Spatio-temporal effects of rainfall on stream/river flow in the Kruger National Park, South Africa.

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Declaration

I hereby declare that this dissertation is my own, original work, except where otherwise acknowledged. It is being submitted in fulfillment for the requirements of an MSc to the University of the Witwatersrand, Johannesburg. I have not submitted it previously for the purpose of obtaining any degree, qualification or otherwise, to this or any other university.

10/09/2017

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Date

Abstract

The primary aim of this research project is to scientifically investigate the impact that climate change has on streams/rivers in selected regions of the Kruger National Park (KNP). Rainfall and stream/river flow data are statistically used to determine the extent to which rainfall events, and in particular, extreme rainfall events, influence flow regimes. The rainfall data obtained for evaluation date back as far as 1911, thus providing a near 100-year record of climate variability and change for the region. Stream/river gauge data date back as far as 1960, thus allowing the analyses of rainfall impacts on streamflow for over half a century. The rainfall data has shown that in some parts of KNP, total annual rainfall is increasing, however, this increase in total annual rainfall is due to the increasing severity of rainfall events. The El Niño Southern Oscillation (ENSO) Is impacting rainfall variability in northeastern South Africa, and thus rainfall events are more sporadic, with longer drought phases. Data has shown a mostly positive correlation between rainfall events and stream/river flow trends. During El Niño years, the rivers of KNP have lower than average flows, and during years of intense rainfall events, stream/rivers have an above average flow trend. Some results have however shown a negative correlation between rainfall events and stream/river flow trends. The literature suggests that this negative correlation is due to additional impacts on stream/river flow such as anthropogenic land activities (Mining, agriculture, forestry). Additional investigation into these impacts can be done through future research. The evaluation of climatic parameters in relation to flow regimes in a protected area is a critical evaluation for the purposes of future projected climate change and hydrological change in the KNP. Management, decision makers and policy planners could use the information obtained from this research to supplement their current water restoration initiatives, and water provisioning objectives, to better manage for the future.

Acknowledgments

My greatest thanks go first and foremost to my supervisor Prof. Stefan Grab, and co-supervisor Dr. Dave Thompson. Their enthusiasm for my project, the hard work they put in to edit my chapters, and for their continuous guidance and understanding was so helpful. The assistance they provided through reading, editing and advising is invaluable.

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Chapter One: Introduction

1.1. Introduction

Global anthropogenic climate change has shown to be the one of the main drivers of ecosystem changes and a threat to natural biodiversity worldwide (Campbell-Lendrum *et al.,* 2007). The average global increase in temperature over the past century has been 0.6 º C, with a further projected 2º C increase in temperature by 2050 (Murray *et al.,* 2012). Future rainfall projections estimate a decrease in global average rainfall by between 10-25%. Changes in climate are also resulting in more frequent extreme events such as droughts and flooding. These extreme changes in climate are directly linked to anthropogenic pressure such as industrialization, deforestation and CO_2 emissions (Campbell-Lendrum *et al.,* 2007). Global climate change has, amongst other effects, led to reductions in freshwater resources, changes in vegetation health, erosion of riverbeds and ecosystem integrity shifts (Markham, 1996). The health and cohesion of river systems worldwide is therefore directly associated with climate change and anthropogenic land-use activities (Palmer *et al.,* 2008).

For example, climate change has substantially affected the Colorado River basin. Over the next century temperatures in the region are projected to increase by an average of 5º C, and rainfall will decrease by between 15-20% (USGS, 2007). Future water stress will be magnified significantly by the increase in human population reliant on this freshwater resource (USGS, 2007). Climate change in the region has also contributed to prolonged drought, resulting in low water flow in the river system (USGS, 2007). An analysis of 20 rivers draining into the Black Sea revealed that there has been a negative or decreasing flow trend since 1960 (Lespinas *et al.,* 2014). In the Yellow River Basin, China, it was observed that from 1956 until present, streamflow has been decreasing due to changes in associated rainfall. It was also exhibited that for the majority of months during the year, there was a decreasing discharge along the Yellow River systems (Zhang *et al.,* 2013). Further, climate change is not only negatively impacting streamflow, but also entire riverine ecosystems including riparian vegetation and freshwater biodiversity (Naiman *et al.,* 1993; Mantyka-Pringle *et al.,* 2016).

More precisely, in northeast South Africa, specifically KNP, projected future climate changes are said to alter rainfall events, and flow dynamics of many rivers encompassing the region (Davis, 2011). Southern Africa is already a water scarce region due to seasonal rainfall events and the semi-arid nature of the environment. Davis (2011) thus emphasizes the importance of understanding these future changes to better understand, and adapt to possible future impacts. Minimum temperatures are projected to increase by between 0.6℃ and 1.16℃ in future (Davis, 2011). The evaporation rate is estimated to increase, posing threats to streamflow in the region, as there will be an increase in water loss in rivers (Davis, 2011). Annual rainfall in this region is estimated to increase by between 85mm and 303mm, with an additional increase in the number of rainfall events. The alteration of the timing, frequency and magnitude of these rainfall/storm events suggest that the risk of flooding in northeast South Africa will increase substantially (Davis, 2011).

An evaluation of the relationship between climate change and riverine dynamics can be extremely valuable if done to include both transformed landscapes and protected areas. The Kruger National Park is a protected area (PA), which, as a study site, can provide streamflow data from human-impacted rivers originating externally from the PA, and relatively undisturbed rivers originating within the park. The comparisons between protected and impacted river systems/catchments will be of benefit in understanding the relative impacts of climate on streamflow and riparian integrity (Roux *et al.,* 2008). KNP is thus an extraordinary natural landscape in which climate change impacts on river systems can be scrutinized.

1.2. Rationale

Climate change is now recognized worldwide (Forman *et al.,* 2008) and is posing a huge threat to the flora and fauna of marine, freshwater and terrestrial ecosystems (Walther *et al.,* 2002). Predicted impacts of future climate change on ecosystems worldwide highlight the importance for further research and monitoring. Global climate change is not only associated with an increase in temperatures worldwide, but also more frequent and prolonged periods of extreme climatic events such as flooding and droughts (IPCC Synthesis Report, 2007). These extremes are already common in southern Africa where the climate is directly affected by both the El Niño Southern Oscillation (ENSO) and rainfall seasonality (Wessels and Dwyer, 2011).

Climate change poses a threat to semi-arid and arid regions in Africa. Southern Africa is highlighted as one of the most susceptible regions to climate change (Masters and Duff, 2011), as projected increases in temperatures for southern Africa will directly influence the hydrological cycle (Arnell, 1999), ecosystem integrity and wildlife biodiversity (Markham, 1996). Even without future projected climate change, large parts of Africa would experience water stress due to increasing populations and economic development (IPCC Climate Change, 2014). However, the influence of climate change in addition to these issues will magnify water stress (Boko *et al.,* 2007). The increasing number of warm periods in southern Africa, coupled with increasing water stress, has resulted in further change in natural ecosystems such as freshwater and coastal environments (Boko *et al.,* 2007).

Rivers are a lifeline for ecosystems in semi-arid regions, such as in the northern KNP (du Toit *et al.,* 2003). Without these freshwater corridors, much local biodiversity would not exist. The protection of rivers and their associated ecosystems has become a popular area of research and management. With the ominous threats of climate change, the increased water extraction rates, and numerous other natural and anthropogenic impacts on river systems, it has become important to i) better understand how river systems are changing; ii) how to plan for these changes (Wang *et al.,* 2006), and iii) accommodate predicted change scenarios into river, catchment and protected area management policies.

Research into climate change impacts on river behaviour will separate the relative roles of the drivers of climate and human land-use activities. The Kruger National Park, situated in the semi-arid savannas of the South African lowveld, presents a unique research opportunity as it provides river systems that originate either beyond or within the PA boundaries, thus removing the direct human influence. The comparison between the two different river systems will allow for a better understanding of how climate alone influences river systems, as well as evaluating the level of impact human land-use activities have on these freshwater ecosystems.

1.3. Aims and Objectives

The aim of this research is to investigate how precipitation patterns influence hydrological flow systems in the Kruger National Park. Rainfall records will be analysed from numerous weather stations located in the river catchments comprising KNP, to generate an understanding of rainfall patterns from the past century to present. Streamflow records, also dating back up to five decades, will be analysed using data from several gauging stations situated within KNP. Changes in rainfall amount and variability will then be compared to streamflow change quantified over the same approximate period.

Objectives:

- To establish and compare rainfall patterns over the past six decades for the KNP.
- To establish streamflow patterns over the past five decades for selected rivers originating within or externally to KNP.
- To compare changes in interannual rainfall variability over the past five decades with changes in interannual streamflow variability.
- To establish the effects of specific climatic phases (El Niño Southern Oscillation) on streamflow in KNP.

1.4. Research Questions

Hypothesis 1: Over the past six decades, rainfall has become more sporadic in the KNP (north to south).

- What are the spatio-temporal rainfall trends adjacent to and within the Kruger National Park?

Hypothesis 2: Inter-annual rainfall variability has a direct impact on inter-annual streamflow variability in KNP.

- What are the spatio-temporal streamflow behaviours in the river catchments of the Kruger National Park?

- What is the relationship between inter-annual rainfall variability and inter-annual streamflow behaviour of the Kruger National Park?

Hypothesis 3: Extreme climatic events have a direct impact on streamflow regimes in KNP, with droughts causing reduced flow levels.

- What scale of impact do extreme climatic occurrences (El Niño) have on streamflow behaviour in the Kruger National Park?

Hypothesis 6: Future rainfall projections will lead to low flow regimes

- Based on available rainfall projection models, what are the likely future scenarios of rainfall and streamflow in KNP?
- How can the outcomes in results from this study aid in planning to adapt to changes in such hydrological resources?

1.5. Structure

To answer the aforementioned research questions this dissertation will unfold as follows:

Chapter two: Outline of study site**:** This chapter presents the setting of the study within the Kruger National Park, with reference to climate, vegetation, geology and river systems.

Chapter three: Literature review**.** This chapter will investigate international and local literature regarding issues of climate change and the impacts changing climate and anthropogenic land cover change are having on streamflow patterns. In this chapter, the primary focus will be to discuss global and local climate change, and its projected impacts on water resources. South African past and future climate trends will be discussed in detail and these trends correlated to significant streamflow research done globally and locally. The El Niño Southern Oscillation will be discussed as South Africa experiences this extreme climatic event, which results in water scarcity for a short-term period. Chapter three will finally look at how dam constructions influence fluvial systems and their downstream flow trends. This literature review also examines management implications for a changing streamflow trends in a protected area such as the Kruger National Park.

***Chapter four: Methodology*.** This chapter outlines the data sets used for the investigation of this study as well as the statistical methods used to investigate trends and patterns in the long-term data. Methods and statistics implemented in similar studies will be employed and explained in detail to gain a better understanding of how the statistics develop trends in the data, and form relationships between variables.

Chapter Five: Results. This chapter consists of two sections, the first being the rainfall results and the second being the streamflow results, which will also incorporate the relationship between rainfall and streamflow. The main findings from this research are depicted in this chapter. A basic outline of the trends found in the data are explored, and then a more detailed interpretation of these results and findings is explored in further detail with the use of statistics.

Chapter Six: Discussion. This chapter discusses the findings from chapter five in much more detail, as well as linking findings to literature explored in chapter three. The research questions are answered with an explanation of how the findings are related to the aims and objectives highlighted in Chapter one. Methodology limitations or challenges are explored in this chapter, and finally, implications of results and projected future changes of rainfall and streamflow are explored.

Chapter Seven: Conclusions. This chapter provides a summary of the dissertation, outlining key findings and drawing conclusions for management implications in KNP, given the findings of trends over the past decades. Knowledge gaps and future research potentials are highlighted in this chapter.

Chapter Two: Study Region and Environmental Setting

2.1. Introduction

The goal of this research is to understand the impact rainfall events have on streamflow in the Kruger National Park. What follows in this chapter is a description of the greater study region – being the Kruger National Park (KNP), and associated catchments to the west, with specific mention of climate impacts on flow.

Many of the rivers originate within the Drakensberg escarpment, and thus both bushveld and lowveld rainfall patterns will be explored in this dissertation (*Figure 2.1*). Weather stations are in and adjacent to the KNP, and within the highland catchments to the west of the park. The rivers investigated include (from north to south) the Luvuvhu, Mutale, Shisha, Shingwedzi, Tsendze, Letaba, Olifants, Timbavati, Nwanedzi, Sand, Sabie, Nsikazi, Crocodile and Komati (*Figure 2.2*).

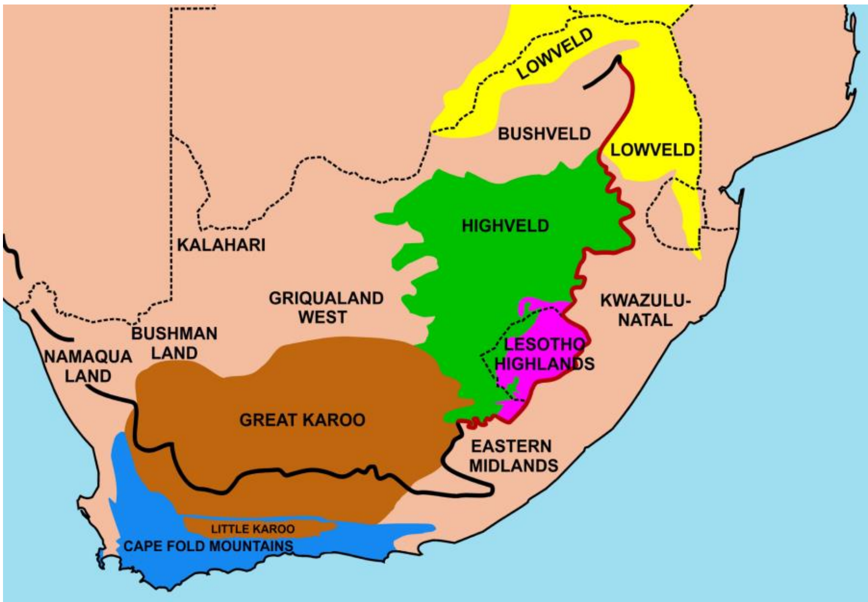


Figure 2.1 Geographical regions of South Africa (Oggmus, 2014 Sourced from: http://creativecommons.org/licenses/by-sa/3.0)

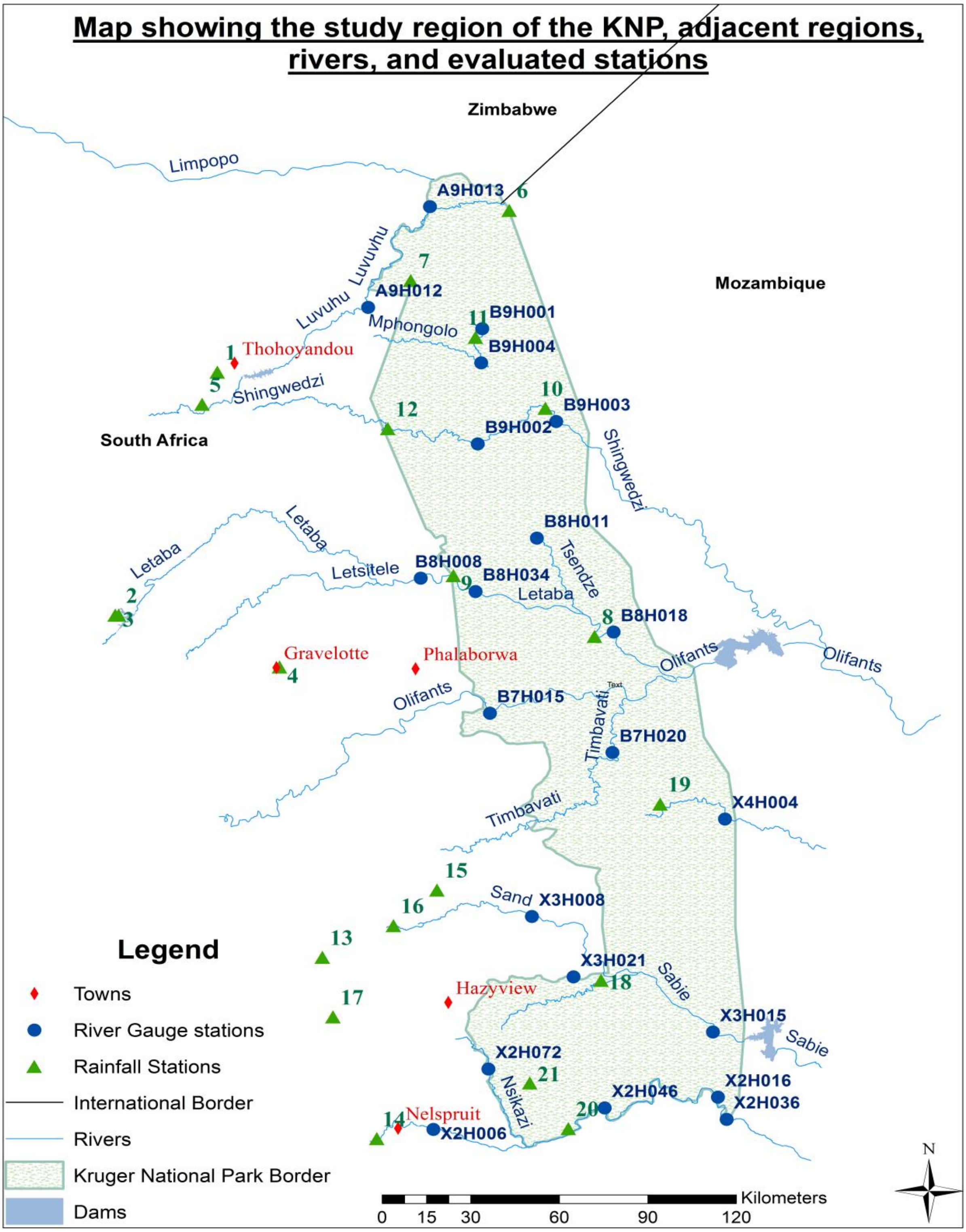


Figure 2.2 Rainfall and river stations in and adjacent to Kruger National Park

2.2 Geography

The Kruger National Park (KNP) is situated in the low-lying savannahs of northeastern South Africa (*Figure 2.3*) and borders Zimbabwe and Mozambique (Pollard *et al.,* 2011). KNP spans 350km from north to south, and 60km from west to east (Plak, 2013) and is bounded by the Crocodile River in the south, the Limpopo River in the north, and the Lebombo hills to the east (du Toit *et al.,* 2003). The area covered by KNP is approximately 19 663km^2 (~2 million hectares), protecting an array of different animal, plant and bird species (Braack, 2006).

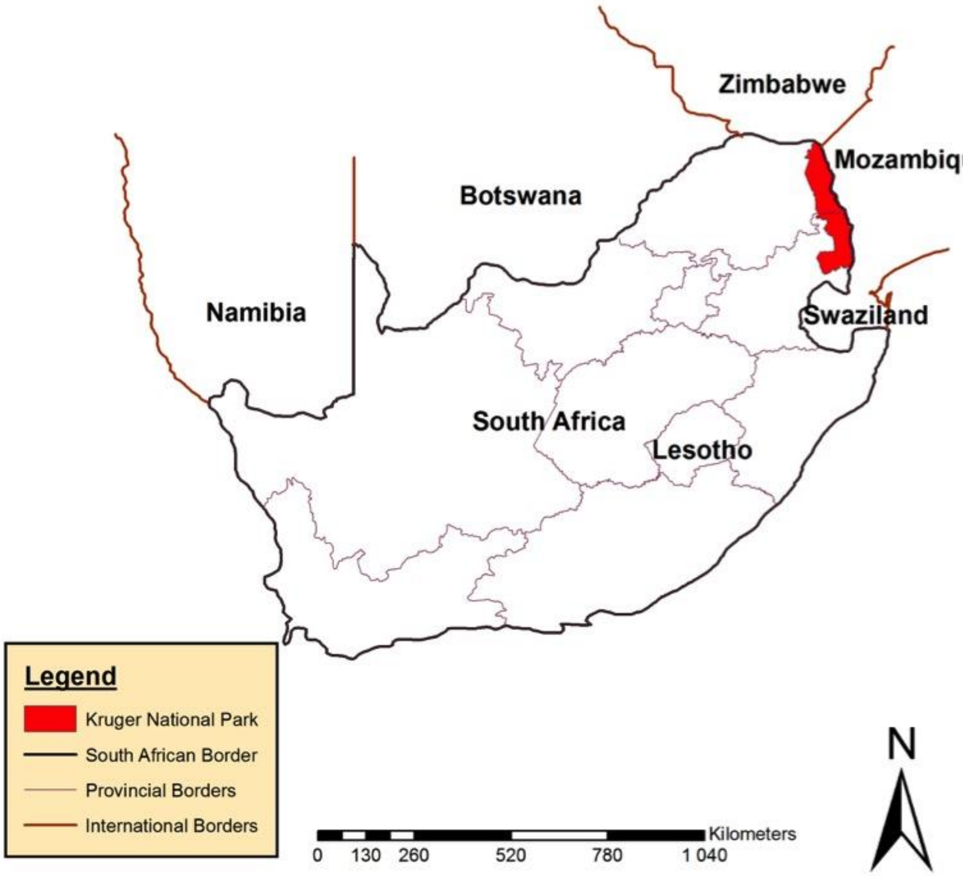


Figure 2.3 Location of KNP in South Africa

2.3 Background of the study site

The Sabie Game Reserve was established in 1902 under the management of game warden James Stevenson-Hamilton (Eckhardt *et al.,* 2000). The park was in the lowveld region, situated between the Crocodile River in the south and the Letaba River in the north. In 1903, the Shingwedzi Game Reserve was established and managed by Stevenson-Hamilton. This game reserve was located north of the Sabie Game Reserve and was bounded by the Letaba River in the south and the Limpopo River in the north (Joubert and Van Gogh, 2007). The establishment of these parks was primarily aimed at the protection and conservation of wildlife, with the notion that these parks would hinder the issue of uncontrolled hunting in the area (Van Der Merwe and Saayman, 2008). On the 31st of May 1926, it was proclaimed that the Sabie Game Reserve and the Shingwedzi Game Reserve would be merging into the first South African National Park (Eckhardt *et al.,* 2000), which was later named the Kruger National Park. The KNP was officially opened to tourist visitors in 1927 (Munyati and Ratshibvumo, 2010), and since then, the park has developed a tourism base of around one million visitors per annum (Chaminuka *et al.,* 2012), rating this park as one of the top five international tourist destinations for tourists in South Africa (Van Der Merwe and Saayman, 2008).

The management of KNP prides itself on a relatively 'hands-off' approach, encompassing management through research and monitoring (Freitag-Ronaldson *et al.,* 2008). KNP is one of the most researched national parks in the world (Braack, 2006), and includes research-monitoring areas encompassing climate change, water distribution and other major ecosystem processes (Braack, 2006). The KNP is known for its good management practices, its variety of different flora and fauna, and its impressive habitat diversity (du Toit *et al.,* 2003). The high level of biodiversity encompassing the KNP is due to the heterogeneity of the park's geology, vegetation, wet-dry cycles and fires (du Toit *et al.,* 2003).

2.4 Climate

The KNP has a characteristically subtropical climate, which varies in temperature and precipitation throughout the year (Scogings *et al.,* 2015). The general climatic conditions for this region vary from hot and humid summers, to dry and mild winters (Venter and Gertenbach, 1986). Southern Africa's geographic location, steep orography, oceanic surroundings and atmospheric dynamics mean that the subcontinent is prone to great interannual variability of the hydrological cycle (Fauchereau *et al.,* 2003), consequently also affecting the lowveld region of the KNP.

During the summer months, the interior of South Africa, as well as the region covered by the KNP, experiences a low-pressure cell over the interior, thus attracting warm moist air from the Indian Ocean, which in turn promotes the development of thunderstorms (Venter and Gertenbach, 1986). The winter months, however, are characterised by mild and dry conditions over the interior of southern Africa (Roux *et al.,* 2008). Rainfall patterns specifically for the lowveld of SA, and KNP will follow.

2.4.1 Rainfall

The KNP has a rainfall gradient, with long-term rainfall amounts ranging from 350mm in the far north of the park, to 750mm in the south (Gertenbach, 1980) (*Figure 2.5*). The rainfall also varies from west to east, with the western highveld region adjacent to the park receiving as much as 1200mm per annum along the escarpment (*Figure 2.4*), yet this is reduced to 500mm per annum along the eastern boundary of the park (Shackleton, 2000). Rainfall in the KNP is highly variable even at the local scale, with patchily distributed rainfall events occurring sporadically as short intense events, usually during afternoons (Braack, 2006). For the purposes of this research, rainfall trends for the bushveld region, located adjacent to the lowveld region, will be analysed to compare rainfall patterns of the two regions. Many of the rivers draining the KNP originate outside the park boundary in the bushveld and as far as the escarpment, and it is thus important to understand these higher altitude rainfall patterns as they directly impact KNP river/streamflow.

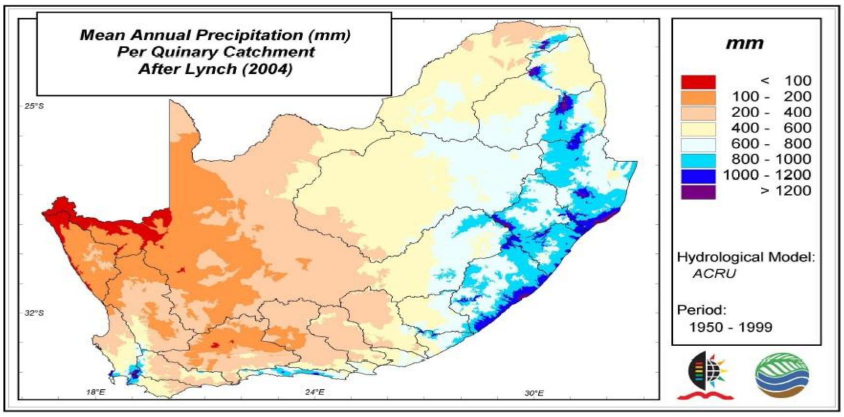


Figure 2.4 Mean annual precipitation map of South Africa (Schulze, 2011).

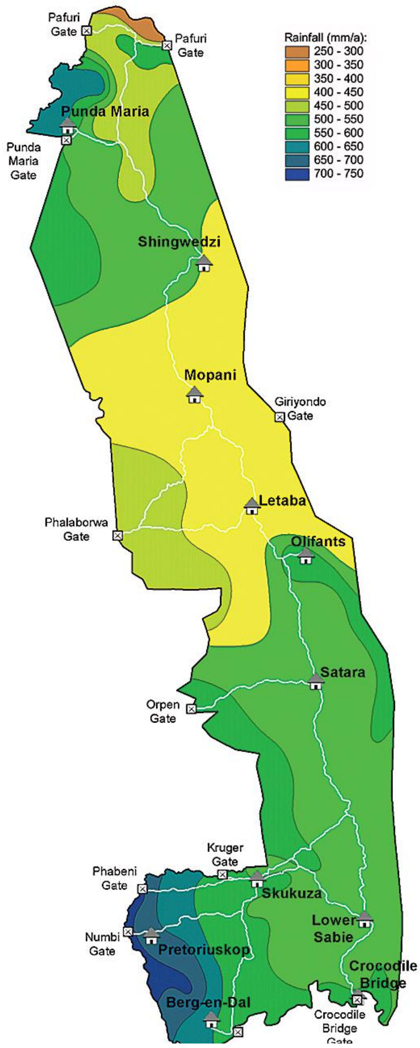


Figure 2.5 Mean annual precipitation of KNP (Siyabona Africa, 2017 Sourced from: http://birding.krugerpark.co.za/birding-in-kruger-rainfall-in-kruger.html).

2.4.2 Temperature

During the austral summer months, maximum daily temperatures range between 21ºC and 40ºC, and temperatures may even exceed 40ºC during extreme conditions (Schutze, 2002). In contrast, during austral winter months, temperatures remain fairly moderate (approx. 6ºC to 26ºC) (Renssen, 2007), with very little chance of temperatures dropping below freezing (Venter and Gertenbach, 1986).

2.4.3 Extreme climatic phenomena

Southern Africa is a region directly affected by the El Niño Southern Oscillation (ENSO) (*Figure 2.6*). ENSO is a natural weather phenomenon that varies every three to seven years (Gupta, 2011). ENSO varies between El Niño, La Niña and neutral weather conditions (McPhaden *et al.,* 2006). ENSO events take place when Sea Surface Temperatures (SST) and winds across the equatorial Pacific Ocean fluctuate (McPhaden *et al.,* 2006). An El Niño event occurs when the easterly equatorial winds are lighter than usual, resulting in warmer SST in the Central Pacific Ocean. La Niña occurs when the easterly pacific winds are stronger than usual, causing a cooling effect of SST in the Central Pacific Ocean (Fewsnet, 2014). Changes that occur within the Central Pacific Ocean therefore cause fluctuating climate occurrences across the world. In southern Africa, and more specifically the KNP, El Niño causes reduced rainfall and drought conditions. It has been highlighted that during phases of El Niño, the most affected areas include south/central Mozambique and the KNP (Wessels *et al.,* 2007).

ENSO has been mentioned as the primary driver of interannual rainfall variability in the KNP (Wessels *et al.,* 2007; Wessels and Dwyer, 2011). Research has shown that there is a strong relationship between ENSO phases and the occurrences of flooding and prolonged periods of drought (*Figure 2.6*). Some of the most devastating droughts that occurred in this lowveld region during recent times include the droughts of 1991-1992; 1997-1998 and 2002-2003 (Kovats *et al.,* 1999; Sivakuma *et al.,* 2005; Kovats *et al.,* 2003; Wessels and Dwyer, 2011) and most recently the drought of 2015-2016 (Null, 2017). La Niña on the other hand, has led to periods of continuous rainfall, and strong rainfall events, which have resulted in flooding events and high vegetation growth during the most notable years of 2000 (Mzezewa *et al.,* 2010) and 2012 (Riddell and Peterson, 2013).

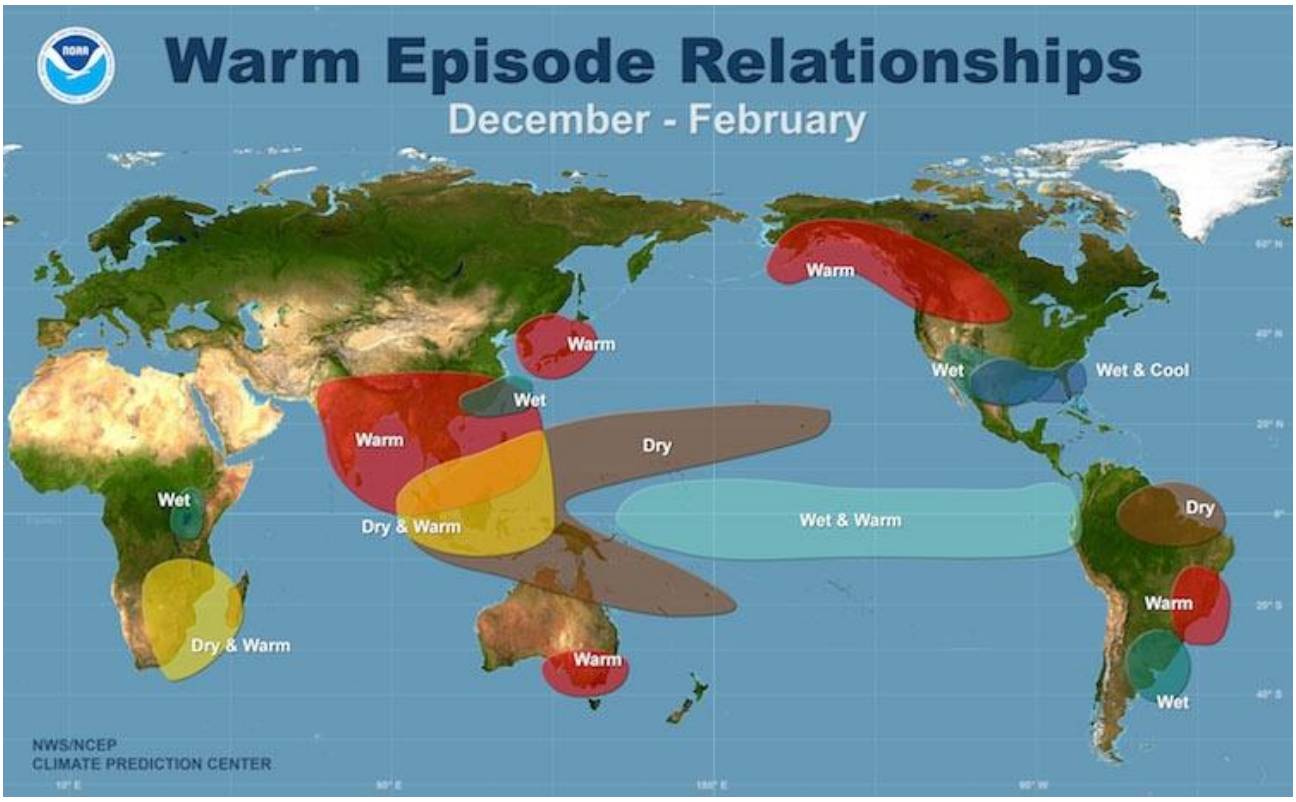


Figure 2.6 Effects of El Nino on different parts of the world Sourced from: http://www.vox.com/2014/11/8/7177709/el-nino-2014-forecast-weakening

2.5 Rivers

The Kruger National Park comprises of many rivers and tributaries. There are six major perennial rivers that flow through the KNP, which include the Crocodile River; representing the southern boundary of the park, the Limpopo River; forming the northern boundary of the park, and the Luvuvhu, Letaba, Olifants and Sabie Rivers (Eckhardt *et al.,* 2000). These main river systems originate outside the KNP boundary, and thus flow through an array of different landscapes before flowing into and through the park (Venter and Deacon, 1995). Consequently, these major rivers and their numerous tributaries suffer substantial anthropogenic impacts (Braack, 2006; Fouche and Vlok, 2012). Due to anthropogenic and climatic impacts, many of these previously perennial rivers are now of a non-perennial nature (Roux *et al.,* 2008), causing great concern for the wellbeing of flora and fauna dependent on these water corridors for survival and habitat (Venter and Deacon, 1995; Roux *et al.,* 2008).

The main demand for water in these rivers is primarily from anthropogenic activities such as agriculture and industry (Pollard *et al.,* 2011). Additionally, the demands for fresh water from mining and afforestation practices have left these rivers with severe water shortages (Pollard *et al.,* 2011). Changes to these river systems have been apparent since the 1960's (Pollard *et al.*, 2011), and this progressive degradation in quantity poses threats to flora and fauna downstream (O'Keeffe and Davis, 1991). The first major insight into the deterioration of these rivers occurred 54 years ago when the previously perennial Letaba River became non-perennial in flow (Pollard *et al.,* 2011). In addition, noticeable decreases in flow, and increases in flow variability were observed in the Olifants and Luvuvhu rivers in the 1960s (Pollard *et al.,* 2011).

2.6 Flora and Fauna of the Kruger National Park

The Kruger National Park is host to a large variety of animal, bird and plant species, which is due to the great variety of habitats, each supporting its own unique vegetation and ecological characteristics (Schutze, 2002). In terms of species variety, research has shown that KNP protects over 2000 plant species, of which 400 are trees/shrubs and over 220 grasses (Eckhardt *et al.,* 2000). There are currently 507 different bird species, 147 mammal species, 114 reptile species, 49 fish species and 34 amphibian species (Schutze, 2002). The huge variety of different flora and fauna is one of the main reasons this park attracts over one million tourists annually (Chaminuka *et al.,* 2012).

2.7 Underlying geology and soils

The exceptional diversity of vegetation found within KNP owes itself to the great variety of rock and soil types (Venter, 1986). The role of soil properties in this protected area is of great importance considering the park's semi-arid environment, and thus factors such as soil depth, texture, structure and nutrient capacity are vital in sustaining and supporting the diversity of the KNP ecology (Venter, 1986).

The KNP has two main underlying geologies; basalt and granite (Venter *et al.,* 2003; Viljoen, 2015) (*Figure 2.7*). The entire eastern part of KNP, the basalts, is underlain with sedimentary and volcanic rocks of the Karoo Supergroup, whilst the western KNP is largely made up of granite and greenstone rock formations (Viljoen, 2015). On the far western region of the park, underlying geology comprises red sandstones. A band of sedimentary rock divides the two geological zones. These different geological zones are responsible for the distribution of vegetation in the park (Venter *et al.,* 2003).

The vegetation of the KNP owes itself to the differing climatic conditions as well as the different types of underlying geology (Viljoen, 2015). In southwest KNP, high rainfall totals paired with deep sandy soils has allowed for the growth of dense savannah trees, and mixed Bushwillow woodlands. In the river valleys of western KNP, the sandy soils become much shallower than they are at higher elevations (Viljoen, 2015). Stony shallow soils are present in many regions of KNP, which are characterised by hilly/steep topography. These stony shallow soils support the growth of large trees, for example, the rock fig tree found in the Berg-en-Dal area (Viljoen, 2015). The soils found in the Lebombo mountain region are characteristic of stony, rocky soils. These rocky soils support the Red Bushwillow mountainveld (Viljoen, 2015). In eastern KNP and regions of the Timbavati gabbro, the soil is characteristically deep and clayey (Viljoen, 2015). Deep clay soils support open tree savannah vegetation, and many pans and wetlands are present in these regions as the soils have poor drainage (Viljoen, 2015).

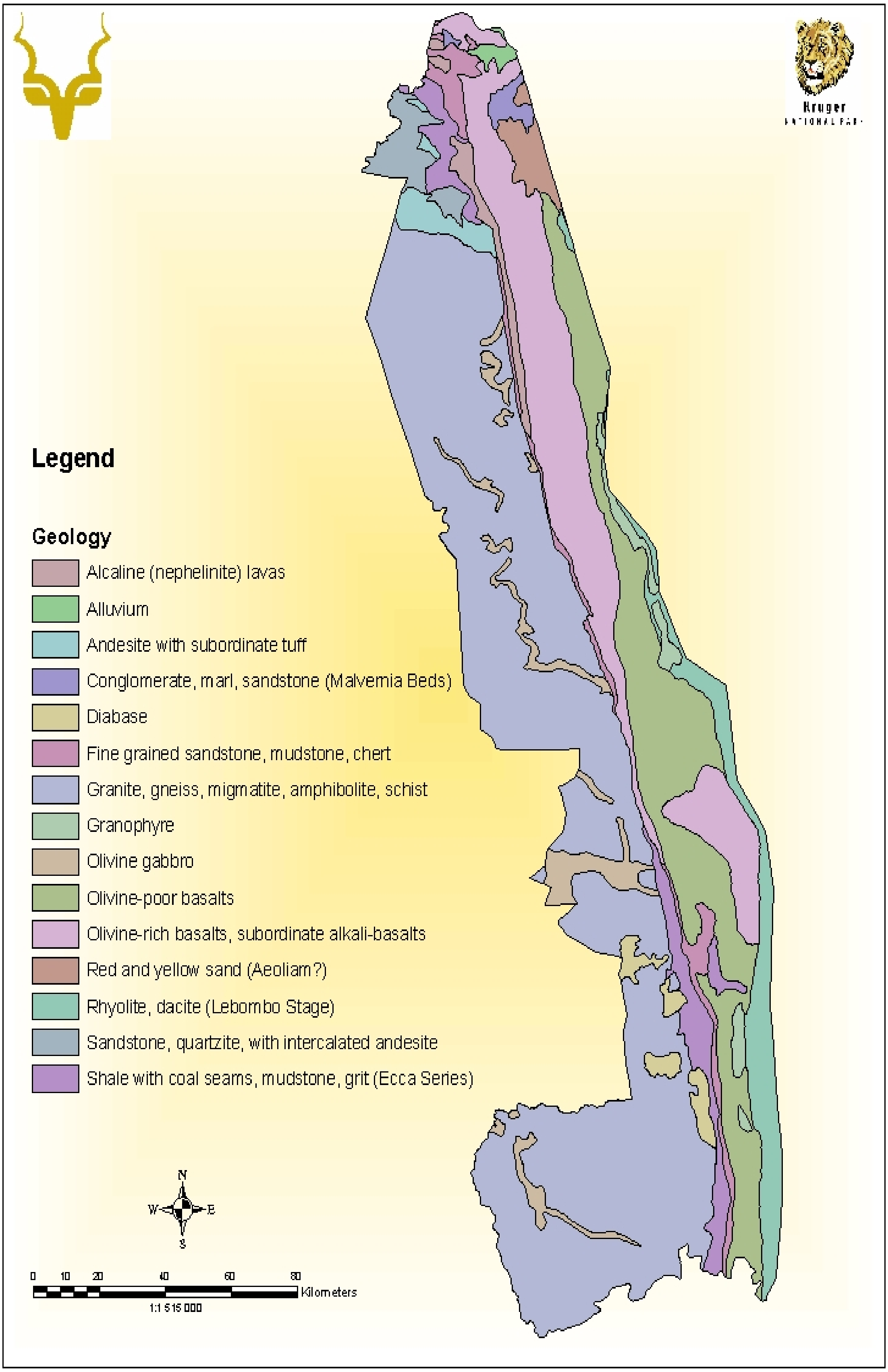


Figure 2.7 Underlying KNP geology (SANParks, 2013)

2.8. Vegetation

One of KNP's greatest assets is its great variety of vegetation (*Figure 2.8*). The diverse vegetation not only provides food and nutrients to many animals, it additionally provides a wide range of habitats, which form the basis for the distribution of most animal populations (Venter and Gertenbach, 1986). The vegetation of the KNP, Limpopo and Mpumalanga has substantially variable vegetation classifications (Schmidt *et al.,* 2002). The primary reasoning behind such variable vegetation types is due to the diverse topography of the region, and differing underlying soils, nutrients and rainfall (Ekblom *et al.,* 2012).

Changes in flow patterns such as intermittent flow, initiated by dam constructions, or decreased flow due to increased extraction of water for anthropogenic activities will have a direct impact on riparian vegetation (Vale *et al.,* 2013). Decreased downstream flow due to dams will cause riparian vegetation fragmentation, which directly impacts faunal species reliant on this vegetation for habitat and food sources (Vale *et al.,* 2013).

Although riparian vegetation fragmentation is not explored in this research, the patterns depicted for rainfall and river/streamflow over time will allow for further research into how these changes in climate and flow regimes are impacting KNP riparian vegetation, and how these changes are impacting flora and fauna of the park.

2.9 Environmental Issues

One of the greatest environmental concerns facing the KNP are those of water scarcity and quality of the rivers that flow through the park (Pollard *et al.,* 2011). Extreme climatic events and the ever-increasing anthropogenic impacts on river systems originating from outside the park boundary are of great concern (Wessels *et al.,* 2007). One of the parks' major objectives is to ensure the regular and healthy flow of water entering the park (Pollard *et al.,* 2011). To manage and protect these freshwater resources, management and monitoring of the freshwater areas needs to occur beyond the protected areas. Management needs to occur upstream in order for downstream river conservation to be successful (Kingford *et al.,* 2011).

Another major concern facing the KNP management and conservation initiatives is the increasing land degradation occurring west of the park. Anthropogenic land use, including agriculture, mining, urbanisation and forestry has led to increased water extraction, dam construction and water pollution of rivers that enter the KNP (Savaira-Okello *et al.,* 2015). Approximately two million people live within 50km west of the KNP boundary in unprotected areas, which means many of the rivers that flow through the park are being heavily exploited upstream (Pollard *et al.,* 2011).

Chapter Three: Literature review

3.1 Introduction

Climate change is a phenomenon that is now accepted worldwide (IPCC, 2012), and is currently recognised as an occurrence that is causing negative impacts in many difference facets of life, including economies, society and the environment (Adger *et al.,* 2003; Beniston, 2010; Moerlein and Carothers, 2012). Climate change is a natural cycle that has now been drastically enhanced by anthropogenic factors (Leemans and van Vliet, 2005; Knutson *et al.,* 2010). Anthropogenic emissions of greenhouses gases have led to worldwide temperature increases which has consequently resulted in significant changes in physical and biological systems in the environment (Rosenzweig *et al.,* 2008). The three most key environmental outcomes related to climate change include (1) rising sea levels, (2) a shift in climatic zones and, (3) an increase in the number of severe climatic events (Rowlands, 1998). Climate change has been reviewed in many world-renowned reports including the Intergovernmental Panel on Climate Change (IPCC), and is a phenomena that has been cited by countless researchers and scientists globally (IPCC, 2001). The United Nations Framework Convention on Climate Change (UNFCCC) recognises the urgency by which anthropogenic climate change needs to be mitigated, and thus frameworks have been developed to allow for countries throughout the world to reduce CO_2 emissions.

The growing awareness on global climate change and the impacts these changes are having on the environment has prompted the formation of the International Panel on Climate Change (IPCC, 1991; Bolin, 2007). The IPCC is a scientific body made up of international researchers and governmental officials who aim to raise awareness about climate change impacts and allow for the communication and increase in scientific knowledge in and around climate change (Bolin, 2007). This panel is the leading international body for the assessment of climate change and was established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO). The IPCC ultimately allows for the discussion of mitigation and adaptation strategies for environmental, economic, biological and social impacts brought about through climate change (IPCC, 1991; Bolin, 2007).

The establishment of the IPCC played a major role in the development of the United National Framework Convention on Climate Change (WMO, 2007). The UNFCCC is an international environmental treaty that was established in 1994, as an agreement that mitigation efforts and controls on anthropogenic climate change needed to be implemented worldwide (WMO, 2007). Key leaders from 195 countries thus took it upon themselves to sign this agreement and implement urgent steps towards controlling anthropogenic climate change (UNFCCC, 2014a). One of the most successful protocols that branched from this treaty was the Kyoto Protocol established in 1997 (UNFCCC, 2014b).

With the implementation of these treaties and the constant communication between countries through environmental conventions and panels, it is hoped that the mitigation and control of climate change will soon be felt. Anthropogenic climate change is exponentially increasing temperatures, making rainfall trends more variable and leading to the destruction of the physical, biological and social facets of earth (McMichael *et al.,* 2015). According to Naiman *et al.* (2008), if the impacts of climate change are not soon mitigated, many of the world's habitats and its occupants will cease to exist.

The African continent is particularly vulnerable to climate change as its ability to adapt to a changing climate is low (Kusangaya *et al.,* 2013), with southern Africa being mentioned as the most vulnerable region on the African continent (IPCC, 2007a). If the observed changes in climate over the past few decades continue at its present rate, the impacts on southern African natural resources will increase in magnitude and severity (IPCC, 2007a), with freshwater resources being severely impacted.

This chapter reviews the current literature concerning global climate change and how it has, and is, expected to impact the global hydrological cycle worldwide. This chapter will ultimately focus specifically on climate change impacts on streamflow in the Kruger National Park, South Africa.

3.2 Climate Change

3.2.1. Global Climate Change

The earth's climate is a complex system that is made up of the interaction of numerous subsystems that include the atmosphere, oceans, biosphere, land surface and cryosphere (Barry and Chorley, 2010). The earth's climate is critical for both the development of the human species as well as for the development of flora and fauna (Mozell and Thach, 2014). Current global climate change suggests that the earth's average temperature is increasing, thus classifying itself as global warming. The climate isn't just experiencing increased atmospheric temperatures, but research also suggests that oceanic temperatures are also on the rise (Mozell and Thach, 2014). Anthropogenic activities have heavily influenced average global temperatures and have initiated an advanced rate of global climate change trends (Kharseh *et al.,* 2015). The burning of fossil fuels, deforestation, the removal of natural carbon sinks, the use of landfills and land degradation are all anthropogenic activities that have contributed to increased levels of greenhouse gases, and increased global temperatures (Kharseh *et al.,* 2015).

The average global temperature has risen by between 0.6- 0.74^0 C over the past century (Li *et al.,* 2011; Naidu *et al.,* 2015), with 66% of that increase occurring between the years of 1960 and 2010 (Mozell and Thach, 2014) The global average temperature is expected to rise by an additional 1.1-6.4^{0}C by the year 2100 (Li *et al.,* 2011). This global warming trend is indicative of an accelerative tendency, which means that temperatures will increase if mitigation efforts are not implemented to decrease anthropogenic climate change (IPCC, 2007a). Not only have atmospheric temperatures increased, but the rise in sea surface temperatures have led to the thermal expansion and melting of glaciers (IPCC, 2007a). The decrease in global ice cover, and the melting of glaciers has led to the 1.8mm/yr. rise in sea level (IPCC, 2007a). To manage these eminent threats to global temperature changes, the primary cause of global warming needs to be managed, namely the greenhouse effect (Venkataramanan, 2011). The threats posed to this planet are concerning, with a statement made my Mozell and Thach (2014: 82) claiming that “even at the lowest rise, the planet faces serious, if not catastrophic results.”

3.2.2 Global Climate Change Impacts

Climate is commonly referred to as the average weather occurrences for a area. The factors that are included under the term ‘climate’ are rainfall, temperature and wind indices (IPCC, 2007b). According to the IPCC (2007) report, climate timeframes are typically measured over a period of weeks and months, but can typically spans over 30 years. The impact that a changing climate can have on the earth’s ecosystems is large. The IPCC (2012) asserts noticeable changes in the frequency and intensity of extreme weather phenomena over the past six decades. It is, however, important to note that some regions of the world have detected a decrease in the frequency and intensity of extreme climatic events (IPCC, 2012). Climate change research is particularly challenging at both regional and global scales as the constant changes in land use, population growth, urbanisation and inadequate instrumental records of flood events make it difficult to record and monitor changes in extreme events. The evaluated changes in climate over the past few decades have allowed for scientists to project future changes in climate, thus allowing for the predication of future changes in environmental and social systems. The more rapidly the climate changes globally, the more extensive and detrimental these impacts will be (Knutson *et al.,* 2008). Systems in which climate changes will influence will be discussed further.

A changing climate can bring about changes in the earths physical, biological and social landscapes (*Figure 3.1, Table 3.1*). For example, a changing climate can impact streamflow dynamics, groundwater resources, or even an entire wetland ecosystem (Vorosmarty *et al.,* 2000). Climate changes can impact primary sectors such as agriculture and forestry. Changes in climate phenomena can affect crop growth, which in turn affects the annual average income through agriculture (Fischer *et al.,* 2005). Not only will a decrease in agricultural production harm the income of a country, it will also lead to devastating social impacts on food security, with eminent risks of hunger and malnutrition (Fischer *et al.,* 2005).

Climate Change: Health Impact Pathways

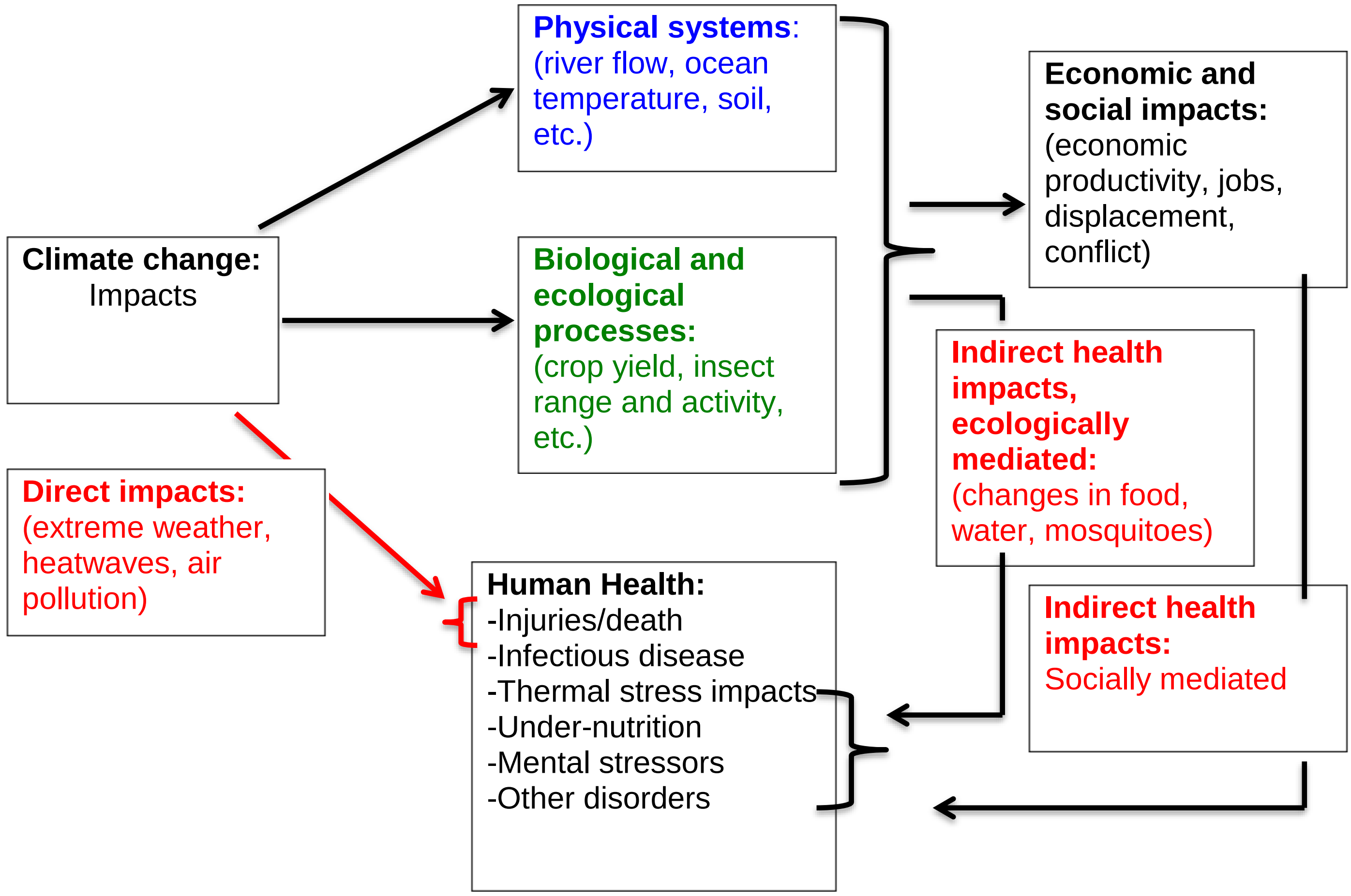


Figure 3.1 Climate change impacts on physical, biological and social systems

(after McMichael *et al.,* 2015)

Table 3.1 Outline of Observed Changes in Global Extreme Climatic Events (Adapted from UCSUSA, 2014)

Extreme Event	Associated Changes	Regions Where Prevalent
Accelerated sea level rise	Increased coastal flooding to low lying communities and coastal properties	Globally
Longer wildfire seasons	With earlier snow melts due to temperature rises, forests stay hotter and drier for longer, leading to prolonged fire seasons	North America
More frequent and intensive heat waves	Increases in temperatures lead to hotter days which can lead to detrimental health issues such as heat stroke and heat exhaustion	Most regions (not all)
Heavier precipitation and flooding	Risks to water side communities, water contamination infrastructure damage	Globally
More severe drought	Crop damage, food and water scarcity, hunger and malnutrition	Europe and West Africa
Increased pressure on groundwater resources	More groundwater will be pumped in order to meet the demands in regions where temperature increases and rainfall decreases have depleted surface water resources	Southern Africa, North America, Australia
Changing seasons	Hotter and drier conditions for longer, Premature snow and ice melt, Vegetation and soils dry out prematurely, more wildfire events	Northern Hemisphere
Melting glaciers	Increasing temperatures are melting the glaciers faster than the new snow/ice can replenish them	Arctic and Polar regions
Increase in tropical cyclone frequency and occurrence	More severe and prolonged periods of intense rainfall. Damaging to infrastructure.	Global

3.2.2.1 Physical Landscape Consequences of Global Climate Change

The changes in climate, be it over a few years, a decade or a century, may impact on physical landscapes. Physical landscapes that are typically affected by climate change include rivers, lakes, oceans, soils, wetlands, agriculture, conservation landscapes and forests (Davis *et al.,* 2010; McMichael *et al.,* 2015), to name a few. For example, climate change can alter hydrological systems in many ways. Intensive rainfall can lead to the flooding of a river system, whereas prolonged periods of drought could dry up a once perennial river system (Kleynhans, 1996). These changes in a hydrological system may thus initiate a chain reaction, which will lead to the alteration of many organisms and biota that depend on these hydrological systems for survival and habitat (Naiman *et al.,* 2008).

Lakes are substantially affected by climate change (Vincent, 2009). When air temperatures and precipitation amounts are altered, a lake will respond to these changes in their physical, biological and chemical characteristics (Vincent, 2009). The physical effects of climate change on lakes include changes in erosion rates, which alter their inflow and outflow dynamics. Changes in precipitation could lead to the alteration of the volume of water in a lake, which in turn will have consequences for the biodiversity of the lake (Vincent, 2009). Altered precipitation and evapotranspiration could lead to the alteration of lake geochemical properties. A change in the amount of rainfall experienced in a region could lead to dissolved oxygen and dissolved organic matter content of a lake. In the Northern Hemisphere, increased temperatures will also result in the additional melting of ice in some lakes. For example, the Great Lakes in the USA, melting of this ice will lead to threats for the reproduction of certain fish species. Changes in lake temperatures will cause a displacement and relocation of some fish species, which prefer cooler waters (Kling *et al.,* 2003).

Additional physical landscapes that will be altered under the current climate change impacts include wetlands, streams and forests (Kling *et al.,* 2003). Increased intensity of rainfall events will lead to increased magnitude and frequency of flooding events. Reduced annual rainfall amounts will deplete groundwater resources, resulting in the drying up of wetlands. The climate induced shrinking of streams and wetlands will lead to a loss in biodiversity of organisms that rely on these systems for food and habitats (Kilng *et al.,* 2003).

3.2.2.2 Biological Consequences of Global Climate Change

The major aim for scientists studying climate change influences on the earth's biota, is to distinguish how specific changes in the earth's climate will influence the physiology, phenology, distribution and adaptation of different flora and fauna (Hughes, 2000). Changes in climate over recent decades has led to awareness that conservation planning and practice needs to incorporate rapid climate change as a threat to all biodiversity (Kittel, 2015). Changes in these characteristics of biota would ultimately alter their competitiveness and interaction with other species, which in turn alters their local abundance and geographic ranges (Hughes, 2000). The main drivers for shifts in biodiversity are rainfall and temperature indices. Temperature is more likely to affect landscapes at higher elevations whereas at lower elevations, changes in rainfall can lead to increased habitat loss (Sekercioglu *et al.,* 2012).

Over the past few decades, climate change has been mentioned as one of the main drivers for shifts in abundance and distribution of thousands of species (Thomas *et al.,* 2004), as well as being one of the main drivers for the modification of ecosystem health, structure and function (Davis *et al.,* 2010). Climate change has also been mentioned to be the biggest drivers of species-level extinction (Thomas *et al.,* 2004). Anthropogenic land use changes are additionally placing pressure on numerous ecosystems, which is also contributing to habitat and species loss. Recent studies have shown that climate change could be so detrimental to biodiversity loss, that it could even surpass anthropogenic habitat destruction as the greatest threat to biodiversity over the next few decades (Leadley *et al.,* 2010).

Climate change leads to the relocation of species as well as less desirable areas/habitats for species to survive in. A decrease in geographic ranges can cause a decrease in genetic diversity (Botkin *et al.,* 2007). Koh *et al* (2004) concluded that out of a study of 9650 interspecific systems (which included parasites and pollinators), 6300 species could disappear following the extinction of their associated species. Climate change alters biodiversity as increases in temperatures and decreases in rainfall events are leading to changes in water supply and food resources. Shifts in phenology have caused detrimental outcomes for both animals that survive on these plant species, as well as their pollinators (Bellard *et al.,* 2012). Changes in vegetation and regional habitats are suggested to grow so substantially, that there will be changes brought to an entire biome.

In South America, studies have suggested that the tropical rainforests will be replaced by tropical savannah (Lapola *et al.,* 2009). By 2050, 16% of Europe will experience a loss in over half its local species (Bakkenes *et al.,* 2002; Bellard *et al.,* 2012), and globally, 15-37% of species will be committed to extinction following the effects of global climate change (Thomas *et al.,* 2004). Through mapping the outcome for the worst-case scenario, it has been concluded that between 39-43% of species could face extinction, with a total loss of 56000 plant species and 3700 vertebrate species (Malcolm *et al.,* 2006). The IUCN used data from 9856 birds, 6222 amphibians and 799 coral reefs and determined that approximately 35% of the world's birds, 52% of amphibians and 71% of coral are susceptible to climate change, which suggests that many species will be facing endangerment or even extinction within the next few decades (Foden *et al.,* 2008). Overall, numerous studies worldwide have shown that by the year 2100, the estimated mean extinction rate for different taxa will be 12.6% for plants, 9.4% for invertebrates, and 17.7% for vertebrates (Bellard *et al.,* 2012).

3.2.2.3 Social Consequences for Global Climate Change

Climate change not only affects the physical and biological landscapes of the planet, it has also brought about negative impacts to the social and economic structure of the world. Examples of ways in which society is being negatively affected by climate change includes sea level rise, more variable and intense precipitation events, more frequent flooding and landslides, prolonged periods of drought, food and water scarcity, displacement and livelihood impacts (Gasper *et al.,* 2011).

Extreme climatic events such as massive thunderstorms or cyclones can lead to damage of property and infrastructure of a community. Prolonged periods of intense rainfall lead to flooding, which results in damage and loss of life. Severe flooding through intense precipitation events has affected cities including Rio de Janeiro, Kampala City, New York, Los Angeles, Bangkok, Ho Chi Minh and Lagos to name a few (Gasper *et al.,* 2011). Prolonged periods of drought lead to food and water scarcity, which has been noticeable in large cities such as Durban (South Africa), Delhi (India) and Mombasa (Kenya). The issue of food insecurity and water scarcity is predicted to only get worse over the next decade as climate change is expected to worsen and lead to increasing numbers of people facing hunger and malnutrition. This is particularly worrying for developing countries (Davis *et al.,* 2008). Sea level rise brought about due to climate change is posing a threat to many coastal communities such as Mombasa, Tunis, Casablanca and Bouregreg. These communities face the risk of displacement and relocation due to threats of flooding. Sea level rise also poses a threat to the spread of disease through water contamination. (Gasper *et al.,* 2011).

In several regions of South Africa, climate change is threating social aspects. Poorer communities relying heavily on natural resources are most vulnerable to changing climates. These communities have become dependent on natural resources such as wood, freshwater resources, wild fruit and herbs for their survival (Davis *et al.,* 2010). With treats of water and food scarcity looming in the face of climate change, many of these communities will find it difficult to provide for themselves and their families, as well as struggle to make a basic income off the cheap natural commodities they depend on. For example, a vital source of income for many households in rural communities around KNP, is the making and selling of Marula beer. Climate change, however, will put added pressure on the natural resources needed to produce this beer, which is likely to have a huge impact on the economic income of many families (Davis *et al.,* 2010).

3.2.3. Climate Change Implications for the Kruger National Park

The Kruger National Park, like any other protected area, is of great importance to the environment because these areas protect wildlife and wildlife habitats for conservation (Western, 2009). Climate change implications for such an important region pose serious threats for the parks future (Pollard *et al.,* 2011), and thus it is important to prioritise management implications, which will enable a steady adaptation for the park (Davis *et al.,* 2010). Not only do these protected areas help in the conservation of plant and animal species, they also conserve and protect surface water sources, they allow for an undisturbed habitat in which plants and animals may interact freely, as well as allowing for tourism based income (Davis *et al.,* 2010). For the area of KNP, it is anticipated that future climate change will alter the structural and functional aspects of numerous tree and grass species, the composition of many flora and fauna species, and will alter KNP hydrology and soil nutrient fluxes (Davis *et al.,* 2010).

Research into future climate change trends suggests that temperatures and evapotranspiration in the KNP will increase over the 21^{st} century, and rainfall will become more intense and variable (Davis *et al.,* 2010). Increases in temperature and evapotranspiration will result in an increased frequency of intense rainfall events (Davis, 2010). Climate change in the park is therefore expected to alter the frequency, timing and magnitude of storms which will ultimately impact on the number of flooding events as well as the intensity and frequency of drought events (Davis *et al.,* 2010; Davis, 2010). Kruger National Park and its surrounding areas are expected to experience an increase in temperature by 0.8-3^{0}C and increase in annual precipitation by 125-500mm over the next decade (Davis *et al.,* 2010).

The savanna plants of KNP are not overly sensitive to increases in temperature; however, the change in rainfall could have a profound effect on specific plants at their seedling stage (Choinski and Touchy, 1991). Savanna seedlings are drought tolerant, but need a small amount of continuous rainfall to be successful. The change in rainfall variability could therefore affect the success of seedling recruitment (Davis *et al.,* 2010). One of the most notable future changes in KNP vegetation will be the range shift of the Mopane (*Colophospermum Mopane).*

Under the current climate change predictions for KNP, bioclimatic modelling suggests that ranges for bird species will contract, leading to the endangerment and extinction of smaller bird populations within the park (Rutherford *et al.,* 1999; Erasmus, 2002). Modelling, specifically for KNP, concluded that climate change would result in a 66% loss of bird species over the next century (Davis *et al.,* 2010). A shift in water dependent species assemblages will be noticeable as water temperatures increase in the park, thus impacting the variety of mammals and bird's dependent on these ecosystems (Davis *et al.,* 2010).

Additionally, research has shown that an increase of 2.5-3^{0}C over the next few decades, could lead to the extinction of 24-59% of mammals, 28-60% of birds, 21-45% of reptiles and 13-70% of butterflies in Africa (iAfrica, 2008). KNP has noted declines in antelope such as Roan, Sable, Eland and Tsessebe since the mid 1980s. This decline is thought to be associated with a 0.4^{0}C increase in mean temperatures since the mid 1980s (Chown, 2010). The 1990s then experience lower than average rainfall amounts, which initiated a change in vegetation and grasses, which led to a growth in the number of competitive herbivores such as Zebra and Blue Wildebeest (Chown, 2010; Chirima *et al.,* 2012; Seydack *et al.,* 2012).

Climate change not only impacts plants and animal species in the park, it also heavily impacts the park's freshwater systems. KNP hydrological systems are particularly stressed during the 21st century, as not only is the climate impacting water quantity, anthropogenic land-use is abstracting water from systems for economic activities outside the park (Fauchereau *et al.,* 2003; Davis, 2010). With increases in temperatures and evaporation, water loss will be experienced in dams and rivers in KNP. Additionally, increases in temperatures will result in an increase in irrigation for agriculture in surrounding areas; therefore, more water will be abstracted from these river systems before they even reach the boundaries of the park (Fauchereau *et al.,* 2003).

3.3 Extreme Climatic Events

Changes in climate are not only reflected in mean rainfall and temperature, but also in the frequency and intensity of extreme climatic events (Meehl *et al.,* 2000). According to the IPCC (2007), extreme climatic events are categorized as ‘rare’ events such as extreme precipitation or warm spells (Cubasch *et al.,* 2013). For extreme weather phases such as heavy rainfall, prolonged drought or heat waves, the duration and intensity of said extreme climatic event needs to be considered (Cubasch *et al.,* 2013). It has been highlighted that globally, precipitation events will become more intense, the number of heavy rainfall events is likely to increase in many regions, there will be increased continental drying and prolonged periods of drought and areas that already experience droughts are likely to experience more prolonged and more frequent drought periods (Cubasch *et al.,* 2013).

Heat waves are said to increase in intensity and frequency in parts of Europe, North America and Australasia (IPCC, 2014a). Heavy rainfall events will increase in frequency and duration for Northern Europe in all seasons, and continental Europe in the winter seasons (IPCC, 2014a). In Australasia, heavy rainfall events will increase due to the increase in extreme storm events, and in North America, heavy rainfall events will increase drastically, causing concern for the projected increase in flooding events. In southern and East Africa as well as Australasia, there will be an increase in extreme climatic events due to the occurrence of the El Niño Southern Oscillation (ENSO) (IPCC, 2014a). El Niño will enhance the length of drought periods in Australia and southern Africa, and bring more heavy rainfall events to East Africa. Due to increasing temperatures and more variable rainfall events, many regions across the world are facing an increase in drought periods and warm spells. This poses threats to the freshwater ecosystems (Conway, 2005) and agricultural regions in many parts of the world (IPCC, 2014a).

