Analysis of hydrological drought risk characteristics using Standardised Precipitation Index in the Free State Province

By

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DECLARATION

I, Mampshe Sunnyboy Nkgudi hereby declare that the work in this dissertation is the original product of my own efforts. All sources used and discussions made have been acknowledged with complete references. This work is submitted in partial fulfilment of the Master in Disaster Management and I also declare that this work has never been submitted in any form or anywhere else for any degree.

Signature ___________________________ Date ___________________

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My grandmother, Maselale Leshalabe (Mahlako) who made all efforts to ensure that I go to school when I was still young; her efforts paved a way for my journey in education, and eventually shaped my life to what it is today, thank you granny - *may your soul rest in peace*.

My parents, after whom my daughter and son are named, are special people in my life - Where will I be without them? What would I have become? I love them so much; a big thank you to them for continuous encouragement and support throughout this work.

To God Almighty, your grace is abundant, especially, for those who seek it. I thank You for Your unconditional love and Your grace, before this study, during this study and forever.

DEDICATION

This work is intended to inspire my children, Moruleng and Mokgadi Nkgudi who were, at the beginning of this work still in high school and first year, respectively. This work is dedicated to them.

ABSTRACT

Drought is a natural hazard that impacts negatively on human life and on ecosystems. Drought has a creeping phenomenon, making it difficult for early detection. Free State Province is a food basket of the Republic of South Africa. The province is prone to drought whilst at the same time it produces agricultural products and is a mass producer of grain in South Africa. This study used higher temporal scales of Standard Precipitation Index to analyse the risk characteristics of hydrological drought in the Free State Province of the Republic of South Africa. Secondary data was extracted for the five sampled meteorological stations in the province from NASA online databases. Quantitative methodology was used to analyse the secondary data in order to make findings.

The main aim was to analyse pattern trends of rainfall, identify the hydrological drought, return periods, as well as determining the intensity and duration of hydrological drought with the intention to make recommendations as well as to provide an early warning to water resource managers, water users, farmers and agribusiness to take proactive measures against hydrological drought risks. The study found that, the rainfall is averaged to less than 430mm across all five sampled meteorological stations during the study period. Severe to extreme hydrological drought events frequented the province with 2014 occurrences exposing the agricultural products, environment and other water end users to harm.

The persistent nature of hydrological drought in this province is a worrying factor because livelihoods and ecosystems are negatively impacted. The researcher strongly recommends a controlled borehole drilling to be implemented whereby the local authority remains the custodian of this function through the help of hydrogeologist; this is in order to allow groundwater resources opportunity to recharge. Notwithstanding the fact that farmers are constructing artificial dams for water harvesting purposes, water harvesting should be made fashionable and where possible be incorporated into building designs where rainwater would be collected into above and below ground tanks for household and small-scale irrigation purposes, but not for human consumption unless accordingly treated.

KEY WORDS: Standardised Precipitation Index, Hydrological drought, Risk characteristics Water Resource Management

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LIST OF ACRONYMS AND ABBREVIATIONS

SPI	: Standard Precipitation Index
DETEA	: Department of Economic Development, Tourism, Environmental Affairs
DAFF	: Department of Agriculture, Forestry and Fisheries
DWA	: Department of Water Affairs
DRINC	: Drought Index Calculator
FAO	: Food and Agricultural Organisation
GAR	: Global Assessment Report
GWP	: Global Water Partnership
IDMP	: Integrated Drought Management Program
IPCC	: Intergovernmental Panel on Climate Change
IWRM	: Integrated Water Resource Management
KPI	: Key Performance Indicators
NASA	: National Aeronautics and Space Administration
NOAA	: National Oceanic and Atmospheric Administration
NDMC	: National Disaster Management Centre
NDMF	: National Disaster Management Framework
NDP	: National Development Plan
UNISDR	: United Nations International Strategy for Disaster Reduction
UNDRR	: United Nations Office for Disaster Risk Reduction
UN	: United Nations
WHO	: World Health Organisation
WMO	: World Meteorological Organisation
WRM	: Water Resource Management

CHAPTER 1: STUDY OVERVIEW

1.1 INTRODUCTION

Drought is a natural hazard and is defined as a temporal reduction of moisture availability, significantly below the normal, caused by decreased and lack of precipitation, over a specified period . The reduction of moisture has a negative bearing on the different forms of water, namely, surface water, stream flow which includes snowmelt and spring flow, lake and reservoir levels, and ground water level. Of the four categories of drought, this study is focused on hydrological drought and the characteristics of its resultant risk, in the Free State Province. Nalbantis defines hydrological drought as a "significant decrease in the availability of water, in all its forms, appearing in the land phase of the hydrological cycle" (Nalbantis 2009). This simply means that, for a hydrological drought to take place, two other categories, namely, meteorological and agricultural drought has to happen and all three manifest into a socio-economic drought. Hydrological drought is further attributed to change in climate, the decreased and lack of precipitation, human activities as well as overexploitation of surface water resulting in depletion of ground water resources (Van Loon and Van Lanen 2013). Therefore, water resources management is a key in this regard.

The Free State Province has experienced drought in the past years. This study used statistical analysis to, among others, analyse the rainfall pattern in the Province, to identify hydrological drought, to determine intensity, and frequency of hydrological drought and at the same time, to provide an early warning, in order for farmers, water resource managers and all other water users to take proactive measures against hydrological drought and its impacts. Water use is a critical and sensitive commodity for human life by virtue of the fact that, too much of it causes floods and shortage of it causes drought. The Standard Precipitation Index was, therefore, used in this study to determine the hydrological drought and the its extent, through analysis of the secondary data, so as to come up with findings.

1.2 SIGNIFICANCE OF THE STUDY

Free State Province boasts of more than 30000 farms, making it the only Province in the Republic of South Africa with vast agricultural land for crop and agricultural production as well as animal farming. According to the Free State Department of Agriculture and Rural Development (2017), the Province produces more grain compared to many other provinces, making it one of the biggest contributors to food security in the country, (DAFF 2019). The main aim of the current study was to analyse hydrological drought risk characteristics for water resources management projects in the Free State Province using high temporal scales of Standardised Precipitation Index (SPI). The findings of this research will contribute to a wide research spectrum of knowledge with regard to hydrological drought; the recommendations will minimise the severity of the hydrological drought impacts that would be meted out to water-resource projects, businesses, agribusinesses, livelihoods of the residents of the Province, as well as the whole populace of the country. The findings would be made available to agribusinesses, water management authorities, government, Non-Governmental Organisations (NGOs), as well as any other interested persons.

1.3 PROBLEM STATEMENT

The world over is faced with drought, which is a natural hazard and threating to human life and to the environment. Africa, as an arid and mainly semi-arid continent, is at high risk, this is due to the fact that economic activities and subsistence are dependent on agriculture. The Free State Province is a breadbasket of South Africa because of the large scale agricultural activities. Just like any other economic activity, agriculture is also highly dependent on water. According to Hisdal and Tallaksen (2003) water shortage causes a significant threat to nature, environment, economy as well as the quality of life. The demand on available water resources is increasing day by day and has led to water users conflicting and competing among themselves for this scarce commodity. This notion is further supported by Sphere Association (2017) identifying water availability as a minimum standard for human life because of the integral part water plays in supporting human life. Shortage of water usually leads to unfavourable medical conditions, as well as unhygienic and unsanitary complications.

According to AgriSA (2020), as a result of drought, the farmers in the Free State Province have seen lower agricultural yields, because they had to start planting late, they also had to change planned-planting commodities. Farmers have had to cut jobs of their farm workers, hence, causing high stress levels for themselves and their workers.

Notwithstanding the slow onset of drought, with hydrological drought, there is a need for early detection, monitoring and prediction. World Meteorological Organisation recommended Standard Precipitation Index as a drought index of choice to be adopted by all nations. The Free State Province in the Republic of South Africa has recently experienced drought events throughout the study period as well as in years 2014, 2015 and 2016, whereby it produced, among others, less maize of 3.9 and 2.2 million tons in 2015 and 2016 respectively. The Province also produced less wheat of 2.5 and 1.7 million tons in 2014 and 2015 respectively, exposing the province and the country to potential impacts of drought (DAFF 2019). Hydrological drought is the worst form of drought, and it persists after agricultural drought. The current study assesses hydrological drought risk characteristics in the Free State, one of the province in the Republic of South Africa. The study aimed to review existing literature and analyse secondary data to enable the researcher to determine drought risk characteristics, rainfall patterns, frequency and intensity of drought, by making use of SPI as a drought index. The analyses and the findings will provide relevant decision makers with relevant information to improve systems and to design early intervention mechanisms so that the hydrological drought risks impact are better mitigated in the study area. The researcher, therefore, undertakes the use of SPI to analyse risk characteristics associated with hydrological drought in the Free State Province.

1.4 OBJECTIVES OF THE STUDY

The objectives of this study are divided into main objective as well as sub-objectives. Main objective and sub-objectives are discussed and illustrated below.

1.4.1 Main objective

To utilise SPI to analyse hydrological drought risk characteristics in the Free State Province of South Africa.

1.4.2 Sub-objectives

- To analyse pattern trends of rainfall in the study area;
- To identify hydrological droughts' return periods;
- To determine the intensity and duration of hydrological drought;

- To provide an early warning system to water-users, farmers and agribusinesses to take proactive measures against hydrological drought risks.

1.5 RESEARCH QUESTION

What are the drought risk characterisation of the hydrological drought, in the Free State Province of the Republic of South Africa?

1.5.1 Sub-questions

- What is a hydrological drought?
- What is Standard Precipitation Index (SPI)?
- What are hydrological drought characteristics?
- What are rainfall trends / patterns, hydrological drought return period and hydrological drought intensity?

1.6 DESCRIPTION OF THE STUDY AREA

The area of focus, in this study, is the Free State Province, one of the nine provinces in the Republic of South Africa. This Province share borders with Lesotho and six other provinces, namely, North West, Northern Cape, Gauteng, Mpumalanga, Eastern Cape and KwaZulu-Natal. The Province is the third largest of the nine, spanning approximately 129,825 km^2 of land area; it has the second smallest population and the second lowest population density of the nine provinces as well (Free State Department of Economic Development, Tourism and Environmental Affairs, 2014). The figure below is a map of South African with the layout of demarcated municipal areas of the Free State Province.

