zimbabwe, resulting in the death of seven people (Hill and Nhamire, 2017). By the 24th of February the Mozambique government reported that thousands of Mozambicans had lost their homes due to the cyclone (IFRC, 2017)

2.2.3 South African rainfall variability

South Africa's average rainfall is estimated 450mm per year, which is below the world's average of about 860mm rainfall per year (Benhin, 2006). Therefore, water is considered a limited resource in the country, and the fluctuations in its level and rainfall distribution, together with rainfall variability makes the country vulnerable (Dennis and Dennis, 2012). An estimate by DWAF (2005) suggest that the country may experience a reduction of 10% on average rainfall by 2025 estimate of the effects of climate change on water resources.

Inter-annual rainfall variability trend in South Africa shows a drying trend of varying intensity and distribution of rainfall across the country (DEA, 2013a). According to Dennis and Dennis 2012, the rainfall in South Africa is decreasing from east to west. The Eastern part been least dry than the west and northern parts of the country. The magnitude and distribution of rainfall in the country subject South Africa to periodic extreme events (Kamara and Sally, 2003). The distribution of its summer rainfall typically composed of wet and dry spells, occurring from late November to late March (Makarau, 1995).

Inter-annual rainfall variability in southern Africa is also linked to larger climatic systems such as the El Niño-Southern Oscillation (ENSO) phenomenon (Kotir, 2011). Links between ENSO and southern Africa's rainfall have been established such that warm ENSO events (El Niño) and cold events (La Niña) are commonly associated with below-average (above-average) summer rainfall over much of the region (Cretat et al., 2012). The ENSO event is driven by ocean-atmospheric interactions due to warming in the Pacific Ocean, causing an El Niño event every three to seven years; La Nina is the cold phase of the cycle, which results in cooler and wetter conditions (Davies, 2010). ENSO events are associated with significant rainfall anomalies over most parts of southern Africa and the long-term trends in ENSO variability are likely to affect rainfall over the region (Mason and Jury, 1997). It has been shown that severe summer drought in SA tends to occur under El Niño conditions (Mason, 2001). It is important to recognise that there are seasons where

El Niño has not occurred, where below-normal rainfall was experienced over the summer rainfall region and also seasons with above-normal rainfall without the simultaneous occurrence of La Nina event (Kruger, 1999).

According to Makarau (1995) the development of flood-producing systems in southern Africa may be characterised by low surface pressure over the interior, moist inflow over the south coast by ridging anticyclones and periodically enhanced subtropical easterly flow. A drought may be induced through sinking motions in a high-pressure system over Botswana often reinforced by the Atlantic Ocean anticyclone and strengthened mid-latitude westerly’s (Makarau, 1995).

Blignaut et al. (2009) studied rainfall variability and rainfall trends between 1970 and 2006 and the results showed that South Africa was drier between 1997 and 2006. Also, a study conducted by Zengeni et al., 2016, in the Eastern Cape showed a significant declining rainfall trend in the 1980s and 1990s period, with the 1970s being significantly wetter years. Shongwe et al., 2009, reported that when the total seasonal or annual mean rainfall increases (decreases) in the country, wet (dry) events are to be expected. Zengeni et al., 2016 study also showed that the frequency and size of wet events significantly influence the annual rainfall, while Dollar and Rowntree, 1995, observed that wet years are associated with an increase in the frequency of daily events. Longer dry periods with more intense rainfall events are associated with droughts and a decreasing rainfall trend in the country (Dennis and Dennis, 2012). Rouault and Richards (2003) postulated that drought characteristics over the years in South Africa are resulting from either total failure in rainfall, or rain falling too late or too early during the rainy season. With the focus on agriculture, the dry spells are crucial as crops may be destroyed by a hot, dry period despite the seasonal rainfall total being favourable (Tennant and Hewitson, 2002).

2.3 Impacts of rainfall variability

A series of drought or floods can be a triggering agent that can worsen social and economic problems of many areas and reduce livelihood security (FAO, 2004). In the African continent, an increase in precipitation would have a beneficial effect on the farming sector whereas a decrease would be detrimental (Kurukulasuriya et al., 2006).

According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, most of the countries in Africa already face semi-arid conditions that negatively impact agriculture, while rainfall variability will mostly reduce the length of growing season (IPCC, 2007). This will affect food availability, the stability of food supply, and access to food, leading to an increase in food prices (Sultan and Gaetani, 2016). In sub-Saharan Africa, high population growth and inadequate agricultural production combined with increasing water scarcity may add strains to economic development (Kamara and Sally, 2003; Sultan and Gaetani, 2016).

There are serious concerns about agriculture and water resources in Africa even without the influence of rainfall variations (IPCC, 2007). Africa's high population growth, water supply variability, soil degradation, and poor agricultural production pose a threat to these sectors and serious limitations to future economic development (Mendelsohn et al., 2000; Sally and Kamire, 2002).

Water supply in Africa is highly variable; dry or wet spells can range from months to decades (Jury and Mwafulirwa, 2002). Sub-Saharan Africa is already facing water scarcity as a result of rainfall variability such as drought, excessive rains and floods (Sultan and Gaetani, 2016). It is projected that South Africa and other African countries will have reached a level of both water stress and scarcity by 2025 (DWAF, 2005; Madzwamuse, 2010).

Rainfall variability will have both direct and indirect impact on humans. The variability may lead to disruptions in trade, and migrations due to social, economic and environmental pressures (DEA, 2014). Rainfall variability brings greater fluctuation in crop yields, increased risk of landslides and erosion, which adversely affect food security and infrastructure (Schmidhuber and Tubiello, 2007).

The changing rainfall trends will increase the pressure to put adaptation measures in place to manage and reduce the effects on the agriculture sector and water resources (IPCC, 2014). Therefore, an evaluation of rainfall variability is not only important for the environment, biodiversity, but also important for the water authorities and farmers (Khan et al., 2009). A detailed understating of these variations in the rainfall at different spatial and temporal scale is of great importance. The section below details the impact of rainfall variability on water resource and the agricultural sector.

2.3.1 Impacts of rainfall variability on water resources

Rainfall variability is the fundamental driver of change in the world's water resources and this water sector is vulnerable to rainfall variations in the form of floods and droughts events (Lesolle, 2012). Southern Africa experiences erratic seasonal variation in rainfall whereby in some years the rain starts early while in other years is arrives late, resulting in incoherent rainfall across the region (Mupangwa et al., 2011). The summer rainfall in the region varies in a see-saw of droughts and floods resulting in a high degree of inter- and intra-seasonal rainfall variability (Makarau, 1995). The water sector is strongly influenced by, and sensitive to, rainfall variability (Boko et al., 2007).

Rainfall variability has the potential to impose additional pressures on water availability, water accessibility and water demand in Africa (IPCC, 2007). Rainfall variability is expected to aggravate the water stress currently faced by some countries, while some countries that currently do not experience water stress will become at risk of water stress (IPCC, 2007). The impacts include both impacts on the water sector (damages to water supply and infrastructure from floods) and impacts from water to agriculture (floods damages to crops) (Doczi and Ross, 2014). Water resources in Africa are variable in both time and space, with water scarcity in some parts of the region, and abundance in others (Lesolle, 2012). Rainfall variability is expected to alter the present hydrological resources in southern Africa (Madzwamuse, 2010).

The magnitude and distribution of rainfall in South Africa, resulting in extremes of periodic drought and floods, increase the need for efficient management of water resources (Sally and Kamire, 2002). The scarcity of water, which is intensified by the high spatial degree of rainfall variability and semi-arid nature of the country, can significantly impact water resources (DEA, 2013a). The changes in water directly affect agriculture and livestock which are critical factors in the NWP economy and also indirectly affect the mining sector in the province, which is the biggest revenue generator (NWREAD, 2015a). Due to the impact of rainfall variability on the water resources, water demand and socio-economic environmental effects, it is urgent to take some measures to use the limited water efficiently (Khan et al., 2009).

2.3.2 Impacts of rainfall variability on agricultural sectors

A number of countries face semi-arid conditions that make agriculture challenging (Mendelsohn et al., 2000). Rainfall is to a large extent the most important factor in determining the potential of agricultural activities and suitability (DEA, 2013b). Rainfall has a strong influence on agriculture and impact on food security, which adds pressure to the agricultural sector (Sultan and Gaetani, 2016). Africa is faced with problems of food insecurity and a possible 50% decline in agricultural production due to rainfall variability (Madzwamuse, 2010).

Increased rainfall variability means additional threats to drought-prone environments and is considered a major risk to agricultural production (Selvaraju et al., 2006). The vulnerability of the agriculture sector has become an important issue because of reduced crop productivity in Africa (Benhin, 2006). The marginal impact of climate variability will depend on the initial temperature and precipitation in the area. Farms that are already located in hotter and drier regions are highly vulnerable to rainfall variability because they are already in the risky state (Kurukulasuriya et al., 2006).

Rainfall variability has impacted many regions whereby the crop yield trends have experienced a marginal decrease (IPCC, 2014). In regions such as southern Africa, where the economy is based on rain-fed agriculture, the impact of rainfall variability would have devastating effects on the economy (Tadross et al., 2005), while in Northern Africa where the economy is more diversified, the economy of these countries is less vulnerable to variations (Kurukulasuriya et al.2006).

Rainfall variability may result in increasing intensity of drought events and increase the vulnerability of communities which are dependent on agricultural production for food security (Lema and Majule, 2009). Increasing variability will worsen development, health and poverty reduction efforts in drought-prone areas (Selvaraju et al., 2006). Rainfall variability contributes to the high risk of farming across most of the southern Africa region, especially in marginal rain-fed agricultural areas that are characterised by low and erratic rainfall such as NWP (FAO, 2004). The variability makes it difficult for the planning of planting and successful cropping and has resulted in a significant reduction in crop yields (Mupangwa et al., 2011).

The major impacts on agriculture include the reduction in the length of the growing season and yields, and the reduction of arable and pastoral agriculture

(Madzwamuse, 2010). These impacts are of great concern in South Africa because agriculture is part of the major contributors to the economy, accounting for some 35 percent of GDP and 63 percent of the labour force (DEA, 2013b). The agriculture sector is affected by rainfall variability more than other sectors because it is highly dependent on rainfall (Benhin, 2006). The impacts of rainfall variability (floods and drought) has the potential to influence the production of agricultural produce and may disrupt international trade in agricultural products (DEA, 2014).

The agriculture sector in South Africa is already under pressure from recurrent droughts and faces water scarcity at the same time as increasing demands for food and for water resources (DEA, 2014). More than 50% of South Africa's water resource is used for agricultural purposes (Benhin, 2006). Rainfall variability threatens this sector (Selvaraju et al., 2006).

2. 4 Summary

This chapter presented literature review on rainfall variability and its impact on different sectors that are highly vulnerable to rainfall variability. Rainfall variability is affecting every part of the world although, vulnerability of each area is determined by their adaptive capacity (Singh and Kumar, 2015). Rainfall variability impacts are severe in southern Africa and Africa as a whole due to lack of facilities and economy to support better adaptation measures. Furthermore, the vulnerability is intensified by the reliance on rainfall-dependent sectors. Literature showed that rainfall variability has the potential to impose additional pressures on water availability, water accessibility and water demand in Africa (IPCC, 2007). Southern African is highly impacted by this variability resulting from recurrent droughts and floods. With the most recent drought having affected the water sector in South Africa and more than five provinces were affected badly by the drought (News24 2016/01/17). North West Province was hit the hardest with water resources and food production severely affected. Statistical methodologies are applied in the study to achieve the objective. The methods are detailed in chapter 3.

CHAPTER THREE

Data and Methods

3.1 Introduction

This chapter presents the data and methods applied in the study to evaluate the inter-seasonal and intra-seasonal rainfall variability of North West Province. The primary data input in the study is the rainfall. The chapter explains in detail the data source and the methods employed to achieve the main objectives of the study, and provides justification for the data analysis techniques used.

3.2 Data and data sources

Daily rainfall data from 26 stations (Table 3.1) covering a period of 31 rainfall seasons (1984 to 2015) is used in the analyses. The rainfall data was obtained from South African Weather Service (SAWS) and Agricultural Research Council (ARC). The analysis period is selected based on the availability of continuous good data record for stations in North West Province (NWP) that reported ≥30 years. Series with too many missing values (more than 10%) were excluded; in series with a smaller number of missing values, the long-term mean of those particular months was used in place of missing data (De Silva et al., 2007).

Geographically, the selected stations represent most parts of the province. Quality control procedures are used to check the data as described in the World Meteorological Organisation (WMO) guide (WMO-No. 488). Southern Africa rainfall occurs mostly from late October to early April of the following year, with peaks in December to February (Makarau, 1995). Seasonal rainfall in this study is computed using the rainfall for October to March.

Table 3.1: Stations

Variable	**Stations Name**	**longitude**	**Latitude**
Var1	Leliefontein	24.993	-27.044
Var2	Vryburg	24.652	-26.954
Var3	Klerksdrop	26.661	-26.91
Var4	Lichtenburg	26.154	-26.155
Var5	Venterdrop	26.7	-26.37
Var6	Mafikeng	25.542	-25.803
Var7	Zeerust	26.078	-25.539
Var8	Rusternburg	27.291	-25.724
Var9	Olifantsport	27.272	-25.812
Var10	De Kroon	27.833	-25.607
Var11	Bakubung Gate	27.063	-25.339
Var12	Potchefstrom	27.083	-26.733
Var13	Delareyville	25.536	-26.848
Var14	Ottostadal	26.017	-26.817
Var15	Swartruggens	26.689	-26.649
Var16	Koster POL	26.907	-25.891
Var17	Mamogaleskraal	27.783	-25.517
Var18	Dwarsfontein	27. 067	-26.002
Var19	Buffelsport	27.482	-25.753
Var20	Brits	27.85	-25.717
Var21	Marico	26.22	-25.28
Var22	Taung	24.46	-27.32
Var23	Koster Grootpan	26.506	-25.989
Var24	Lichtenburg Sensako	26.66	-25.166
Var25	Schwezerreneke	25.318	-27.192
Var26	Vryburg Louwa	24.144	-26.906

3.3 Methodology

This section presents the methods used to achieve the objectives of the study. The methods applied in the analysis include statistical analysis that involves basic statistics such as mean, standard deviation and standardisation. Advanced statistical methods used include time series analysis, Principal Component Analysis (PCA) and Cluster Analysis (CA); these were carried out using Microsoft Excel and STATISTICA v13. In addition, to determine rainfall trends, trend analysis is performed using the MAKESENS template for Microsoft Excel. The techniques are explored and discussed in more detail in the subsequent subsections. The schematic framework for the methodology and data analysis is summarised in Figure 3.1.

Rainfall is not homogeneous across the whole of NWP. It is subject to influences such as the southerly flow from the Atlantic Ocean, which brings in cool air, reduces rainfall availability, and stratifies the climate of the province. (Mosepele, 2016). Principal Component Analysis (PCA) and Cluster Analysis (CA) are used in this study to classify North West Province into various rainfall regimes, and are explained in detail below. Knowledge of regions that have similar rainfall characteristics is beneficial in the planning and management of rain-fed agricultural activities and water resources management (Basalirwa et al., 1999).