The KNP is affected directly by the El Niño Southern Oscillation (ENSO) and thus experiences prolonged periods of drought lasting approximately 18 months every 2-7 years (Wessels and Dwyer, 2011). In northeast South Africa, the region that includes KNP, future climate change is suggested to increase the frequency and severity of extreme climatic events in the form of flooding and drought (Davis, 2011).

Changes in extreme climatic events are directly impacting changes in streamflow trends worldwide. Streamflow decreases are consistent with increasing temperatures and the increasing number of dry spells (IPCC, 2014b). Climate change and increases in extreme climatic events will have impacts on rivers, whether it is increased intensity of flooding events, or the changing nature of a river system due to prolonged droughts.

3.4 Rainfall Studies

3.4.1 Global Rainfall Studies

With the estimated increases in global temperatures and evaporation rates expected over the next few decades, it is expected that there will be a rise in the frequency and duration of droughts. However, with increased temperature and evaporation, increases in sporadic rainfall events are likely (Trenberth, 2010). With even 1^0C increase in temperature, the air in the atmosphere can hold 7% more water vapour (Mason *et al.,* 1999; Trenberth, 2010), thus more intense rainfall, and storm events (Mason *et al.,* 1999) will be expected even in areas that are experiencing a decrease in annual mean precipitation (Trenberth, 2010). Precipitation has decreased in the tropics and subtropics, with noticeable decreases in countries occupying the Mediterranean, southern Asia and throughout Africa, but has increased in areas with higher altitudes, specifically over North America, Argentina and Eurasia (Trenberth, 2010). In the Northern Hemisphere, research is indicative that precipitation is falling as rain rather than snowfall in the winter months.

In the USA, precipitation amounts have increased by 10% from 1910-1990. This increase in precipitation was brought about through extreme and intense rainfall events (measured above 50.8mm daily) (Karl and Knight, 1998). Flooding frequency has increased and the amount of intense rainfall events has risen substantially between 1991 and 2000 (Karl and Knight, 1998). The flooding of the Mississippi in 1993, the New England floods of 1996 and the Ohio River flood during 1997 were among the numerous flooding phases that brought about the research into climate change scenarios in the country (Karl and Knight, 1998).

More recently, climate change events have caused concern for the coastal populations of the USA (Kirschen *et al.,* 2008). Increased global temperatures are causing a rise in sea levels, which are posing a great threat to the coastlines of northern America. Frequencies of coastal flooding along the Jersey shore are suggested to increase greatly over the next 30-100 years because of the dramatic increase in sea level rise (SLR) (Cooper *et al.,* 2005). The cities of Boston, Massachusetts and Atlantic City are the most vulnerable cities, as these locations are likely to experience the greatest increases in flooding events and storm surges by the year 2050 (Kirschen *et al.,* 2008).

In Asia, research has shown that over the past century, light-moderate summer rainfall over central-eastern India has decreased by between 10-20% (Yao *et al.,* 2008; Roxy *et al.,* 2014). India has, however, experienced an increase in the amount of intense precipitation events (>100mm daily). The same findings have been noted for Korea (Ho *et al.,* 2003). In Pakistan, an increase in the number of intense rainfall events such as cyclones, floods and severe thunderstorms has also been recorded (Salma *et al.,* 2012). Rainfall events in Pakistan have become so variable and erratic, that it makes it difficult to predict extreme events, therefore it is challenging to establish arrangements and issue warnings around potential catastrophic storm occurrences (Salma *et al.,* 2012). These changes in precipitation noted in china have been linked to increases in temperatures, and increased anthropogenic climate change (increases in CO_2 and aerosols) (Yao *et al.,* 2008).

In Africa, Global Climate Models (GCM) have predicted increases in annual rainfall for most the continent, with exceptions for southern Africa and the Horn of Africa, where rainfall is projected to decline approximately 10% by 2050 (IPCC, 2007b; Niang *et al.,* 2014). This increase in rainfall is associated with temperature increases. Interannual and multi-decadal rainfall variability will intensify substantially over central Africa and the Sahel (Hulme *et al.,* 2001).

Literature suggests that rainfall in Africa will become more intense with a higher frequency in tropical cyclones (IPCC, 2007b; Niang *et al.,* 2014).

3.4.2 Rainfall Studies in the Kruger National Park: The highveld vs. the lowveld

In northeast South Africa, the region that encompasses KNP, temperatures are projected to increase by approximately 1-3^{0}C by the year 2050 (IPCC, 2007b; Gbetibouo and Ringler, 2009; Joubert, 2011). With such increases in temperature, South Africa, and more specifically the KNP, are expected to experience an increase in the frequency and intensity of rainfall events, specifically thunderstorms (Mason *et al.,* 1999; Davis, 2010). It is to be noted that although rainfall intensity is to increase, this does not necessarily result in an increase in the countries total rainfall (Mason *et al.,* 1999). It is, however, expected that KNP total annual rainfall will decline by between 5-10% by 2050 (IPCC, 2007b). An increase in extreme rainfall events is most likely to occur during the wet summer months (Davis *et al.,* 2010).

There are differences between the regional climates of the highveld escarpment and the lowveld regions of South Africa. Many of the major rivers that flow into the KNP originate in the escarpment (highveld) and thus it is imperative to discuss available literature for both sub-regions. The highveld region along the escarpment has an altitude of 1000-1350m above sea level and is categorised as having a temperate climate with warm summers. The lowveld region lies at an altitude of 100-300m above sea level with a climate categorised as semi-arid (Hachigonta *et al.,* 2013). The lowveld experiences a mean summer maximum temperature of approximately 30^{0}C, which is 3^{0}C higher than the mean maximum temperature of the highveld (Moyo *et al.,* 2014). Rainfall is highest along the escarpment region (av= 900-1250mm), whereas in the lowveld region the mean annual rainfall varies between 660-700mm (Hachigonta *et al.,* 2013; Moyo *et al.,* 2014).

3.4.3 Rainfall Impacts on Vegetation

Future projected change in rainfall amounts as well as the redistribution of rainfall events will lead to the alteration and modifications of soil water contents, which subsequently affect vegetation (Zeppel *et al.,* 2014). Rainfall is not only going to intensify in many regions around the world (Smith, 2011), it is also suggested that seasonal shifts in rainfall events will be experienced in many regions of the world, particularly Africa (Zeppel *et al.,* 2014). The biomes that are most impacted by alterations in seasonal rainfall are suggested to be boreal forests (Brovkin, 2002), rain forests, Amazon forests (Mitchell *et al.,* 1995), savannas (DEA, 2013) and arctic tundra (IPCC, 2014c).

In California, USA, climate changes together with anthropogenic activities have led to the complete alteration of many biomes and physical landscapes (Lenihan *et al.,* 2003). Wetlands and riparian zones have been degraded, forests have been logged and have suffered a severe decline, and approximately 90% of native grasslands have disappeared (Lenihan *et al.,* 2003). In Canada, the USA and Mexico, tree mortality is increasing due to increased temperatures, prolonged and more severe drought phases, and increased rainfall variability (IPCC, 2014a). Forest Biomes in some parts of North America are becoming more susceptible to wildfire due to an increase in rainfall variability (IPCC, 2014a). The annual mortality rates for tree vegetation in North America has risen from 0.5% of trees per annum in the 1960s to approximately 1.5% in the 2000s (van Mantgem *et al.,* 2009).

In Asia, it has been revealed that boreal forests are showing an increased ‘greening trend’ (increasing NDVI, a rough proxy for increasing plant growth) since 2000 (IPCC, 2014c). Overall greening for these boreal forests is due to increasing temperatures, which are causing increased summer warmth with premature ice retreat. In China, increasing temperatures have resulted in prolonged drought phases, which are impacting water dependent plant species (IPCC, 2014c). The region occupied by northern Kazakhstan has revealed an overall ‘browning’ (decreased NDVI) trend since 1982 (IPCC, 2014c), due to subsequent variability in rainfall events. Drastic changes in Asian biomes have been reported, where tree species are now invading grassland biomes. Projected changes of Asian vegetation responses to climatic changes include limitations to seed dispersal, competition between plant species and increased fragmentation in habitats (Corlett and Wescott, 2013). Biomes will change substantially with arctic tundra decreasing in area and boreal forests increasing in area and encroaching on northward and eastward land surfaces (IPCC, 2014c). Evergreen conifers will replace summer-green larch vegetation and the tundra biome will be heavily encroached by woody vegetation such as trees and shrubs (Pearson *et al.,* 2013). Such drastic changes in Asian vegetation and biomes are suggested to lead to a decrease in species richness by approximately 30% by 2070 (Klorvuttimontara *et al.,* 2011).

Looking specifically at South Africa, it is evident that climate change will significantly impact many plant species due to the richness of vegetation species in the country. South Africa is a country that hosts a wide variety of vegetation types in numerous biomes. South Africa is made up of nine different biomes; namely Albany Thicket, Coastal Belt, Desert, Forest, Fynbos, Grassland, Nama-Karoo, Savanna and Succulent Karoo (DEA, 2013).

KNP occupies the savanna biome, which is made up of a wide range of vegetation types. Under the current climate change scenarios, the savanna biome is expected to expand in size as the vegetation in this biome thrives in hotter, drier conditions (DEA, 2013). Other biomes that are expected to expand in area include the desert biome, and the succulent karoo biome (DEA, 2013). The forest biome, which is dependent on rainfall and moisture, is likely to suffer under projected climate scenarios. One of the major concerns for South African vegetation is the risk posed to the Fynbos biome. This biome is unique to the country and is suggested to experience substantial pressure under future climate scenarios. The Fynbos biome will likely start to develop the vegetation traits of the Succulent Karoo or Albany thicket biome (DEA, 2013). Lastly, the grassland biome is suggested to be the biome under the greatest threat for significant change. Woodland and shrub vegetation from the savanna biome are projected to significantly encroach on the grassland biome. This is due to the projected increases in temperatures, decreases in total annual rainfall and the rise in atmospheric CO_2 (Ziervogel *et al.,* 2014).

3.4.4 Impacts of Rainfall on Streamflow

River ecosystems are one of the most important natural habitats worldwide, as they provide one of the most basic needs for flora and fauna to survive. Without water, most species on earth would cease to exist (Bunn and Arthington, 2002). However, river channels have been influenced by direct and indirect human impacts, as well as natural changes to the environment (Ye, 2003; Li *et al.,* 2007; Zaimes, 2008; Mix *et* al., 2012; Zhang *et al.,* 2015). The ever-increasing degradation of rivers worldwide, has initiated the introduction of extensive research in order to determine the scale of impact caused by anthropogenic and climatic factors, as well as determining management and planning initiatives in order to diminish impacts and restore rivers to a somewhat natural state (Menke and Nijland, 2008).

Research on the impacts of rainfall on streamflow has been ongoing since the 1950s, and has indicated that there is a direct impact of rainfall in streamflow trends (Jewitt *et al.,* 2001; Wang *et al.,* 2008; IPCC, 2014a). Although climate change has a clear influence on streamflow trends, changing landscapes and anthropogenic impacts also alter these freshwater resources. It is thus important that any study determining the impacts of climate change on riverine ecosystems takes place within a protected area, where no external impacts take place along the river systems (Stahl *et al.,* 2010).

In Europe, a study was conducted to determine the influence of rainfall on streamflow along rivers that are categorised as (near-natural), thus not influenced by anthropogenic impacts, to provide a clear representation of the impact rainfall has on streamflow (Stahl *et al.,* 2010). In northern Europe, streamflow trends were positive and approaching ‘wetter’ conditions, whereas in southeast Europe streamflow trends are decreasing (Stahl *et al.,* 2010). Where there are increasing streamflow trends, there has been a direct linkage to increased winter snowmelt and increasing rainfall events. For areas that are experiencing decreased flow regimes such as the United Kingdom, Spain, Czech Republic and Slovakia, increasing severity of drought conditions were apparent, with a noticeable ‘drying’ of the summer and spring seasons (Stahl *et al.,* 2010; Salmoral *et al.,* 2015). Precipitation patterns were also strongly linked to changes in streamflow regimes in China where it was apparent that

67 out of 80 rainfall stations in the Yellow River Basin showed an average decreasing trend of 10.7% since 1950, which led to direct decreases in streamflow (Yang and Lui, 2011). The precipitation elasticity of streamflow is measured as the proportional change in mean annual streamflow divided by the proportional change in mean annual rainfall. In simplistic words, it is used to determine how much streamflow will change in relation to rainfall changes (Sankarasubramanian and Vogel, 2001). The precipitation elasticity of streamflow showed that decreasing rainfall is the main driver for the reduction in streamflow (Yang and Lui, 2011). A decrease in the Yellow River streamflow is directly linked to the 12% decrease in annual average rainfall during the summer months. However, increases in streamflow are noticeable along the Yangtze River, which is associated with an increase in the frequency and intensity of monsoon rainfall events (IPCC, 2014a).

In the KNP, little research has been done to directly link the impact of rainfall on streamflow trends. This gap in knowledge is one that needs to be addressed to initiate strict management implementations for water conservation in the park. With regards to extreme climatic events, it has been noted that extreme rainfall events directly impact streamflow levels of the KNP (Riddell and Peterson, 2013). Hydrological research conducted during the year of 2012 revealed that Cyclone Dando, which impacted northeast South Africa and much of Mozambique, had a significant impact on KNP rivers. The extreme rainfall event named Cyclone Dando was such a significant contributing factor to streamflow that the cyclone caused the Olifants River to have one of the largest documented floods for any South African river over the last 11 000 years (Riddell and Peterson, 2013).

3.5 Hydrological Studies

Table 3.2 Summary of international publications addressing the impacts of climate change and anthropogenic land cover changes on streamflow

Author	Year	Location	River/Basin	Drivers of change
Jha *et al.*	2003	USA	Upper Mississippi River Basin	• Projected climate change scenarios
Ye, B	2003	Siberia	Lena River Basin	• Human activities • Variations in climate
Conway, D.	2005	Tanzania	Ruaha River Basin	• Increased severity in ENSO events
Roald *et al.*	2006	Norway	46 River basins	• Projected changes from 2071-2100
Walker, K.F. and Thoms, M.C	2006	Australia	The Murray River	• Dam construction led to 44% decreased flow
Li *et al.*	2007	China	Wuding River Basin	• Increased climate variability • Human activities on streamflow
Chen *et al.*	2008	China	Bosten Lake Basin	• Future climate change scenarios • Increase summer flow due to increased temperatures
Yang, Z. and Lui, Q	2011	China	Yellow River Basin	• Decreased rainfall annually
Mix *et al.*	2012	New Mexico	Upper Rio Grande Basin	• Water abstraction
Ficklin *et al.*	2013	Western USA	Colorado River	• 30% reductions in flow under current climate change scenarios
Marquez *et al.*	2013	The Mediterranean	Francoli River Basin	• Changes in extreme climatic events • Increased water demand
Salmoral *et al.*	2015	Spain	Upper Tunia River Basin	• Increased temperature • Climate variability • Scrubland clearing
Zhang *et al.*	2015	Northwest China	Heihe River Basin	• Anthropogenic demands • Increased temperature • Streamflow has risen in the higher elevations

Table 3.3 Summary of local publications addressing the impacts of climate change and anthropogenic land cover changes on streamflow

Author	Year	Location	River Basin	Drivers of change
Mason *et al*	1999	South Africa	All catchments in northeast South Africa	• Increased temperature • Increased frequency of thunderstorms
Jewitt *et al.*	2001	South Africa	Sabie River	• Increased sedimentation • Rainfall Variability
Sanders *et al*	2002	South Africa	All catchments in northeast South Africa	• Upstream anthropogenic activities
Odiyo *et al.*	2007	South Africa	Luvuvhu River	• Increased interannual rainfall variability • Dam construction
Zaimes	2008	South Africa	All catchments in northeast South Africa	• Direct and indirect human impacts
Davis *et al*	2010	South Africa	Northeast South Africa	• Increased evapotranspiration • Increased temperatures
Wray	2010	South Africa	Olifants River Catchment	• Dam construction has decreased downstream river flow
Pollard *et al*	2011	South Africa	Luvuvhu, Olifants, Letaba, Sabie and Crocodile river catchments	• Intensive upstream anthropogenic activities • Abstraction • Dam construction • pollution
Wessels and Dwyer	2011	South Africa	KNP River catchments	• El Niño
Fouche, P.S.O and Vlok, W	2012	South Africa	Shingwedzi River	• Anthropogenic land use activities • Increased water demand
Riddell and Peterson	2013	South Africa	All catchments in northeast South Africa	• Increases in extreme rainfall events will lead to increased flooding.
Okello *et al.*	2014	South Africa	Inkomati River Basin	• Dam construction • Land-use changes

3.5.1 Freshwater Resources of the Kruger National Park

The KNP hosts a variety of different freshwater reservoirs; namely, lakes, rivers, groundwater and wetlands. The rising concern for impacts on these freshwater resources has called for plans of action to sustainably conserve these resources (Rychwalski *et al.,* 2007). The biological diversity of these water resources is important for the park's tourism, as well as for terrestrial and freshwater conservation. *Table 3.4* highlights some of the direct and indirect impacts threatening the freshwater of KNP, specifically rivers. This chapter will further discuss the state of these resources and the potential impacts facing water quality and quantity of freshwater in the KNP.

Table 3.4 Direct and indirect impacts on streamflow change (Taylor, 2010: 15)

Direct Impacts
• Groundwater abstraction (agriculture and forestry) • Erosion • Discharges of pollutants from upstream anthropogenic land use activities (agriculture, forestry, urbanisation and mining) • Flooding due to the construction of dams • High population increases upstream • Increased rainfall variability • Overgrazing and trampling of riparian vegetation and riverbanks • Intensifying impacts of ENSO
Indirect Impacts
• Sedimentation build up from dams • Anthropogenic climate change • Sediment diversion by dams • Hydrological alterations from infrastructure

3.5.1.1 Artificial Waterholes in Kruger National Park

Artificial water holes were built in KNP to deal with numerous issues faced by the park. One of the main issues for the development of these water holes was to alleviate the impacts of water scarcity in the park (van Wyk, 2010). Water provision in KNP has been a long-standing management goal for the park

(Travers, 2006). In 1933, it was recognised by park warden, James Stevenson-Hamilton, that natural water resources were drying up, and thus the need for increased water supply was of great importance (Pienaar, 1998). The increased abstraction and pollution of water to the main rivers that flow through the park also initiated concern for KNP water resources (Pienaar, 1998). Additionally, drought phases experienced in the park caused concerns for water scarcity and thus all these contributing factors led to the implementation of these artificial waterholes (van Wyk, 2010). Furthermore, the fencing of KNP in the 1960's raised concern for many animal species as their migration routes were blocked off (Pienaar, 1998), and thus management aimed to provide more surface water for these animals (Travers, 2006). To deal with these stressors, over 300 boreholes were drilled in the park, as well as various dams constructed along KNP rivers in the 1970s and 80s in order to manage water quantity (Smit *et al.,* 2007a). The implementation of these fixed water sources aimed to provide water for animals throughout the park, thus ensuring perennial water supply, even during months and years where natural surface water was scarce (Smit *et al.,* 2007a).

The implementation of artificial waterholes caused controversy, as some believed it to be beneficial to the park and its animals. As well as adding value to tourism by increasing game viewing locations (Pienaar, 1998; Travers, 2006). However, the opposing opinion believes that artificial water points impacted negatively on animal migrations, biodiversity and vegetation (Epaphras *et al.,* 2008), and has created an increased competition for water (Smit and Grant, 2007). For example, the vegetation of many plant species found around artificial waterholes has been damaged due to trampling and overgrazing (Thrash *et al.,* 1993; Epaphras *et al.,* 2008). The area of vegetation destruction and soil erosion can occur up to 250-500m away from the waterhole (Thrash, 1993). The loss of this edible vegetation has had noticeable changes in food availability for grazing animals, especially during periods of drought (Thrash, 1993).

The issues of previous water scarcity in the park meant that animals had to travel long distances to drink water (van Wyk, 2010). One of the main management aims of artificial waterholes was to thus provide water to animals within a smaller proximity. Waterholes were thought to provide surface water to rarer antelope species in KNP, which was thought to increase their population numbers (Travers, 2006). However, it was later discovered that artificial waterholes were in fact decreasing the numbers of rare antelope such as Sable and Roan because an increase in Zebra and Wildebeest were noted (Smit *et al.,* 2007b; Chown, 2010; Chirima *et al,* 2012). The increase in Zebra and Wildebeest led to a decline in the antelope population because the rate of predation increased (Smit *et al.,* 2007b). Roan and Sable antelope were therefore targeted by predators due to their greater vulnerability to predation (Travers, 2006).

It is widely agreed that the provision of water in protected and conservation areas is of vital importance to the survival of numerous animal species. It is, however, stressed, that the over-abundant provision of surface water shpuld not be introduced, as this will have negative impacts on migration patterns and predation around water holes. The construction of too many artificial waterholes could counteract the management and conservation aims of the park. Too many water points will lead to increases in animal mortality during dry seasons or droughts, thus further leading to a decline in the park’s biodiversity (van Wyk, 2010). The implications for too many waterholes have been witnessed in KNP and thus the closure of most these artificial waterholes were seen as a necessary water management initiative (van Wyk, 2010).

3.5.1.2 Groundwater Studies

Groundwater is any freshwater resource that is present at subsurface level (Schmidt and Hahn, 2012). There are many definitions for the term ‘groundwater’ and one that is largely accepted is that “Groundwater (is) any water that lies beneath the land surface” (Oskin, 2015: 1). Groundwater is thus classified as the water that enters the subsurface level through infiltration (Schmidt and Hahn, 2012). Groundwater is commonly recharged during rainfall events, as much of the rainfall seeps through soils and contributes to the water table (Oskin, 2015). A healthy water table also contributes to surface water during dry seasons. When river water is depleted during the dry season, the ‘invisible’ groundwater is largely responsible for the ‘visible’ flow (base flow) (Smit, 2007), hence, subsurface water can replenish river beds in the form of pools, pans and wetlands (Smit, 2007) Groundwater is a vitally important natural resource that contributes widely to the functional roles in the ecosystem (Smit, 2007) and thus the management and conservation of groundwater is important.

Groundwater resources are important to protected areas such as the KNP. With increases in population adjacent to the park as well as projected changes in climate for the region, park management has adopted ecosystem management goals based on certain environmental factors and their ‘thresholds of potential concern’ (TCP) (Leyland and Witthuser, 2008). The quality and quantity of KNP groundwater is one of the many environmental indicators that is monitored and for which TCPs will have to be implemented (Leyland and Witthuser, 2008). The Department of Water Affairs (DWA) works together with the management of KNP in monitoring regional groundwater resources.

If the groundwater that supports KNP depletes, the biodiversity of the park will be jeopardised (Smit, 2007). Over-pumping of groundwater will cause the water table to drop, which will initiate a variety of ecosystem stressors. The depletion of this water resource will negatively impact vegetation and other groundwater-dependent ecosystems that rely on this water for their survival. Groundwater quantities are directly linked to rainfall events and amounts (Smit, 2007). In 2003/2004 KNP experienced heavy rainfall, and the total annual rainfall was higher than average. The groundwater level had risen substantially over these two years according to the measurements taken from 120 boreholes across the park (Smit, 2007). Management initiatives are therefore placing emphasis on the conservation of these groundwater resources under projected rainfall change scenarios.

3.5.1.3 Wetland Studies

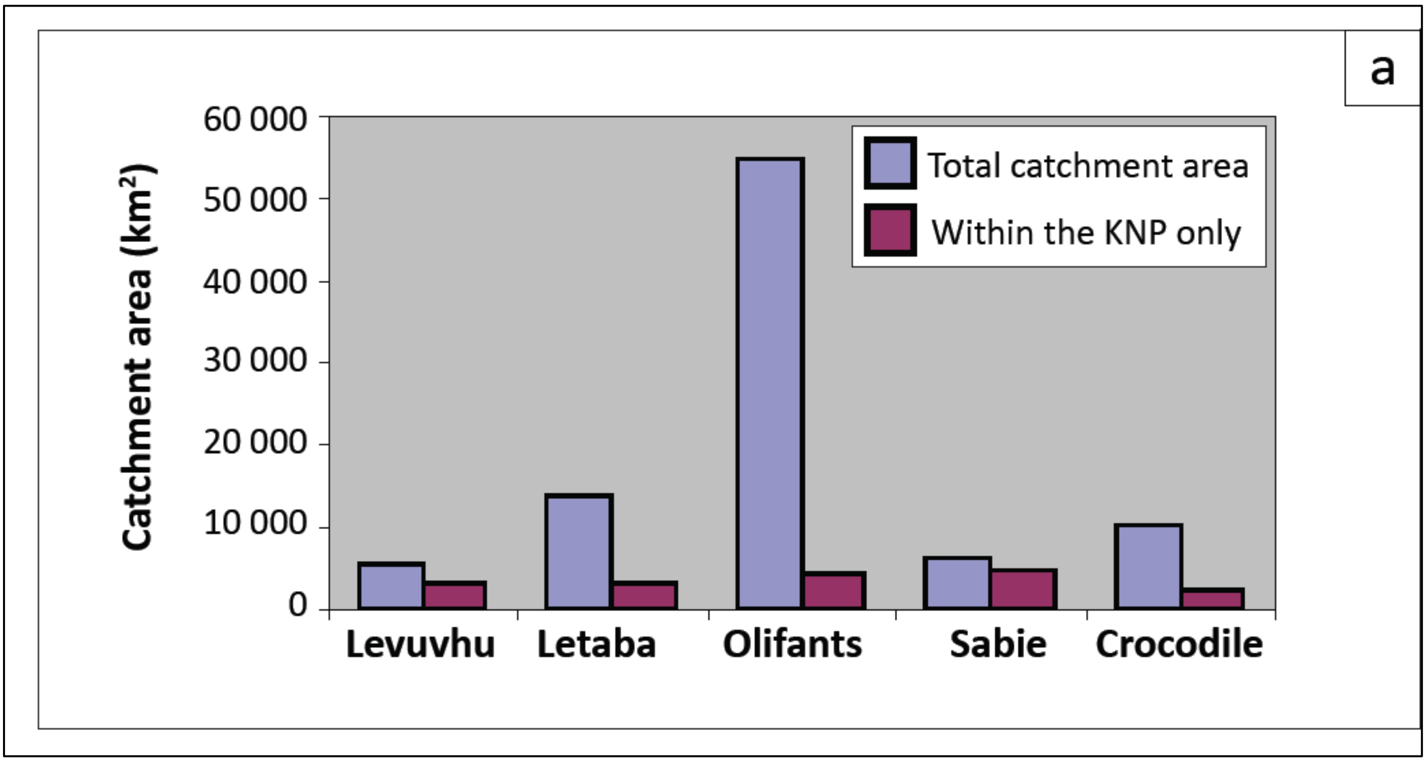
A wetland is an area of marsh, fen or peatland (Mhlari, 2006), and forms the transitional zone between terrestrial and aquatic ecosystems. The South African Water act states that wetlands are shallow water regions where the water table is at or near the surface (Mhlari, 2006). There are three characteristics that intrinsically define a wetland area; namely a high-water table, hydromorphic soils, and hydrophytic plants living in these hydromorphic soils (Mhlari, 2006). Wetlands are vitally important to the environment as they support a wide variety of vegetation and animal species that survive in saturated soils (Mhlari, 2006). The health and management of KNP wetlands is crucial as these hydrological systems contribute to water purification, groundwater recharge and streamflow regulation (Mhlari, 2006).

In the far northern region of KNP, wetlands within the flood plains of the Luvuvhu and Limpopo rivers have proven beneficial during the dry seasons. The literature has revealed that many of the major rivers in KNP have experience reduced flow (Kleynhans, 1996), with numerous rivers not having surface water during the drier months. Research has shown that the wetlands and pans along these rivers hold water even when the rivers are dried up and not flowing (Antrobus, 2014). These wetlands thus provide drinking water to mammals during the dry seasons, as well as water for vegetation along these floodplains. With the current and future projected climate change scenarios, it is a concern that these wetlands will dry up, and stop providing water for animals during the dry seasons. Not only are the rivers in the park being impacted, but the wetlands too (Antrobus, 2014).

3.5.2. Anthropogenic Impacts to Kruger National Park Streamflow

River ecosystems are one of the most important natural habitats worldwide, given that they provide basic needs for riverine flora and fauna to survive. Without water, most species on earth would cease to exist (Bunn and Arthington, 2002). However, river channels have been widely influenced by direct and indirect human impacts, as well as natural changes to the environment (Zaimes, 2008). Leopold (1941:200) states “freshwater systems are affected by any activity taking place upstream or uphill in the catchment”; where these activities will directly alter nutrient loads, water temperatures, pollution and sediment accretion (Sanders *et al.,* 2002). The ever-increasing degradation of rivers worldwide, has initiated the introduction of extensive research methods in order to determine the scale of impact caused by anthropogenic and climatic factors, as well as determining management and planning initiatives in order to diminish impacts and restore rivers to a somewhat natural state (Menke and Nijland, 2008).

Climate change and anthropogenic land-use activities have resulted in many KNP rivers changing from perennial to non-perennial in annual flow dynamics (Kleynhans, 1996). Pollard *et al.* (2011) highlight that the major rivers that flow through the park are particularly vulnerable due to their catchments originating outside KNP boundaries. For example, of the total 840km long Olifants River, only 11% (100km) falls within KNP. With the Crocodile and Letaba rivers, only 36% and 18% respectively flow through the park. *Figure 3.2* highlights the comparison between (a) the total catchment areas, and (b) river lengths of the 5 main rivers flowing though the KNP.



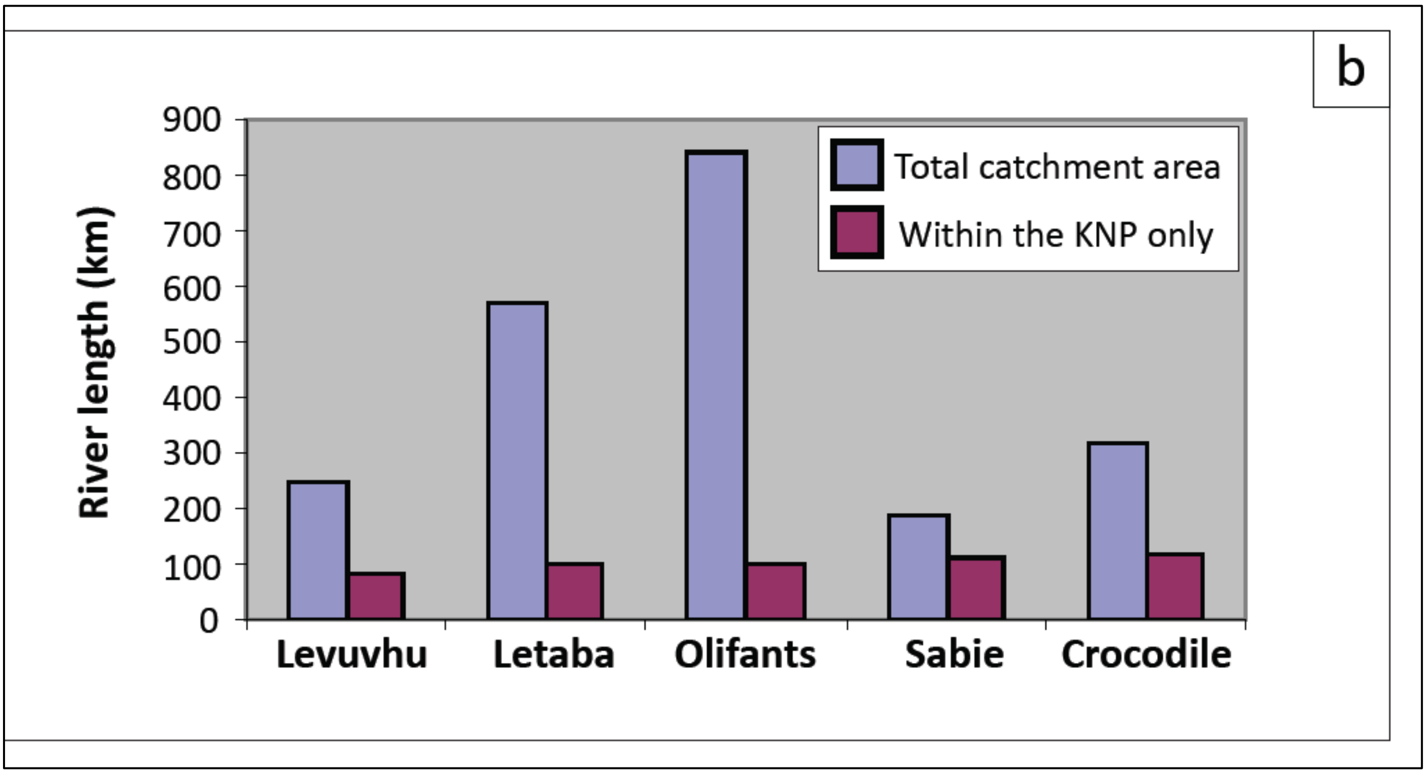


Figure 3.2 Graphs comparing total area and river length of major rivers that flow through KNP (Pollard *et al.*, 2011).

There are 8 river catchments comprising KNP, 4 sub-catchments located in the Limpopo River Basin and 4 Sub-catchments within the Inkomati River Basin. Each of these catchments is uniquely impacted on by human land-use activities. The Luvuvhu River catchment, with a total area of $5941km^2$, originates in the Soutpansberg Mountains and this river flows through an array of different land-use types (DWAF, 2011a). The Luvuvhu river catchment encompasses agricultural practices and subsistence farming that takes place near the water's edge. This has resulted in a loss of riparian forest, causing the demise of the riparian buffer zone, which directly leads to poor water quality from terrestrial runoff (DWAF, 2011a). Waters in the Luvuvhu River and its tributaries are used commonly for washing clothes, which was noted specifically in the Tshiombedi River (A tributary of the Mutale river) (DWAF, 2011a). South of the Luvuvhu catchment is the Shingwedzi River catchment covering a total area of $5300km^2$, with a characteristically low rainfall of between 450-650mm annually (Fouche and Vlok, 2012). The human activities characteristic of this catchment include irrigation, afforestation, commercial and informal farming. Small-scale mining activities also take place in some regions of the catchment (Fouche and Vlok, 2012). These activities have impacted flow so dramatically that annual water requirements exceed annual yield, thus forcing human activities to extract groundwater for production (DWAF, 2012).

The Letaba River catchment covering an area of $13670km^2$ is one of the largest catchments. The vulnerabilities for surface water resources for this catchment consist of water-use activities from informal settlements, forestry and commercial farming. The occurrence of deforestation in this catchment has also led to the demise of the riparian forest and the introduction of alien plant species to the riparian buffer zone leading to the demise of surface water flow (DWAF, 2011b). Deforestation has additionally led to the erosion of riverbeds and high sediment loads. Within the Letaba River catchment, KNP has had to build dams to provide wildlife with drinking water resources because flow levels are too low.

The Lower Olifants river catchment is one of the most threatened catchments in South Africa due to the extensive economic activities impacting surface water resources (DWAF, 2004). Heavy metal mining, coal mining and electricity production are compromising the quality of water in the rivers of this catchment, and population increase is resulting in excessive water extraction. Future development for this catchment suggests that the impacts on water quality and flow levels will only ruin the integrity of the rivers even more.

South of the Olifants river catchment, are 4 more river catchments that encompass KNP, comprising of the Inkomati River Basin. The first two river catchments are two minor catchments that fall within KNP; these are the Nwanedzi catchment and the Nwaswitsontso Catchment (DWAF, 2012). The fact that these river catchments fall within a protected area means that there is no external human impact on the river systems, and proves valuable for the comparison with river catchments that originate from outside KNP.

The Sabie River catchment is in the southern KNP and covers a total land area of 6320km². This catchment originates in the Drakensberg Mountains where annual average rainfall is ~ 2000mm and occupies a land area all the way to the KNP, where the average annual rainfall is ~ 800mm (DWAF, 2001a). The upper Sabie catchment is characterised by forest plantations and economic growth of urban centers. The economy of this catchment is also centered on coal mining and oil refining (DWAF, 2001a). The middle catchment comprises rural settlements and subsistence fruit and cattle farming. Livestock farming has resulted in overgrazing, causing extensive damage to the riparian buffer zone with consequent increased erosion and the demise of the ecosystem. The lower Sabie River catchment falls within the protected area of KNP (DWAF, 2001a).

The southernmost catchment is the Crocodile River Catchment covering an area of 10450km². The human water-use in this catchment is divided between five sectors. Agriculture utilizes 49% of water extractions, 43% is utilized by forestry, and the remaining 8% is distributed between industry, mining and commerce (DWAF, 2001b).

Most the river catchments cover hundreds of kilometers of land-use before reaching KNP, and thus their water resources are fairly diminished before reaching the park. It is thus important to evaluate and understand the impacts these human activities have on surface waters. The freshwater resources in South Africa and especially KNP are becoming limited in the light of projected climate scenarios (DWAF, 2009), as well as the distribution and unsustainability of these resources has led to their demise (IPCC, 2007b). The increasing population in southern Africa is predicted to experience severe water stress by the year 2025, with climate change increasing this water stress (IPCC, 2007b). Streamflow monitoring is thus important to help understand future hydrological changes. The deterioration of these biodiversity corridors thus needs to be addressed through management and planning to secure future freshwater provision (DWAF, 2009).

3.5.3 Impact of Dam Construction on Streamflow

One of the components that have taken place to ensure year-round access to water, has been the construction of dams. Dams are implemented as a form of water storage, thus enabling communities and regions to an annual access of freshwater which can be used for mining, agriculture, industry and residential use (Pottinger, 1996). However, dams are suggested to be harmful to river dynamics, and have been called “a cataclysmic event in the life of a riverine ecosystem” (Ligon *et al.,* 1995: 183). The construction of dams not only alters flow, but also disrupts sediment, nutrients, biota, and energy, thus altering an ecosystem in its entirety (Ligon *et al.,* 1995). Dams alter river health and downstream habitat (Muir, 2010), with downstream riverine habitats arguably the most affected by dam constructions. Dams hold back previously distributed river sediments, which help nourish and enrich riverside banks, enabling the new growth of riparian species (Shafroth *et al.,* 2002). Consequently, riverbeds are eroded substantially as the downstream flow attempts to recapture sediments by eroding the riverbank (Pottinger, 1996).

The construction of dams along rivers has initiated worldwide concerns for the health of riverine ecosystems (Nilsson and Berggren 2000). This widespread concern has initiated ecological response projects, which call for better management and flow plans to restore streamflow regimes back to less altered behaviour (Nilsson and Berggren, 2000). The Hoover dam in the USA caused a lowering of the downstream riverbed by 4 meters within 9 years of dam construction (Pottinger, 1996). The evaluation of 72 major dammed rivers in the USA showed that dams reduced discharges between 67% and 90% in extreme cases (Graf, 2006), as well as a decrease in annual mean flow by 60%. The Aswan Dam along the Nile River suspended 99% of sediment that previously flowed through the river system enriching the riverbed soil (Pottinger, 1996). The Murray River in Australia had a highly variable flow even before the installation of dams; however, the introduction of dams to this river system reduced its flow by 44% and has caused issues such as salinisation (Walker and Thoms, 2006). The downstream Murray River has also experienced erosion and the demise of certain fish species after the implementation of storage reservoirs (Walker and Thoms, 2006).

In Africa, the construction of dams is crucial for the survival of human populations. Africa, and especially southern Africa, experiences dry conditions, and thus these regions are already susceptible to water stress due to seasonal rainfall and periodic droughts (Deane, 1997). It is thus understandable why dams are so important in Africa, to provide populations and human activity with perennial water supply. In Morocco, dams were built in the 1970s to irrigate vast areas of land. The climatic variability, torrential nature of rainfall, soil degeneration, and low vegetation density results in huge erosion along river basins in northern Africa (Lahlou, 1996). In South Africa, according to records from the Department of Water Affairs and Forestry (DWAF), there are approximately 500 000 small farm dams (Mantel *et al.,* 2010). Farm dams are used primarily for agriculture, but investigations into the impact these dams have on flow levels have indicated significant reductions in base flow as well as negative impacts on river water quality (Mantel *et al.,* 2010).

3.5.3.1 Impacts of Dam Constructions on Kruger National Park Rivers

In semi-arid regions of southern Africa, such as the Savanna biome, the impacts of damming have been substantially examined. Seasonal rivers throughout KNP support riparian ecosystems and woodland species, which are key habitats for wildlife in the national park (O'Connor, 2002). Dams affect the catchment area of KNP as they decrease flow between 20-50% (O'Connor, 2002). Specifically, in KNP, hydromorphic grassland and woody tree species form a crucial habitat for many wildlife species (Hughes, 1988), and thus these species are reliant on streamflow. The deterioration of flow and lowering of the water table will lead to desiccation, decreased riparian vegetation cover (Pottinger, 1996) and bush encroachment, proving harmful to grassland dependent species (O'Connor, 2002).

The Kwena Dam is the main reservoir built along the Crocodile River system. The construction of this dam took place in 1984 to improve water supply to agricultural practices in the region (Riddell and Peterson, 2013). To determine the impacts this dam may have on flow levels, the gauging station X2H013 (Montrose gauge station), located a few kilometers downstream of the Kwena dam, has monitored flow for two decadal periods (from 1959-1984 and 1986-2011) (Okello *et al.,* 2014). The Kwena dam was found to have significant impacts on downstream flow levels, with decreases in peak flow as and an increased frequency in low flows (Okello *et al.,* 2014). Other research also found variability in base flow levels and overall flow trends of the rivers in the Crocodile River basin over the past half-century (Riddell and Peterson, 2013).

In the Groot Letaba River Catchment, approximately 20 large dams have been constructed over the past several decades, with the two largest dams being the Tzaneen dam and the Middel Letaba dam (State of Rivers Report, 2001). The Modjaji dam in the Letaba River catchment has negatively impacted rivers by restricting downstream flow, and detrimentally impacted riverine vegetation species downstream of the dam. The impact of the dam wall can be seen in flow levels and riparian ecosystems for between 20-30km downstream (State of Rivers Report, 2001).

The Dams along river systems in the Letaba River Catchment have impacted fish species negatively, as fish are unable to migrate beyond the dam wall. There have been no records or sightings of the Tiger Fish species outside the boundaries of KNP since 1990 (State of Rivers Report, 2001). The Tiger fish species prefers warmer waters, and the dam walls prevented their migration to warmer waters during cold spells (State of Rivers Report, 2001). After the major flooding event in KNP during January 2000, many dam walls were destroyed. Management of the park decided that not all dam walls were to be restored. The Black Heron dam along the Letaba River was not restored, but rather converted into a low flow-gauging weir with a fish ladder (State of Rivers Report, 2001), whilst the Shimuwini dam was destroyed and never restored.

The Albasini dam along the Luvuvhu River catchment is responsible for the low flows downstream (State of Rivers Report, 2001). The Nandoni dam has negatively impacted downstream riparian vegetation and caused the increased erosion of riverbanks. This dam has additionally degraded the habitat of the Luvuvhu River catchment by contributing excessive siltation (State of Rivers Report, 2001). In the Sabie-Sand River Catchment, the construction of the Injaka dam on the Marite River, which was completed in 2001 (Postel and Richter, 2003), severe ecological impacts have been noted along parts of the river, downstream from the dam (Postel and Richter, 2003).

3.5.4 Anthropogenic Impacts to Kruger National Park Riverine Vegetation

Riparian vegetation forms the transition zone from freshwater to the terrestrial landscape (Pusey and Arthington, 2003) and is known to be an important ecosystem in riverine channels. Riparian zones rely on river and groundwater to supplement their survival and growth (Likens, 2010). Factors that influence the integrity of these riparian ecosystems include microclimates, water access, and water quality (Likens, 2010). The loss or degradation of these important ecosystems will result in the loss of habitat and biodiversity (Pusey and Arthington, 2003). In many semi-arid regions of the world, the decreasing flow regimes and changes in climatic phases (flooding and prolonged drought) are having synergistic effects on the riparian vegetation dependent on these hydrological processes (Stromberg *et al.,* 2012). The ever-increasing degradation of these natural ecosystems has initiated widespread concern for the conservation and restoration of these habitats in the face of future predictions for these ecosystem changes (Kundzewicz *et al.,* 2008).

South African rivers are said to have the most variable flow regimes worldwide because of direct and indirect effects of human activities (Biggs *et al.,* 2003), with the coefficient of variance (CV) being 0.78 for mean annual runoff. The Sand River for example, has a CV of 2.1. Along the Sabie River, abstractions occur mostly upstream due to these areas being unprotected commercial farmlands, which results in reduced sediment capacity (Biggs *et al.,* 2003). Through the evaluation of temporal changes in riparian vegetation using aerial photography, it was found that changes along the Sabie River caused concern and the need for further evaluation along other KNP rivers (Biggs *et al.,* 2003). Changes in riverine vegetation included woody plants, shrubs and trees, from 1940 to 2000. In 1940, the riverine ecology changed to more herbaceous vegetation and wider river channels, following flooding. From 1965-1985 reed beds were colonized by trees and from 1986-1996, there was a reduction in riverine vegetation and increase in riverbed erosion due to extensive periods of drought (Biggs *et al.,* 2003). The flood event in 2000 then caused the reversal in the vegetation established over the past 60 years. Large areas of riparian vegetation (trees and shrubs) were replaced by rock, sand and water, completely altering the ecosystem (Biggs *et al.,* 2003).

3.6 Conclusion

This literature review has highlighted the extent to which streamflow trends respond to both anthropogenic land-uses, as well as climatic changes. Consequently, to better realise the extent to which increasing climate variability and ongoing climate change is impacting streamflow responses, and additionally other freshwater bodies, it is necessary to study as many rivers and freshwater bodies in as many locations as possible. While it is necessary to study as many regions as possible, that experience many different climate scenarios, it is of utmost importance to conduct hydrological studies in protected areas. It is within these protected areas where crucial research can be conducted to determine the independent influence climate change has on streamflow trends. Many research studies have been conducted worldwide, evaluating the impact that changing rainfall has on streamflow behaviours. It is, however, fundamental to also evaluate rivers, which have not been influenced by anthropogenic land-use activities, to better determine climate change impacts on streamflow. With very few studies being undertaken on the independent relationship between rainfall variables and streamflow trends, this study would serve to fill this research gap.

Chapter 4: Data and Methodology

4.1 Introduction

The broad aim of this study is to contribute to the existing collection of research regarding the hydrological response of rivers and streamflow to a changing climate- more specifically, to changing rainfall patterns. The focus is on rivers/streams that flow through the protected area of KNP in the lowveld of northeastern South Africa. The protected area of KNP is a widely-studied area of South Africa. The acquisition of both a rainfall and streamflow dataset that spans numerous decades; statistical analysis of temporal trends; and the subsequent analysis of the relationship between rainfall and river flow trends will allow for the assessment of these associations in KNP.

This chapter outlines the procedure of data acquisition, methods used to analyse trends in both the rainfall and the river flow data, which were acquired from The South African Weather Services (SAWS) and The Department of Water and sanitation (DWS). This is followed by an account of the methodology used to determine trends and relationships between rainfall and streamflow variables.

4.2 Data

4.2.1 Data Acquisition

Given this research project aims to explore the relationship between rainfall and streamflow trends in KNP and, more specifically, the changes in streamflow trends in response to rainfall events, acquired datasets needed to be lengthy – spanning at least five decades to be reliable. The first half of the study focused specifically on how rainfall trends in and adjacent to KNP had changed spatio-temporally. Upon consultation of available datasets, it was discovered that rainfall datasets for this research location were, for the most part, lengthy and continuous, with more than half of the selected weather stations in the research area providing continuous rainfall records spanning 90 years. Streamflow records exist from the 1960s, although some gaps are present in the dataset, the dataset is rich with data. The stations that had too many gaps, or too lengthy gaps in data were omitted from the study. Rainfall trends were thus examined for the past ~century to determine patterns of change, whereas river flow trends and the relationship between rainfall and river flow trends was examined for the period 1960-2014.

4.2.1.1 Rainfall Data

The rainfall dataset for this study comprises 21 SAWS weather stations located within and adjacent to KNP, and collectively span the period 1907-2014. In addition to data richness and continuity, data were also included based on the location of the weather station in relation to KNP river catchments. Data from each weather station were collected from their date of inception; thus, all data sets differed in length (*Table 4.1*). Rainfall data is recorded daily at 08:00 South African time (SAWS, 2013). New spread sheets were then compiled which accounted for daily rainfall amounts throughout the years, daily, monthly mean, and total annual rainfall for all stations.

Of the 21 selected weather stations, more than 60% provide records for more than half a century, with 45% providing between 80-110 years' worth of rainfall records. These depths of data are exceptional in ecological studies and provide a unique opportunity to investigate changes in rainfall patterns in KNP from 1900s to 2015. Half of the selected weather stations are located externally to the KNP border, with the remainder within KNP. Weather stations sited within KNP river catchments prove invaluable as they provide ecological motivation rather than logistical motivation for inclusion.

Table 4.1 Details of the weather stations in and adjacent to KNP that provided data for this study.

		Years of data collection			Location (decimal degrees)	
Region	**Station name**	**Start**	**End**	**Total**	**Latitude**	**Longitude**
Northern Bushveld	Palmaryville	1907	2014	107	-22°58’48”	30°25’48”
	Zomerkomst	1923	2014	92	-23° 46’48”	30°07’12”
	Hans Merensky Hoerskool	1927	2014	88	-23°46’48”	30°07’48”
	Gravelotte	1971	2011	40	-23°56’59”	30°37’12”
	Thohoyandou	1983	2014	32	-22°58’12”	30°30’01”
Northern Lowveld	Punda Maria	1924	2012	89	-22°40’48”	31°01’12”
	Pafuri	1925	2014	90	-22°26’59”	31°19’12”
	Letaba	1928	2012	85	-23°51’01”	31°34’48”
	Shingwedzi	1958	2005	48	-23°06’01”	31°25’48”
	Krugerwildtuin Shangoni	1958	2014	57	-23°10’12”	30°56’24”
	Shingwedzi Vlakteplas	1983	2014	32	-22°52’12”	31°13’12”
	Letaba Mahlangeni	1987	2014	27	-23°38’59”	31°08’59”
Southern Bushveld	Pilgrams Rest	1904	2014	112	-24°53’59”	30°45’01”
	Nelspruit	1906	2014	109	-25°30’00”	30°53’36”
	Champagne Nat	1924	2007	84	-24°40’48”	31°06’01”
	Onverwag Bos	1964	2014	51	-24°48’00”	30°58’12”
	Sabie	1973	2014	42	-25°06’00”	30°46’48”
Southern Lowveld	Skukuza	1912	2012	101	-24°59’24”	31°35’24”
	Satara	1933	2013	81	-24°23’59”	31°46’48”
	Malelane	1939	2014	76	-25°28’12”	31°30’00”
	Stolznek	1983	2014	32	-25°19’12”	31°22’48”

4.2.1.2 River/river flow Data

The river flow data acquired comprises 21 river gauging stations located at weirs on some major rivers originating externally to KNP, as well as some rivers originating within the protected area. The daily river flow records were sourced from the National Department of Water and Sanitation, which host nationwide river flow data online at (https://www.dwa.gov.za/hydrology/hymain.aspx)

Of these 21 gauging stations, seven provide records spanning more than 50 years; nine stations provide daily river flow data between 30 - 50 years' river flow and the remaining six provide daily records for between 20 - 30 years (*Table 4.2*). The gauging stations on the larger rivers typically have earlier inception dates; however, the recording of river flow does not date back as far as the rainfall data collected for this research.

Table 4.2 River gauge stations in the four regions of KNP. They are categorised according to location, northernmost river to southernmost river (* indicated rivers that originate within KNP boundaries)

	River	Station Name	Station Number	Latitude	Longitude	Years of data collection	Total
Far Northern KNP	Luvuvhu	Mhinga	A9H012	-22° 53'12''	30°46'13''	1987-2014	27
	Mutale	Mutale	A9H013	-22°26'45''	31°04'30''	1981-2014	33
	Shisha*	Shisha	B9H001	-22°50'16''	31°14'14''	1960-2014	54
	Mphongolo*	Sirheni Dam	B9H004	-22°56'42''	31°13'37''	1983-2014	31
	Shingwedzi	Silwervis	B9H002	-23°12'55''	31°13'12''	1983-2014	31
	Shingwedzi	Kanniedood Dam	B9H003	-23°08'10''	31°27'17''	1984-2014	30
Northern KNP	Tsendze*	Tsendze	B8H011	-23°34'00''	31°25'36''	1961-2014	53
	Letaba	Letaba Ranch	B8H008	-23°39'30''	31°03'00''	1984-2014	30
	Letaba	Black Heron Dam	B8H034	-23°42'06''	31°13'03''	1981-2014	33
	Letaba	Engelhard Dam	B8H018	-23°50'19''	31°38'27''	1959-2014	51
Central KNP	Olifants	Mamba	B7H015	-24°03'32''	31°14'14''	1987-2014	27
	Timbavati	Piet Grobler	B7H020	-24°14'14''	31°38'25''	1981-2014	33
	Nwanedzi*	Nwanedzi	X4H004	-24°27'00''	31°58'42''	1960-2014	54
Southern KNP	Sand	Exeter	X3H008	-24°46'08''	31°23'24''	1967-2014	37
	Sabie	Kruger Gate	X3H021	-24°58'03''	31°31'00''	1990-2014	24
	Sabie	Lower Sabie	X3H015	-25°08'13''	31°56'42''	1987-2014	27
	Nsikazi*	Nsikazi	X2H072	-25°16'18''	31°15'23''	1990-2014	24
	Crocodile	Karino	X2H006	-25°28'10''	31°06'00''	1929-2014	81
	Crocodile	Riverside	X2H046	-25°23'56''	31°36'38''	1985-2014	29
	Crocodile	Ten Bosh	X2H016	-25°21'44''	31°57'24''	1960-2014	54
	Komati	Komatipoort	X2H036	-25°26'10''	31°58'56''	1982-2014	31

One of the most beneficial aspects of this research is the investigation into the impact rainfall has on rivers/streams originating either externally or internally to

KNP, with the latter being free from direct anthropogenic impacts. The major rivers examined have their headwaters originating some few hundred kilometers outside KNP in the escarpment of South Africa, and are subject to multiple anthropogenic influences across different land uses before finally entering KNP. Five of the rivers examined originate within KNP (*viz*. Shisha, Mphongolo, Tsendze, Nwanedzi and Nsikazi).

4.2.2 Data Limitations

The data were sourced from credible national departments, allowing for confidence in the data. Limitations were however present in both datasets as there was, in some instances, missing data (*Tables 4.3 and 4.4)*. Numerous explanations account for these missing data, including station malfunction, calibration errors, mismanagement or natural disasters. For example, several river flow gauging stations were damaged due to severe flooding in 2000, resulting in concurrent data gaps.

Stations with data gaps that spanned too long a period (more than a year of consistently missing data) were excluded from this research project. For example, the Phalaborwa weather station is in a prime location for this study given its proximity to the Mamba gauging station along the Olifants River. However, a 30-year gap exists in the rainfall record.

Another limitation to this study is the relatively short temporal record for which rainfall and more particularly, river flow data are available for analysis. Most the records were too short for comprehensive trend analysis, thus limiting the detection of cyclical trends. In addition, many of the stations had differing dates of inception, and thus when comparing rainfall and river flow trends, the data set of the shortest durations had to be used to do correlation tests.

The lack of high quality long-term river flow data is of concern for this study. For instance, most of the river stations provide between 30-50 years of flow data. Longer river flow data sets would have allowed for the analysis of a longer temporal trend analysis for rainfall impact on river flow in the area.

Table 4.3 Percentage missing data from the selected weather stations

Station Name	Total Number of days	Number of Days with data	Percentage of Data Missing
Pafuri	29432	28946	1.65%
Punda Maria	33261	31023	6.73%
Shingwedzi Vlakteplas	11657	11350	2.64%
Shingwedzi	17652	17095	7.16%
Thohoyandou	11871	11687	1.55%
Palmaryville	39447	38351	2.78%
Krugerwildtuin Shangoni	20965	20759	0.09%
Letaba Mahlangeni	10378	10073	2.94%
Hans Merensky Hoerskool	32261	32261	0%
Zomerskonst	33631	33630	0.01%
Letaba	30347	27178	10.45%
Gravelotte	15630	15629	0.02%
Hoedspruit	7364	7347	0.23%
Satara	26784	24343	8.11%
Champagne Nat	30987	28639	7.58%
Allendale	15856	15276	3.66 %
Onverwag Bos	18809	18472	1.81%
Pilgrams Rest	40694	39720	2.4%
Skukuza	37828	35023	7.42%
Sabie	15399	15398	0.01%
Stolznek	11808	11807	0.01%
Nelspruit	40083	32544	18.8%

Table 4.4 Percentage missing data from selected river-gauging stations

River	Station number	Total number of days	Number of days with data	Percentage missing data
Luvuvhu	A9H012	9862	9441	4.3%
Mutale	A9H013	8766	7174	18%
Shisha	B9H001	19723	18054	8%
Mphongolo	B9H004	10593	10356	2.2%
Shingwedzi	B9H002	11323	11046	2.4%
Shingwedzi	B9H003	10593	10530	0.6%
Tsendze	B8H011	19723	19398	1.7%
Letaba	B8H008	20089	16836	16%
Letaba	B8H034	9496	6684	29%
Letaba	B8H018	10957	9527	13%
Olifants	B7H015	9862	8862	10%
Timbavati	B7H020	9862	8822	10.5%
Nwanedzi	X4H004	20089	16465	18%
Sand	X3H008	17167	14336	16%
Sabie	X3H021	8766	8764	0%
Sabie	X3H015	10227	9090	11%
Nsikazi	X2H072	9131	6658	27%
Crocodile	X2H006	31411	31401	0.03%
Crocodile	X2H046	10592	10401	1.8%
Crocodile	X2H016	19732	17887	9%
Komati	X2H036	11688	10939	6.4%

The stations that have missing data from their records remained as omitted data rather than being completed by intercalated values which could be misleading due to the inter-annual variability within the data which has been shown in the trends in *Chapter Five*. The fact that missing data remained omitted, allows for the assurance that there were no misleading trends generated through the inclusion of intercalated values.

Lastly, another limitation to be highlighted is the distance between the weather stations and the gauging stations. In most cases, rainfall stations were chosen based on their location within proximity to flow gauging stations. However, in some cases, weather stations were chosen for the richness of their data, and instead of being located within a proximity to the gauging station, they are located upriver of the gauging stations. This is however beneficial because the rainfall upriver of the gauging station will allow for further analysis of how river flow trends react to rainfall phases upriver.

4.3 Methodology

4.3.1 Initial Data Analysis

Initial data manipulation for both the rainfall and river flow datasets involved sorting the sourced data and compiling average monthly and annual rainfall and river flow as well as the variability of the data over the period. The number of annual rain days, as well as the number of extreme annual rain days, was counted. Rainfall exceeding 15mm a day was categorised as a heavy rainfall event and rainfall exceeding 25mm per day was categorised as an extreme rainfall event (Dyson, 2009).

Initial analyses involved depicting time-trends for both total annual rainfall and river flow data for each station. Correlation / regression analyses allowed for investigation into whether a variable (either rainfall or streamflow) has increased or decreased with increasing time. (Longobardi and Villani, 2009). *Microsoft Excel* and *InStat* were used for correlation and regression analyses, and their statistical significance.

To determine the variability of the rainfall and river flow in the study region the standard deviation and coefficients of variation were determined for each individual rainfall station. The coefficient of variation provides information on inter-annual rainfall variability, with higher coefficients of variation reflecting higher temporal rainfall variability (Black, 2011). Coefficients of variation were calculated for rainfall records for each weather station per decade to determine changes in rainfall variability between decades. The coefficient of variation is calculated by taking the decadal standard deviation of rainfall and dividing it by the mean annual rainfall for that decade:

$$\textbf{Coefficient of Variation (CV)} = \frac{\textbf{Standard Deviation}}{\textbf{Mean}} \textbf{ X 100}$$

$$\textbf{CV} = \frac{\sigma}{\bar{\chi}}$$

Additional rainfall analyses explored the changes in the length of the wet season (defined here as October-April after Halpert and Bell, 1996), as the changes in the length of the rainfall season have implications for many environmental factors. The three main aspects analysed include changes in the onset of the rainy season, changes in the length of the wet season and trends in the frequency of occurrence of extreme rainfall events.

In semi-arid regions of the world, for example the study location, the determination of the start of the wet season is a crucial factor for many ecological reasons. The onset of the rainy season in the semi-arid parts of South Africa is defined as:

(i) The date of the first two pentads (pentad=5 consecutive days) experiencing at least 25mm rainfall provided the following 4 pentads experience 20mm rain (Reason *et al*., *2005)*.

(ii) The date of the first two days where at least 10-30mm rainfall is recorded, with no dry period exceeding 10 consecutive days thereafter (Kniveton *et al.,* 2008).

(iii) The date where an accumulative 25mm rain has fallen over 10 days and at least 20mm falls in subsequent days (Tadross *et al.,* 2005, Moeletsi and Walker, 2012).

The third definition was adopted here. More specifically, the start of the wet season was defined as the start date where at least 25mm of rain was recorded over 10 days, and a consistent rainfall of 20mm or more was experienced in the days that followed.

The end of the wet season is defined as the last date on which an accumulative 25mm of rain has occurred over 10 days (Moeletsi and Walker, 2012) and is needed to calculate the length of the wet season for each year. The length of the wet season is therefore calculated by subtracting the start date of the rains (in Julian days) from 365, then adding the Julian days for the end of the rains (Moeletsi and Walker, 2012).

The streamflow data constitutes daily readings of flow volumes, taken each morning, for a river. The daily streamflow values were averaged and totaled for monthly and annual values for each of the 21 gauging stations. The timing of the wet season was then compared to the timing of the start of river flow events (a non-zero flow in annual rivers) to determine the relationship between the two variables. Specifically, changes in the timing of the wet season over the study period were compared to concurrent changes in river flow patterns within the park.

4.3.2 Further statistical analysis

Inter-annual, seasonal and 5-year moving average rainfall trends were analysed over the long-term for each region (*Table 4.1*) to determine spatial patterns of change in rainfall. The rainfall and river flow data were divided into early-, mid- and late- rainfall seasons to account for within-season changes. The early season was defined as October and November, mid-season as December-February, and late season as March and April (Tyson, 1986).

Rainfall and streamflow data were further analysed using the Mann Kendall (MK) statistic. The non-parametric Mann Kendall test is best suited to detect monotonic and non-linear trends in environmental data such as hydrological data and rainfall and river flow records (Pohlert, 2016). The reasoning behind using non-parametric analysis, compared to parametric testing, is that the former has a higher power for non-normally distributed data sets, which is particularly characteristic of hydrological records (Pohlert, 2016).

MK statistical analysis tests the null hypothesis (H_0) that the data is independent and distributions free and that no trend exists in the data set (Pohlert, 2016). MK calculates an S variable (sum of the difference between data points):

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(X_j - X_i)$$

Where *n* is the number of values in the data set, sgn is sign and *S* is normally distributed when *n* is greater than or equal to 8 (Novotny and Stefan, 2007), which allows for the calculation of the variable Z, with a mean value of 0 and a variance of 1 (Pohlert, 2016), calculated by:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \quad S > 0 \\ 0 & if \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \quad S < 0 \end{cases}$$

Where *var* is the variance (Pohlert, 2016).

The normalised test statistic was calculated using the Excel template *Makensens* (MK test for trends and Sens slope estimates) (Makensens, 2002). Positive values for Z_{MK} indicate increasing trends, whilst negative Z_{MK} values indicate decreasing trends (Shadmani *et al.,* 2011). The null hypothesis (which states there is no significant trend), is rejected if there is a significance value (p-value) of <0.05 allocated to the Z value. A significant increasing trend is thus present when the Z value is positive, and the significance value is <0.05. A significant decreasing trend is indicative of a negative Z value and a significance level of <0.05. The p-value was calculated using the Microsoft Excel function. A significance level of p=0.05 was used throughout this study.

For the comparison of rainfall and river flow data, the Sens non-parametric method, as well as the MK Tau method, were used to determine correlation coefficients and magnitudes of trend slopes.

The Sens non-parametric method was used specifically to determine magnitudes of trend slopes. This method is advantageous here as it limits the influence of outliers on the slope (Shadmani *et al.,* 2011). The Sens slope estimator is a good statistical test for hydrological data sets, as many climate and river flow data sets exhibit a marked skewness due to extreme natural phenomena (Shadmani *et al.,* 2011), and do not follow a normal distribution pattern. Sens slope is used to estimate the direction of a slope for a linear trend (here change over time).

$$f(t) = Qt + B$$

Where Q is the slope, B is a constant and t is time (Drapela and Drapelova, 2011).

The MK Tau method was used to determine the correlation between rainfall and streamflow over the same period, in the same region. The MK Tau correlation coefficient is regarded as the non-parametric alternative to the Pearson's correlation coefficient. To determine the correlation between the variables rainfall and river flow, Winstat was installed into Excel, and the MK Tau correlation coefficient calculated.

MK Tau values range from -1 to +1, with positive values indicating that the two variables increase together and negative values indicating an inverse relationship (Helsel and Hirsch, 1992).

The MK statistic, MK Tau and Sens slope were applied to the inter-annual, seasonal and 5 year-moving averages of rainfall and river flow data, as presented in *Chapter 5*.

4.3.3 Determining the relationship between rainfall and streamflow

To determine the relationship between rainfall and streamflow, correlation statistics are used to depict the strength of the relationship between rainfall and river flow between the two closest related stations within the same catchment. Due to Southern Africa being impacted directly by El Niño phases, these El Niño phases have been identified using the literature (Null, 2017), and a graphic representation of streamflow during El Niño years is depicted. Each river gauging station is analysed in relation to El Niño phases. The percentage of deviation of river flow from the annual mean will be compared to each El Niño phase that is mentioned in the literature.

4.3.4 Impacts of dams on downstream flow

Lastly, the evaluation of the impact of dams on river flow will be analysed at the end of *chapter Five.* Due to limiting length of data sets from the gauging stations, it is not ideal to compare flow patterns before and after dam construction, as gauge station records begin around the date of dam wall construction. Analysing flow patterns before and after a dam wall breach depicts the impact of dams on downstream flow. The floods of 2000 and 2012 resulted in the breakage of a few dams along the river Letaba, and thus this river data was analysed for the period before and after dam wall breakage. Rainfall events of the same or similar intensity and length were used for before and after dam breakage, and flow patterns were compared for these different rainfall events. Dam impact on flow was not a major focus of this research and thus this initial analysis opens a potential further research question for evaluation in the future.

CHAPTER FIVE: RESULTS

Chapter 5 has been organised into two sections due to the differing nature of the datasets. This dissertation aims to outline the impacts that varying rainfall trends have on river/stream flow patterns of the KNP rivers. The rainfall datasets span a much longer period than those of the river gauge datasets, as these rainfall stations were installed long before river gauge stations were built in the KNP. Some rainfall records span 80-100 years, whereas the river records only span 30-50 years in length. Rainfall trends are outlined in section A, and the relationships between rainfall and river/stream flow trends are outlined in section B.

Section A

5.1 Introduction

Due to the location of the KNP and the importance of this protected area for both the conservation of wildlife species and the added benefit of tourism income for South Africa, this study proves invaluable to the management and protection of freshwater sources in the face of an ever changing and variable climate. Initial analysis of the data available highlights considerable interannual rainfall variability in all areas observed in and around the KNP over the past century. Consequently, trends and relationships were assessed for each of the variables, first by station, then through a comparison of all stations within and adjacent to the park.

5.2 Rainfall results

This dissertation collected data from 21 weather stations located within the KNP as well as adjacent to the KNP, along the highveld region. The study area includes regions outlying the KNP boundary so to analyse climate conditions and trends in and around the park. Many of the river systems that flow through the KNP have their origins approximately 100 kilometers outside the park boundary, and it is thus imperative to analyse rainfall patterns in these outlying regions. For the purposes of analyzing results, the weather stations chosen are categorised into different regions based on elevation variables. The weather stations fall into one of three regional categories including the lowveld (elevation >500m), the bushveld (elevations 501-1400m) and the highveld (elevation <1500). The weather stations have been categorised in Table 5.1.