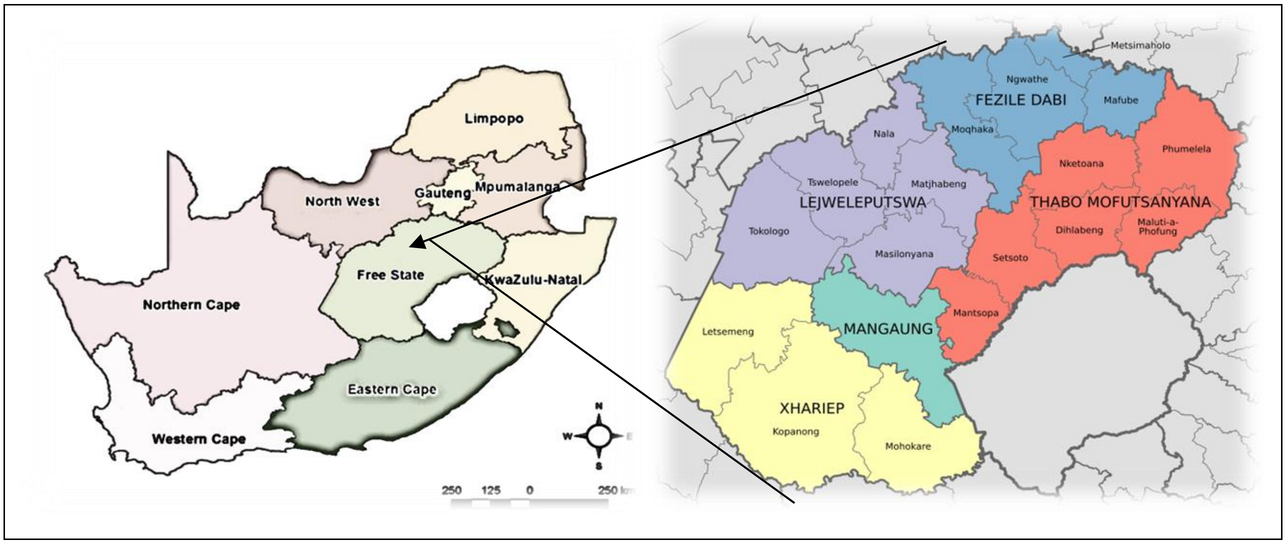

Figure 1.1: South African Map with municipalities in the Free State Province on far right

Source: Norval and Wright (2017)

According to Detea (2014), the Province is sub divided into “one Metropolitan Municipality and four district municipalities, namely, Mangaung Metropolitan Municipality and, Fezile Dabi, Xhariep, Thabo Mofutsanyane as well as Lejweleputswa District Municipalities”, respectively. Notwithstanding the fact that, the day-to-day life of every person and business depends on water availability, mining and agriculture are some of the economic activities that are most dependent on water. Free State Province contributes significantly to the agricultural economy of the country; for example, approximately 40% of the national maize production is from the Free State (DAFF 2019). The arable land covers about 3.2 million hectors, whilst natural veld and grazing cover about 8.7 million hectors, the total of these represent only 10% or less of the arable land under mechanical irrigation. Large scale agriculture and farming in the Province, inclusive of subsistence, small scale and emerging farmers are highly dependent on rainfall. Survival of livestock, crops and any other farming activity is also dependant on rainfall. The Province has vast agricultural land and produces more than 70% of the country's grain within its farms which are in excess of 30,000 in counting. The gross agricultural income in excess of two-thirds in the Province is made from field crop yields (Department of Agriculture and Rural Development 2018). Other than maize, the Province produces other agricultural yields, such as 53% of sorghum, 37% of wheat, 33% of potatoes, 30% of groundnuts, 18% of red meat, and 15% of wool (DAFF 2019).

Manufacturing also forms part of economic activity of the Province, being home to Sasol, one of the biggest synthetic fuel companies in South Africa.

1.7 RESEARCH DESIGN METHODOLOGY

Research methodology is defined as “the study of the logic or rationale underlying the implementation of the scientific approach to the study of reality, a theory of correct scientific decisions” (Mahlangu 1987:3-4). Saunders, Lewis, and Thornhill (2009), accordingly refers to methodology as the theory of how research should be undertaken, including the theoretical and philosophical assumptions upon which research is based and the implications of these for the method or methods adopted. It is illustrated by these definitions that methodology encompasses research design methods, which, for this study, was the quantitative method; this is because the study is based on secondary data that is freely available from NASA online database. Five meteorological stations in the Free State Province were sampled; data was extracted from their databases, tested for homogeneity and analysed by making use of excel and other statistical software packages in order to make findings.

1.8 ETHICAL CONSIDERATION

The data is freely available from the NASA online databases, therefore, the researcher only needed to apply for an ethical clearance from the University of Free State. The clearance was granted with the following number: UFS-HSD2020/0742/306

1.9 SUMMARY

Conclusions were derived from the findings to see if the research questions had been answered; the findings from the research and the researcher’s recommendations to the community, authorities, non-governmental organisations, water-resource managers and other interested stakeholders formed the last sections

1.10 STRUCTURE OF THE DESERTATION

As illustrated in Table 1.1 below, the dissertation is partitioned accordingly into five chapters. Chapter one introduces the problem statement, the research objectives, the research questions and the study area. Chapter two discusses the literature review of published and unpublished work of other researchers. Chapter three focused on the research design and methodology. Chapter four focuses on data analyses and Chapter five is about conclusions and recommendations.

Table 1.1: Structure of the dissertation

Chapter	**Title**	**Content**
1	Study overview	This chapter provides the reason for the research. It underlines the background of the study area in relation to the problem statement. The objectives of the study are outlined here to indicate how they will answer the main research question.
2	Literature review	Literature review focusses on the views of other researchers pertaining to hydrological drought. In this chapter, literature related to definitions, drought impact, drought characterisation, legislative framework, drought indices were looked into. A review of literature is compulsory, as research is continuous; it is evolving, therefore, an analysis of the views of other researchers, and their findings are equally essential and relevant. The review in this instance offered a justification for the research.
3	Methodology	The research tools for data collection are discussed in this chapter. Means and procedure of data validity, reliability and analysis are also discussed here. The advantages and disadvantages of chosen methods of data collection in relation to the study area, ethical considerations are also important; for primary data, among others, consent, confidentiality must be taken into considerations, therefore, permissions must be sought by the researcher. In this study, the study required the University's clearance certificate because only freely-available secondary data was used.

4	Data analyses	Statistical methods as well as software packages are used for data and trend analysis and these are presented in this chapter.
5	Conclusions and recommendations	This chapter concludes the research and the findings thereof are presented herein and recommendations are made.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

Droughts are risks that are threatening the livelihood of the human species; in fact, the world's ecosystem is at risk as the human species' existence depends on the existence of different aspects of the ecosystem. The study is about analysis of hydrological drought using SPI, hence drought is one of the potential impacts of climate change. Climate change is a potential threat to human life, environment and nature at large; this is associated with raising global temperatures, whereby, "temperatures are due to rise by 1.5°C to 3°C by 2050" (Collier, Conway, and Venables 2008; Gemeda and Sima 2015). The United Nations Framework Convention on Climate Change (UNFCCC) defined 'climate change' as "a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods" (UNFCCC, 2007b, p. 2).

Even though the whole world is faced with the challenges related to extreme weather patterns due to climate change, Africa is said to be more vulnerable than all other regions, since the anticipated impact, could be extreme (Clements 2009). Africa is ranked the lowest in greenhouse gases emissions due to low industrialisation; however, Africa is still anticipated to bear the full impact of climate change, (Gemeda and Sima 2015).

The global impact of climate change include extreme weather patterns, disturbance of ecosystem and biodiversity and poor socio-economic conditions. The impact of the extreme weather patterns and climate change on the African continent, will be dire. The impact includes drought, floods, acidic oceanic water, decrease in rainforest precipitation and threatened food security.

Floods and drought have been experienced in South Africa due to the recent weather incidents that are taking place, however, of interest to this study, is the drought situation, which has been felt in the country in the previous years, particularly in the provinces of Western Cape, Free State and North West. These provinces are agricultural food baskets of South Africa (Botai et al 2016); hence, droughts in these places threaten the livelihood of South Africans, Africans and the export world, in general.

Due to decreased rainfall, droughts might befall the mentioned areas. Droughts due to their creeping nature, might evolve, unnoticed, through all categories of drought until it reaches the hydrological drought category, hence, the analysis to identify, early, the risk characteristics of a hydrological drought, using the Standard Precipitation Index (SPI) in the study area.

2.1.1 Hydrological drought

The definition of hydrological drought relates to the insufficient ground water measured by lakes and reservoir levels, surface water, as well as stream flow. Nalbantis and Tsakaris (2009) define hydrological drought as the significant decrease in availability of water, in all its forms, appearing in the land phase of a hydrological cycle.

Some definitions of drought will help us understand this drought phenomenon. World Meteorological Organisation (WMO) acknowledges that, there is no definite definition of drought (Handbook of Drought Indicators and Indices 2016). It is, however, accepted that a drought is a condition of insufficient moisture caused by a deficit in precipitation, over some time period (McKee 1993).

The four drought categories are as follows:

i. Meteorological drought
ii. Agricultural drought
iii. Hydrological drought
iv. Socio-economic drought

It appears that due to varying definitions of individual category, definition of drought is, therefore, dependent on the nature of a drought, at a given time period; for example, the meteorological drought is strictly related to the amount of rainfall or precipitation on a timescale. Agricultural drought, on the other hand, has its own definition relating to the agricultural crops not receiving water due to insufficient precipitation or a lack thereof. Socio-economic drought takes place as a result of the economic difficulty from insufficient precipitation to sustain agricultural crops.

Economic, social and environmental impacts are the direct results of a hydrological drought, hence, the need for the use of Standard Precipitation Index (SPI) to analyse the risk characteristics of the hydrological drought. The progression of drought is such that, the end result is the hydrological drought; Figure 2.1 below illustrates the sequence or progression of drought and the after effects of water deficiency for three types of droughts.