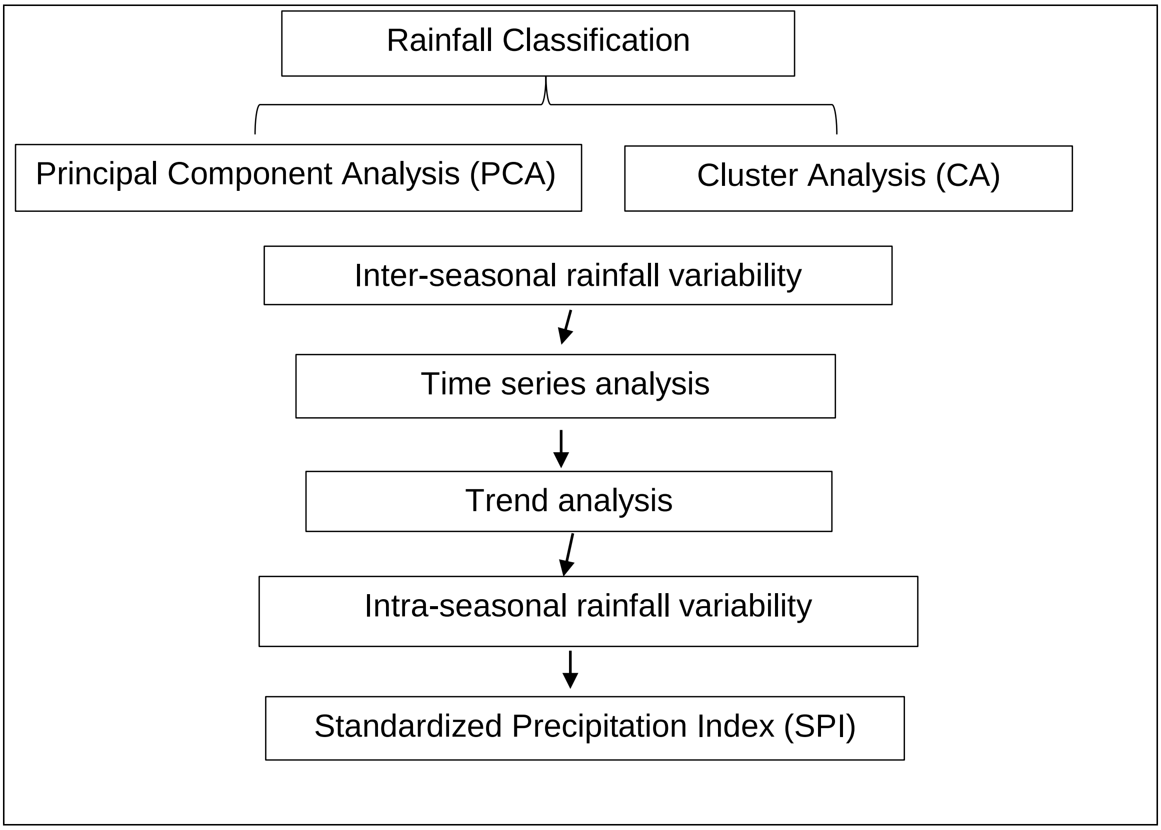


Figure 3.1: Schematic flow of the research organisation and procedure

3.3.1 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) involves a linear transformation of a matrix of standardised variables, based on the eigenvalues and eigenvectors of either correlation matrix or covariance matrix (Kabanda and Nenwiini, 2016). It creates new variables composed of a manually orthogonal linear combination of the original variable, each accounting for a specific fraction of the original total variance as indicated by the size of its associated eigenvalue (Fovell and Fovell, 1993). In this study, PCA is used as a tool for reducing a large number of stations into fewer variables and still represent a significant fraction of the original variance in the dataset which are called Principal Components (PC).

PC's are obtained as a linear combinations of the original variables. The first PC account for highest possible variance and explains the largest percentage of the total variance (Borgognone et al., 2001). The first principal component (C_1) is given by the linear combination of the variables $X_1, X_2 ... X_p$ .The application continues until a total of PC has been calculated. With the condition that the next PC is uncorrelated with the previous PC and that it accounts for the next highest variance.

$$C_1 = A_{i1}x_1 + A_{i2}X_2 + \cdots + A_{ip}X_P \qquad \text{Eq. 3.1}$$

Where A is the weight attached,

X is the variable.

The main objective of PCA is the explanation of as much of the variability of the original data as possible, while trying to retain fewer principal components Borgognone et al., 2001). The PCA is computed using the long-term monthly means for each station. The resulting components are further evaluated to select which variables (stations) to use in the study. There are several criteria's used in deciding the number of component to retain, although a clear cut number of PCs is rarely obtained (Costello and Osborne, 2005). The criteria adopted in this study to aid the selection of the number of components to retain include; total variance explained, scree plot and component loadings (Jolliffe, 1990). The number of retained components is expected to reduce the noise present in the data and to contain a significant proportion of the original variance. The data is subjected to Principal

Component Analysis using the Statistica software, and the results are detailed in the following subsections.

3.3.2 Cluster analysis (CA)

Cluster Analysis is one of the tools used in in the data mining process for discovering groups or clusters in the data (Halkidi et al., 2001). Cluster analysis is used as an effective statistical tool for grouping the stations into homogeneous regions (Munoz-Diaz and Rodrigo, 2004). The objective of the clustering method is to discover significant clusters in the data set by grouping the data into clusters based on their degree of similarity (DeGaetan, 2001).

The data is standardised and normalised in cluster analysis to allow the user to obtain comparable data to describe the variability. Data standardisation is a method whereby individual raw scores in the distribution are converted to a z-score, which is a number that indicates whether a given score is above or below normal in the dataset (Vafaei et al., 2018). When all the scores of distribution are standardised the average z-score of the distribution is always 0, and the standard deviation of the distribution will always be 1.0. Data was normalised sing the following equation:

$$Z = \frac{x_i - \mu}{\sigma} \qquad \text{Eq. 3.2}$$

where x is the sample data,

μ the population mean

σ is the standard deviation.

The clustering methods used to partition data set by their natural measures of similarities in this study is the K-means clustering (Estivill-Castro and Yang, 2004). K represents the number of clusters, and its value is pre-defined by the user (Pham et al., 2005). The k-means methods finds locally optimal solutions by minimizing the sum of the distance between each data point to the nearest cluster centre (Bradley and Fayyad, 1998). Using the pre-defined number of clusters as input, the algorithm randomly selects a centre for each cluster (Sarstedt and Mooi, 2014). K-means clustering finds the nearest centre for each station using the Euclidean distance metric and each station in then assigned to the cluster centre to the closest distance to it. (Domroes and Ranatunge, 1993, Satyanarayana and Srinivas, 2008). The Euclidean distance between two stations x_1 and x_2 is represented as $d(x_1, x_2)$. This technique attempts to minimise the distance of each point from the centre of the cluster (Halkidi et al., 2001). The procedure is defined using equation 3.3.

$$E = \sum_{i=1}^{c} \sum_{x \in C_i} d(x, m_i)$$

Eq. 3.3

where m_i is the centre of cluster

C_i, $d(x, m_i)$ is the Euclidean distance between a point x and m_i.

Thus, the criterion function E attempts to minimise the distance of each point from the centre of the cluster (Halkidi et al., 2001).

3.3.3 Time series analysis

Rainfall time series are used in modelling and forecasting rainfall, and predicting future series using historical data (Meher and Jha, 2013). In this study time series are used to analyse the rainfall variability in the inter-seasonal scale. A time series often consists of four components: the trend component, which represents the systematic long-term movement over the period of the series; the cycle, which describes the smooth movement around the trend; the seasonal component, which consists of intra-year fluctuations; and the irregular component (Bemrose et al., 2010).

The rainfall time series are developed for each cluster or component. From the retained PC or clusters, the stations that form part of each component (cluster) are composited (Eq.3.4) together to form a mean representation of each regime. The 5-year moving average is superimposed on the time series for comparison, to examine and analyse the rainfall variations of the province. The moving average technique is used to evaluate the periodicity in the data. Rainfall is subjected to 5-year moving average to filter out climatic forcing such as sunspot and El Niño Southern Oscillation (ENSO,) that irregularly influences rainfall (Nenwiini and Kabanda, 2013).

i) Composite analysis

Composite analysis is a technique used to study similar features and patterns in the observed data. The techniques reduce the number of plots thus making the analysis easier to handle and interpret (Levey and Jury, 1996). In this study, the variables are composited according to their PC or cluster. The composite analysis consists of summing together the selected climatic fields and dividing by a total number of cases to get the average value of each point. In this study, seasonal rainfall for each variable per principal component or cluster are averaged for the observed period (1984-2015). Composite analysis is calculated using equation 3.4.

$$Y_j = \frac{\sum_{i=1j}^{n} x_j}{n} \qquad \text{Eq. 3.4}$$

Where Y is the rainfall for each cluster or component

X is individual stations

j is the year in consideration

n is the total number of stations

3.3.4 Trend analysis

The long-term trends in the North West Province (NWP) time series are evaluated. A trend is a significant change over time exhibited by variable, detectable by statistical parametric and non-parametric procedures (Longobardi and Villani, 2010). The time series were subjected to trend analysis to quantify the magnitude and significance of the change using non-parametric methods. In this study, the statistical significance of the trend is analysed using the Mann-Kendall (MK) test and the magnitude of the trend in the time series is analysed using the Sen’s estimator. The methods used for analyses are further explained in detail as follows:

i) Mann-Kendall test

Mann-kendall test is a nonparametric test that determines the whether a change in the trend occurred with time (Partal, and Kahya, 2006). The Mann- Kendall test is based on time data ranking whereby each data point is compared with all the data point that follow in time (Nguyen et al., 2014). The method searches for a trend in a time series without specifying whether the trend is linear or nonlinear, and is often used to detect the presence of an increasing or decreasing trend in the in the time series (Gocic and Trajkovic, 2012; Al-Houri, 2014). The null hypothesis is that the data are independently and identically randomly distributed (Nguyen et al., 2014). In this study, the Mann-Kendall test was calculated using the following equations.

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sng(x_j - x_i) \qquad \text{Eq. 3.5}$$

Where n is the number of data points

x_j and x_i are data values in time series

i and *j (j>i)* denotes the time indices associated with individual values

sgn $(x_j - x_i)$ is determined as follows:

$$sng\left(x_j - x_i\right) = \begin{cases} +1, if\ x_j - x_i > 0 \\ 0, if\ x_j - x_i = 0 \\ -1, if\ x_j - x_i < 0 \end{cases} \qquad \text{Eq. 3.6}$$

The variance is computed as

$$Var(s) = \frac{1}{18} n(n-1)(2n+5) - \sum_{i-1}^{m} (t_i - 1)(2t_i + 5) \qquad \text{Eq. 3.7}$$

n is the number of data points and m is the number of tied groups. t_i denotes the number of ties of extent *i*. A tied group is a set of sample data having the same value. In this study the observed period is from 1984-2014 rainfall seasons, making up 31 seasons. Since the sample size n>10, the standard normal test statistic *Zs* is computed using equation 3.5.

$$Zs \begin{cases} \frac{s-1}{\sqrt{Var(s)}} if\ , s > 0 \\ \frac{s+1}{\sqrt{Var(s)}} if\ , s < 0 \end{cases} \qquad \text{Eq. 3.5}$$

Positive values of *Zs* indicate increasing trends, and negative values show decreasing trends. The seasons observed in these methods are employed in the intra-seasonal analysis. The Mann-Kendall method has the advantages of making no assumptions about the distribution of the underlying data and being relatively insensitive to outliers (DEA, 2013b). The following symbols are used in the MAKESENS template to represent the level of significant (Salmi et al., 2002).

*** 0.001 level of significance

** 0.01 level of significance

* 0.05 level of significance

+ 0.1 level of significance

ii) Sen’s slope estimate

Sens slope estimate is a non-parametric procedure for estimating the trend slope in the sample of data (Gocic and Trajkovic, 2014). The Sen’s method assumes a linear trend in the time series and is used for determining the magnitude of a trend in hydro-meteorological time series (Jain et al., 2013). Sen’s slope is calculated as

$$Q_i = \frac{x_j - x_k}{j - k} for\ i = 1 \ldots.,N \qquad \text{Eq. 3.8}$$

Where $_j$XJ and $_k$*XK* are data values at the times *jK (j>k),* respectively.

Q_i is Sen’s slope estimator, which is the median of the slopes calculated between all pairs of data points in the series. The Sen’s estimator was adopted to determine the magnitude of change per unit time of trend detected in the study (Nenwiini and Kabanda, 2013).

3.3.5 Standardises Precipitation Index (SPI)

McKee et al., (1993), developed standardised Precipitation index primarily for defining and monitoring drought. SPI is the number of standard deviations that observed value would deviate from the long-term mean, for normally distributed random values (Rouault, 2003). SPI in this study is used to determine the occurrence and the persistence of wet and dry events in the intra-seasonal rainfall patterns thus defining the presence of normal, above normal and below normal rainfall. The values of SPI are defined in a standard deviation with a negative (positive) value indicating below normal (above normal) rainfall (Rostamian et al., 2013). The SPI is computed as

$$SPI = Z = \frac{x - \mu}{\sigma} \qquad \text{(Equation 3.2)}$$

Where x is the sample data, μ the population mean and σ is the standard deviation.

SPI are calculated with different time steps (Rostamian et al., 2013). In this study, the SPI was calculated using pentads rainfall. By using pentads, you avoid noise, which are brought by the day-to-day data analysis (Levey, 1993). The pentads are developed as an average of 5-day daily rainfall data. By using pentads, noise that is brought by the day-to-day data analysis is avoided (Levey, 1993). The first pentad in the year is from 1-5 January and the last pentad (pentad 73) is from the 27-31 December. In a leap year, the last pentad in February (pentad 12) will have 6 days to cover the extra day (29th February) (Sun and Liu, 2016). Therefore, the pentad 12 in leap year is from 25 February to 1 March. In this study, the focus is on seasonal rainfall in North West Province, which commences in October and ends in March of the following year. Therefore, the pentads used in this study is the first that fall in the month of October to the last pentad that fall March of the following year. The rainfall pentad of the observed seasons is from 3-7 October (pentad56) to 26-30 April (pentad18).

3.4 Summary

This chapter outlined the data and methods used and gave a detailed explanation of various steps used to achieve the study objectives. The analysis applied in the dissertation mainly uses statistical techniques. This study focuses on two rainfall scales: the inter-seasonal followed by the intra-seasonal rainfall variability. Therefore, the methods implemented are based on analysis of each rainfall scale. Firstly, multivariate techniques are used to classify NWP into different rainfall regimes. The province’s rainfall is unevenly distributed from east to west. Thus, classification of the study area divides NWP according to its rainfall regimes. Principal Component Analysis (PCA) and Cluster Analysis (CA) are the selected classification techniques used in the study.

The study follows the order of the schematic flow in Figure 3.1. Firstly, inter-seasonal rainfall variability of NWP is evaluated. The stations that fall within each component or cluster are composited together to form rainfall regimes. The composite analysis of each cluster or principal component are used to develop time series analyses of rainfall behaviour and characteristics in the province. The Mann-Kendall and Sen’s estimator methods are used to determine the long-term rainfall trends of the study area. The methods are used to identify seasons of high magnitude and seasons that are highly significant in each cluster. The identified seasons are used to evaluate intra-seasonal rainfall variability NWP.

In the Intra-seasonal rainfall variability, daily data is used to evaluate intra-seasonal rainfall time series. The SPI was computed using rainfall pentads to evaluated intra-seasonal rainfall variability. Pentads data was used to remove diurnal variability in the analysis. The first pentad is from October 3-7 and the last pentad is from 26-30 April for each season. The pentad were standardised to a mean of zero (normal rainfall) and a standard deviation of 1 (above normal rainfall).

CHAPTER FOUR

Rainfall classification of North West Province

4.1 Introduction

In this chapter, rainfall classification in North West Province is presented. The area is classified into different rainfall regimes by applying Principal Component Analysis (PCA) and Cluster Analysis (CA) techniques. A rainfall climate classification can be explained as an attempt to divide areas into regions or zones with a roughly homogeneous set of climate conditions (Kabanda and Nenwiini, 2016). Classification provides a convenient way to grouping data set into climatologically homogeneous regions (Munoz-Diaz and Rodrigo, 2004).

Global climate classifications were created to delineate the various existing local climates to an adequate number of climate types and to determine the spatial distribution of these categories by climatic data for a reference period (Beck et al., 2005). For example, the classification of Sri-Lanka based on rainfall distribution classified the area in terms of wet Zones which comprises the south west lowlands and the dry land covered most of the country (Puvaneswaran and Smithson, 1993). There are also other different factors that have been used in climate classification; these include vegetation, altitude and other climate indicators such as Outgoing Longwave Radiation (OLR) (Kousky, 1988; Gonzalez et al. 2007). For example, Fauchereau et al., (2009) performed K-means clustering of daily OLR anomalies from 1979 to 2002 over the Southern Africa Southwest Indian Ocean (SWIO) region during austral summer were seven classes were statistically retained. They showed well-separated recurrent patterns of large- scale organized convection.