Table 5.1 Station location and elevation

Station	Elevation (m)	Regional category
Pafuri	408	Northern lowveld
Punda Maria	466	Northern lowveld
Shingwedzi	367	Northern lowveld
Shingwedzi Vlakteplas	347	Northern lowveld
Palmaryville	647	Northern bushveld
Hans Merensky Hoerskool	775	Northern bushveld
Gravelotte	549	Northern bushveld
Thohoyandou	601	Northern bushveld
Zomerkomst	789	Northern bushveld
Letaba	227	Northern lowveld
Letaba Mahlangeni	303	Northern lowveld
Krugerwildtuin Shangoni	425	Northern lowveld
Onverwag Bos	930	Southern bushveld
Champagne Nat	541	Southern bushveld
Nelspruit	857	Southern bushveld
Sabie	1043	Southern bushveld
Pilgrams Rest	1278	Southern bushveld
Skukuza	263	Southern lowveld
Satara	270	Southern lowveld
Malelane	333	Southern lowveld
Stolznek	562	Southern lowveld

Section A of chapter 5 will outline total annual rainfall, changes in frequency and intensity of rainfall events, and a comparison between rainfall and rain days for all four regions of the study area. Observations and the analysis of trends in early, mid and late rainfall seasons will represented for all regions, Mann Kendall trend statistics for seasonal rainfall are represented, as well as the role El Nino plays in the variable rainfall analysed for these weather stations in and around the KNP.

5.2.1 Northern bushveld

The northern bushveld region includes 5 weather stations all with varying dataset length (*Table 5.2*). The rainfall variability of rainfall recorded at these stations is high, varying from interannual ranges of 1944mm to 2175mm (*Table 5.2*).

5.2.1.1 Total annual rainfall trends

It is important to analyse cyclical trends with longer rainfall datasets to determine running means. The longer datasets (70-100 years) will represent cyclical analysis and statistical significance will be determined for these long-term rainfall trends. Palmaryville, Hans Merensky and Zomerkomst will be further analysed for long-term climate trends. Gravelotte and Thohoyandou rainfall datasets will be used to determine more recent trends (last 3 decades) to see if rainfall trends are changing more drastically over time.

For the weather stations with longer data sets, the 5-year moving average trend line indicates a cyclical trend to the rainfall patterns. Linear trends indicate that Palmaryville has a highly significant decreasing linear trend (-2.00mm/annum) from 1907-2014, within the significance level of 95% (*Figure 5.1*). Hans Merensky Hoerskool has a non-significant decreasing linear trend (-0.34mm/annum) from 1927-2014 (*Figure 5.2*), and Zomerkomst has a non-significant increasing linear trend (+1.96mm/annum) from 1923-2014 (*Figure 5.3*). The shorter weather stations, Gravelotte and Thohoyandou, rainfall trends depict a non-significant increasing trend during the period 1971-2012 (*Figure 5.4*) and 1983-2014 (*Figure 5.5*) respectively.

The cyclical pattern for rainfall experienced at all rainfall stations (*Figures 5.1 to 5.5*) for this region contribute to the extremely high interannual rainfall ranges experienced for the northern bushveld. This cyclical pattern indicates that rainfall variability has a major impact on this region. Reasons for interannual rainfall variability in southern Africa will be further investigated and discussed at the end of this section, and throughout chapter 6.

Table 5.2 rainfall characteristics for stations in northern bushveld region

Station	Years of data	Mean annual rainfall (mm)	Lowest recorded annual rainfall	Highest recorded annual rainfall	Range (mm)
Palmaryville	1907-2014	907.7	1983: With 338mm	2000: With 2282.7mm	1944.7
Hans Merensky Hoerskool	1927-2014	991.38	2002: With 224mm	2000: With 2402.9mm	2158.9
Gravelotte	1971-2011	445.3	1982: With 154mm	2000: With 1044.5mm	840.5
Thohoyandou	1983-2014	765.02	1983: With 330mm	2000: With 1653.9mm	1323.2
Zomerkomst	1923-2014	1080.97	1923: With 449.7	2000: With 2624.8mm	2175.1

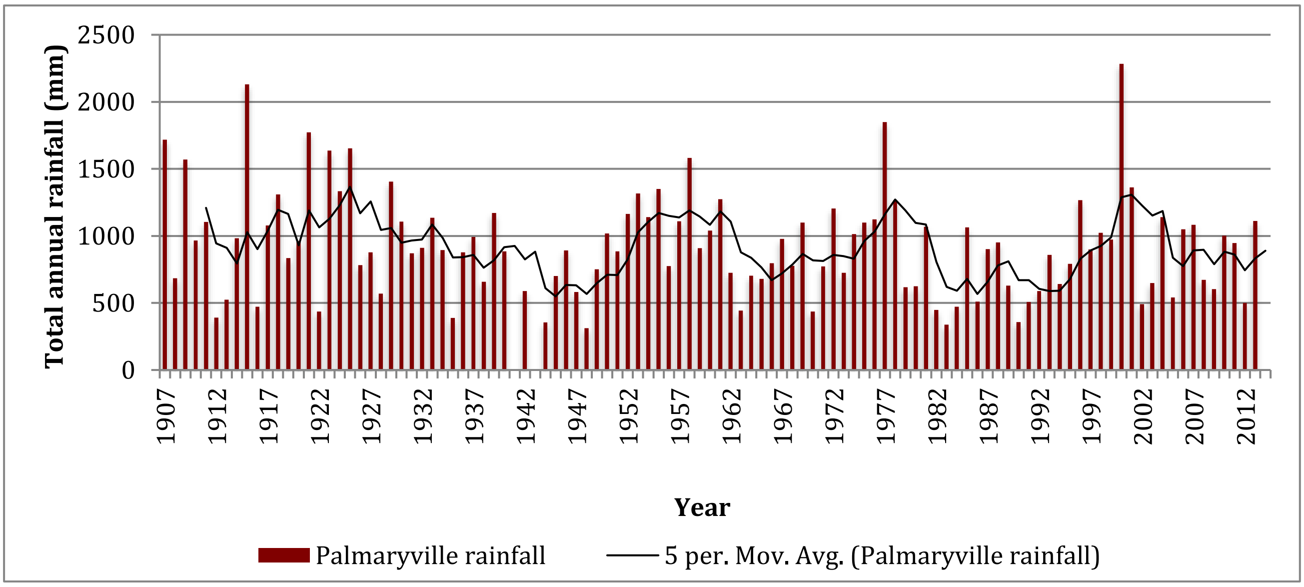


Figure 5.1 Total annual rainfall of Palmaryville weather station (1907-2014)

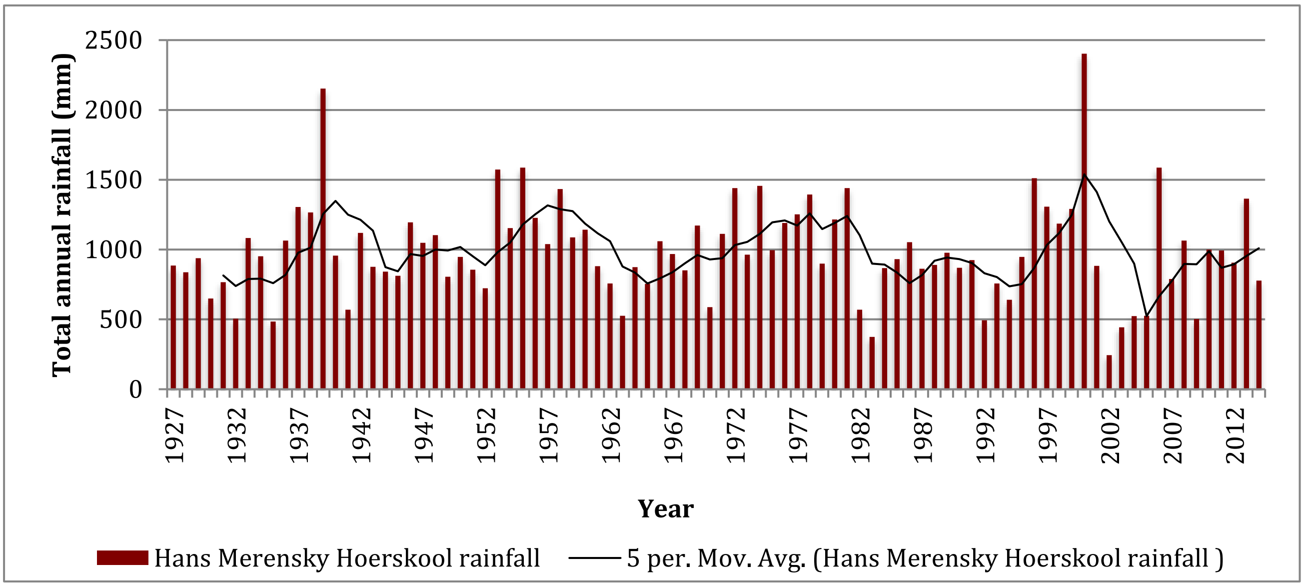


Figure 5.2 Total annual rainfall and 5 year moving average trend line of Hans Merensky Hoerskool rainfall station

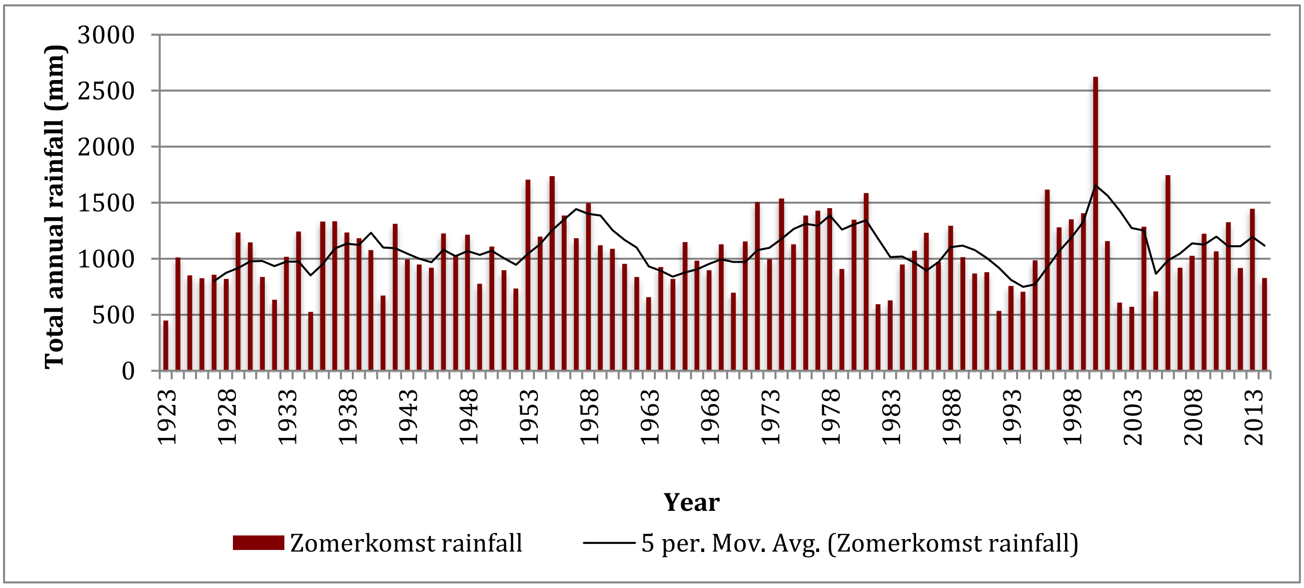


Figure 5.3 Total annual rainfall and 5 year moving average trend line of Zomerkomst rainfall station

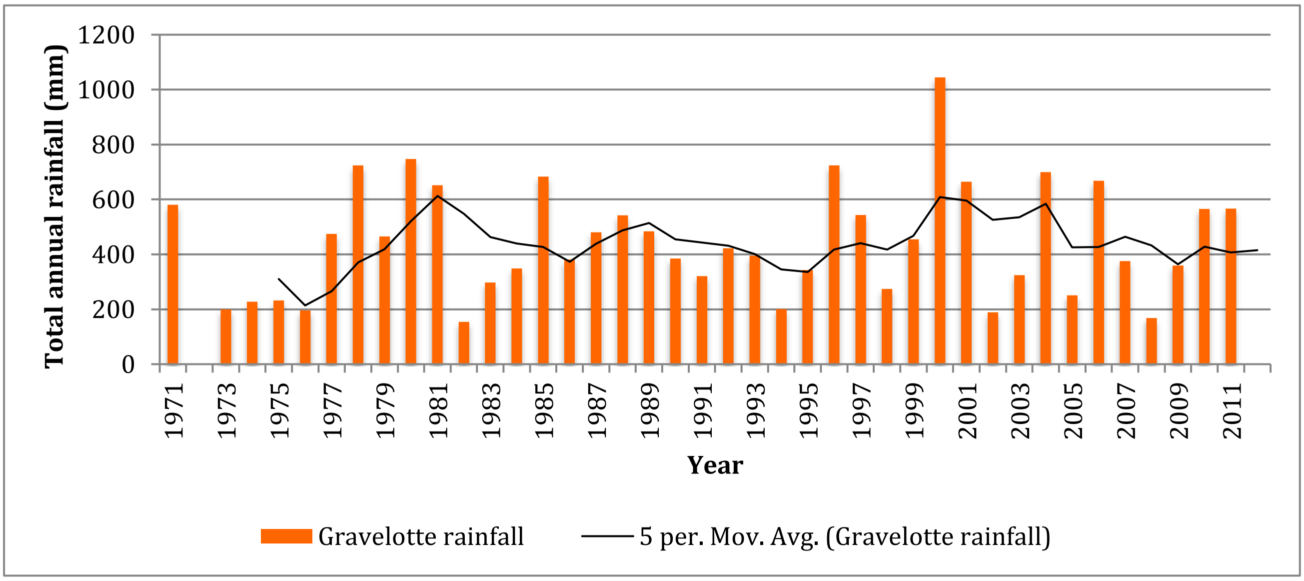


Figure 5.4 Total annual rainfall of Gravelotte weather station (1971-2011)

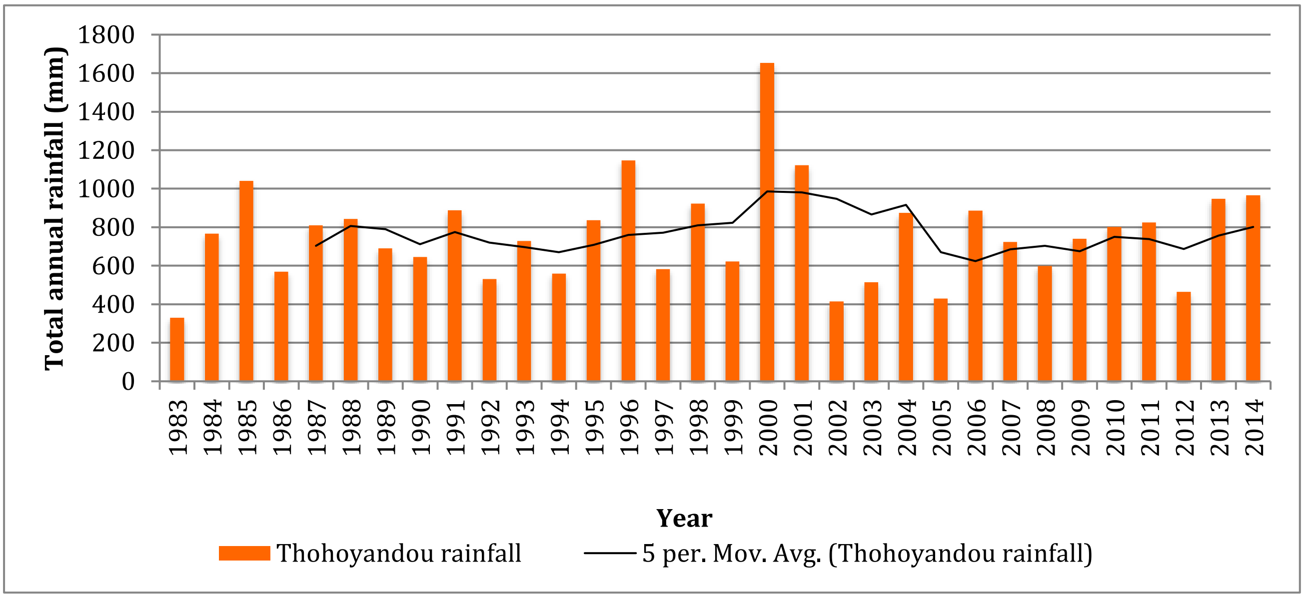


Figure 5.5 Total annual rainfall of Thohoyandou weather station (1983-2014)

5.2.1.2. Total annual rainfall days

Analysing patterns and trends for total annual precipitation in northeast South Africa will show no significant linear trends as rainfall in Southern Africa is cyclical and varies from year to year. Variations in total annual precipitations can be caused by changes in the frequency of precipitations events as well as changes in the intensity of these events, or a combination of the two. To better the understanding of rainfall behaviour as an indicator of climate change in KNP over the last century, daily precipitation series must be analysed.

Trends and patterns in wet days for each weather station will be represented for all regions of the study area. This study aims to analyse the variations in heavy and extreme rainfall events. The behaviours and patterns generated for extreme rainfall events could indicate projections for future events, which will impact the environment and management of the KNP, protected area.

Few studies have focused on this area of study, probably due to the lack of high quality daily rainfall data. It is thus re-emphasized, that the weather stations chosen for representation for this dissertation have been included due to their high-quality data records, and low percentage of missing data.

Palmaryville, Hans Merensky Hoerskool, Thohoyandou and Zomerkomst all reflect a decrease in the total number of annual rainy days, with the decline in rain days at Hans Merensky and Zomerkomst being highly statistically significant at the 95% significance level (*Table 5.3*). Palmaryville depicts a decline in the number of annual rain days (down 10%) and heavy rain days (down 9%) but an increase in extreme rain days (up 16%) during the period 1907-2014. Hans Merensky Hoerskool depicts a highly significant decrease in total annual rain days by 12.4%, with a non-significant decrease in heavy rain days by 0.5% during the period 1927-2014. Zomerkomst rainfall station depicts a highly significant decrease in annual rainfall days by 6.4%, and an insignificant decrease in heavy rain days, whilst the extreme rain days at Zomerkomst depict an increase of 3% respectively during the period 1923-2014. Trends for rainfall days at Thohoyandou are all non-significant within the 95% significance level, with total annual rainfall days declining by 3%, whilst heavy and extreme rainfall days increase by 3.5% and 10.6% respectively during the period 1983-2014. Gravelotte is the only rainfall station to depict an increase for total annual rain days, heavy and extreme rain days, with a highly significant increase of 47% for total annual rain days, and a non-significant increase in heavy (1%) and extreme (16.3%) rain days. An overall analysis of rain day behaviour for the northern bushveld region suggests that total annual rain days are decreasing over time, however, heavy and extreme rainfall days are generally increasing, suggesting that heavy and extreme rainfall events are becoming more common, and more days during the year are experiencing heavier rainfall over time. The increase in heavy and extreme rainfall events for Zomerkomst, Hans Merensky Hoerskool, Thohoyandou and Gravelotte are therefore contributing factors to the stations overall increasing total annual rainfall trends.

Table 5.3 Mann Kendall trend statistic results for the annual rainfall day characteristics for the northern bushveld (*WD represent Wet Days).

Station	Category	Normalised Test Statistic (Z)	P-Value	Trend (A 95% Significance level)	Sens Q (Slope)	Sens B (Slope)
Palmaryville	WD	-1.19	0.12	Decreasing	-0.088	58.6
	Heavy	-1.80	**0.04***	**Decreasing**	-0.044	19.8
	Extreme	1.77	**0.04***	**Increasing**	-0.032	12.6
Hans Merensky Hoerskool	WD	-1.91	**0.03***	**Decreasing**	-0.152	63.97
	Heavy	-0.27	0.4	Decreasing	0	20
	Extreme	0.10	0.46	Increasing	0	12
Gravelotte	WD	3.34	**0.0004***	**Increasing**	0.5	18.5
	Heavy	0.26	0.38	Increasing	0	9
	Extreme	1.09	0.14	Increasing	0.038	3.29
Thohoyandou	WD	-0.78	0.21	Decreasing	-0.225	94.42
	Heavy	0.62	0.27	Increasing	0.056	13.81
	Extreme	0.93	0.18	Increasing	0.053	7.50
Zomerkomst	WD	-1.79	**0.04***	**Decreasing**	-0.123	78.49
	Heavy	-0.43	0.33	Decreasing	0	20
	Extreme	0.34	0.37	Increasing	0	12

5.2.1.3 Total annual rainfall vs. rainfall days in the northern bushveld

The analysis of total annual rainfall vs. total annual rain days for the northern bushveld region produced a myriad of results. Some weather stations experienced a positive correlation between rainfall and rain days while others experienced a negative correlation between the two variables.

Palmaryville (*Figure 5.6*), Zomerkomst (*Figure 5.7*) and Hans Merensky Hoerskool (*Figure 5.8*) weather stations were used to represent the comparison between total annual rainfall and total annual wet days for the period 1927-2014. The longer rainfall datasets provide an 87-year record for analysis. The analysis of these variables over such a lengthy time allows for detailed analysis into the changes in the trends of these variables over time as well as the evaluation of the relationship between the two variables. Palmaryville station experiences a decrease in wet days and an increase in total rainfall (1922-

1931) (*Figure 5.6).* During these time periods the rainfall is more intense, suggesting shorter more intense burst of rainfall, for example afternoon thundershowers and tropical cyclones. Zomerkomst and Hans Merensky weather station shows a consistent and positive relationship between the two variables. In chapter six, an in-depth analysis into these finding will be outlines, where tropical cyclones and massive storm events are explored to determine the reasoning behind these trends.

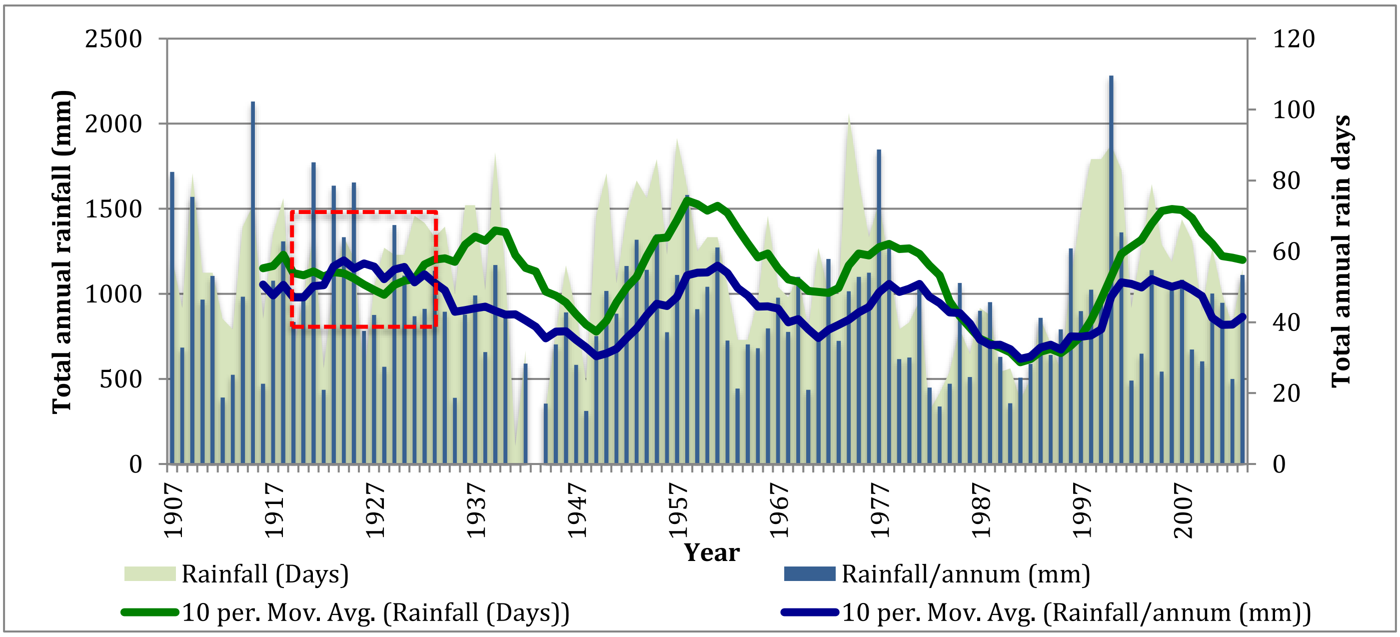


Figure 5.6 Total annual rainfall vs. total annual wet days for Palmaryville weather station (1927-2014) Red boxes highlight periods of inversed results

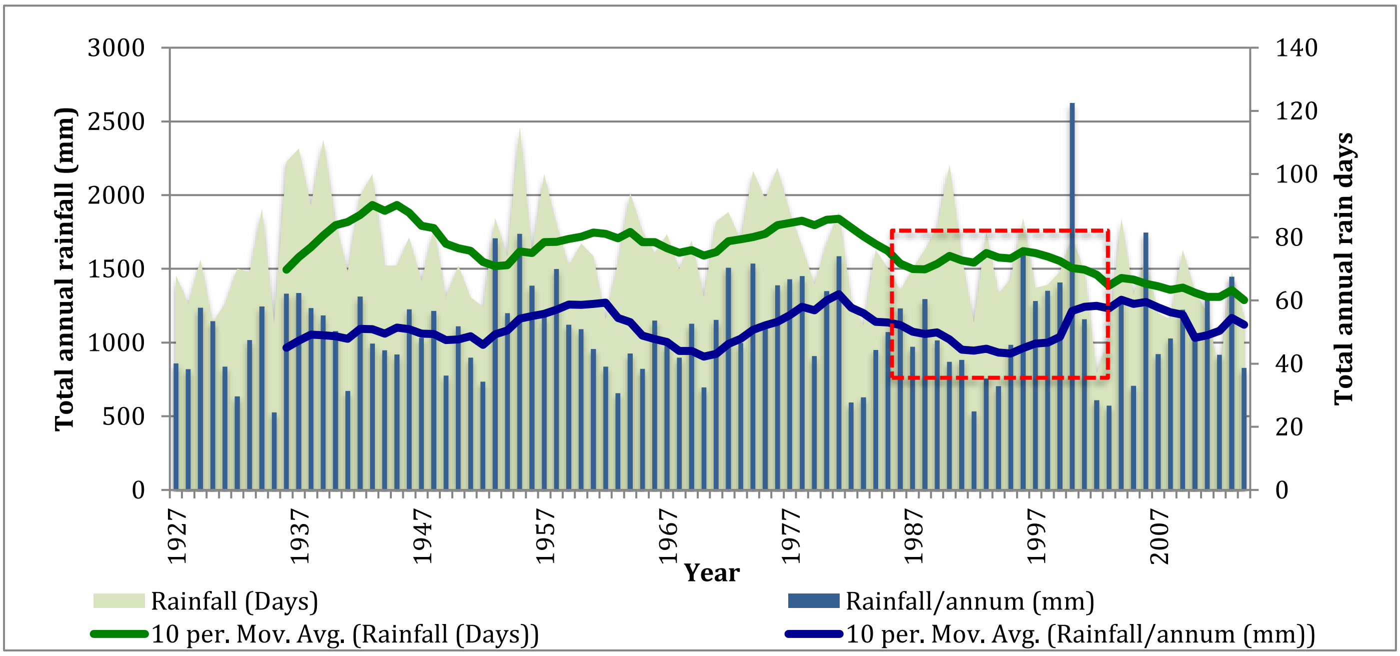


Figure 5.7 Total annual rainfall vs. total annual rain days for Zomerkomst weather station (1927-2014) Red boxes highlight periods of inversed results

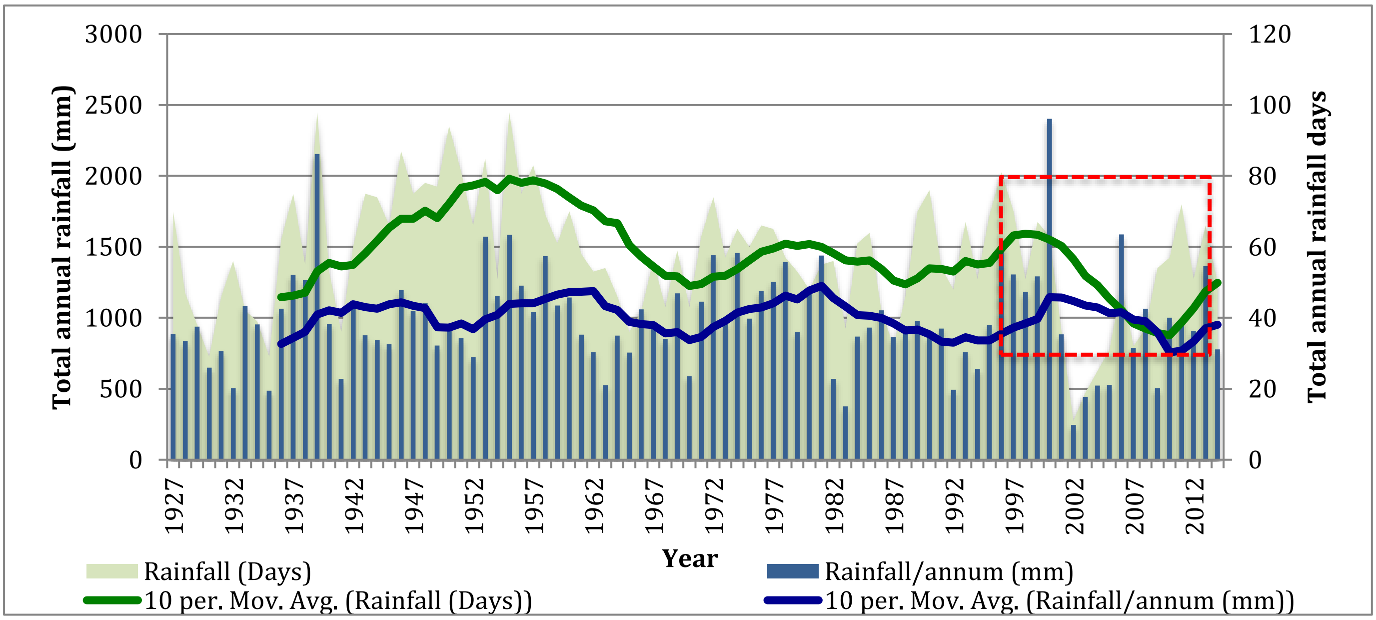


Figure 5.8 Total annual rainfall vs. total annual rain days for Hans Merensky Hoerskool weather station (1927-2014) Red boxes highlight periods of inversed results

5.3.1 Northern lowveld

The northern lowveld region includes 7 weather stations all with varying dataset lengths (*Table 5.4*). The rainfall variability recorded at these weather stations is high, with interannual rainfall variations of between 736.2mm to 1168.8mm (*Table 5.4*).

5.3.1.1 Total annual rainfall trends

All seven northern lowveld rainfall stations were graphed with a 5-year moving average trend line. The 5-year moving average trend lines for all rainfall stations show a cyclical trend for the rainfall. The longest rainfall stations, including, Pafuri, Punda Maria and Letaba, all depict increasing temporal rainfall trends, with Pafuri (*Figure 5.9*) experiencing an increase of 5.7% in rainfall from the first to the second half of its recorded period (1924-2014). Punda Maria (*Figure 5.10*) experiences an increase of 8.2% from 1925-2014, and Letaba (*Figure 5.11*) depicts a 7.9% increase in rainfall from 1928-2012. Mid length rainfall stations, Shingwedzi and Krugerwildtuin, however, depict decreasing rainfall trends with Shingwedzi (*Figure 5.12*) recording a decrease in rainfall of 10.6% from 1958-2005, and Krugerwildtuin Shangoni (*Figure 5.13*) depicting a highly significant decrease in rainfall by 20% between 1958-2014. The shorter rainfall datasets which include Shingwedzi Vlakteplas (*Figure 5.14*) and Letaba Mahlangeni (*Figure 5.15*), both depict non-significant increasing trends in rainfall, by 15% and 20.7% respectively.

The rainfall in this region is highly variable (*Table 5.4*) with ranges between 114.4mm (Pafuri 2006) and 1327.6mm (Punda Maria, 2000). High interannual rainfall variability is indicative of the influences of the El Nino Southern Oscillation, a topic that will be discussed further on in chapter 5.

Table 5.4 rainfall characteristics for stations in the northern lowveld region

Station	Years of data	Mean annual rainfall (mm)	Lowest recorded annual rainfall	Highest recorded annual rainfall	Range (mm)
Pafuri	1925-2014	414.9	2006: With 114.4mm	1930: With 850.6mm	736.2
Punda Maria	1924-2013	533.9	1983: With 160.8mm	1925: With 1327.6mm	1168.8
Shingwedzi	1958-2014	456.6	2002: With 147.4mm	2000: With 1149.6mm	1002.2
Shingwedzi Vlakteplas	1983-2014	467	1983: With 134.1mm	2000: With 995.2mm	861.1
Letaba	1928-2012	415.6	2002: With 105.9mm	2000: 1041.9mm	936
Letaba Mahlangeni	1987-2014	431.4	1994: With 227.3mm	2000: With 1077.2mm	849.9
Krugerwildtuin Shangoni	1958-2014	507.8	2009: With 125.8mm	2000: With 1229.2mm	1103.9

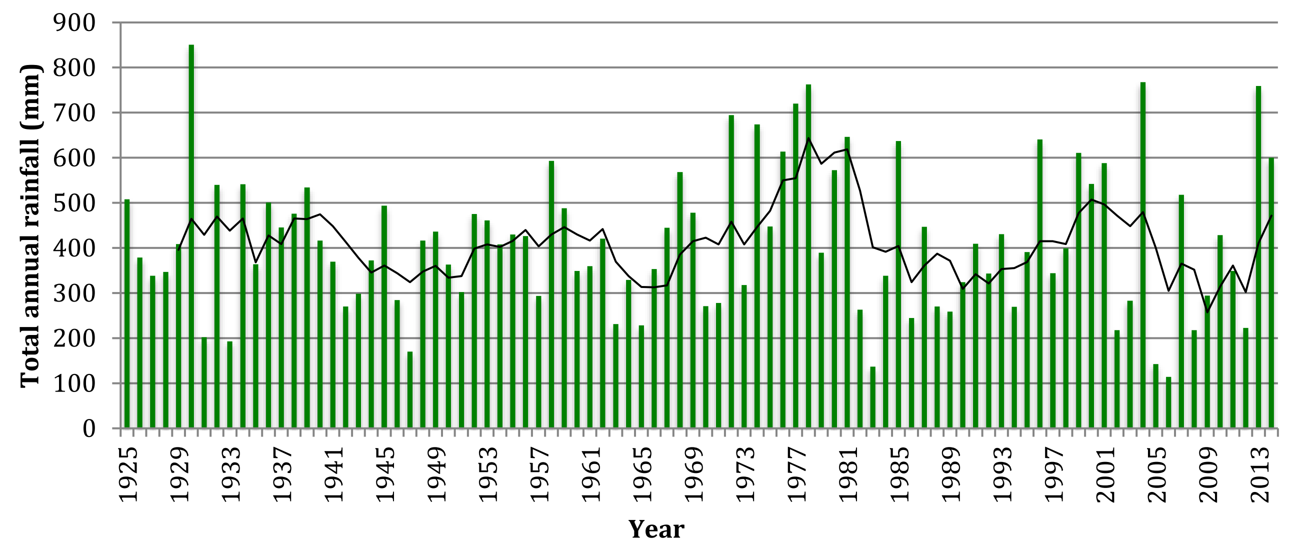


Figure 5.9 Total annual rainfall and 5 year moving average trend line of Pafuri rainfall station

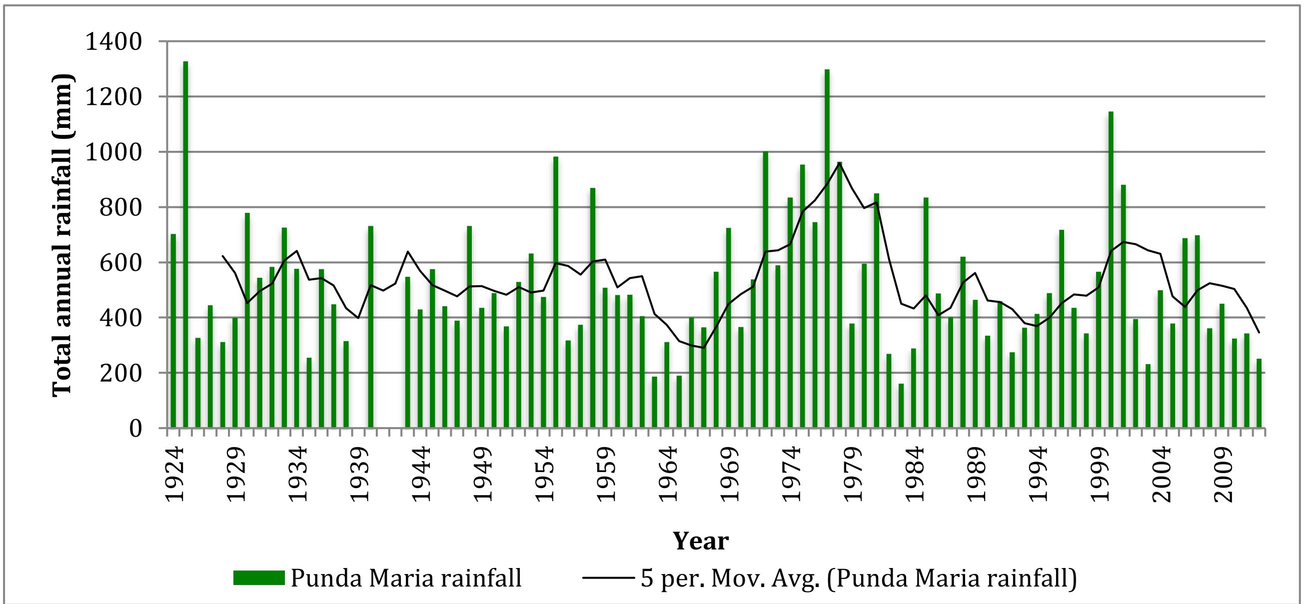


Figure 5.10 Total annual rainfall and 5 year moving average trend line of Punda Maria rainfall station

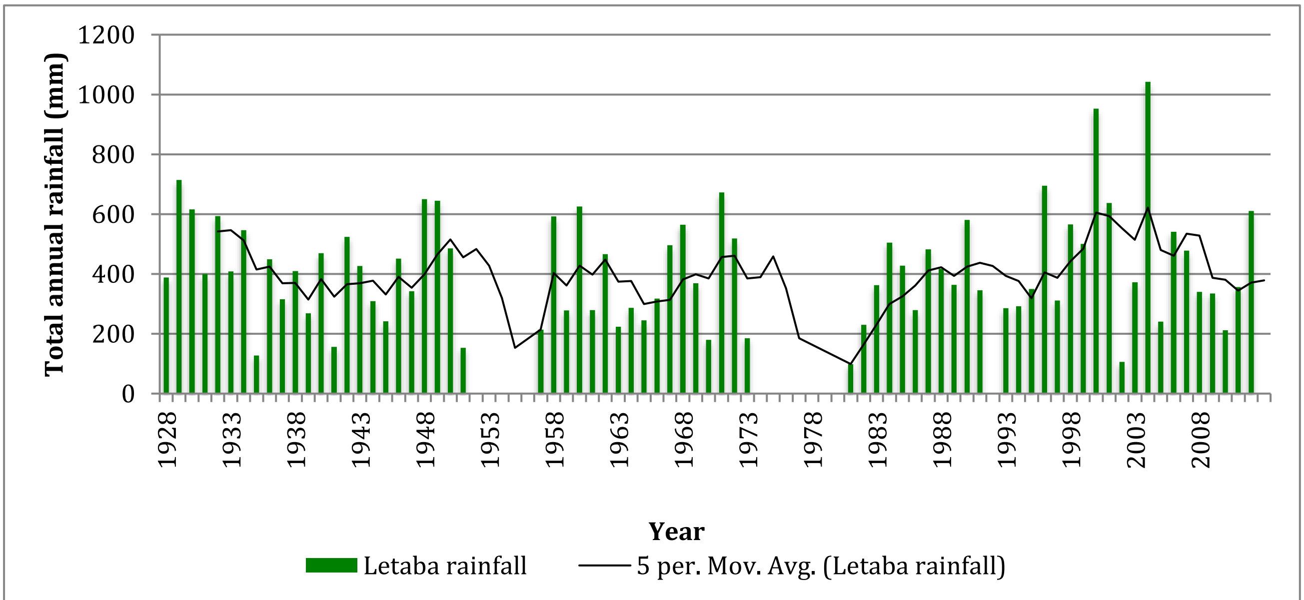


Figure 5.11 Total annual rainfall and 5 year moving average trend line of Letaba rainfall station

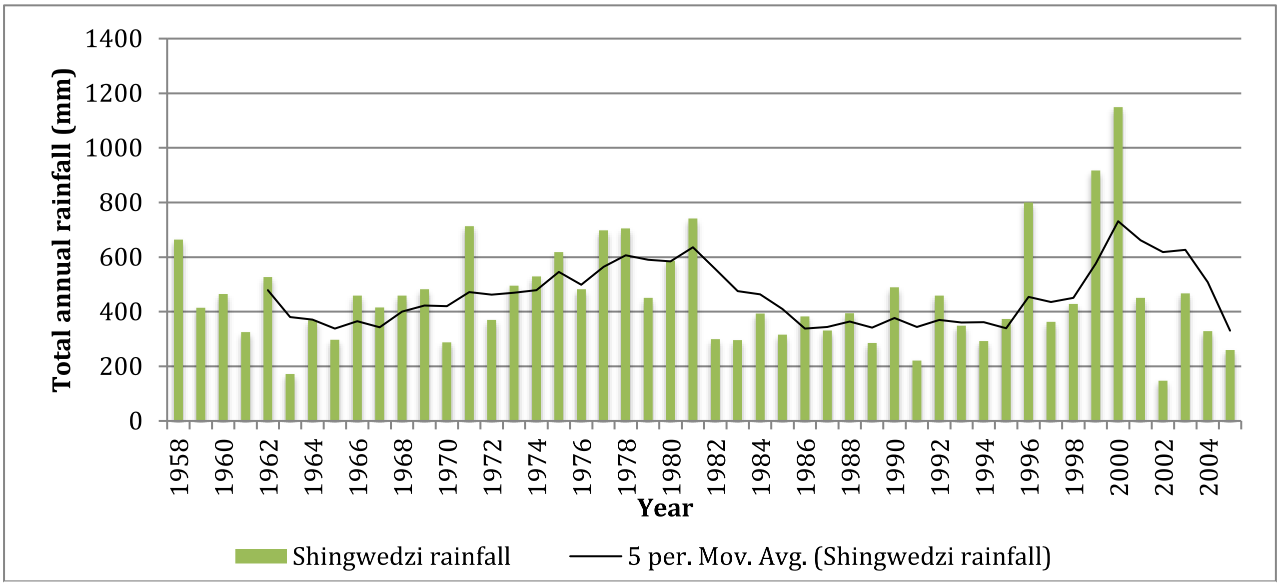


Figure 5.12 Total annual rainfall and 5 year moving average trend line of Shingwedzi rainfall station

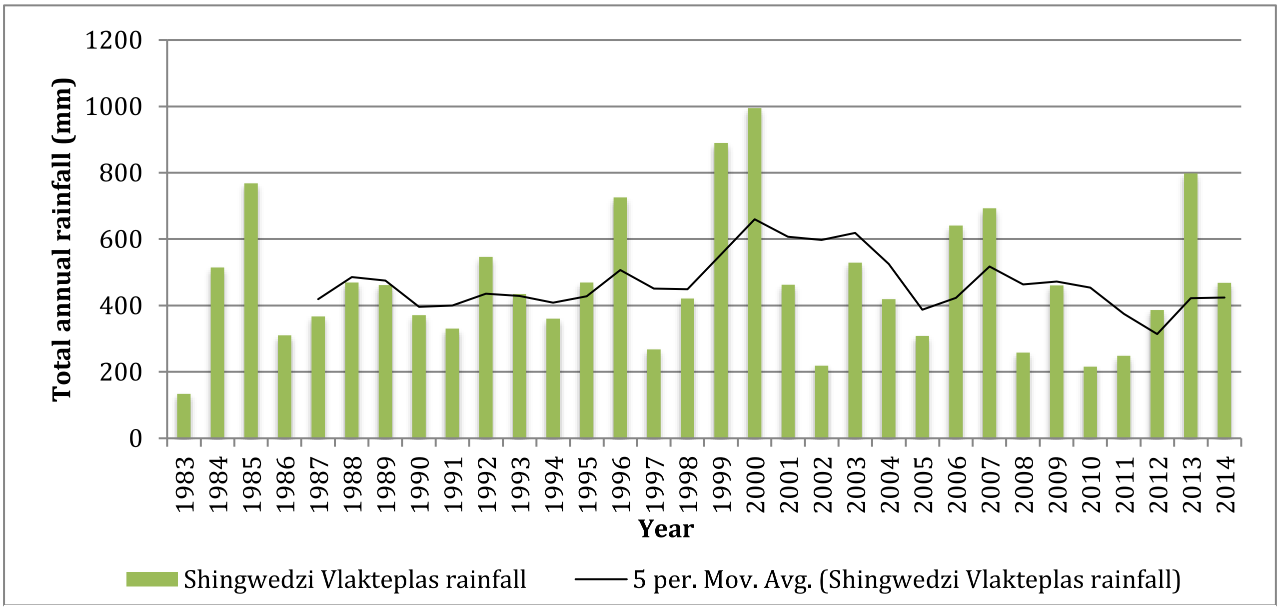


Figure 5.13 Total annual rainfall and 5 year moving average trend line of Shingwedzi Vlakteplas rainfall station

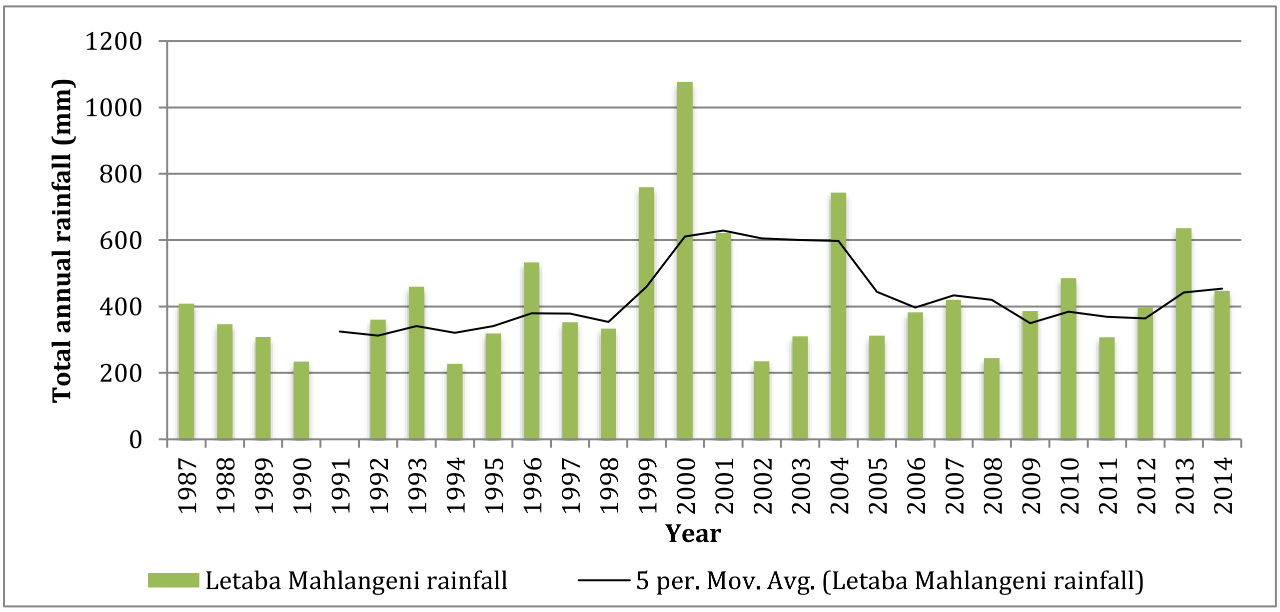


Figure 5.14 Total annual rainfall and 5 year moving average of Letaba Mahlangeni rainfall station

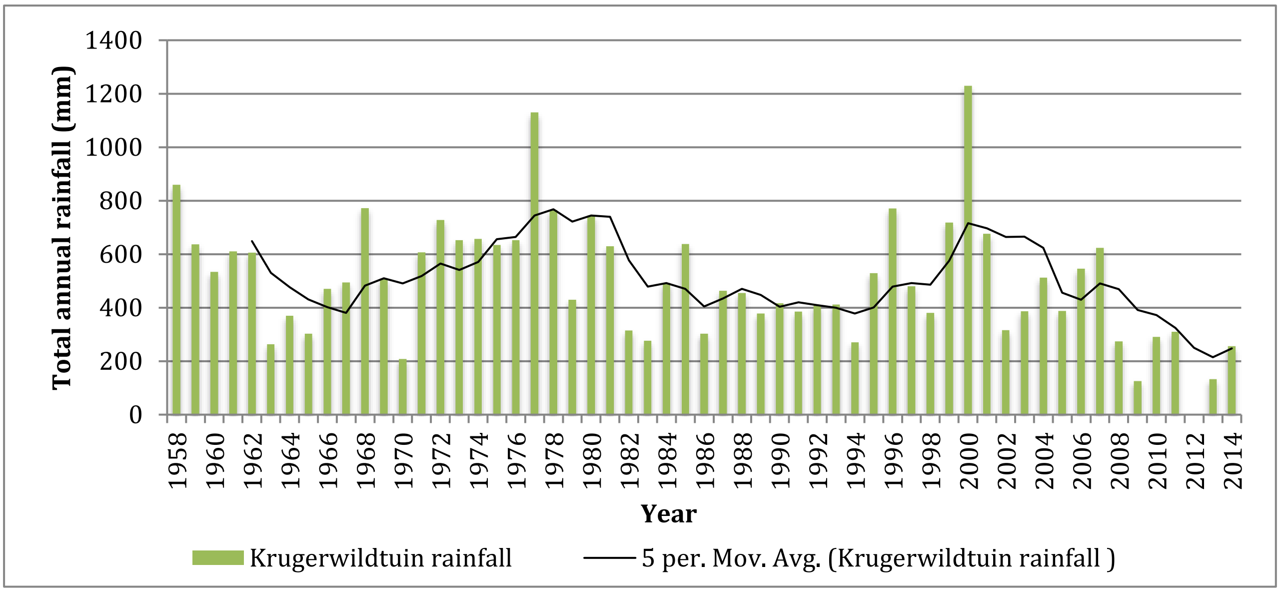


Figure 5.15 Total annual rainfall and 5 year moving average of Krugerwildtuin Shangoni rainfall station

5.3.1.2 Total annual rainfall days

Pafuri rainfall station depicts non-significant increasing trends for total annual rainfall days (11%), heavy rain days (6.4%) and extreme rain days (0.6%) during the period 1924-2014. The increase in the number of rain days is a major contributor to the overall increase in total annual rainfall for Pafuri (*Figure 5.9*). Punda Maria rainfall station depicts a non-significant increase of 25% for total annual rain days as well as a non-significant increase in heavy rain days (16%), whilst there is a decline in extreme rainfall days by 6.25% during the period 1924-2012. The high percentage increase for the total number of wet days, as well as the increase in heavy rainfall is a contributor to the overall increase in total annual rainfall for Punda Maria. Letaba Rainfall station depicts a non-significant increase in the number of total annual rain days, heavy rainfall days and extreme rainfall days during the period 1928-2012. The total annual rain days has increased by 12.5% whilst heavy and extreme rainfall days have increased by 7.8% and 9.5% respectively. Shingwedzi rainfall station depicts a decrease in the number of annual rainfall days (4.3%), as well as a decrease in annual heavy rainfall days (13.3%), whilst there is an increase in extreme rainfall days by 22% during the period 1958-2005. Shingwedzi Vlakteplas depicts a highly significant increasing trend in total rain days of 18% during the period 1983-2014, whilst heavy and extreme rainfall trends increase nonsignificantly by 8.8% and 30% respectively. This very interesting result suggests that although there is a decline in total annual rain days for Shingwedzi Vlakteplas, the increase in total annual rainfall as displayed earlier in this section, is a result of the high increase in the number of extreme rainfall days. Therefore, more intense rainfall events are occurring more frequently. Letaba Mahlangeni depicts an increase in all rain day categories, with an increase in total annual rain days by 4%, heavy rain days by 2.5% and extreme rain days by 22.5%. The increase in the number of rain days and the high increase in the number of extreme rain days is a major contributor to the increase in total annual rainfall experienced at Letaba Mahlangeni for the period 1987-2014. Lastly, Krugerwildtuin Shangoni depicts a highly significant decrease in total annual rain days (14%), heavy rain days (17%) and extreme rain days (25%), (*Table 5.5*). The decline in total annual rain days as well as the decline in extreme rain days is a major contributing factor to the 20% decline in total annual rainfall at Krugerwildtuin Shangoni (*Figure 5.15*).

Table 5.5 Mann Kendall trend statistic results for the annual rainfall day characteristics for the northern lowveld

Station	Category	Normalised Test Statistic (Z)	P- Value	Trend (A 95% Significance level)	Sens Q (Slope)	Sens B (Slope)
Pafuri	WD	1.66	0.05	Increasing	0.1	34.5
	Heavy	0.06	0.47	Increasing	0	8
	Extreme	0.75	0.22	Increasing	0	4.5
Punda Maria	WD	2.87	**0.002***	**Increasing**	0.222	39.67
	Heavy	0.52	0.3	Increasing	0	9
	Extreme	-1.70	**0.04***	**Decreasing**	-0.016	6.1
Letaba	WD	0.75	0.22	Increasing	0.026	39.7
	Heavy	0.18	0.43	Increasing	0	8
	Extreme	0.06	0.47	Increasing	0	4
Shingwedzi	WD	-0.05	0.48	Decreasing	0	43
	Heavy	-0.18	0.43	Decreasing	0	9
	Extreme	1.16	0.12	Increasing	-0.032	5.86
Shingwedzi Vlakteplas	WD	-2.10	**0.02***	**Decreasing**	-0.524	48.17
	Heavy	0.02	0.49	Increasing	0	9
	Extreme	1	0.16	Increasing	0.05	3.83
Letaba Mahlangeni	WD	0.97	0.17	Increasing	0.333	35.5
	Heavy	1.61	0.05	Increasing	0.128	6.03
	Extreme	1.40	0.08	Increasing	0.091	2.86
Krugerwildtuin Shangoni	WD	-1.75	**0.04***	**Decreasing**	-0.209	48.33
	Heavy	-1.77	**0.04***	**Decreasing**	-0.064	11.92
	Extreme	-2.46	**0.006***	**Decreasing**	-0.059	7.06

5.3.1.3 Total annual rainfall vs. rainfall days in the northern lowveld

For the northern lowveld region, Pafuri and Punda Maria will be further studied in detail due to their long data sets. For the Pafuri weather station the 10 year moving average trend lines for both variables appear to have a direct relationship with one another for most of the time series. However, close to the beginning of the time series between the years 1941-1945 annual rainfall decreases whereas annual rain days increase (*Figure 5.17*). As rainfall is decreasing in volume and rain days are increasing in number, it is suggested that less rain is precipitating over a higher number of days.

The Punda Maria weather station depicts 2 periods where the two variables, total annual rainfall, and total annual rain days, show interesting results (*Figure 5.16*). In the time period of 1944-1946, rainfall volume is increasing whereas the total number of rain days is decreasing according to the 10 year moving average trendlines for both variables. Intense rainfall might have taken place during this brief period, however there are 3 complete years of missing data : 1939, 1941 and 1943, which could also contribute to this finding. Secondly, from the years 1977-1982, both variables are increasing, however total rainfall has a greater increasing slope than that of the rain days, suggesting heavy rainfall over a less amount of days during this period (*Figure 5.16*).

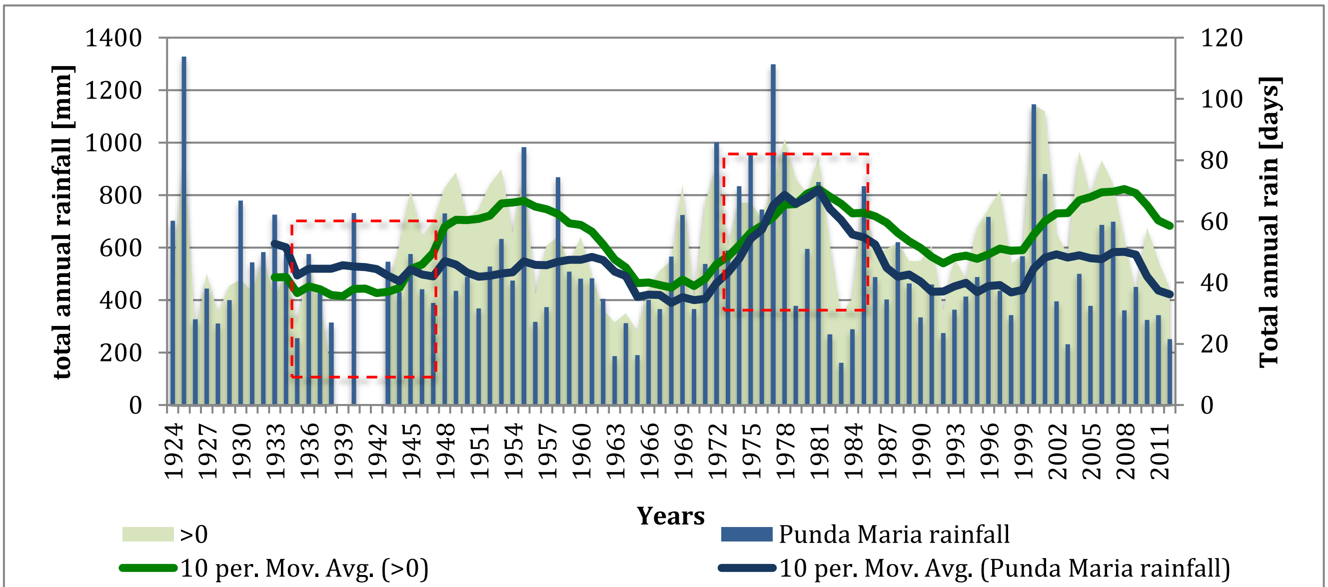


Figure 5.16 Rainfall vs. rain days of the Punda Maria weather station Red boxes highlight periods of inversed results

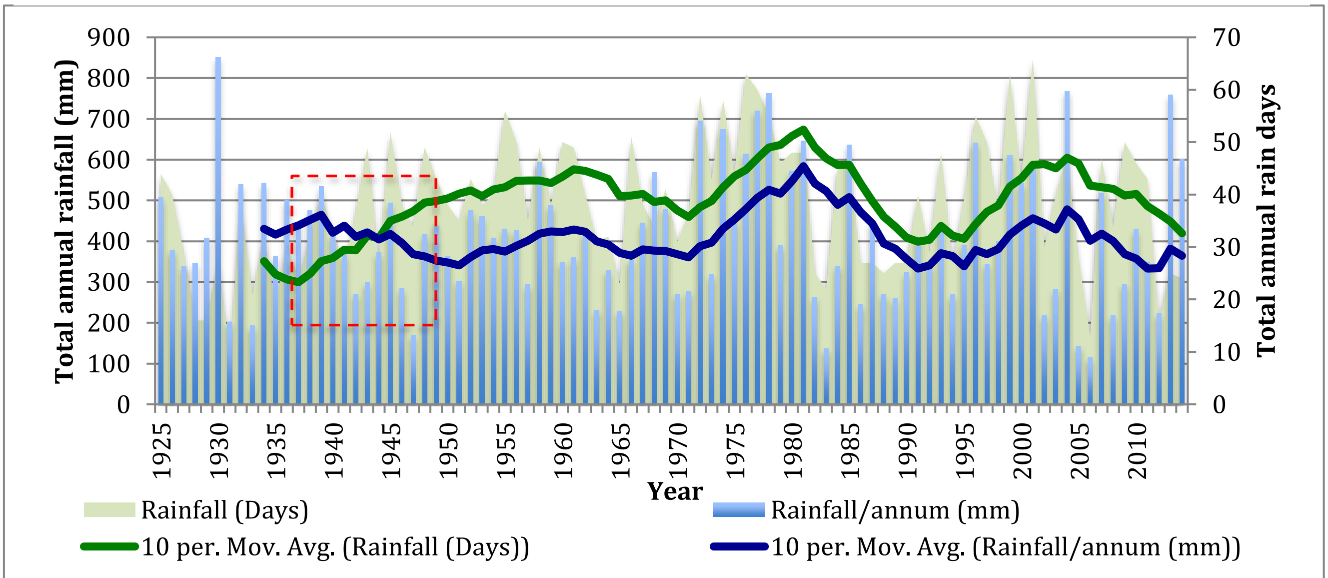


Figure 5.17 Rainfall vs. rain days of the Pafuri weather station. Red boxes highlight periods of inversed results

5.4.1 Southern bushveld

The southern bushveld region includes 5 weather stations, 3 with long datasets (Pilgrams Rest, Champagne Nat and Nelspruit) and 2 weather stations with shorter datasets (Onverwag Bos and Sabie). *Table 5.6* highlights the mean annual rainfall as well as the highest rainfall ranges experienced at these 5 weather stations.

5.4.1.1 Total annual rainfall trends

All total annual rainfall graphs display a 5-year moving average trend line, as a linear trend line is not a sufficient trend line for this data, as it has a high interannual variability. All rainfall stations in the southern lowveld have their highest recorded rainfall in the year 2000 (*Table 5.6*). Tropical cyclone Eline, off the coast of Mozambique and Kwa Zulu Natal, brought huge amounts of rainfall over three days, and caused devastating flooding in the region of eastern South Africa, and more specifically KNP. Annual rainfall in southern lowveld ranges from 103mm at Pilgrams rest (1973) to 2457.8mm at Onverwag Bos (2000). These very high interannual rainfall ranges will be discussed and further investigated throughout chapter 5 and 6.

The longer rainfall stations, including Pilgrams Rest (1904-2014), Nelspruit (1906-2014) and Champagne Nat (1924-2007), all depict an increase in rainfall from the first half of the recorded period, to the second half. Pilgrams Rest depicts a non-significant increase of 0.6% total annual rainfall (*Figure 5.18*), Champagne Nat depicts a non-significant increase of 4.8% total annual rainfall (*Figure 5.19*) and Nelspruit depicts a non-significant increase of 0.7% total annual rainfall (*Figure 5.20*). The shorter rainfall stations including Onverwag Bos (*Figure 5.21*) and Sabie (*Figure 5.22*), however, both depict non-significant decreases in total annual rainfall by 6.7% and 2.4% respectively. This is a good indication that over the longer period rainfall has had an increasing trend, but looking over the past 30-50 years, rainfall trends are however decreasing due to increasing rainfall variability.