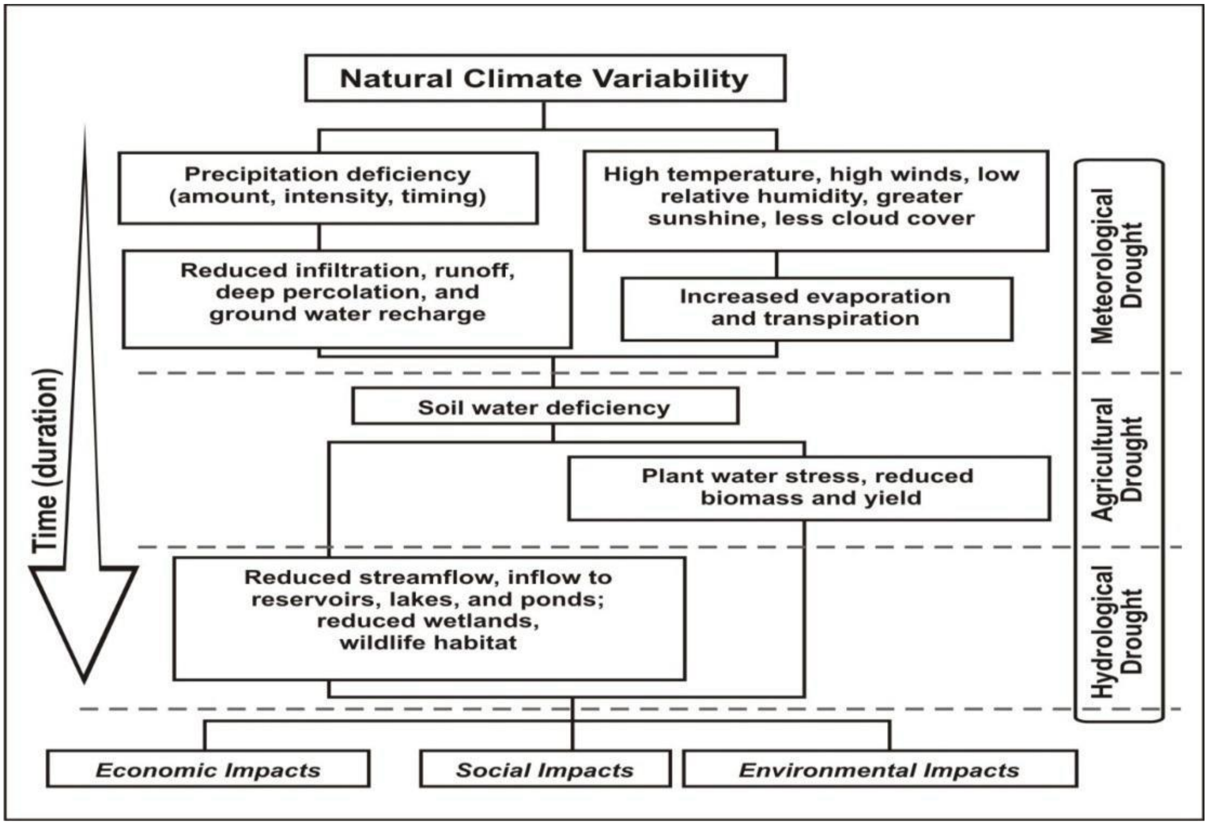

Figure 2.1: Progression towards hydrological drought

Source: (NDMC 2000).

South Africa has experienced drought in several provinces in the past years. Of interest, to this study, is the drought that befell the Province of Free State over the years of study period. The impact was felt in the farming communities of Free State Province (Botai et al. 2016).

2.2 DEFINITION OF TERMS

2.2.1 Drought

Drought is defined as a temporary reduction of moisture availability which is significantly below the normal, within a specified period.

2.2.2 Climate

This is statistical information, a synthesis of weather variation focusing on a specific area for a specified interval. Climate is usually based on the weather in one locality, averaged for at least 30 years.

2.2.3 Climate change

"Climate change refers to a change in the state of the climate that can be identified (for example, by using statistical tests) due to changes in the mean and/or the variability of its properties, and which persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use" (IPCC 2007).

2.2.4 Standard Precipitation Index

This is used to describe an extremely dry or wet weather situations, over a set period of time.

2.2.5 Precipitation

This can simply be defined as the amount of rainfall.

2.2.6 Vulnerability

These are the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards (UNISDR 2016).

2.2.7 Capacity

"The combination of all the strengths, attributes and resources available within an organization, community or society, to manage and reduce disaster risks and strengthen resilience" (UNISDR 2016).

2.2.8 Disaster

A serious disruption of the functioning of a community or a society, on any scale, due to hazardous events interacting with conditions of exposure, vulnerability and capacity; and leading to one or more of the following: human, material, economic and environmental losses and negative impacts. (UNISDR 2016)

2.2.9 Disaster management

This means a continuous and integrated multi-sectoral multi-disciplinary process of planning and implementation of measures aimed at (a) preventing or reducing the risk of disasters; (b) mitigating the severity or consequences of disasters; (c) ensuring emergency preparedness; (d) providing a rapid and effective response to disasters; and (e) facilitating post-disaster recovery and rehabilitation (NDMC 2016)

UNISDR defines disaster management as the organization, planning and application of measures preparing for, responding to and recovering from disasters (UNISDR 2016).

2.2.10 Disaster impact

This is the total effect, including negative effects such as economic losses and positive effects such as economic gains of a hazardous event or a disaster. The term includes economic, human and environmental impacts, and may include death, injuries, disease and other negative effects on human physical, mental and social well-being (UNISDR 2016).

2.2.11 Early warning

An integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities, systems and processes that enable individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events (UNISDR 2016).

2.2.12 Hazard

A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation (UNISDR 2016)

2.2.13 Disaster Risk

The potential loss of life, injury, or destroying or damaging of assets which could occur to a system, society or a community in a specific period of time, determined, probabilistically, as a function of hazard, exposure, vulnerability and capacity (UNISDR 2016).

2.2.14 Mitigation

The term 'mitigation' means the lessening or minimizing of the adverse impacts of a hazardous event (UNISDR 2016).

2.2.15 Resilience

This refers to the ability of a system, community or society exposed to hazards, to resist, absorb, accommodate, adapt to, transform and recover from the effects in a timely and efficient manner; these include the preservation and restoration of the essential basic structures and functions, through risk management (UNISDR 2016).

IPCC further defines resilience as:

The capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganising in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation. (IPCC 2014).

2.3 IMPACTS OF DROUGHT

According to the Food and Agricultural Organisation of the United Nations (FAO), a drought is seen as a devastating hazard which occurs naturally, affecting a significant proportion of the global population, especially those who live in arid and semi-arid regions (FAO 2020).

The impacts of natural hazards are classified as direct and indirect impacts (Spinoni et al. 2016). Drought falls within the category of natural hazards, therefore, the impacts of drought would then be of either direct or indirect nature.

2.3.1 International impacts of drought

An article in Reuters indicates that, “severe drought and scorching heat has damaged over a million hectors of farmland in China’s Henan and Inner Mongolia provinces”. According to the article, “the drought in Henan was the worst in 40 years and precipitation was at less than half of its normal levels, with more than 900 000 hectares of crops damaged” (Reklev, 2014).

According to a CNBC article by (Koba, 2014), “water-rich states will be able to lure manufacturing and agriculture away from water-scarce nations, that can lead to limits in economic growth in the drought-prone states”.

Accordingly, an estimated 55 million people globally are affected by droughts every year, and they are the most serious hazard to livestock and crops in nearly every part of the world. Droughts threaten people’s livelihoods, increase the risk of disease and death, and fuel mass migration. Water scarcity impacts 40% of the world’s population (WHO 2020).

According to National Oceanic Atmospheric Administration, droughts are the second highest causes of death, after tropical cyclone in the United States of America, (NOAA 2020). Table 1 below illustrates the drought impact in the United States of America, whereby 2993 deaths were recorded between 1980 and 2019. The Table also illustrates the fact that, droughts are the second highest causes of death after tropical cyclones. The Table further illustrates the impact in the monetary value, whereby, the drought monetary value of mortality is the second highest when compared to the monetary impact cause by tropical cyclones.

Table 2.1: Billion-dollar events to affect the U.S. from 1980 to 2019 (CPI-Adjusted), Drought impact compared to other disasters

DISASTER TYPE	EVENTS	EVENTS/ YEAR	PERCENT FREQUENCY	TOTAL COSTS	PERCENT OF TOTAL COSTS	COST/ EVENT	COST/ YEAR	DEATHS	DEATHS/YEAR
Drought	26	0.7	10.1%	$249.7	14.2%	$9.6	$6.2	2,993	75
Flooding	32	0.8	12.4%	$146.5	8.3%	$4.6	$3.7	555	14
Freeze	9	0.2	3.5%	$30.5	1.7%	$3.4	$0.8	162	4
Severe Storm	113	2.8	43.8%	$247.8	14.1%	$2.2	$6.2	1,642	41
Tropical Cyclone	44	1.1	17.1%	$945.9	53.9%	$21.5	$23.6	6,502	163
Wildfire	17	0.4	6.6%	$84.9	4.8%	$5.0	$2.1	347	9
Winter Storm	17	0.4	6.6%	$49.3	2.8%	$2.9	$1.2	1,048	26
All Disasters	**258**	**6.5**	**100.0**	**$1,754.6**	**100.0%**	**$6.8**	**$43.9**	**13,249**	**331**

Source: Adapted from National Oceanic and Atmospheric Administration (NOAA)

Global Assessment Report (GAR) however, reports that, “since the 1990s, internationally recorded drought mortality has been negligible, with only 4,472 fatalities from 1990 to 2009”, (GAR, 2011). “Drought impacts are poorly recorded internationally. Reasons include the lack of visible damage outside of the agriculture sector”, (GAR 2011). Table 2 below illustrates drought impact as adapted from (GAR 2011)

Table 2.2: International drought impact

Mortality and well-being	Internationally, drought mortality risk is currently severely under recorded, and drought mortality may be significantly higher than reported, with many fatalities going unrecorded or attributed to other causes. For example, in Mozambique only 18 deaths were reported, and internationally between 1990 and 2009. In contrast, Mozambique's disaster loss database recorded 1,040 deaths for the same period. Poor rural households with livelihoods that depend on rain-fed agriculture are more vulnerable to drought and less able to absorb and buffer the losses. Consequences include increased poverty, reduced human development and negative impacts on health, nutrition and productivity, declining purchasing power and increasing income inequality. As with the Navajo, poor rural households can rarely mobilize sufficient assets to buffer crop and livestock losses, while droughts tend to undermine household and community coping mechanisms because large numbers of households are affected simultaneously and for long periods.
Rural livelihoods, food security and agricultural production	In the Caribbean, the 2009–2010 drought saw the banana harvest on Dominica reduced by 43 percent, agricultural production in Saint Vincent and the Grenadines 20 percent below historic averages, and onion and tomato yields in Antigua and Barbuda decline by 25–30 percent. Australia experienced losses of US$2.34 billion during the 2002–2003 drought, reducing national GDP by 1.6 percent. Two thirds of the losses were agricultural, the remainder attributed to knock-on impacts in other economic sectors. During the 2002 drought, food grain production in India dropped to 183 million tonnes, compared to 212 million tonnes the previous year. In the 2007–2008 drought in the Syrian Arab Republic, 75 percent of the country's farmers suffered total crop failure, and the livestock population was 50 percent below the pre-drought level more than a year after the drought ended. Mozambique is one of the few countries with a disaster database that systematically records drought losses, so the real scale of drought risk becomes visible. Since 1990, drought events damaged 8 million hectares of crops, half of which were destroyed and affected 11.5 million people. Thus, international under-reporting of drought losses undermines the visibility of drought risk and the political and economic imperative for its reduction, and also hides the significant implications for livelihoods of small-scale farmers, especially elderly and women farmers and female-headed households.
Urban and economic development	Droughts reduce water supplies for domestic and industrial use, and for power generation, affecting cities and non-agricultural sectors of the economy. During the 1991–1992 drought in Zimbabwe for example, water and electricity shortages and a decline in manufacturing productivity of 9.5 percent resulted in a 2 percent reduction in export receipts. The overall cost to the economy of the drought-driven decline in energy production was more than US$100 million and 3,000 jobs. In 2008, a severe drought in the south-eastern United States of America threatened the water supplies for cooling more than 24 of the nation's 104 nuclear power reactors. The 2003 European drought and heat wave reduced France's nuclear power generation