The main aim of the study focuses on evaluating inter-seasonal and intra-seasonal rainfall variability in the North West Province. However, to evaluate the variabilities, it is essential to determine rainfall regimes of the province to understand the spatial distribution of rainfall within the study area. In developing NWP rainfall regimes, 26 stations (Table 3.1) were selected from the available data. The rainfall stations are referred to as variables (Var) in this study, resented as Var1 to Var26.

The criteria for selecting stations was based on the availability of stations that have consistent data for 30 years or more and having missing data of less than 10% (De Silva et al., 2007). The seasonal rainfall mean for a period of 1984 to 2015 was selected for this analysis due to a large number of stations having data and a good spatial coverage of the province.

4.2 Principal Component Analysis (PCA)

In this study, PCA is used as a tool for reducing a large number of stations into fewer variables and still represent a significant fraction of the original variance in the dataset. There are several criteria’s used in deciding the number of component to retain, although a clear cut number of PCs is rarely obtained (Costello and Osborne, 2005). The criteria adopted in this study to aid the selection of the number of components to retain include; total variance explained, scree plot and component loadings (Jolliffe, 1990). The number of retained components is expected to reduce the noise present in the data and to contain a significant proportion of the original variance. The data is subjected to Principal Component Analysis using the Statistica software, and the results are detailed in the following subsections.

4.2.1. Total Variance explained

The first criteria applied to select the number of components to retain is Kaiser-Gutmann method by using the eigenvalues. The Kaiser-Gutmann method states that only components that have eigenvalues greater than 1.0 to be retained (Osborne and Costello, 2009). The rationale for the method (>1.0) was that since each observed variable contributed one unit of the variance of the total variance explained in the dataset, any component that displayed an eigenvalue of >1.0 was accounting for a more significant amount of variable (Mandleni and Amin, 2001).

When applying this criterion, seven components recorded eigenvalues of >1.0 in the analysis (Table 4.2). The first principal component (PC) has an eigenvalue 11.634, PC2 has an eigenvalue of 2.639, and the remaining PC (PC3- PC7) has eigenvalues ranging from 1.704 to 1.025. The total variance explained by all the seven components is 81%. PC1 accounts for 45 % of total variance and PC2 explained a variance of 10%, which makes up 55% cumulative variance while the remaining retained components account for 26% of the total variance explained.

Table 4.1: PCA eigenvalues results

Component	Eigenvalues	%Total variance	Cumulative eigenvalue	Cumulative %
1	11.637	44.747	11.634	44.747
2	2.639	10.15	14.273	54.896
3	1.704	6.554	15.977	61.45
4	1.593	6.128	17.57	67.578
5	1.289	4.959	18.86	72.537
6	1.123	4.319	19.983	76.856
7	1.025	3.942	21.007	80.798
8	0.855	3.287	21.862	84.085
9	0.803	3.088	22.665	87.173
10	0.683	2.628	23.348	89.801
11	0.551	2.117	23.899	91.919
12	0.429	1.648	24.327	93.567
13	0.333	1.279	24.66	94.846
14	0.265	1.019	24.925	95.865
15	0.198	0.761	25.123	96.627
16	0.179	0.689	25.302	97.316
17	0.162	0.623	25.464	97.939
18	0.125	0.479	25.589	98.418
19	0.117	0.452	25.706	98.87
20	0.099	0.379	25.805	99.249
21	0.075	0.29	25.88	99.539

22	0.06	0.232	25.94	99.771
23	0.031	0.121	25.972	99.892
24	0.016	0.062	25.988	99.954
25	0.009	0.033	25.997	99.987

4.2.2 Scree Plots

The second criterion used in selecting the number of components to retain in the study is the scree plot analysis. In the scree plot, Eigenvalues are plotted against their corresponding PC numbers, and the plot illustrates the rate of change in the magnitude of the Eigenvalues (Jolliffe, 1990). The scree plot examines the graph of eigenvalues and selects the cut-off point in the data where the curve flattens out (Osborne and Costello, 2009). A cut-off point is determined by a section in the plot whereby the slope of the graph goes from steep to flat and only components that are before the transition are to be retained (Ledesma and Valero-Mora, 2007). As a result, components that fall on the steep slope are the considered. In Figure 4.1, the cut-off point is noticeable in component three when the plot started moves from a steep to flat position. Thus component one to component three are the suggested components to retain in this study.

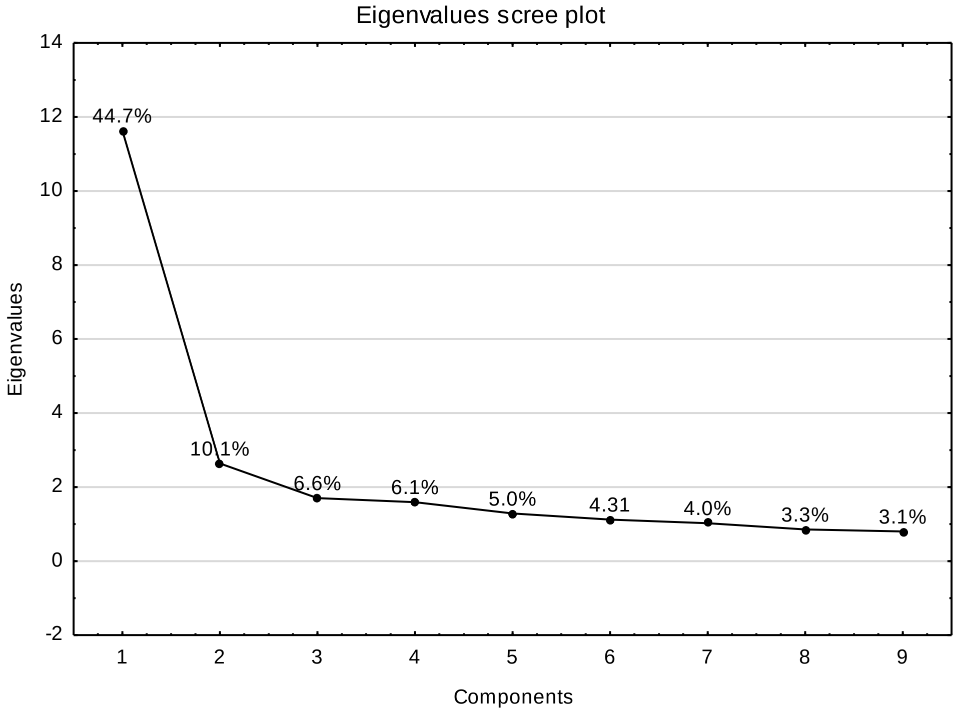


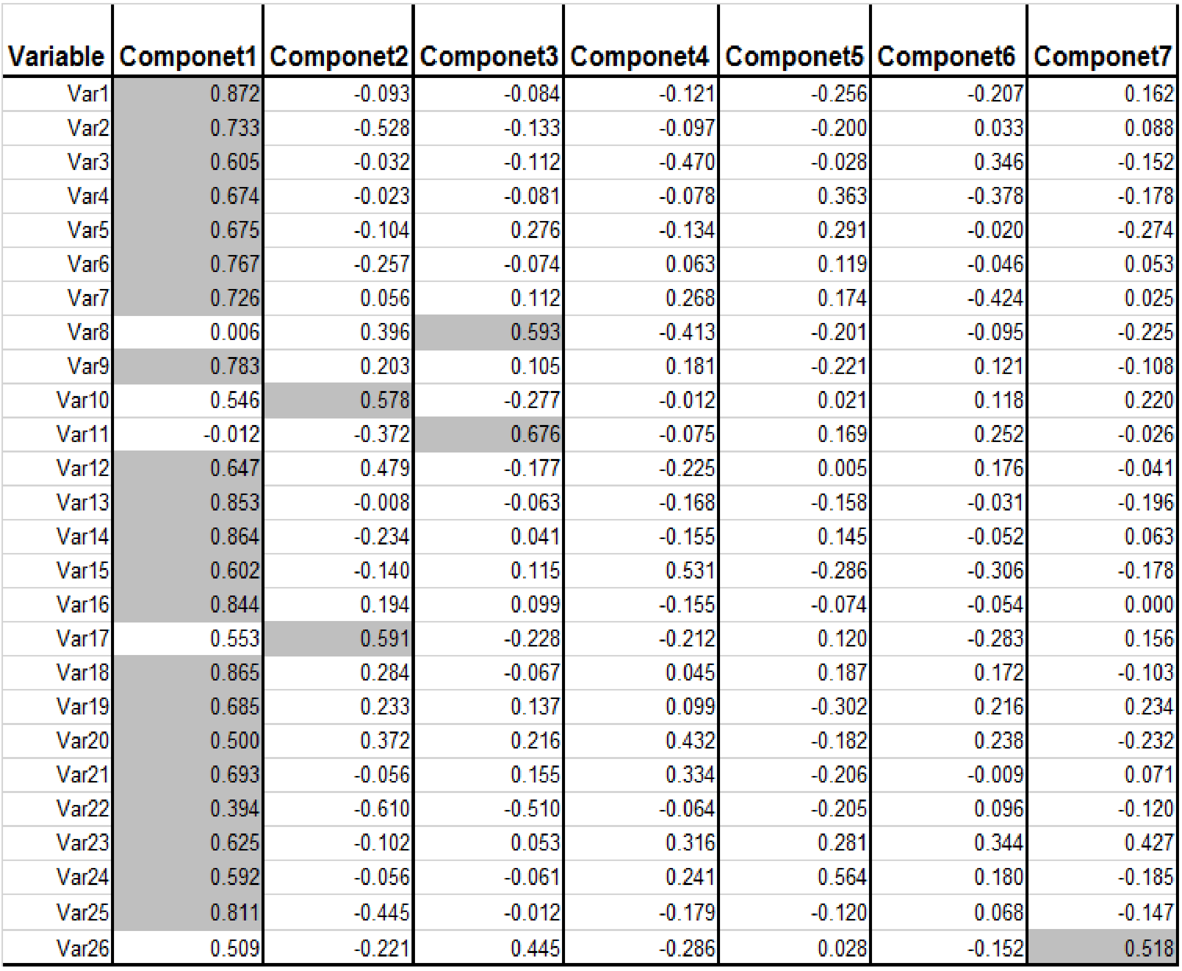
Figure 4.1: Scree test plot of PCA showing cut-off point.

4.2.3 Factor loading

The last method used in selecting the number of components to retain is the factor loading. Each component in PCA is a representative of a region and stations are assigned to regions where they have highest loadings (Rao and sinnivas, 2006). The grouping of variables was done by observing the magnitude of variables in each component. From the table (Table 4.3), variables with a high magnitude of each component are highlighted in the table.

The results show that PC1 has 21 variables from the original 26 variables while PC2 has two variables (Var17 and Var10) and PC3 has two variables (Var8 and Var11). PC4 to PC6 have no variable loading highly, and PC7 has one variable (Var26). Therefore, there are four components retained in this criterion which include; PC1, PC2, PC3 and PC7.

Table 4.2: Loading spread sheet



Variable	Componet1	Componet2	Componet3	Componet4	Componet5	Componet6	Componet7
Var1	0.872	-0.093	-0.084	-0.121	-0.256	-0.207	0.162
Var2	0.733	-0.528	-0.133	-0.097	-0.200	0.033	0.088
Var3	0.605	-0.032	-0.112	-0.470	-0.028	0.346	-0.152
Var4	0.674	-0.023	-0.081	-0.078	0.363	-0.378	-0.178
Var5	0.675	-0.104	0.276	-0.134	0.291	-0.020	-0.274
Var6	0.767	-0.257	-0.074	0.063	0.119	-0.046	0.053
Var7	0.726	0.056	0.112	0.268	0.174	-0.424	0.025
Var8	0.006	0.396	0.593	-0.413	-0.201	-0.095	-0.225
Var9	0.783	0.203	0.105	0.181	-0.221	0.121	-0.108
Var10	0.546	0.578	-0.277	-0.012	0.021	0.118	0.220
Var11	-0.012	-0.372	0.676	-0.075	0.169	0.252	-0.026
Var12	0.647	0.479	-0.177	-0.225	0.005	0.176	-0.041
Var13	0.853	-0.008	-0.063	-0.168	-0.158	-0.031	-0.196
Var14	0.864	-0.234	0.041	-0.155	0.145	-0.052	0.063
Var15	0.602	-0.140	0.115	0.531	-0.286	-0.306	-0.178
Var16	0.844	0.194	0.099	-0.155	-0.074	-0.054	0.000
Var17	0.553	0.591	-0.228	-0.212	0.120	-0.283	0.156
Var18	0.865	0.284	-0.067	0.045	0.187	0.172	-0.103
Var19	0.685	0.233	0.137	0.099	-0.302	0.216	0.234
Var20	0.500	0.372	0.216	0.432	-0.182	0.238	-0.232
Var21	0.693	-0.056	0.155	0.334	-0.206	-0.009	0.071
Var22	0.394	-0.610	-0.510	-0.064	-0.205	0.096	-0.120
Var23	0.625	-0.102	0.053	0.316	0.281	0.344	0.427
Var24	0.592	-0.056	-0.061	0.241	0.564	0.180	-0.185
Var25	0.811	-0.445	-0.012	-0.179	-0.120	0.068	-0.147
Var26	0.509	-0.221	0.445	-0.286	0.028	-0.152	0.518

4.3 Cluster Analysis (CA)

Cluster Analysis (CA) is used in the study in attempt to classify the North West Province (NWP) into different rainfall regimes. CA is used in data mining for regionalisation of areas and identifying patterns in the data (Halkidi et al., 2001). The objective of CA is to determine significant clusters in the data set whose members have high degree of similarities and are separated (De Gaetano, 2001). Distance metric is used as a measure of similarities of the variable to the centre point. The K-means cluster analysis was employed to determine rainfall regimes of NWP.

To use k-means clustering the number of cluster needs to be pre-defined by the user, and defining the appropriate number of clusters is a trial- and-error process and made difficult by the subjective nature of what constitute correct clustering (Pham et al., 2005). In cases where, K is too low (high) most clustering algorithms combine (divide) natural cluster in order to reduce (increase) the cluster to the specified K (Rousseeuw, 1987).

To find a satisfactory clustering result, different K values were applied and trialled in attempt to select the best suitable K value for this study. The validity of the CA results was assed visually and by the aid of spatial distribution map. The spatial distribution maps were created using the ArcGIS software and for every trailed K value, the map was created to visually represent how each variable per cluster are distributed in NWP. From all the trialled K-values, the satisfactory K value in this study is when K= 2 due to its best spatial representation of the study area (Figure 4.2). Therefore, NWP is clustered into two clusters namely; Cluster one (C1) and Cluster two (C2).

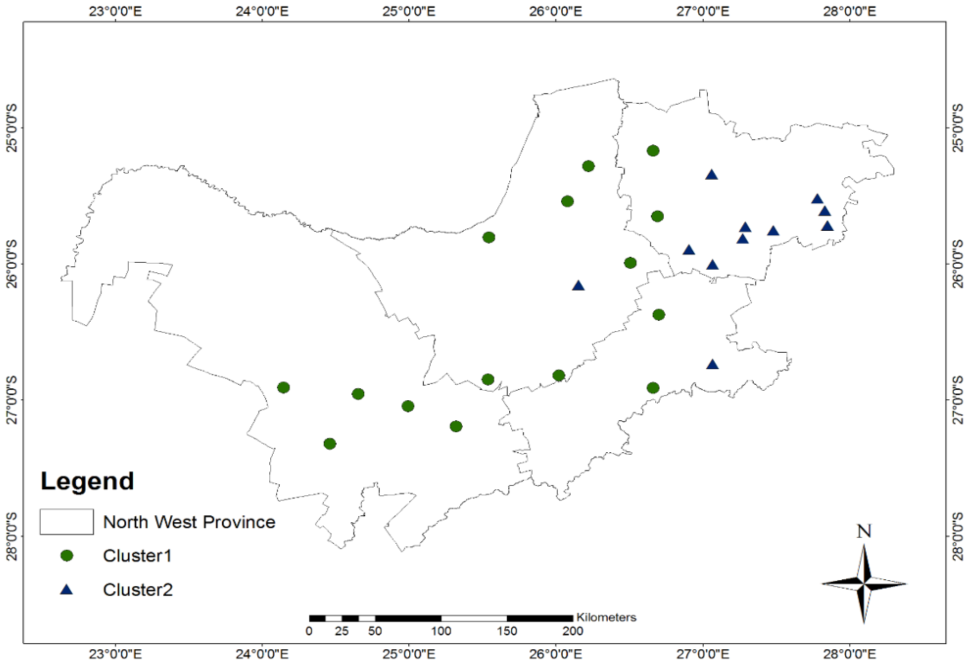


Figure 4.2: Cluster Analysis (CA) variables spatial distribution

The cluster one rainfall regime is made up of 15 variables that cover most part of the province. The stations are distributed in the southwest and central regions of the province with few found in the east. The stations that formed part of C1 are listed in table 4.4. The cluster two rainfall regime is made up of 11 variables that are distributed in the north-eastern areas in the province. Stations that formed part of C2 are listed in Table 4.5.