Table 5.6 Rainfall characteristics for stations in the southern bushveld

Station	Years of data	Mean annual rainfall (mm)	Lowest recorded annual rainfall	Highest recorded annual rainfall	Range (mm)
Pilgrams Rest	1904-2014	894.1	1973: With 130mm	2000: With 1555.8mm	1425.8
Champagne Nat	1924-2007	764.5	1940: With 383.8mm	2000: With 1415.4mm	1031.6
Nelspruit	1906-2014	715.4	1951: With 289.95mm	2000: With 1379.4mm	1089.5
Onverwag Bos	1964-2014	1230.4	2005: With 600.2mm	2000: With 2457.8mm	1857.6
Sabie	1973-2014	1004.2	2003: With 230mm	2000: With 1555.8mm	1698.4

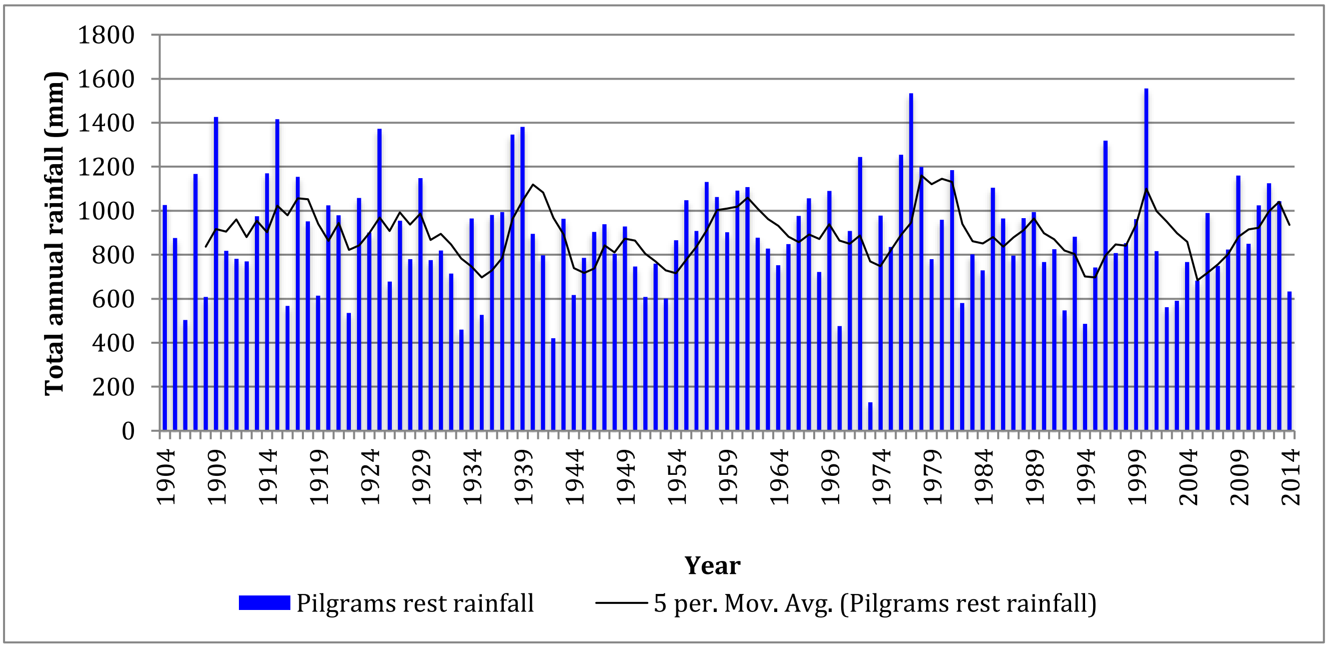


Figure 5.18 Total annual rainfall and 5 year moving average trend line of Pilgrams Rest rainfall station

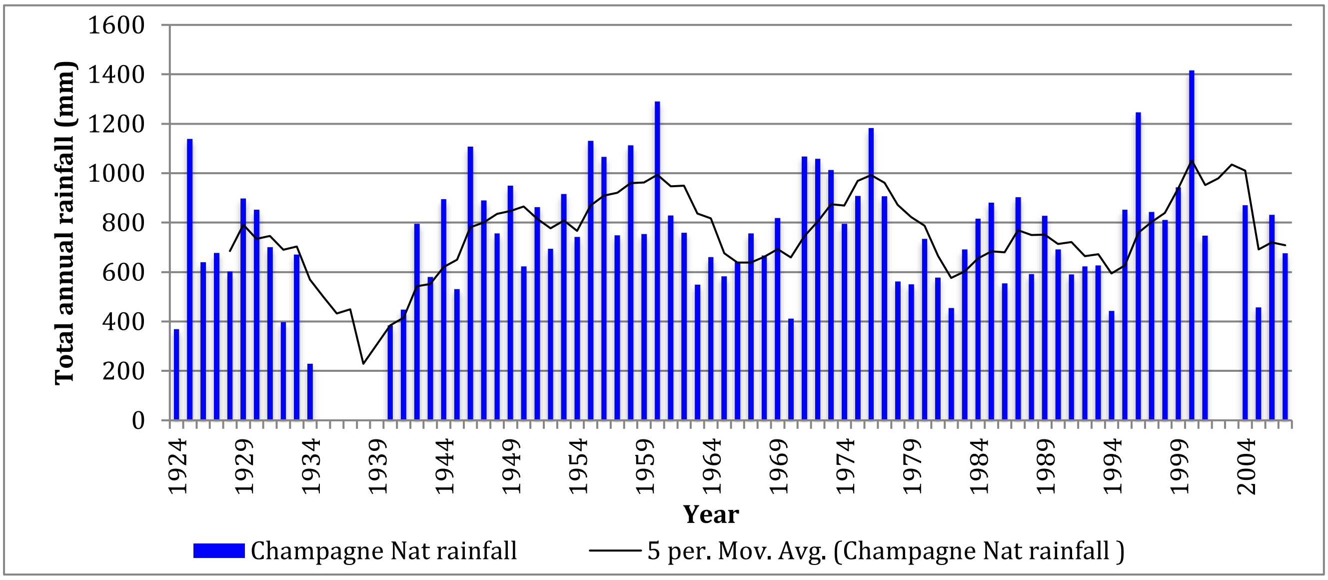


Figure 5.19 Total annual rainfall and 5 year moving average trend line of Champagne Nat rainfall station

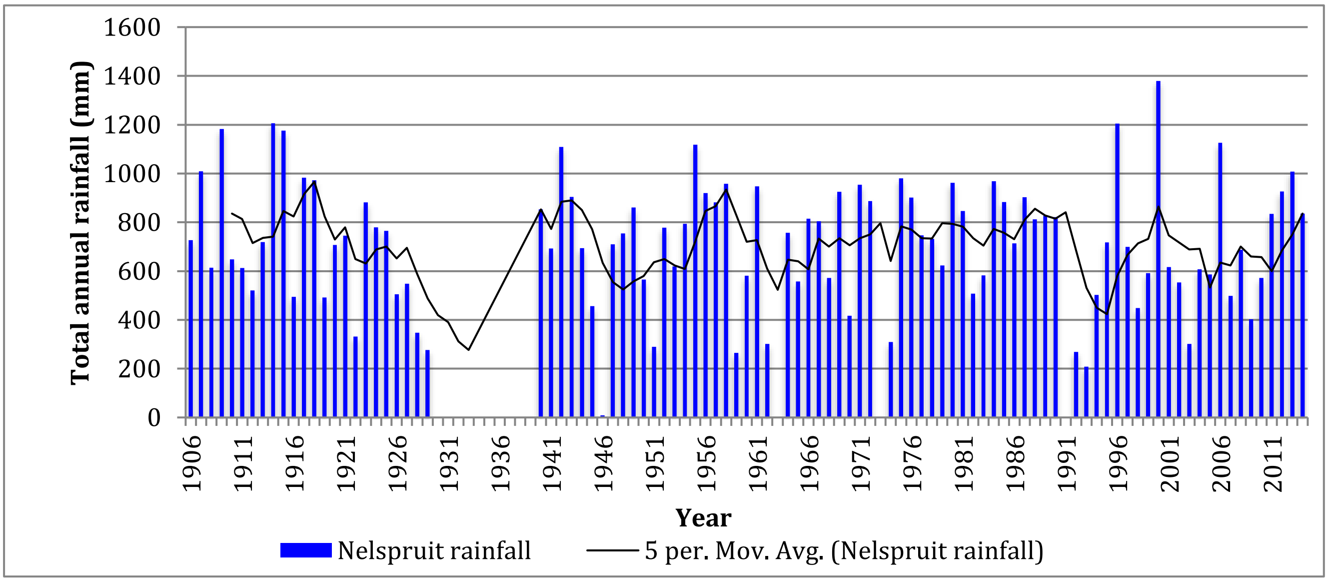


Figure 5.20 Total annual rainfall and 5 year moving average trend line of Nelspruit rainfall station

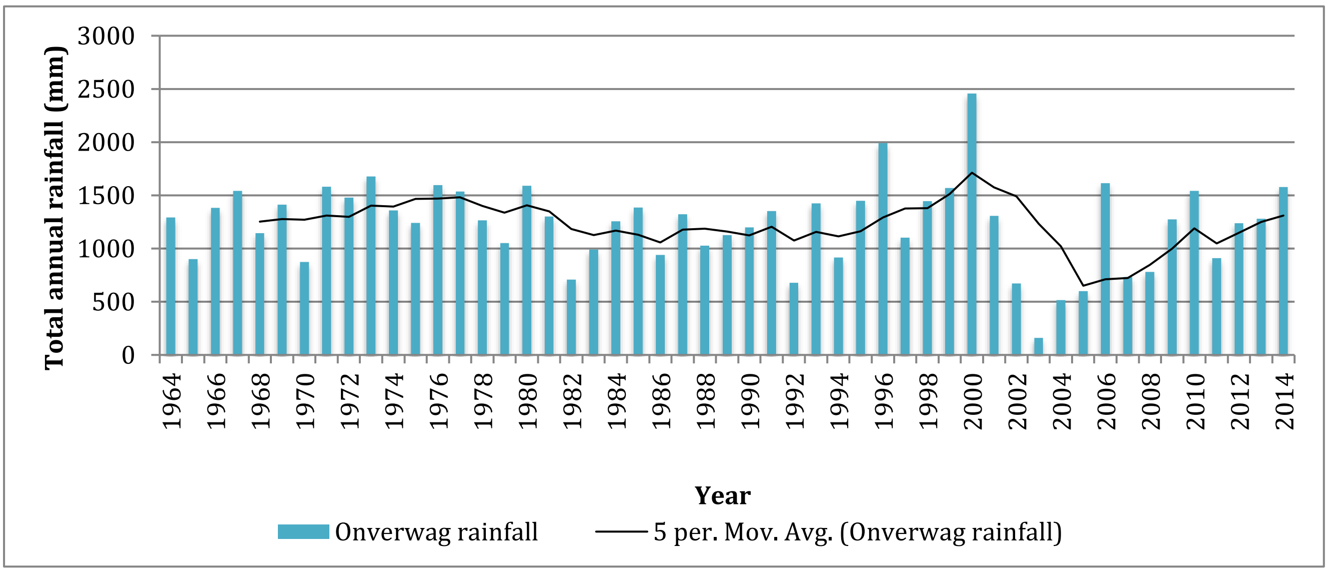


Figure 5.21 Total annual rainfall and 5 year moving average of Onverwag Bos rainfall station

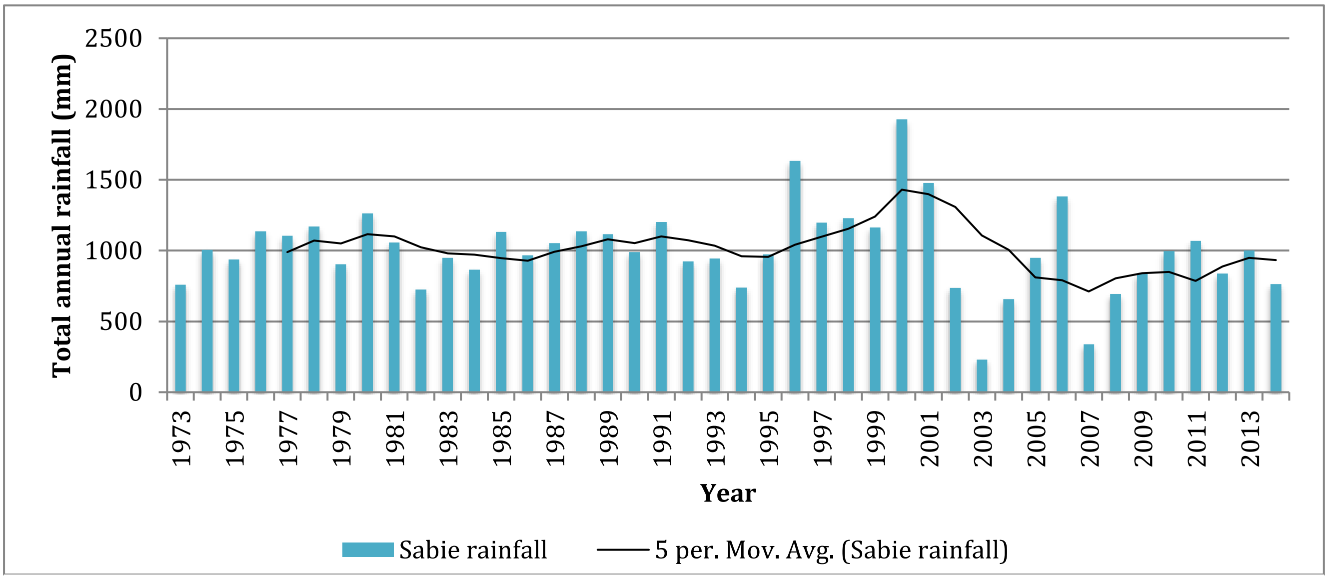


Figure 5.22 Total annual rainfall and 5 year moving average trend line of Sabie rainfall station

5.4.1.2 Total annual rainfall days

Pilgrams Rest and Champagne Nat both experience a decline in total annual wet days (17% and 21% respectively), but experience an increase in both heavy (5% and 13% respectively) and extreme (7.4% and 10% respectively) rainfall days. The 21% decline in total annual wet days for Champagne Nat is a highly significant trend, when using the 95% significance level. The Nelspruit rainfall station depicts a highly significant decline of 35% in total annual wet days during the period 1906-2014 (*Table 5.7*), as well as a decline of 15% in extreme rainfall days, whilst heavy rainfall days depicts a non-significant increase of 4%. The decline in total annual wet days, as well as the decline in extreme rainfall days indicates that fewer, but more intense rainfall events must be occurring, as the total annual rainfall for Nelspruit is increasing during this period (*Figure 5.20*).

Sabie rainfall station depicts a non-significant decrease of 2.5% for total annual wet days during the period 1964-2014, an increase of 2.4% for heavy rainfall days, and a 2.7% decline in extreme rainfall days. These percentage declines are consistent with the previously mentioned 2.4% decrease in total annual rainfall for Sabie (*Figure 5.22*). Lastly, Onverwag Bos rainfall station depicts a highly significant decrease in total annual wet days by 15.6% during the period 1964-2014, as well as a non-significant decrease in heavy (1.2%) and extreme

(4.8%) rainfall days. The high percentage decline in total annual rain days for Onverwag Bos is a major contributor to the declining trend in the total annual rainfall for this weather station (*Figure 5.21*).

Table 5.7 Mann Kendall trend statistic results for the annual rainfall day characteristics for the southern bushveld

Station	Category	Normalised Test Statistic (Z)	P-Value	Trend (A 95% Significance level)	Sens Q (Slope)	Sens B (Slope)
Pilgrams Rest	WD	-0.43	0.33	Decreasing	-0.03	83.85
	Heavy	0.5	0.3	Increasing	0	18.5
	Extreme	0.43	0.33	Increasing	0	9
Nelspruit	WD	4.23	**0.00002***	**Increasing**	0.2	4.58
	Heavy	0.95	0.17	Increasing	-0.05	7.6
	Extreme	-0.14	0.44	Decreasing	-0.05	15
Champagne Nat	WD	-2.88	**0.002***	**Decreasing**	-0.217	59.47
	Heavy	1.48	0.07	Increasing	0.046	13.37
	Extreme	0.66	0.25	Increasing	0	8
Onverwag Bos	WD	-2.54	**0.005***	**Decreasing**	-0.0552	86.89
	Heavy	-0.38	0.35	Decreasing	-0.025	26.36
	Extreme	-0.59	0.28	Decreasing	-0.2	15.29
Sabie	WD	-0.23	0.41	Decreasing	-0.1	81.40
	Heavy	-0.11	0.45	Decreasing	0	21
	Extreme	-0.64	0.26	Decreasing	0	10.50

5.4.1.3 Total annual rainfall vs. rainfall days in the southern bushveld

The analysis of the relationship between total annual rainfall vs total annual rain days in southern highveld produced interesting results for the Pilgrams Rest weather station (*Figure 5.23*). This weather station is the only one to show a completely indirect relationship between the two variables, for the entire time series. The 10 year moving average trend line highlights that when one variable is increasing, the other variable is doing the opposite. During the time periods between 1942-1962; 1988-2001 and 2006-2014, the number of rain days is increasing and the volume of rainfall Is decreasing. During the preiods 1937-

1941 and 1963-1987 the patterns show the opposite trend, where rainfall volumes are increasing and river/stream flow volumes are decreasing.

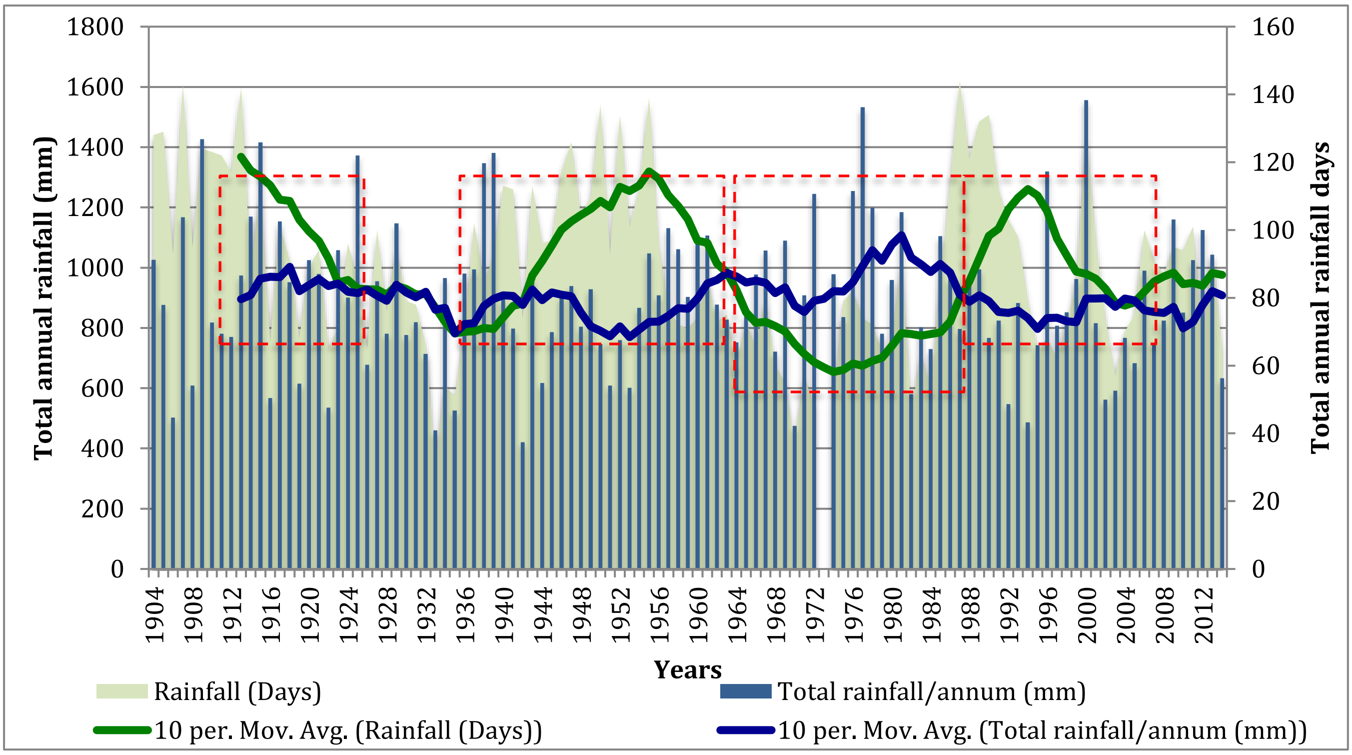


Figure 5.23 Total annual rainfall vs. rain days of Pilgrams Rest weather station. Red boxes highlight periods of inversed results

5.5.1 Southern lowveld

The southern lowveld region comprises four weather stations, including, Skukuza, Satara, Stolznek and Malelane. *Table 5.8* highlights the general rainfall trends for each weather station in this region.

5.5.1.1 Total annual rainfall trends

The rainfall in the southern lowveld region ranges from 82mm (Satara, 2002) to 1550.4mm in Stolznek (2000). Skukuza rainfall depicts a highly significant increasing trend of 10% for the period 1912-2012 (*Figure 5.24*). Satara rainfall station depicts a non-significant decreasing trend of 6.2% for the period 1933-2013 (*Figure 5.25*). Stolznek rainfall has a non-significant increasing trend for the period 1983-2014 (*Figure 5.26*). Lastly, Malelane depicts a non-significant decreasing trend of 0.4% for the period 1939-2014 (*Figure 5.27*).

Table 5.8 Rainfall characteristics for stations in the southern lowveld

Station	Years of data	Mean annual rainfall (mm)	Lowest recorded annual rainfall	Highest recorded annual rainfall	Range (mm)
Skukuza	1912-2012	555.2	1941: With 214.2mm	2000: With 1115.6mm	901.4
Satara	1933-2013	490.6	2002: With 82mm	2000: With 814.9mm	732.9
Malelane	1939-2014	610.6	1982: With 203mm	2000: With 1353mm	1150
Stolznek	1983-2014	656.6	1993: With 229.6mm	2000: With 1550.4mm	1320.8

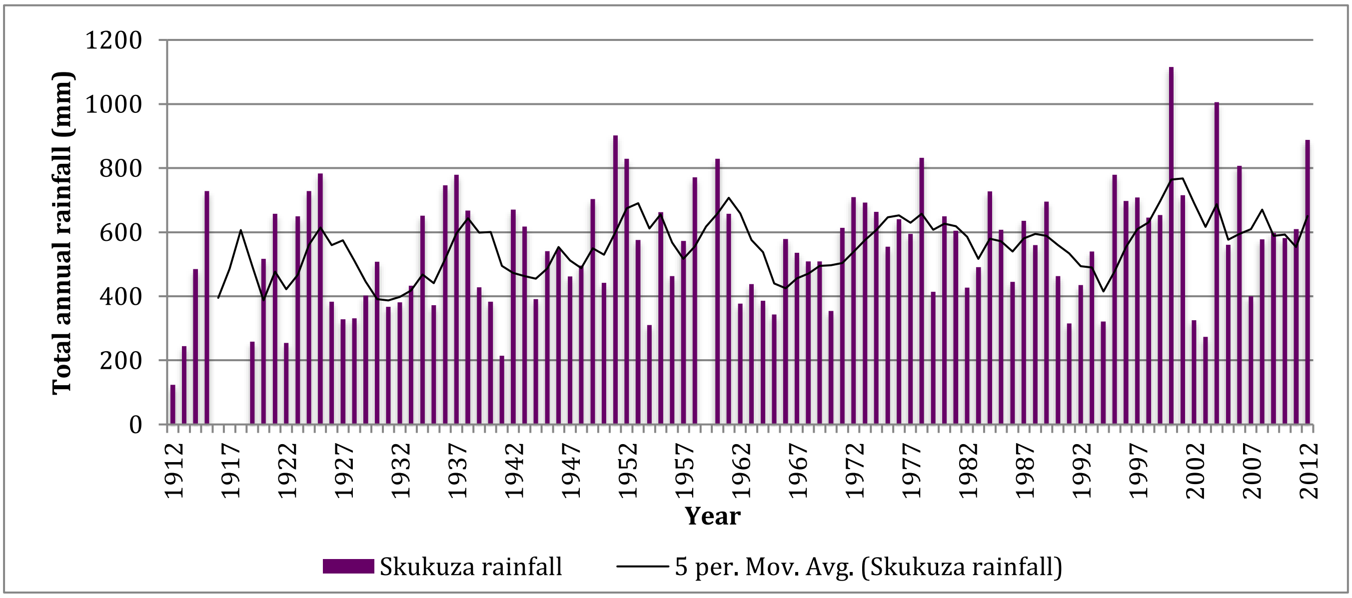


Figure 5.24 Total annual rainfall and 5 year moving average trend line of Skukuza rainfall station

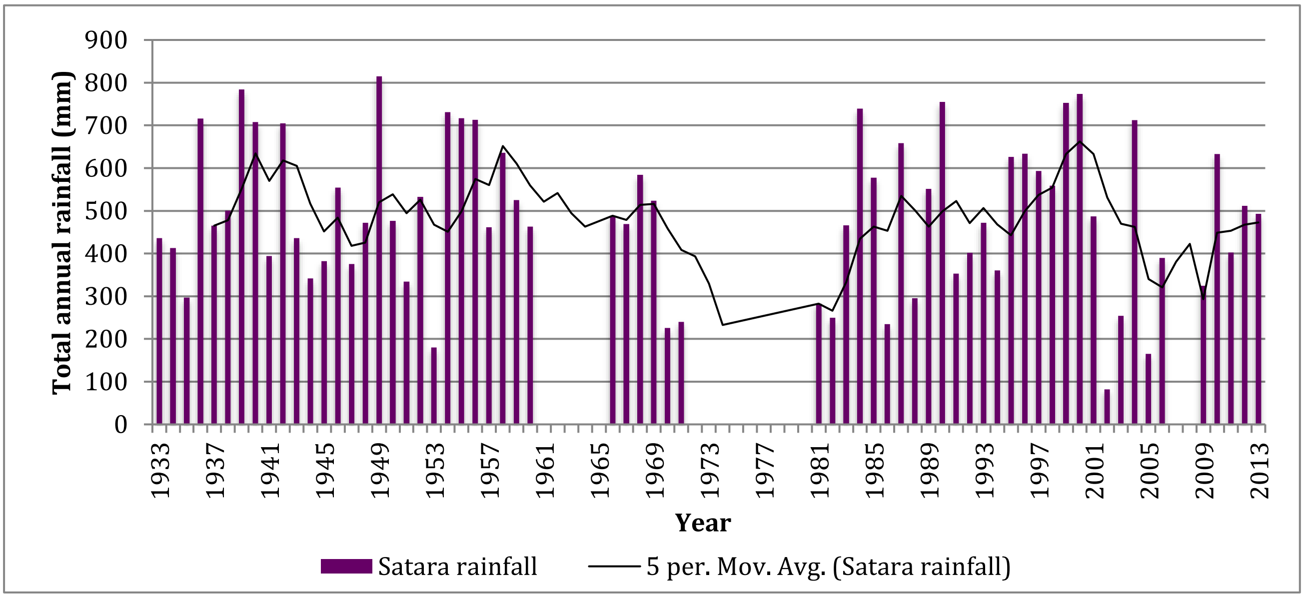


Figure 5.25 Total annual rainfall and 5 year moving average trend line of Satara rainfall station

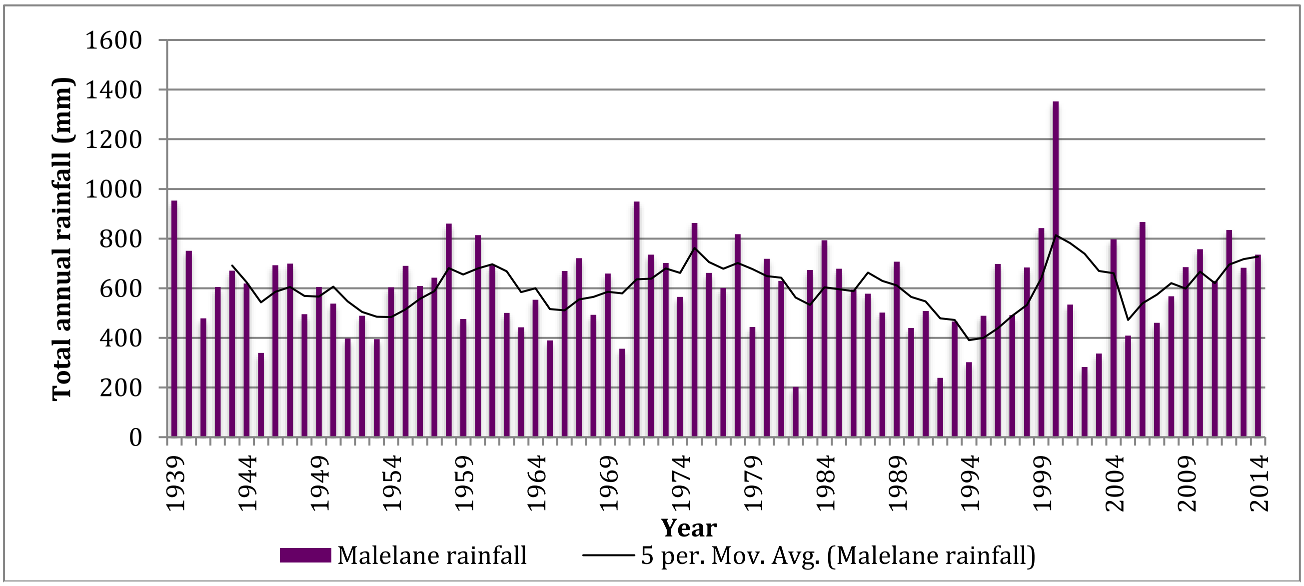


Figure 5.26 Total annual rainfall and 5 year moving average trend line of Malelane rainfall station

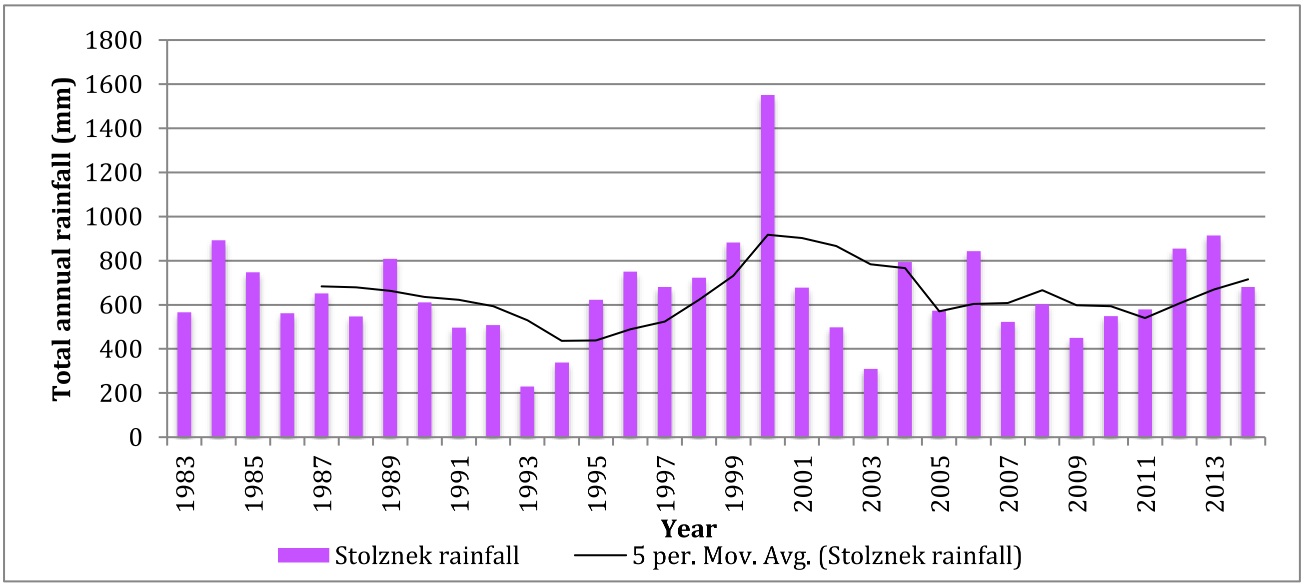


Figure 5.27 Total annual rainfall and 5 year moving average trend line of Stolznek rainfall station

5.5.1.2 Total annual rainfall days

Skukuza rainfall station displays some very interesting results, with all three-rain day categories depicting highly significant increases for the period 1912-2012 (*Table 5.9*). Total annual wet days in Skukuza increase by 68.3%, while the heavy and extreme rainfall days increase by 22.9% and 5.3% respectively. This massive incline in the number of wet days is the main contributing factor to the overall increase in Skukuza rainfall by 10% (*Figure 5.24*). Satara and Malelane rainfall stations both depict a non-significant increase in total annual wet days by 0.1% and 10% respectively. They both also depict a non-significant increase for heavy rainfall days by 3% each, whilst they both experience an increase in extreme rainfall days by 3.5% and 0.2% respectively. Lastly, Stolznek rainfall station depicts a highly significant decrease in total annual wet days by 5.1% during the period 1983-2014, however depicting a non-significant increase in heavy (13.4%) and extreme (2.9%) rainfall days.

Table 5.9 Mann Kendall trend statistic results for the annual rainfall day characteristics in the southern lowveld

Station	Category	Normalised Test Statistic (Z)	P- value	Trend (A 95% Significance level)	Sens Q (Slope)	Sens B (Slope)
Skukuza	WD	7.18	**0.00001***	**Increasing**	0.514	32.8
	Heavy	3.32	**0.0005***	**Increasing**	0.499	8.43
	Extreme	1.58	**0.006***	**Increasing**	0.013	5.42
Satara	WD	-0.72	0.23	Decreasing	0	41
	Heavy	-0.3	0.38	Decreasing	0	9
	Extreme	0.47	0.32	Increasing	0	5
Malelane	WD	-1.39	0.08	Decreasing	-0.127	60.5
	Heavy	-0.47	0.32	Decreasing	0	12
	Extreme	0.07	0.47	Increasing	0	6
Stolznek	WD	-2.01	**0.02***	**Decreasing**	-0.563	70.44
	Heavy	0.02	0.49	Increasing	0	12
	Extreme	-0.52	0.3	Decreasing	0	6.5

5.5.1.3 Annual rainfall vs. rainfall days in the southern lowveld

Due to the length of their data sets and their low percentage of missing data, the skukuza and Malelane weather stations were further evaluated to find patterns and relationships between total annual rainfall and annual rain days. For skukuza weather station, the 10 year running average linear trends for both variables were in direct relationship with one another until the year 1964, where the total annual rainfall was decreasing, but the total annual rain days were increasing (*Figure 5.28*).

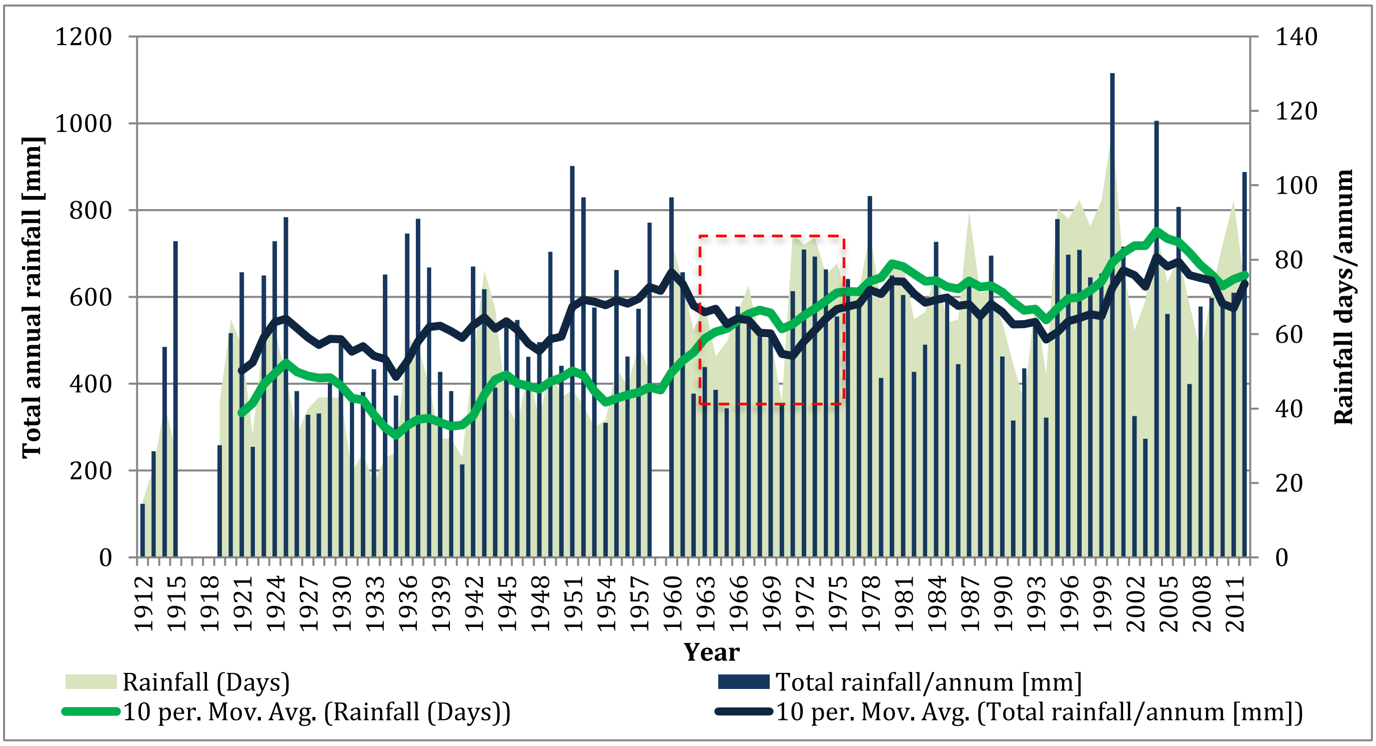


Figure 5.28 Total annual rainfall vs. rain days for Skukuza weather station. Red boxes highlight periods of inversed results

The Malelane weather station showed the complete opposite results than from the skukuza weather station. Malelane rainfall had similar behaviours as those recorded by Palmaryville, Zomerkomst, Punda Maria and Pilgrams Rest. for this particular weather station, during the years 1958-1965, as well as 1984-1990, average annual rainfall increased while annual average rain days decreased (*Figure 5.29*).

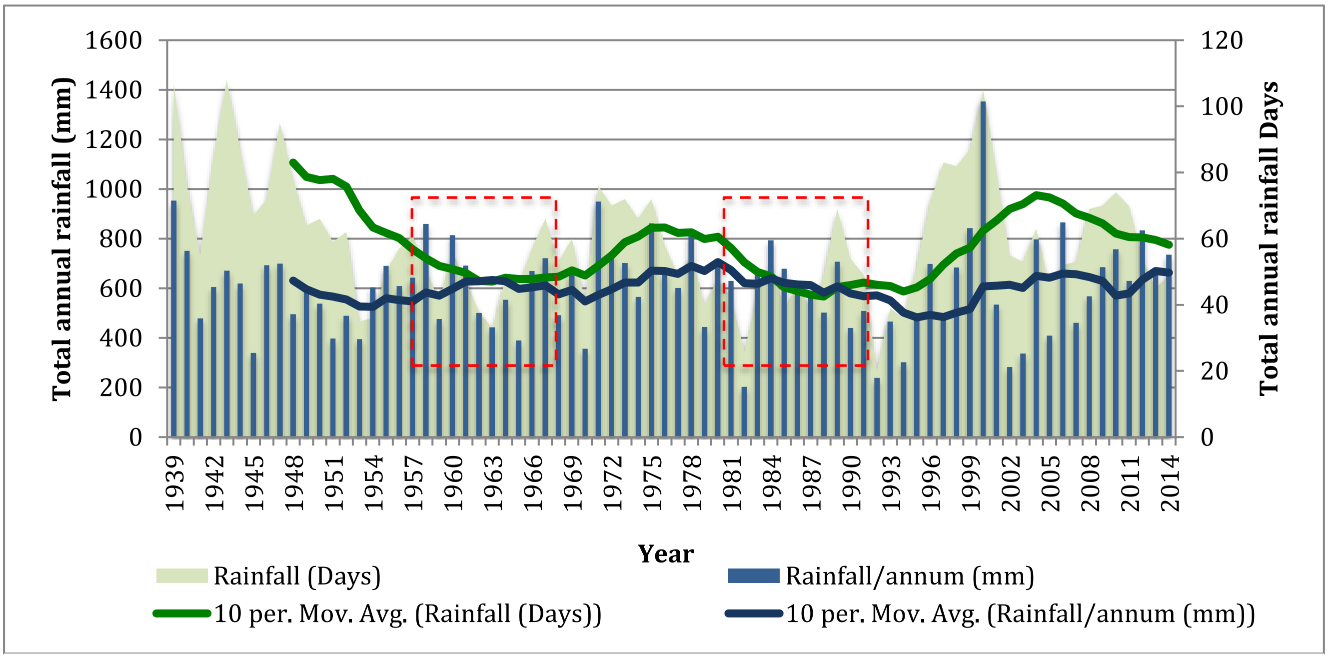


Figure 5.29 Total annual rainfall vs. rain days for the Malelane weather station. Red boxes highlight periods of inversed results

5.5.4 Changes in the monthly rainfall trends of the longer rainfall stations

The changes in the trends of rainfall over all the months for the stations which have between 80-110 years of data, have depicted decreases in winter rainfall, and increases in spring rainfall (*Table 5.10 and 5.11*). Rainfall trends have been variable across the stations for the months of January, February and December. The literature highlights that winter rainfall is showing decreasing temporal patterns, whereas spring rainfall is showing increasing temporal patterns (UCT, 2008). There is also a significant decrease in the amount of autumn rainfall across a majority of the weather stations (MacKellar *et al.,* 2014). The increase in spring rainfall and increase in variability of summer rainfall is linked to the increase in the intensity and occurance of extreme rainfall events in north east South Africa (DEA, 2013).

Table 5.10 Changes in monthly rainfall volumes (mm) per annum for weather stations with more than 100 years of data

	NB	SB	SB	SL
	Palmaryville	**Pilgrams Rest**	**Nelspruit**	**Skukuza**
Jan	-0.97	+0.06	-0.5	+0.07
Feb	+0.31	-0.16	+0.06	+0.03
Mar	-0.48	-0.62	-0.03	-0.13
Apr	-0.18	+0.03	+0.14	+0.21
May	-0.26	-0.11	-0.05	-0.05
Jun	+0.01	+0.04	+0.02	+0.04
Jul	-0.06	-0.07	-0.003	-0.05
Aug	-0.01	-0.01	-0.03	-0.02
Sep	+0.03	+0.01	+0.06	+0.002
Oct	+0.02	+0.2	+0.04	+0.08
Nov	+0.04	+0.01	+0.01	+0.31
Dec	-0.15	-0.06	-0.25	+0.5

Table 5.11 Changes in monthly rainfall volumes (mm) per annum for weather stations with between 80-100 years of data

	NB	NB	NL	NL	SB
	Hans Merensky Hoerskool	**Zomerkomst**	**Pafuri**	**Punda Maria**	**Champagne Nat**
Jan	-0.36	+0.2	+0.53	-0.33	-0.33
Feb	+0.04	+0.97	-0.07	+0.13	+0.04
Mar	-0.27	-0.05	-0.02	-0.98	-0.27
Apr	-0.31	+0.22	-0.05	-0.19	-0.31
May	-0.12	-0.05	+0.06	+0.03	-0.12
Jun	+0.05	+0.05	-0.03	+0.03	+0.05
Jul	-0.02	-0.05	-0.03	-0.02	-0.01
Aug	-0.02	-0.03	-0.01	-0.04	-0.02
Sep	+0.06	+0.03	+0.02	+0.09	+0.05
Oct	+0.08	+0.22	+0.08	+0.07	+0.07
Nov	+0.42	+0.29	+0.16	+0.11	+0.43
Dec	+0.16	-0.01	-0.16	-0.31	+0.11

5.6 Annual regional rainfall characteristics

When comparing the bushveld regional rainfall, to that of the lowveld, it becomes apparent the bushveld region receives significantly higher rainfall (av=889.55mm) than the adjoining eastern lowveld (av=513.56mm). The northern and southern bushveld regions experienced an average annual rainfall of 945.14mm and 833.97mm respectively for the years 1907-2014 (*Figure 5.30*). However, in contrast, the northern lowveld receives lower mean annual rainfall (av=468.7mm) than the southern lowveld (av=558.42mm). The Great South African escarpment, as well as the bushveld region in eastern South Africa, recieves considerably higher rainfall than the lowveld regions due to enhances orographic uplift associated with rainfall along the escarpment (McCartney and Yawson, 2010). Such orographic rainfall regularly produces amounts exceeding 1000mm per annum, in particular, this is evident from stations such as Palmaryville, Hans Merensky, Zomerkomst, Sabie and Onverwag Bos. Althought it is known thast the northern subtropical KNP is drier than the southern temperate parts (Schultze, 2002), recent decadal scale changes in these regions have not been previously quantified.

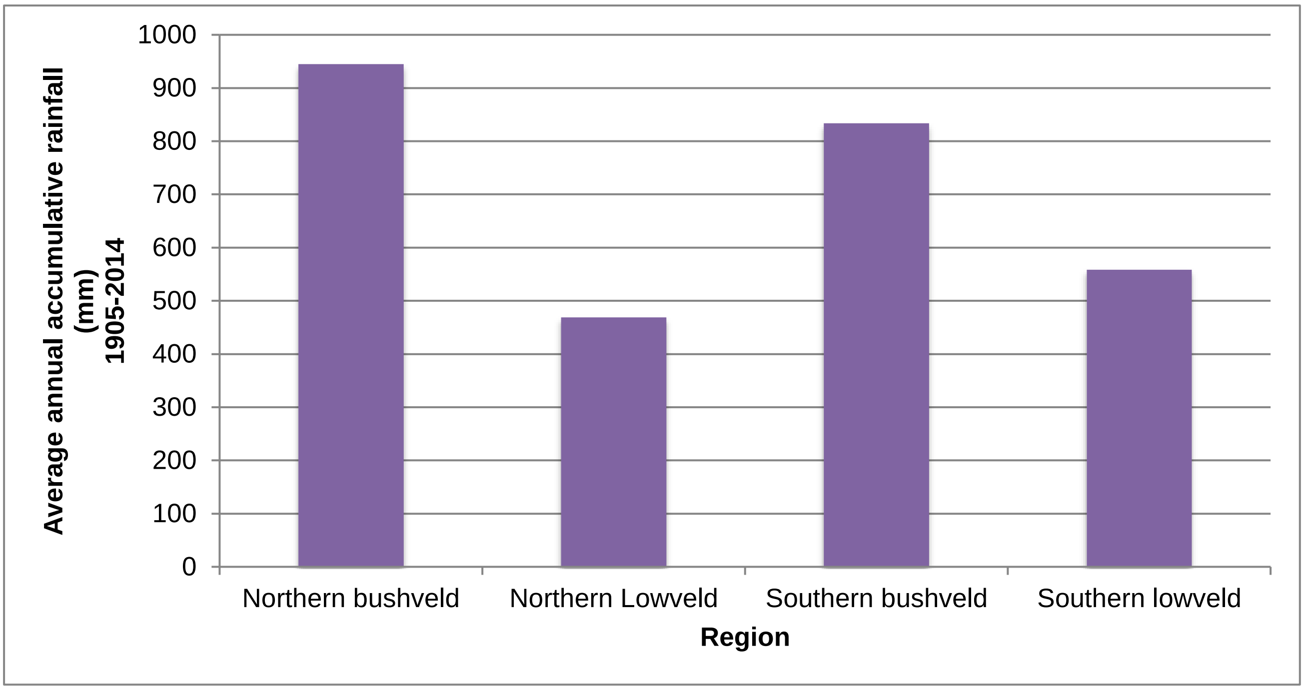


Figure 5.30 Average annual rainfall per region over study period

5.7 Variability of KNP rainfall

The high interannual rainfall variability is owing to variable climatic conditions influencing rainfall in the region, such as El Nino Southern Oscillation and tropical cyclone circulation. For the northern bushveld region, it is apparent that the percentage of years above annual mean rainfall are decreasing over time, with 60% of the years recorded rainfall above the long-term mean (945.1mm) for the period 1910-1929, whereas for the latter decades, the percentage of years recorded above the long-term mean were 30% (1990-1999; 2000-2009) and 20% (2009-2014) (*Table 5.12*). In the northern bushveld, the decades, which recorded the highest percentage deviations from the long-term mean rainfall include 1910-1919 (33.5% above the mean and 41.2% below the mean), 2000-2009 (49,1% above the mean and 32.6% below the mean). Percentage deviations from long term mean rainfall were significantly higher in the former years (*Figure 5.31*). The year with the highest recorded deviation from the long-term mean was the year 2000. It is evident that in the latter years, the northern bushveld experienced an increased number of years falling below the long-term mean (*Figure 5.31*).

The northern lowveld has variable rainfall for the period 1924-2014, with rainfall becoming more deviated in the latter years (*Figure 5.32*). During the decade 1970-1979, rainfall deviated from the long-term mean (468.7mm) by 50.7%. 1990-1999 and 2000-2009 recorded a 50% and 41% deviation above the long-term mean. Much like the northern bushveld, it is apparent in the northern lowveld, that the percentage of years above the annual mean are decreasing over time, with the former decades recording 40-50% of the years above the long-term mean, whereas the latter years record between 20-30% (1980-1990; 1990-1999; 2000-2014) above the long-term mean. More years are thus recording below average rainfall for the latter years at both northern bushveld and northern lowveld rainfall stations. The rainfall for the northern region however is highly variable. The variability of this regional rainfall will be explored further in chapter 6.

Northern bushveld

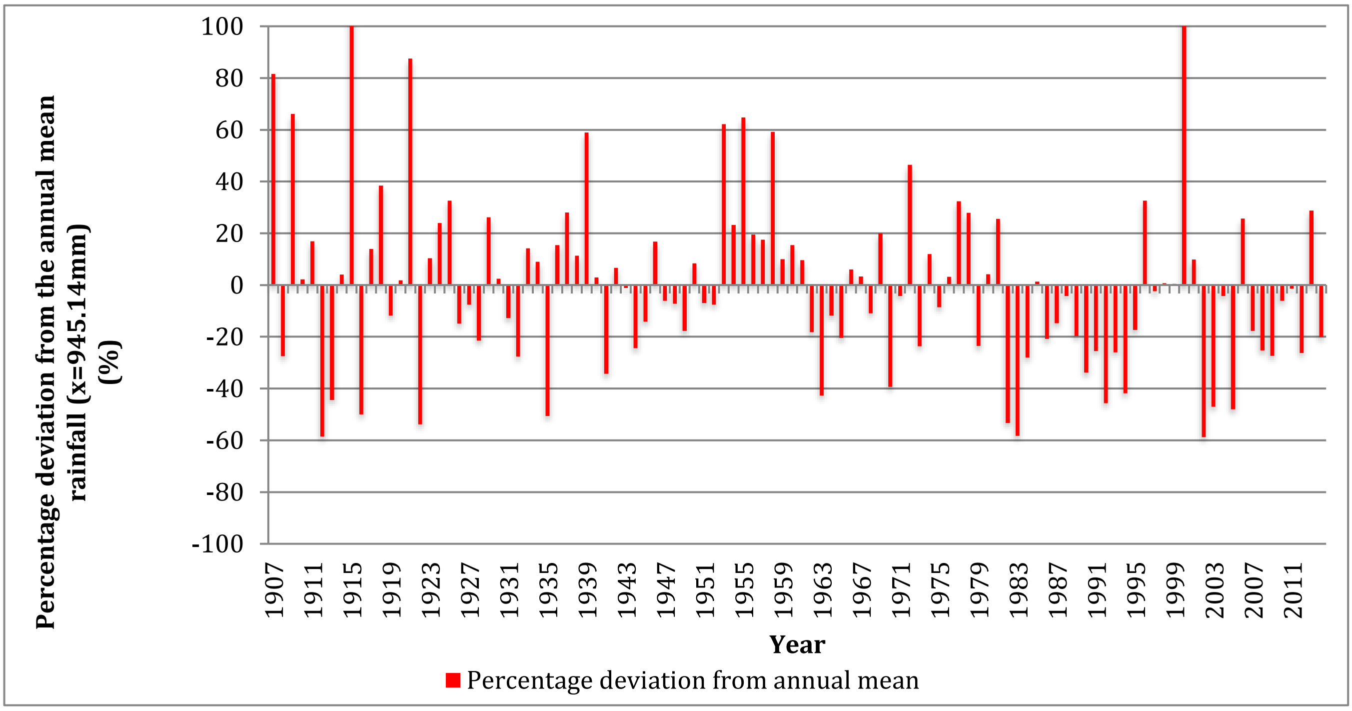


Figure 5.31 Rainfall fluctuations for the northern bushveld, 1907-2014 (expressed as a percent departure from the long-term mean

Table 5.12 Percentage years below and above mean annual rainfall for the northern bushveld

	Mean percentage above average rainfall (%)	Mean percentage below average rainfall (%)	Percentage of years above mean (%)	Percentage of years below mean (%)
1910-1919	33.5	-41.2	60	40
1920-1929	30.4	-24.5	60	40
1930-1939	19.9	-30.3	70	30
1940-1949	8.8	-15	30	70
1950-1959	33.1	-7.3	80	20
1960-1969	0.9	-20.8	50	50
1970-1979	24.4	-19.9	50	50
1980-1989	10.3	-28.4	30	70
1990-1999	11.2	-27.5	30	70
2000-2014	38.9	-23.1	25	75

Northern lowveld

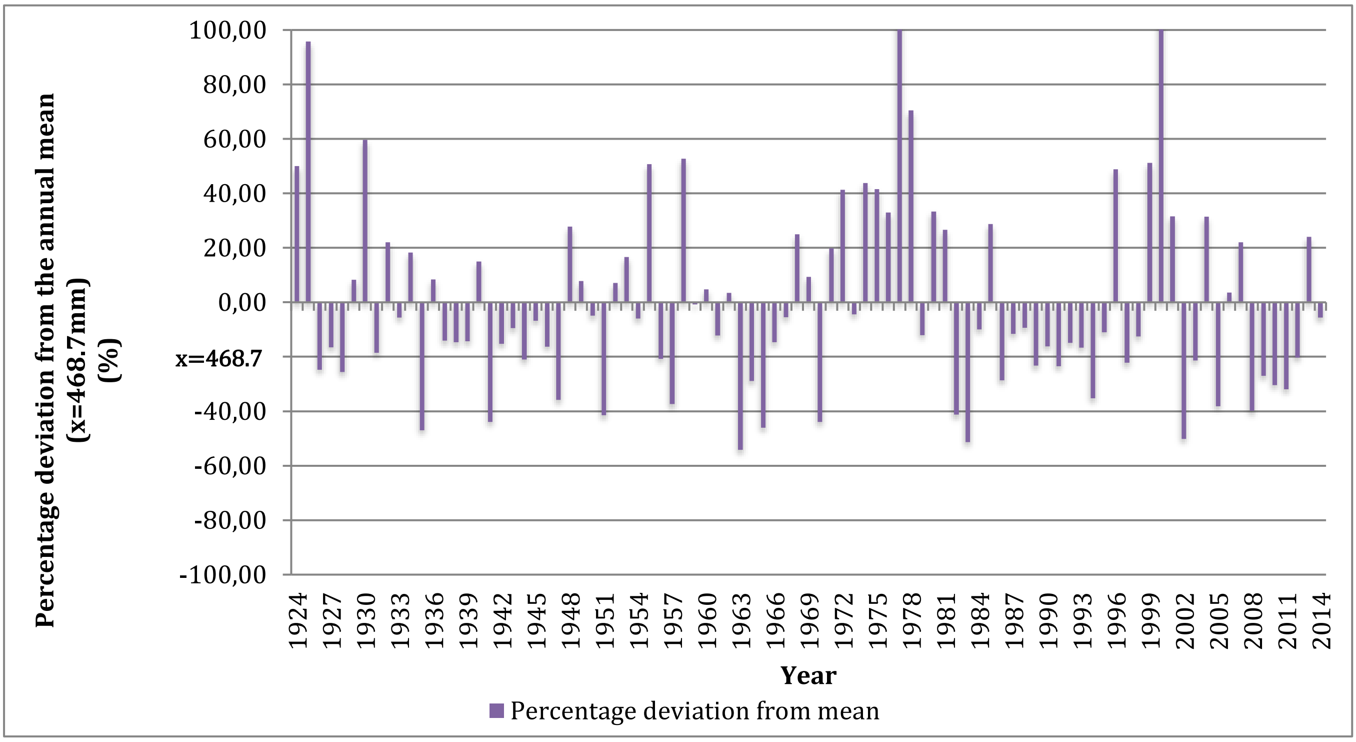


Figure 5.32 Percentage of rainfall deviation from annual mean for northern lowveld

Table 5.13 characteristics of rainfall deviation from annual mean for northern lowveld

	Mean percentage above average rainfall (%)	Mean percentage below average rainfall (%)	Percentage of years above mean (%)	Percentage of years below mean (%)
1920-1929	51.3	-22.3	50	50
1930-1939	27.1	-19	40	60
1940-1949	16.9	-21.2	30	70
1950-1959	31.7	-18.5	40	60
1960-1969	10.6	-26.9	40	60
1970-1979	50.7	-20.1	70	30
1980-1989	29.5	-25.1	30	70
1990-1999	50	-19	20	80
2000-2014	31.4	-24.1	30	70

The southern bushveld and lowveld region show differing results from the northern region. In the southern region, the percentage of years where rainfall is greater than the long-term mean is increasing over time, with the former years showing a 30-40% of the years falling above the mean, whereas the latter years depict 70-80% of the years falling above the long-term mean (*Table 5.14*). For the southern bushveld, the last two decades (1990-1999; 2000-2014) show substantially higher percentage deviations from the long-term mean (*Figure 5.33*). Specifically, for the years 1996 (61%), 2000 (97%) and 2003 (-67%). These higher than usual deviations suggest that the rainfall in the southern bushveld region is becoming more variable over time.

The southern lowveld depicts variable rainfall for the period 1912-2014. For the period 1910-1919, substantially high deviations from long-term mean rainfall are recorded, specifically for 1912 (-78%) and 1913 (-55%). Rainfall over the former decades, are evenly distributed in percentage deviations from the long-term mean (551.9mm), however, in the latter years, total annual rainfall deviations are much greater (*Figure 5.34*). The year 2000 recorded the highest percentage deviation, with over 100% deviation from the long-term mean.

Southern bushveld

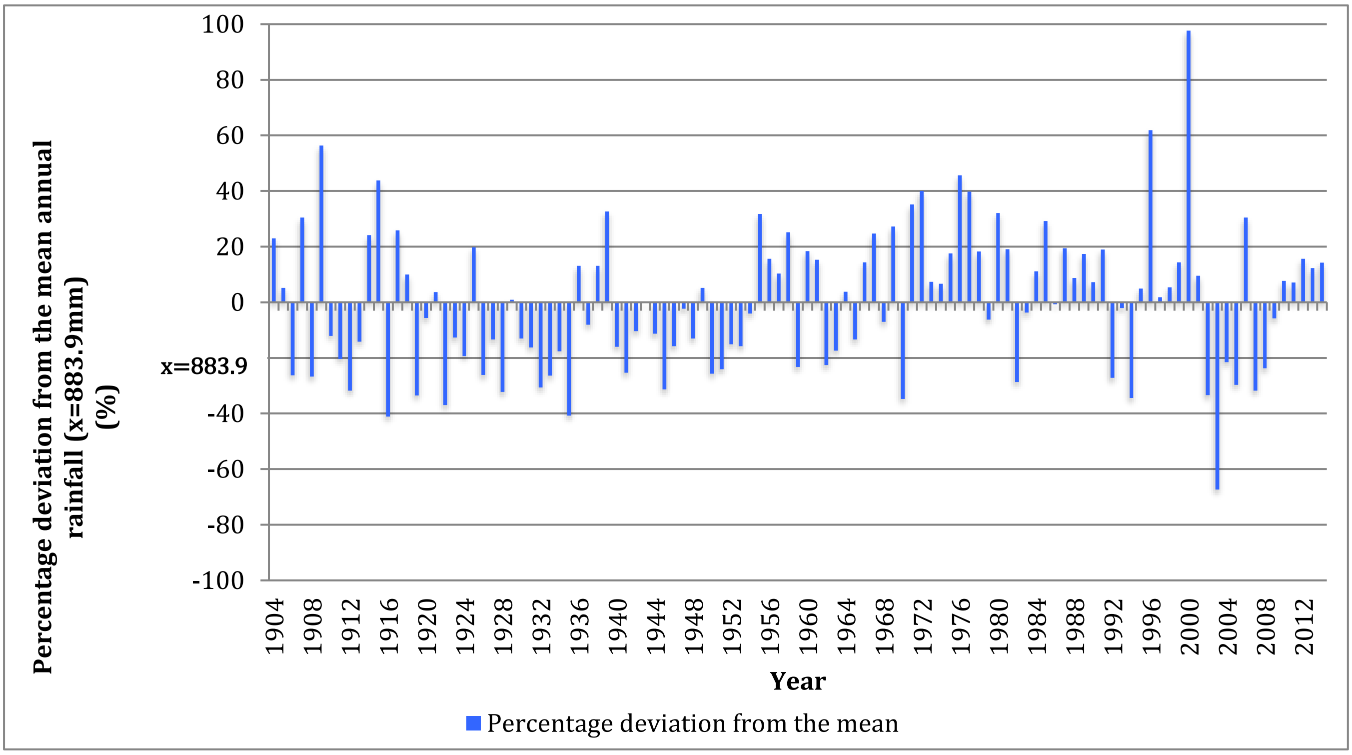


Figure 5.33 Percentage of rainfall variation for annual mean for southern bushveld

Table 5.14 Characteristics of rainfall deviation from annual mean for southern bushveld

	Mean percentage above average rainfall (%)	Mean percentage below average rainfall (%)	Percentage of years above mean (%)	Percentage of years below mean (%)
1910-1919	25.9	-25.5	40	60
1920-1929	8.1	-20.9	30	70
1930-1939	19.6	-21.8	30	70
1940-1949	5.2	-14	10	90
1950-1959	20.7	-18	40	60
1960-1969	17.3	-15.1	60	40
1970-1979	26.3	-20.5	80	20
1980-1989	19.6	-11	70	30
1990-1999	16.3	-21.2	70	30
2000-2009	28.6	-30.5	50	50

Southern lowveld

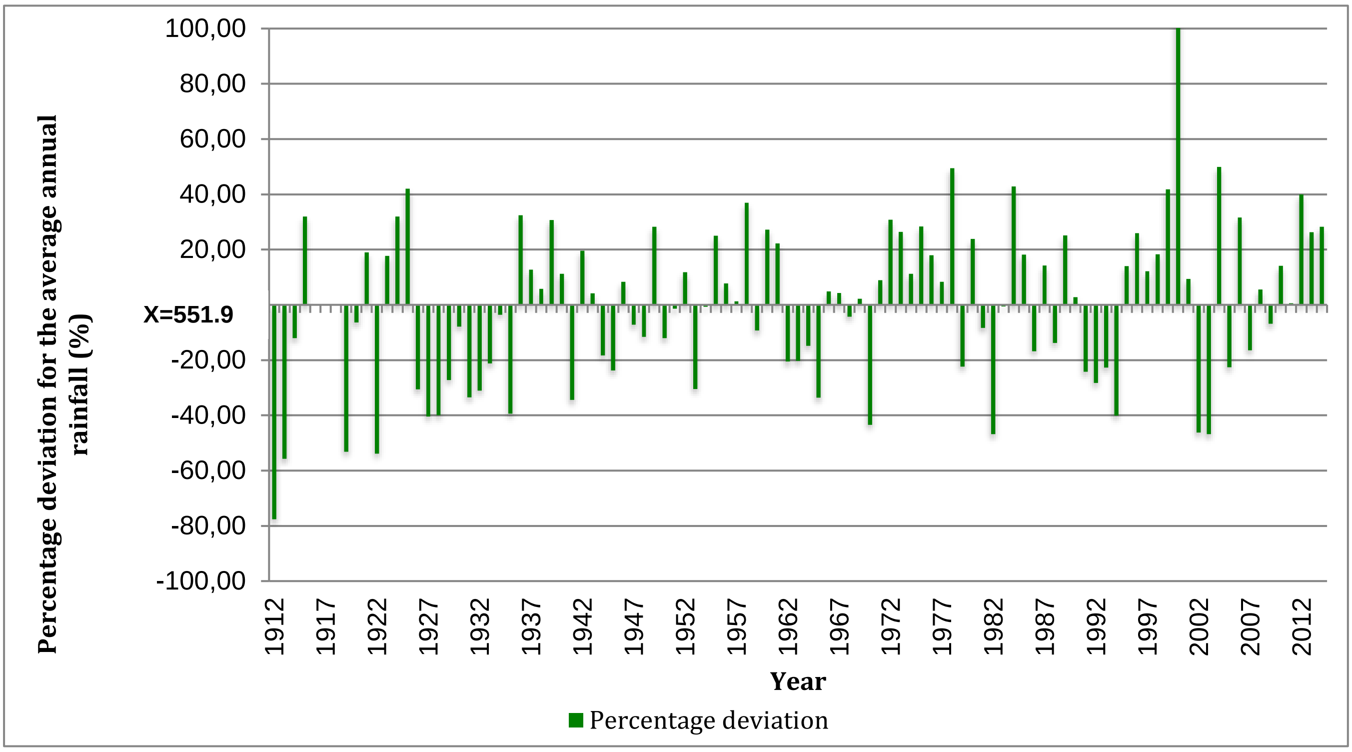


Figure 5.34 Percentage of rainfall variation from annual mean for southern lowveld

Table 5.15 Characteristics of deviations of rainfall from annual mean for southern lowveld

	Mean percentage above average rainfall (%)	Mean percentage below average rainfall (%)	Percentage of years above mean (%)	Percentage of years below mean (%)
1910-1919	31.9	-49.7	20	80
1920-1929	27-7	-33.1	40	60
1930-1939	20.3	-22.8	40	60
1940-1949	14.3	-19	50	50
1950-1959	16.6	-10.8	50	50
1960-1969	12.1	-18.7	50	50
1970-1979	22.7	-32.9	80	20
1980-1989	24.9	-17.3	50	50
1990-1999	19.1	-28.8	60	40
2000-2014	32.3	-27.7	60	40

5.7.1 Coefficient of variations for decadal rainfall

To determine the variability of the rainfall in the study region, statistical evaluations were initiated. The standard deviation and coefficients of variation were determined for each individual rainfall station observed. The coefficient of variation provides information on interannual rainfall variability (Black, 2011).

The coefficient of variation was developed by Karl Pearson to determine the variability of two or more data sets with a differing unit of measurement as well as comparing two variables with the same unit of measurement, but the mean values of the data sets are widely dissimilar (annual rainfall vs. standard deviation of annual rainfall). Simply put, the CV measures the standard deviation of a data set relative to the mean, as a percentage. *Table 5.16* highlights that the average decade with the greatest CV values is the last decade (2000-2014) with a CV of 49%.

On average, between all 21 weather stations, the decades with the lowest CV were 1940-1949 and 1960-1969. For all decades preceding the last one, the CV for rainfall in all regions lay between 26-34%. However, during the last decade, variability in rainfall increased significantly. According to the literature, the climate in Southern Africa is becoming more variable by the year as weather conditions are becoming more extreme, and interannual variability is more notable in the recent years (ref). It can be noted from this analysis that all weather stations have a large characteristic interannual variability value, thus indicating as previously mentioned, that KNP rainfall is heavily impacted by extreme climatic events such as droughts from El Nino and flooding from extreme rainfall events (Reason *et al.,* 2006).

Table 5.16 Standard deviation and co-efficient of variance for each rainfall station

Region	Station	Std Dev. (mm)	CV (1900-1909)	CV (1910-1919)	CV (1920-1929)	CV (1930-1939)	CV (1940-1949)	CV (1950-1959)	CV (1960-1969)	CV (1970-1979)	CV (1980-1989)	CV (1990-1999)	CV (2000-2014)
Northern Bushveld	Palmaryville	385,5		52%	42%	26%	28%	22%	29%	40%	39%	34%	51%
	Hans Merensky Hoerskool	354,2				48%	20%	25%	22%	24%	33%	33%	71%
	Zomerkomst	366,2			27%	28%	20%	26%	16%	24%	29%	34%	44%
	Gravelotte	202,7								52%	42%	36%	53%
	Thohoyandou	261,2									31%	27%	40%
Northern Lowveld	Pafuri	157,7			17%	41%	27%	21%	28%	38%	48%	29%	53%
	Punda Maria	240,9			67%	32%	25%	39%	40%	39%	47%	29%	53%
	Shingwedzi Vlakteplas	204,5									45%	39%	48%
	Shingwedzi	192,2							27%	27%	37%	47%	76%
	Krugerwildtuin Shangoni	218,9							31%	36%	34%	33%	65%
	Letaba Mahlangeni	193,6										42%	48%
	Letaba	183,9				35%	39%	54%	37%	63%	25%	35%	58%
Southern Bushveld	Hoedspruit	230,8										35%	54%
	Champagne Nat	241,5			31%	33%	32%	21%	28%	31%	22%	29%	38%
	Onverwag Bos	394,1							18%	19%	22%	28%	42%
	Pilgrams Rest	249,2	37%	29%	25%	34%	21%	21%	16%	44%	20%	28%	30%
	Sabie	298,4								15%	15%	22%	46%
	Nelspruit	256,7	29%	36%	37%		42%	39%	30%	33%	19%	50%	40%
Southern Lowveld	Satara	175,1				34%	32%	34%	10%		42%	27%	48%
	Skukuza	182,5			38%	30%	29%	32%	28%	23%	17%	30%	39%
	Stolznek	234,8									20%	34%	42%
	Malelane	186,5					21%	25%	23%	28%	27%	35%	40%
Average CV			**33%**	**39%**	**36%**	**34%**	**28%**	**30%**	**26%**	**34%**	**31%**	**33%**	**49%**

5.8 Trends in seasonal rainfall

The rainfall stations located in the bushveld and lowveld of northeast South Africa all receive summer rainfall. South African rainfall exhibits a distinct seasonality with each year (Tyson, 1978), with the most rainfall received between the months of October and March, except for the western cape, which receives most its annual rainfall in the winter months. The most important months for rainfall analysis in this part of South Africa include December, January and February, as during these months, the atmospheric circulation over southern Africa is dominated by circulation features such as tropical easterlies and easterly waves. The following section reviews the trends in seasonal rainfall for the rainfall stations with the richest datasets.

As mentioned previously, the rainfall season for the location of this study region is between the months of October and March. For more in-depth analysis into how these seasons are changing over time, the rainfall season has been divided into 3 categories, namely early, mid and late rainfall seasons (*Table 5.17*). Only 2 stations from each region were selected to be graphically represented, the remaining graphs can be found in appendix 5.

Table 5.17 Seasons and rainfall seasons categorised, adapted from (du Toit and O'Connor, 2014)

	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Spring			■	■	■							
Summer						■	■	■	■			
Autumn										■	■	
Winter	■	■										■
Rainy season				■	■	■	■	■	■	■		
Early				■	■							
Mid						■	■	■				
Late									■	■		

5.8.1 Northern bushveld

All 5 weather stations in the northern bushveld indicate an increase in the early (October and November) seasonal rainfall, with increases ranging from 7.9% at Palmaryville (1907-2014) to 16% at Gravelotte (1970-2014). Palmaryville rainfall indicates a decrease in mid (16%) and late (15%) season rainfall (*Figure 5.35*), which suggests that the mid and late rainfall seasons are the major contributors to the overall annual decreasing trends observed for Palmaryville. Hans Merensky Hoerskool indicates an increase of 1% in mid-season rainfall (1927-2014), but a decrease of 4.4% in late season rainfall (*Figure 5.36*). Gravelotte and Zomerkomst rainfall indicate an increase in rainfall across all rainfall seasons, with increases of between 6-10% in mid seasonal rainfall and 5-41% in late season rainfall. The high range of percentage change in rainfall during the late season is indicative of high rainfall variability in late season rainfall. The greatest incline in average late season rainfall was experienced at Gravelotte rainfall station (41%), the average late season rainfall was 33.9mm during the period 1971-1992, which increased to an average of 55.5mm during the period 1993-2014. This massive incline in the percentage rainfall in the late season suggests this season is the major contributor towards the 9.5% overall increase in Gravelotte rainfall (1971-2014). The trends depicted for rainfall across all three-rainfall seasons for the northern bushveld are not highly significant trends as the p-values for all trends across all stations were below the 95% significance level (*Table 5.18*).