	capacity by 15 percent for five weeks and also led to a 20 percent reduction in the country's hydroelectric production. In the middle of Spain's 1991–1995 drought, hydroelectric production was reduced by 30 percent and 12 million urban residents experienced severely restricted water availability.
Migration	Droughts are associated with migration. In the Syrian Arab Republic, a million people left rural areas for cities after successive crop failures from 2007–2009. In response to both recurring droughts and marginal rural livelihoods, half of all rural Mexicans migrated to urban centres during the twentieth century. In Rajasthan, India, droughts regularly lead to forced migration, increased debt and borrowing, reduced food consumption, unemployment and poorer health. Given that drought occurred in 47 years in the past century, this imply a profound impact on rural livelihoods. Migration leads to changing household decision-making patterns, often resulting in an increase in female-headed households. Case studies from Jordan and Lebanon show that family dynamics and women's public roles may also change significantly as a result of drought-associated migration.
Conflict	Droughts contribute to the likelihood of conflict by causing displacement and migration, increasing competition for scarce resources and exacerbating ethnic tensions, and by encouraging poor rural farmers to join armed resistance groups. Since the 1950s, droughts precipitated waves of migration and contributed to intense conflicts in India and Bangladesh, and droughts during the 1980s and 1990s were a factor that precipitated ethnic conflict and border skirmishes between Mauritania and Senegal. A 1,100-year analysis of drought in equatorial East Africa found evidence of drought induced famine, political unrest and large-scale migration during the six centuries before 1895. They may have also helped precipitate the 1910 Mexican Revolution. More recently, droughts were associated with riots in Morocco during the 1980s and contributed to Eritrea's secession from Ethiopia in 1991.
Environment	Droughts affect habitats, bodies of water, rivers and streams, and can have major ecological impacts, increasing species vulnerability and migration, and loss of biodiversity. Between 1999 and 2005, droughts contributed to the loss of at least 100,000 hectares of salt marshes along Florida's coastline. In Spain, the 1991–1995 drought indirectly resulted in the draining of wetlands, causing saltwater intrusion of coastal aquifers; and the area affected by forest fires in southern Spain increased by 63 percent compared to the previous decade.
Public spending	Downstream impacts indicate increased competition and conflict between different sectors of water users and a need for increased government spending on relief and compensation. In Andhra Pradesh, India for example, rice irrigation increasingly relies on pumped groundwater. As energy for pumping is subsidized by the government, this results in even lower groundwater levels, and rice cultivation also drains state funds and contributes to periodic blackouts. The cost of food and non-food assistance provided in response to the 1991–1992 drought in ten southern African countries exceeded US$950 million, and during the 2007–2009 drought in Kenya, 70 percent of the population of one region depended upon food aid.

Source: Adapted from Global Assessment Report (GAR 2011)

2.3.2 Impacts of drought in Africa

Impacts of drought are significant in Africa due to variety of factors, such as limited capacity as well as decreased resilience. The fact that the continent is arid and semi-arid imposes risks on agricultural yields because of the uncertainty of adequate water supply arising from insufficient rainfall as well as overexploitation of water resources.

Figure 2.2 below illustrates the number of people who were affected by drought between 1971 and 2000 as compared to other natural disasters in Africa.

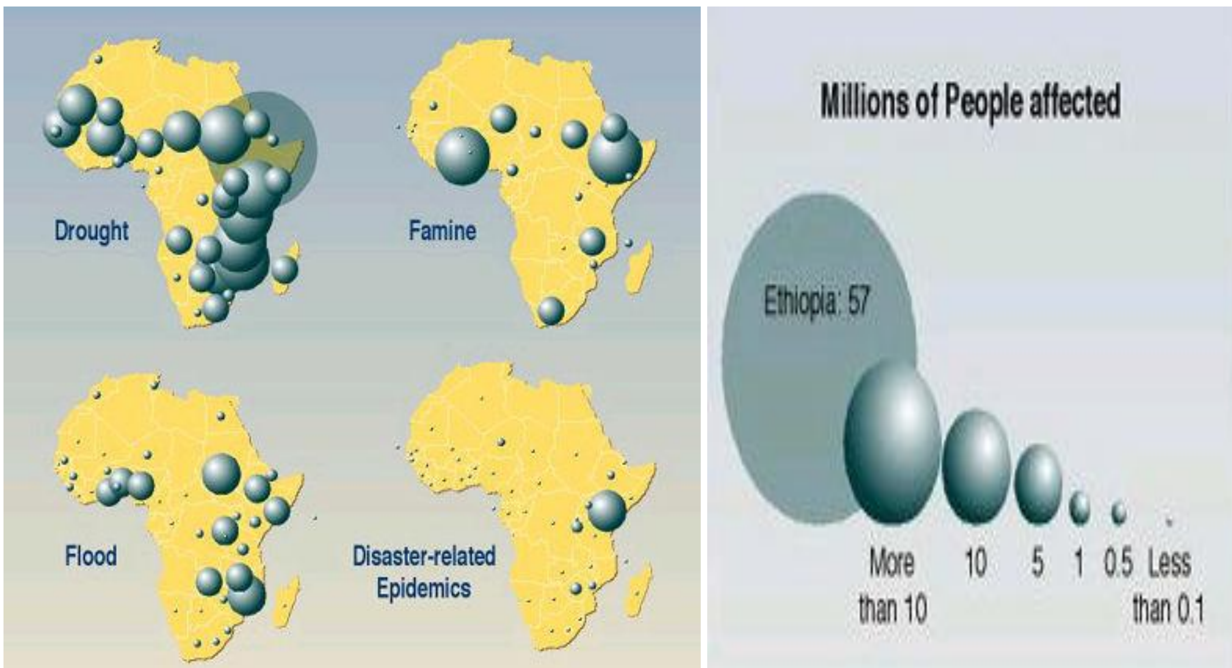

Figure 2.2: Drought impact in the Sub-Saharan Africa as compared to other disasters

Source: Disaster Risk Reduction in the Sub-Saharan Africa Region (2008)

Figure 2.3 below illustrates the drought-related crop damage in Mozambique, in the years between 1990 and 2009, whereby, between 140 and 40000 hectares of crops were damaged.

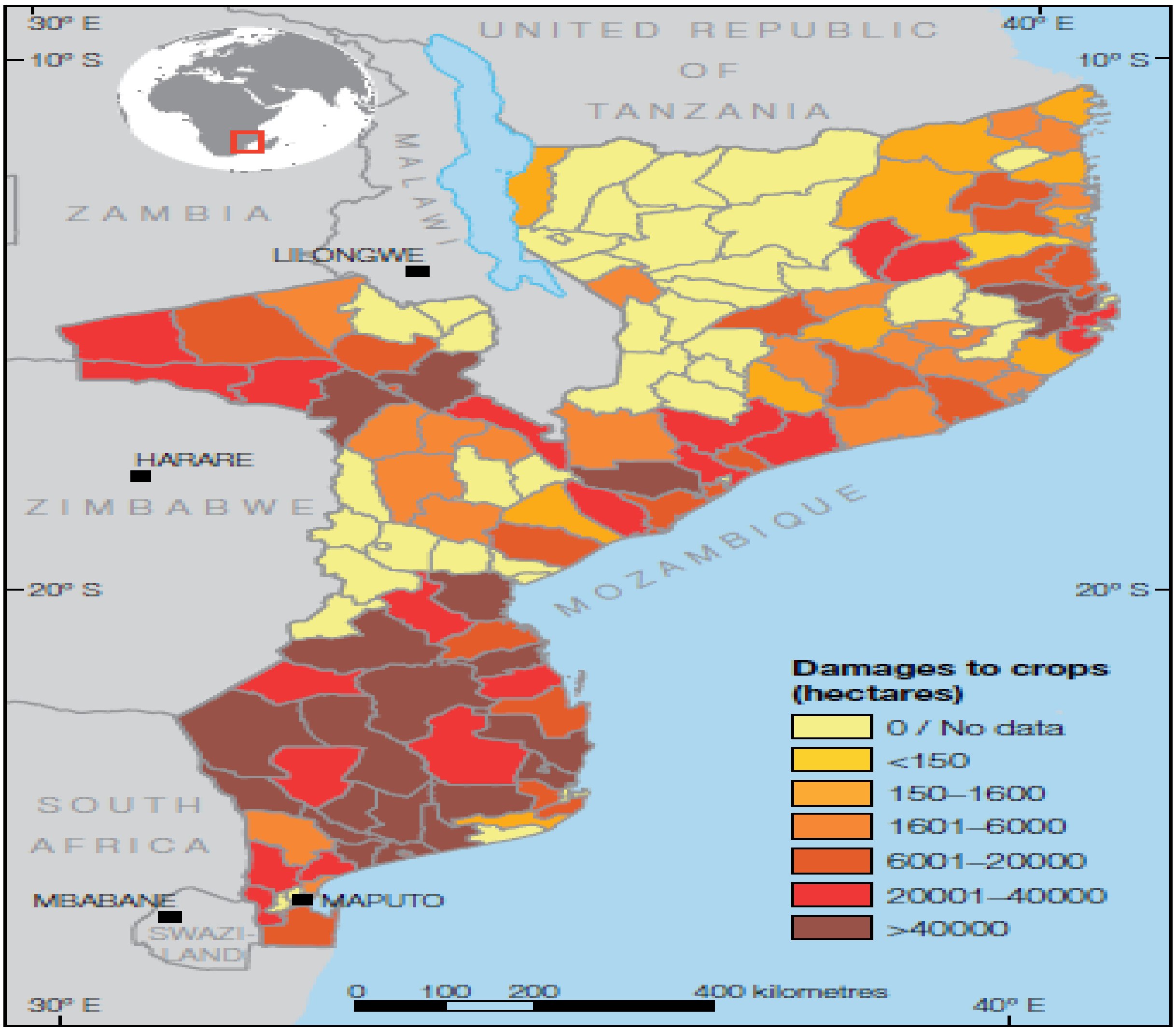

Figure 2.3: Drought-related crop damage in Mozambique, 1990-2009

Source: (GAR 2011)

2.3.3 Impacts of drought in the Free State, South Africa

Free State is one of the nine provinces in the Republic of South Africa and is one of agricultural food baskets of the country (Botai et al. 2016). The Province produces more maize as compared to all other provinces in the Republic of South Africa, (DAFF 2010). Abstract of the Agricultural

Statistics of 2019 still shows the Free State as the main maize producer in the Republic of South Africa; it also shows the drop in crop yields for 2016 (DAFF 2019). Agricultural yields are more dependent on rainfall, now that, the Province is drought-prone, farmers are finding it difficult to cope; insufficient rainfall means that, the costly mechanical means of irrigation should be used largely, although, only 10% of the farm land in the province uses mechanical irrigation, (DAFF 2010). The creeping nature of drought has seen the Province plunge into disaster in recent years and farmers lost many crops as well as live stock. The drop in maize yields prompted the country to import maize from other maize-producing countries. According to Hlalele, Mokhatle and Motlogeloa (2016), droughts negatively affect the basic needs of water for human survival, food and hydropower energy, whilst, at the same time, impacting on agricultural production. AgriSA reports that, the drought conditions of 2013, 2015, 2016 and 2019 have left many maize producers in the North West and parts of the Free State in a very challenging environment, as a result, agricultural output was 9.2% lower in the first half of 2019, than in the corresponding period of 2017 (AgriSA 2019). The researcher believes that, there is a need for the water reource managers and users to know the hydrological risk characteitsics so that, informed decisions regarding good water use can be made.