Table 4.3: Members of cluster one

cluster1	**Station name**
Var1	Leliefontein
Var2	Vryburg
Var3	Klerksdrop
Var5	Ventersdrop
Var6	Mafikeng
Var7	Zeerust
Var13	Delareyville
Var14	Ottosdal
Var15	Swartruggens
Var21	Marico
Var22	Taung
Var23	Koster Grootpan
Var24	Lichtenburg
Var25	Schwezerreke
Var26	Vryburg Louwna

Table 4.4: Members of cluster two

Custer2	**Station name**
Var4	Lichtenburg
Var8	Rusternburg
Var9	Olifantsport
Var10	De kroon
Var11	Bakubung gate
Var12	potchefstroom
Var16	Koster POL
Var17	Mamogaleskraal
Var18	Dwarsfontein
Var19	Buffelspoort
Var20	Brits

4.4 PCA VS CA

This section presents the comparisons between the PCA and CA. When applying the PCA multivariate method and evaluating all the criteria used for retaining components, the results showed a considerable difference in the number of components to retain. The first criteria applied suggested seven components to be retained in the study using the eigenvalue >1.0. The retained components explain a total variance of 81%, and approximately 45% of the province can be classified into Principal Component one while the other components each explain a total variance ≤ 10. %.

The scree plot analysis suggests that the cut-off point in the plot should be on the third component. Thus, from this criterion, only three components can be retained (PC1 PC2 and PC3). The last criterion suggests four components to be retained. The components retained using factor loadings are PC1 (21 variables), PC2 (2 variables), PC3 (2 variables) and PC7 (1 variable). Therefore, the three used criterion to retain components in PCA suggest three different number of components to retain.

In the Cluster Analyses (CA), NWP was classified into two clusters using the K-means classification where K=2. Distance was used as a factor when classifying components by creating centre point the variables are clustered according to their distance from these point. Therefore, the region is clustered into two clusters C1 and C2. Cluster one has 15 variables which are mostly distributed in the southwest and central region of the province. C2 has 11 variables which cover stations that are found in the North-eastern part of NWP excluding variable four (Var4) which in the central.

The PCA results show considerable discrepancy in the number of components to retain using the selected criterion resulting in a subjective decision when determining rainfall regimes for NWP. As a result, PCA was unable to capture much of the total variance explained in NWP rainfall. The results suggest that the spatial variation of NWP rainfall is very complicated and contributes to significant rainfall variability in NWP. The variables distribution in CA are presented in Figure 4.2

The PCA method was not suitable in classifying North West Province into homogeneous rainfall regimes, because there was no specific number of components to retain as each method used had suggested different values. While with cluster analysis method, K=2 was selected indicating that the number of components to retain is two. The retained cluster in CA showed a clear spatial representation of variables and proved to be more beneficial. The study adopts the cluster analysis results and suggest that NWP be classified into two homogeneous rainfall regimes (C1 and C2). Thus, the schematic flow in Figure 3.1 in the methodology (chapter3) is disregarded in the following chapters, as PCA methods is not applied further in the.

Therefore, the subsequent chapters are structured using schematic flow in Figure 4.3. The rainfall data for stations in cluster one (C1) and cluster two (C2) variables (stations) are composited to develop a long-term seasonal rainfall for each cluster. Inter-seasonal rainfall variability of each cluster is analysed in chapter 5. Time series analysis are performed for C1 and C2, followed by the trend analysis of both clusters.

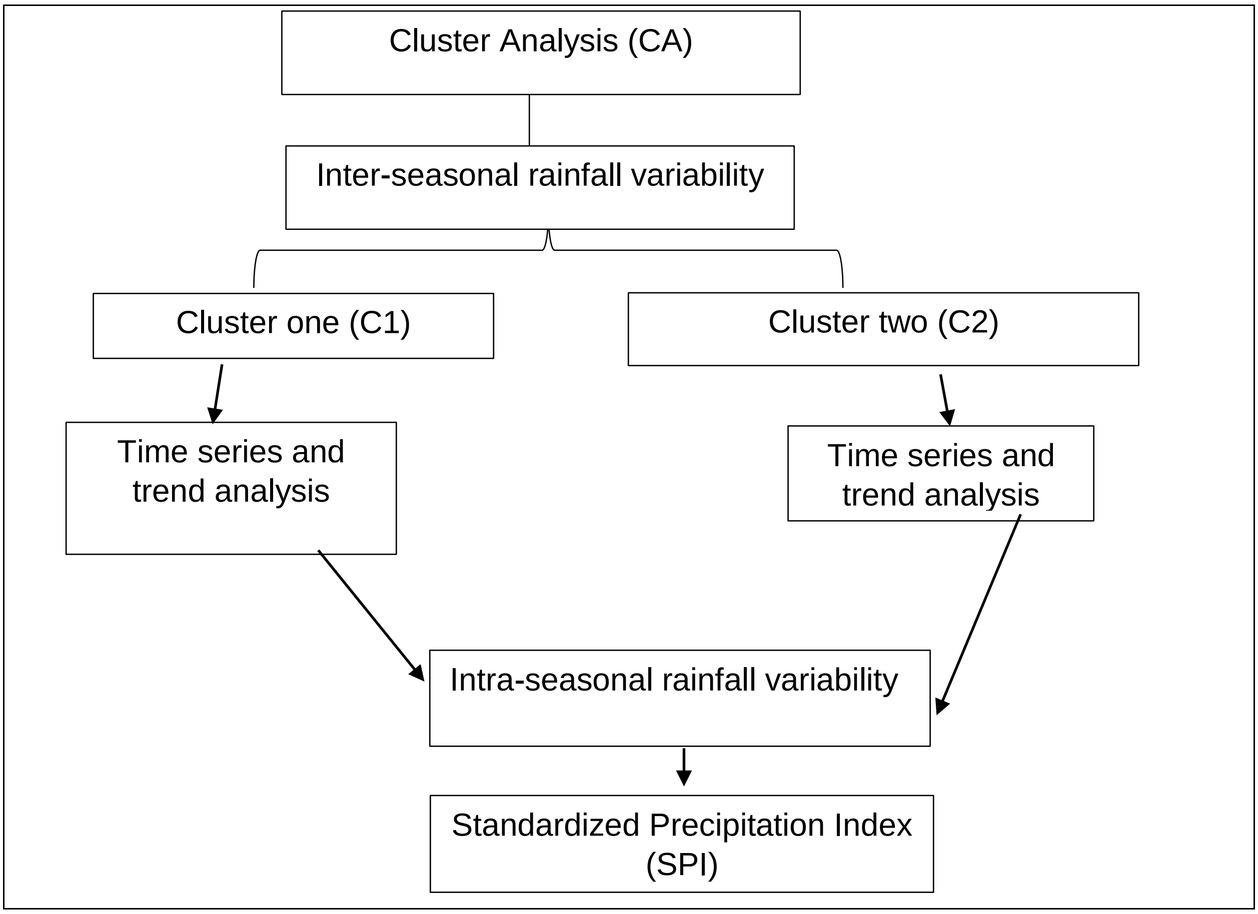


Figure 4.3 Schematic flow of the Cluster Analysis (CA) and associated methods

4.5 Summary

This chapter presented the analysis and results of rainfall classification of the North West Province (NWP) into statistically homogeneous rainfall regimes. In this study, two classification methods (Principal Component Analysis (PCA) and Cluster Analysis (CA)) are used in order to select the best technique for classifying NWP. The results of the study are presented in the form of tables and graphs.

The first method applied in the study was the PCA, whereby three criteria were used to select number of components to retain. In the Kaiser-Guttmann method seven components were retained which accounted for 81%. The three components were retained from the scree plot analysis. While in the factor loading method, four methods were retained. PC1 had 21 components, PC2 and 3 had two components each and the last component was retained in PC7.

The clustering process starts by randomly assigning stations to a (pre-specified) number of clusters. K=2 was the pre-specified number of clusters to retain in this study. In the method a centroid is created in the analysis and used as a measuring point to which station are clustered to base on shortest distance to it. Hence, two clusters were retained. Cluster one covered stations that are in the south-western and central regions of the province which contained 15 variables, while cluster two covered the north-eastern region of NWP and made up of 11 variables.

The results of CA showed a clear spatial representation of the region rainfall regimes (Figure 4.2), while the spatial representation of PCA results the stations are scattered across the province although they are within the same PC. Therefore, in the analysis CA was the principal classification method that had a better spatial representation of rainfall regimes in NWP. Thus making it the selected methodology for this study. Therefore, North West Province (NWP) is classified into two homogenous rainfall regimens; cluster one (C1) and cluster two (C2). The following sections of the study adopted the schematic flow in Figure 4.4 and disregard the flow in chapter 3 Figure 3.1.

CHAPTER FIVE

Inter-Seasonal Analysis

5.1 Introduction

In this chapter, the inter-seasonal rainfall variability of the North West Province is examined. Section 5.2 presents the analysis of the second objective, which focuses on examining inter-seasonal rainfall time series. In section 5.3, the analysis and results for the third objective are presented – it deals with determining the inter-seasonal rainfall trends in NWP. The 31 mean rainfall seasons are used in the analysis. The stations are divided according to their clusters. Were cluster one is a composite of 15 stations and cluster two is composite of 11 station.

5.2 Inter-seasonal time series analysis

This section investigates rainfall characteristics observed in the time series for each cluster and analysis of the rainfall variation in each series. The rainfall variability is analysed by looking at seasonality, oscillatory factors and rainfall patterns in the time series. Monthly rainfall data from 26 rainfall stations of which, C1 (15 stations) and C2 (11 stations) for a period of 31 years (1984-2015) were used. The stations in each cluster were composited to form mean seasonal rainfall for each cluster (Figure 5.1 and 5.2).

The mean rainfall time series is overlaid with the 5-year moving average curve. The moving average technique is used to evaluate the periodicity in the data. Rainfall is subjected to 5-year moving average to filter out climatic forcing's (see sec 3.2.3).

5.2.1 Cluster One

Figure 5.1 shows a time series analysis of rainfall composite for cluster one. It shows a quasi-sinusoidal rainfall variability with a pattern showing a negative trend from 1987 that reached the lowest point in 1991. This period was characterised by relatively dryer episodes in most parts of southern Africa, with 1991 classified as the worst drought to have hit the region in the century (Vogel and Drummond, 1993). From the Figure (Figure 5.1), the reduction in rainfall from 1987 to culminate in 1991 and cause the worst drought in southern Africa – is in agreement to Kabanda (2004) who observed that severity of drought results from accumulation of consecutive dry spells within a rainfall season and sometimes even consecutive dry rainfall seasons. Similarly, Rouault and Richards, (2003) and Gebrehiwot et al.,(2010) found that the drought characteristics over the years are resulting from either total failure of rainfall, late or too early rain during the rainfall season. In addition, from the cluster time series, a gradual increase in rainfall was observed after the lowest rainfall event (1991) to reach highest rainfall in 1996. Thereafter, inter-annual rainfall variation was gentle until 2008 rainfall season. A steep rainfall reduction then followed that reached the lowest level in 2012.

The fitted 5 year moving average pattern displayed a quasi-stationary rainfall which lacked the real features of oscillatory cycles as observed by Tyson (1990), since it showed a rather more of a damped wave. These could be due to the fewer data period used in this study as compared to what Tyson used. In this study, the data used covered 31 years, thus not including the return period.

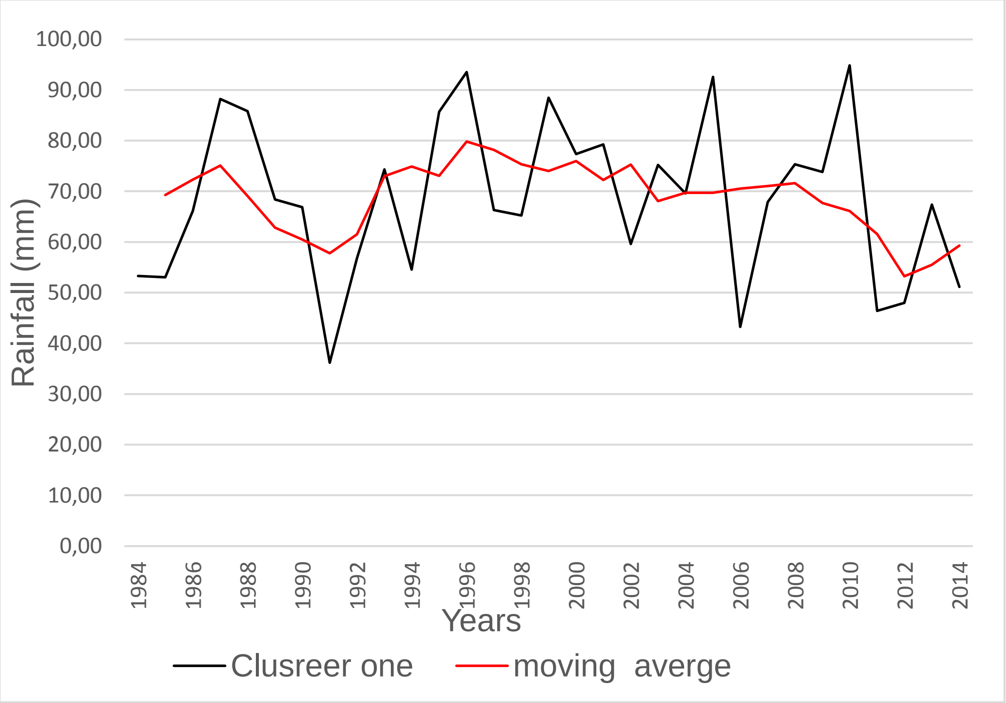


Figure 5.1: Cluster one (C1) rainfall time series

5.2.2 Cluster Two

Figure 5.2 represents rainfall time series of cluster two (C2) which covers north eastern part of NWP. The time series shows a more pronounced sinusoidal pattern than seen in C1 (section 5.2.1). The rainfall season of 1991 recorded the lowest rainfall in the cluster, which was associated with drought in southern Africa (Kabanda 2004). The moving average pattern indicates the features of the cyclic pattern which are not clearly evident in the actual seasonal data.

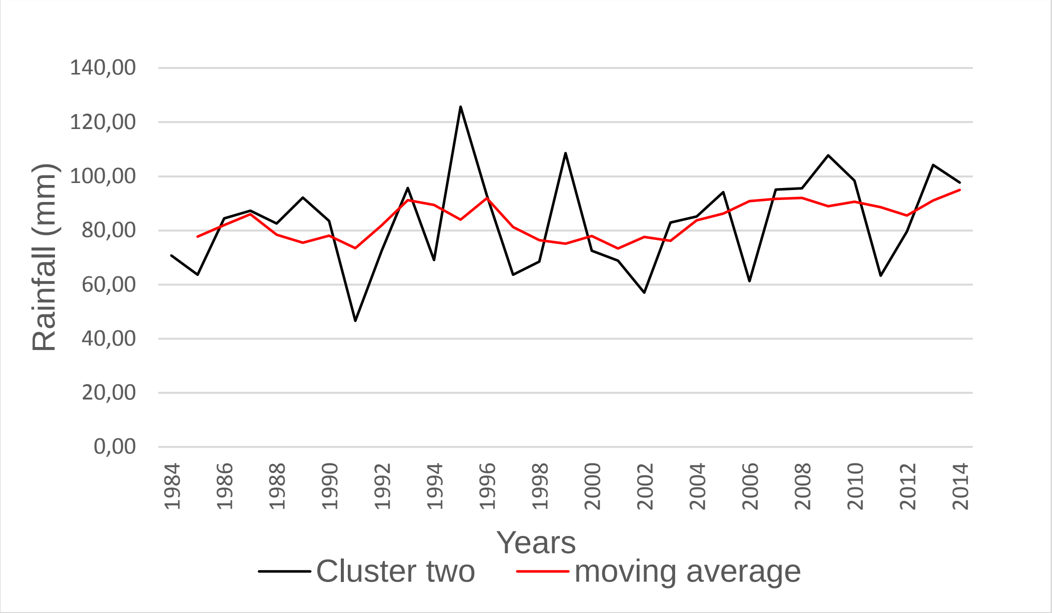


Figure 5.2: Cluster two (C2) rainfall time series

5.3. Trend Analysis

This section focuses on detecting trends in the seasonal rainfall of NWP at the inter-seasonal scale. The non-parametric statistical method that includes Mann-Kendall and Sen’s slope estimator are used. In this study, the Mann-Kendall test was performed on composited time series data for each cluster and for the corresponding individual stations for a period of 1984 to 2014 rainfall seasons. The analysis intends to detect the magnitude of the trend and the occurrence of rainfall change in the time series.