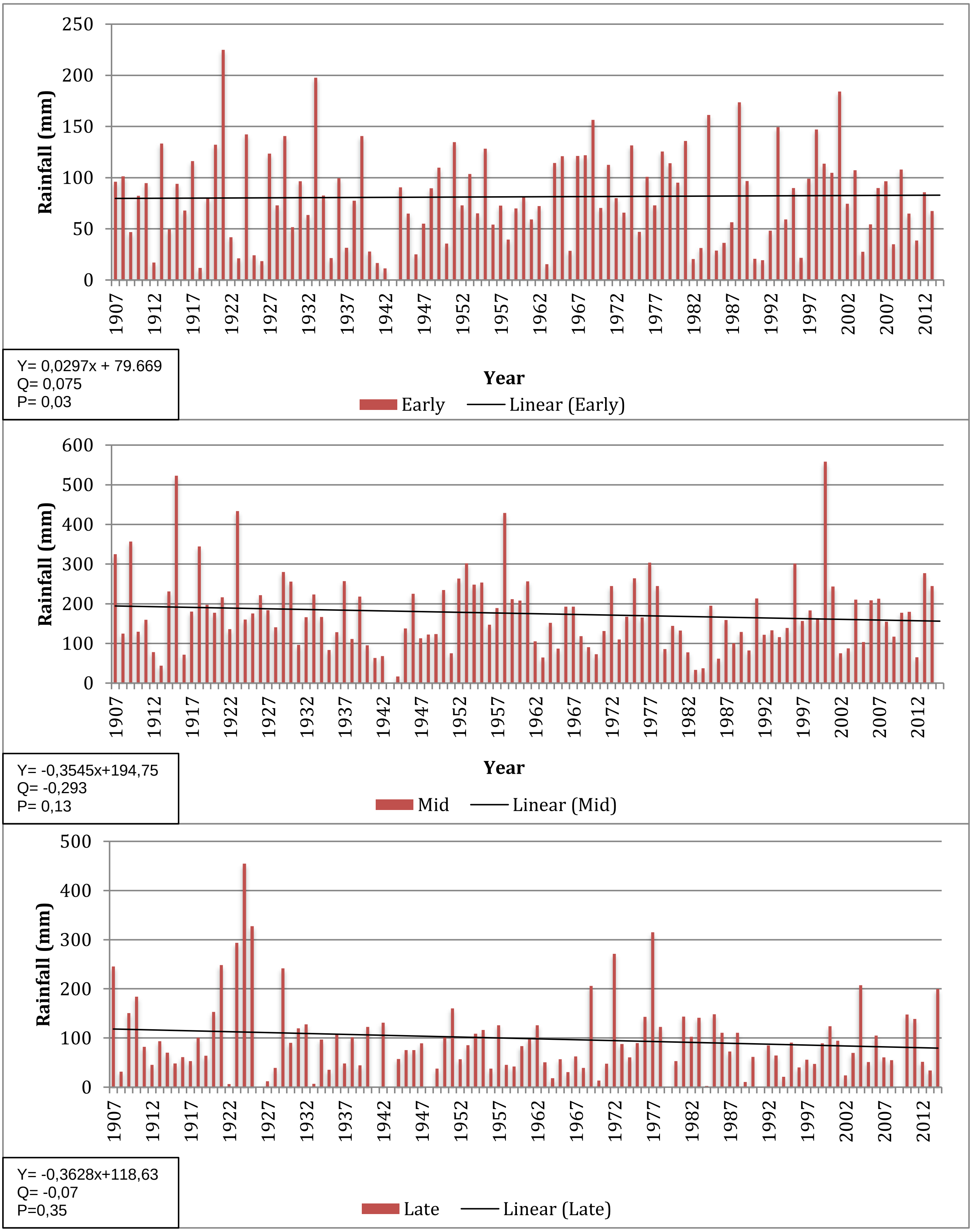


Figure 5.35 Early, mid and late rainfall season trends for Palmaryville rainfall station in the northern bushveld

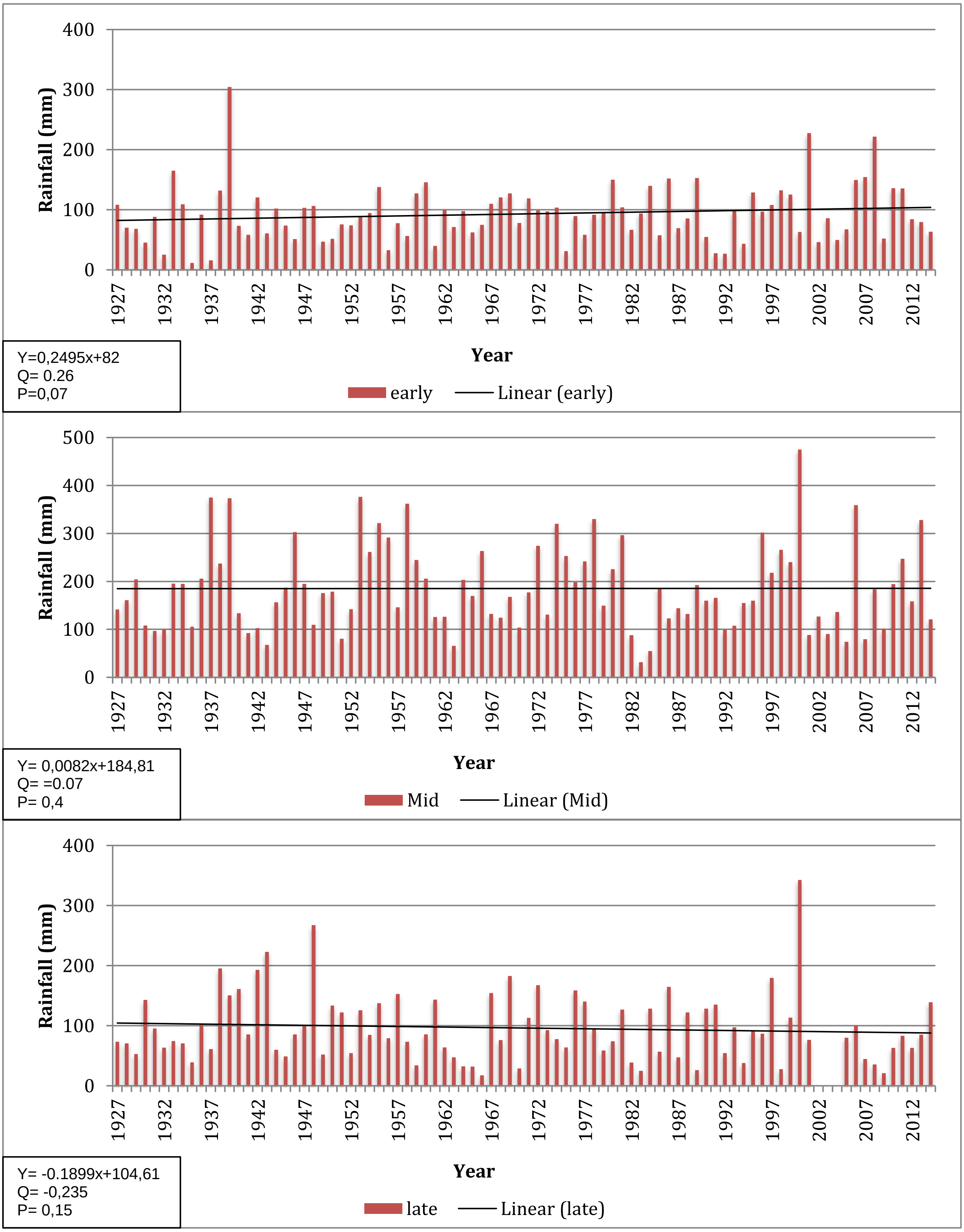


Figure 5.36 Early, mid and late rainfall season trends for the Hans Merensky Hoerskool rainfall station in the northern bushveld

5.8.2 Northern lowveld

The rainfall stations for the northern lowveld depict an array of results, with 71% of the rainfall stations depicting a decline in early seasonal, and the other 29% depicting an incline in rainfall. Decline in early season rainfall ranges from between 2% at Pafuri (1924-2014), to 22% at Shingwedzi Vlakteplas (1983-2014). Punda Maria and Letaba rainfall stations both indicate an increase in early season rainfall, and a decline in mid and late season rainfall. The increase in rainfall for early season ranges between 26% for Punda Maria and 18% for Letaba, these trends are however not significant within the 95% significance level. Mid-season rainfall increases between 2% (Punda Maria) and 3% (Letaba), and declines in late season rainfall from between 14-22% for Letaba and Punda Maria respectively. The decline in late season rainfall at Punda Maria (*Figure 5.38*) and Pafuri (*Figure 5.37*) rainfall stations is highly significant at the 95% significance level (*Table 5.18*). Shingwedzi and Krugerwildtuin Shangoni weather station were the only two stations that depict a decline in rainfall across all three rainfall seasons for the period of 1958-2014, with declines of 20% for both stations in early season rainfall, highly significant declines of between 19-29% for mid-season and non-significant declines of between 1-18% in the late season. The decline in rainfall across all rainfall seasons is a major contributor towards the overall decline in Krugerwildtuin Shangoni (20%) and Shingwedzi (10.6%) rainfall (*Figure 5.15 and 5.12*). Letaba Mahlangeni depicts a significant decline of 11% for the early season rainfall, and a non-significant decline of 1% for the mid-season rainfall. The rainfall for the late season at Letaba Mahlangeni depicts an increase of 29% during the period 1987-2014.

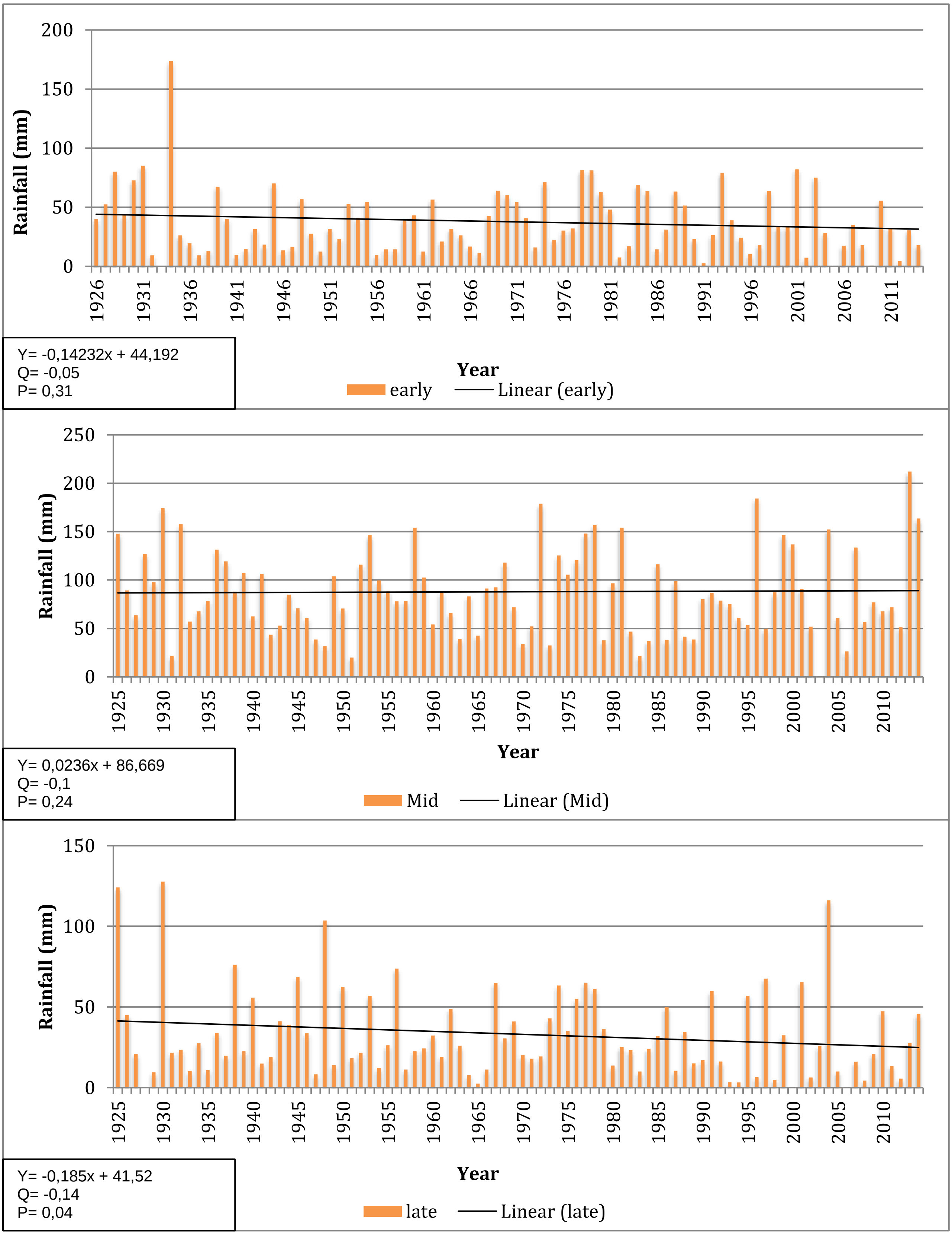


Figure 5.37 Early, mid and late rainfall season trends for the Pafuri rainfall station in the northern lowveld

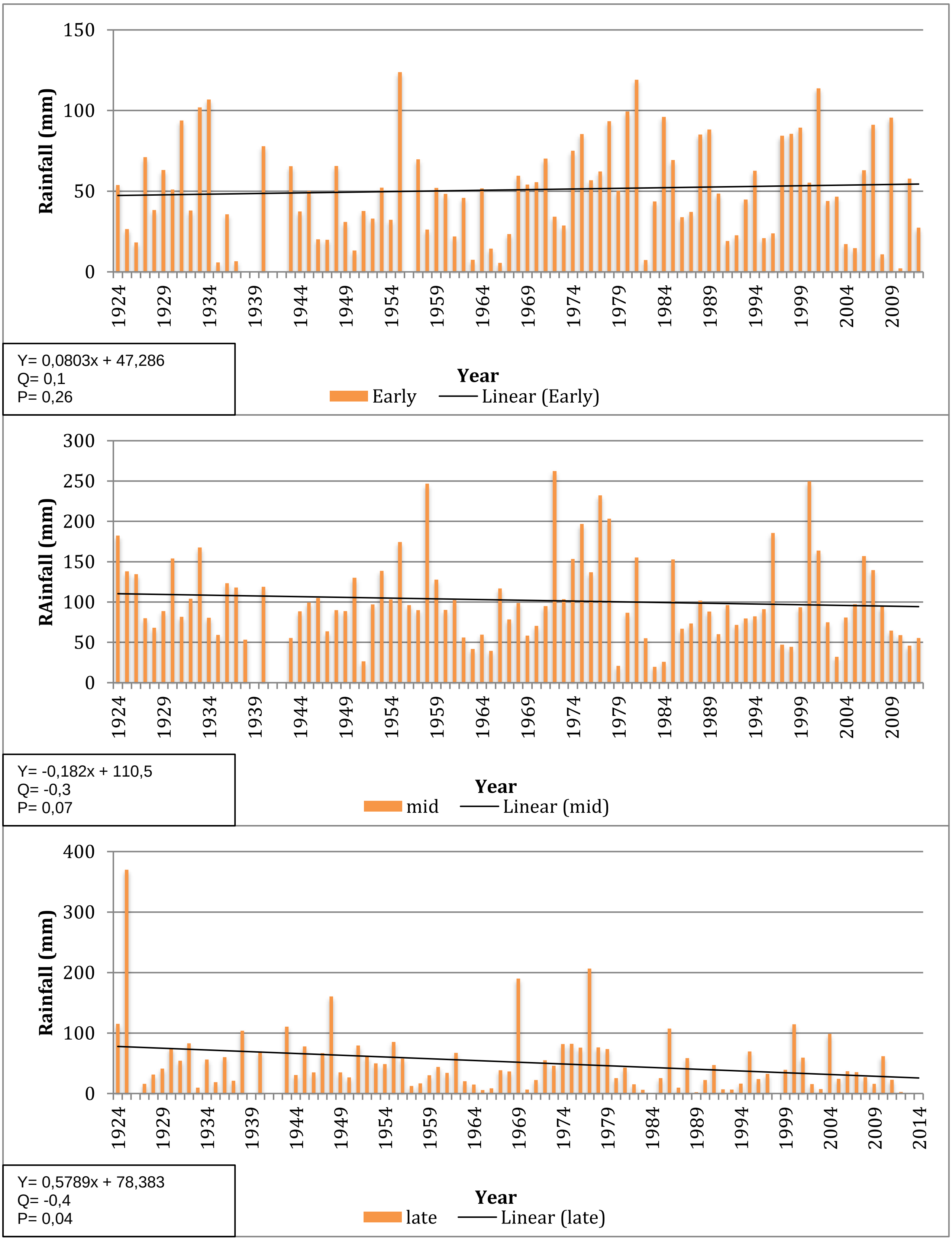


Figure 5.38 Early, mid and late rainfall season trends for the Punda Maria rainfall station in the northern lowveld

5.8.3 Southern Bushveld

The early rainfall season for the Pilgrams Rest (*Figure 5.39*) station indicates a 16.6% increase in rainfall whilst the mid and late seasons exhibit a 0.5% and 21.5% decreasing trend for the period 1904-2014. The Champagne Nat rainfall station records display a non-significant decrease in rainfall across all rainfall seasons, with a decrease of 5%, 0.2% and 7.5% in the early, mid and late seasons respectively. The Nelspruit rainfall station indicates an increase in early season rainfall by 7.6% whilst the mid and late seasons exhibit a decline in rainfall by 8.4% and 0.4% respectively during the period 1906-2014 (*Figure 5.40*). Onverwag Bos rainfall indicates a decrease of 7.8% for the early season, as well as a decline of 0.3% in the late season, whilst the mid-season exhibits and increase in rainfall by 3.4% between 1964-2014. Sabie rainfall station exhibits an increase in rainfall in both the early and late rainfall seasons with an increase of 7.8% and 26.8% respectively. The mid-season rainfall exhibits a decline in rainfall by 5.4% during the period 1973-2014. The sharp decline in rainfall for Sabie late rainfall season is a majority contributor to the overall annual rainfall decline of 2.4% (*Figure 5.22*).

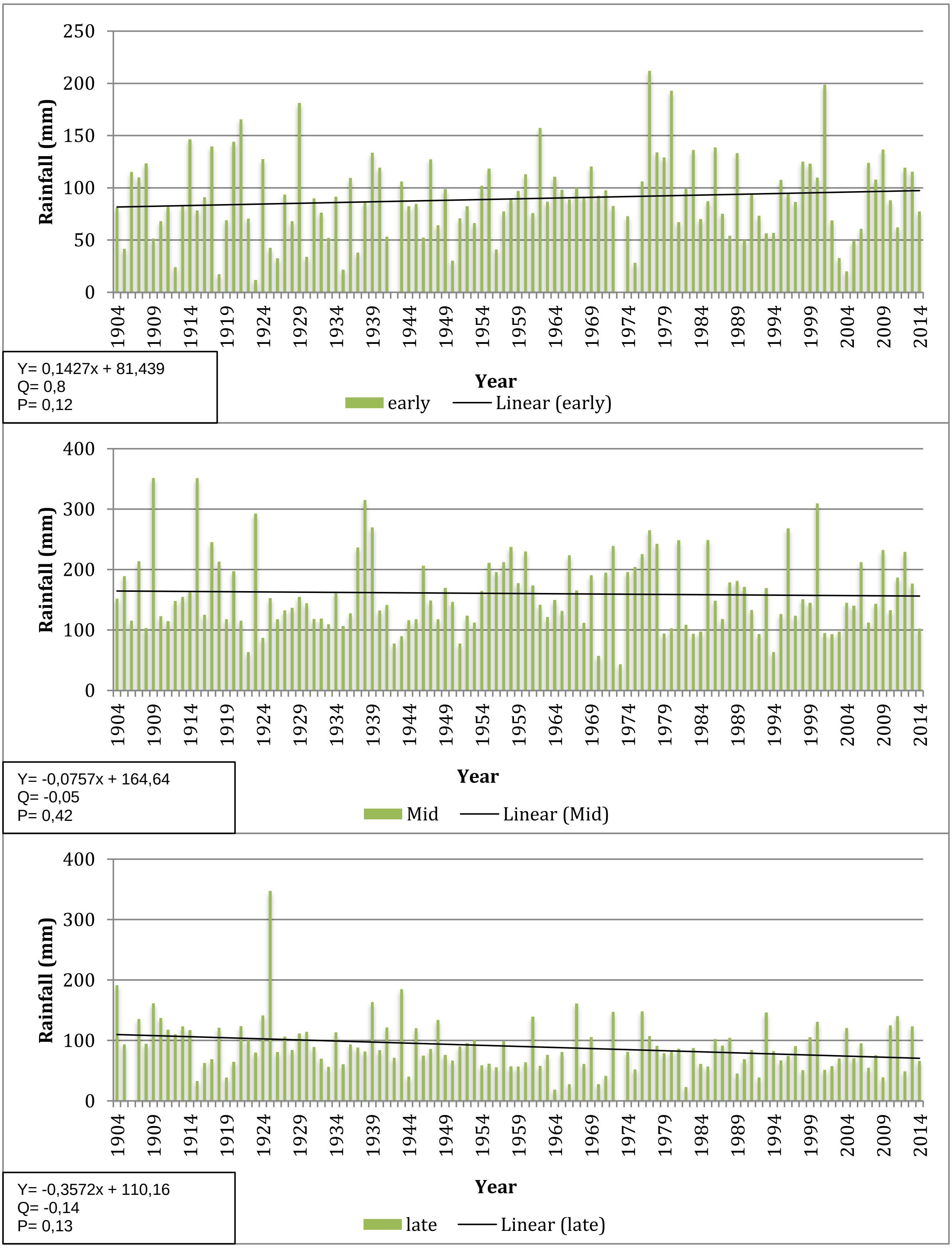


Figure 5.39 Early, mid and late rainfall season trends for the Pilgrams Rest rainfall station in the southern bushveld

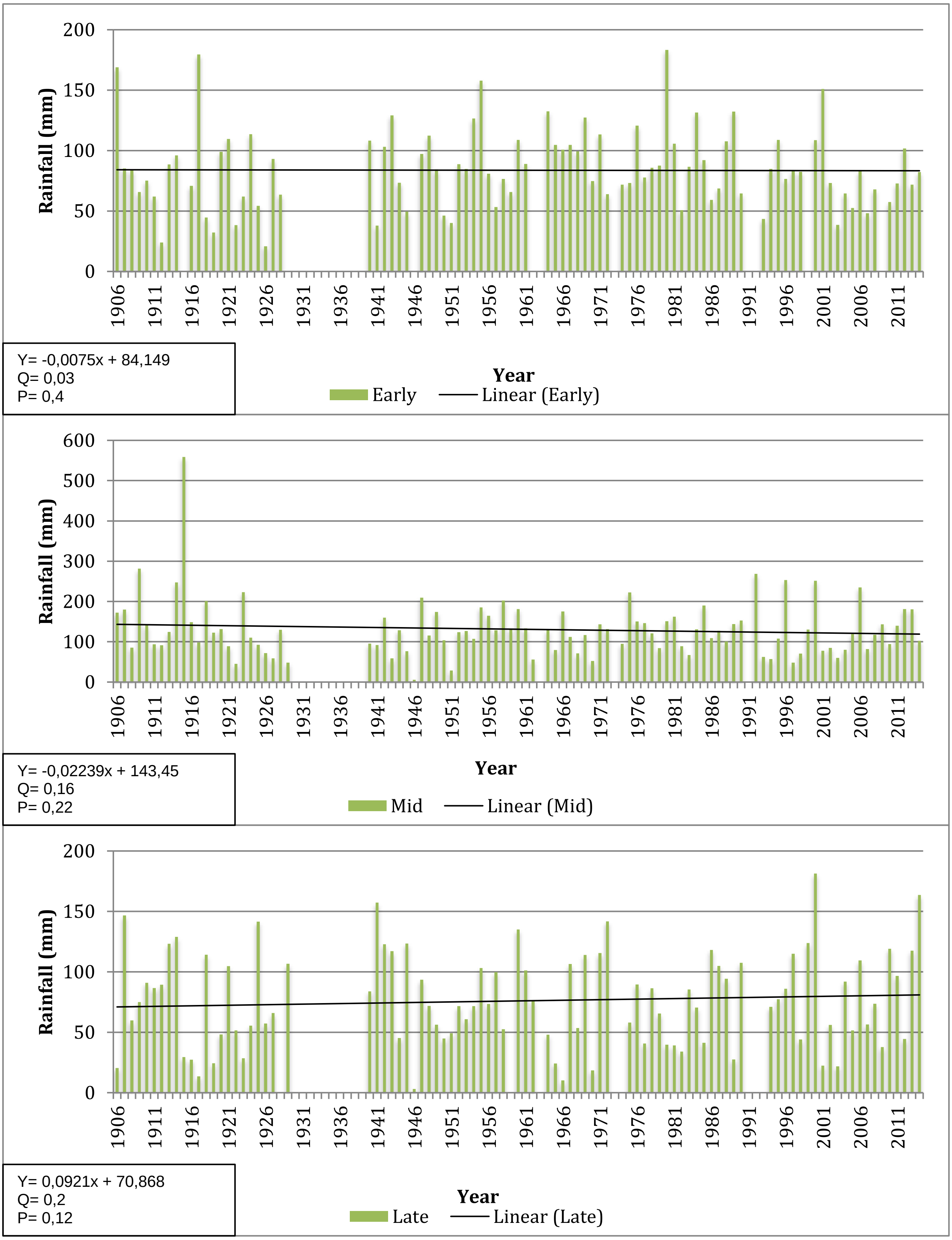


Figure 5.40 Early, mid and late rainfall season trends for Nelspruit rainfall station in the southern bushveld

5.8.4 Southern lowveld

Skukuza, Stolznek and Satara rainfall records exhibit an increase in rainfall across all three seasons, with Skukuza depicting a highly significant increase of 9.5%, 10.6% and 3.6% for early, mid and late seasons respectively (*Figure 5.41*). Stolznek rainfall depicts a 0.6%, 27.5% and 18.3% non-significant increase in rainfall for early, mid and late seasons respectively. The high percentage increase in rainfall experienced during mid and late seasons for Stolznek is a main contributing factor to the overall increase in Stolznek annual rainfall (*Figure 5.27*). Satara weather station depicts non-significant trends for all three-rainfall seasons, with increases in rainfall by 3.4%, 2.3% and 5.7% for early, mid and late seasons respectively. The Malelane rainfall station depicts a non-significant decline in early season rainfall by 4.6%, whilst the mid and late seasons depict a decrease in rainfall by 1.2% and 11.1% respectively (*Figure 5.42*).

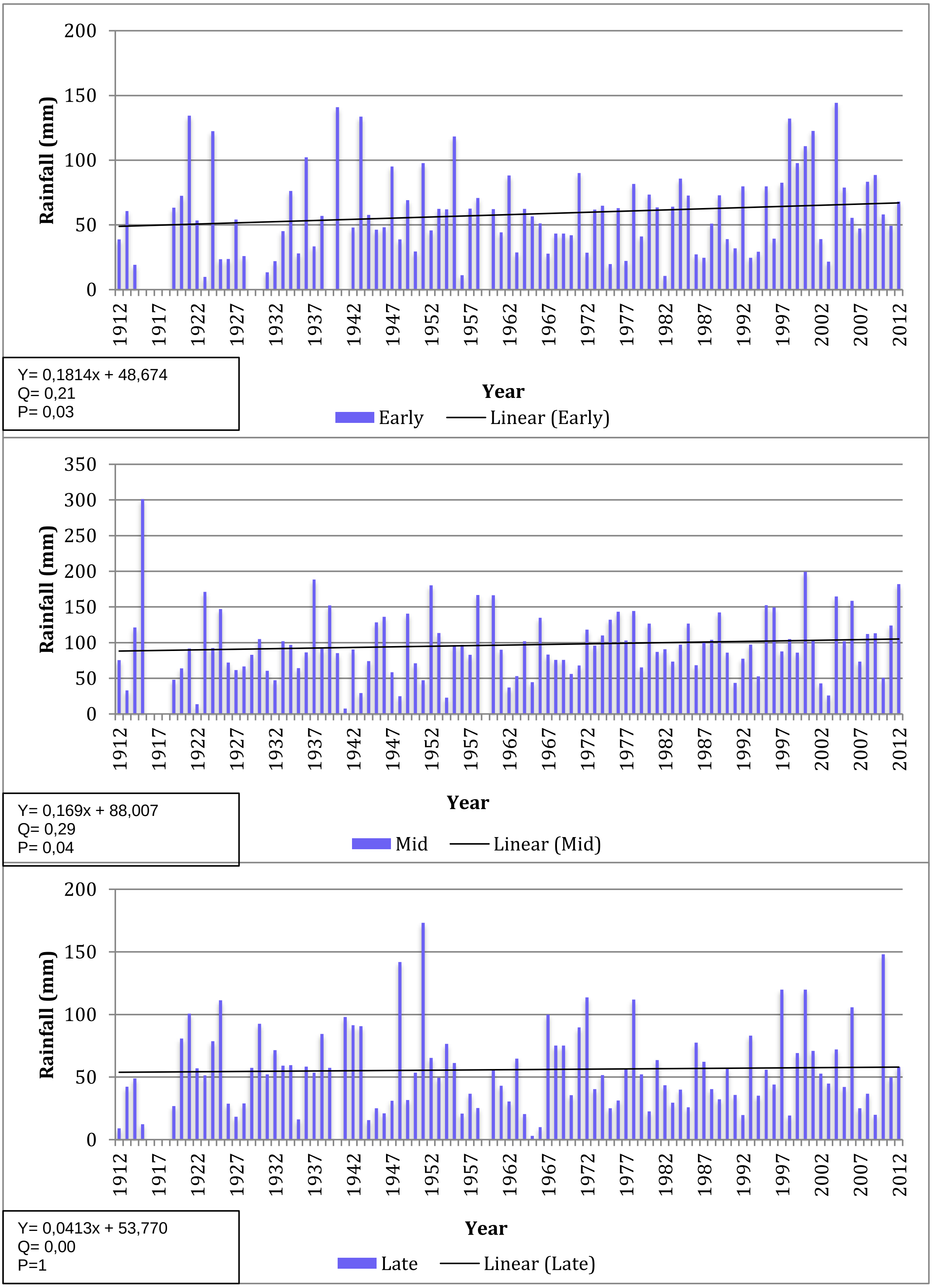


Figure 5.41 Early, mid and late rainfall season trends for Skukuza rainfall station in the southern lowveld

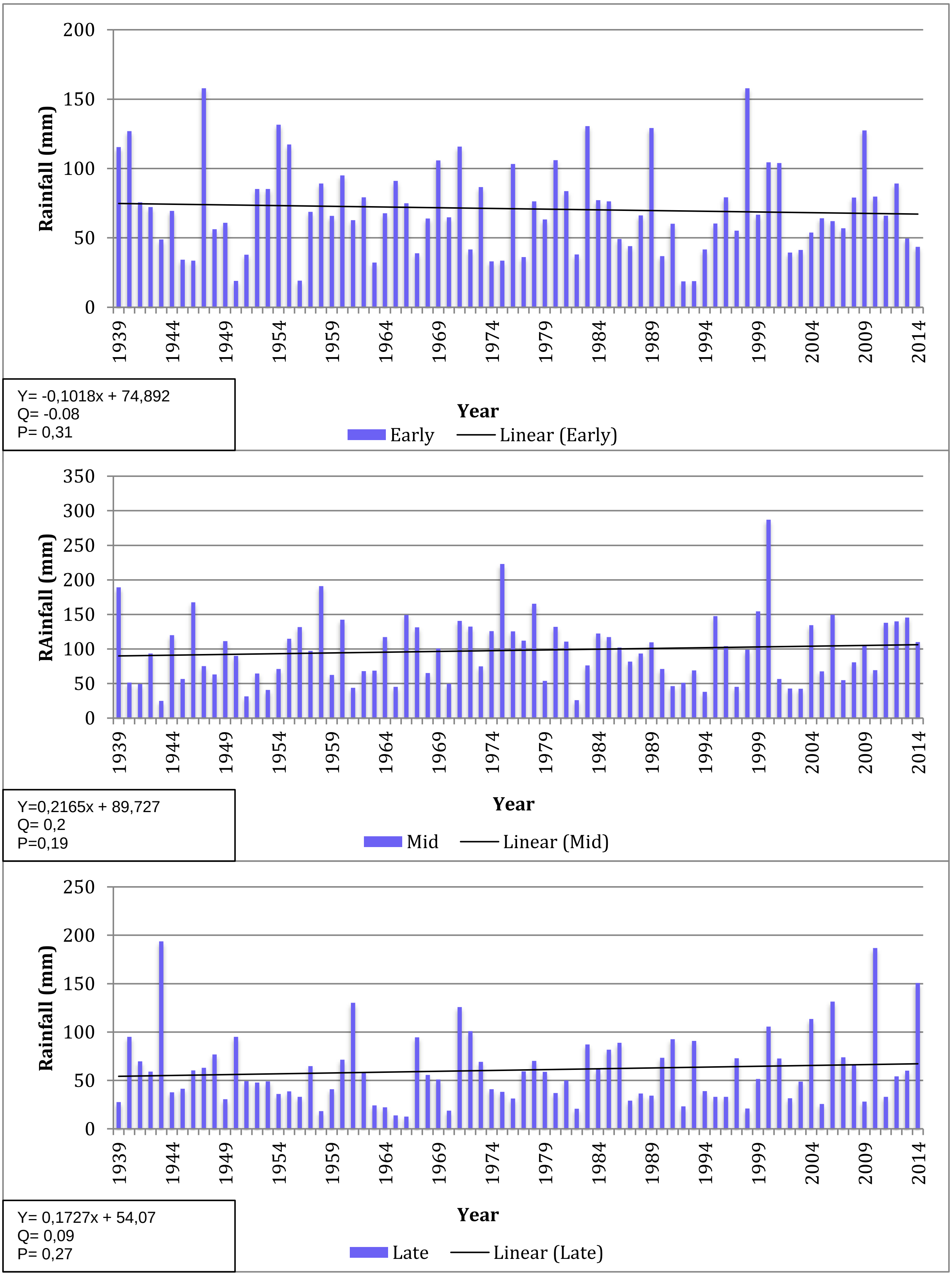


Figure 5.42 Early, mid and late rainfall season trends for Malelane rainfall station in the southern lowveld

Table 5.18 Mann Kendall trend statistic results for the seasonal rainfall for the northern bushveld and northern lowveld

Region	Station	Rainfall season	Normalised Test Statistic (Z)	P-Value	Trend (A 95% significance level)	Sens Q (slope)	Sens B (Intercept)
Northern Bushveld	Palmaryville	Early	0.43	0.33	No Trend	0.075	73.78
		Mid	-1.12	0.13	Decreasing	-0.293	178.5
		Late	-0.39	0.35	Decreasing	-0.069	87.81
	Hans Merensky Hoerskool	Early	1.42	0.07	No Trend	0.256	78.91
		Mid	-0.23	0.4	Decreasing	-0.065	170.02
		Late	-1.03	0.15	Decreasing	-0.238	93.35
	Zomerkomst	Early	1.65	**0.04***	**Increasing**	0.289	81.22
		Mid	0.73	0.23	Increasing	0.267	170.51
		Late	-0.31	0.38	Decreasing	-0.066	92.63
	Gravelotte	Early	0.61	0.27	Increasing	0.215	34.96
		Mid	0.53	0.3	Increasing	0.366	59.29
		Late	1.47	0.07	Increasing	0.591	22.18
	Thohoyandou	Early	-0.1	0.46	Decreasing	-0.077	68.73
		Mid	1.31	0.09	Increasing	1.548	92.29
		Late	0.83	0.2	Increasing	0.741	46.01
Northern Lowveld	Pafuri	Early	-0.49	0.31	Decreasing	-0.052	34.18
		Mid	-0.70	0.24	Decreasing	-0.122	87.18
		Late	-1.72	**0.04***	**Decreasing**	-0.136	30.33
	Punda Maria	Early	0.64	0.26	Increasing	0.103	44.69
		Mid	-1.46	0.07	Decreasing	-0.272	104.71
		Late	-2.62	**0.004***	**Decreasing**	-0.371	57.25
	Letaba	Early	1.44	0.07	Increasing	0.17	32.22
		Mid	0.31	0.39	Increasing	0.053	60.19
		Late	-0.48	0.32	Decreasing	-0.064	34.18
	Letaba Mahlangeni	Early	-0.38	0.35	Decreasing	-0.153	45.06
		Mid	0.93	0.18	Increasing	0.971	59.75
		Late	1.23	0.1	Increasing	0.693	16.79
	Shingwedzi	Early	-0.15	0.44	Decreasing	-0.048	38.17
		Mid	-1.72	**0.04***	**Decreasing**	-0.549	86.78
		Late	0.96	0.17	Increasing	0.258	25.67
	Shingwedzi Vlakteplas	Early	-0.92	0.18	Decreasing	-0.568	47.2
		Mid	0.92	0.18	Increasing	0.869	59.9
		Late	1.57	0.06	Increasing	0.714	26.3
	Krugerwildtuin Shangoni	Early	-1.16	0.12	Decreasing	-0.293	53.77
		Mid	-1.96	**0.02***	**Decreasing**	-0.767	108.38
		Late	-0.24	0.4	Decreasing	-0.05	37.43

Table 5.19 Mann Kendall trend statistic results for the seasonal rainfall for southern bushveld and southern lowveld stations

Region	Station	Rainfall season	Normalised Test Statistic (Z)	P-Value	Trend (A 95% significance level)	Sens Q (slope)	Sens B (Intercept)
Southern Bushveld	Pilgrams Rest	Early	1.18	0.12	Increasing	0.181	80.31
		Mid	0.21	0.42	Increasing	0.046	142.26
		Late	-1.13	0.13	Decreasing	-0.14	87.69
	Champagne Nat	Early	0.3	0.38	Increasing	0.05	69.03
		Mid	0.14	0.44	Increasing	0.042	122.2
		Late	-0.41	0.34	Decreasing	-0.08	74.64
	Nelspruit	Early	-0.26	0.4	Decreasing	0.032	85.37
		Mid	0.75	0.22	Increasing	0.155	118.8
		Late	1.18	0.12	Increasing	0.2	62.63
	Onverwag Bos	Early	-1.20	0.12	Decreasing	-0.525	125.46
		Mid	-0.08	0.47	Decreasing	-0.039	230.24
		Late	-0.56	0.29	Decreasing	-0.342	129.59
	Sabie	Early	-0.04	0.48	Decreasing	-0.05	100.23
		Mid	-1.31	0.09	Decreasing	-0.98	204.40
		Late	0.69	0.24	Increasing	0.583	89.32
Southern Lowveld	Skukuza	Early	1.83	**0.03***	**Increasing**	0.214	46.82
		Mid	1.78	**0.04***	**Increasing**	0.288	78.25
		Late	0.00	1	Increasing	0.00	52.05
	Satara	Early	-0.01	0.5	Decreasing	-0.001	48.58
		Mid	-1.01	0.15	Decreasing	0.29	79.85
		Late	-0.61	0.27	Decreasing	-0.119	48.65
	Malelane	Early	-0.49	0.31	Decreasing	-0.078	69.74
		Mid	0.86	0.19	Increasing	0.195	90.25
		Late	0.6	0.27	Increasing	0.087	48.28
	Stolznek	Early	-0.60	0.27	Decreasing	-0.37	72.56
		Mid	1.02	0.15	Increasing	0.81	81.01
		Late	-0.13	0.44	Decreasing	-0.09	64.55

5.9. Rain season lengths

The change in the length of the wet/rainy season is detrimental to both the environment of the study area, as well as the animals and plants that occupy the region of KNP. Many, if not most of the freshwater resources are highly dependent on rainfall during the wet season to replenish stream flow, ground water and surface water availability for flora and fauna. Majority of KNP rivers are non-perennial, and will start flowing once the first rains of the season begin. A change in the wet season, specifically a decrease in the length of the wet season will lead to a decline in the water supply to the region, as well as the later onset of stream flow.

In the northern region of the study area, all weather stations depict a decreasing trend in the length of the wet/rainy season over time. For the longer running weather stations, including Palmaryville, Zomerkomst and Hans Merensky Hoerskool, the changes in the length of the wet season are all decreasing by an average of 0.23, 0.19 and 0.17 days per annum (*Table 5.20*). Gravelotte weather station has a decreasing length of season on average of 0.75 days per annum (*table 5.20*). The longer running weather stations in northern lowveld, include Pafuri, Punda Maria and Letaba, these stations depict a decreasing change in the length of the wet season by an average of 0.17, 0.40 and 0.47 respectively. The shorter running weather stations, which include Shingwedzi, Shingwedzi Vlakteplas, and Krugerwildtuin Shangoni which depict a decreasing, trend in the length of the wet season by an average of 0.48, 1.07 and 1.21 days per annum respectively (*table 5.20*).

Overall, all weather stations for the northern bushveld have depicted decreasing trends in the length of the rainfall season, with the longer running weather stations depicting a total decrease in the length of the rainy season 9% for the period 1930-2014, and the shorter running stations depicting a decrease of 14% for the period 1980-2014. In the northern lowveld, the longer stations depict an average decrease of 6% during the period 1930-2014, whereas the shorter stations depict an average decrease of 10% from 1980-2014.

The only exception is the Letaba Mahlangeni weather station, which only has 25 years of data; the last 2 decades (1990-1999 and 2000-2014) record an increase in rainfall by 12% from 1990-2014. Which suggests that although long-term data suggests a total decline in the length of the rainfall season over time, in fact, the length of the season has increased over the past 2 decades. The reasoning for this will be discussed further in chapter 6.

In the southern region of the study location all weather stations depict a decreasing trend in the length of the wet/rainy season. The longer weather stations in the southern highveld including Champagne Nat, Pilgrams Rest and Nelspruit all depict a decrease in the length of the wet season by an average of 0.33, 0.08 and 0.06 days per annum. The shorter weather stations including Onverwag Bos, Hoedspruit and Sabie all depict an average annual decrease in the wet season by 0.68, 0.17 and 1.3 days respectively.
In the southern lowveld region, the 3 longer weather station including Skukuza, Satara and Malelane all depict a decrease in the length of the wet season by an average of 0.11, 0.52 and 0.63 days per annum respectively. The shorter weather station of Stolznek depicts an average annual decrease in the length of the wet season by 0.79 days per annum (*Table 5.20*).

Overall, the weather stations for the southern bushveld have depicted decreases in the length of the rainy season across all weather stations. The longer stations depict a decrease of 6.5% for the period 1930-2014, and the shorter weather stations depict a total decrease of 13% for the period 1980-2014. In the southern lowveld, the longer weather stations depict a decrease of 10% for the period 1930-2014, and the shorter weather stations depict a change of 6% for the period 1980-2014.

Table 5.20 linear trends and average annual rates of change for the length of the rainy season

Region	Station	Dates of data	Linear trend	Change in days per annum
Northern Highveld	Palmaryville	1907-2014	Decreasing	0.23
	Hans Merensky Hoerskool	1927-2014	Decreasing	0.17
	Zomerkomst	1923-2014	Decreasing	0.19
	Gravelotte	1971-2011	Decreasing	0.75
	Thohoyandou	1983-2014	Decreasing	0.55
Northern Lowveld	Pafuri	1925-2014	Decreasing	0.17
	Punda Maria	1924-2012	Decreasing	0.40
	Shingwedzi Vlakteplas	1983-2014	Decreasing	1.07
	Shingwedzi	1958-2005	Decreasing	0.48
	Letaba Mahlangeni	1987-2014	Increasing	0.3
	Letaba	1928-2012	Decreasing	0.47
	Krugerwildtuin Shangoni	1958-2014	Decreasing	1.21
Southern Highveld	Onverwag Bos	1964-2014	Decreasing	0.68
	Champagne Nat	1924-2007	Decreasing	0.33
	Hoedspruit	1994-2014	Decreasing	0.11
	Pilgrams Rest	1904-2014	Decreasing	0.08
	Sabie	1973-2014	Decreasing	1.3
	Nelspruit	1906-2014	Decreasing	0.06
Southern Lowveld	Satara	1933-2013	Decreasing	0.52
	Skukuza	1912-2012	Decreasing	0.11
	Malelane	1939-2014	Decreasing	0.63
	Stolznek	1984-2014	Decreasing	0.79

It is noticeable throughout all regions, that the weather stations with the shorter records depict a greater decrease in the length of the wet season per annum. It is suggested by these findings, along with the literature, that the wet seasons in this semi-arid area, are getting increasingly shorter throughout the years. As time progresses, weather and climate events are getting more and more extreme, and periods of drought are becoming more prolonged over the years DEA, 2013). The longer the droughts settle in, the shorter the wet seasons will be. The changing of the climate and the evidence of the variability of the rainfall in this location suggests an linear decline in the length of the wet season and thus the stations with only 30-40 years of records will depict a greater decline in the wet season than the weather stations that are able to show trends in the changes of the wet season over the past century.

More of the weather stations experience a later start of the wet season and an earlier end to the season. This has obvious effects on the trend patterns of the length of the wet season over a temporal time scale (discussed in next sub section). However, some weather station records produced differing results. For example, Shingwedzi Vlakteplas, Gravelotte and Letaba Mahlangeni all show increasing linear trends lines for the end of season rainfall (*table 5.21*). Increasing linear trends suggest that the end of the wet/rainy season occurs later in the year, whereas all other weather stations depict that the end of the rainy season is occurring earlier in the year. These linear trends are assumed to be differing since these weather stations have a much shorter temporal scale than the stations depicted previously. These 4 weather stations only have +/- 30 years of data, whereas the other weather stations have between 80-110 years of data, and thus it can be said that these linear trends would presumably be negative trends if their datasets were as lengthy as the rest of the weather stations (*table 5.21*).

Table 5.21 Trends in the start and end dates of the rainy season

Region	Station	Linear trend (start date)	Average change in start dates (per annum)	Linear trend (end date)	Average change in end dates (per annum)
Northern bushveld	Palmaryville	Increasing	0.17	Decreasing	0.07
	Hans Merensky Hoerskool	Decreasing	0.02	Decreasing	0.2
	Zomerkomst	Increasing	0.13	Decreasing	0.07
	Gravelotte	Increasing	0.87	Increasing	0.09
	Thohoyandou	Increasing	0.12	Decreasing	0.08
Northern lowveld	Pafuri	Increasing	0.04	Decreasing	0.2
	Punda Maria	Increasing	0.23	Decreasing	0.19
	Shingwedzi Vlakteplas	Increasing	1.63	Increasing	0.59
	Shingwedzi	Decreasing	0.03	Decreasing	0.44
	Krugerwildtuin Shangoni	Increasing	0.77	Decreasing	0.45
	Letaba Mahlangeni	Increasing	0.42	Increasing	0.4
	Letaba	Increasing	0.25	Decreasing	0.3
Southern bushveld	Champagne Nat	Increasing	0.2	Decreasing	0.14
	Onverwag Bos	Increasing	0.38	Decreasing	0.08
	Pilgrams Rest	Decreasing	0.02	Decreasing	0.03
	Sabie	Increasing	0.7	Decreasing	0,61
	Nelspruit	Decreasing	0.02	Decreasing	0.1
Southern lowveld	Satara	Increasing	0.15	Decreasing	0.34
	Skukuza	Increasing	0.01	Decreasing	0.12
	Stolznek	Increasing	0.54	Decreasing	0.3
	Malelane	Increasing	0.3	Decreasing	0.3

Section B

Analysis of KNP streamflow, and the relationship between rainfall and streamflow in the region

5.10 Introduction

There are 16 rivers analysed for the purposes of this Masters project. Four of which have more than one gauging station located along the river. These four rivers, (i.e. Shingwedzi, Letaba, Sabie and Crocodile), all prove advantageous to this research as the analysis of data from the upstream and downstream gauge stations can be analysed to determine changes in flow characteristics along different sections of the river. The Shingwedzi and Sabie River have two gauge stations along the length of the river, and the Crocodile and Letaba River have three gauge stations.

To analyse the characteristics of these river/stream flow patterns, the rivers are categorised, to enable appropriate analysis based on their location, influence and perennial nature. It is important to categorize these rivers accordingly as the rivers that originate outside the park borders have different impacts than those that have their source area within the park. Perennial and non-perennial rivers also need to be categorised as they behave differently, and will react differently to rainfall events and phases of flooding and drought occurrences.

The comparison of river/stream flow characteristics help to determine external effects on river systems that develops outside the security of the KNP boundary. *Table 5.22* indicates the origin of the river systems as well as their perennial or seasonal nature. For the purposes of this research, three of the river systems originate from within KNP boundaries, namely, Shisha (B9H001), Tsendze (B8H011) and Nwanedzi (X4H004).

Table 5.22 Characteristics of the rivers/streams analysed

River	Perennial	Non-perennial	Rivers sourced outside the park	Rivers sourced within the park
Luvuvhu	✓		✓	
Mutale	✓		✓	
Shisha		✓		✓
Mphongolo		✓		
Shingwedzi		✓		✓
Tsendze		✓		✓
Letaba	✓		✓	
Olifants	✓		✓	
Timbavati		✓	✓	
Nwanedzi		✓		✓
Sand		✓	✓	
Sabie	✓		✓	
Nsikazi		✓		✓
Crocodile	✓		✓	
Komati	✓		✓	

Due to rainfall weather stations being categorised based on their regional location, rivers will be analysed in the same way. Rivers have been categorised into a northern or southern region, and according to the literature, all rivers including, and north of the Letaba River are placed in northern KNP territory, all rivers and stations located south of the Letaba River are placed into the southern territory.

Table 5.23 Location of river gauging stations

River Gauge stations							
Far North				North			
A9H012	A9H013	B9H001	B9H004	B8H011	B8H018	B8H008	B8H034
B9H002	B9H003						
Central				South			
B7H015	B7H020	X4H004		X3H008	X3H021	X3H015	X2H072
				X2H006	X2H046	X2H016	X2H036

Table 5.24 Length, location and catchment area of river gauge stations

River	Station Number	Years	Latitude	Longitude	Catchment Area (Km^2)
Luvuvhu	A9H012	1987-2015 **(28)**	22.76851	30.88926	1758
Mutale	A9H013	1981-2015 **(34)**	22.43773	31.07783	1776
Shisha	B9H001	1960-2015 **(55)**	22.83854	31.23709	648
Mphongolo	B9H004	1983-2015 **(32)**	22.95097	31.23374	739
Shingwedzi	B9H002	1983-2015 **(32**)	23.21688	31.22355	810
Shingwedzi	B9H003	1984-2015 **(31)**	23.14327	31.46262	4540
Tsendze	B8H011	1961-2015 **(54)**	23.52660	31.40346	432
Letaba	B8H008	1984-2015 **(31)**	23.65837	31.04990	4710
Letaba	B8H034	1981-2015 **(34)**	23.70217	31.21662	10652
Letaba	B8H018	1959-2015 **(52)**	23.83532	31.63754	12938
Olifants	B7H015	1987-2015 **(28)**	24.00623	31.24288	49826
Timbavati	B7H020	1981-2015 **(34)**	24.23100	31.63400	935.5
Nwanedzi	X4H004	1960-2015 **(55)**	24.44972	31.97694	986
Sand	X3H008	1967-2015 **(38)**	24.77003	31.38861	1064
Sabie	X3H021	1990-2015 **(25)**	24.96847	31.51542	2407
Sabie	X3H015	1987-2015 **(28)**	25.14953	31.94067	5715
Nsikazi	X2H072	1990-2015 **(25)**	25.27228	31.24618	240
Crocodile	X2H006	1985-2015 **(30)**	25.46978	31.08814	5097
Crocodile	X2H046	1943-2014 **(71)**	25.39889	31.61056	8473
Crocodile	X2H016	1960-2014 **(54)**	25.36386	31.95572	10365
Komati	X2H036	1982-2014 **(31)**	25.43661	31.98244	21652

5.11 Temporal changes in river/stream flow characteristics in KNP

5.11.1 Northern most KNP

The northern territory can be further divided into two more regions, the northern KNP and northern most KNP. To make the graphic representation in the trends of these river systems the rivers were categorised according to their sub regions. Due to the huge differences in flow volumes of the different rivers, the graphic representation of these flow records could not be represented on the same set of axes.

The northern most KNP includes the rivers Luvuvhu (A9H012), Mutale (A9H013), Shisha (B9H001), Mphongolo (B9H004) and Shingwedzi (B9H002 and B9H0023 river stations.

Table 5.25 Streamflow characteristics for gauge station in far northern KNP

Station	River	Years of data	Mean annual flow (m^3/S)	Lowest recorded flow (m^3/S)	Highest recorded flow (m^3/S)	Range (m^3/S)
A9H012	Luvuvhu	28	2659,16	447,65 (1994)	8734 (2000)	8286,35
A9H013	Mutale	34	964,9	86,33 (2004)	3486,7 (1999)	3400,4
B9H001	Shisha	55	118,1	0 (multiple yr)	3188,8 (2009)	3188,8
B9H004	Mphongolo	32	171,6	0 (multiple yr)	967,2 (2004)	967,2
B9H002	Shingwedzi	32	328,3	0 (multiple yr)	3574,4 (2000)	3574,4
B9H003	Shingwedzi	31	952,5	0 (multiple yr)	6430,7 (1992)	6430,7

Stations along the Luvuvhu, Shisha and Shingwedzi rivers depict increasing linear trends over time. The only station depicting a significant increasing trend within the 95% confidence level is the Shisha (B9H001) station, with an increase in flow by 6,67m^3/S per annum between 1960 and 2015 (*Figure 5.45*), the Luvuvhu gauge station (A9H012) depicts a non-significant increase of 55.18m^3/S per annum between 1987 and 2015 (*Figure 5.43*), the Mphongolo (B9H004) station depicts a non-significant increase in flow by 4.08m^3/S per annum between 1983 and 2015 (*Figure 5.47*). The stations that depict a decreasing linear flow trend include the Mutale station (A9H013), and downstream Shingwedzi station (B9H003). A9H013 depicts a non-significant decreasing linear trend of 13.4m^3/S per annum between 1981 and 2015 (*Figure 5.44*).

The Interesting finding from the following graphs is the flow for the Shingwedzi River. The upstream station (B9H002) depicts a non-significant increase in flow of 4.08m^3/S per annum (1984-2014), whereas the downstream station (B9H003) depicts a non-significant decreasing trend of 10.29m^3/S per annum (1984-2015).

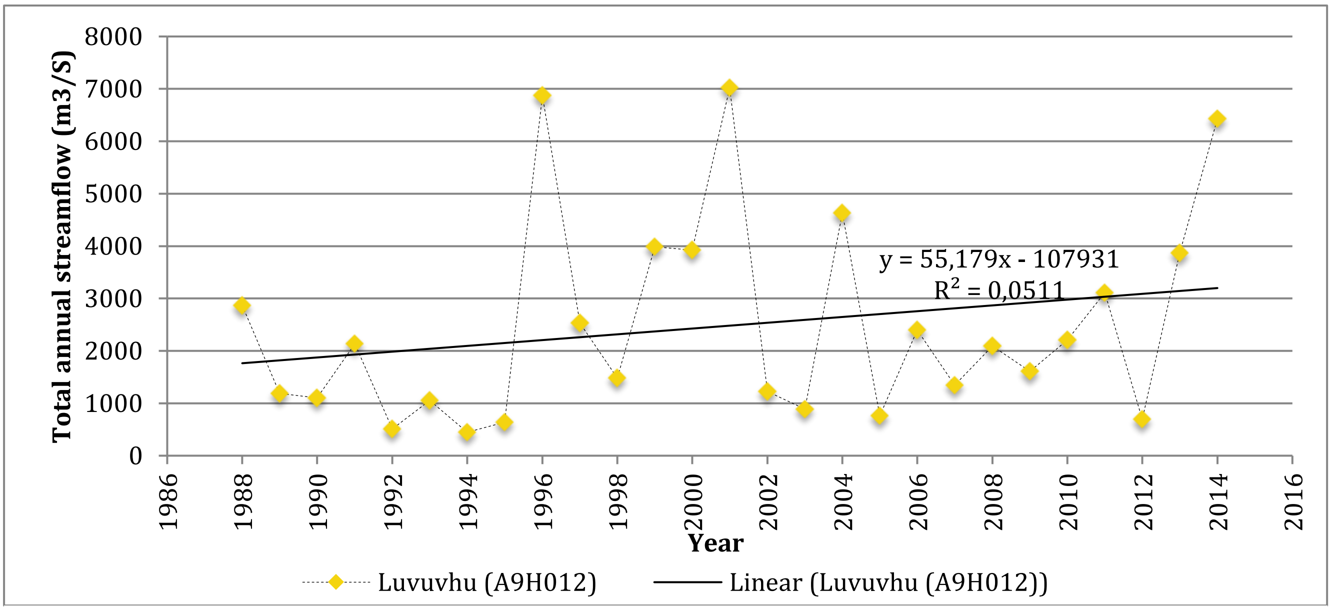


Figure 5.43 Total annual streamflow and linear trend line of Luvuvhu (A9H012) gauge station

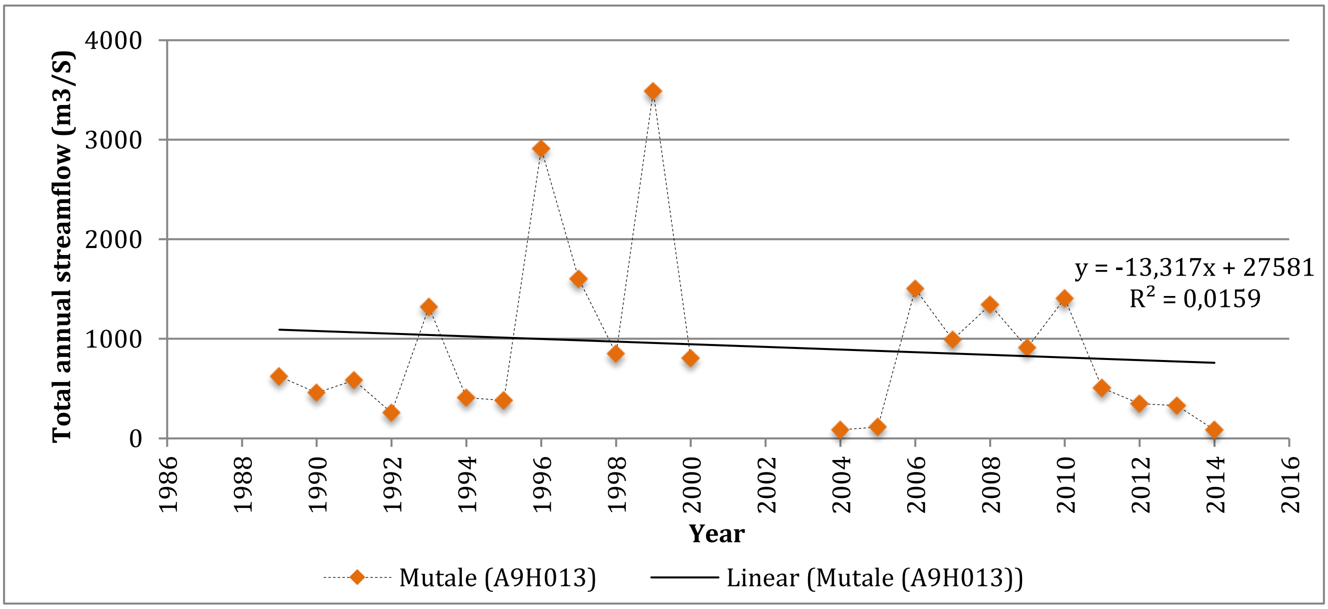


Figure 5.44 Total annual streamflow and linear trend line of the Mutale (A9H013) gauge station

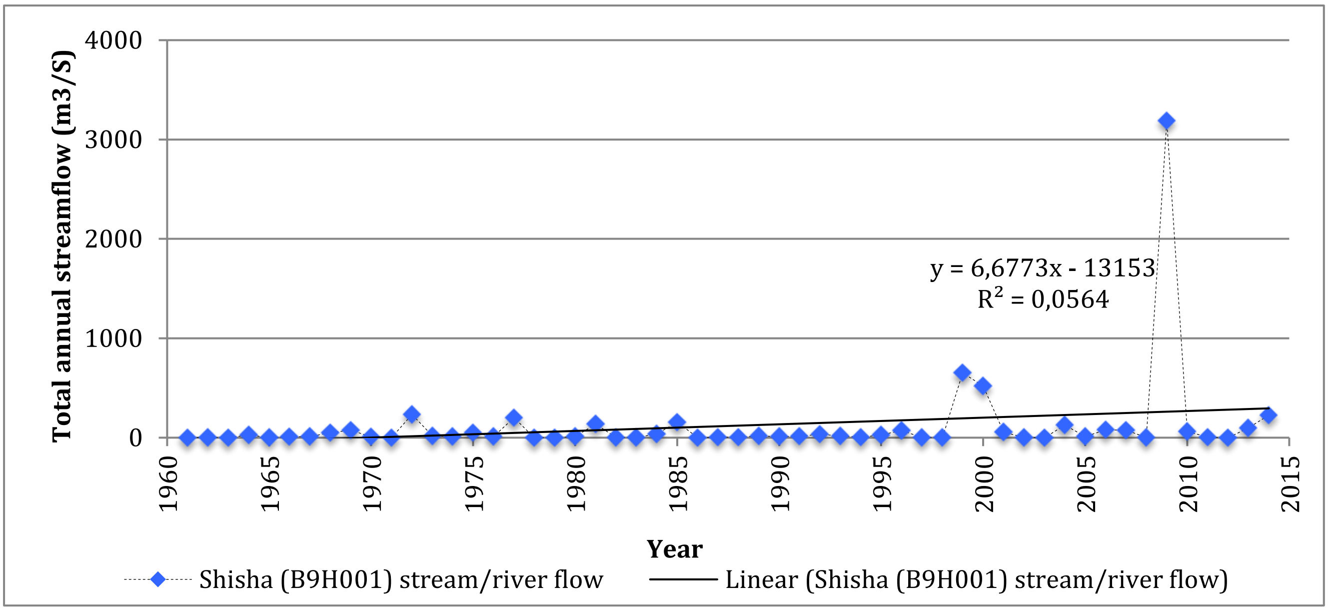


Figure 5.45 Total annual streamflow and linear trend line of Shisha (B9H001) gauge station

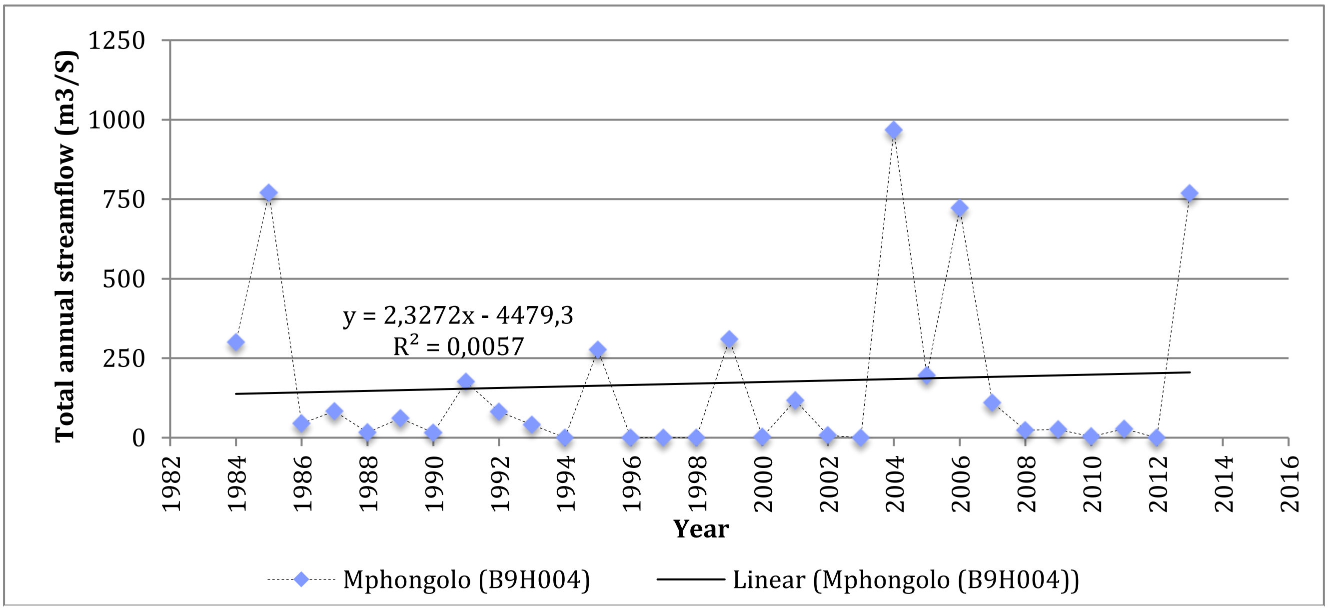


Figure 5.46 Total annual streamflow and linear trend line of Mphongolo (B9H004) gauge station

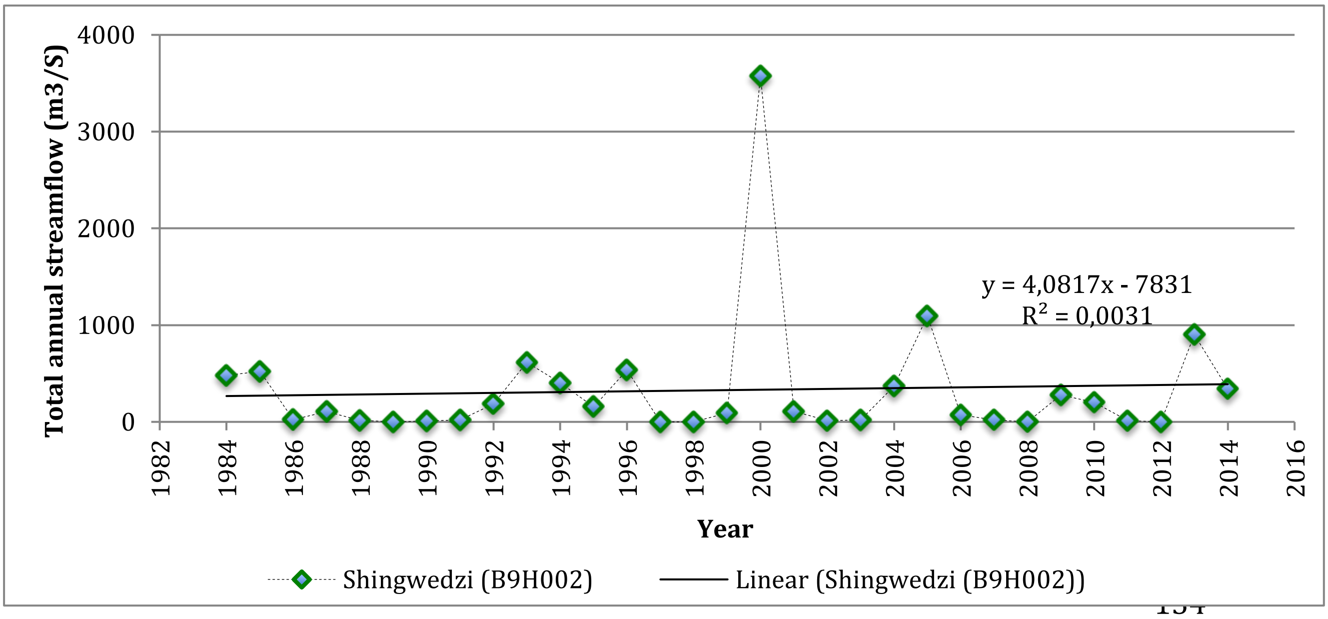


Figure 5.47 Total annual streamflow and linear trend line of Shingwedzi (B9H002) gauge station

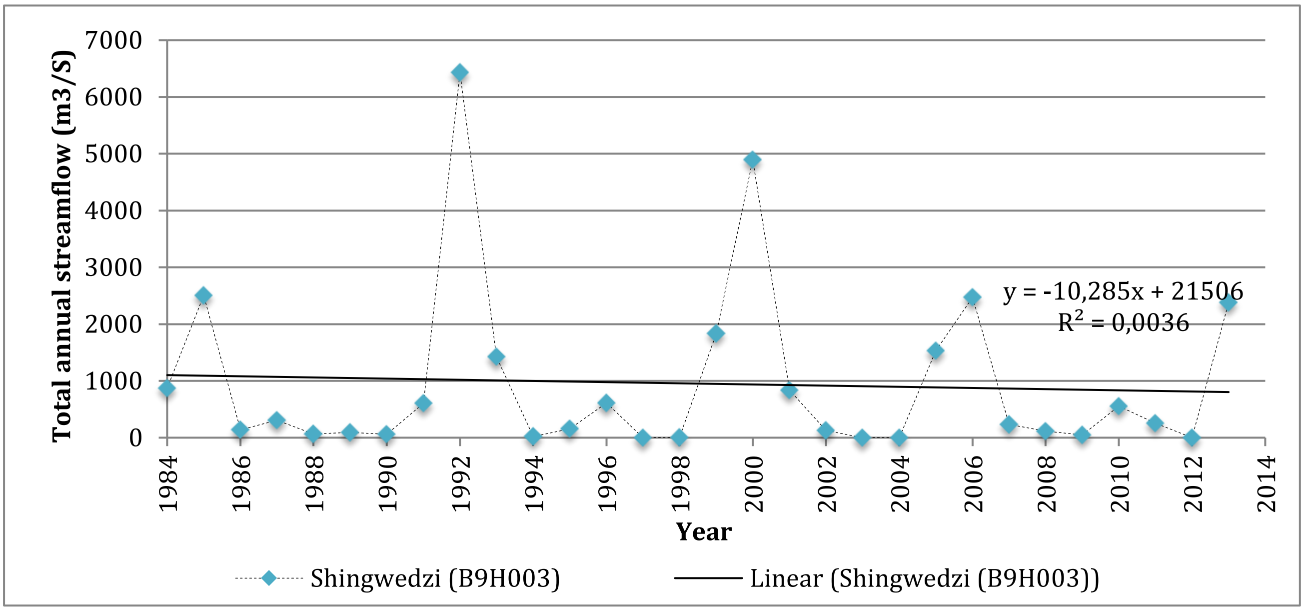


Figure 5.48 Total annual streamflow and linear trend line of Shingwedzi (B9H003) gauge station

5.11.2 North KNP

The region of northern KNP comprises the land that lies between the tropic of Capricorn and the Olifants River. This region includes four river gauging stations along two different rivers. These stations include B8H011 (Tsendze), B8H008 (Letaba), B8H034 (Letaba) and B8H018 (Letaba).