Literature has shown that, South Africa has faced several drought events in the past years, this is attributed to the decreased levels of rainfall which is way below the global average. Droughts have slow onset phenomenon, hence, by the time a hydrological drought emerges, the impacts of the drought are severe. Reduced levels of Precipitation, over a prolonged period, affect surface and subsurface water supplies, thus, reducing streamflow, groundwater, reservoir and lake levels; these result in hydrological drought ended (Heim 2002). Hydrological drought persists longer after a meteorological drought has ended (Heim 2002). Survival of water-resourced projects is premised on good use of water, through what is now referred to as Integrated Water Resource Management (IWRM). Global Water Partnership (GWP) defines IWRM as a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP 2000).

The use of this natural resource, water, is largely premised on the four guiding principles that had emerged out of the International Conference on Water and Environment that was held in Dublin in 1992. The four principles were then presented to the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992, (World Meteorological Organisation 1992). The principles, known as the 'Dublin Principles' state that, "(1) Fresh water is a finite and vulnerable resource essential to sustain life, development and the environment; (2) Water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels; (3) Women play a central part in the provision, management and safeguarding of water; and (4) Water is a public good and has a social and economic value in all its competing uses". It is obvious from these principles that, water is a natural commodity that needs to be conserved and protected by all means possible because it supports life; it supports the environment and it is essential for development. It is, therefore, important that, the water resource managers become considerate about the use of water for any envisaged projects, with hydrological drought in mind. Statistics South Africa, in its discussion document titled water management areas in South Africa described inland water resources as "the rivers, dams, lakes, wetlands, and subsurface aquifers" (SatsSA 2010).

2.4 DROUGHT HAZARD CHARACTERISATION METHODS

Drought characterisation entails the measure of the extent of a drought. According to Giannikopoulou et al. (2014:1), "contrary to other extreme climate events, such as floods, the analysis of drought characteristics namely severity, duration, probability, frequency and spatial extent have been a challenging task, resulting in a large number of drought definitions and methods for drought hazard analysis". World Meteorological Organisation resolved that the Standard Precipitation Index as the recommended drought index to be used by all nations in order to determine the extent of droughts (Hayes et al. 2011). This was in response to the recommendations that were made in February 2009 in the International Workshop on Drought and Extreme Temperatures in Beijing, China, where one of the main recommendations was for the WMO to identify methods and marshal resources to develop standards for agricultural drought indices (Hayes et al 2011). For SPI and other drought indices to be calculated, a set of indicators are available as drought characterisation is defined more in terms of drought indicators. Accordingly, drought indicators are typically derived from hydro-climatic variables like precipitation, climatic water balance, soil moisture, river flow, and groundwater (Vogt et al. 2017). Notwithstanding the fact that only precipitation data is needed for SPI computation and analysis, Table 2.3 below illustrates the different variable indicators in this regard.

Table 2.3: Main variables to characterise drought events

Variable	Description	Relevance
Frequency	Number of drought events per defined time interval	More frequent droughts can cause long-term impacts on affected ecosystem
Severity (magnitude)	Related to the water deficit. Computed as the sum of the differences, in absolute values, between the drought indicator (DI) values and the threshold used to define the level of dryness. $S_{ii} = \Sigma\ \lvert DI_{ii} \rvert < \text{Threshold}$	Deficit of water in relation to the water needed for specific uses (among others: irrigation, domestic water consumption, energy production)
Intensity	Severity divided by duration of the event.	Characterizes the overall potential for impacts
Duration	Number of days, months or time steps of the event.	Longer droughts are propagated further through the hydrological cycle with a higher potential for cascading and secondary effects.
Onset	First day, month or time step for which the indicator is below a given threshold.	Relevant if a drought starts in sensitive periods with greater water demand like, seeding and flowering periods. Relevant for drought management and the declaration of farming emergencies
Cessation	Meteorological indices have returned to normal, soil moisture is restoring, pasture growth re-establishes, forest growth re-establishes, reservoirs and lakes refill.	Relevant for management

End point	Agricultural and natural ecosystem productivity returns to average pre-drought conditions, lake and reservoir levels return to average pre-drought conditions. Socioeconomic conditions return or stabilize to normal.	Relevant for management
Peak month	Day or month with the lowest value of the drought indicator.	Period with the potentially strongest impact
Affected area	Area or percentage of a region (or country) with values of the drought indicator below a certain threshold.	The wider the area, the more exposed assets are affected

Source: Adapted from drought risk assessment and management, a conceptual framework technical report (Vogt et al. 2017)

2.5 HYDROLOGICAL DROUGHT INDICES

According to WMO and GWP (2016), indices aim to measure the qualitative state of droughts on the landscape for a given time period, and are technically indicators as well. Indices are used to provide quantitative assessment of the severity, location, timing and duration of drought events (WMO and GWP 2016). This means that, hydrological drought indices, as part of drought indices, are necessary in order to enable informed-decision making as well as to allow for early warning in order for preparedness and mitigation strategies to be activated and to predict the end of the drought. Indices, essentially, are premised on, among others, the onset, the end, the extent, severity and frequency; to a large extent, certain variables are computed depending on which index used (WMO and GWP, 2016). Precipitation, temperature, soil moisture, stream flow, surface and ground water are some of the variables out of which collected data are used to compute chosen drought index.

2.5.1 Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) was first introduced by Tsakiris and his colleagues in National Technical University of Athens, (Tsakaris et al. 2007). The RDI is based on the ratio between two aggregated quantities of precipitation and potential evapotranspiration. It is advisable to use the periods of 3, 6, 9 and 12 months if RDI has to be calculated as a general index of meteorological drought. In its initial formulation, RDI, for a 12 months' time period can be directly compared with the Aridity Index produced for the area under study (Tsakaris et al. 2007).

Reconnaissance Drought Index (RDI) is one of the variety of indices to monitor the onset and offset of drought. RDI has almost similar characteristics to Standard Precipitation Index (SPI), hence, similar variables are used for the calculations. In order for calculations to be done, data is collected from hydrological and precipitation stations over a period of time. The data is then computed, after which, the determination is then made of the extent of the drought. McKee, Doesken and Kleist (1993) developed SPI after several definitions of drought were developed. RDI responds in a similar manner to SPI, although, the RDI was found to be more sensitive and more suitable in cases of changing environment, (Tsakiris et al. 2007).

Droughts have detrimental effects on the ecosystem and also on the livelihood of the general population, hence, the need to monitor the onset and the offset of droughts, over a period of time.

Monitoring should be undertaken in order to assist the authorities to make informed decisions for pre-planning and mitigation purposes. It is, however, noted that drought has a creeping nature, meaning that the onset of drought is slow and increases in intensity over time; simply put, droughts develop slowly and quietly. The definitions of drought will help us understand this phenomenon. World Meteorological Organisation (WMO) acknowledges that, there is no definite definition of drought, (Handbook of Drought Indicators and Indices 2016), however, generally accepted is that a drought is a condition of insufficient moisture caused by a deficit in precipitation over some time period (McKee et al. 1993).

2.5.2 Standard Precipitation Evapotranspiration Index (SPEI)

After the development of Palmer Drought Severity Index (PDSI) in 1965 by WC Palmer, there have been many attempts at improving the index. These were done by developing new indices to make them easy to use. After the development of PDSI, there have been other indices, such as Standard Precipitation Index, Reconnaissance Drought Index, to name but a few (Vicente-Serrano, Beguería and López-Moreno 2010)

2.5.3 Palmer Drought Severity Index (PDSI)

This drought index was developed by Wayne Palmer, the meteorologist, who first published his method in a 1965 paper titled "Meteorological Drought for the Office of Climatology of the U.S." (Palmer 1965). The Palmer Drought Severity Index (PDSI) uses readily available temperature and precipitation data to estimate relative dryness (Palmer 1965). PDSI is a standardized index that generally runs between -10 (dry) and +10 (wet). For the wetness and dryness levels to be determined, the variables in the form of temperature, precipitation are computed, together with other variables. The use of PDSI is complicated by the computational procedure which warrants - the use of water balance calculated from monthly or weekly data, historic temperature and precipitation data, soil moisture and potential evapotranspiration, which is calculated by using the much-criticized Thornthwait method (Alley 1984).

Integrated Drought Management Program (IDMP) identifies the advantages of the use of PDSI as being a tool to be used around the world, and that the code and output are widely available. Scientific literature contains numerous papers related to PSDI. The use of soil data and a total water balance methodology makes PDSI quite robust for identifying drought (IDMP 2020). IDMP, however, identifies the need for serially-complete data as a limitation; also that PDSI has a timescale of approximately nine months, which leads to a lag in identifying drought conditions based upon simplification of the soil moisture component within the calculations. This lag may be up to several months, which is a drawback when trying to identify a rapidly-emerging drought situation. Seasonal issues also exist, as the PDSI does not handle frozen precipitation or frozen soils, well (IDMP 2020).

2.5.4 Crop Specific Drought Index (CSDI)

The values produced by indices such as the PDSI and CMI cannot be directly linked to drought impacts on crop production and yield since each crop responds differently to moisture and heat stress, hence, the development of Crop-Specific Drought Index (CSDI), (Hubbard and Hong 2005).

2.5.5 Standard Precipitation Index (SPI)

McKee et al. (1993) developed SPI after several definitions of drought and many other drought indices were developed. The intention here was to develop an uncomplicated and reliable drought index which will respond quickly to the onset and end of droughts, hence the 3, 6, 9, 12 and 24 month time scale is used as a measure (McKee et al. 1993). SPI responds in the similar manner to the RDI, however, the SPI was found to be more sensitive and more suitable in cases of changing environment, (Tsakiris, Pangalou and Vangelis 2007). SPI is much more relevant as a drought index, because it is based on the presence or absence of precipitation data. The measure of soil moisture and ground water is based on the rainfall levels; decreased soil moisture and decreased ground water level over a certain time scale, defines the extent of a drought, hence the importance of precipitation data for SPI computation purposes. Standard Precipitation Index (SPI) is therefore one of the variety of indices used to monitor the onset and offset of drought. In order for calculations to be done, data for the study period is collected from hydrological and precipitation stations. The data is then computed after which, a determination is then made of the extent of the drought, be it meteorological or hydrological. Table 2.4 below demonstrates drought severity after computation of rainfall data, whereby, the extent of drought is measured by the negative outcome and the end of a drought is measured by the positive outcome (Mishra and Desai 2005). Mishra, Desai and Singh (2007) argue that, the time interval of SPI is found to have a significant effect on the probabilistic characteristics of drought. This confirms the fact that, SPI has the capability of determining the extent of dryness and wetness, therefore, can determine a creeping drought and the end of it.