The trend analysis is computed using MAKESENS excel template that was developed for estimating and detecting trends in the time series of the annual values of atmospheric and precipitation concentrations (Salmi et al., 2002). In a trend statistics, a positive Z indicates a decreasing trend while a negative Z suggests an increasing trend (Salmi et al., 2002). Narrow angels between the confidence lines and Sen’s estimate linear trend indicate high level of statistical significance in the trend Figures (Nenwiini and Kabanda, 2013). This observation is also in agreement with that of Rehman, (2013) who stated that, the narrower the lines of significance the better the trend estimate.

5.3.1 Composite rainfall trend analysis

In this trend analysis, rainfall in each cluster was composited to produce time series as presented in Table 5.1. There are two major columns in the table, one represents the Mann-Kendall trend while the other is for the trend magnitude (Sen's slope estimate). The results show that C1 has a Z-value of 0.03 and C2 1.56 - both clusters did not register a statically significant trend. However, there is a notable increasing trend in cluster two seasonal rainfall.

The Sen's slope estimate (Q) indicates that seasonal rainfall change in cluster one for 31 years was a minimal increase of 0.02 mm/year. Cluster two registered an increase of 0.58 mm/year. The Q - value indicates the steepness of the trend, therefore, in this case the trend is very gentle – indicating that since 1984 to 2014 little changes were detected in the rainfall seasons.

Table 5.1: NWP Clusters trend statistics

Mann-Kendall trend						Sen's slope estimate
Time series	First year	Last Year	n	Test Z	Significance	Q **(mm/year)**
Cluster1	1984	2014	31	0.03		0.02
Cluster2	1984	2014	31	1.56		0.58

Figure 5.3 and 5.4 show rainfall trends results of C1 and C2. According Salmi et al. (2002), when applying Sen's slope estimate, a point of change in the rainfall trend is detected at the point where the lower and upper limits of the confidence interval (conf. min, conf. max) and the Sen’s estimate line meet. In this study, it is shown from Figure 5.3 that the change in the rainfall trend was observed in 2000. However, C2 (Figure 5.4), did not show a definite time when the changes occurred, since the Sen’s estimate line intersected the conf. min and conf. max differently. It can therefore, be inferred from the Figure that (Figure 5.4) rainfall in C2 experienced two

major positive trends that were not significant (a longer positive trend that reached a peak in 1995 and a shorter positive trend that peaked in 2009).

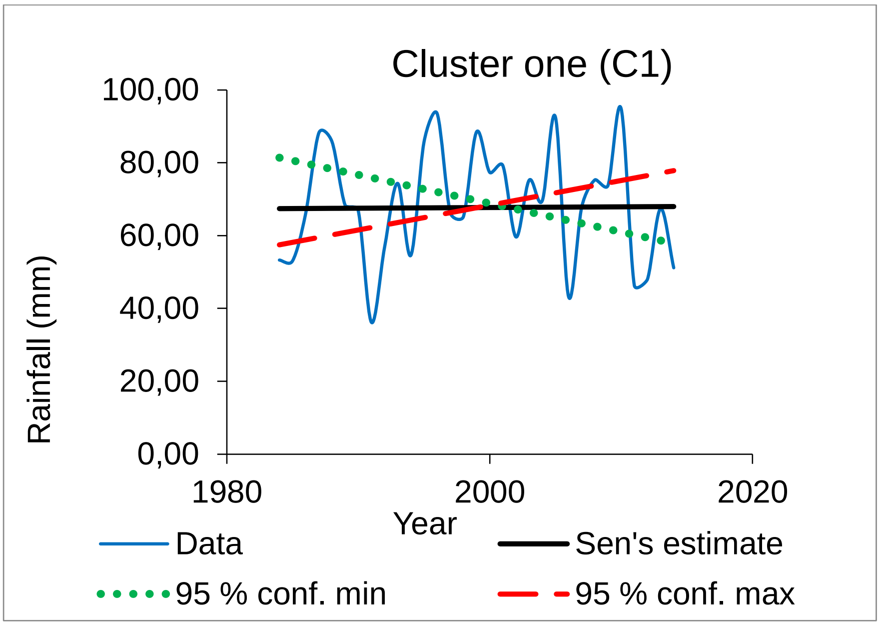


Figure 5.3: Cluster one rainfall trend

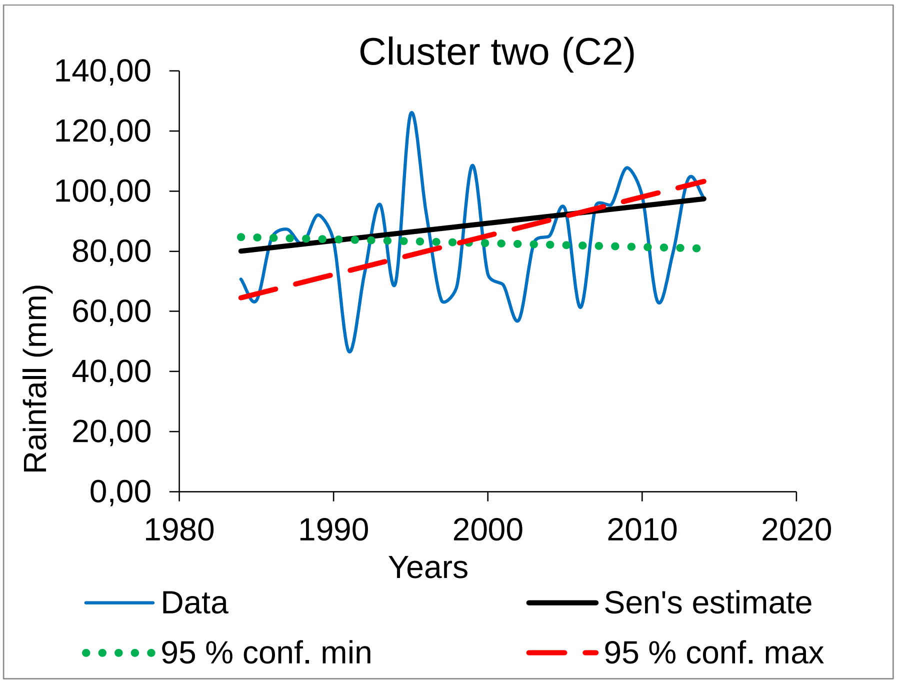


Figure 5.4: Cluster two rainfall trend

5.3.2 Rainfall trend analysis for Stations in Cluster one

There are 15 stations in cluster one and rainfall data for each was analysed for trends (Table 5.2). The results indicate that 9 stations in C1 experienced a decreasing rainfall trend and the remaining six stations showed an increasing trend. However, one station (Delareyville (Z=1.77)) experienced a statistically significant trend. While a negative, statistically significant trend at 0.05 was registered by Taung station with Z value of -2.55. A general decline in seasonal rainfall is apparent in most stations, suggesting that C1 is in a drying tendency with time.

Q (mm/year) represents the magnitude of the trend (Table 5.2). A large decrease in magnitude was registered in Taung (-0.89 mm/year) which observed a statistically significant downward trend. The Sen's slop estimate shown by Delareyville, was an increasing rainfall at 0.67mm/year.

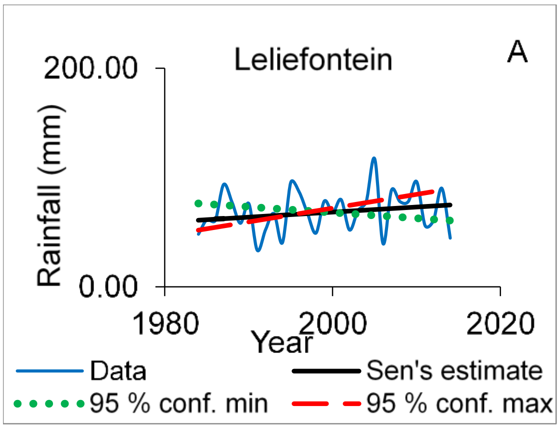
Table 5.2: Cluster one stations trend statistics

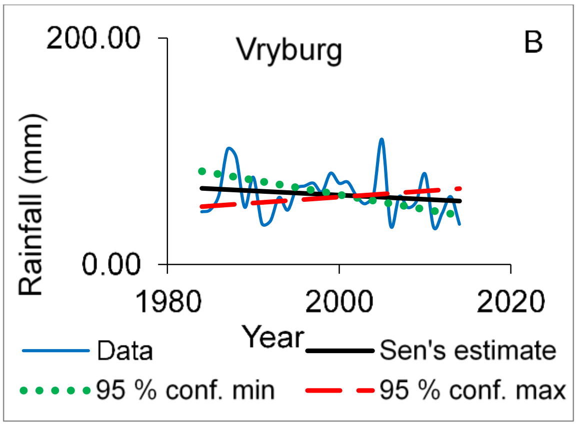
Mann-Kendall trend						**Sen's slope estimate**
Time series	**First year**	**Last Year**	**n**	**Test Z**	**Significance**	**Q (mm/year)**
Leliefontein	1984	2014	31	1.04		0.46
Vryburg	1984	2014	31	-0.92		-0.37
Klerksdorp	1984	2014	31	0.14		0.06
Ventersdorp	1984	2014	31	-0.17		-0.07
Mafikeng	1984	2014	31	-0.48		-0.15
Zeerust	1984	2014	31	0.92		0.37
Delareyville	1984	2014	31	1.77	**+**	0.67
Ottosdal	1984	2014	31	-0.41		-0.23
Swartruggens	1984	2014	31	1.22		0.62
Marico	1984	2014	31	1.09		0.50
Taung	1984	2014	31	-2.55	*****	-0.89
Koster grootpan	1984	2014	31	-0.49		-0.26
Lich sensako	1984	2014	31	-1.19		-0.49
Schwezerreneke	1984	2014	31	-0.44		-0.21
Vryburg L	1984	2014	31	-0.78		-0.44

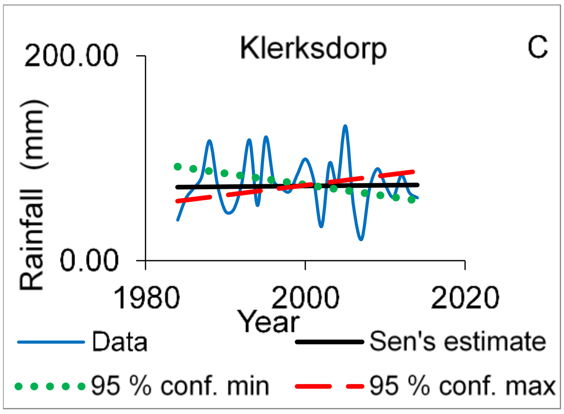
***** = 0.05 level of significance **+** = 0.1 level of significance

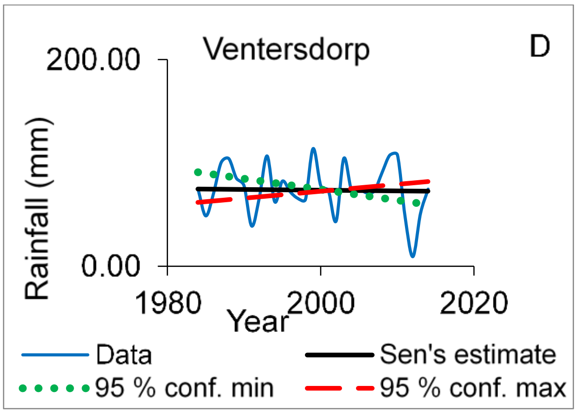
Rainfall trends plots for Cluster one stations are presented in Figure 5.5 (A to O). Each Figure is indicated by the alphabet and name of the station; later, the representative alphabets are used to avoid writing the names. For example, A-Leliefontein indicates Figure 5.5 A that represents Leliefontein rainfall station and so forth. The two stations that observed a statistically significant trend are present in Figure 5.5 G and K. Sen’s estimate shows that there is a steep change in the rainfall trend of Delareyville (Figure 5.5 G). The change in the rainfall trend of G started to occur in 1998 since that year is when the Sen’s estimate line and the confidence limit lines meet. Figure 5.5 K represents Taung station, which showed a negative rainfall trend. The change in rainfall trends for K occurred in 1999 based on the intersection of Sen’s estimator and the confidence limit lines.

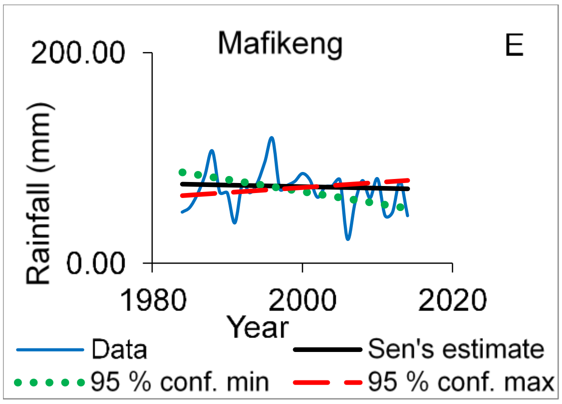
The other stations which were not statistically significant for example C, which recorded the lowest positive magnitude in the analysis show that Sen’s estimator line is simply a straight line. Stations A, J, and I recorded relative high positive trends (0.46, 0.62 and 0.50 respectively) although insignificant.