Table 5.26 Streamflow characteristics for gauge station in the northern KNP

Station	River	Years of data	Mean annual flow (m^3/S)	Lowest recorded flow (m^3/S)	Highest recorded flow (m^3/S)	Range (m^3/S)
B8H011	Tsendze	54	28,07	0 (Multiple yr)	332,3 (2000)	332,3
B8H008	Letaba	31	1019,84	34,42 (1970)	3229,3 (1999)	3194,9
B8H034	Letaba	34	2558,4	0 (2001; 2004)	13366 (2011)	13366
B8H018	Letaba	52	3627,54	153,5 (1992)	15505,6 (2004)	15352,04

All four of the gauge stations in northern KNP depict an increasing trend. The Tsendze (B8H011) and Letaba (B8H008) gauge station depict significant increasing trends within a 95% confidence level. B8H011 (*Figure 5.49*) depicts an increase in flow by 1m^3/S per annum (1960-2014), and B8H008 (*Figure 5.50*) depicts an increase in flow of 20m^3/S per annum (1960-2014). The two downstream Letaba stations (B8H034 and B8H018) depict non-significant increasing trends of 114.23m³/S and 159.1m³/S per annum respectively between 1985 and 2014 (*Figures 5.51* and *5.52*). The downstream stations along the Letaba depict substantially greater flow levels than the upstream station (*Table 5.26*).

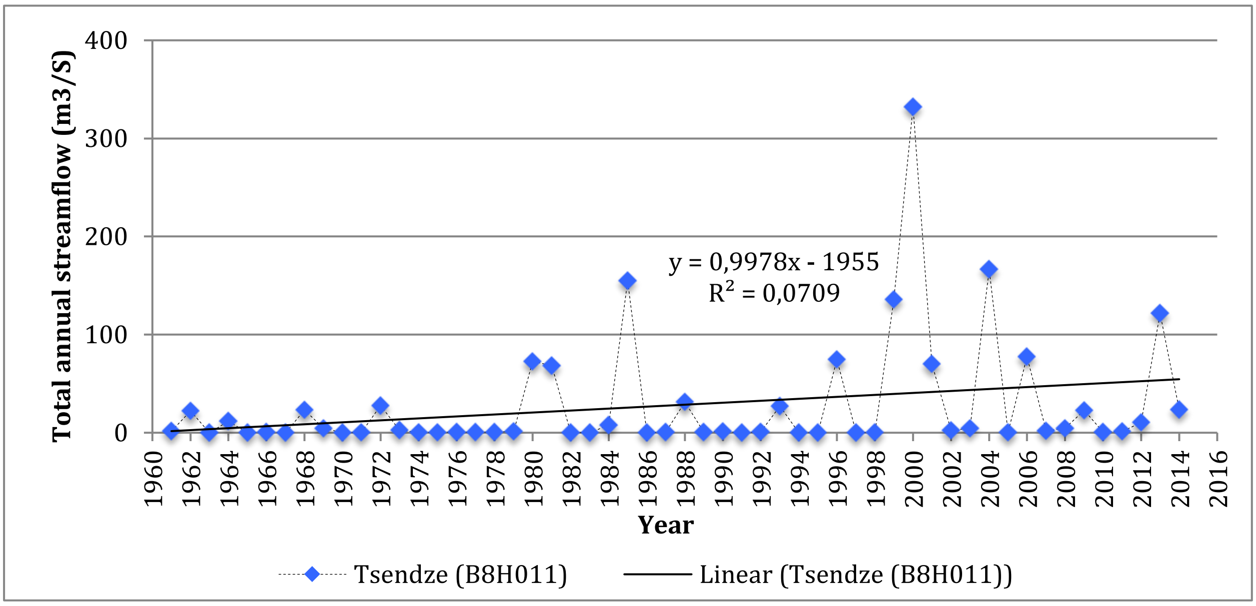


Figure 5.49 Total annual streamflow and linear trend line of Tsendze (B8H011) gauge station

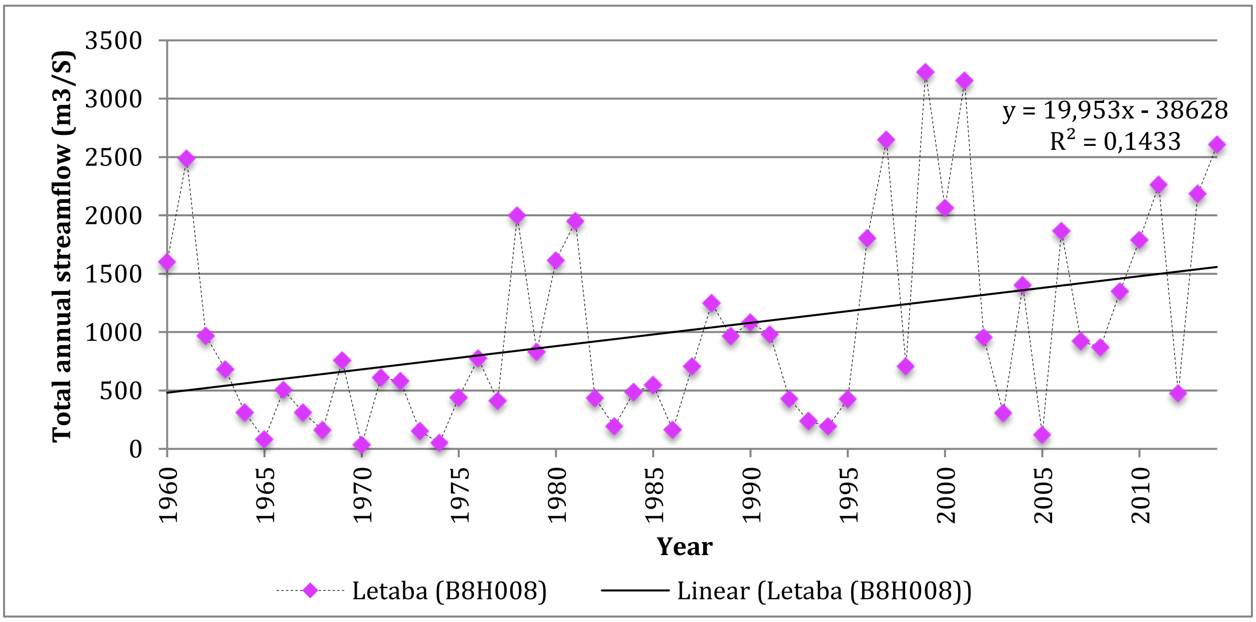


Figure 5.50 Total annual streamflow and linear trend line of Letaba (B8H008) gauge station

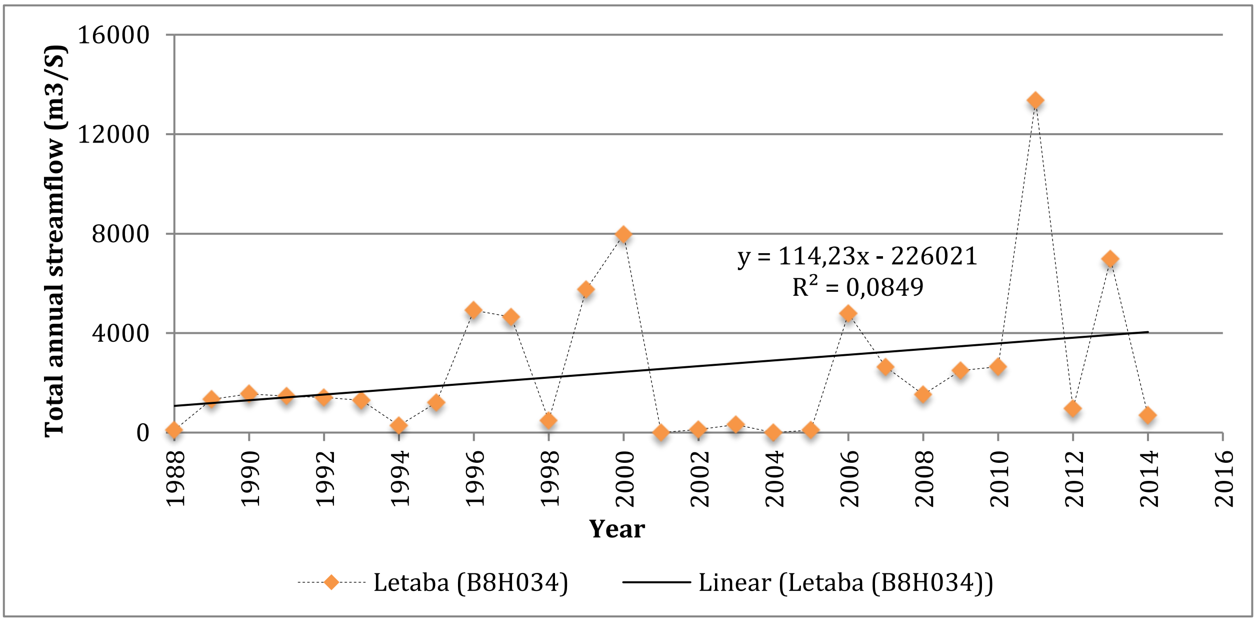


Figure 5.51 Total annual streamflow and linear trend line of Letaba (B8H034) gauge station

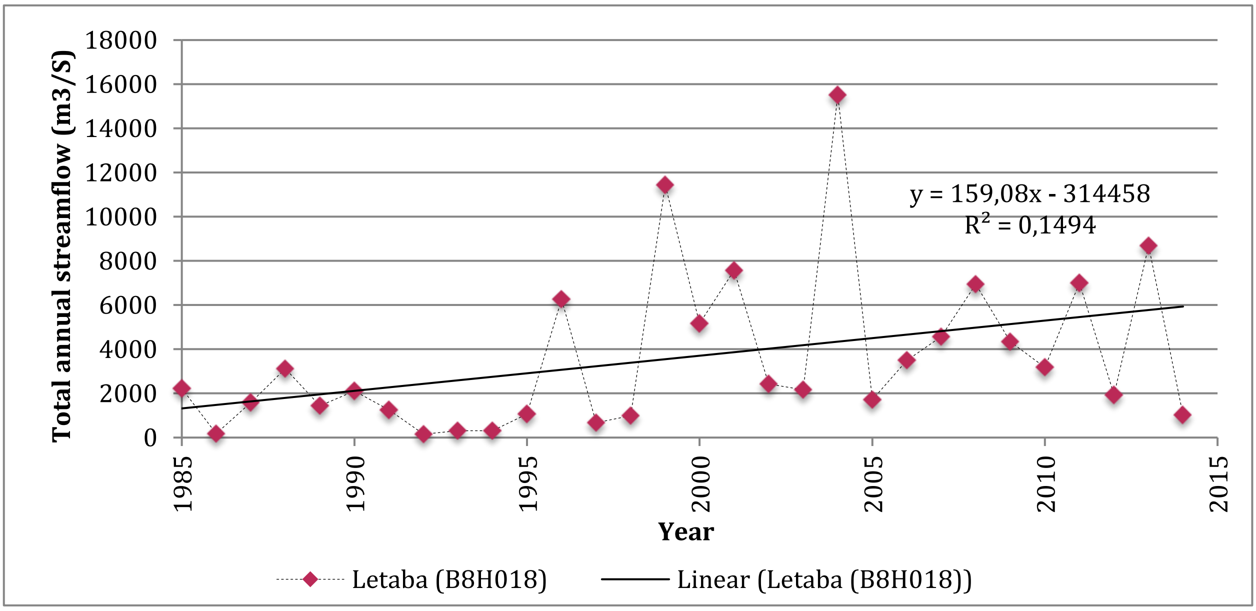


Figure 5.52 Total annual streamflow and linear trend line of Letaba (B8H018) gauge station

5.11.3 Central KNP

The region of central KNP comprises the land north of the Sabie River and south of the Olifants River. This region includes three river gauging stations located along three different rivers. These stations include Olifants (B7H015), Timbavati (B7H020) and Nwanedzi (X4H004).

Table 5.27 Streamflow characteristics for gauge stations in central KNP

Station	**River**	**Years of data**	**Mean annual flow (m^3/S)**	**Lowest recorded flow (m^3/S)**	**Highest recorded flow (m^3/S)**	**Range (m^3/S)**
B7H015	Olifants	27	13264,4	433,3 (2003)	522210,4 (2000)	51777,1
B7H021	Timbavati	33	1027,3	0 (Multiple yrs.)	20708,2 (1994)	20708,2
X4H004	Nwanedzi	54	102,9	0 (Multiple yrs.)	431,6 (2000)	431,6

The Olifants (B7H015) and Nwanedzi (X4H004) gauge station both depict increasing trends between 1987 and 2015. B7H015 depicts a significant increasing trend (*Figure 5.53*) of 343.1m^3/S per annum (1988-2014). Nwanedzi (X4H004) gauge station depicts a non-significant increasing trend (*Figure 5.54*) of 1.88m^3/S per annum (1960-2014). Timbavati (B7H020) gauge station depicts a non-significant decreasing trend (*Figure 5.55*) of 87m^3/S per annum (1988-2014).

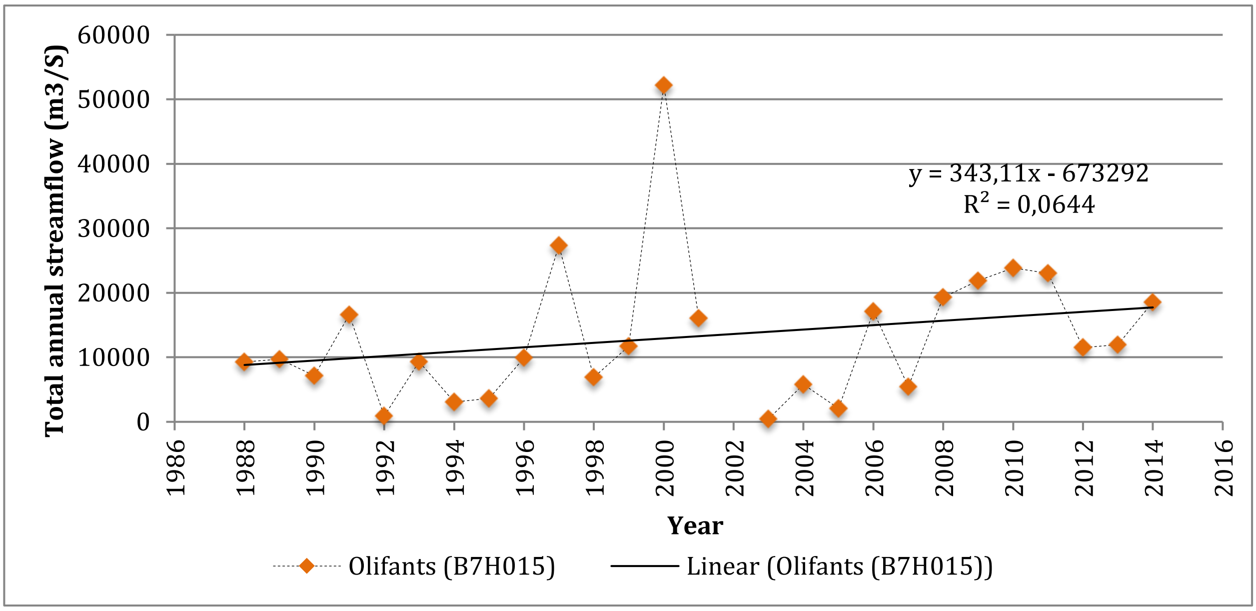


Figure 5.53 Total annual streamflow and linear trend line of Olifants (B7H015) gauge station

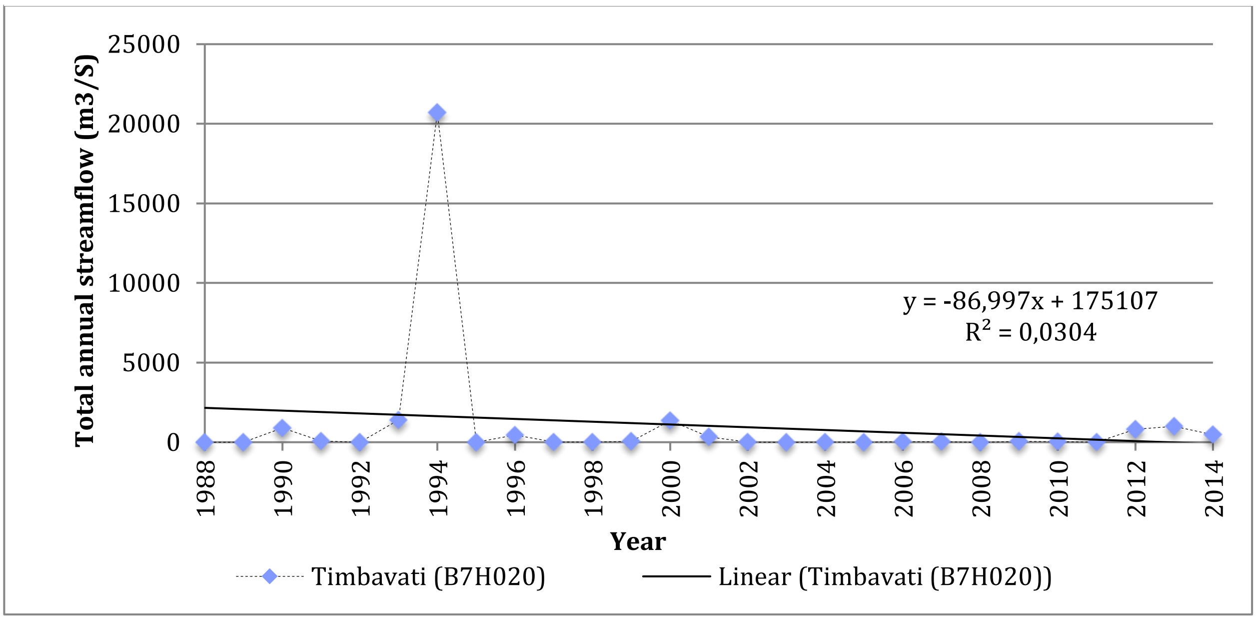


Figure 5.54 Total annual streamflow and linear trend line of Timbavati (B7H020) gauge station

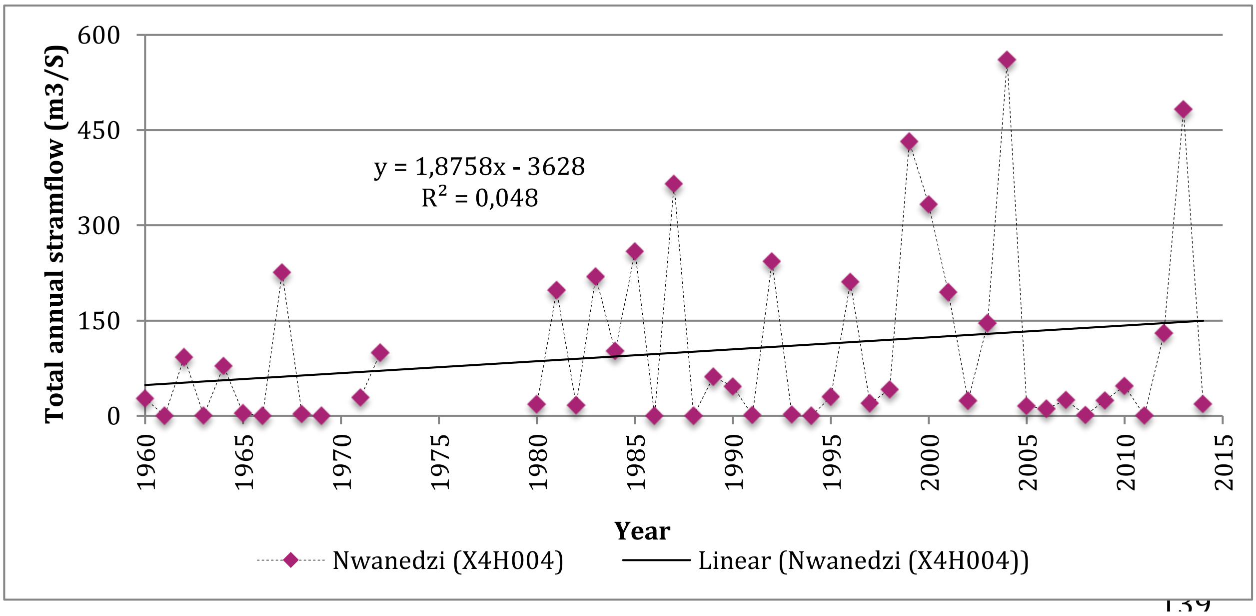


Figure 5.55 Total annual streamflow and linear trend line of Nwanedzi (X4H004) gauge station

5.11.4 Southern KNP

The region of southern KNP includes the land south of the Sabie River, and north of the Crocodile River. This region includes eight gauge stations located along five different river systems. These stations include: Sand (X3H008), Sabie (X3H021), Sabie (X3H015), Nsikazi (X2H072), Crocodile (X2H006), Crocodile (X2H046), Crocodile (X2H016) and Komati (X2H036).

Table 5.28 Streamflow characteristics of gauge stations in southern KNP

Station	River	Years of data	Mean annual flow (m^3/S)	Lowest recorded flow (m^3/S)	Highest recorded flow (m^3/S)	Range (m^3/S)
X3H008	Sand	37	1314,49	42,5 (1982)	18493,7 (2000)	18451,14
X3H021	Sabie	24	6859,5	877,3 (1992)	32253,8 (2000)	31376,5
X3H015	Sabie	27	4725,8	1151,9 (1992)	17207 (1996)	16055,1
X2H072	Nsikazi	24	719,64	6,84 (1994)	4066,1 (1996)	4059,2
X2H006	Crocodile	81	6453,3	1658,3 (1992)	18324 (2000)	16665,7
X2H046	Crocodile	29	7780,2	1056,7 (1994)	29382 (2000)	28325,3
X2H016	Crocodile	54	6849,6	223,7 (1994)	19358,4 (1972)	19134,7
X2H036	Komati	31	11257,2	350,6 (1994)	34787,4 (1996)	34436,8

The Sand (X3H008), and both Sabie River gauge stations depict an increasing trend in flow over time. X3H008 (*Figure 5.56*) depicts a significant increasing trend of 45.03m^3/S per annum (1968-2014). X3H021 depicts a significant increasing trend of 250.9m^3/S per annum between 1990 and 2014 (*Figure 5.57*), and the downstream station of Sabie (X2H015) depicts a non-significant increasing trend of 52,94m^3/S per annum (1987-2014) (*Figure 5.58*). The Nsikazi (X2H072) gauge station depicts a non-significant decrease in flow from 1990-2014 by 3.47m^3/S per annum (*Figure 5.59*). Along the Crocodile River, the upper stream gauge station (X2H006) depicts a non-significant decreasing trend (*Figure 5.60*) of 7.83m^3/S per annum (1943-2014), it is to be noted that this is the longest streamflow record for this study. Station X2H046 (*Figure 5.61*) depicts a significant increase in flow by 169,6m^3/S per annum (1986-2014). Downstream Crocodile River station (X2H016) depicts a non-significant decreasing trend (*Figure 5.62*) with a decrease in flow by 20.77m^3/S per annum

(1960-2014). Lastly, the Komati (X2H036) gauge station depicts a non-significant increasing flow of 144.9m³/S (*Figure 5.64*) per annum (1983-2014).

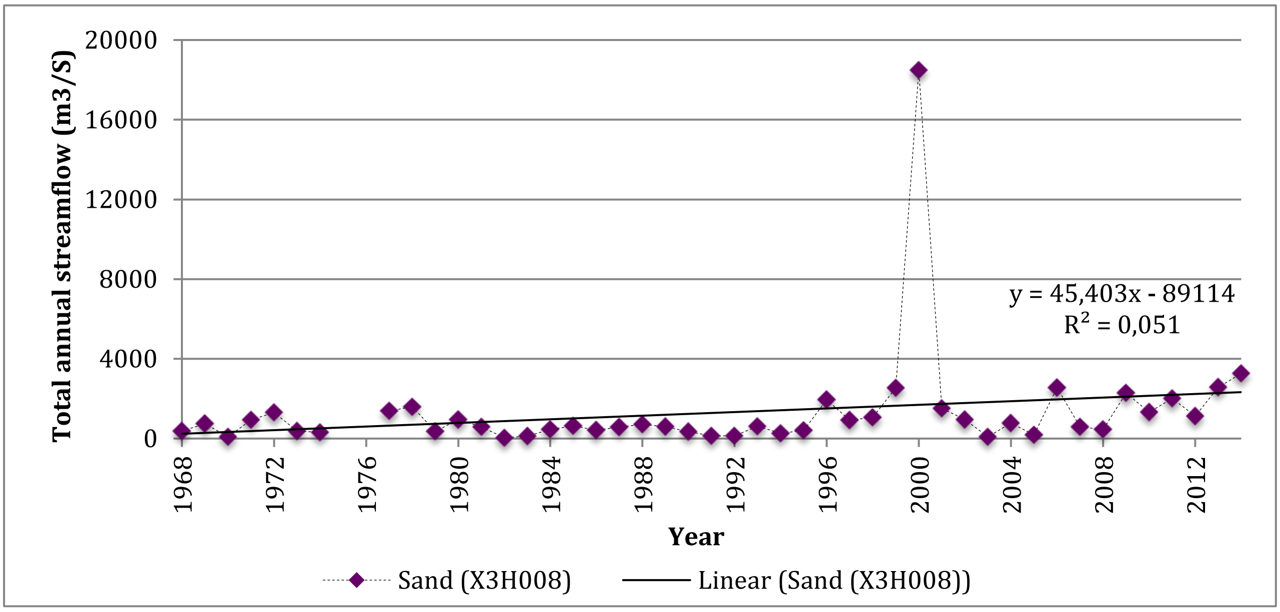


Figure 5.56 Total annual streamflow and linear trend line of Sand (X3H008) gauge station

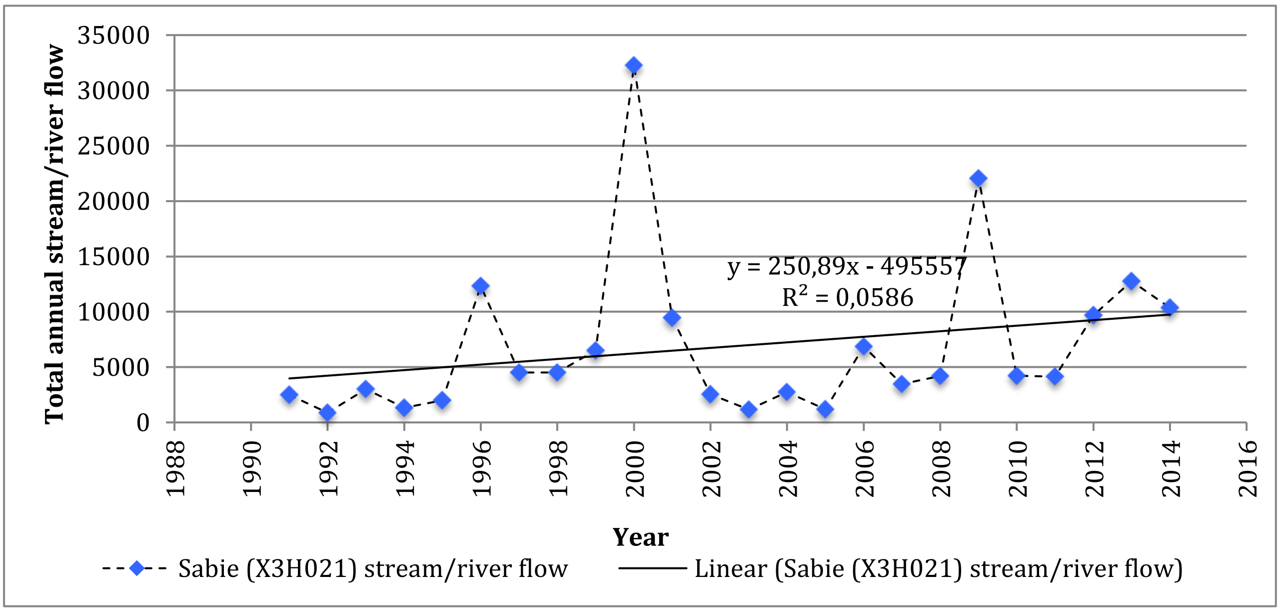


Figure 5.57 Total annual streamflow and linear trend line of Sabie (X3H021) gauge station

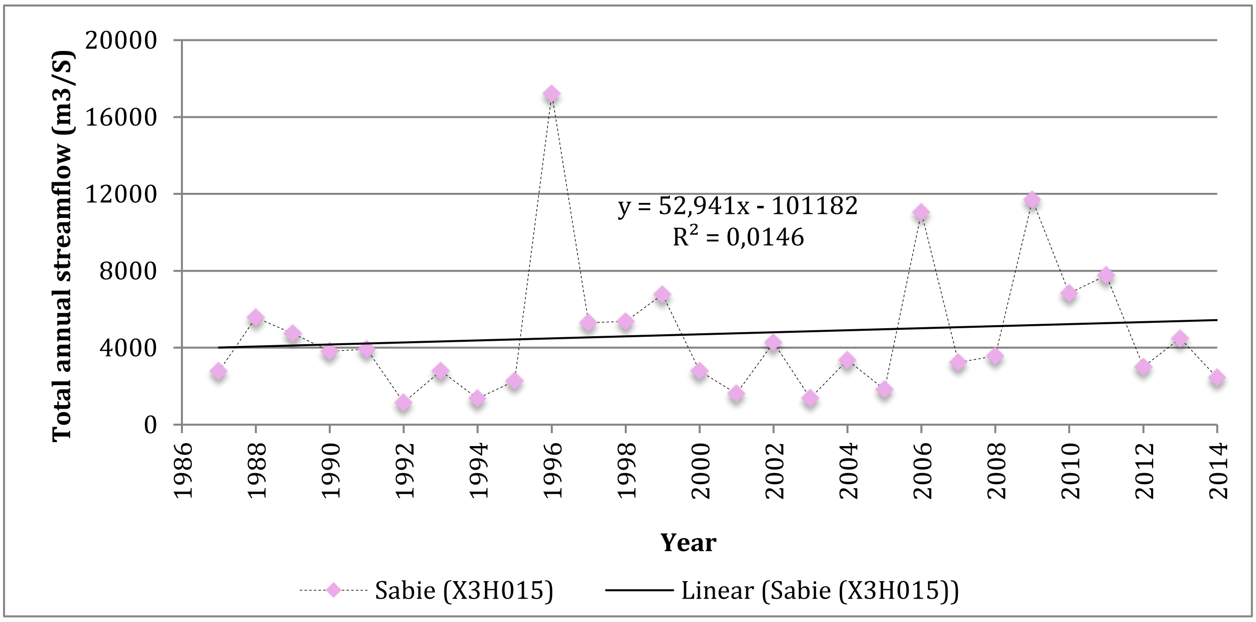


Figure 5.58 Total annual streamflow and linear trend line of Sabie (X3H015) gauge station

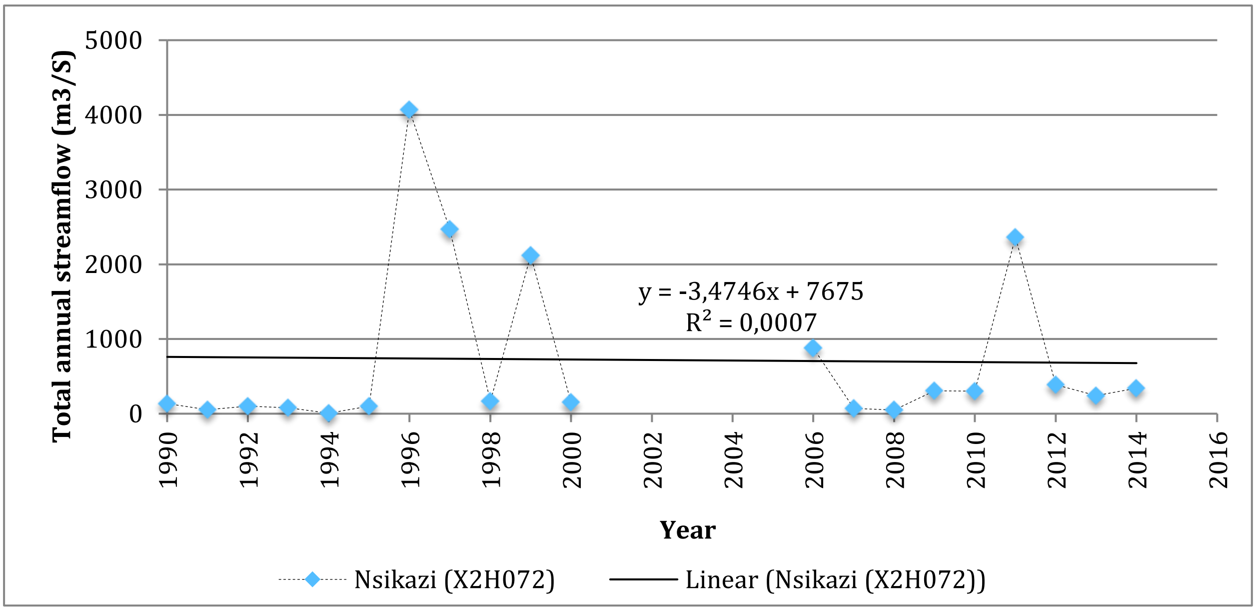


Figure 5.59 Total annual streamflow and linear trend line of Nsikazi (X2H072) gauge station

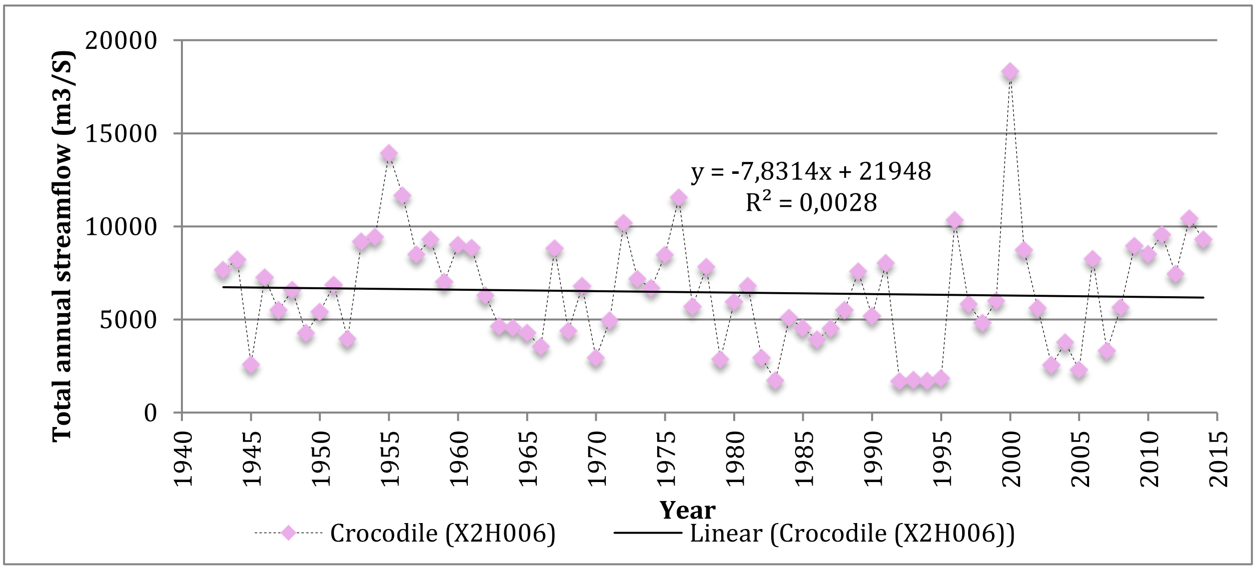


Figure 5.60 Total annual streamflow and linear trend line of Crocodile (X2H006) gauge station

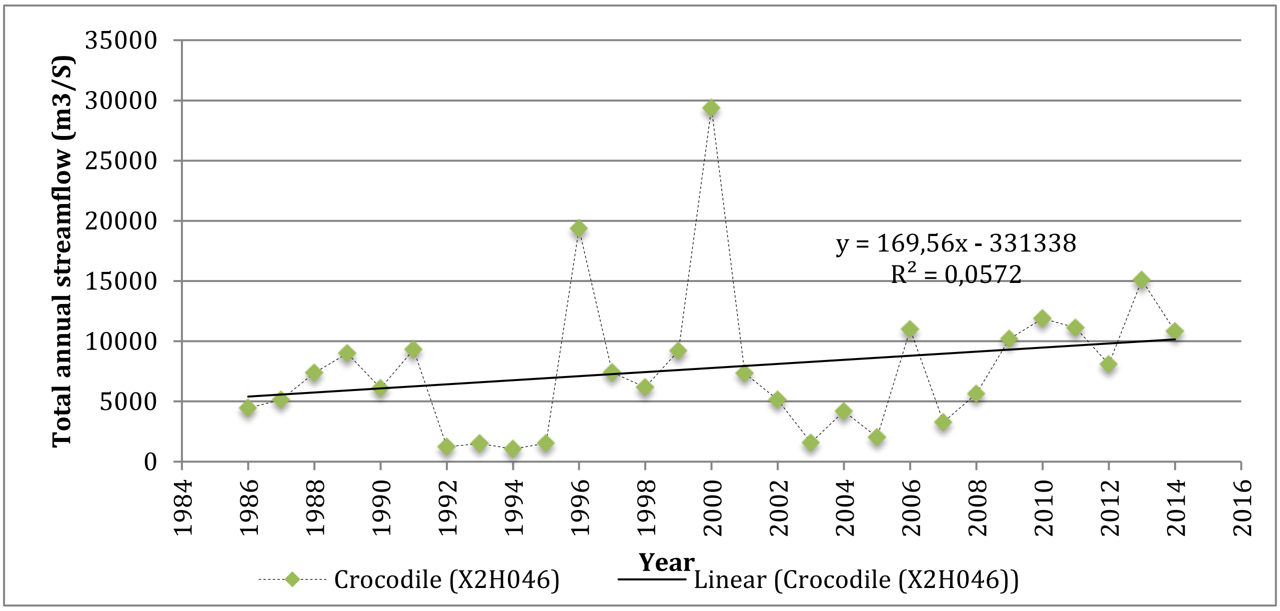


Figure 5.61 Total annual streamflow and linear trend line of Crocodile (X2H046) gauge station

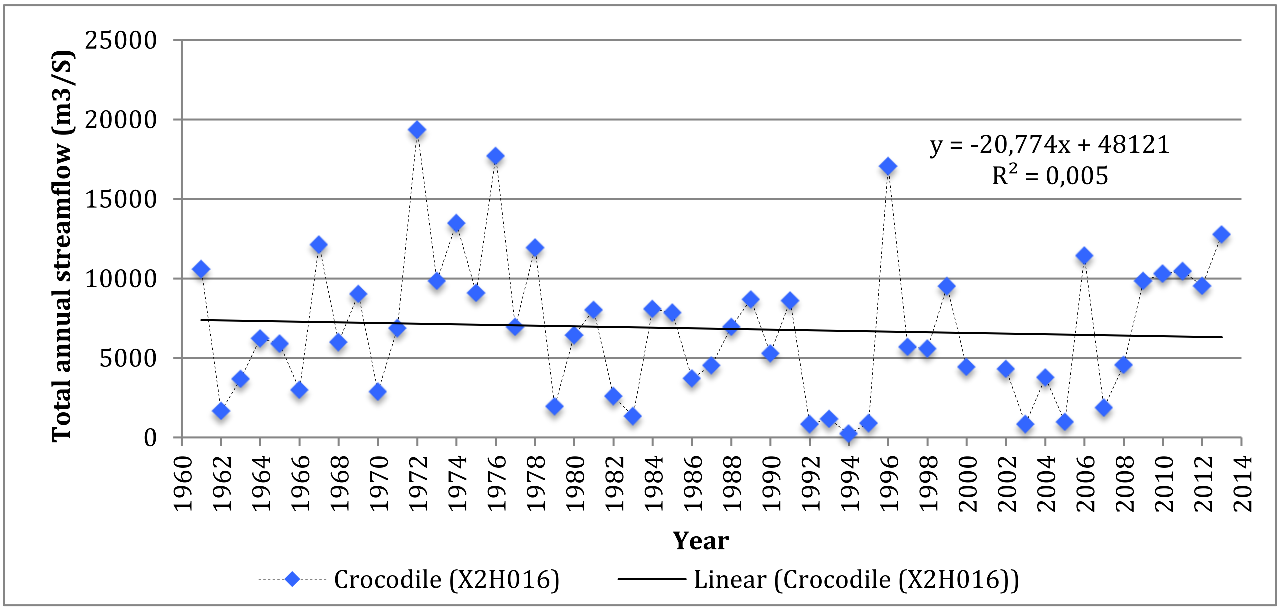


Figure 5.62 Total annual streamflow and linear trend line of Crocodile (X2H016) gauge station

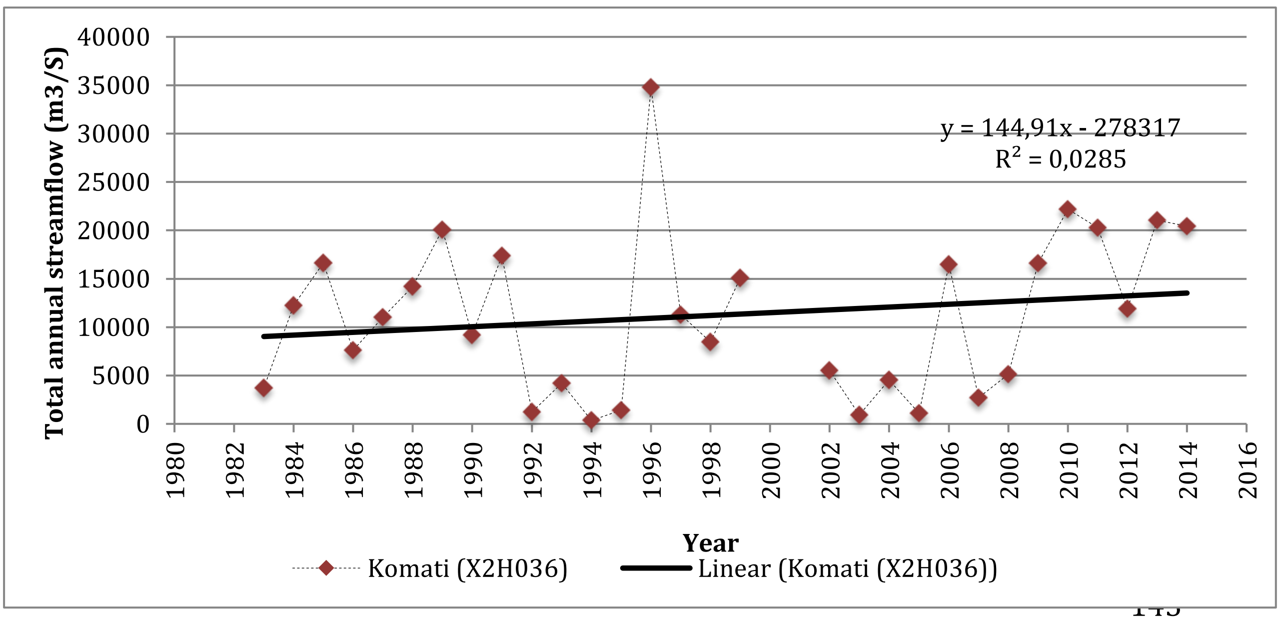


Figure 5.63 Total annual streamflow and linear trend line of Komati (X2H036) gauge station

5.12 Overall streamflow characteristics

Mann-Kendall trend analysis for streamflow stations depict that 73% of the stations record an increase in flow, whereas 23% of stations record a decrease in flow (*Table 5.29*). In the northern region of KNP 8 of the 11 stations depict an increase in annual streamflow. Luvuvhu (A9H012; 1987-2015), Shisha (B9H001; 1960-2015), Tsendze (B8H011; 1960-2015), Letaba (B8H008; 1960-2015) and downstream Letaba (B8H018; 1959-2015) all depict a significant increase in streamflow. Shingwedzi (B9H002; 1983-2015), Mphongolo (B9H004; 1983-2015), and Letaba (B8H034; 1981-2015) all depict a non-significant increase in annual streamflow (*Table 5.29*). The two stations that depict a non-significant decreasing flow include Mutale (A9H013; 1981-2015), and downstream Shingwedzi (B9H003; 1983-2015). It is important to note that along the Shingwedzi River, the upstream station (B9H002) depicts an increasing trend, whereas the downstream station depicts a decreasing flow trend (1983-2014).

Table 5.29 Man-Kendall trend analysis for streamflow stations

Station	Station number	Period	Normalised test statistic (Z)	P-Value (two-tailed)	Trend	α	Significant
Mhinga	A9H012	1987-2014 **(27)**	1.25	0.09*	Increasing	0.10	Yes
Mutale	A9H013	1981-2014 **(33)**	-0.11	0.45	Decreasing	0.05	No
Shisha	B9H001	1960-2014 **(54)**	1.87	0.03**	Increasing	0.05	Yes
Sirheni Dam	B9H004	1983-2014 **(31)**	0.59	0.28	Increasing	0.05	No
Silwervis	B9H002	1983-2014 **(31**)	0.00	0.5	Increasing	0.05	No
Kanniedood Dam	B9H003	1984-2014 **(30)**	-0.64	0.26	Decreasing	0.05	No
Tsendze	B8H011	1961-2014 **(53)**	2.35	0.009**	Increasing	0.05	Yes
Letaba Ranch	B8H008	1984-2014 **(30)**	2.74	0.003**	Increasing	0.05	Yes
Black Heron Dam	B8H034	1981-2014 **(33)**	0.85	0.19	Increasing	0.05	No
Engelhard Dam	B8H018	1959-2014 **(51)**	2.32	0.01**	Increasing	0.05	Yes
Mamba	B7H015	1987-2014 **(27)**	1.90	0.02**	Increasing	0.05	Yes
Piet Grobler	B7H020	1981-2014 **(33)**	-0.84	0.2	Decreasing	0.05	No
Nwanedzi	X4H004	1960-2014 **(54)**	0.69	0.24	Increasing	0.05	No
Exeter	X3H008	1967-2014 **(37)**	2.77	0.02**	Increasing	0.05	Yes
Kruger Gate	X3H021	1990-2014 **(24)**	2.21	0.01**	Increasing	0.05	Yes
Lower Sabie	X3H015	1987-2014 **(27)**	0.73	0.23	Increasing	0.05	No
Nsikazi	X2H072	1990-2014 **(24)**	1.40	0.08*	Decreasing	0.10	Yes
Karino	X2H006	1943-2014 **(71)**	-0.67	0.24	Decreasing	0.05	No
Riverside	X2H046	1985-2014 **(29)**	2.01	0.02**	Increasing	0.05	Yes
Ten Bosh	X2H016	1960-2014 **(54)**	-0.39	0.34	Decreasing	0.05	No
Komatipoort	X2H036	1982-2014 **(31)**	1.11	0.13	Increasing	0.05	No

5.12.1 Total annual flow vs. total annual flow days

The relationship between river/stream flow and total annual flow days is an important aspect of this study as it shows to what extent river/streams changing from perennial to non-perennial, it also gives insight into how dam systems are changing total annual flow days along river systems. In section 5.17, the impact of dams on KNP river/stream systems will be investigated in much greater detail. *Table 5.30* highlights the trends as well as the significance of the trends for total annual river flows as well as total annual, river flow days.

Interesting findings to note include the Mutale (A9H013), Shingwedzi (B9H003), Olifants (B7H015), Timbavati (B7H020), Sabie (X3H015), Nsikazi (X2H072), and Crocodile (X2H006 and X2H016) gauging stations. These gauging stations have variable trends when comparing total annual flow vs. total annual flow days (*Table 5.31*). A9H013, B9H003, B7H020, X2H072, X2H006 and X2H016 all show decreasing trends for total annual river/stream flow over time, but an increase in total annual flow days. The decrease in annual flow but an increase in flow days is indicative of a below average flow level occurring more frequently along the river.

Gauging stations B7H015 (Olifants) and X3H015 (lower Sabie) show opposite results. These gauge stations record an increase in total annual flow over time, but a decrease in flow days (*Table 5.30*). An increase in flow and decrease in flow days is indicative of a river that is non-perennial in nature. Total annual flow is increasing due to climatic conditions and extreme rainfall; however the river is flowing for fewer days each year, meaning, rivers are no longer flowing all year round.

Table 5.30 Trend analysis for total annual flow vs. total annual flow days for KNP rivers/streams

River	Station Number	Trend of total annual river/stream flow			Trend of total annual river/stream flow days		
		Z Value	P Value	Trend	Z Value	P Value	Trend
Luvuvhu	A9H012	1.25	0.09*	Increasing	1.65	0.04*	Increasing
Mutale	A9H013	-0.11	0.45	Decreasing	2.63	0.004*	Increasing
Shisha	B9H001	1.87	0.03**	Increasing	2.27	0.01*	Increasing
Mphongolo	B9H004	0.59	0.28	Increasing	0.43	0.33	Increasing
Shingwedzi	B9H002	0.00	0.5	Increasing	0.05	0.48	Increasing
Shingwedzi	B9H003	-0.64	0.26	Decreasing	0.02	0.49	Increasing
Tsendze	B8H011	2.35	0.009**	Increasing	3.38	0.0004*	Increasing
Letaba	B8H008	2.74	0.003**	Increasing	2.53	0.005*	Increasing
Letaba	B8H034	0.85	0.19	Increasing	2.04	0.02*	Increasing
Letaba	B8H018	2.32	0.01**	Increasing	3.87	0.00005*	Increasing
Olifants	B7H015	1.90	0.02**	Increasing	-1.07	0.14	Decreasing
Timbavati	B7H020	-0.84	0.2	Decreasing	1.49	0.06	Increasing
Nwanedzi	X4H004	0.69	0.24	Increasing	2.01	0.02*	Increasing
Sand	X3H008	2.77	0.02**	Increasing	2.69	0.003*	Increasing
Sabie	X3H021	2.21	0.01**	Increasing	0.61	0.27	Increasing
Sabie	X3H015	0.73	0.23	Increasing	-1.66	0.04*	Decreasing
Nsikazi	X2H072	1.40	0.08*	Decreasing	2.15	0.01*	Increasing
Crocodile	X2H006	-0.67	0.24	Decreasing	1.54	0.06*	Increasing
Crocodile	X2H046	2.01	0.02**	Increasing	0.00	0.5	Increasing
Crocodile	X2H016	-0.39	0.34	Decreasing	0.62	0.26	Increasing
Komati	X2H036	1.11	0.13	Increasing	1.27	0.1	Increasing

5.13 Streamflow characteristics for the wet and dry season

In the northern regions of the KNP, increasing streamflow trends for the wet season range between 0.97m^3/S and 115.3m^3/S. Decreasing streamflow trends for the wet season (depicted at three stations) range from between -7.5m^3/S and -2.94m^3/S. Increasing streamflow trends for the dry season range between 0.03m^3/S and 43.96m^3/S. Decreasing flow trends for the dry season range from between -2.95m^3/S to -0.02m^3/S (*Table 5.31*). Annually, stations with data sets between 1980-2014 have flow trends ranging -10.3m3/S to 114.3m3/S per annum. Stations with data sets between 1960-2014 have flow trends ranging from 0.99m^3/S to 159.1m^3/S per annum (*Table 5.31*).

Stations A9H012 (Luvuvhu), B9H001 (Shisha), B8H034 (mid Letaba) and B8H018 (downstream Letaba) all depict an increase in flow during the wet and the dry season. B9H001 and B8H018 both depict significant increases in flow during the wet and dry season between 1960-2014 (*Table 5.31*). Stations A9H012, B8H010 and B8H034 all depict non-significant increase in wet and dry season streamflow. Stations A9H013, B9H004 and B9H003 all depict decreasing streamflow trends for both the wet and the dry seasons (1980-2014).

The interesting findings occur at stations B9H002 (upstream Shingwedzi), B8H011 (Tsendze) and B8H008 (upstream Letaba), where all stations depict an increasing streamflow trend during the wet season, but a decreasing flow trend during the dry season (*Table 5.31*). B9H002 depicts a non-significant increase of 4.67m^3/S between 1983-2014, whereas there is a significant decrease in flow during the dry season by 0.6m^3/S. B8H011 depicts a significant decrease in wet season flow by 0.97m^3/S (1961-2014), and a significant decrease in dry season flow by -0.02m^3/S. Lastly, B8H008 shows a significant increase in wet season flow by 19.1 m^3/S per annum (1984-2014) and a non-significant decrease in dry season flow by -0.24 m^3/S per annum (*Table 5.31*). An increase in wet season flow corresponds with the general trends shown across most flow gauge stations, rainfall is becoming more variable, and streamflow is consequently reacting to this increase in variability.

Flow trends between 2000-2015 indicate more extreme flow events (see preceding figures), leading to higher streamflow readings in recent decades, which are a major contributing factor to increasing trends depicted in the results.

In the southern region of KNP, increasing flow trends for the wet season range from 1.76 m^3/S to 300.33 m^3/S per annum between 1960 and 2015 (*Table 5.31*). Decreasing flow trends for the wet season range from -78.6 m^3/S to -1.5 m^3/S. Increasing flow trends for the dry season range from 0.25 m^3/S to 343.11 m^3/S. Decreasing trends for the dry season range from -86.9 m^3/S to -3.6 m^3/S between 1960 and 2015 (*Table 5.31*).

Stations B7H015 (Olifants), X4H004 (Nwanedzi), X3H008 (Sand), X3H021 (upstream Sabie), X3H015 (Downstream Sabie), X2H046 (midstream Crocodile) and X2H036 (Komati) all depict increasing trends in the wet and dry seasons as well as annual streamflow (*Table 5.31*). Four of these seven stations depict significant increasing flow for both the wet and dry seasons within the 95% confidence level (*Table 5.31*). The Sabie River gauge stations (X3H021 and X3H015) both depict an increase in both wet and dry season flow, with increases in wet season flow by 203.5 m^3/S and 24.9 m^3/S, and increases in dry season flow by 47.4 m^3/S and 28 m^3/S respectively. The downstream gauge station along the Sabie River (X3H015) has a much lower flow level than the upstream station; this will be explored further in this chapter.

The section of the Crocodile River in this study includes three gauge stations (X2H006, X2H046 and X2H016). The upstream gauge station (X2H006) depicts a non-significant decrease in flow for both the wet and dry season (1943-2014) by -1.5 m^3/S and 6.3 m^3/S respectively (*Table 5.32*). The middle station depicts an increase in flow for both the wet and dry season by 140.32 m^3/S and 29.24 m^3/S respectively. However, the downstream station (X2H016) depicts a decreasing trend in flow for both the wet and dry season by 1.84 m^3/S and 9.54 m^3/S respectively (*Table 5.31*).

Table 5.31 Wet, Dry and annual streamflow trends in KNP Mann-Kendall Z-Value, (*p*-value) and [magnitude, m^3/S per annum). Values in bold represent statistical significant trends at 95% confidence level

Station	Station number	Period	Wet season (Oct-Apr)	Dry Season (May-Sept)	Annual (Jan-Dec)
Mhinga	A9H012	1987-2014 **(27)**	1.7 (0.12) [48.7]-	1.46 (0.07) [6.5]	1.21 (0.1) [52.2]
Mutale	A9H013	1981-2014 **(33)**	-0.23 (0.41) [-5.57]	-0.81 (0.2) [-0.6]	-0.11 (0.45) [-6.6]
Shisha	B9H001	1960-2014 **(54)**	**1.88 (0.03) [6.34]**	**1.39 (0.08) [0.33]**	**1.55 (0.06) [6.67]**
Sirheni Dam	B9H004	1983-2014 **(31)**	0.52 (0.3) [2.94]	**1.34 (0.08) [0.6]**	0.59 (0.27) [2.3]
Silwervis	B9H002	1983-2014 **(31**)	0.00 (0.49) [4.67]	**-0.88 (0.09) [-0.6]**	0.00 (0.49) [4.08]
Kanniedood Dam	B9H003	1984-2014 **(30)**	-0.54 (0.29) [-7.5]	-0.4 (0.18) [-2.95]	-0.69 (0.26) [-10.3]
Tsendze	B8H011	1961-2014 **(53)**	**2.40 (0.008) [0.97]**	**-2.76 (0.002) [-0.02]**	**2.26 (0.01) [0.99]**
Letaba Ranch	B8H008	1984-2014 **(30)**	**2.95 (0.001) [19.1]**	-1.43 (0.07) [-0.24]	**2.74(0.03) [20.02]**
Black Heron Dam	B8H034	1981-2014 **(33)**	0.59 (0.27) [91.82]	**2.39 (0.008) [12.48]**	0.85 (0.19) [114.23]
Engelhard Dam	B8H018	1959-2014 **(51)**	**1.89 (0.02) [115.3]**	**3.14 (0.0001) [43.96]**	**2.32 (0.01) [159.1]**
Mamba	B7H015	1987-2014 **(27)**	**1.71 (0.04) [300.33]**	**1.36 (0.008) [34.01]**	**1.9 (0.02) [343.11]**
Piet Grobler	B7H020	1981-2014 **(33)**	-0.96 (0.16) [-78.6]	-0.15 (0.4) [-8.4]	0.84 (0.2) [-86.9]
Nwanedzi	X4H004	1960-2014 **(54)**	0.48 (0.31) [1.76]	0.97 (0.16) [0.25]	**2.23 (0.01) [1.87]**
Exeter	X3H008	1967-2014 **(37)**	**3.12 (0.0004) [44.34]**	**2.19 (0.01) [3.03]**	**2.77 (0.02) [45.4]**
Kruger Gate	X3H021	1990-2014 **(24)**	**2.16 (0.01) [203.5]**	**1.19 (0.02) [47.4]**	**2.21 (0.01) [250.9]**
Lower Sabie	X3H015	1987-2014 **(27)**	0.3 (0.38) [24.9]	**2.23 (0.01) [28.0]**	0.73 (0.23) [52,9]
Nsikazi	X2H072	1990-2014 **(24)**	-1.72 **(0.04)** [21.5]	**-1.93 (0.02) [-24.6]**	-1.4 (0.08) [-3.6]
Karino	X2H006	1943-2014 **(71)**	-0.52 (0.3) [-1.5]	-0.94 (0.17) [-6.3]	**-0.76 (0.03) [-7.83]**
Riverside	X2H046	1985-2014 **(29)**	**1.86 (0.03) [140.32]**	**1.89 (0.02) [29.24]**	**2.01 (0.02) [169.6]**
Ten Bosh	X2H016	1960-2014 **(54)**	-0.00 (0.49) [-1.84]	-1.2 (0.1) [-9.54]	-0.02 (0.49) [-20.8]
Komatipoort	X2H036	1982-2014 **(31)**	1.18 (0.1) [114.3]	0.97 (0.16) [22.86]	0.96 (0.16) [137.2]

5.14 Variability of KNP river/stream flow

Table 5.32 provides statistics on the mean annual, standard deviation, and coefficient of variation in flow for the KNP gauging stations. The mean annual flow ranges from 28.1m^3/S at Tsendze, to 3627.5m^3/S at Letaba (B8H018) for the northern KNP. The standard deviation for flow for all northern KNP rivers is significantly high, which is a strong indicator of high flow variability in the river volumes. The coefficient of variation for northern KNP ranges from 83% (Letaba Ranch) to 375% (Shisha). The high values of CV recorded for these rivers suggests that there is a significant variation in streamflow over the years. The higher the CV, the greater the level of dispersion around the mean.

In the southern KNP, the mean annual flow ranges from 87.9mm at Nwanedzi (X4H004) to 13264.4m^3/S at The Olifants (B7H015). Much like the northern KNP rivers, the southern rivers also have a significantly high standard deviation for overall flow, which suggests high, flow variability for all rivers. The coefficient of variation for the southern KNP Rivers ranges from 19% (X3H008) to 385% (B7H020). (*Table 5.33*)

Table 5.32 Mean, Co-efficient of variation and standard deviation of flow for KNP rivers

Station	Station number	Record years	Mean annual flow (m^3/S)	CV	Standard Deviation
Mhinga	A9H012	1987-2014 **(27)**	2659.9	0.85	2268.1
Mutale	A9H013	1981-2014 **(33)**	972.5	0.90	879.9
Shisha	B9H001	1960-2014 **(54)**	118.07	3.75	442.3
Sirheni Dam	B9H004	1983-2014 **(31)**	171.59	1.58	271.55
Silwervis	B9H002	1983-2014 **(31**)	328.28	2.02	664.53
Kanniedood Dam	B9H003	1984-2014 **(30)**	952.5	1.59	1516.5
Tsendze	B8H011	1961-2014 **(53)**	28.1	2.10	58.96
Letaba Ranch	B8H008	1984-2014 **(30)**	1019.8	0.83	844.59
Black Heron Dam	B8H034	1981-2014 **(33)**	2558.4	1.21	3112.64
Engelhard Dam	B8H018	1959-2014 **(51)**	3627.5	0.99	3623.8
Mamba	B7H015	1987-2014 **(27)**	13264.4	0.82	10987.4
Piet Grobler	B7H020	1981-2014 **(33)**	1027.3	3.85	3957.4
Nwanedzi	X4H004	1960-2014 **(54)**	87.9	1.54	135.3
Exeter	X3H008	1967-2014 **(37)**	1314.5	0.19	245.21
Kruger Gate	X3H021	1990-2014 **(24)**	6859.5	1.07	7331.39
Lower Sabie	X3H015	1987-2014 **(27)**	4725.8	0.76	3598.12
Nsikazi	X2H072	1990-2014 **(24)**	719.6	1.55	1118.1
Karino	X2H006	1929-2014 **(81)**	6453.3	0.48	3077
Riverside	X2H046	1985-2014 **(29)**	7780.2	0.77	6034.7
Ten Bosh	X2H016	1960-2014 **(54)**	6889.1	0.67	4648.2
Komatipoort	X2H036	1982-2014 **(31)**	10992.4	0.74	8143.43

Rivers flowing through the KNP have high interannual flow variability, as previously discussed; this high variability of flow is linked to high variability of rainfall, as well as extreme weather events (such as tropical cyclones and the El Niño Southern Oscillation). The relationship between these river/streamflow behaviours with subsequent weather events will be explored to find the correlation between rainfall and river/streamflow patterns.

5.15. Spatio-temporal relationship between rainfall and river/stream flow patterns.

The relationship between rainfall and river/stream flow is an important relationship to analyse to understand variation in flow patterns. *Table 5.33* indicates the weather stations that are located closest to a selected river gauge station. The rainfall stations located closest to the river gauge stations allow for the fairest and strongest relationship between rainfall and flow records.

Table 5.33 Rainfall stations located in the closest proximity to river gauge stations

River	Station	Closest rainfall station	2nd closest rainfall station
Luvuvhu	A9H012	Punda Maria	Pafuri
Mutale	A9H013	Punda Maria	Pafuri
Shisha	B9H001	Shingwedzi Vlakteplas	Punda Maria
Mphongolo	B9H004	Shingwedzi Vlakteplas	Punda Maria
Shingwedzi	B9H002	Shingwedzi	Krugerwildtuin Shangoni
Shingwedzi	B9H003	Shingwedzi	Krugerwildtuin Shangoni
Tsendze	B8H011	Letaba Mahlangeni	Letaba
Letaba	B8H008	Hans Merensky Hoerskool	Zomerkomst
Letaba	B8H034	Letaba Mahlangeni	Letaba
Letaba	B8H018	Letaba	
Olifants	B7H015	Phalaborwa	Hoedspruit
Timbavati	B7H020	Hoedspruit	Satara
Nwanedzi	X4H004	Satara	
Sand	X3H008	Champagne Nat	Onverwag Bos
Sabie	X3H021	Skukuza	
Sabie	X3H015	Skukuza	
Nsikazi	X2H072	Stolznek	Malelane
Crocodile	X2H006	Nelspruit	
Crocodile	X2H046	Nelspruit	
Crocodile	X2H016	Stolznek	Malelane
Komati	X2H036	Stolznek	Malelane

5.15.1 Correlation between rainfall and river/stream flow in KNP

Correlation of data sets allows for researchers to understand the relationship between two elements. A positive correlation suggests a direct relationship, whereas a negative correlation suggests no relationship between the two variables. *Table 5.34* depicts the correlation values according to Dancey and Reileys catagorisation (University of Strathclyde, 2013).

Table 5.34 Correlation categorizations (adapted from University of Strathclyde, 2013)

Correlation coefficient relationship categories (values -1 to +1)	
Values	**Catagorisation**
-1 to -0.7	Strong negative relationship
-0.3 to -0.7	Moderate negative relationship
-0.3 to 0	Weak negative relationship
0 to 0.3	Weak positive relationship
0.3 to 0.7	Moderate positive relationship
0.7 to 1	Strong positive relationship

The relationship between rainfall and river/stream flow is evident in *tables 5.35* and *5.36*, where most of the relationships depict a positive correlation value. A correlation value of between 0.3 and 1 suggests a moderate to high relationship between the two variables and thus concludes that as the one variable changes, so does the other. The correlation between variables is higher for the stations that originate within the park, such as the Tsendze and Nwanedzi (*figure 5.35* and *5.36*). The correlation for the Shisha River is only high in relation to Shingwedzi rainfall as that is the weather station located closes to the river gauge station.

In the case where correlation values are low (0-0.3) or negative, it can be suggested that there is no relationship between the two variables. This proposes that there is an alternate impact on river flow characteristics. Rivers such as the Mutale, Mphongolo, Letaba, Timbavati, Nsikazi, and some parts of the Crocodile River show a weak relationship between rainfall and flow volumes.