Table 2.4: Precipitation classification based on SPI

SPI values	**Class**
≥ 2	Extremely wet
1.50-1.99	Severely wet
1.0-1.49	Moderately wet
0 to 0.99	Mildly wet
-0.99 to 0	Mild drought
-1.49 to-1.00	Moderate drought
-1.99 to-1.50	Severe drought
≤ -2	Extreme drought

Source: Drought characterization: a probabilistic approach. Stochastic Environmental Research Risk Assessment (Mishra et al 2007)

2.5.5.1 Why Standard Precipitation Index

Despite the SPI's disadvantages, it is widely preferred because of its simplicity and all the other advantages that SPI comes with. It is obvious that the advantages outweigh the disadvantages; this is the reason the WMO (2009) made it the drought index of choice for drought monitoring as it has displayed advantages that completely outweigh its disadvantages. Table 2.5 below illustrates the advantages and disadvantage of SPI.

Table 2.5: Advantages and disadvantages of SPI

Item	Description
Advantages	It uses precipitation data only, making it easy to compute. It is applicable in all climate regimes; meaning that SPI values for every different climates can be compared. It accommodates computation even with missing data Easy to use and is a readily available software. It is capable of calculating over a multiple time scale, from one to 48 months, even higher
Disadvantages	Uses only precipitation as a variable for computation purposes and excludes temperature Exclusion of temperature might create a difficulty making a comparison of similar SPI values, for different temperature scenarios. Calculation of a short period or the computation of no data might lead to misuse of the output. SPI assumes a prior distribution, which may not be appropriate in all environments, particularly when examining short-duration events or entry into, or exit from a drought

Source: Adapted from Integrated Drought Management Programme IDMP (2016)

According to Pai et al (2011), realistic outcomes were achieved by analysing droughts in India in 458 districts. This prove that SPI has been applied across different locations, topographical areas and in a large variety of geographical conditions and climates; its performance, therefore, does not depend on the size of the area. The current author, therefore, chose the SPI as a drought index to undertake this analysis in the Free State Province because the size of the area, topographical, geographical conditions would not have an influence on the outcome. SPI index is able to accommodate data covering over 20years; it also has the characteristics to carry out hydrological drought determination as it has the capability to determine hydrological drought of timescale of 12 and 24 months and from as little as 3 or 6 months. The current study uses 6-, 9- and 12-month time scales.

2.6 COMMONLY USED FRAMEWORKS IN DISASTER MANAGEMENT STUDIES

The theoretical frameworks are geared towards addressing poverty, in essence, reducing vulnerability. In the book, At Risk, Wisner et al. (2003) place poverty as a main contributor towards vulnerability progression. Sustainable Livelihood Framework sees vulnerability as being characterised by five capitals, namely, social, economic, human, physical, and natural (GLOPP 2009). Meaning that, if the capitals are addressed, levels of vulnerability would automatically decrease significantly.

2.6.1 Pressure and Release Model

The Pressure and Release (PAR) theoretical framework recognizes the fact that, for vulnerability to prevail, there should be influencing factors, hence, for vulnerability progression. At the same time, the PAR model recognizes the fact that if the vulnerability progression is reversed, and the safety progression is adopted, resilience will be strengthened and vulnerability will be reduced. Implying that, if root causes, dynamic pressures, are reversed, eliminated or reduced, the unsafe conditions would not thrive (Wisner et al. 2003).

Wisner et al. (2003) further identified seven objectives of risk reduction as to (i) understand and communicate the nature of hazards and vulnerabilities and capacities. (ii) Conduct risk assessment by analysing hazards, vulnerabilities and capacities. (iii) Reduce risks by addressing root causes, dynamic pressures and unsafe conditions. (iv) Build risk reduction into sustainable development, (v) reduce risks by improving livelihood opportunities. (vi) Build risk reduction into disaster recovery. (vii) and building a safety culture.

Reversal of the PAR model and adopting a safety progression are the ways to go in order to strengthen capacity, whilst, at the same time building resilience in the communities and lessening vulnerability. Third Risk Reduction Objective emphasises the need to reduce risks by addressing root causes, dynamic pressures and unsafe conditions (Wisner et al. 2003). The authors recognise the fact that disasters are a complicated mixture of natural hazards together with human action, and also the fact that, Least Developed Countries (LDCs) vulnerable people often suffer repeatedly, multiple times, and the hazards sometimes simultaneous shocks their families, their settlements and their livelihoods (Wisner et al. 2003).

The progression of vulnerability demonstrates the fact that if the root causes and the dynamic pressures are not addressed, the unsafe conditions will prevail. The root causes, the dynamic pressures and unsafe conditions give way to hazards like - flooding, sea level rise, drought, and global warming - to prevail. The formula below summarises the notion of this model in simple form:

Risk = Hazard x Vulnerability……………………………………………….Equation 2.1

To put this into the context of hydrological drought impact as a result of climate change, the world, through the research programs of United Nations, is aware of causes of climate change. IPCC estimates that the global temperature is due to rise by 0.3°C every decade; this rise in the temperature is associated with climate change, which is directly linked to multiple hazards and potential impacts, such as a rise in sea level, floods, drought, (IPCC 1992). Without going into extensive details, it is important, however, to mention how the climate system works.

According to IPCC, the Earth absorbs radiation from the Sun, mainly at the surface. Thus, this energy is redistributed by the atmosphere and ocean, then re-radiated to space at longer wavelengths. Some of the thermal radiation is absorbed by radiatively active greenhouse gases in the atmosphere; principally water vapor but also carbon dioxide, methane, the chlorofluorocarbons (CFCs) ozone and other greenhouse gases. The absorbed energy is re-radiated in all directions, downwards as well as upwards such that the radiation that is eventually lost to space is from higher, colder levels in the atmosphere. The result is that the surface loses less heat to space than it would do in the absence of the greenhouse gases and consequently stays warmer than it would otherwise be. This phenomenon, which acts rather like a 'blanket" around the Earth, is known as the greenhouse effect. The release of greenhouse gases into the atmosphere is said to be the cause for global warming (IPCC 1992).

The IPCC Fourth Assessment Report (2007) reiterates the fact that, the ozone layer depleted due to the excessive greenhouse emissions has a potential of negatively affecting biophysics as well as ecosystem, among others; the eventual effect will be the warming of the globe. This will have detrimental effects on the planet and the end results will be, among others, the rising of sea levels, drought and floods. The ecosystems would be negatively affected as a result. Figure 2.4 below illustrates the greenhouse effect. Human activities, such as burning of fossil fuel and deforestation among others, increases the blanket effect, which in return increases the risk of rising global temperatures, (IPCC 2007)

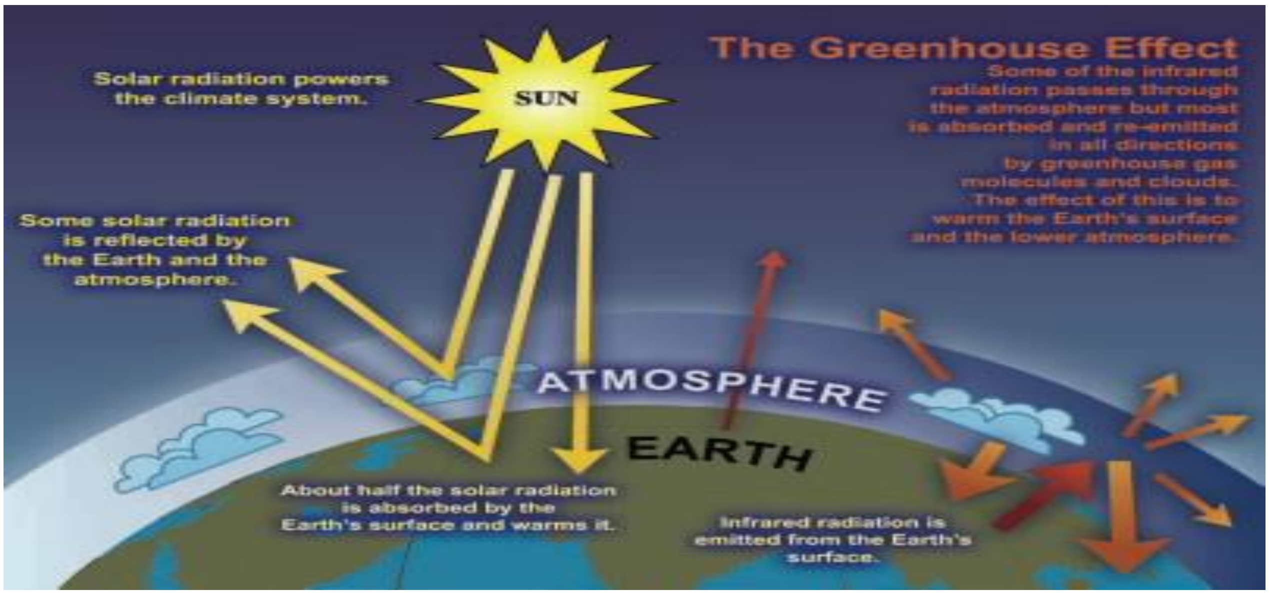

Figure 2.4: Illustrates the greenhouse effect of solar radiation on the Earth's surface caused by greenhouse gases

Source: IPCC Fourth Assessment Report (2007), Chapter 1

The PAR model warns the decision-makers of the after-effects of letting the vulnerability progress to the state of no return - level 3 of the progression - where resilience is depleted, therefore, the risk becomes high as a result.

The researcher in this instance would like to argue that, because the hydrological drought is the worst form of drought as this implies that the ground water is diminishing, this has to be prevented by way of reversing the vulnerability, as argued by the safety progression of the PAR model. It is known that carbon emission is the cause of global warming, thus, the world is now focused on reducing the emissions so that the temperature can be prevented from rising above the 1.5°C. Africa is contributing less to the greenhouse gases emissions; it is, however, indicated in the IPCC report that, Africa is more vulnerable to the impacts of climate change (IPCC 1992). Africa is an arid and semi-arid continent, therefore, a little bit of rain or no rain at all, will exacerbate the risk of hydrological drought. Figure 2.5 below demonstrates the progression of vulnerability, whereby, drought as one of the hazards, will become a disaster if the root causes are not reversed.