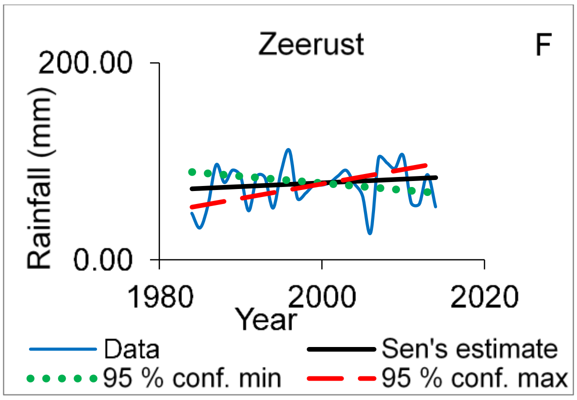

Leliefontein
A
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max

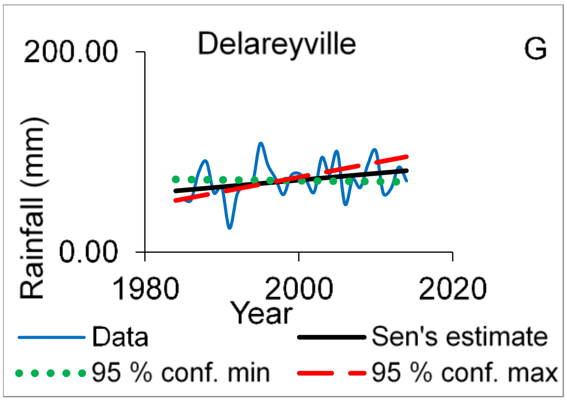

Vryburg
B
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max

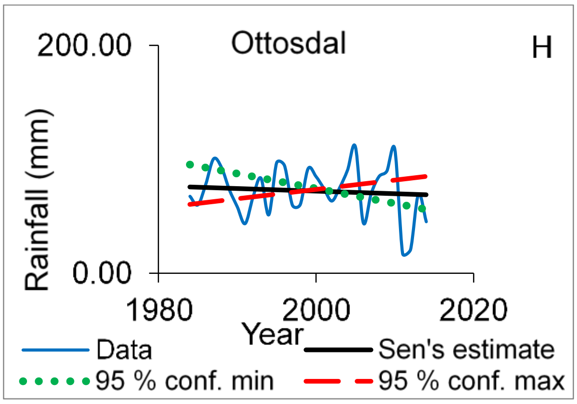

Klerksdorp
C
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max


Ventersdorp
D
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max


Mafikeng
E
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max


Zeerust
F
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max


Delareyville
G
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max


Ottosdal
H
200.00
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Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max

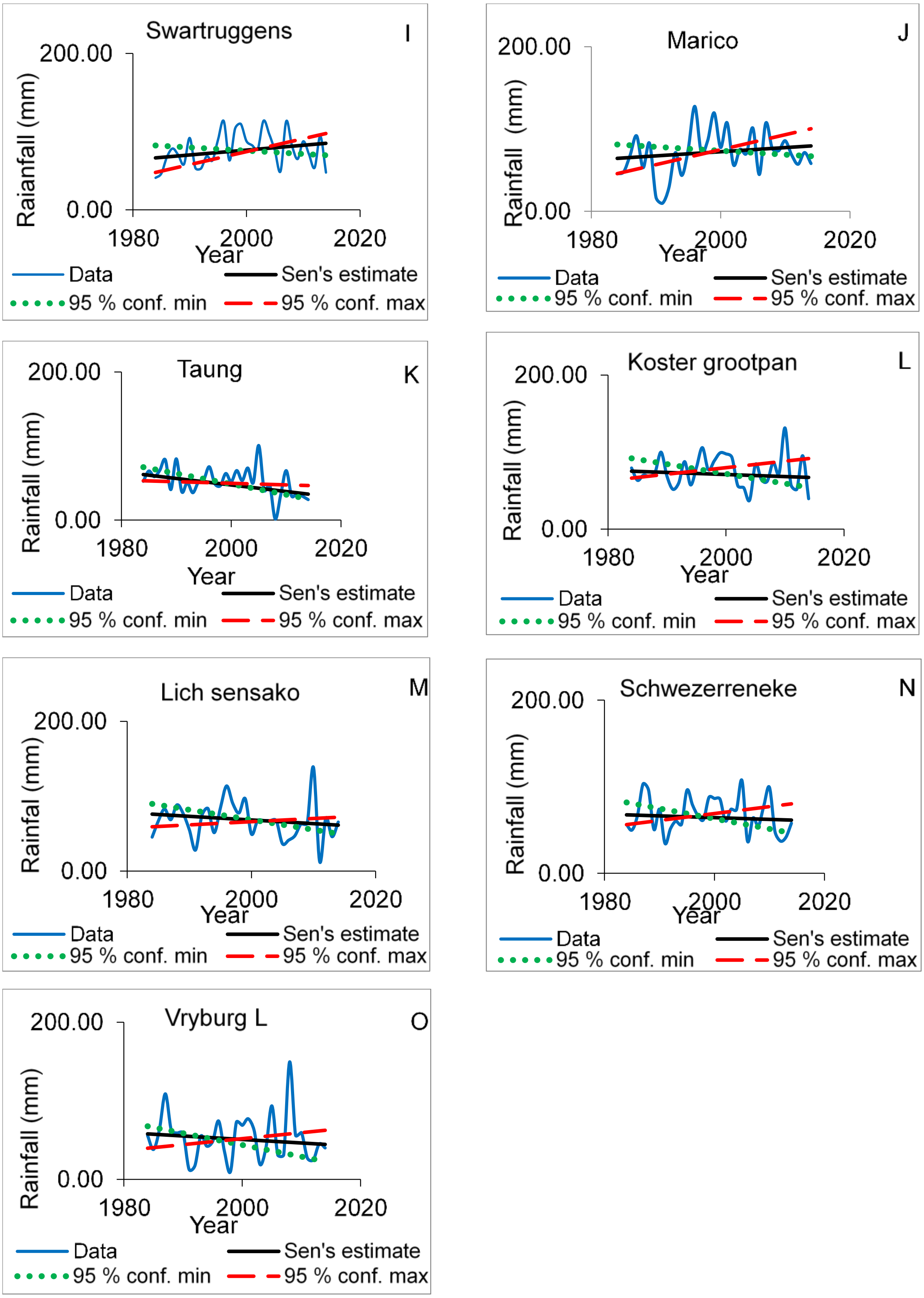


Figure 5.5: Rainfall trends for Cluster one (C1) stations

5.3.3 Rainfall trend analysis for Stations in Cluster two

Trend analysis was performed for 11 stations that form cluster two (C2) to determine the magnitude and significance of the rainfall trend. The results showed that 9 stations in the cluster show a positive rainfall trend while only two stations namely; De kroon and Dwarstfontein observed a negative rainfall trend. However, the two stations did not record a statistically significant trend and both registered a low magnitude where Q was -0.21mm/year and -0.03mm/year with Z value of -0.31 and -0.12. This shows that the rate of change in the stations that observed negative trends was minimal when compared with other stations in the group.

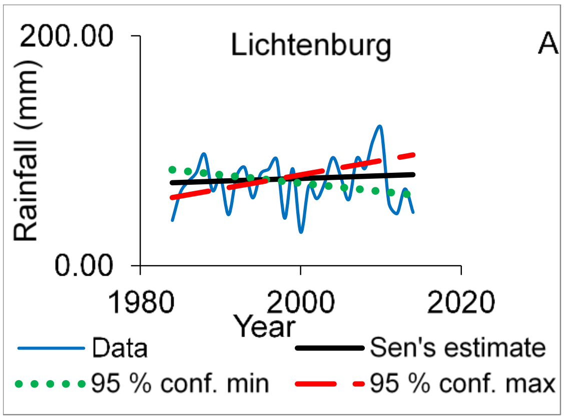
Two stations were statistically significant at 0.1 level of significance, Olifantsport with Z value of 1.84 and Potchefstroom recording a Z value of 1.67; with Sen's trend estimate Q of 0.70mm/year and 0.75mm/year respectively. The highest positive magnitude in the analysis was observed in Rustenburg with Q= 0.97 mm/year. However, it was not statistically significant.

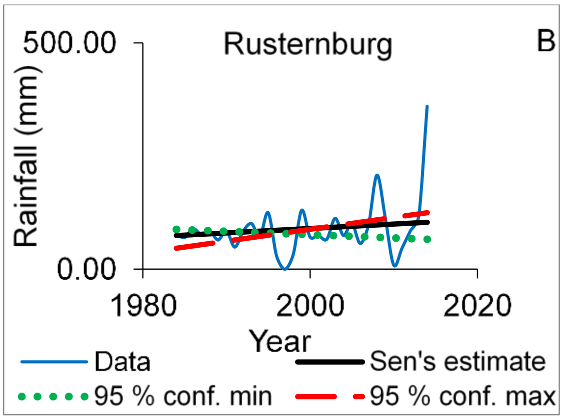
Table 5.3: Cluster two stations trend statistics

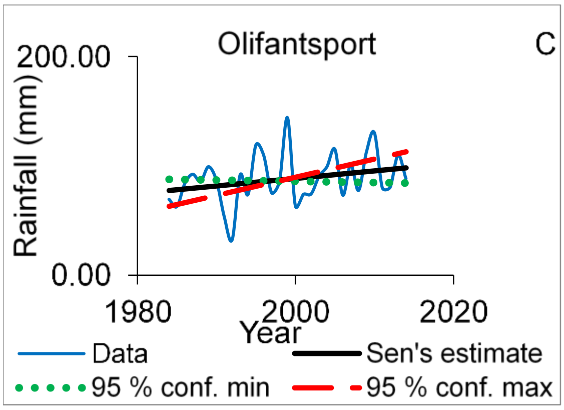
Mann-Kendall trend						**Sen's slope estimate**
Time series	**First year**	**Last Year**	**n**	**Test Z**	**Significance**	**Q (mm/year)**
Lichtenburg	1984	2014	31	0.44		0.23
Rusternburg	1984	2014	31	1.16		0.97
Olifantsport	1984	2014	31	1.84	**+**	0.70
De kroon	1984	2014	31	-0.31		-0.21
Bakubung gate	1984	2014	31	0.68		0.25
Potchefstroom	1984	2014	31	1.67	**+**	0.75
Koster	1984	2014	31	1.02		0.60
Mamogaleskral	1984	2014	31	0.10		0.04
Dwarstfontein	1984	2014	31	-0.12		-0.03
Buffelsport	1984	2014	31	0.65		0.48
Brits	1984	2014	31	0.65		0.17

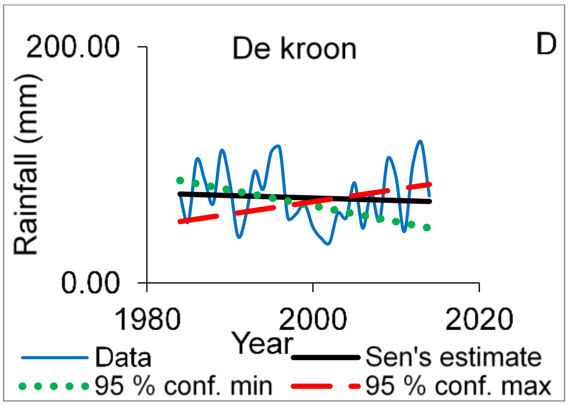
+ = 0.1 level of significance

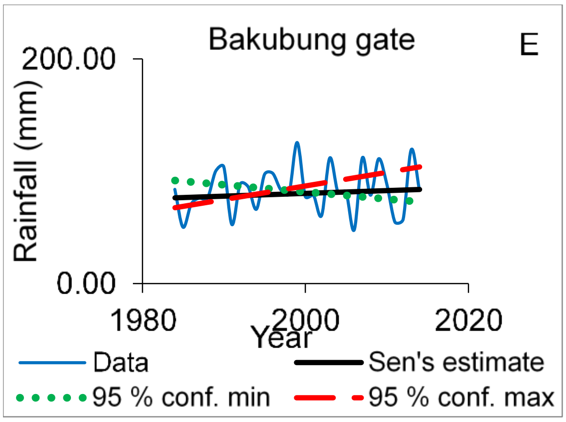
In order to determine the change in rainfall trend in Cluster two stations, the rainfall trend analysis are illustrated in Figure 5.6 (A to K). The stations, which are statically significant in the cluster are represent by C and F. The point of change in C was noted in 1998 since it is where the Sen's estimate line and the confidence line overlap. The area started to show a tendency towards increase of the rainfall. While in K, the line the change was observed during 1999. In D, the station showed a decrease in the rainfall trend and the Sen Estimator line showed a slight downward trend in the rainfall however the point of change was not explicit – suggesting that the area experienced multiple changes in rainfall trends.

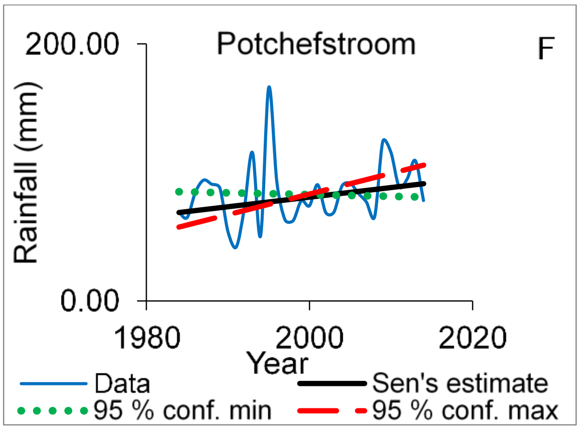

Lichtenburg
A
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max

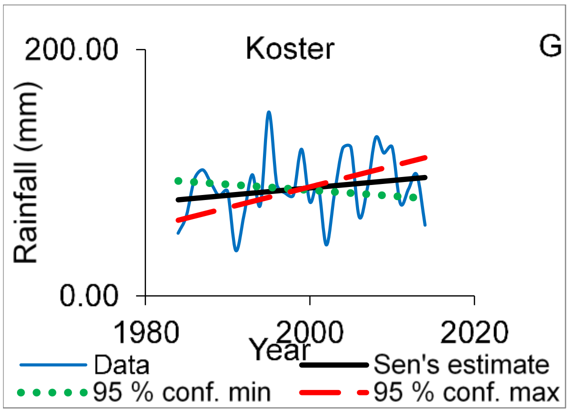

Rusternburg
B
500.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max


Olifantsport
C
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max


De kroon
D
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max


Bakubung gate
E
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max


Potchefstroom
F
200.00
0.00
Rainfall (mm)
1980
2000
2020
Year
Data
Sen's estimate
95 % conf. min
95 % conf. max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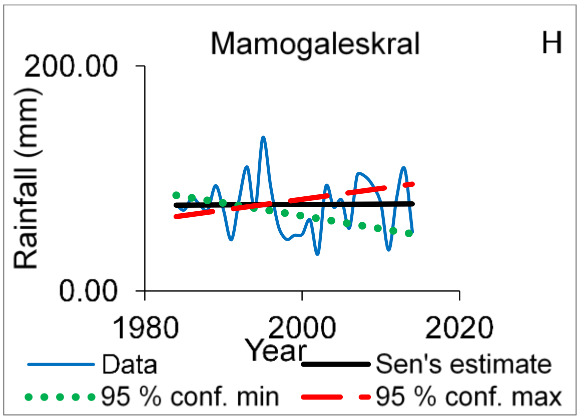
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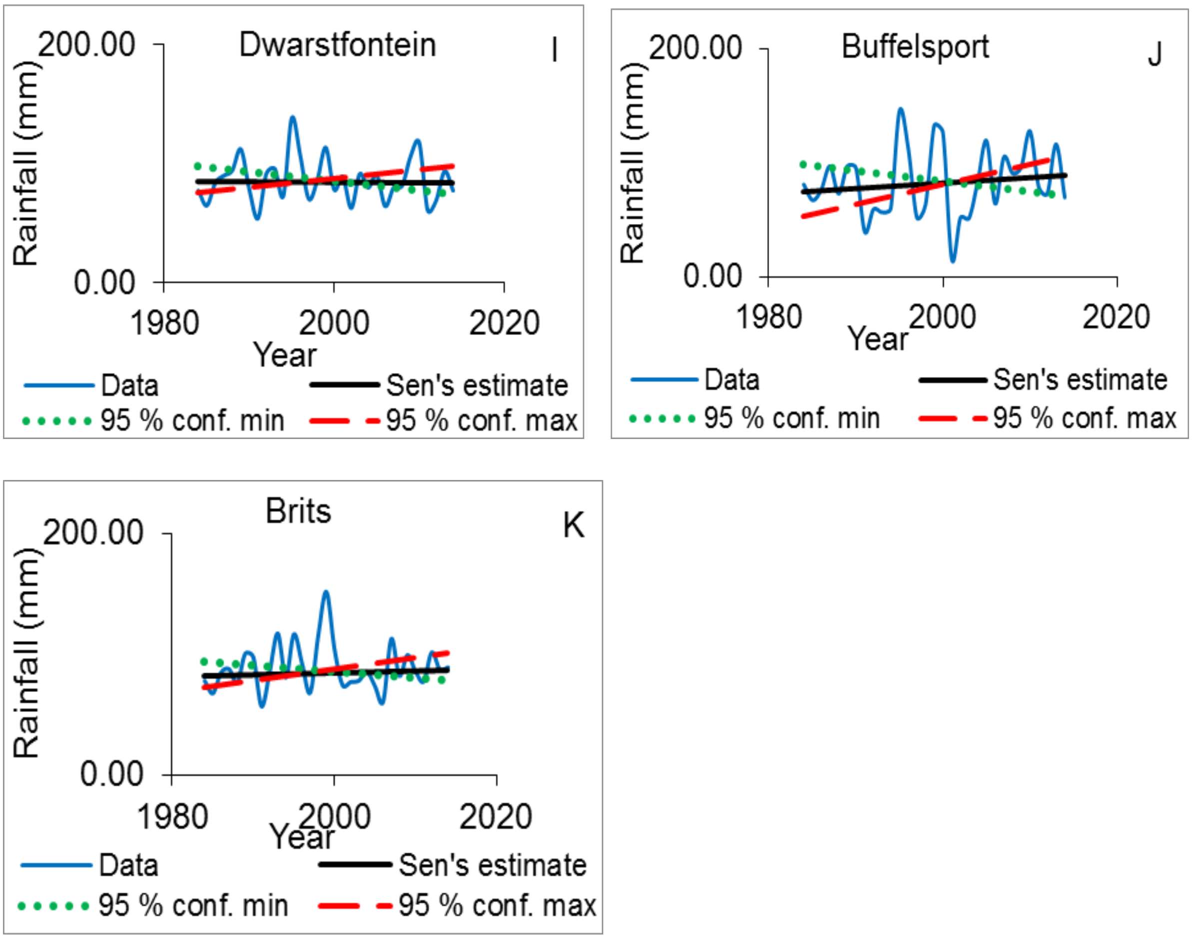


Figure 5.6: Rainfall trends for Cluster two (C2) stations

5.4 Summary

The inter-seasonal rainfall variability of the North West Province was examined while the rainfall characteristics were observed in the time series for each cluster (C1 and C2). C1 featured a weak quasi-sinusoidal rainfall variability while C2 depicted a more pronounced sinusoidal feature.