Table 5.35 Correlation between rainfall and river/stream flow in northern KNP

	Palmaryville	Hans Merensky Hoerskool	Zomerkomst	Gravelotte	Thohoyandou	Punda Maria	Pafuri	Letaba Mahlangeni	Letaba	Shingwedzi Vlakteplas	Shingwedzi	Krugerwildtuin Shangoni
Luvuvhu	0.65				0.65	0.65	0.7					
Mutale	0.26				0.13	0.3	0.23					
Shisha						0.08	0.03			0.18	0.65	
Mphongolo						0.26	0.37			0.28		
Shingwedzi	0.68				0.63					0.54	0.62	0.59
Shingwedzi	0.39				0.34					0.57	0.46	0.41
Tsendze								0.92	0.62			
Letaba		0.38	0.46	0.62				0.58				
Letaba		0.6	0.61	0.77				0.35				
Letaba		0.17	0.41	0.38				0.6	0.6			

Table 5.36 Correlation between rainfall and river/stream flow in southern KNP

	Phalaborwa	Onverwag Bos	Champagne Nat	Sabie	Nelspruit	Skukuza	Satara	Malelane	Stolznek	Pilgrams Rest
Olifants	0.52									
Timbavati							-0.1			
Nwanedzi							0.45			
Sand		0.56	0.59			0.54				0.48
Sabie		0.67	0.83	0.57		0.6				0.81
Sabie		0.41	0.48	0.39		0.18				0.56
Nsikazi					0.35			0.13	0.14	
Crocodile										
Crocodile					0.49			0.48	0.37	
Crocodile							0.77	0.8	0.78	
Komati							0.58	0.44	0.31	

5.15.2 Precipitation elasticity of streamflow

The precipitation elasticity of streamflow analysis allows for the understanding of long-term streamflow trends in relation to long-term rainfall trends. The elasticity of streamflow is defined as the “proportional change in mean annual streamflow, divided by the proportional change in mean annual rainfall” (Chiew, 2006:613).

The elasticity of streamflow was calculated for all gauging stations against their closest rainfall stations (*Table 5.37*). The precipitation elasticity of streamflow varies from 0.21 to 2.27. The average elasticity of streamflow was calculated to be 1.54, that is: a 1% change in mean annual rainfall results in a 1.54% change in mean annual streamflow.

Table 5.37 Precipitation elasticity of streamflow

River	Station Number	Rainfall station	Period	Elasticity
Luvuvhu	A9H012	Punda Maria	1988-2012	1,79
Mutale	A9H013	Pafuri	1989-2014	1,43
Mutale	A9H013	Punda Maria	1989-2012	1,32
Shisha	B9H001	Shingwedzi Vlakteplas	1984-2014	2.27
Shisha	B9H001	Pafuri	1961-2012	1.77
Mphongolo	B9H004	Shingwedzi Vlakteplas	1984-2014	1.83
Shingwedzi	B9H002	Krugerwildtuin Shangoni	1984-2014	0.97
Shingwedzi	B9H003	Krugerwildtuin Shangoni	1984-2014	2.09
Tsendze	B8H011	Letaba	1961-2014	1.92
Letaba	B8H008	Letaba	1960-2012	0.6
Letaba	B8H034	Hans Merensky Hoerskool	1988-2014	2.14
Letaba	B8H018	Letaba	1985-2014	1.98
Olifants	B7H015	Gravelotte	1988-2012	1.79
Timbavati	B7H020	Satara	1988-2014	-0.21
Nwanedzi	X4H004	Satara	1960-2014	1
Sand	X3H008	Champagne Nat	1968-2007	0.87
Sabie	B9H021	Onverwag Bos	1991-2014	1.36
Sabie	B9H021	Skukuza	1991-2014	1.45
Sabie	B9H015	Skukuza	1987-2014	0.52
Nsikazi	X2H072	Stolznek	1990-2014	2.07
Crocodile	X2H046	Malelane	1986-2014	1.78
Crocodile	X2H016	Malelane	1961-2014	1.68
Komati	X2H036	Malelane	1983-2014	1.92

5.16 Extreme climatic events and their impact on river/stream flow trends

5.16.1 River trends patterns and extreme rainfall events

It is suggested that interannual river flow patterns are highly variable due to the variable nature of the rainfall in this semi-arid region, and thus linear trends are not statistically significant. Although the flow trends are highly variable, the river trends are not decreasing linearly over time. One of the main reasons for this finding is the fact that in the past 30 years, there has been a significant amount of extreme rainfall events, which have led to high and short spikes in the flow trends of these gauging stations. Over the past 50 years, specifically in the KNP region there have been 14 big scale tropical cyclones that have obstructed the Mozambique/KNP and KZN coastline. With these tropical cyclones comes an immense amount of rainfall (*Table 5.38*), which has led to the flooding of many of the

KNP rivers. *Table 5.38* highlights the tropical cyclones recorded for the KNP area since 1958, their impact and their dates. These tropical cyclones have a very strong correlation to the river/stream flow trends, which are to be discussed in the next sub section.

Table 5.38 Tropical cyclones that impacted KNP regions and rivers (adapted from SANParks, 2009 and SANParks, 2013).

Date	Cyclone Name	Cyclone details	Rainfall intensity
27 Dec 1957- 5 January 1958	Astrid	Category of cyclone (Saffir- Simpson scale): 1 Lowest pressure: 930 hPa Strongest winds: 80km/hr Areas affected: Madagascar, Mozambique, Swaziland, South Africa Fatalities: unknown	Over 500mm of rainfall was recorded for the period of the cyclone at rainfall stations in the northern province of South Africa
24 December 1965 - January 1966	Claude	Category of cyclone (Saffir- Simpson scale): 2 Lowest pressure: 928 hPa Strongest winds: 75km/hr Areas affected: Madagascar, Mozambique, Swaziland, South Africa Fatalities: unknown	Maputo experienced 650mm of rain between 3-9 January, and Komatipoort recorded 250mm.
3 -14 February 1972	Caroline	Category of cyclone (Saffir- Simpson scale): 2 Lowest pressure: 921 hPa Strongest winds: 55km/hr Areas affected: Madagascar, Mozambique, Swaziland, South Africa Fatalities: 0	Heavy rains occurred throughout KNP with between 68-158mm of rain recorded.
21-22 February	Eugenie	Category of cyclone (Saffir- Simpson scale): 1 Lowest pressure: 936 hPa Strongest winds: 120km/hr Areas affected: Madagascar, Mozambique, Swaziland, South Africa Fatalities: unknown	Heavy rain was experienced in Levubu (175mm), Phalaborwa (75mm) and Piet Retief (84mm).
27-31 January 1976	Danae	Category of cyclone (Saffir- Simpson scale): 3 Lowest pressure: 964 hPa Strongest winds: 175km/hr Areas affected: Madagascar, Mozambique, Swaziland, South Africa Fatalities: 50	Acornhoek (135mm), Levubu (114mm), Skukuza (108mm) and Louis Trichardt (60mm).
6-8 February 1977	Emilie	Category of cyclone (Saffir- Simpson scale): 3 Lowest pressure: 980 hPa Strongest winds: 100km.hr Areas affected: Madagascar, Mozambique, Swaziland, South Africa Fatalities: 300	More than 200mm of rain was recorded in the KNP and rainfall stations across the northern province in South Africa.
25 February-13 March 1980	Kolia	Category of cyclone (Saffir- Simpson scale): 2 Lowest pressure: Strongest winds: 110km/hr Areas affected: Madagascar, Mozambique, Swaziland, South Africa Fatalities: unknown	

16-25 March 1982	Justine	Category of cyclone (Saffir- Simpson scale): 1 Lowest pressure: 941 hPa Strongest winds: 150km/hr Areas affected: Madagascar, Mozambique, Swaziland, South Africa Fatalities: 0	
29-31 January 1984	Domoina	Category of cyclone (Saffir- Simpson scale): 3 Lowest pressure: 936 hPa Strongest winds: 100km/hr Areas affected: Madagascar, Mozambique, Swaziland, South Africa Fatalities: 242	Recorded rainfall events varied between 500-700mm over 3 days for South Africa and Mozambique.
10-18 February 1984	Imboa	Category of cyclone (Saffir- Simpson scale): 3 Lowest pressure: 976 hPa Strongest winds: 95km/hr Areas affected: Mozambique, South Africa, Madagascar Fatalities: 4	Recorded rainfall of 258mm over 5 days at Komatipoort station. At Goba station in Mozambique, rainfall of 430mm over 5 days was recorded.
1-29 February 2000	Eline	Category of cyclone (Saffir- Simpson scale): 4 Lowest pressure: 928 hPa Strongest winds: 185km/hr Areas affected: Zimbabwe, South Africa, Mozambique and majority of southern Africa Fatalities: 722	Levubu recorded 503mm of rainfall over 3 days. Limpopo rainfall stations measured 283mm of rainfall in 24 hours. 90mm of rainfall was recorded in Malawi and between 50-100mm in Botswana
11-23 February 2007	Favio	Category of cyclone (Saffir- Simpson scale): 4 Lowest pressure: 925 hPa Strongest winds: 195km/hr Areas affected: Madagascar, Mozambique, Tanzania, Zimbabwe, Malawi, South Africa Fatalities: 10	Rainfall records show that this cyclone produced between 15-25mm of rainfall per hour at its most intense phase.
17-29 January 2012	Funso	Category of cyclone (Saffir- Simpson scale): 4 Lowest pressure: 963 hPa Strongest winds: 205km/hr Areas affected: Mozambique, Malawi, South Africa Fatalities: 40	Mozambique rainfall records show Funso produces 460mm of rainfall over 5 days.

It is important to also note that some years experienced extremely heavy rainfall in KNP, but was however not classified as a tropical cyclone. These heavy rains still caused widespread flooding and extensive damage to some regions of the KNP and need to be mentioned. *Table 5.39* highlights all the major rainfall events that have occurred in northeast South Africa over the past 50 years that have caused flooding events and extremely high river/stream flow volumes. These events also have a high correlation with the depicted streamflow trends previously mentioned. For example, at Shingwedzi camp, KNP, a huge flooding event of the river took place in 2006, and this was due to the massive rainfall event that took place over 72 hours in January 2006.

Table 5.39 Extreme and continuous rainfall events, which lead to higher than average, flow volumes in KNP Rivers

Date	Rainfall event	Description
3-23 January 1915	Continuous heavy rainfall	More than 1000mm rainfall recorded at Palmaryville over 20 days, with 6 days receiving between 100-200mm or rain per day
10-16 January 1925	Continuous heavy rainfall	An average of 240mm of rainfall occurred over 5 days
16-22 March 1925	Continuous heavy rainfall	An average of 250mm of rain occurred over 5 days
7-20 February 1939	Continuous heavy rainfall	Rainfall averaged between 20-30mm per day for a continuous near 2-week period
January 1953	Continuous moderate rainfall	Continuous moderate-heavy rainfall occurred over the entire month of January, causing rising levels in river volumes
1-14 February 1955	Continuous moderate rainfall	The first 2 weeks of February saw continuous down pour which lead to higher than usual flow volumes
January 1981	Heavy thunderstorms on multiple days	Every few days in January thunderstorms would occur and precipitate between 60-80mm per day, which resulted in a very wet month
9-23 January-February 1996	Continuous moderate rainfall	A continuous down pour of moderate rainfall resulted in a higher than usual month of rain
January-February 1999	Heavy sporadic thunderstorm events	Intense burst of rainfall over the months of January and February lead to a high recorded rainfall for the year
14-28 January 2004	Continuous moderate rainfall	Over the month of January there was a continuous rainfall event which saw over 100mm of rainfall on 2 days
February-March 2006	Short extremely heavy rainfall	Short intense burst of rain over 72 hours caused onset flooding on the Shingwedzi river with many people having to be evacuated at Shingwedzi camp
January 2011	Sporadic intense rainfall events	Throughout the entire month of January, intense rainfall events occurred which allowed a few days to receive more than 80mm of rain per day
January 2013	Short extremely heavy rainfall	Flooding of all major rivers occurred with many of the bridges being submerged by water

5.16.2 Impacts of different categories of extreme rainfall on river/stream flow

To determine how rivers, behave in relation to different extreme rainfall events, these extreme rainfall events were categorised into three sections, and each event was further analysed in order to determine how river/stream flow patterns behaved after each event. The three extreme rainfall categories include (1) tropical cyclones, (2) short intense rainfall events, and (3) long continuous rainfall events. Tropical cyclones for KNP are listed in *Table 5.39.* In this research, short intense rainfall events will be categorised using the same definitions as Dyson *et al.,* (2015), where intense rainfall is >50mm rain per day over no more than 2 days. Therefore, short intense rainfall is categorised as >100mm over a 2-day period. For the purposes of this research, long continuous rainfall is categorised as mild to heavy rainfall that occurs for more than 5 consecutive days.

The frequencies of these 3 categorised extreme rainfall events were calculated for each rainfall station (*Table 5.40*) to determine the regularity of these events on a decadal scale. Each rainfall event for each region (far north, north, central and south) was then used to calculate how long river/streams had significant flow reading for each event. It is important to determine how long river/streams have significant flow after each extreme rainfall event.

Table 5.40 Frequency of extreme rainfall events per decade for each region of KNP

Region	Rainfall category	1960-69	1970-79	1980-89	1990-99	2000-2014
Far Northern KNP	Tropical cyclone	1	4	4	0	3
	Short intense	2	6	2	2	6
	Long continuous	14	22	13	14	16
Northern KNP	Tropical cyclone	1	4	4	0	3
	Short intense	2	6	10	7	6
	Long continuous	12	33	20	14	22
Central KNP	Tropical cyclone	1	4	4	0	3
	Short intense	2	8	2	3	5
	Long continuous	25	20	18	15	19
Southern KNP	Tropical cyclone	1	4	4	0	3
	Short intense	2	5	2	3	6
	Long continuous	24	20	20	16	39

All regions of KNP show that river/streams flow for a longer period after a continuous rainfall event. Short intense rainfall events lead to significant river/streamflow for an average of 7.4 days after the rainfall event (*Table 5.41*), tropical cyclones had comparable impact on river/stream flow patterns, with an average significant flow period of 8 days. Long continuous rainfall events lead to a longer flow time, on average 11.5 days (*Table 5.41*). It must be noted that on many occasions, readings from gauge stations were missing after the event of a tropical cyclone. This is suggestive that tropical cyclones have overwhelmed rivers and lead to the malfunction of gauging station equipment.

Table 5.41 Average days of streamflow after a specific rainfall event

Station	**Station number**	**River**	**Average days flow after tropical cyclone**	**Average days flow after a short intense rainfall event**	**Average days flow after long continuous rainfall event**
Mhinga	A9H012	Luvuvhu	9	6	13
Mutale	A9H013	Mutale	8	7	12.5
Shisha	B9H001	Shisha	8	5	10
Sirheni Dam	B9H004	Mphongolo	7.5	6	11
Silwervis	B9H002	Shingwedzi	10	7	10.5
Kanniedood Dam	B9H003	Shingwedzi	9	8	11
Tsendze	B8H011	Tsendze	10	6	10
Letaba Ranch	B8H008	Letaba	9	8	10
Black Heron Dam	B8H034	Letaba	9	9	12
Engelhard Dam	B8H018	Letaba	9	8	10
Mamba	B7H015	Olifants	9	10	12
Piet Grobler	B7H020	Timbavati	7	7	12
Nwanedzi	X4H004	Nwanedzi	7	6	11
Exeter	X3H008	Sand	10	7	13
Kruger Gate	X3H021	Sabie	9.5	10	15
Lower Sabie	X3H015	Sabie	9	8	12
Nsikazi	X2H072	Nsikazi	7	7	13
Karino	X2H006	Crocodile	10	8	12
Riverside	X2H046	Crocodile	8	7	10
Ten Bosh	X2H016	Crocodile	8	8	12
Komatipoort	X2H036	Komati	8	8	11
Average			**8.5**	**7.4**	**11.5**

5.16.3 Comparisons of short intense vs. long continuous rainfall on subsequent flow days

To further emphasize this finding, specific river/stream flow patterns were graphed. The rivers chosen for each region include a river that originates outside the park boundary, as well as a river that originates from within the park boundary. For the far northern KNP, the rivers represented are the Luvuvhu (A9H012) and the Shisha (B9H001). In 2001, the Luvuvhu River flowed significantly for 35 days after a continuous rainfall event (*Figure 5.64*). Short intense rainfall events are much less frequent than the long continuous rainfall

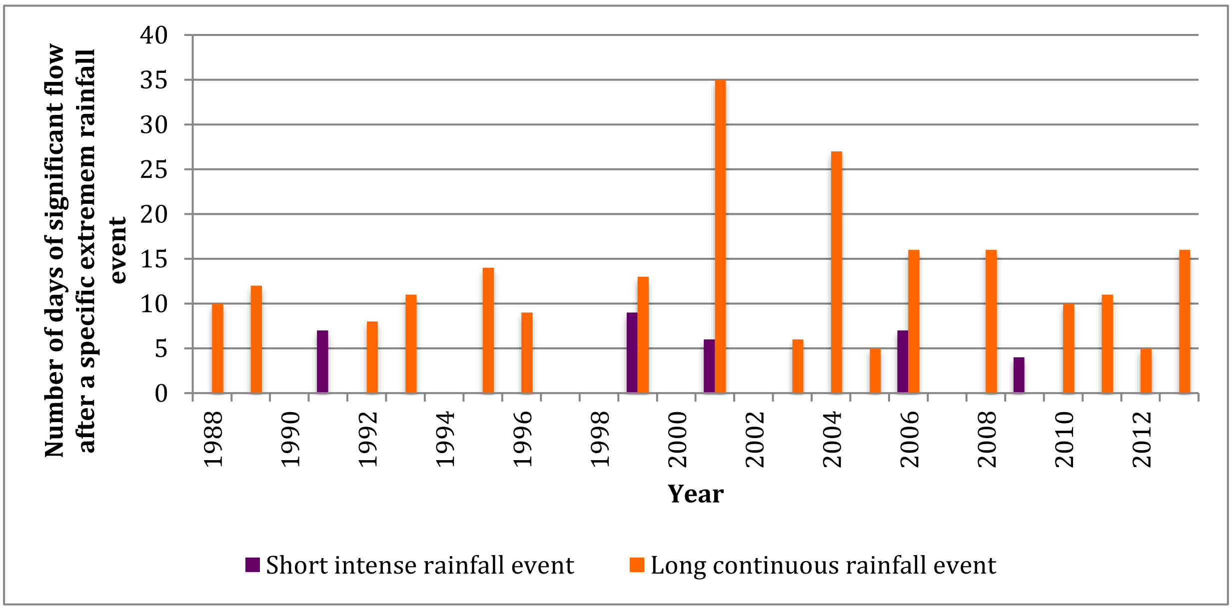


Figure 5.64 Number of days flow of the Luvuvhu (A9H012) after specific rainfall events

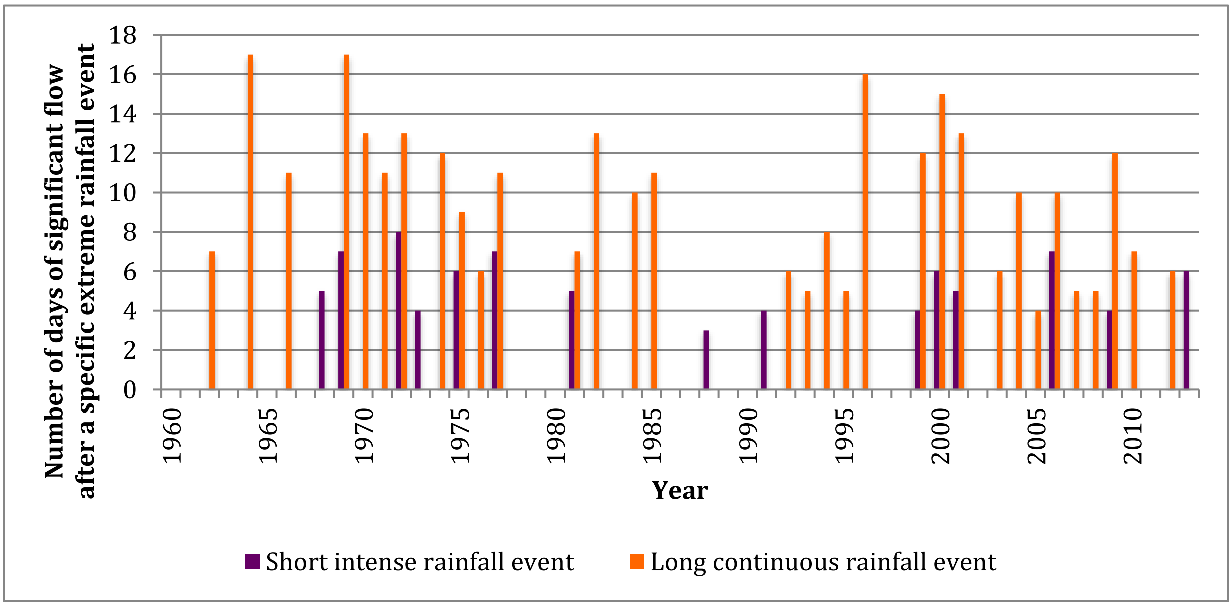


Figure 5.65 Number of days flow for the Shisha (B9H001) after specific rainfall events

events, however, these short intense events recorded a much lower flow time for both rivers (*Figure 5.64* and *5.65*).

In northern KNP, the Letaba (B8H008) and the Tsendze (B8H011) are represented below. The Letaba River shows a drastic increase in flow days (17 and 23 days respectively) after a short intense rainfall event in the year 1999 and 2000 (*Figure 5.66*). During the year 2000, the tropical cyclone Eline impacted the KNP drastically and caused major flooding of all river systems through the park. The flooding and subsequent river flow during these years caused prolonged significant flow readings due to the sheer intensity of these rains. Significant flow is flow that is on average, in the 90th percentile, meaning that, a river discharge with flow in the 90th percentile is equal or greater than 90 percent of the discharge values recorded during all the years that measurements have been recorded (USGS, 2011).

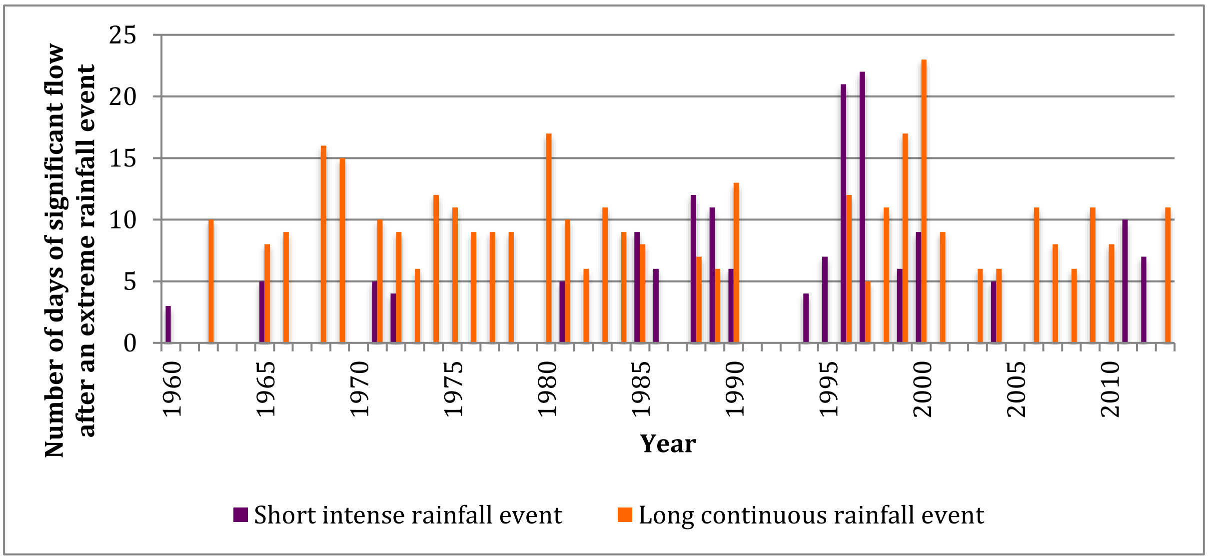


Figure 5.66 Number of days flow for Letaba (B8H008) after a specific rainfall event

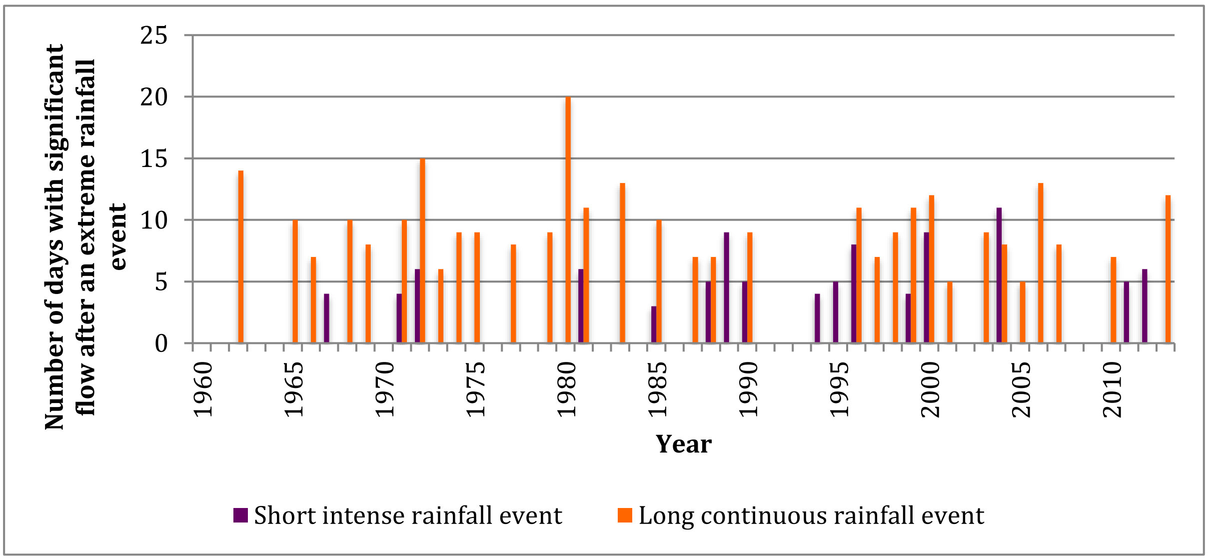


Figure 5.67 Number of days flow for Tsendze (B8H011) after a specific rainfall event

In central KNP, the rivers represented include the Sabie (X3H021) and the Nwanedzi (X4H004). There were fewer short intense rainfall events that occurred in the central KNP region. Some of the short intense rainfall events couldn't be represented as the readings for flow after these extreme rainfall events were missing (due to gauge station malfunction). Along the Sabie River (*Figure 5.68*), the days of significant (90th percentile) river/stream flow after a short intense rainfall event were notably higher than the other years. Extremely

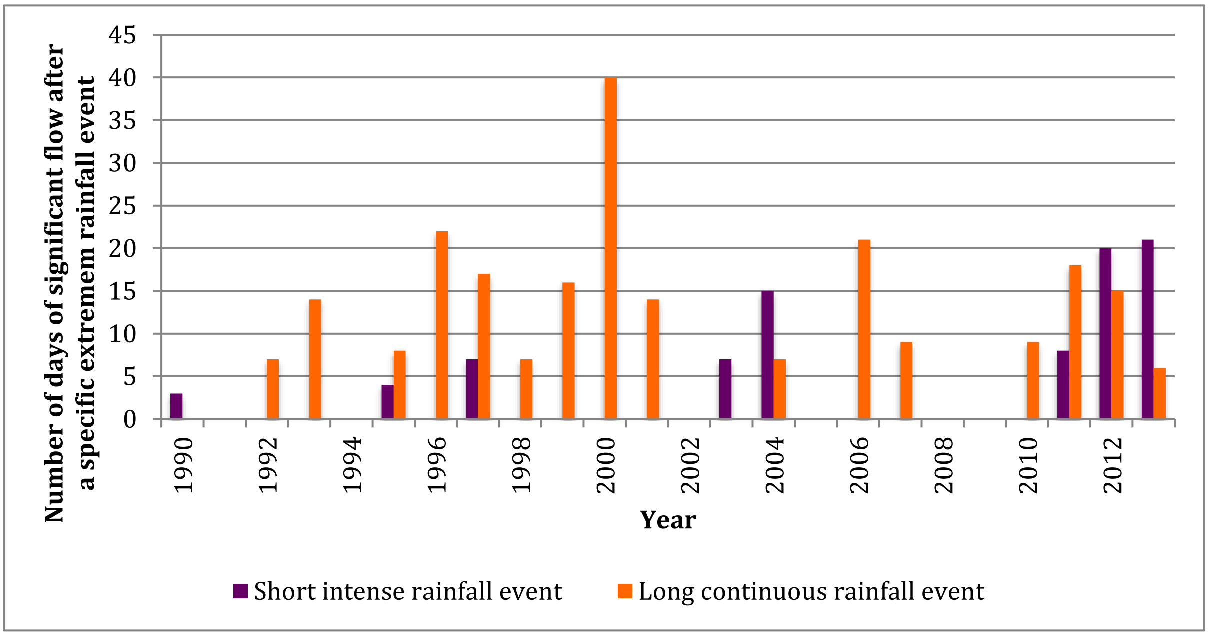


Figure 5.68 Number of days flow for the Sabie (X3H021) after a specific rainfall event

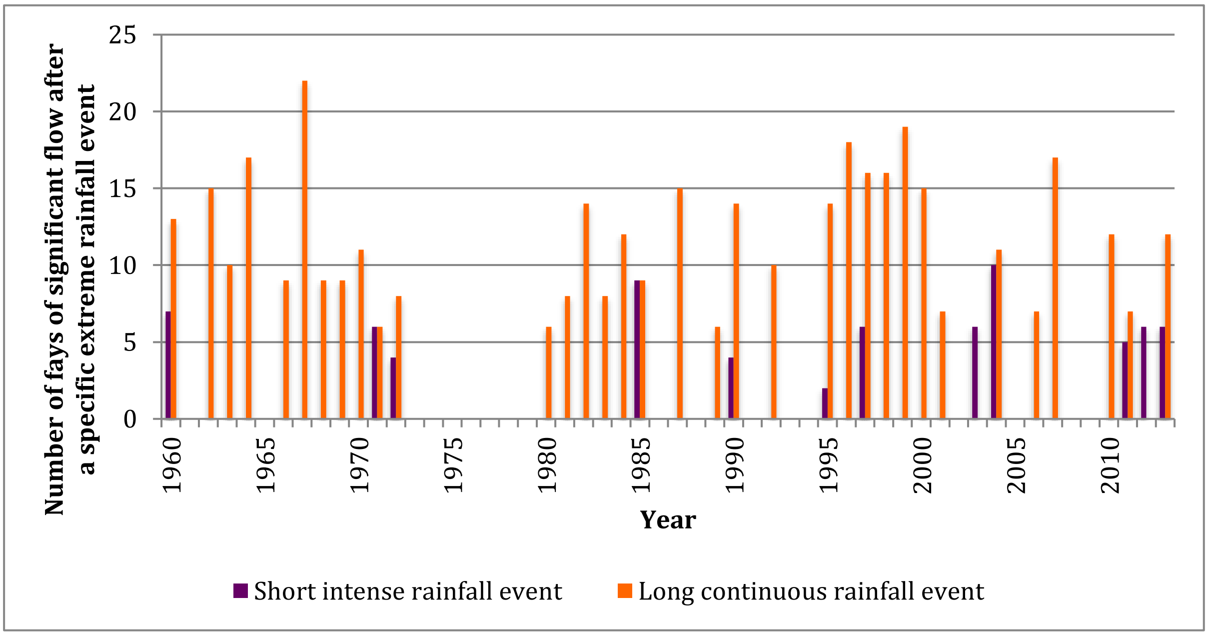


Figure 5.69 Number of days flow for the Nwanedzi (X4H004) after a specific rainfall event

heavy bursts of rainfall during these years caused flooding along the major rivers of KNP, which accounts for these higher than usual recordings.

In the southern KNP, the Crocodile River (X2H006) is represented below (*Figure 5.70*). During the years 2012-2013, short intense rainfall events for the southern region (similarly to the central region) were a lot more intense, registering more that 200mm rainfall over 1-2 days, and thus the days of significant flow following these rainfall events is higher than during the rest of the record period (*Figure 5.70*).

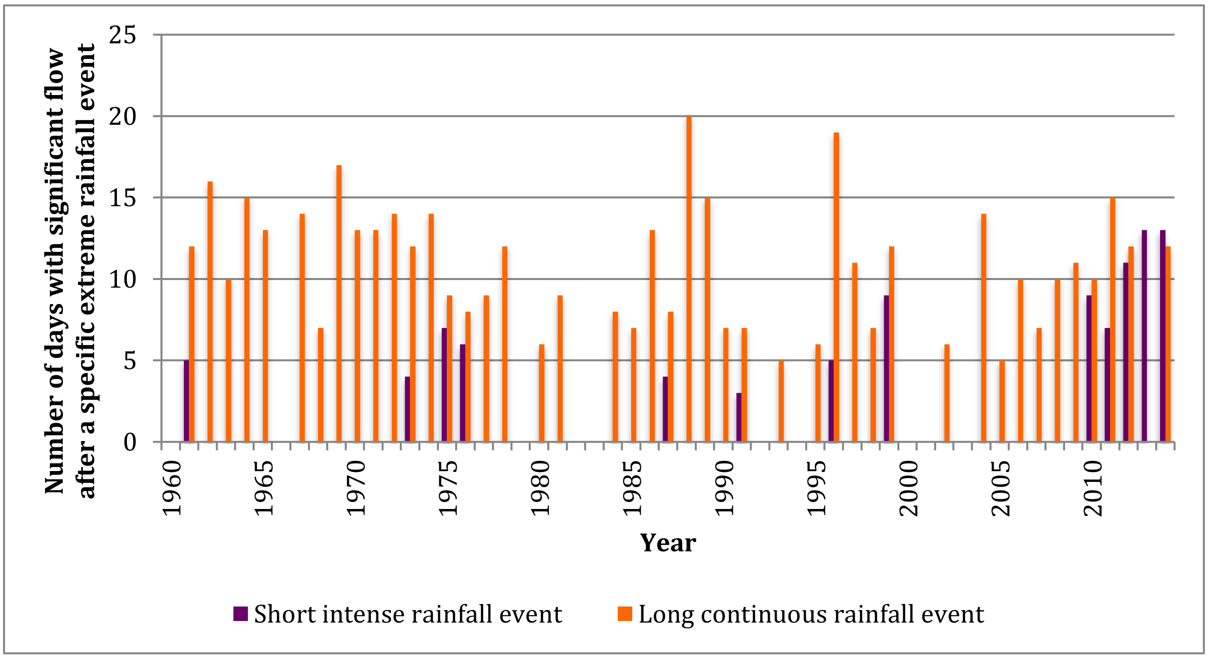


Figure 5.70 Number of days flow for the Crocodile (X2H006) after a specific rainfall event

Extreme rainfall events do have a major impact on the flow of rivers/streams in the KNP, and ultimately determine how long a river/stream will receive significantly higher than average flow. It is important to understand how different rainfall intensities impact rivers and streams as this can give an indication into flood warnings, as well as how much significantly high flow is expected to occur after each rainfall event. Management and river bio monitoring can benefit hugely from these findings.

5.16.2 Impacts of the El Niño Southern Oscillation (ENSO) on river/stream flow patterns

The impact of El Niño on river/streamflow in KNP is evident in the following graphs. During ENSO years, river/stream flow is below average along majority of the rivers (*Figures 5.71- 5.74*). Over the past 60 years, there have been 23 El Niño phases that have impacted the South African environment (*Table 5.42*). El Niño cycles range from weak, to very strong events, and impact rainfall in the country, which subsequently impacts the flow levels of South African rivers. El Niño events impact the rainy seasons of South Africa, and thus the figures represented below indicate data for the rainy seasons. For example, the rainy season for South Africa lies between the months of November and March. The graphs represent November and December rain of the former year and January, February and March rain of the subsequent year (November, December of 1970- January, February and March of 1971).

Table 5.42 El Niño events that impacted South African rainfall events (modified Tisdale, 2010))

Weak	Moderate	Strong	Very strong
1951-1952	1963-1964	1957-1958	1982-1983
1952-1953	1986-1987	1965-1966	1997-1998
1953-1954	1987-1988	1972-1973	2015-2016
1958-1959	1991-1992		
1968-1969	2002-2003		
1976-1977	2009-2010		
1977-1978			
1979-1980			
1994-1995			
2004-2005			
2006-2007			

5.16.2.1 ENSO and flow patterns in the northern KNP

The northern KNP rivers depict impacts on flow in the years where El Niño is present. The Luvuvhu river (A9H012) records show variable summer flow between 1988 and 2015; however, an El Niño event is present for 43% of these below flow years (*Figure 5.71*). Summer flow for the years 1991-1992 are the lowest recorded at the Luvuvhu (A9H012) station (*Figure 5.71*), showing a deviation of -100% below the annual average. The second lowest flow level recorded is for the years 2004-2005 and 2006-2007, which are also years where El Niño events are present (*Figure 5.71*).

Along the Letaba River, El Niño events are present for 50% of the recorded below average flow years (*Figure 5.72*). The lowest flow levels recorded at B8H034 were during the years 1997-1998 (97% less than average annual flow) and 2004-2005 (98% less than average annual flow). Station B8H018 recorded its lowest summer flow during the 1991-1992 El Niño event, with flow deviating from the annual average by 94% (*Figure 5.72*). 44% of the below average summer flow years are impacted by ENSO events at the Letaba station B8H008 (*Figure 5.72*). The lowest flow years recorded at B8H008 were during the rainy months of 1972-1973, where flow was 92% below the annual average, 1982-1983, with flow 82% below the average and 2004-2005 where flow is 78% below the annual average (*Figure 5.72*).

Although the present of El Niño is not responsible for all the low flow recordings of the rainy months, El Niño is present in almost half of the low flow years, and is present in all the lowest recorded flow years (*Figures 5.71* and *5.72*). Interannual variation of flow for KNP rivers is expected, due to the interannual variability of rainfall in the region, El Niño is an additional impact on the rivers in the area, and has a definite impact on the northern KNP river flows.

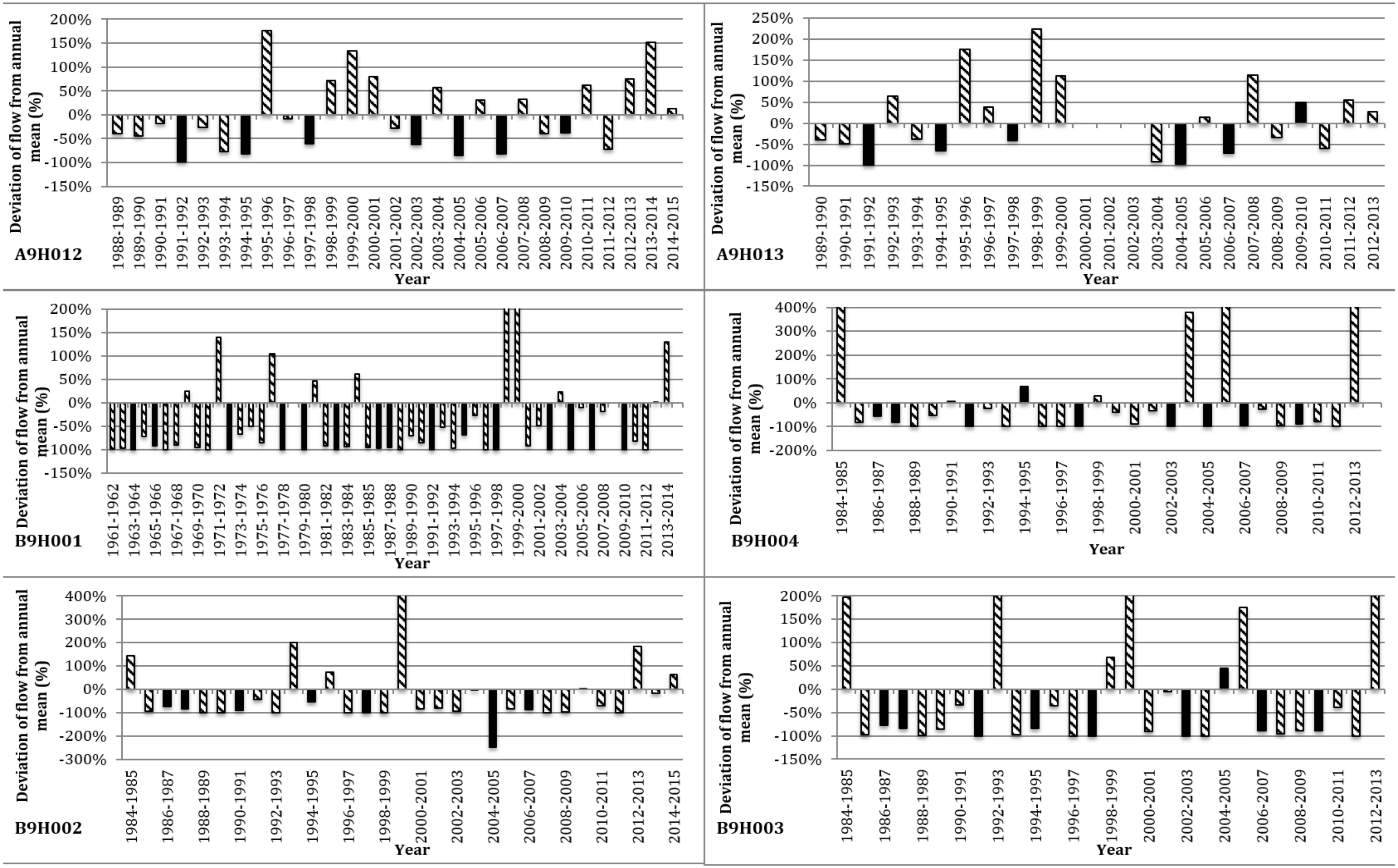


Figure 5.71 Standard deviation of rainy season river/stream flow for all far northern KNP rivers (*solid black bars indicate the years where ENSO is present)

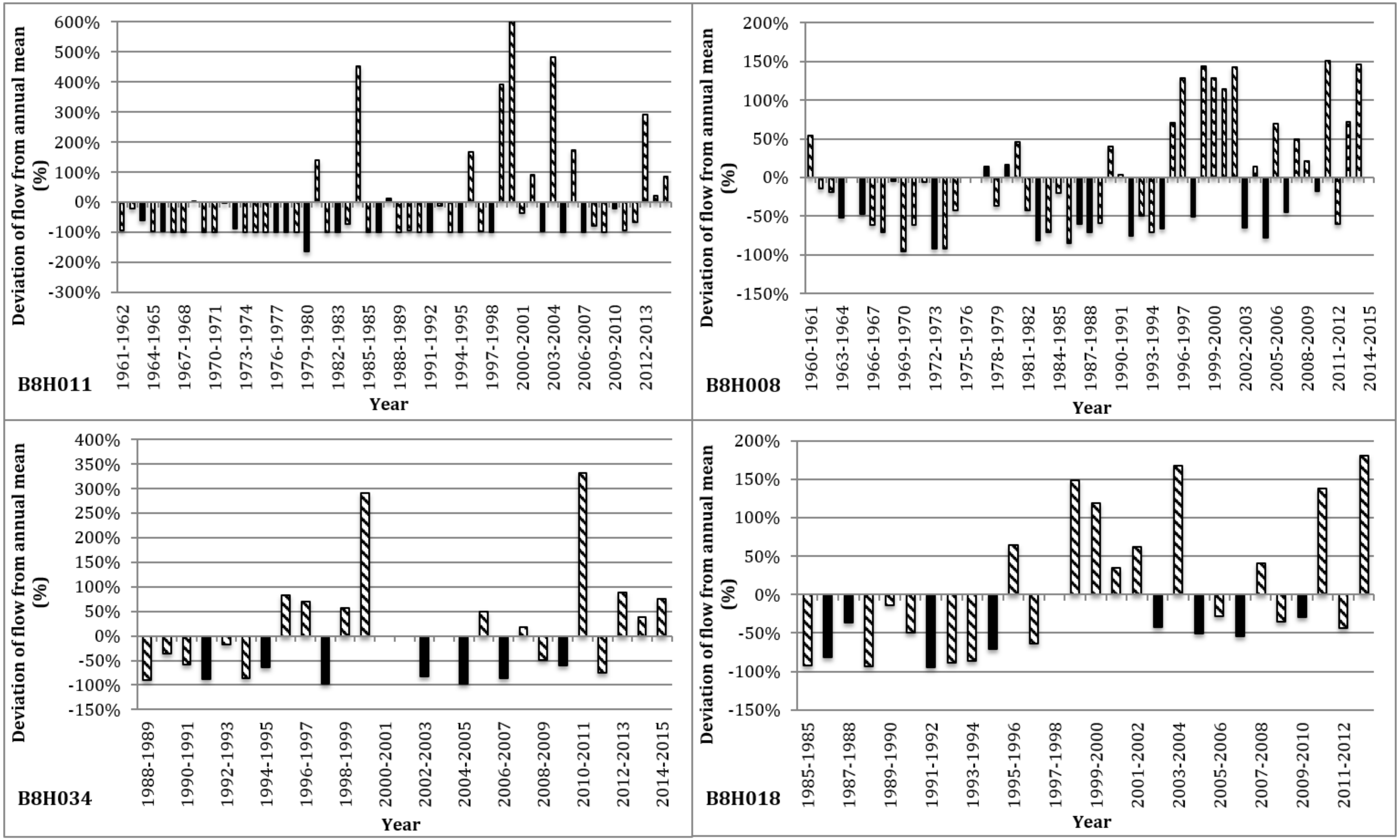


Figure 5.72 Standard deviation of rainy season river/stream flow for all far northern KNP rivers (*solid black bars indicate the years where ENSO is present)

5.16.2.2 El Niño and river/stream flow patterns in the southern KNP

The southern KNP rivers depict impacts on flow levels where an El Niño event is present. At the Sand River station, El Niño events are present for 48% of the years where flow was recorded below the annual average (*Figure 5,73*). The years with the lowest flow records are all years where El Niño is present. The greatest deviation of flow from the average was during the El Niño phase of 1991-1992 (-98%) and1982-1983 (-96%), the rest of the El Niño phases saw similar negative flow deviations: 1972-1973 (-90%), 2002-2003 (-89%), 2004-2005 (-88%), 1986-1987 (-85%), 1994-1995 (-84%) and 2006-2007 (-74%).

At the Komati station (X2H036), 50% of the below average flow years were impacted by an El Niño event (*Figure 5.74*). The years where the lowest recorded rainy season flow levels were 1991-1992 (-86%), 1993-1994 (-97%), 1994-1995 (-96%), 2002-2003 (-85%), 2003-2004 (-71%), 2004-2005 (-90%) and 2006-2007 (-82%). The only years where ENSO is not present is the 1993-1994 and 2003-2004 phase. However, these years fall between or after years where significant El Niño events have been present, and thus low flow for these subsequent years is probable.

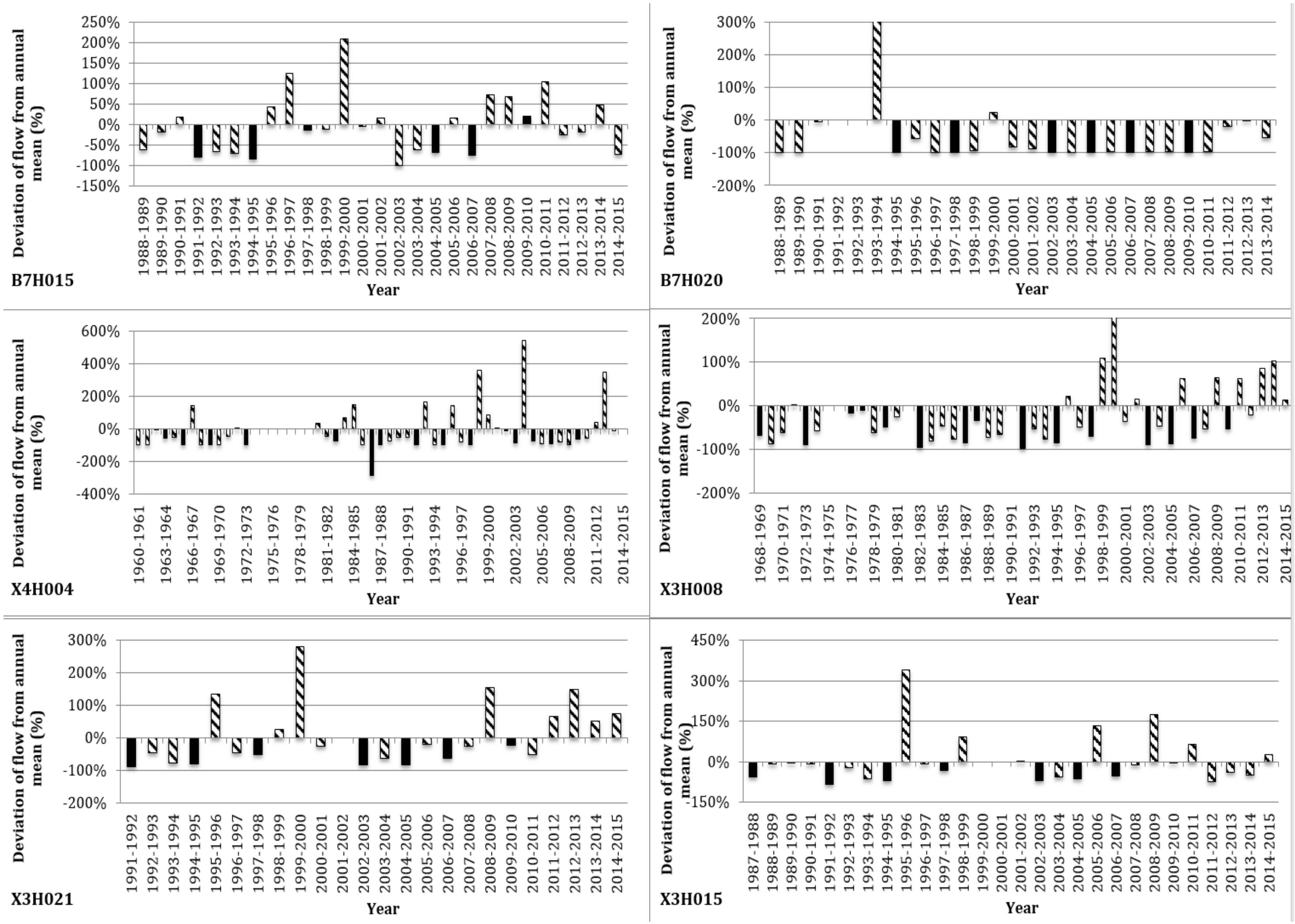


Figure 5.73 Standard deviation of rainy season river/stream flow for all central KNP rivers (*solid black bars indicate the years where ENSO is present)

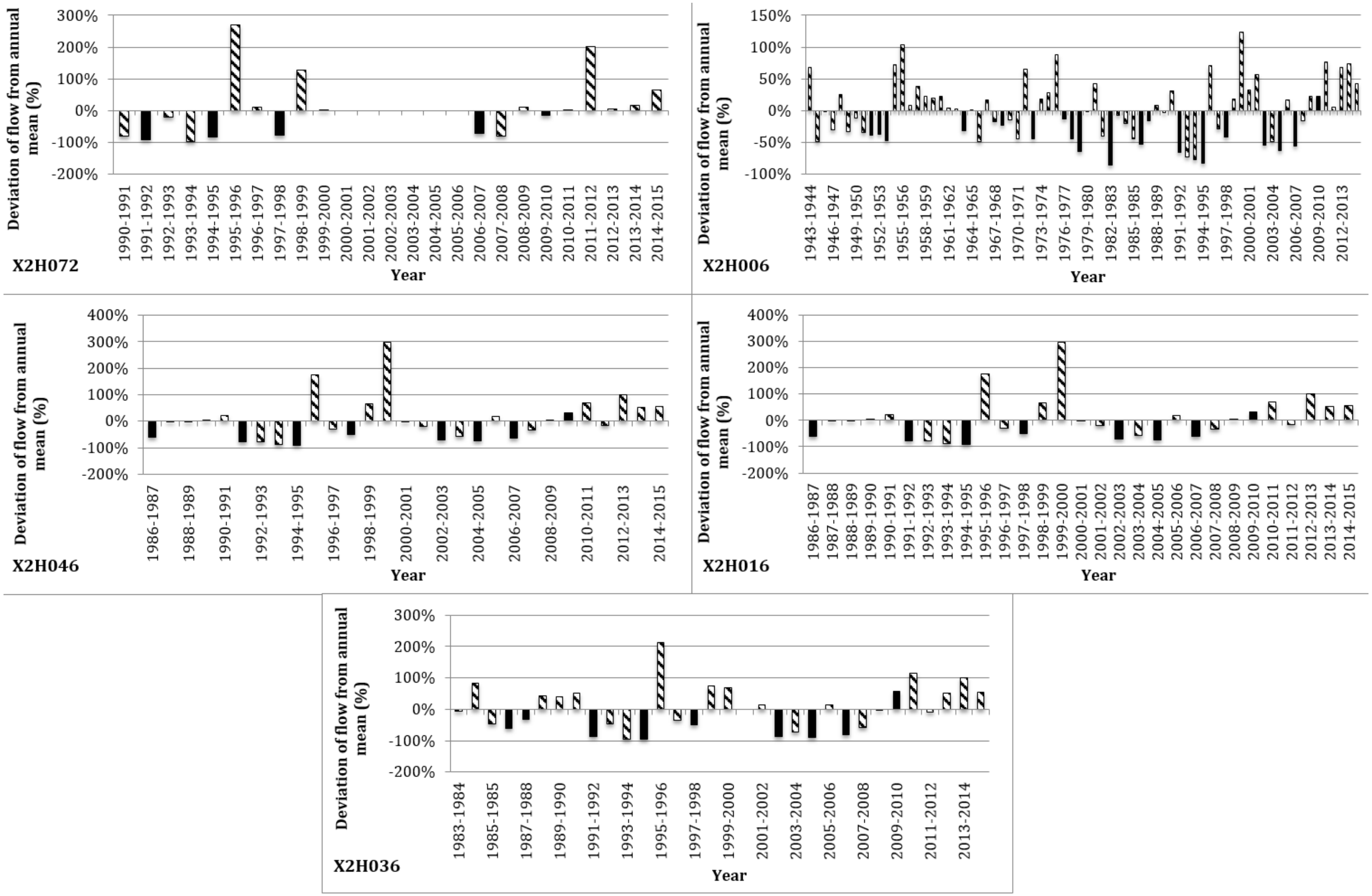


Figure 5.74 standard deviation of rainy season river/stream flow for all southern KNP rivers (*solid black bars indicate the years where ENSO is present)

Table 5.43 highlights the correlation between El Niño phases and KNP river/stream flow. It can be noted that all the gauge stations depict a negative correlation with El Niño phases. A negative result indicates that when El Niño events are present/high, river/stream flow of KNP will be low due to the resultant drought like conditions. El Niño events are one of the main drivers of inter annual flow variability within the park, as drought conditions bring about long periods of low-no flow volumes along the rivers of the park.

Table 5.43 Correlation between river/stream flow and El Niño phases

River	Station	Correlation	Catagorisation
Luvuvhu	A9H012	-0.34	Moderate Negative
Mutale	A9H013	-0.07	Weak Negative
Shisha	B9H001	-0.04	Weak Negative
Mphongolo	B9H004	-0.25	Weak Negative
Shingwedzi	B9H002	-0.29	Moderate Negative
Shingwedzi	B9H003	-0.29	Moderate Negative
Tsendze	B8H011	-0.3	Moderate Negative
Letsitele	B8H010	-0.25	Weak Negative
Letaba	B8H008	-0.29	Moderate Negative
Letaba	B8H034	-0.26	Weak Negative
Letaba	B8H018	-0.39	Moderate Negative
Olifants	B7H015	-0.08	Weak Negative
Timbavati	B7H020	-0.06	Weak Negative
Nwanedzi	X4H004	-0.12	Weak Negative
Sand	X3H008	-0.2	Weak Negative
Sabie	X3H021	-0.29	Moderate Negative
Sabie	X3H015	-0.01	Weak Negative
Nsikazi	X2H072	-0.04	Weak Negative
Crocodile	X2H006	-0.24	Weak Negative
Crocodile	X2H046	-0.3	Moderate Negative
Crocodile	X2H016	-0.18	Weak Negative
Komati	X2H036	-0.3	Moderate Negative

5.17 Impact of dams on river/stream flow

The previous sections have explored the natural impacts on river/stream systems in KNP. This section will explore one of the many impacts anthropogenic activity has on river/streams. KNP freshwater systems are impacted substantially by upstream anthropogenic activities such as water impoundments and water extraction. The water from these major KNP rivers is extracted for agriculture, forestry, domestic and industrial use, and most the study rivers are impounded for water storage for the dry seasons so that anthropogenic activities will have all year-round water supply.

To determine the impact dams, have on KNP rivers, two different river systems will be analysed through case studies. This will give insight into how flow changed after the construction of a dam, and in some cases, how flow changed after a dam wall has been broken or damaged. Annual flow patterns as well as changes in total annual flow days will be further explored through these case studies, to see if any patterns and findings are significant. The two river systems chosen for analysis were based on their richness of data, as well as the availability of information regarding dam construction and maintenance. The two rivers are the Shingwedzi (B9H002 and B9H003) and the Letaba (B8H008, B8H018 and B8H034. These rivers were also chosen as they have more than one gauge station, allowing for a more in depth analysis of river flow behaviour downstream.

5.17.1 Dams along KNP rivers

The construction dates, location and operation status of all the significant dams along KNP rivers is recorded in the following tables (*Tables 5.44* and *5.45*). There is insufficient data available to do an analysis on dam impacts on all the rivers. Due to the short length of the river flow data, the only river that can give a true analysis on the impact of dams on flow levels is the Letaba River. A Case study of this river will be done in section 5.17.2 to determine how flow is impacted by the construction of a dam wall.

Table 5.44 Dam constructions along northern KNP river/streams

River	Dam	Location	Completion of construction	Reason for construction	Operation	Comments
Luvuvhu	Nandoni	Outside KNP	2005	Steady water supply for domestic use	Yes	
	Tshakhuma	Outside KNP	1990	Irrigation	Yes	
	Albasini	Outside KNP	1952	Irrigation scheme	Yes	
Mutale	Mutale weir	Inside KNP		River flow monitoring	Yes	
Shisha	Shisha weir	Inside KNP	1960	River flow monitoring	Yes	
Mphongolo	Sirheni Dam	Inside KNP	1972	Agriculture, watering livestock	No	Dam wall was damaged beyond repair in the 2013 floods and was demolished and removed in late 2015
Shingwedzi	Kanniedood	Inside KNP	1973	Agriculture, watering livestock	No	Dam wall broken in 2013 floods
	Silwervis	Inside KNP	1982	Agriculture, watering livestock	Yes	
	Wik-en-Weeg	Inside KNP	1973	Agriculture, watering livestock	No	Dam wall was damaged in 1996 floods and removed
Tsendze	Pioneer	Inside KNP	1977	Agriculture, watering livestock	Yes	
	Tsendze weir	Inside KNP	1960	River flow monitoring	Yes	
Letaba	Engelhard	Inside KNP	1971	Agriculture. Watering livestock	Yes	
	Black Heron	Inside KNP	1988	Agriculture, watering livestock	No	Dam broken in 2000 floods
	Shimuweni	Inside KNP	1970	Agriculture, watering livestock	No	Damaged in 2000 floods and removed
	Mingerhout	Inside KNP	1974	Agriculture, watering livestock	Yes	
	Tzaneen	Outside KNP	1976	Irrigation	Yes	
	Ebenezer	Outside KNP	1959	Municipal and industrial water usage	Yes	

Table 5.45 Dam constructions along southern KNP river/streams

River	Dam	Location	Completion of construction	Reason for construction	Operation	Comments
Olifants	Loskop	Outside KNP	1939	Irrigation	Yes	Reconstructed in 1979
	Flag Boshielo	Outside KNP	1987	Domestic water use		Previously known as Arabie dam. Dam wall was raised in 2006
	Middelburg	Outside KNP	1978	Domestic water supply	Yes	
	Witbank	Outside KNP	1971	Municipal and industrial water usage	Yes	
	De Hoop	Outside KNP	2014	Water to mining and industrial usage	Yes	Largest dam to be built since the 1970s
	Mamba weir	Inside KNP	1983	River flow monitoring		
Timbavati	Piet Grobler	Inside KNP	1962	Agriculture, watering livestock	Yes	
Nwanedzi	Nwanedzi weir	Inside KNP	1960	River flow monitoring	Yes	
Sand	Exceter weir	Inside KNP	1966	River flow monitoring	Yes	
Sabie	Lower Sabie weir	Inside KNP	1987	River flow monitoring	Yes	
	Kruger gate weir	Inside KNP	1990	River flow monitoring	Yes	
	Lower Sabie camp dam	Inside KNP	1984	Agriculture, watering livestock	Yes	
	Injaka	Outside KNP	2001	Irrigation	Yes	
	Witklip	Outside KNP	1969	Irrigation	Yes	
	Da Gama	Outside KNP	1971	Irrigation	Yes	
Nsikazi	Nsikazi weir	Inside KNP	1990	River flow monitoring	Yes	
Crocodile	Karino weir	Inside KNP	1930	River flow monitoring	Yes	
	Riverside weir	Inside KNP	1985	River flow monitoring	Yes	
	Ten Bosh weir	Inside KNP	1960	River flow monitoring	Yes	
	Kwena dam	Outside KNP	1984	Irrigation	Yes	
	Van Graan	Outside KNP			Yes	
Komati	Maguga	Outside KNP	2001	Irrigation	Yes	
	Driekoppies	Outside KNP	1998	Irrigation, energy production	Yes	
	Komati weir	Inside KNP	1982	River flow monitoring	Yes	

5.17.2 A Case study of the Letaba River

Along the Luvuvhu River there are three gauging stations, upstream is B8H008, midstream is B8H034 and downstream is B8H018. There are many dams along the Letaba river, most which are outside the KNP park boundary, and are used to store water for anthropogenic activities such as agriculture, forestry, domestic and industrial use (Katambara and Ndiritu, 2009). Beneficial to this case study is the breach of two dams along the Letaba during the 2000 floods. The Black Heron dam and the Shimuweni dam were damaged and removed following the massive flooding during the year 2000, where tropical cyclone Eline devastated many parts of Mozambique and KNP.

Table 5.46 Similar rainfall events over different years used to show the flow levels of the rivers before and after dam wall breach

River Gauge Station	Rainfall events	Flow level before breach (m^3/S)	Flow level after breach (m^3/S)	Comments
B8H034	**Letaba**			
	1990 (580mm) / 2006 (550mm)	1549.8	4787.4	Increase of 209%
	1991 (345mm) / 2008 (340mm)	1464.5	2367.8	Increase of 61.7%
	1998 (565mm) / 2006 (550mm)	490.8	4787.4	Increase of 875%
	Letaba Mahlangeni			
	1989 (308mm) / 2011 (307mm)	1333.3	13366.0	Increase of 902%
	1993 (459mm) / 2013 (446mm)	1294.5	6978.9	Increase of 439%
B8H018	**Letaba**			
	1987 (480mm) / 2007 (478mm)	1582.9	4566.2	Increase of 188%
	1989 (363mm) / 2003 (373mm)	1434.1	2163.3	Increase of 51%
	1990 (580mm) / 2006 (550mm)	2112.9	3495.9	Increase of 65%
	1991 (345mm) / 2008 (340mm)	1256.5	6953.4	Increase of 453%
	1996 (694mm) / 2001 (642mm)	6264.3	7568.0	Increase of 21%
	Letaba Mahlangeni			
	1999 (760mm) / 2004 (740mm)	11436.3	15505.6	Increase of 36%
	1989 (308mm) / 2011 (307mm)	1434.1	7001.9	Increase of 388%
	1993 (459mm) / 2013 (446mm)	316.3	1020.3	Increase of 222%

5.17.3 Impact of dams on the Letaba River

The Letaba River is a major river that supplies water to the region of the KNP and is one of the biggest tributaries to the Olifants River. The Letaba River flows eastwards across the Limpopo region of South Africa, and through KNP before joining the Olifants River at the Lebombo hills. There are more than 20 large dams constructed along the Groot Letaba river (RHP, 2012), six of which were tabulated (*Table 5.46*) for the purposes of this research. Due to the Letaba gauge stations not dating back before 1960, only one dam construction and one dam breach could be represented graphically to determine the impact the dams have on the Letaba river flow (*Figures 5.75-5.77*).

The anthropogenic impact on the Letaba River is high, with the river water being utilized for activities such as forestry, commercial farming, subsistence farming and irrigation schemes (RHP, 2012). Once the Letaba reaches the KNP, the impact the dams and weirs have on flow is minimal, but do form significant fish barriers (RHP, 2012). The two dam's events represented in the following graphs are the construction of the Black Heron dam in 1998, and the damage and removal of the Black Heron and Shimuweni dam in the 2000 floods. Both dams were located within the KNP and thus had a direct impact on the flow levels recorded at the gauge stations.

All three-gauge stations along the Letaba recorded a dramatic increase in flow and flow days following the breach of the Black Heron and Shimuweni dams (*Table 5.47*). B8H002 showed an increase in total annual flow from 883.4m^3/S to 1487.8m^3/S. B8H034 total annual flow increased from 2037.7m^3/S to 4012.1m^3/S and B8H018 total annual flow increased from 2207.6m^3/S to 5041.5m^3/S (*Table 5.48*).

It is evident from *Figures 5.85-5.87* that the amount of flow days per annum increased substantially following the breach of the dams in the year 2000. At gauge station B8H008; a 38.7% increase in flow days was recorded after the breach of the dams (*Figure 5.85*). Station B8H034 and B8H018 recorded an increase in flow days by 66.3% and 161.6% respectively (*Figures 5.76* and *5.77*).