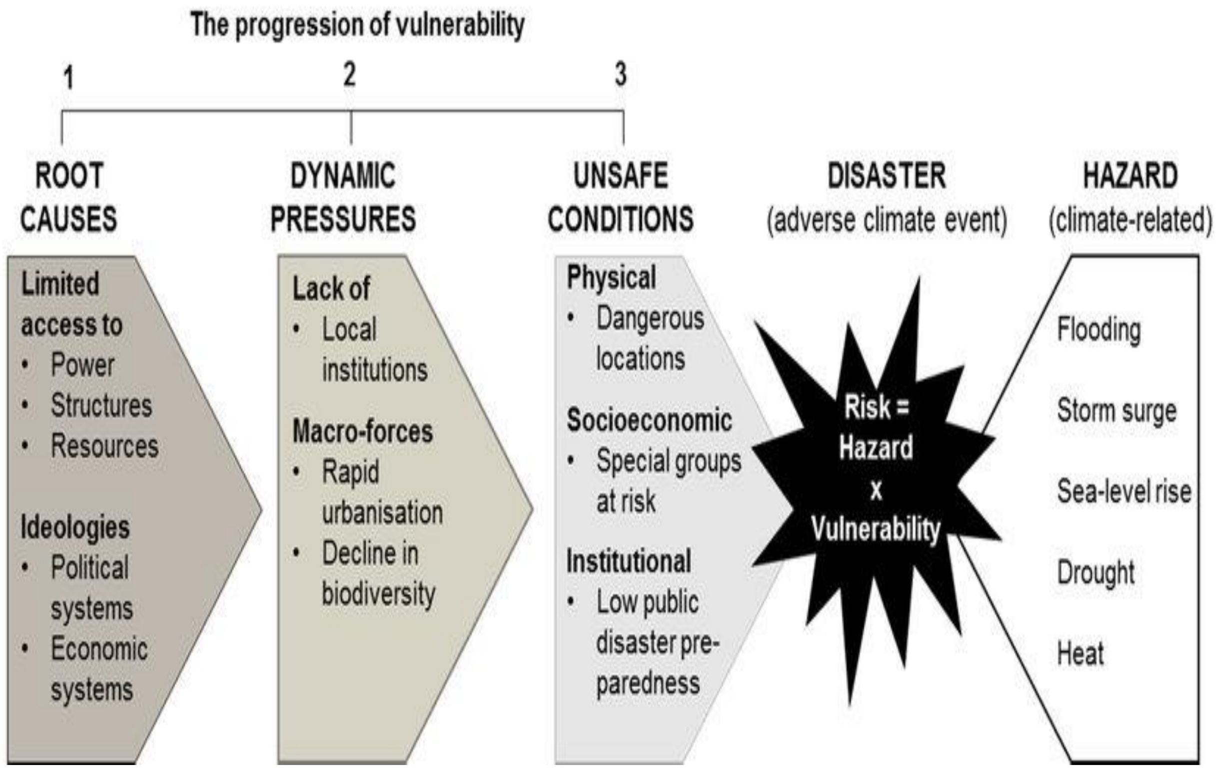

Figure 2.5: PAR Model, Progression of vulnerability

Source: At Risk (Wisner et al. 2003)

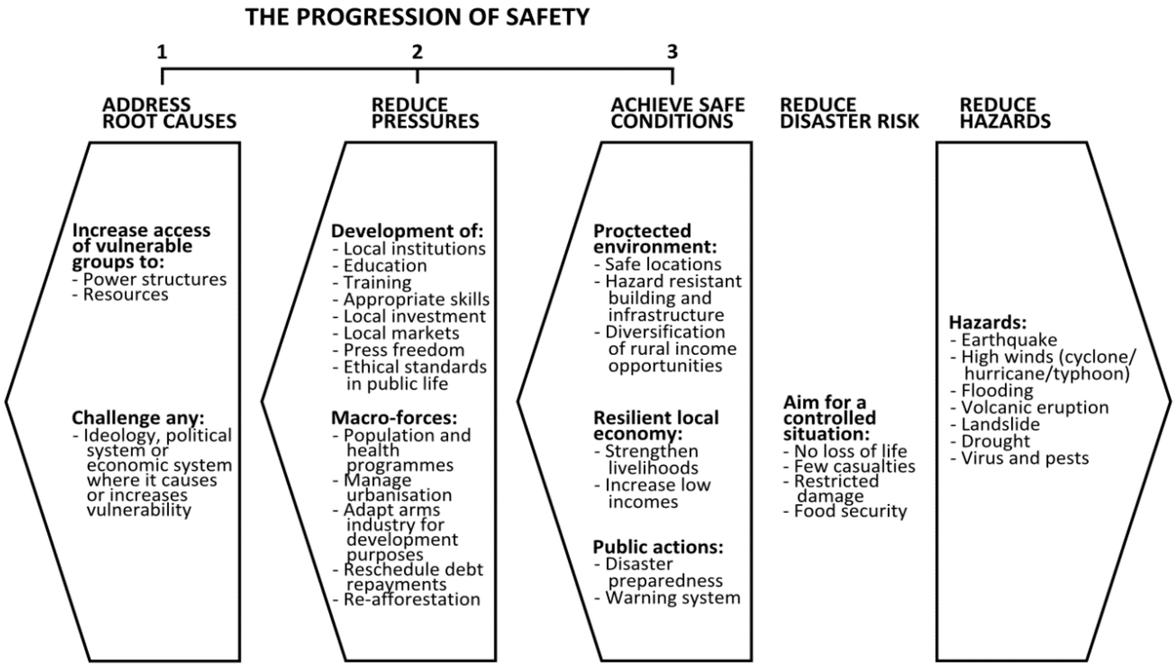

Figure 2.6: PAR Model, Progression of safety Source

Source: At Risk (Wisner et al. 2003)

Figure 2.6, illustrates the progression to safety of the PAR model. The root causes are addressed in Figure 2.6. It is noted that immediately when the root causes, dynamic pressures and unsafe conditions are addressed, the disaster risks are automatically reduced. When the pressures are reduced, the unsafe conditions become safer, and the risk of a disaster is reduced as the hazard's capability to cause harm or damage is reduced. Drought as one of the hazards has a creeping phenomenon. The slow onset nature of drought calls for early warning systems to be in place. Hydrological drought takes place after agricultural drought has taken place. This study will determine the hydrological drought trends, intensity and frequency so that the water user and water resource managers can make informed decisions and as a result, minimising the risk by turning the progression of vulnerability into progression of safey. Progression of safety in PAR model suggests that, education, training, skills strengthening of local institutions are some of the threats that needs to be improved in order to reduce pressures. This means that the end users of water as well as the water resource managers need to know more about the hazards, in context of this study, the hydrological drought. Focus is mainly on vulnerable communities and businesses. The subsistence and small-scale farmers are also vulnerable because they are normally unable to afford insurance policies so as to improve their resilience.   This could be achieved through the use of existing knowledge and skills and to encourage crop diversification.

2.6.2 Sustainable Livelihood Framework

The Sustainable Livelihood Framework (SLF) was developed by British Department for International Development (DFID). Poor countries are more susceptible to increased vulnerability, therefore, are unable to recover speedily from a disaster. Risk, (which in simpler terms, is the measure of likelihood of a hazard to strike), has been in existence, as part of human life since the inception of life itself; it has a direct or indirect proportionality to vulnerability, hence, the higher the vulnerability, the higher the chance of the hazard manifesting into a disaster. There is never a nil risk, therefore, as the vulnerability lowers, the risk also lowers. This SLF was developed by DFID to eliminate poverty in poor countries (GLOPP 2008).

Vulnerability, either increased or reduced, seems to be at the center of it with regards to the aftermath of a disaster, even the impact of a disaster is dependent on the nature of the vulnerability and its proximity towards the hazards. The nature of vulnerability is also dependent on poverty from which it draws its strength. It becomes obvious that the Sustainable Livelihood Framework was developed as a tool with which to eliminate poverty in poor countries, (DFID 2000)

This framework comprises the capabilities, assets and activities required for a means of living. Livelihood must be sustainable, as illustrated in DFID. A “livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base.”

Livelihood is designed in a way that, its application is adaptable to any place or area, according to its socio-economic and political dispensation.

In context of climate change, SLF is directly linked to the fact that, the impacts of climate change have direct effect on the livelihood of the communities. This is because, the world has already seen the extreme weather patterns, whereby lives were lost and properties were damaged. Cyclone Idai caused extensive damage to properties and loss of lives in Mozambique. As a direct impact, the farming community suffered crop damage, soil erosion; therefore, food security was threatened.

The domino implication is that, when the commercial farmer experiences crop damage, the demand for goods will be high, whilst the supply will be limited; this causes prices to go up directly impacting the poor communities. The same will apply to the communal farmers who will most likely have no means to bounce back because of the lack of insurance to restore their lives to normal. The Figure below illustrates the Sustainable Livelihood Framework, whereby, it is shown that when the assets pentagon is fixed, livelihood outcome becomes positive.

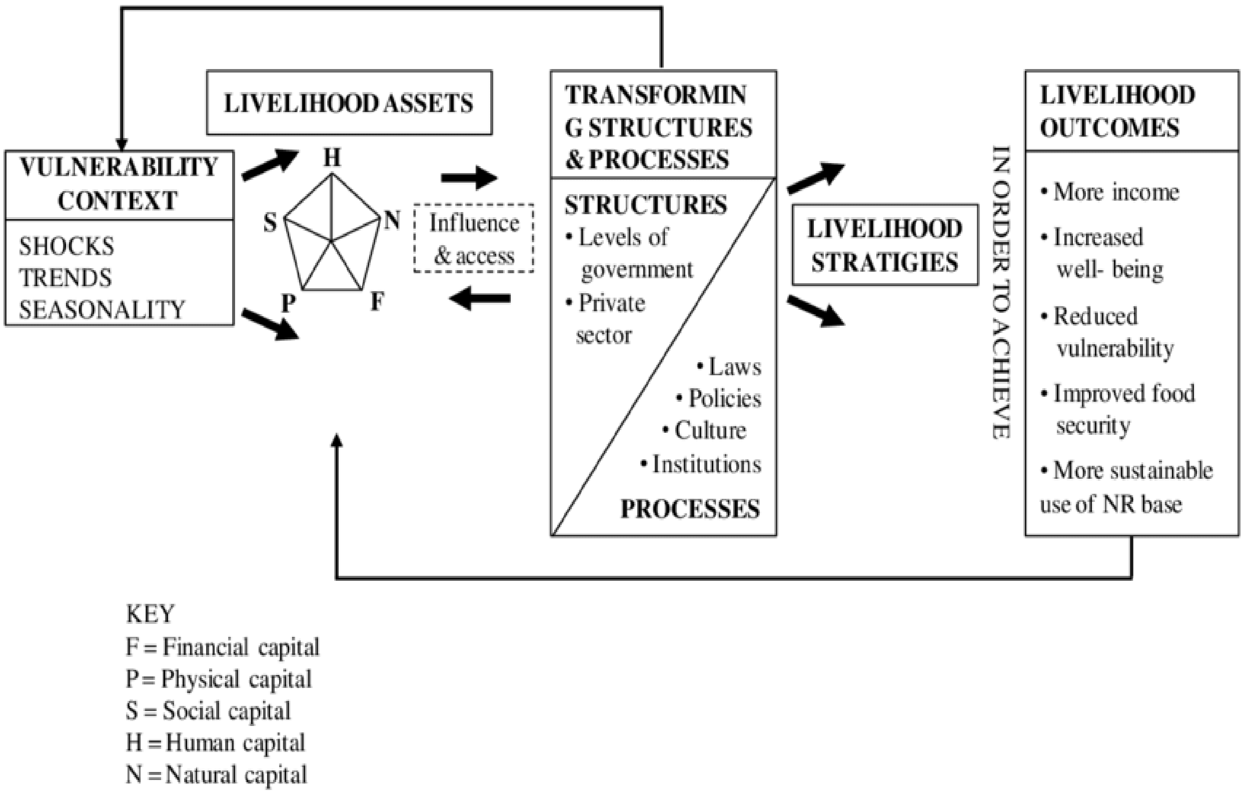

Figure 2.7: Sustainable Livelihood Framework Source

Source: Sustainable Livelihood Framework, (GLOPP 2008)