The non-parametric statistical method that includes Mann-Kendall and Sen’s slope estimator were used to determine trends in both clusters. The following results were established:

- Mann-Kendall trend for the composited rainfall stations in C1 and in C2 are Z = 0.03 and 1.56 respectively and both show no statically significant trend. However, there is a notable increasing trend in C2 seasonal rainfall.

- The Sen's slope estimate (Q) indicates that seasonal rainfall change for C1 and C2 were 0.02 mm/year and 0.58 mm/year respectively.

Rainfall trend analysis was then performed for all individual stations in the clusters. The most important observation was that nine stations in C1 experienced a decreasing rainfall trend while the remaining six stations showed an increasing trend - the significant trends detected are Delareyville (Z=1.77) at 90% and Taung station with Z value of -2.55 at 95%. In C2, nine stations out of eleven showed a positive rainfall trend while two stations observed a negative rainfall trend. From these observations, the results showed that a pronounced differences exist between C1 and C2. For example, C1 is becoming more arid while C2 is tending to be wetter.

CHAPTER SIX
Intra-Seasonal Analysis

6.1 Introduction

This chapter focuses on the intra-seasonal rainfall variability in North West Province (NWP). Daily rainfall data is converted into Pentad rainfall data (Table 6.1) and used for analysis. The data is standardised and normalised to develop the Standardized rainfall anomalies time series. Pentads data is used to remove the diurnal weather effect in the analysis (Sun and Liu, 2016).

Table 6.1: Pentads

Pentad No:	**Date**	**Pentad No:**	**Date**	**Pentad No:**	**Date**
pentad 56	03-07 OCT	pentad 68	02-06 DEC	pentad 7	31-04 FEB
pentad 57	08-12 OCT	pentad 69	07-11 DEC	pentad 8	05-09 FEB
pentad 58	13-17 OCT	pentad 70	12-16 DEC	pentad 9	10-14 FEB
pentad 59	18-22 OCT	pentad 71	17-21 DEC	pentad 10	15-19 FEB
pentad 60	23-27 OCT	pentad 72	22-26 DEC	pentad 11	20-24 FEB
pentad 61	28- 01 NOV	pentad 73	27-31 DEC	pentad 12	25-01 MAR
pentad 62	02-06 NOV	pentad 1	01-05 JAN	pentad 13	02-06 MAR
pentad 63	07-11 NOV	pentad 2	06-10 JAN	pentad 14	07-11 MAR
pentad 64	12-16 NOV	pentad 3	11-15 JAN	pentad 15	12-16 MAR
pentad 65	17-21 NOV	pentad 4	16-20 JAN	pentad 16	17-21 MAR
pentad 66	22-26 NOV	pentad 5	21-25 JAN	pentad 17	22-26 MAR
pentad 67	27-01 DEC	pentad 6	26-30 JAN	pentad 18	27- 31 MAR

The time series are developed for all the stations in the study area that showed statistically significant rainfall trends (Chapter 5). The stations used in the analysis include two stations from cluster one (Delareyville and Taung) and two from C2 (Olifantsport and Potchefstroom). In the analysis, three seasons from each stations are analysed. The first season is identified in the trend analysis when the significance line intersects with Sen’s slope estimator line and the lines of confidence. The intersection represents the point in trend were changes started to occur (Salmi et al., 2002). The season before and after the point of transition are also used in the analysis to compare and contrast how the rainfall performed before and after the point of change. The analysis and results are presented in the subsequent subsections.

6.2. Delareyville

The Delareyville station is statistically significant at 0.1 level showing a positive rainfall trend (Chapter 5). The changes in the rainfall trend of this station started to be apparent during 1998 rainfall season, when the rainfall of the area started to show an increase in the trend. For this station, intra-seasonal rainfall time series are developed for 1997 to 1999 rainfall seasons (Figure 6.1).

The 1997 rainfall season which happened before the observed trend change, was dominated by pentads of below normal rainfall. There was a period of 14 consecutive below normal that occurred at the beginning of the rainfall season and lasted for 13 pentads (pentad 59-71) – that is 65 days of below normal rainfall. Although, pentad 1 (1-5 January) performed exceptionally above normal, it was not enough to offset the continuation of below normal rainfall that continued to pentad 9. Thereafter, seasonal rainfall anomalies of >1.0 where registered during pentad 10 and 18. The results suggest that the 1997 rainfall season was maintaining a relatively negative trend although rainfall started to peak towards the end of the season.

The rainfall trend change was evident in 1998, because that is when rainfall started to peak and records of more episodes of above normal rainfall pentads occurred. The major dry spell during this season was observed from pentad 3 to pentad 9. The following part of the season observed alternating wet and dry spells with more pronounced wet pentads.

The 1999 rainfall season over Delareyville was initially dry for 15 pentads (75 Days) until pentad 71 when substantial above normal rainfall was experienced. The subsequent ten days were above normal. Therefore, over Delareyville, it is evident that the positive trend that started towards the end of 1997 continued to beyond 1998 as indicated in Chapter 5.

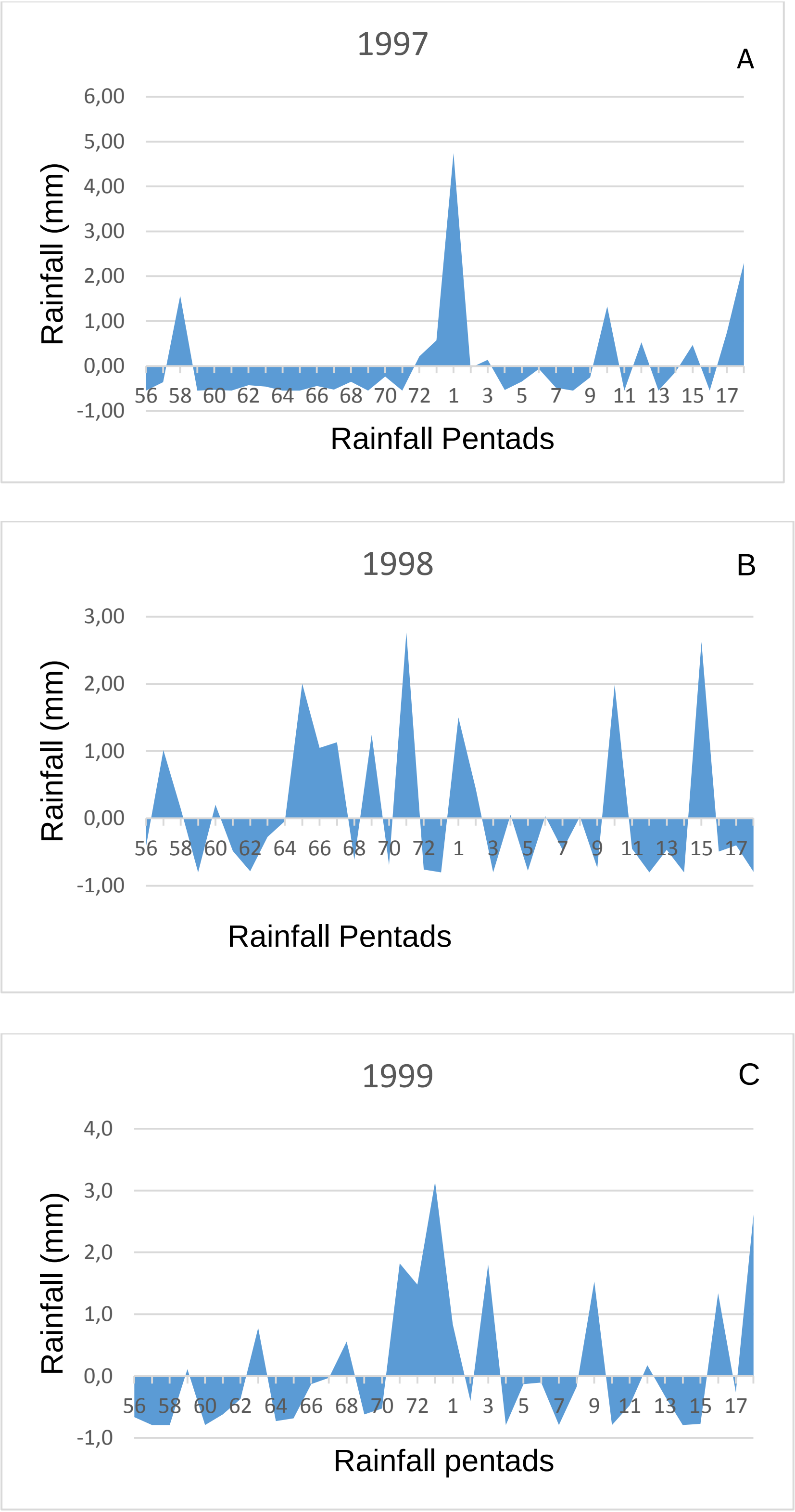
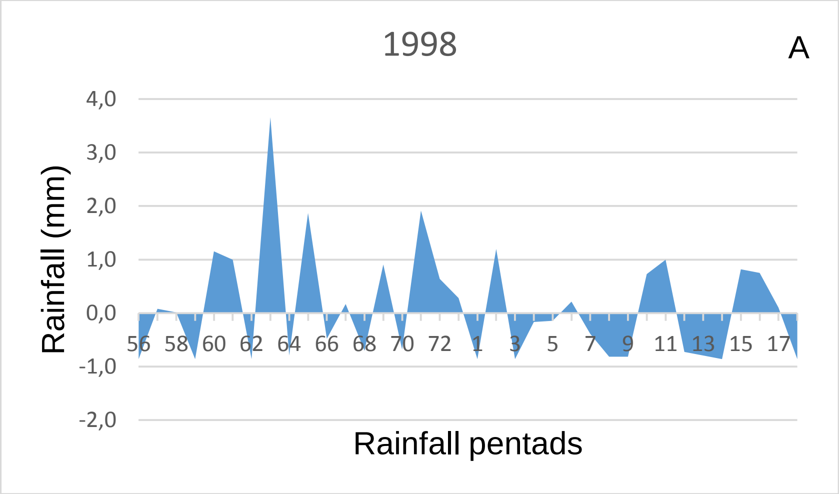
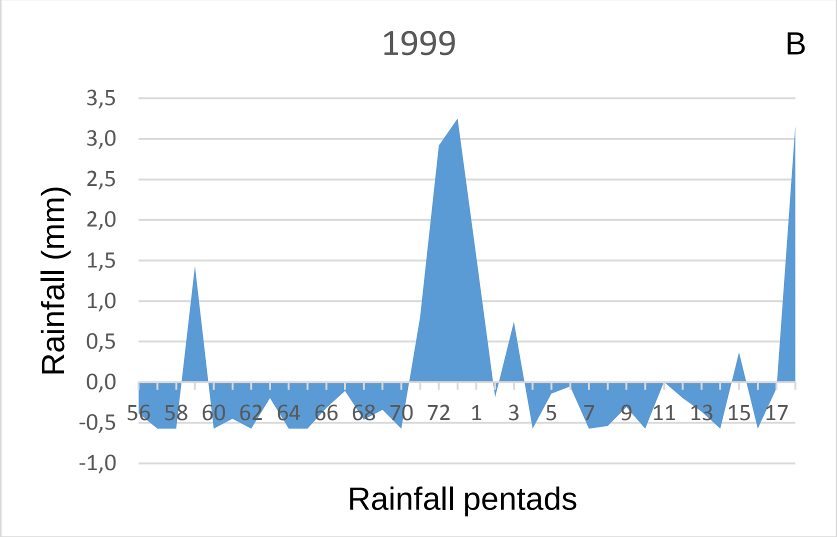


Figure 6.1: Standardised rainfall anomalies of Delareyville station A-1997 season B-1998 season and C-1999 season.

6.3 Taung

Taung rainfall station showed a statistically significant negative rainfall trend (Table 5.2). The evidence for such behaviour is evident in Figure 6.2, where rainfall started to decrease in 1998 after pentad 02. Rainfall decrease continued until pentad 18 of 2000 rainfall season. However, in between (pentad 02 of 1998 and pentad 18 of 2000) there were substantial wet spells. The longest wet spell lasted 20 days (4 pentads) others were shorter than that. Consequently, few wet spells were not enough to offset the persistent negative trend during that period.





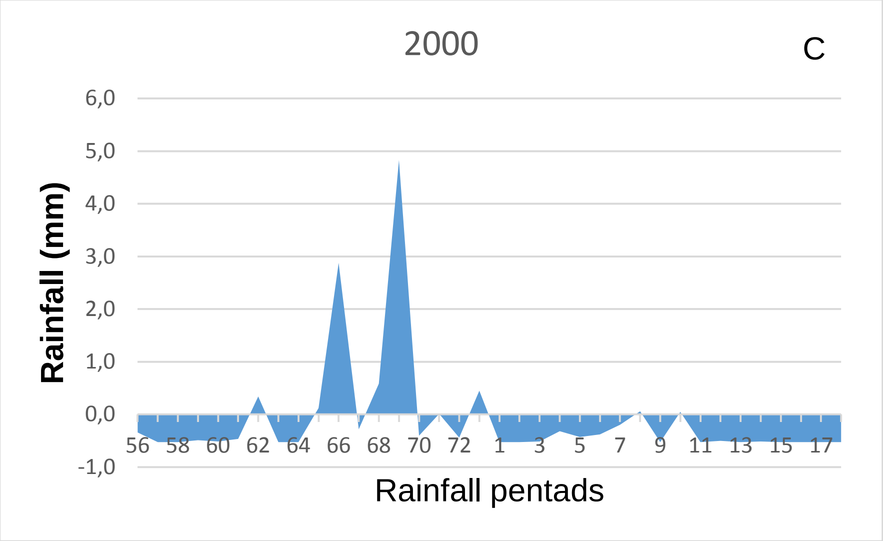


Figure 6.2: Standardized rainfall anomalies of Taung station A-1998 season B-1999 season and C-2000 season.

6.4 Olifantsport

Olifantsport station is found in cluster two of the rainfall classification in the North West Province. The station registered a statistically significant (90%) positive trend. The point of change in the station was observed during 1998 rainfall season when the line of confidence meets the Sen's estimate. Therefore, the analysed season in this station includes; 1997, 1998 and 1999 presented in Figure 6.3.

The 1997 rainfall season started with below normal rainfall pentads that lasted for 9 consecutive pentads. Thereafter, the first above normal rainfall was experienced in pentad 66 followed by four other that occasionally occurred between below normal rainfall events. The 1998 rainfall season registered the first episode of wet event in pentad 65. Thereafter, a series of wet spells continued until Pentad 16.

In the 1999 rainfall season, below normal rainfall events were more dominant and persistent except for 10 days (pentad 8 and 9).