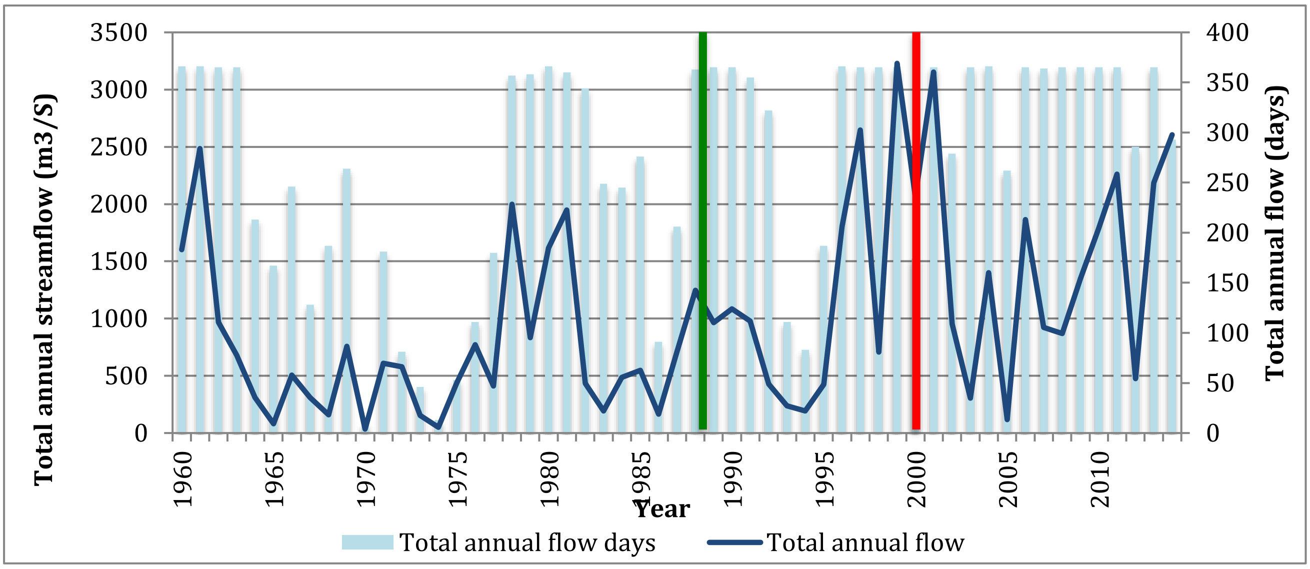


Figure 5.75 Total annual flow and flow days for B8H008 (solid green line indicates dam construction, solid red line indicates dam breach)

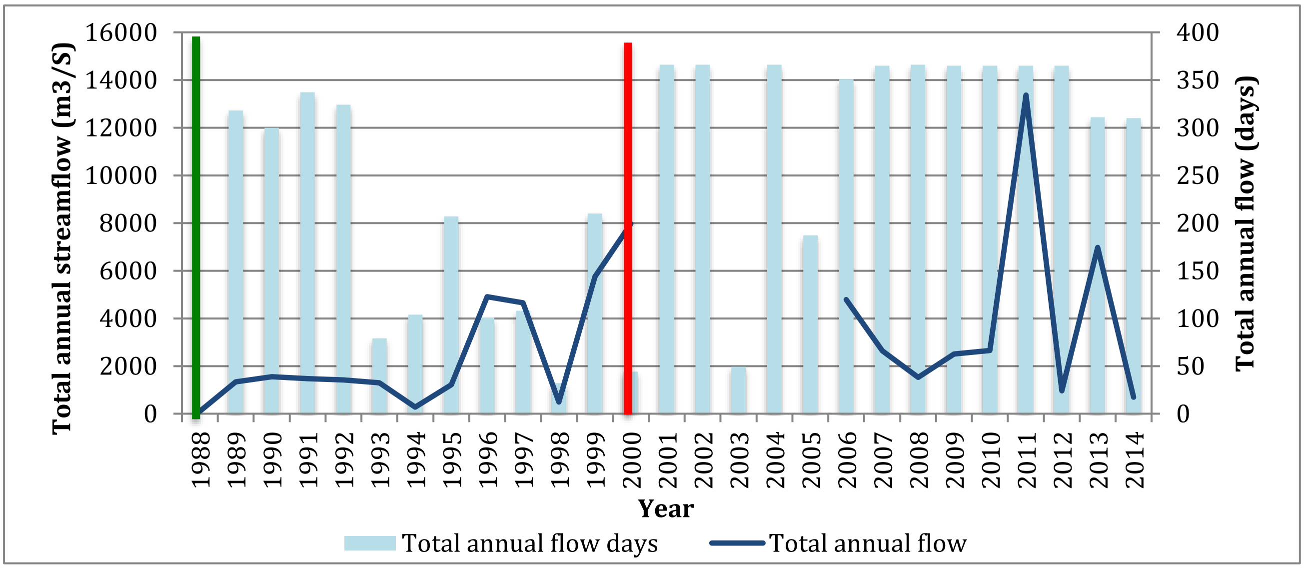


Figure 5.76 Total annual flow and flow days for B8H034 (Solid green line indicates dam construction, solid red line indicates dam breach)

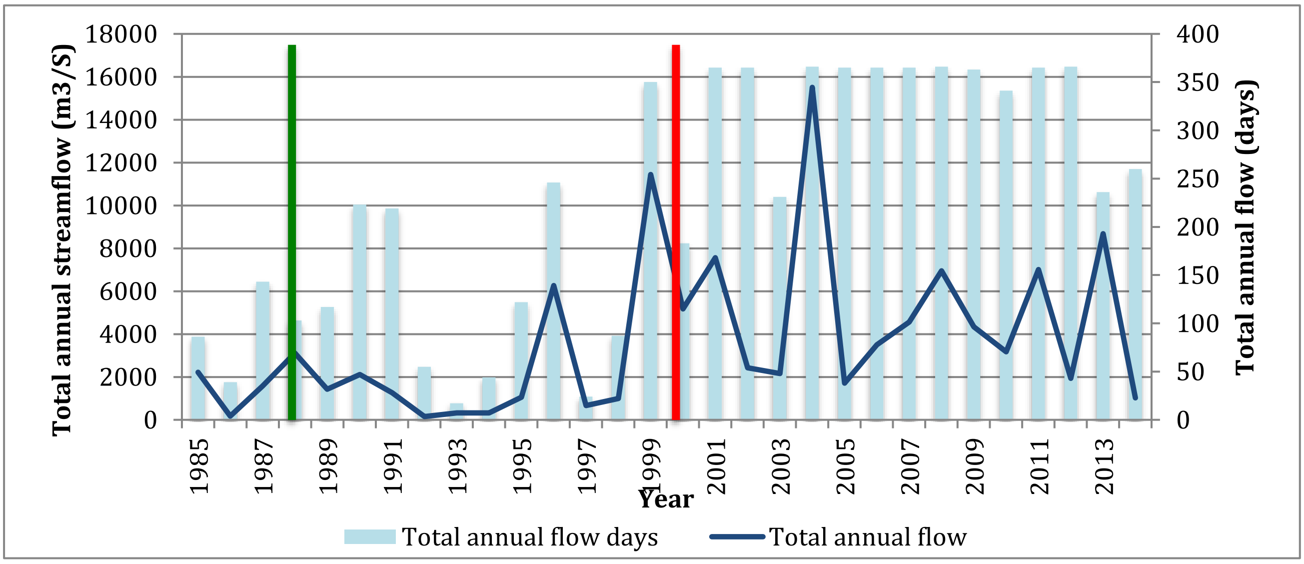


Figure 5.77 Total annual flow and flow for B8H018 (solid green line indicates dam construction, solid red line indicates dam breach)

Table 5.47 Similar rainfall events over different years used to show the flow levels of the rivers before and after dam wall breach

Dam wall breach	Statistical analysis	B8H008		B8H034		B8H018	
		Annual flow	Annual flow days	Annual flow	Annual flow days	Annual flow	Annual flow days
Before the construction of Black heron dam	Mean	708.15	221.17				
	Z-Value	0.09	-0.43				
	P-Value	0.46	0.33				
	Trend	Increasing	Decreasing				
After the construction of Black heron dam	Mean	1343.07	316	3115.2	256.2	3993.2	241
	Z-Value	0.78	0.16	1.53	-1.99	0.75	0.34
	P-Value	0.21	0.43	0.06	0.02	0.22	0.36
	Trend	Increasing	Increasing	Increasing	Decreasing	Increasing	Increasing
Before the Black heron and Shimuweni dam breach	Mean	884.3	245.1	2037.7	192.7	2207.6	125
	Z-Value	2.57	-1.63	1.53	-1.99	0.75	0.34
	P-Value	0.005	0.05	0.06	0.02	0.22	0.36
	Trend	Increasing	Decreasing	Increasing	Decreasing	Increasing	Increasing
After the Black heron and Shimuweni dam breach	Mean	1487.8	340.7	4012.1	321.21	5041.5	326.8
	Z-Value	0.99	0.24	1.54	2.01	0.31	0.33
	P-Value	0.15	0.4	0.06	0.02	0.37	0.36
	Trend	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing

Chapter Six: Discussion

6.1 Introduction

The primary aim of this study is to determine the response streamflow in KNP should changing and variable rainfall patterns over the past decades. In doing so, it contributes to the existing body of scientific research on rainfall patterns, streamflow patterns and climate change in the northeastern lowveld of South Africa, more specifically the KNP. This discussion analyses the results obtained in this study in comparison to results reported from other studies. The extent of these results, and their comparisons can add to the existing body of knowledge of climate change in KNP and the impacts of climate change on streamflow.

The second section of this discussion explores the potential impact of El Niño on river/streamflow patterns in KNP. El Niño events have been known to contribute to climate and rainfall in specific regions, with a known impact on South Africa. Extreme weather phenomena and their impacts on KNP rivers will be discussed in detail in this section, drawing on comparisons of the impact of El Niño on other rivers around the world with similar climates.

The final section of this chapter discusses potential management strategies to cope with projected changes in climate, the potential for further research and the various limitations in this study, from data collection and management to missing data constraints and statistical restrictions. It further suggests additional causal factors that may influence the results in this study.

6.2 Analysis of Results

6.2.1. Analysis of rainfall results

While the rainfall trends for all four of the study regions are variable over the past 50-100 years, this is not unusual for rainfall patterns in southern Africa (Mason and Jury, 1997; Fauchereau *et al.,* 2002; Reason and Jagadheesha, 2005; van Wilgen *et al.,* 2015). Rainfall trends show very few statistically significant trends, with most rainfall stations showing no significance in trend over time (*Figures 5.1-5.29*). This analysis is complimentary to many studies in this region, and all over South Africa (MacKellar *et al.,* 2014; van Wilgen *et al.,* 2015), because South African annual precipitation is significantly variable from year to year (Fauchereau *et al.,* 2003; Nel, 2009; Buitenwerf *et al.,* 2011; MacKellar *et al.,* 2014; van Wilgen *et al.,* 2015). The considerable variability of rainfall, although expected from this study, is distinctive of climatic conditions related to the El Niño Southern Oscillation (Reason and Jagadheesha, 2005).

Rainfall is higher in the bushveld region per annum than in the lowveld region (*figure 5.30*), with northern bushveld rainfall receiving 103% more annual rainfall than the northern lowveld, and the southern bushveld receiving on average 50% more rainfall than the southern lowveld. The South African escarpment, as well as the bushveld region in eastern South Africa, recieves considerably higher rainfall than the lowveld regions due to orographic uplift associated with rainfall along the escarpment (McCartney *et al.*, 2004). Such orographic rainfall regularly produces amounts exceeding 1000mm per annum; this is particularly evident from stations such as Palmaryville, Hans Merensky, Zomerkomst, Sabie and Onverwag Bos. Although it is known that the northern subtropical KNP is drier than the southern temperate parts (Schultze, 2002), recent decadal changes in these regions have not been previously quantified.

Of interest was the finding that the southern lowveld receives higher rainfall than the northern lowveld, however the northern bushveld receives higher rainfall than the southern bushveld (*Figure 5.30*). There is a definite knowledge gap for this research. The northern bushveld receives 11.9% more annual rainfall than the southern bushveld, whereas the northern lowveld receives 16.1% less rainfall than the southern lowveld. As mentioned in the literature review (*chapter 3*), the northern lowveld of the Kruger Park receives significantly lower annual rainfall than the southern region of the park (Schutze, 2002). Similar findings were made by Gertenbach (1980), and Siyabona (2013) (*Figure 6.1*), where rainfall in KNP decreased the further north, except for Punda Maria (*Figure 5.10* and *Table 5.4*). Punda Maria was the weather station that recorded the highest average annual rainfall for the northern lowveld region. This higher rainfall is the result of this weather station being located at a higher altitude than the other stations (Gertenbach, 1980). The research done by Gertenbach (1980) proves valuable to this research as it allows for the comparison of results, as well as additional analysis of rainfall patterns from 1980-2015. The most recent decadal records will allow for the evaluation of how rainfall has changed recently, and to gain a better understanding of what patterns are to be expected in the decades to come.

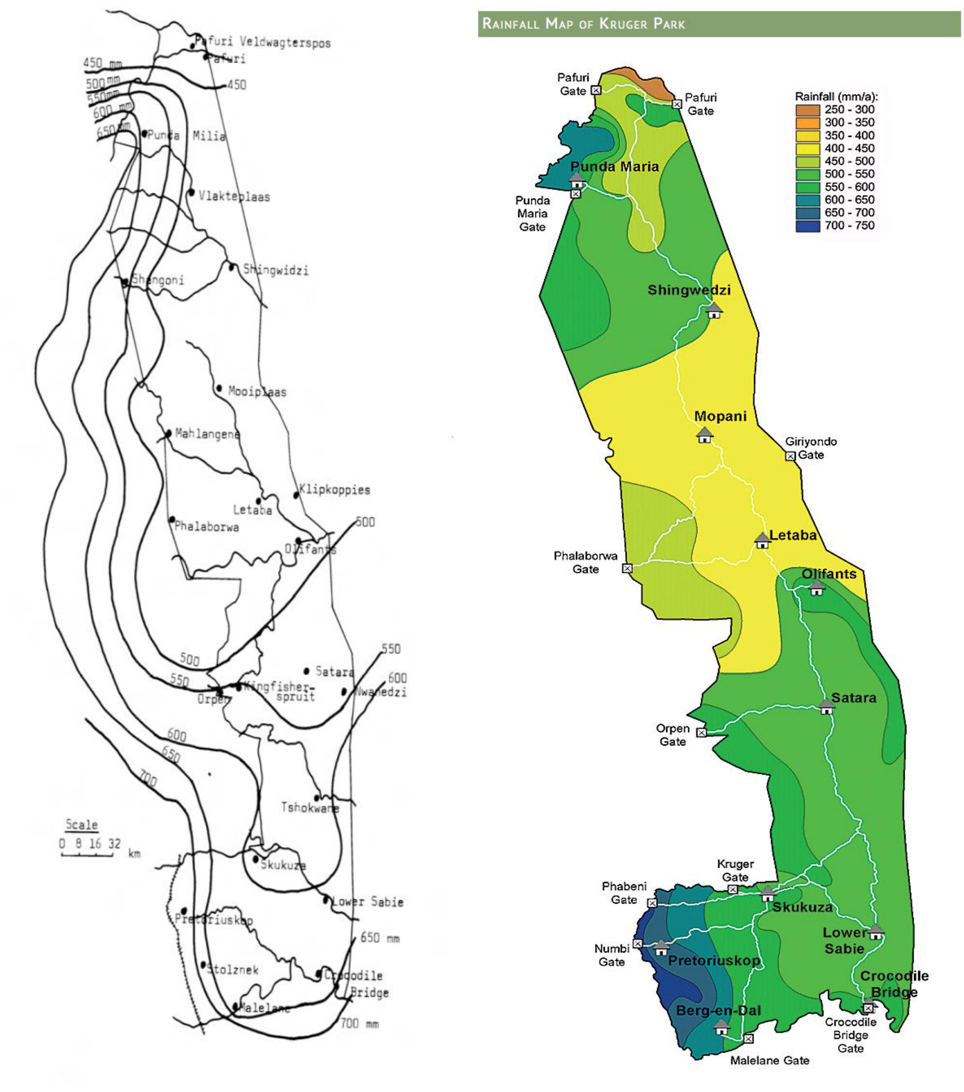


Figure 6.1 Maps showing KNP rainfall from previous research findings. Map on the left after Gertenbach (1980), Map on the right after Siyabona Africa (2013)

6.2.2. Rainfall versus rain days

Analysing rainfall behaviour and patterns over time is beneficial to determine trends, and project rainfall trends for future years, but to truly understand the patterns and behaviours of rainfall patterns, the analysis of rain days, and their relation to total rainfall needs to be evaluated. Examining trends in rainfall in relation to rain day's gives good insight into how rainfall frequencies, intensities and lengths are changing, which links to the evaluation of how extreme rainfall events are changing over time. It is extreme rainfall events, which are significant to the environment, flooding risks and socio-economic factors, as extreme rainfall events have greater impacts on the environment than long continuous events (MacKellar *et al.,* 2014).

South African rainfall is characterised by wet and dry periods, and the occurrence of extreme rainfall events (MacKellar *et al.,* 2014). Previous research has found the rainfall events are becoming significantly more intense and frequent in different parts of South Africa such as eastern South Africa (Groisman *et al.,* 2005), southern Free State (Kruger, 1999), eastern Cape (Kruger, 1999), and general South African rainfall patterns are depicted as increasing in intensity and frequency (Mason *et al.,* 1999; New *et al.,* 2006).

For the northern bushveld, trends in rainfall intensities differ across stations, generally the trends are not significant, and this corresponds to the literature, as rainfall is variable in this region (Hulme *et al.,* 2001; van Wilgen *et al.,* 2015). The weather stations with longer data sets depict decreasing trends for total annual rain days and total annual heavy rain days, but an increasing trend for total annual extreme rainfall days. The weather stations with shorter data sets (1971-2015) depict that there is an increase in wet days from 1970-2015, an increase in heavy rainfall days as well as an increase for extreme rainfall days. This suggests that although over a longer period (1920-2015), average rain days have been decreasing, more recently, over the past three to four decades, average rainfall days have been increasing as well as extreme rainfall days.

The southern bushveld shows similar results to the two previous regions, where there are some inconsistencies between stations; however, the general trend is that wet days are decreasing, as seen for all stations (*Table 5.7*), and insignificant increases in extreme rain days are depicted at four of the five stations. Nelspruit weather station was the only station to depict a non-significant decrease in extreme rain days for this region.

Southern lowveld shows similar results, with an interesting finding. Like the previous regions, wet days are decreasing over time (three of the four weather stations, with a significant decrease at Stolznek (*Table 5.9*). Extreme rain day's increase over time at all weather stations, with a significant increase in extreme rain days at Skukuza. The only weather station, which showed a great consistency in trends was Skukuza, this station depicted a significant increase in wet days, heavy rain days and extreme rain days. All rain day categories increased significantly over time (1912-2015). This suggests that Skukuza is increasing in rainfall events for both long continuous rainfall, as well as short intense rainfall events. Rainfall trends for Skukuza are non-significant, which corresponds with the literature (Kruger *et al.,* 2002), however the significant increase in rain days, specifically extreme rain days suggests that rainfall in this area is becoming more intense.

Kruger (2006) discovered that for most of the northern Limpopo region, rainfall trends were decreasing, but were not significantly decreasing in trends, it was concluded that because rainfall was not significantly increasing over the years, but days with extreme rainfall events were increasing, that it can be assumed that that daily rainfall is becoming more intense and heavy in this region of northeast South Africa (Kruger, 2006; Riddell and Peterson, 2013). The increase in the trend of extreme rainfall days has significant impacts on streamflow patterns for KNP.

Interesting findings, worthy of noting, are the inconsistencies in the relationship of total annual rainfall, and total annual rain days depicted for the longest weather stations (*Figures 5.6, 5.16, 5.17, 5.23* and *5.28*). When trends for total annual rainfall, and total annual rain days are graphically represented, some inconsistencies in the relationship between the two variables are noticeable.

Palmaryville weather station (*Figure 5.6*) portrays an inconsistency in the relationship between rainfall and rain days, where between 1923 and 1931, rainfall increases, but rain days decrease. Similar findings occurred at Punda Maria (*Figure 5.16*) between 1936 and 1945 and at Skukuza (*Figure 5.28*) between 1951 and 1967. An increase in rainfall, but decrease in rain days is due to an increase in the frequency and/or intensity of rainfall events, in this case, an increase in extreme rainfall events. Similar results were found in Italy, where negative trends in rain days and increases in total precipitation concluded that an increase in extreme rainfall events, and a decrease in non-extreme events was evident (Brunetti *et al.,* 2001). Increases in extreme rainfall trends were established in northeastern Pakistan, where daily rainfall indices were becoming more intense over time, and more rainfall was recorded over a shorter number of days (Ikram *et al.,* 2016). It can therefore be concluded that a reduction in the number of wet days, but an increase in total annual rainfall is indicative of an increase in extreme precipitation for that period.

An interesting finding at the Pilgrams Rest weather station was observed between the years 1904 and 2015 (*Figure 5.23*). The relationship between total annual rainfall and total annual rain days was variable for most the data recording. Between the years 1943 and 1962, total annual rainfall was decreasing whilst total annual rain days increased. From 1963-1987, the opposite relationship was depicted where total annual rainfall decreased whilst total annual rain days increased. From 1988-2003, rainfall increased and rain days decreased, and finally between 2004-2012, rainfall increased whilst rain days decreased (*Figure 5.23*).

6.2.3 Rainfall Variability

The literature widely represents the perception that rainfall is becoming more variable worldwide (Tyson, 1986; Greenough *et al.,* 2001; Yilmaz *et al.,* 2014). Rainfall variability is directly linked to extreme weather events such as the change in the frequency, intensity and duration of storms (Greenough *et al.,* 2001), as well as the frequency and intensity of droughts (Mason and Jury, 1997). Changes in rainfall variability experienced in the USA, Australia, southern Africa, Europe and Northern Africa have been linked to anthropogenic causes, with impacts on the environment varying between different continents. In the USA, rainfall has led to the increase in extreme rainfall events and increased precipitation during hurricane events. Increase in intense rainfall has brought increased risks of flooding, impacting the environment and displacing communities (Greenough *et al.,* 2001).

6.2.3.1 Seasonal and Decadal Rainfall Variability

The variability of rainfall in South Africa, and specifically KNP is due to changes in decadal rainfall patterns. Rainfall oscillations are regarded as the reasoning for variable rainfall patterns, and the general lack of any sufficient linear trends in rainfall patterns (DEA, 2013). It is thus very important to look at seasonal and decadal rainfall variability for the stations. Previous research has shown that rainfall in northeastern South Africa follows a *quasi* 20-year oscillation for summer rainfall (Dyer and Tyson, 1977; Kane, 2009), while other, more current literature depicts 10-12-year rainfall cycles for South Africa (Kane, 2009; Rouault, 2007; MacKellar *et al.,* 2014; Odiyo *et al.,* 2015).

Seasonal patterns in rainfall for KNP and the bushveld region show very inconsistent trends for all four regions which corresponds with findings by MacKellar *et al.,* (2014: 3), where "there is a mixed signal in the spatial distribution of changes in rainfall indices in most seasons". The months that depict a decrease in rainfall across all regions (both long and short data records) are the months of March, July and August (*Tables 5.10* and *5.11*).

Seasonal rainfall trends for South Africa, and the lowveld depict increases in summer rainfall (DJF), but decreases in autumn (MAM) and winter rainfall (JJA). This finding suggests that rainfall in this region is becoming more pronounced as seasonal cycles, which corresponds to findings that early season rainfall is increasing and late season rainfall decreasing (MacKellar *et al*., 2014; van Wilgen *et al.,* 2015). Summer rainfall patterns are inconsistent in

December and January (*Table 5.10* and *5.11*), patterns are generally decreasing for autumn months, which is consistent with findings from MacKellar *et al.,* (2014), and decreasing for winter months except for June, where most regions are noticing an increase in rainfall.

Decadal rainfall patterns for rainfall stations in this research show that over all four-study regions, rainfall is becoming more variable over time (*Table 5.16*). Variations in decadal rainfall anomalies found in this research correspond to the literature that South African rainfall, specifically KNP rainfall, shows decadal rainfall fluctuations (Odiyo *et al.,* 2015). The climate of northeastern South Africa is categorised as variable on an interannual and decadal level (Reason *et al.,* 2006). Decadal variability of rainfall accounts for the lack of statistical trends for daily rainfall patterns and rain day patterns depicted in *Figures 5.6; 5.7; 5.8; 5.16; 5.17; 5.23; 5.28* and *5.29,* as secular trends are difficult to detect against interannual and decadal rainfall anomalies (New *et al.,* 2006). Similar results were found in Queensland, Australia, where decadal rainfall patterns were observed from the late nineteenth century until present (Klingaman *et al.,* 2012). Much like the results depicted in this study, trends in decadal rainfall are linked directly to ENSO, bringing drought to Queensland (Klingaman *et al.,* 2012).

6.2.3.2 Changes in the length of the rainy season

Rainfall variability is not the only rainfall factor that influences people and the environment. Changes in the length of a rainfall season will have a huge effect on agriculture, in terms of crop development and growth, which will influence the timing of the seed planting period. A negative impact on agriculture will lead to the risk of food shortages and hunger for the world’s population (Guenang and Kamga, 2014). Studies into changes in the length and timing of the rainy season in Africa are limited, as researchers struggle with data quality, and data record lengths (Guenang and Kamga, 2014).

The best way to measure changes in the length and start date of the rainy season, is to evaluate daily rainfall for the stations, and compare start dates of rainy seasons throughout the years (Guenang and Kamga, 2014). 20 out of 21 weather stations depict a decrease in the length of the rainy season (October-April), except for Letaba Mahlangeni weather station (*Table 5.20*). The length of the rainy seasons in this study region is thus decreasing by between 0.08 and 1.21 days per annum. More of the weather stations experience a later start of the wet season and an earlier end to the season. Another study that focused on changing patterns in KNP rainfall found decreasing lengths in rainfall seasons, leading to a drier climate and increased seasonality which is cause for concern (van Wilgen *et al.,* 2015). This has obvious effects on the trend patterns of the length of the wet season over a temporal time scale. However, some weather station records produced differing results. For example, Hoedspruit, Shingwedzi Vlakteplas, Gravelotte and Letaba Mahlangeni all show increasing linear trends lines for the end of season rainfall (*table 5.20*). Increasing linear trends suggest that the end of the wet/rainy season occurs later in the year, whereas all other weather stations depict that the end of the rainy season is occurring earlier in the year. These linear trends are assumed to be differing since these weather stations have a much shorter temporal scale than the stations depicted previously. These 4 weather stations only have +/- 30 years of data, whereas the other weather stations have between 80-110 years of data, and thus it can be said that these linear trends would presumably be negative trends if their datasets were as lengthy as the rest of the weather stations (*table 5.20*).

The change in the wet season is detrimental to both the environment of the study area, as well as the animals that occupy the region of KNP. Many, if not most of the rivers and freshwater resources in the study location are highly dependent of the rainfall of the wet/rainy season to replenish their flow and/or water supply. A lot of the river systems that flow through the region of KNP are non-perennial and thus only flow during the wet months of the year (spring and summer months). A change in season, specifically a decrease in the length of the wet season would thus mean less annual water supply to the region, as well as a later onset of rains would mean a later onset of river/streamflow to the region, impacting growth of riparian vegetation, growth of specific plant species as well as the prolonged dryness of the water resources in this already semi-arid region. The shortening length of the wet/rainy season can lead to prolonged environmental drought [a combination of meteorological drought (rainfall well below the average), hydrological drought (low rivers, lakes and groundwater levels) and agricultural drought (low soil moisture)].

One of the most interesting findings was the change in the 'rate of change' of the wet/rainy season over the different temporal scales analysed. When individually analysed, some weather stations depict differing rates of change in length of season per annum dependent on the time scale the linear trend is plotted. For example, when individually analysed over its specific temporal scale between the year 1971and 2012, Gravelotte weather station depicts an average annual decrease in the length of the wet/rainy season by 0.75 days per annum. However, weather stations with much longer data sets (1907-2015) show a smaller rate of change (decrease in length of season by 0.28 days per annum). It can therefore be assumed that the changes in the length of the wet season have become more noticeable over the past few decades when compared to the changes seen overall over the past century.

When comparing these findings to the literature, similar results were found in a study of a Mediterranean-arid climate extending from the Judean Mountains to the Dead Sea (Aviad *et al.,* 2004). The consequences for this finding in the Mediterranean-arid climate, was that due to shortening rainy seasons, the region was becoming even more arid. Rainy seasons were starting later, and ending sooner every year, which negatively impacted the agricultural, botanical and ecological processes of the area (Aviad *et al.,* 2004). In South Africa, a drier climate is being detected in the southern cape region, with a negative impact on the forest biome in this region due to drying. In the Savanna region, changes in rainfall show no significant trends, but there are several indications showing the increase in rainfall variability and changes in the length of the seasons. Seasonality and a reduction in the length of the seasons, with notably shorter rainfall seasons is evident in northeast South Africa (van Wilgen *et al.,* 2015).

In Africa, more specifically southern regions of Africa such as Botswana, Zimbabwe and South Africa, the start dates of the rainy season, although largely dependent on wet and dry periods, have started up to four days later in the year between 1978 and 2002 (Kniveton *et al.,* 2008). This research further looked at different wet season thresholds, specifically 10mm, 20mm and 30mm. The findings concluded wet seasons within the thresholds of 10, 20 and 30mm rainfall, will start later in the year by an average of 0.28-0.37; 0.43-0.48; and 0.65 and 1.0 days per annum between 1978 and 2002 (Kniveton *et al.,* 2008).

In Malawi, wet season trends were analysed over 40 years, for eight weather stations. The trends for the onset of rains, seven stations depict insignificant trends, but one station depicts a significant decreasing trend for the length of the wet season (Kimaro and Sibande, 2007), meaning that the onset of rains is shifting to a later date (Kimaro and Sibande, 2007; Sutcliffe *et al.,* 2016). Results on the length of the rainy season for Malawi conclude that the rainy season is becoming shorter, and this is going to negatively impact the production of maize in agriculture. The rainy seasons are not and will not be long enough for the maize crops to grow and reach maturity (Kimaro and Sibande, 2007; Sutcliffe *et al.,* 2016).

6.2.4 El Niño Southern Oscillation and Extreme Rainfall events

Research into patterns of climate variability and extreme rainfall events has been receiving increased attention over the past years, as these phenomena has been affecting not only the environment, but human life and quality as well (Easterling *et al.,* 2000). Southern Africa is characteristic of variable rainfall trends, particularly South Africa and Mozambique, as these regions are affected by the El Niño Southern Oscillation (Cao *et al.,* 2005; Wessels *et al.,* 2007).

The El Niño Southern Oscillation is known to have a direct impact on South African rainfall patterns (Tyson, 1986; Jury, 1996; Reason and Mulenga, 1999;

Reason and Rouault, 2002; Fauchereau *et al.,* 2009; Hoell *et al.,* 2016 and Nash *et al.,* 2016). The effect of ENSO events on southern African rainfall has been a topic for discussion for many years, and the literature is extensive. ENSO has been linked to variable rainfall patterns, as well as increases in extreme rainfall events all over the world. In South America, ENSO has contributed to intense precipitation, which has resulted in floods and mudslides in densely populated areas (Hirata and Grimm, 2016), as well as interannual variability of rainfall, and warm season increases in heavy thunderstorms (Hirata and Grimm, 2016). Over the Hawaiian and tropical Pacific region, ENSO plays an important role in recurring warm and cold periods, interannual and decadal variability (He, 2015). ENSO impacts many areas around the world such an Indonesia (Hendon, 2002), Australia (Power *et al.,* 1999; Beaumont *et al.,* 2016), East Africa (Plisnier *et al.,* 2000; Abdi *et al.,* 2016), Southern Africa (Tyson, 1986; Jury, 1996; Reason and Mulenga, 1999; Reason and Rouault, 2002; Fauchereau *et al.,* 2009; Hoell *et al.,* 2016 and Nash *et al.,* 2016) and Mexico (Maza-Villalobos *et al.,* 2013), to name a few. The importance around the study of the impact of ENSO on rainfall is vital to the prediction, mitigation and adaptation for future changes in climate and specifically rainfall. Projections for future climate changes allows for planning and risk profiling to ensure readiness and planning for future extreme rainfall events (in terms of flooding, human displacement, and mass movements of land), and periods of extreme drought (in terms of agriculture and food security, water shortages and natural fire hazards), as well as the impacts ENSO will have on the flora and fauna species (Beaumont *et al.,* 2016). Without studies into how ENSO has altered rainfall patterns over the many centuries, future projections into ENSO and climate behaviour will be difficult.

Marked interannual variability in rainfall is noted throughout all rainfall stations (*Figures 5.1- 5.29*), and corresponds with the literature surrounding the South African climate (Usman and Reason, 2004). El Niño in southern Africa brings very dry conditions, which are drought phases that impact the entire country (Usman and Reason, 2004). The years where El Niño events were particularly dry were the years1911-1912 (*Figure 5.31, 5.34*), 1916 (*Figures 5.31, 5.33*), 1922 (*Figures 5.31, 5.33*), 1935 (*Figures 5.31, 5.32* and *5.33*), 1970 (*Figures 5.31, 5.32* and *5.33*), 1982-1983 (*Figures 5.31-5,34*), 1992-1993 (*Figures 5.31-5.34*) and 2002-2003 (*Figures 5.31-5.34*).

According to the literature (Belbase and Morgan, 1994; Richard *et al.,* 2001; Vogel *et al.,* 2010; Null, 2017), from 1950- present, the years with the greatest (moderate to very strong) El Niño influence are:

- Moderate: 1963-1964; 1965-1966; 1986-1987; 1987-1988; 1991-1992; 2002-2003; 2005-2006; 2009-2010.
- Strong: 1957-1958; 1965-1966; 1972-1973.
- Very strong: 1982-1983; 1997-1998; 2015-2016.

For the earlier half of the 20th century, the El Niño years are listed as: 1911-1912; 1914-1915; 1918-1919; 1922-1923; 1925-1926; 1932-1933; 1941-1942; 1951-1952 (Rouault and Richard, 2005; Manasta *et al.,* 2008; Wolter and Timlin, 2011).

Table 6.1 Years with the least annual rainfall, and their percentage deviations from annual mean, for all four regions

Northern Bushveld		**Northern Lowveld**		**Southern Bushveld**		**Southern Lowveld**	
Year	Below mean rainfall (%)	Year	Below mean rainfall (%)	Year	Below mean rainfall (%)	Year	Below mean rainfall (%)
1912/1913	59	1935	47	1911/1912	21	1912/1913	66
1922/1923	53	1941/1942	43	1914/1915	41	1918/1919	53
1935	51	1951/1952	41	1922/1923	37	1935	39
1963/1964	43	1957/1958	37	1935	41	1941/1942	35
1970	39	1963/1964	54	1945/1946	31	1953/1954	30
1972/1973	24	1970	50	1970	35	1965/1966	33
1982/1983	58	1982/1983	46	1982/1983	29	1970	44
1992/1993	45	1994/1995	35	1992/1993	27	1982/1983	47
2002/2003	58	2002/2003	50	2002/2003	67	1994/1995	40
2005/2006	48	2005/2006	38	2007/2008	32	2002/2003	46

An interesting finding is the below average (dry year) experienced during 1935 and 1970, experienced across all four regions. Mussa *et al* (2014) highlights that in the Crocodile River Catchment, 1970-1971 was a phase of significantly low rainfall, and drought conditions. The drought of 1970 in southern Africa was also recorded in the literature of Edossa *et al* (2014). Even though 1970 was not a recorded El Niño event, drought conditions were present in southern Africa, and thus low rainfall was recorded at these stations for this year. Other years with drought conditions, but not categorised as El Niño years in South Africa include 1968 and 1984 (Edossa, 2014).

One of the worst periods of drought experienced in southern Africa in the last 50 years recently occurred in 2015-2016 (Rautenbach, 2016). This intense drought brought water scarcity, agricultural difficulties, and intense heat and food insecurity during these years, and food insecurities are projected to carry through to 2017 (Rautenbach, 2016). An interesting finding is that the summer of 2015/2016 was much drier than that of 1997/1998, even though the latter was a much more intense El Niño Event (Rautenbach, 2016). This was attributed to the high ocean temperatures, these above-normal ocean temperatures of 1997/1998 blew rain moisture to the African continent, which is why the 1997/1998 was less dry than the 2015/2016 event (Rautenbach, 2016).

6.3. Trends in River/Stream flow

The impacts on climate change and rainfall variability on river/streamflow has been a topic for discussion for many years. Streamflow patterns are variable and impacted by different natural and anthropogenic influences, and the study into these impacts, and the extent to which they influence river/streamflow is vital for understanding how river/streams behave, and how they are expected to behave in the future (Young, 2003). Investigations into river/streamflow trends have been analysed extensively all over the world, including Australia (Young, 2003; Chiew *et al.,* 2006; Zhao *et al.,* 2011), America (Jha *et al.,* 2003; Strauch *et al.,* 2015;) and Africa (Odiyo *et al.,* 2014; Akpoti *et al.,* 2016).

The findings in this study relate very closely to the findings highlighted in the Literature review (*Chapter 3*), and thus these findings will be referred to in comparison to the findings for this research. The main objective of this section is to review and discuss how natural rainfall variability impacts upon streamflow in northeastern South Africa, specifically focusing on KNP. This study does not attempt to predict future climate, and is thus an indicative discussion, which will suggest *potential* future impacts of changing flow regimes on the management of water resources in KNP.

Although studies into the effects of rainfall variability on streamflow is examined for selected river systems of KNP, this research is unique in that it determines the overall rainfall impacts on the main rivers/streams in the park, allowing for a general overview into past impacts and events linked to rainfall, and potential impacts future rainfall variability can have on KNP rivers. This research focused mainly on natural (rainfall) impacts on river/streamflow, and has only looked slightly into the impacts of dams on river/streamflow. It would be very beneficial to take this study further in future research to determine the extent to which anthropogenic activities such as agriculture, industry, mining and land cover changes impact these rivers, as this is a very influential driver of river/streamflow change (Akpoti *et al.,* 2016).

6.4 Relationships between Rainfall patterns and River/Streamflow responses.

6.4.1 General relationship between rainfall and river/streamflow

Observed trends in river/streamflow were indicative of variable patterns in flow for all the rivers of KNP. Alternating wet and dry periods are evident (*Figure 5.43* to *figure 5.63*). Variable streamflow is directly linked to variable climates (Jewitt *et al.,* 2001; IPCC, 2014a; O'Neil *et al.,* 2016). Trend analysis for KNP streamflow produced inconsistent findings, where 73% of gauge stations record increases in flow over time, the significance of these trends varies from significant to non-significant (*Table 5.30*). The other 23% of rivers depict decreasing trend results over time. The difficulty with this trend analysis is that it does not provide conclusive findings as to what impacts rivers are experiencing from climate and anthropogenic impacts, it also does not consider additional factors influencing this trend. For a more in depth analysis and a better understanding into the trends of these river systems, further analysis into climate factors needs to be considered.

The increase in extreme rainfall events, as highlighted in previous discussion, plays a vital role in the trends depicted in river/streamflow results. An increase in extreme events will lead to increases in short intense flow records, which can cause a spike in gauge readings, which will lead to the depiction of increasing flow trends, when this is not the case, rather streams are flowing at much higher volumes, for shorter time periods. The differences between continuous average/low flow, versus sporadic high flow has major differences in ecological and environmental impacts. It is thus essential to analyse impacts of different rainfall indices on river/streamflow regimes, and gain a better understanding to how these events are impacting river systems, their surrounding environments, and what these impacts and changes mean for the future of these water environments and the flora, fauna, and communities they provide for.

6.4.2 Impacts of Intense Rainfall vs. Continuous Rainfall on Streamflow

To understand how intense rainfall events impact rivers, it is important to understand the correlation between rainfall and river/streamflow. The rivers/streams in this study were categorised with rainfall stations that were located within the closest proximity to the gauge station. Rainfall stations located upstream from gauge stations were also analysed to determine impacts of upstream rainfall on downstream flow. The correlation between rainfall and river/streamflow is mostly a moderate positive relationship, meaning that the correlation values for rainfall and river/streamflow are between values 0.3 and 0.7. Change in rainfall therefore impact changes in streamflow. A few cases depicted a strong positive relationship between variables, which is a correlation values above 0.7. This strong relationship suggests that rainfall has a strong impact on the patterns of river/streamflow (*Table 5.36* and *5.37*). It can therefore be noted, that rainfall has a positive relationship with streamflow, and some gauge stations just depict a stronger relationship to rainfall than others.

The reason why many gauge stations don't depict a very strong relationship to rainfall is due to other external impacts on river systems. For example, many KNP Rivers are impacted by anthropogenic activities such as water abstraction and extraction, and therefore, these impacts will skew correlation values in relation to rainfall. Dams will also generally cause delays in downstream flow response to upstream changes in rainfall.

One of the strongest correlations for rainfall and river/streamflow was found between Letaba rainfall and Tsendze (B8H011) river/streamflow (*Figure 6.2*). The correlation between these variables is 0.92, which suggests a very strong relationship between rainfall and river/streamflow. One of the main reasons for this finding is that this river originates within KNP boundaries and is therefore not impacted at all by external anthropogenic impacts. The Tsendze River therefore is only impacted by rainfall events. This finding proves valuable for future research, as well as an introduction into the impacts humans have on river systems, especially rivers that flow through protected areas. The premise of this finding opens an opportunity to explore further the impacts anthropogenic activities have on KNP rivers, and to what extent these rivers are being exploited in comparison to the natural, protected rivers of the park. These findings related closely to the study conducted in the area Serra da Mantiqueira (Brazil), where significant changes in flow were related directly to changes in land cover and occupation in watersheds, as these factors do not influence rivers in protected areas (Vilanova, 2014). Therefore, it is concluded that the analysis between protected and unprotected areas is vital to the study of rainfall impacts on river/streamflow (Vilanova, 2014).

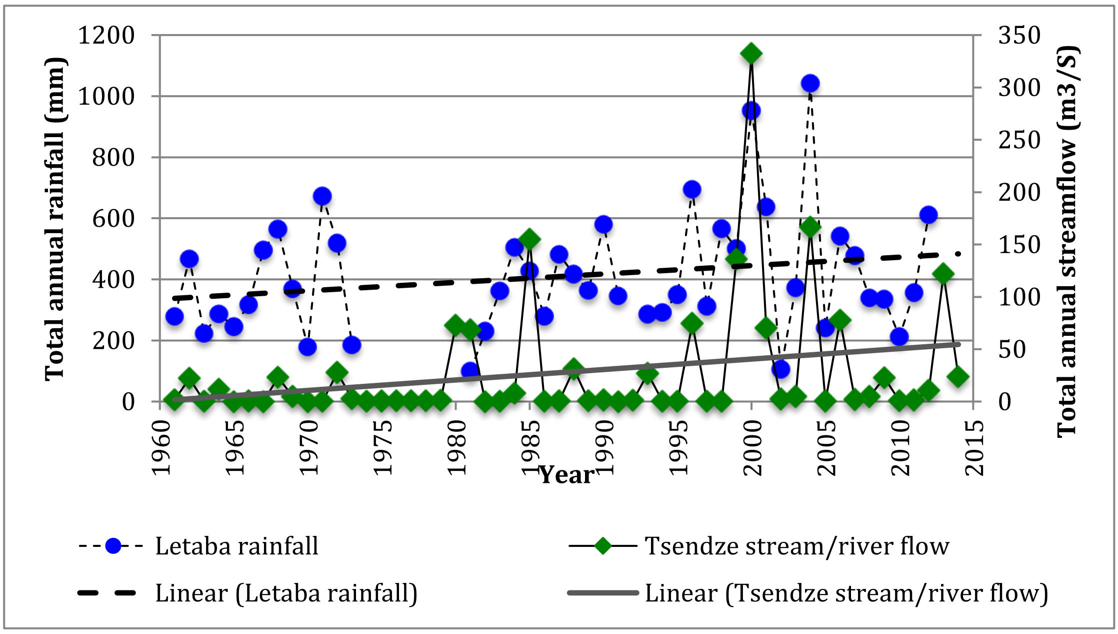


Figure 6.2 Relationship between Letaba rainfall and Tsendze streamflow

Impacts of extreme rainfall events like tropical cyclones and intense thunderstorms were evaluated to determine how rivers react after different rainfall events. Short intense rainfall events lead to spikes in river flow volumes, and flow for a much shorter time than when a river is exposed to long continuous rainfall. Rivers experience high flow levels for a longer period, up to 25% longer, than during intense rainfall events (*Table 5.42*).

Evaluation into the impacts of intense rainfall events on major KNP rivers is depicted in *Figures 5.64* to *5.70,* and it is noticeable that most flow is much longer after a long continuous rainfall event, then after a short intense rainfall event. Very little research has been done in terms of comparing river/streamflow responses to intense rainfall and long continuous rainfall. It can, however, be assumed from the findings that long continuous rainfall is better for river management as flow durations are continuous. Long continuous rainfall will also be beneficial to flora and fauna reliant on these river systems as a continuous flow of water allows for a more stable environment. While Intense rainfall, especially from tropical cyclones is erratic, and has detrimental impacts to river systems (Mallin *et al.,* 2002). Including the increased risk of flooding (Venter and Gertenbach, 1986) degradation of water quality, fish community displacement, erosion of river banks (Darby *et al.,* 2013), reduction of riparian vegetation (Chabreck and Palmisano, 1973), and the displacement of river sediments (Mallin *et al.,* 2002).

In South Africa, specifically KNP, one of the biggest floods on record was the result of tropical cyclone Eline in 2000 (Reason and Keibel, 2004). Eline was the longest-lived tropical cyclone observed in the southwest Indian Ocean, and occurred during a La Nina year (Reason and Keibel, 2004). The effects of the major tropical cyclones experienced in South Africa are mentioned in the *Literature Review (Chapter 3).* The impacts of tropical cyclones on KNP rivers are listed in images below.

Image 1: Flooding of the N'waswitshaka river during tropical cyclone Eline (Photograph taken by Joep Stevens, 2000)

Image 2: Devastation of flooding of the Sabie river, KNP, after tropical cyclone Eline (Photograph taken by Joep Stevens, 2000)

Image 3: Flooding of Lower Sabie river, KNP during tropical cyclone Dando, January 2012 (Photography taken by Dave Walker,

6.4.3 Precipitation Elasticity of Streamflow

Streamflow sensitivity to changes in precipitation are vital to the understanding of how climate and rainfall variability will impact flow regimes, which in turn will allow for better management and sustainability of water resources in the future (Chiew *et al.,* 2006). One way to determine the sensitivity of streamflow in relation to rainfall is by analyzing the precipitation elasticity of streamflow (Shaake, 1990; Chiew *et al.,* 2006; Kibria *et al.,* 2016). Precipitation elasticity of streamflow (ε_p), describes the "proportional change in mean annual streamflow divided by the proportional change in mean annual precipitation" (Shaake, 1990 in Chiew *et al.,* 2006: 256). For example, an elasticity of 3 would mean that a 1% change in precipitation would result in a 3% change in streamflow (Chiew *et al.,* 2006). Determining the sensitivity of streamflow to rainfall changes is beneficial for long-term climate analysis, and can be used in comparative analysis for streamflow trends across different regions (Chiew, 2010).

ε_p results for this study indicate that changes in precipitation are amplified in streamflow (*Table 5.38*). ε_p estimates ranged from 0.21 to 2.27, that is, a 1% change in mean annual rainfall results in a 0.21% to 2.27% change in mean annual streamflow. Chiew *et al.,* (2006) found that elasticity estimates generally ranged from 1.0 to 3.0. The areas with higher elasticity estimates included Australia and southern and western Africa. For this study, the average elasticity estimate was 1.54%, which corresponds with the literature (Chiew *et al.,* 2006; Kibria *et al.,* 2016).

A study conducted in America showed that 62% of results depicted elasticity estimates between 1.0 and 3.0 (Kibria *et al.,* 2016), 28% of the results were below 1.0, and this indicates that a change in rainfall has little to no effect on streamflow (Kibria *et al.,* 2016). There was an interesting finding showing that a station produced a negative elasticity estimate, which corresponds to a finding in this study, where Satara streamflow produced a -0.21 estimate in relation to Timbavati rainfall (*Table 5.38*). According to the literature, a negative elasticity estimate means that a 10% change in rainfall would amount, in this case, to a 2.1% change in streamflow (Kibria *et al.,* 2016).

Research into ε_p is widely conducted around the world, as it proved valuable to the literature, and knowledge of the impact of rainfall and streamflow. ε_p has been extensively research in America (Sankarasubramanian, 2001; Fu *et al.,* 2007; Kibria *et al.,* 2016), South America (Guimberteau, 2013), Ethiopia (Legesse, 2010), Australia (Chiew *et al.,* 2006; Chiew, 2010), China (Fu *et al.,* 2007; Yang, 2011; Zhou, 2015), and many more global studies (Chiew *et al.,* 2006). ε_p however is not widely studied in South Africa, and the literature regarding this impact on streamflow presents s knowledge gap. It would be very beneficial to analysis trends in ε_p for South Africa, and particularly KNP, as it allows for future projections of flow regimes, which is vital to water management.

6.4.4 El Niño Impacts on Streamflow

One of greatest natural drivers of river/streamflow variability is the El Niño Southern Oscillation, with significant impacts on southern Africa (Reason and Jagadheesha, 2004). El Niño creates drought conditions for most of Southern Africa, and more specifically KNP. Much of the literature around El Niño, its impacts on South Africa, and its links to rainfall and climate variability was discussed in *section 6.2.4* and so this section will cover the impacts of El Niño on streamflow for the study region.

Streamflow variability of KNP is depicted in *Figures 5.71* to *5.74,* where flow patterns follow a trend of wet and dry phases over time. Due to the moderate to high correlation between rainfall and streamflow, it is assumed that El Niño will have a direct impact on flow regimes in the park. In the northern KNP, El Niño was responsible for up to 50% of low flow years along rivers/streams (*Figures 5.71* and *5.72*), and the lowest recorded flow levels for Luvuvhu and Letaba were during El Niño events. In the southern KNP, El Niño was present in up to 46% of low flow years (*Figures 5.73* and *5.74*), and years where ENSO is present, streamflow volumes are below mean annual volumes by between

71% and 98%. During an El Niño phase, on average, KNP river/streamflow drops 82% below mean annual flow volumes. The years with the lowest flow volumes are 1982/1983 with a 96% deviation from total mean annual flow, and 1991/1992 with a 98% deviation.

An extensive amount of literature reviews the impacts of El Niño on rainfall variability in South Africa; however, little literature covers the impacts that El Niño has on river/streamflow regimes in South Africa. Australian climate is similar to that of South Africa, and El Niño impacts Australian rainfall and river/streamflow in a similar aspect to South Africa, and thus literature from Australia can be used to make links to the impacts El Niño has on KNP rivers. There is a strong link between low flow volumes in Australia and New Zealand, and the presence of El Niño (Chiew and McMahon, 2002). High river/streamflow variability is paired with El Niño events, and thus areas such as Australia and South Africa which experience high interannual flow variability, are more likely to be experiencing El Niño phases (Chiew and McMahon, 2002).

During the El Niño phases of 2002/2003, the middle Letaba River was only 0.5% full, and the Nsami dam in Mopani was only 15% full (Makana, 2013). This was a particularly extreme ENSO phase, and during this time period, KNP rivers dropped by 89% below average flow volumes.

One of the most intense and recent El Niño phases occurred in 2015/2016 in South Africa. This drought had a negative effect on the water resources of KNP, but little research has been done into this event, as it is so recent. The following images of water sources in KNP during the 2015/2016 droughts are indicative of the severity of this El Niño phase (Brassett, 2016).

Image 4: Effects of ENSO on the Mazithi Dam. Top image is what the Mazithi Dam looks like during a wet year, with good summer rainfall. The bottom image is the Mazithi Dam during the ENSO phase of 2015 (Photograph by Brassett, 2016)

Image 5: Effects of ENSO on the Nsemani Dam. Top image is what the Nsemani Dam looks like during a wet year, with good summer rainfall. The bottom image is the Nsemani Dam during the ENSO phase of 2015 (Photograph by Brassett, 2016)

6.5 Anthropogenic influences

6.5.1 Dams and Reservoirs

Only one of the Study Rivers had enough data to allow for the analysis of the impact dams have on flow patterns along the rivers. The Letaba River has three gauge stations along it that are indicative of flow levels for the section of the river that flows through KNP. One of the stations has a data set from 1960-2015, and the other two have data from that late 1980s till 2015. This allows for the analysis of three gauge stations at different downstream locations, which will give insight how dams influence downstream river/streamflow.

There are 20 dams along the Letaba River (Pramond, 2015) which allow for a consistent supply of water to the surrounding communities and their economic activities such as farming, agriculture, industry, forestry and mining (DWA, 2012). Streamflow of downstream Letaba River is dependent on the demand of water for irrigation, as demands from KNP to maintain flow volumes (Katambara and Ndiritu, 2009). Flow patterns of the Letaba were found to be 'complex' due to irregular flow releases from the major dam (Tzaneen), direct extractions of water from the river for irrigation, unmonitored surface-groundwater interactions, evaporation of water from rivers and unmonitored contributions of water supply from tributaries (Katambara and Ndiritu, 2009). The demand for water from the Letaba river is approximately 103.9 x $10^6 m^3$ for irrigation, 7.13 x $10^6 m^3$ for domestic and industrial use, and 18.9 x $10^6 m^3$ for ecological requirements (Katambara and Ndiritu, 2009).

The impacts of anthropogenic activities on this river system are noticeable in trends. Erratic flow patterns and moderate correlation with rainfall (between 0.17 and 0.62) suggests that external impacts on rivers are present. Due to restrictions in the lengths of data sets in relation to dates of dam construction, and dates of dam wall breach, it was not feasible to compare trends of river/streamflow before and after dam construction and dam wall breach. Therefore, the one way to analyse impacts of dams along the Letaba was to compare flow regimes for downstream stations before and after dam wall construction and/or breach under the same rainfall conditions.

Increased flow following the breach of the Black Heron and Shimuweni dams during the 2000 floods in KNP is evident at all three gauge stations (B8H008, B8H034 and B8H018). The increase in flow volumes after the dam wall breach rose between 21% and 902% (*Table 5.47*). It is evident that flow volumes along downstream Letaba were higher and more constant after the breach of the Black Heron and Shimuweni dams in 2000 (*Figures 5.75-5.77*).

The implications for the removal of dam walls has shown to not always have a 'positive' outcome. The investigation into dam wall removal/breach suggests that previously perennial rivers may change in nature to ephemeral flow. Ephemeral flow is defined as shallow rivers flowing with water for brief periods of time, but will be mostly dry for most the year, and only flow in response to rainfall events (Constantz and Essaid, 2007). This characteristic of river flow is not beneficial to the environment, or the species reliant on these rivers for survival. The change in river behaviour from perennial to ephemeral would have detrimental impacts on the spatio-temporal patterns of streamflow and habitats (Constantz and Essaid, 2007). Removal of dams will also impact groundwater resources, as the pumping of groundwater will need to be exploited to meet demands for irrigation and anthropogenic activities when river flow volumes are too low (Constantz and Essaid, 2007).

Although these dams provide certain socio-economic values, the re-evaluation of the benefits of these dams is been considered due to their impeding environmental impacts (Magilligan and Nislow, 2005). Ecological and environmental agencies are now pointing out the immediate need to remove many of these dams, with many NGOs and environmental agencies leading the removal of over 500 dams worldwide (Magilligan and Nislow, 2005). The removal of many dams, and the initiate to remove many more comes with the negative ecological effects that these dams have on river systems, by altering natural flow regimes, primarily through the changes in the timing, magnitude and frequency of high and low flow patterns (Nislow *et al.,* 2001; Gopal and Vass, 2013).

6.6 Implications of Results for the KNP- potential for future research

6.6.1 Implications of extreme climate and variability for the KNP ecosystem

Societies around the world have become more vulnerable to changes in the climate and extreme weather due increased population and infrastructure (Easterling *et al.,* 2000). Populations situated along water sources such as rivers, downstream from dams, and along the coast, are susceptible to rising sea levels, flooding and storm damage in the event of intense rainfall events and extreme storm events (Easterling, *et al.,* 2000).

Many regions in South Africa will be impacted in many ways by changing climates; the Kruger National Park is one area that is susceptible to changes in rainfall, temperatures and atmospheric carbon dioxide. These changes are projected to enhance bush encroachment in the Savanna regions (Wigley *et al.,* 2009). Climate will therefore not only impact the river and water resources of the park, but also the population dynamics of the flora and fauna. Protected areas in South Africa- specifically KNP will also be threatened by invasive alien vegetation. This transformation of the landscape will threaten all indigenous animals in these parks as these animals are dependent upon displaced indigenous plants for their survival (Griffin, 2012). Further information regarding the implications of climate and rainfall changes for KNP is covered extensively in *Section 3.2* and *3.3*.

6.6.2 Future Trends

Analysis into future climate changes, especially changes in rainfall and temperature have gained much attention over the years. The study into these changes is vital to the sustainability of the environment, as well as to map areas of high risk for water shortages and increased temperatures for farming communities and areas with a high population. The Global Circulation Model (GCM) has predicted, that whilst some northern parts of southern Africa may receive more rain over the next years, the southern regions of Africa such as South Africa and Mozambique will in fact become drier over time, (Christensen *et al.,* 2007; Engelbrecht *et al.*, 2015). Southern Africa is expected to become drier according to most studies, and climatic projection models, whereas

Western Africa is expected to become wetter. This finding is linked directly to the ENSO phenomena, where southern Africa experiences drought and western Africa experiences increased rainfall. Southern Africa will be impacted more substantially as this area is mostly semi-arid, and this semi arid region in Africa is predicted to experience increases in temperature by 6-7^{o}C, whereas the global average increase in temperature is expected to range between 4-5^{o}C (Engelbrecht *et al.*, 2015).

Increases in temperatures, paired with more sparse rainfall events, means that southern Africa is expected to experience more frequent and intense periods of drought with drastic increases in the amount of 'high-fire' days (Engelbrecht *et al.*, 2015). This will be detrimental to water resources and agriculture in southern Africa (Engelbrecht *et al.*, 2015).

Projected climate change in southern Africa not only has a potential impact on the environment, but also on humans. Decreased frequency of rainfall, and increases in temperatures impacts crop yields, livestock farming and human disease (Baleta and Pegram, 2014). In South Africa, the extreme rainfall events in general are projected to increase in the Summer and Spring months, and decrease in the Autumn months (DEA, 2013), however, rainfall trends in general do not show any significance, which corresponds to what was found in this study. With rainfall trends being non-significant, but rainfall days showing a significant decrease in the future, it supports evidence for an increase in the frequency of extreme rainfall events (High bursts of intense rainfall, sporadically).

In Zone One of South Africa, which is mainly the region of Limpopo and northern Mpumalanga- relevant to this study, rain days are projected to decrease mainly in the summer season, but show an increase in intense rainfall events. Projections also show a high interannual and inter decadal variability of rainfall for this region. Lastly, extremely hot days are projected to increase significantly in the summer and spring months (DEA, 2013).

Very little research has looked into how future rainfall and temperature projection will impact the rivers that flow through KNP. This gap in the literature opens up for potential future research, and this topic is hugely beneficial to KNP, and its surrounding areas. Water resources are such an integral part of the KNP ecosystem, without which the functioning of the park would be compromised. For many other regions, where projections have been made, the state of the rivers in the future are threatened due to such significant changes in rainfall patterns and temperature indices. Decreases in rain days, increases in temperatures, and increases in evapotranspiration will lead to higher demands in water due to higher irrigation requirements for agriculture (Gondim *et al.,* 2009).

Chapter Seven: Conclusions

7.1 Introduction

The study of climate change, and specifically rainfall trends is becoming an increasingly significant body of work among researchers worldwide. Rainfall trends and projected rainfall models are meaningful in determining future rainfall projections (van Wilgen *et al.,* 2015). Climate changes over recent decades have had a direct impact on the environment, specifically flora and fauna (Thomas *et al.,* 2004). Climate studies have the potential to allow for observation and a clearer understanding of the variability of the earth's climate system and its responses to anthropogenic and natural climate change impacts (Moss *et al.,* 2010). Studies into changing climates and climate indices allows for the mitigation and adaptation of people and the environment to cope with projected climate changes, and to prepare for better management of natural resources such as freshwater. Climate research is particularly important for the management and sustainability of national parks around the world. The research into projected changes in rainfall and temperature proves valuable to resource and park managers as it highlights future threats to the ecosystems, which directly impact the species of the park (van Wilgen *et al.,* 2015). Research into the impact of changing rainfall on streamflow quantities, and anthropogenic impacts on river water quality, is imperative for the management and conservation of protected areas and their flora and fauna (Pollard *et al.,* 2011).

Within this context, the primary aim of this study was to contribute to establishing rainfall and river flow characteristics over time in the Kruger National Park and adjacent higher lying catchment regions. Through the analysis of rainfall variability and river flow trends within and outside KNP, this study contributes to the improved understanding of how susceptible river flow is to changes in climate. Rainfall trends have a direct impact on river flow trends, and studies into these future trends and variability will help in the management and conservation of these natural resources in KNP. Furthermore, this study provides information, which can assist in maintaining freshwater resources within the park, and the relative impacts rainfall variability has on river flow throughout the park.

This chapter integrates the key findings of the study. It first establishes the extent to which the aims and objectives have been achieved, and highlights some of the primary outcomes. Finally, a summary of findings will be explored with mention of potential future research.

7.2 Achievement of Study Aims

The main objectives to this study involved the analysis of rainfall data over the long term (1920-2015) and the nature of the relationship between rainfall and river flow (1960-2015), whilst exploring differences in rainfall variability and trends across the park. The extent to which each study objective has been achieved will be discussed in the order in which the objectives are outlined in *section 1.3.*

1. *To establish and compare rainfall patterns over the past six decades for the KNP.*

This aim required the analysis of daily rainfall data from all 21 weather stations. Some rainfall stations provided very rich data sets dating back to at least 1910, and thus proved valuable to the observation of rainfall trends over the past century. To achieve this aim, the rainfall stations were divided into four different regions, notably the northern bushveld, northern lowveld, southern bushveld and the southern lowveld. The rainfall trends of each region were depicted. Although all regions depicted insignificant trends in rainfall for the longer period (1920-2015) as well as the shorter time period (1970-2015), all regions showed significant variability in rainfall, increases in extreme rainfall days and drier rainfall seasons, with noticeably shorter rainy seasons. These findings agree strongly with similar research done by van Wilgen *et al* (2015) in KNP and other SANParks national parks, South Africa. Rainfall trends were not significant, but were influenced by extreme events.

Rainfall amounts differed from the north to the south, with the south receiving more annual rainfall than the northern KNP. These findings were expected as the literature has found a definite rainfall gradient between the northern and southern KNP (Gertenbach 1980). Rainfall also decreased from the bushveld regions to the lowveld regions. This was expected, as rainfall is known to progressively decrease from the west to the east, the further east one travels from the escarpment (Gertenbach, 1978). One of the most interesting findings regarding the north-south divide of KNP rainfall was that the northern KNP recorded a higher interannual rainfall variability (41%), than the southern KNP (29%).

2. *To correlate changes in interannual rainfall variability over the past five decades with changes in interannual streamflow variability.*

Trend analysis was used to determine if there were any significant trends in the flow data over the period of study. It was evident that river flow was alternating between wet and dry periods. The variability of river flow was apparent and is directly linked to the impact of extreme weather conditions such as tropical cyclones and drought. The variability of river flow for all rivers was high, producing variation (CV) values between 19 and 375%. The correlation between rainfall and river flow was surprisingly not as high as previously expected. The highest correlation between rainfall and river flow was for Tsendze gauge station and Letaba rainfall station. The high correlation is linked to the fact that the Tsendze river originates within the park boundary and is thus not impacted by external anthropogenic activities. Low and negative correlations are suggested to be linked to anthropogenic impacts of rivers from activities occupying adjacent lands such as agriculture, mining and industry.

The impact of different rainfall intensities on river flow was then explored, and it was found that long continuous rainfall events led to longer river flow durations when compared to short intense bursts of rainfall. The average number of days of flow following a continuous rainfall event was 36% longer than average flow days following an intense rainfall event. Long continuous rainfall events also resulted in 27% longer flow than flow after a tropical cyclone event. Rivers thus have a much longer flow behaviour following a continuous rainfall event than a short intense rainfall event. This is to be noted for future trends as the research suggests extreme rainfall events are increasing in frequency, which suggests short intense bursts of river flow.

3. *To establish the effects of specific climatic phases (El Niño Southern Oscillation) on streamflow in KNP.*

El Niño has a direct impact on the flow patterns of KNP rivers. River flow is variable in all rivers analysed, however, El Niño phases accounted for nearly half of the low flow years for each station. During the most intense El Niño phases, the river flows were at their lowest, showing the greatest deviations from the annual mean. For example, along the southern KNP rivers, the most intense El Niño years (1972/1973 and 2002/2003) resulted in flow levels recorded at 89 and 90% below annual mean flow respectively. There is a direct correlation between low flow recordings and El Niño phases. El Niño phases are projected to become more intense in the future, which poses a threat to the integrity of KNP rivers.

7.3 Management Initiatives for Future Water Conservation in Kruger National Park

The provision of hydrological monitoring in relation to natural riverine ecosystems has implications for the management of important conservation areas. The extensive knowledge of the interaction between climate and freshwater corridors in semi-arid areas could benefit management strategies (Conrad and Raucher, 2013). National Parks and protected areas, not only in southern Africa, offer a precious landscape in which environmental monitoring can take place for the improvement of management strategies and future planning (Fancy *et al.*, 2008). Hydrological modeling is useful as a management tool for future water resource conservation, as it allows for national parks to plan for climatic conditions projected as well as implement strategies now, which will benefit future water resources and riverine ecosystems. Planning now for the future will not only enable access to water resources in future, but will also guarantee the natural restoration of habitats that are dependent on rivers for their health (Erwin, 2009).

It is essential that management monitor river dynamics in relation to 'normal' and 'extreme' climatic scenarios. A study conducted by DWAF (2009) along the Orange River, highlighted that environmental monitoring, especially in terms of such stressed resources; needs to be scrutinized to benefit future planning. Monitoring natural resources such as rivers will allow for goals of water resource management to be met in a certain region (DWAF, 2009). Environmental planning requires "monitoring of water resource quality to be an integral part of water resources management in South Africa" (DWAF, 2009: 6), thus continuous research into these resources is essential.

To manage the increasing concerns regarding the state of the KNP perennial rivers, the Kruger National Park River Research Programme (KNPRRP) has been initiated (Pollard *et al.,* 2011). The KNPRRP addresses the major concerns that encompass water quality and quantity issues of the perennial river systems in KNP. The KNPRRP has highlighted that the implementation of the 1998 Water Act has proven beneficial to the lowveld regions of the rivers that flow through the park (Pollard *et al.,* 2011). The Water Act of 1998 re-oriented the provisioning of water management at a catchment level in South Africa, with consideration from stakeholder participation. This water act states that there must be a balance between water use to sustain basic human needs but the sustainability of the water source itself needs to be just as high a priority (Pollard, *et al.,* 2011). The KNP encompasses three water management areas viz. Inkomati, Olifants and Luvuvhu-Letaba. The initiation of this new water act has been beneficial to the KNP as there is a precedent for the conservation of water resources, and there is now a high level of participation on the conservation sector (especially KNP), which thus gives KNP a much stronger voice than they previously had (Pollard *et al.,* 2011). This new water act will allow for the sustainability of water along these main perennials rives, that are not protected by the boundaries of KNP, and will thus allow for better management and improvement of these water resources before they flow through the park (Pollard *et al.,* 2011).

It is imperative that KNP rivers are managed successfully in future. The quality and quantity of water in KNP rivers has previously been directly linked to tourism revenue (Turpie and Joubert, 2001). Visitors to KNP rated the quality of river water of great importance when they visit the park. Four qualities of rivers were named in this study, with tourists directly linking the quality of river water to the number of hippos and crocodiles in the rivers, the number of waterbird species present, the diversity of the river landscape and the density of riparian vegetation. The potential for decreased water quality and volume would therefore alter animal biodiversity in and adjacent to these rivers, which would negatively impact tourism in the park (Turpie and Joubert, 2001).

7.4 Recommendation for Future Research

This research focused on the broader aspect of how rainfall variability might impact on KNP river flow over time. The first recommendation is that there are opportunities for studies at much more detailed scales. Observations of rainfall trends can be done at a catchment scale, or even a river scale. Focusing on the impact of rainfall on one river will open the opportunity to evaluate exactly how rainfall affects a specific river system at different levels of the river system. By evaluating river flow at source, and determining how flow is impacted by different anthropogenic impacts would help in determining the extent to which anthropogenic land use activities impact rivers, and how downstream flow is altered due to these differing water extraction/abstraction points. Research into the extent to which anthropogenic activities alter downstream flow is crucial in planning for future water requirements.

Secondly, this research can be used to help in future studies, particularly those that consider future climate and rainfall scenarios for this region. The changes that have occurred over the past century suggest that rainfall is shifting to a more variable and extreme pattern, and this will have serious implications for the future of the environment and the people of South Africa. It is thus imperative to research exactly how rainfall is predicted to change, and to what extent it is expected to change and shift over the next few decades. It will allow for adaptation and mitigation strategies to be implemented to deal with upcoming changes and to manage natural resources for the considered changes. It is important to focus on projections, but it is also just as important to focus on what is happening right now in KNP. This study, together with the study conducted by van Wilgen *et al* (2015), suggest that future research is to focus on: (a) the impacts of temperature and rainfall changes in the park, and what these changes mean for water resources and the flora and fauna which depend on these water sources; (b) the impacts of a drying climate on the park and its rivers; (c) the implications of more frequent flooding events in the park and how these events will impact the infrastructure of the park, in particular the camps and roads and (d) the research and monitoring of land use changes on river flow regimes of KNP.

7.5 Conclusion

The research aimed to explore rainfall and river flow patterns of KNP and surrounding areas, to determine trends in rainfall over the past 50-100 years and to determine patterns in river flow for the past 50 years. Although there was no detection in absolute change in annual rainfall for the lowveld and surrounding bushveld, there was an indication of increased rainfall variability, with increases in extreme rainfall events, and more severe El Niño phases. Rainfall seasons are becoming shorter, which suggests that the climate is becoming drier, which will have implications on river flow in the park and the flora and fauna that rely upon these natural resources. This research proves valuable for future research into how exactly these changes over the past decades will indicate changes to come over the next few decades, and what exactly this implies for KNP, its water resources and the ecosystem. If mitigation and adaptation strategies are not implemented at management level, there will be implications for the future integrity of KNP rivers. Further research into anthropogenic impacts paired with climate change impacts on these rivers will allow for an extensive evaluation on how to best manage the water sources of KNP.

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