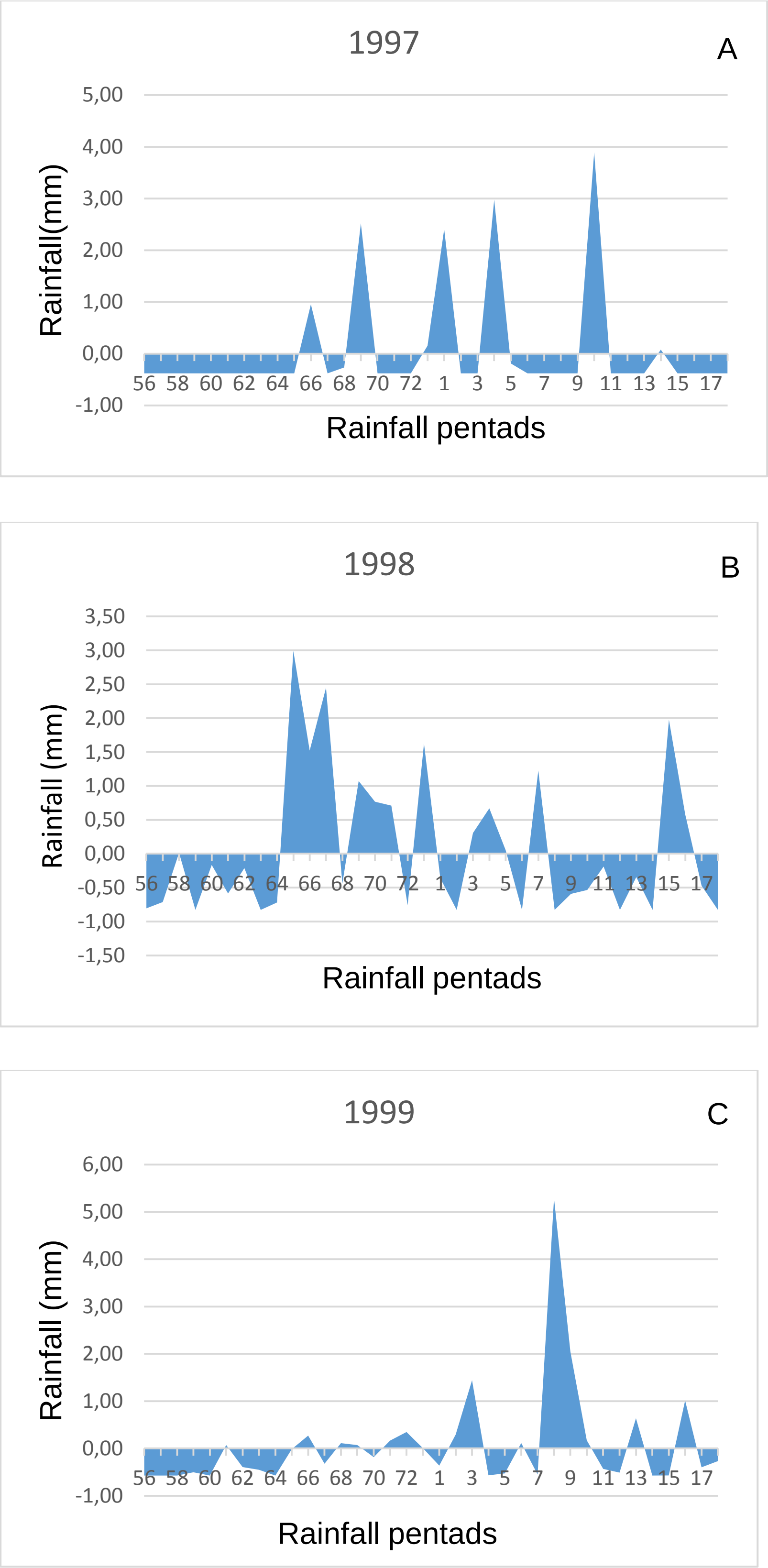
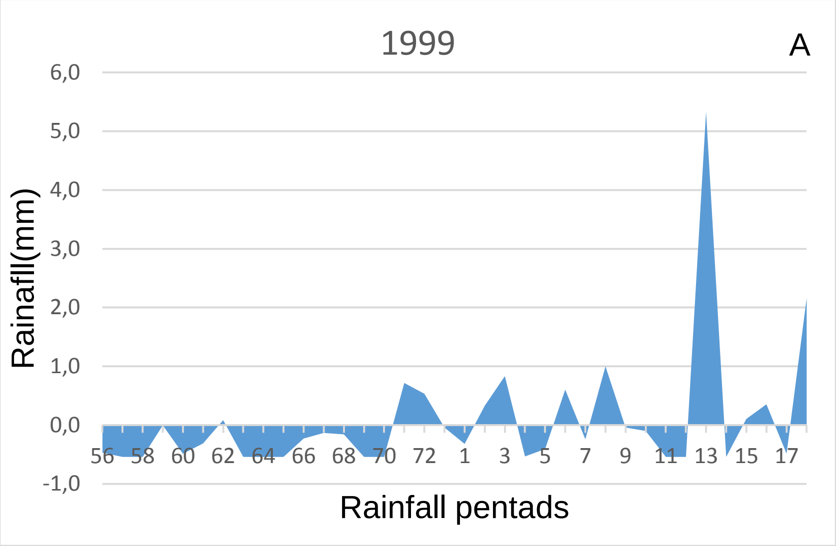


Figure 6.3: Standardized Rainfall anomalies of Olifantsport station A-1997 season B-1998 season and C-1999 season.

6.5 Potchefstroom

The Potchefstroom station is also found in cluster two. The station rainfall trend is statistically significant showing a positive trend (at 90%). The changes in its rainfall trend were observed in 2000, and the analysis is based on the 1999, 2000 and 2001 rainfall season (Figure 6.4). The 1999 rainfall season which occurred before the changes were observed in the station, started with a series of below normal rainfall pentads lasting till pentad 71.

Thereafter, from pentad 72 the seasonal rainfall started to peak up and the season had a positive rainfall trend which prevailed till the end of the season and continued to 2000. The changes in the rainfall trend started to be more noticeable in 2000 when more pronounced wet events occurred. This trend continued to 2001 rainfall season whereby the whole season recorded above normal rainfall events of high magnitude that persisted throughout the season.



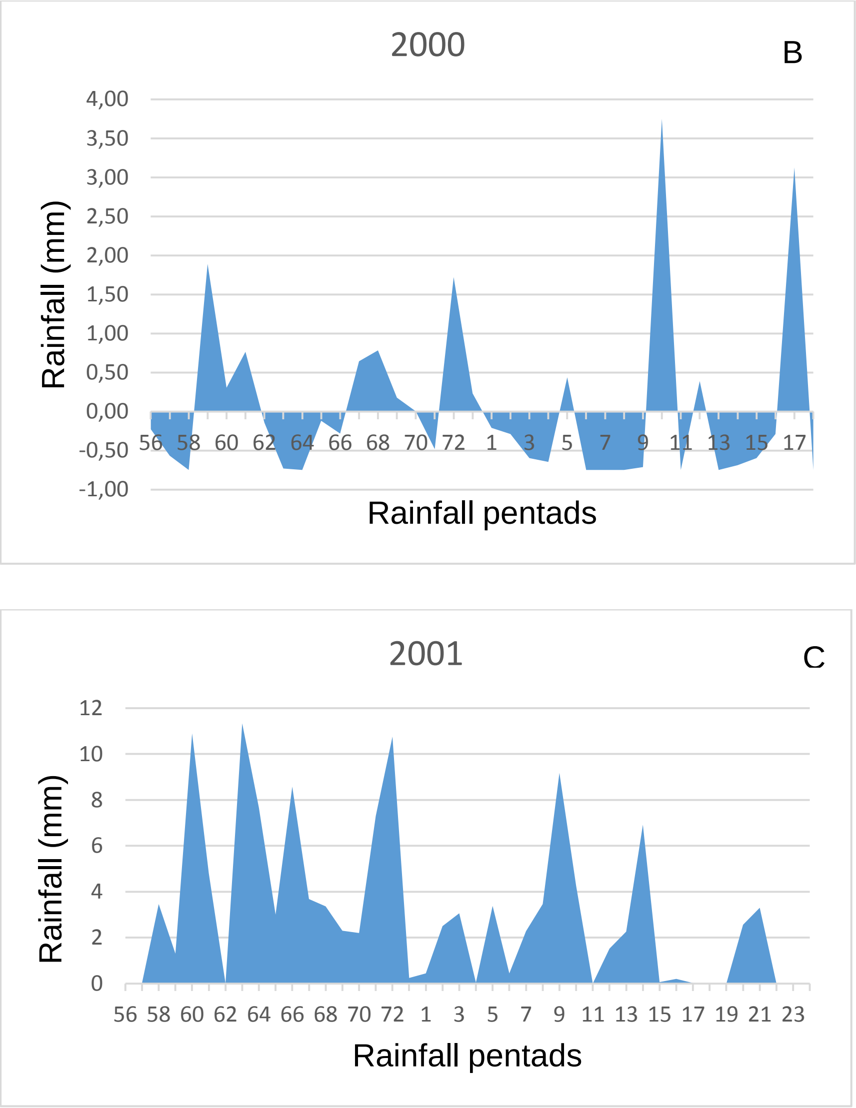


Figure 6.4: Standardized Rainfall anomalies of Potchefstroom station A-1998 season B-2000 season and C-2001 season.

6.6 Summary

The intra-seasonal rainfall variability of the North West Province (NWP) is analysed in this chapter. Rainfall pentad are used to analyse intra-seasonal rainfall time series in the study area. The first pentad in the study is from 03-07 October (pentad 56) and the last pentad is Pentad 18 (27-31 March). In this chapter, the four statistically significant rainfall stations (see chapter 5) were used. For each station, three rainfall seasons that are centred on the rainfall trend change (intersection between Sen's slope estimator line and the lines of confidence) are analysed. The purpose was to compare and contrast how the rainfall performed before and after the point of change and relate the observations with the trends observed in Chapter 5.

The following are the main findings of this chapter:

- One station reported weak positive trend while another one weak negative trend in C1 with more counts of dry spells.
- Both stations in C2 experienced strong positive rainfall trends, with substantial amount of wet spells. For example Potchefstroom station reported all wet pentads throughout the 2001rainfall season.

CHAPTER SEVEN

Summary and Conclusion

7.1 Introduction

This dissertation was dedicated at evaluating inter-seasonal and intra- seasonal rainfall variability of the North West Province (NWP), South Africa. In Chapter one, an overview of the study was given. The problem statement highlighted the importance of this study in North West Province. In addition, Chapter 1 highlights on the following: - the potential of rainfall variability to have impact on the socio economic sectors in NWP; that scarcity of water in North West Province is increased by the climate state of the area such as the semi-aridity and rainfall variability in the region. Therefore, there is a need to study rainfall variability in NWP.

In Chapter 2, a review of literature on rainfall variability at different spatial scales was conducted. Emphasis was made on the southern Africa region and the impacts of rainfall variability on vulnerable sectors such as water resources and agricultural sector. In the review, it was identified that rainfall variability impacts are severe in southern Africa due to lack of facilities and economy to support better adaptation measures and the vulnerability is intensified by the reliance on rainfall-dependent sectors (Dennis and Dennis, 2012). The vulnerability had the potential to add additional pressure in already impacted sectors (IPCC, 2007

Data and methods were discussed in Chapter 3. The analysis applied in the dissertation mainly uses statistical techniques. Rainfall data for 31 season (1984-2015) was used. Principal Component Analysis (PCA) and Cluster Analysis (CA) were the selected classification techniques used in the study to classify NWP into different rainfall regimes. For each regime, time series were developed and analysed. While the Mann-Kendall and Sen's estimator methods were used to determine the long-term rainfall trends in NWP. In the Intra-seasonal rainfall variability, daily data was used to evaluate intra-seasonal. The data was converted in to pentads rainfall and the Standardised Precipitation index was performed.

The original work of this study are mostly found in Chapter 4 and the subsequent chapters - they are summarised in the following sections in this chapter (Chapter 7)

7.2 Rainfall classification of North West Province

In chapter 4, two classification methods (Principal Component Analysis (PCA) and Cluster Analysis (CA)) were used in order to select the best technique for classifying NWP. The criteria used to retain components in PCA method showed that all three methods had different number to PC to retain which PCA results showed a discrepancy in the number of components to retain, resulting in a subjective decision in classifying NWP rainfall.

However, with CA, the number of components retained was specified using the K-means clustering technique where K represents the number of clusters, and its value is pre-defined by the user (Pham et al., 2005), In this study the value of K=2. Therefore, clusters were retained. The CA results are spatially presented in Figure 4.2 showing two distinct clusters. The clusters were made up of the following rainfall stations; C1 was formed by 15 rainfall stations which are mostly distributed in the South-west and central region of the province. While C2 was formed by 11 rainfall stations which cover the north-eastern part of NWP.

PCA technique did not capture much of total variance explained in NWP rainfall. Hence, CA was adopted and used in this study which resulted in the province being clustered into homogeneous rainfall regimes as Cluster one (C1) and Cluster two (C2).

7.3 Inter-Seasonal Analysis (Chapter 5)

North West Province (NWP) rainfall time series and rainfall trends were evaluated in chapter 5. Time series plot of each cluster was analysed. C1 time series showed quasi-sinusoidal rainfall variability with a pattern displaying a negative trend from 1987 that reached the lowest point in 1991. C2 rainfall showed a more pronounced sinusoidal pattern. The 1991 recorded the lowest rainfall in the two clusters and was identified as the most severely intense drought to have affected southern Africa. The rainfall time series of cluster one shows a decreasing tendency while C2 is the wet region in the area.

Regarding the trend, Mann Kendal trend test and Sens' slope estimator were used to study variability and trends of inter-seasonal rainfall in NWP. Trend analysis results of North West Province 1984-2015 seasonal rainfall indicated a general decrease overtime. The following results indicated major observations identified in NWP rainfall trends.

- Only four stations registered a statistically significant rainfall trend.
- One of the stations (Taung) showed a negative trend whereby the magnitude was approximately 1 mm/year. The station form part of C2 and is located in the western regions of NWP.
- 60% of C1 rainfall stations (9 out of 15) reported negative rainfall trend, suggesting that C1 was increasing in aridity.
- In C2, 82% of the stations showed a positive rainfall trend suggesting that the area is gradually becoming wetter.
- Tendency towards aridity due the minimal magnitude at which rainfall trends in the province it’s occurring.

According to these observations, generally North West Province features a high spatial and temporal rainfall variability when considering Inter-Seasonal scale. Then the study probed further into rainfall seasons (Intra-Seasonal) that experienced significant trends in order to determine trend changes at a pentad scale.

7.3 Intra-Seasonal Analysis (Chapter 6)

Chapter 6 examined the Intra-seasonal rainfall variability of NWP at pentad scale. The criteria used to select the data for analysis in this chapter was based on the stations that experienced statistically significant rainfall trends in Chapter 5. Three stations (Delareyville, Potchefstroom and Olifantsport) showed statistically increasing trend, while one station (Taung) had a decreasing rainfall trend. The daily rainfall data was converted to pentads and standardised.

The most important finding in this chapter was that rainfall in North West Province showed strong spatial and temporal variability at Intra-seasonal scale.

- Rainfall in the province is dominated by periods of below normal rainfall fall
- The frequency of rainfall is low. However, the wet spell events occurs at high intensity.
- The rainfall in the region can go for about 14 consecutive recording below normal events.

- From pentad 56 to Pentad 71 little to no rainfall can be expected in the province
- Wet spells in the region can be expected from pentad 71 which may extend to not more than 5 pentads.
- Tendency towards aridity due to the delay and frequency of below normal rainfall experienced in NWP.
- The rate at which above normal rainfall is occurring is very marginal such that dry and below normal rainfall are prevalent and may increase the aridity.

7.4 Conclusion

The new elements of knowledge, which this research added to climate studies in southern Africa is the classifications of large areas into homogeneous - small manageable entities that can be easily handled in climate research. In this study, the most effective method was found to be the Cluster analysis. Rainfall trend analysis was another approach that was used to develop a typing schemes that related the spatial and temporal climate of North West Province. Using this method, a statistically significant increase or decrease in area rainfall was determined. However, some limitations (e.g., data length), were encountered in this study. Therefore, it is recommended that the analyses should be updated as the data density improves.

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