2.6.3 Sustainable Livelihood Framework and climate change

Livelihood is defined as a set of the capabilities, assets and activities that are required for one to make a living (Chambers and Conway 1992). Africa is more vulnerable to the impacts of climate change; this is despite the fact that Africa contributes minimally to the world greenhouse emissions (Overseas Development Institute 2015). This vulnerability has to do with the dependence of African economies on agriculture for economic activities and food security. Poverty is at the center of Sustainable Livelihood Framework, as the poor people become more vulnerable to impacts of disaster due their inability to cope or bounce back in the aftermath of a disaster. In order for livelihood to be sustainable, it should be able to cope with and recover from stress and shocks, thereby, maintaining or enhancing its capabilities and assets while not compromising opportunities for subsequent generations, (Chambers and Conway 1992).

Climate change has direct effects; these impacts are linked to the ability of the affected community, society, businesses and governments to cope, to adapt and to bounce back in the aftermath of a disaster. Drought is exacerbated by climate change, therefore, is a threat to human kind in Africa; Africans are very dependent on agriculture, which in turn is dependent on water supply. Rainfall deficit has direct implication on the soil moisture and as a result of lack of moisture, the survival of agricultural crops and live-stock are threatened. Agricultural drought precedes hydrological drought.

Standard Precipitation Index is used to determine the level of dryness and wetness for a specific time scale in order to determine, if, there is a drought or not.

2.6.4 Application of Sustainable Livelihood Framework

In the context of hydrological drought and in relation to SLF, notwithstanding the fact that Africa is an arid and semi-arid area, a drought is still a measure of low or no precipitation and a drought is exacerbated by climate change.

Capacity building and sustainability is vital. Risk reduction is a systematic approach to identifying, assessing and reducing the risks of a disaster; it aims to reduce socio-economic vulnerabilities to disasters and also it deals with environmental and other hazards that trigger them.

Adopting from SLF, minimising the risks identified in this study, will be by way of addressing the asset-mix aspect of SLF. Empowering the people in as far as the asset-mix pentagon is concerned, thus, will minimize the effects or impact of shocks that might strike. Economic stability will need to be effected first but also a base needs to be laid down by institutional structures, therefore, education, jobs and health are the basis from which the approach should begin. This will, however, be dependent on the available resources in the way of a budget from government or private sector.

A healthy community is capable of obtaining the much-needed education and skills. Skilled and educated people are able to provide the much-needed labour. Employed people with improved wages are able to fend for themselves, their families, thereby, eliminating poverty. Poverty is the main problem that contributes to migration, and rapid urbanisation.

2.7 POLICIES AND LEGISLATIONS IN DISASTER MANAGEMENT

In order to deal with the impacts of hydrological drought, relevant policies and legislation have to be adopted by the interested organisations and governments. Hydrological drought is exacerbated by climate change. Emission of greenhouse gases is a contributing factor towards global warming, (IPCC 1992). The United Nations (UN) is an organisation that was established in 1945 (UN 2019), and has the following functions "i) To maintain international peace and security, ii) Protect human rights, iii) Deliver humanitarian aid, iv) Promote sustainable development, and v) Uphold international law".

Promotion of sustainable development is relevant to this research, in that it talks about ways to improve the livelihood of people, (UN 2019). "The main priorities of the United Nations are to "achieve international co-operation in solving international problems of an economic, social, cultural, or humanitarian character and in promoting and encouraging respect for human rights and for fundamental freedoms for all without distinction as to race, sex, language, or religion. Improving people's well-being continues to be one of the main focuses of the UN" (UN 2019)

2.7.1 International disaster management policies and legislations

To achieve sustainable development, the UN Yokohama strategy was formulated as a tool thereof and was preceded by Hyogo Framework for Action, (HFA) 2005-2015 for member states to follow. The Framework advocated that an "integrated, multi hazard approach to disaster risk reduction should be factored into policies, planning and programming related to sustainable development, relief, rehabilitation, and recovery activities in post disaster and post-conflict situations, in disaster prone countries" (UNISDR 2005)

The advent of the Sendai framework was regarded as a work in progress, wherein goals were set for member states to accomplish by 2030. Priority 1 of the Sendai Framework requires the member states to understand disaster risk, whereby disaster risk management needs to be based on an understanding of disaster risk in all its dimensions of vulnerability, capacity, exposure of persons and assets, hazard characteristics and the environment (UNISDR 2015).

Priority 2 requires the member states to strengthen disaster risk governance so as to manage it, showing that, disaster risk governance at the national, regional and global levels is vital to the management of disaster risk reduction in all sectors. This is to be achieved through ensuring the coherence of national and local frameworks of laws, regulations and public policies that, by defining roles and responsibilities, guide, encourage and incentivize the public and private sectors to take action and address disaster risk (UNISDR 2015)

The priorities set out a strategic path for member states to adopt in order for the identified disaster risks to be known and understood so that the relevant mitigating strategies can be drawn. Understanding the hydrological drought through its risk characteristics as a disaster risk in terms of priority one above is vital so that priority two can be effected. Formulation of laws, regulations and guidelines flows from understanding the disaster risk, risk characteristics of hydrological drought in this instance.

2.7.2 South African disaster management policies and legislations

Climate change is a reality with the associated risks and challenges in South Africa, Africa and globally. Social, economic and environmental impacts are bound to be felt as a result of climate related impacts, especially drought impacts. South Africa has the task of balancing the acceleration of economic growth and transformation with the sustainable use of environmental resources and responding to climate change (Department of Environmental Affairs 2016). Climate change exacerbates drought in that, the global increasing temperature is a cause for natural disaster incidents (Overseas Development Institute 2015). In order for the South African Government to comply with the international requirements, the following policies and legislation were put in place:

2.7.2.1 National Development Plan

National Development Plan (NDP) is a South African vision 2030 strategy, developed by South African National Planning Commission (NPC) in the office of Presidency of the Republic (NPC 2011). The NDP is aligned with the seven targets and four priorities in the Sendai Framework that are to be achieved in 2030 - Agenda 2030. The priorities as outlined in Sendai Framework are – "(i)understanding disaster risk, (ii) strengthening disaster risk governance to manage disaster risk, (iii) resilience, (iv) and enhancing disaster preparedness for effective response and to build back better in recovery, rehabilitation and reconstruction" (UNDRR 2015). Now that hydrological drought have a creeping phenomenon, efforts have to be made for the risk characteristics of hydrological drought to be known and understood, coherent framework has to be put in place in order for priority four to be effected. National Disaster Management Act, Act 57 of 2002 as amended and Disaster Management Framework (2005) in the Republic of South Africa are a good example coherent legislative framework. The act directs the local municipalities as well as state owned enterprises to submit disaster plans to the national disaster management center through provincial disaster management centers where possible. It is at this level that, the local municipality would perform risk assessment with regards to various aspects of risks including hydrological drought risk characteristics so that mitigation strategies can be designed and be implemented when the need arises.

2.7.2.2 National Disaster Management Act

Nation Disaster Management Act, Act 56 of 2002 (The Act) was enacted in response to the need to have a coordinated effort to put together resources in anticipation of a disaster that might strike. The Act recognizes the fact that prevention, pre-planning, mitigation strategies are at the forefront of disaster management.

In the Act, Disaster Management is defined as "a continuous and integrated multi-sectoral, multidisciplinary process of planning and implementation of measures aimed at: (i) preventing or reducing the risk of disasters (ii) mitigating the severity or consequences of disasters (iii) emergency preparedness (iv) a rapid and effective response to disasters and (v) post-disaster recovery and rehabilitation".

The disaster management Act, therefore, is a legislative framework to give effect to the implementation of efforts to reduce the risks of disaster and to have a common approach after disaster has struck.

The Act has an escalation process, wherein, if unable to deal with a disaster, the local authority would escalate the situation to the provincial government, whereby a provincial state of disaster would be declared. In the event that the provincial government is unable to deal with the disaster, it would be escalated to the national level for a national state of disaster to be declared. In the context of droughts, since their impacts are severe, the Disaster Management Amendment Act, gives legislative injunction that, disaster risk-reduction should be the starting point, in as far as disaster management is concerned. This point is referred to in the definition of disaster risk reduction ‘‘disaster risk reduction means either a policy goal or objective, and the strategic and instrumental measures employed for: (i) anticipating future disaster risk (ii) reducing existing exposure, hazard or vulnerability; and (iii) improving resilience’’ (Nation Disaster Management Amendment Act, Act 16 of 2015). The definition of disaster risk gives effect to the true meaning of the Priority one of the Sendai Framework. Understanding the risk in this regard would be in the line with hydrological drought disaster risk assessments, in order for hydrological drought to be know and anticipated, so that risk reduction and improved resilience can be achieved. Accordingly, priority two of the Sendai Framework would be in a good position to be effected and achieved.

2.7.2.3 National Disaster Management Framework

The National Disaster Management Framework (NDMF) recognizes the fact that South Africa is exposed to a wide range of weather hazards, including drought, cyclones and severe storms that can trigger widespread hardship and devastation, (NDMF 2005). The NDMF also realizes the need for capacity-building and incorporating disaster management in development, hence “the NDMF also gives priority to developmental measures that reduce the vulnerability of disaster-prone areas, communities and households” (NDMF 2005). For better implementation and monitoring, the national disaster management framework has four key performance areas (KPAs). There are three enablers required to achieve the objectives set out in the KPAs. “The KPAs and enablers are informed by specified objectives and, as required by the Act, key performance indicators (KPIs) to guide and monitor progress” (NDMF 2005). NDMF is therefore a guiding document to enable the implementation of the NDMA.

2.7.2.4 National Environmental Management Act

The preamble of NEMA, Act no 107 of 1998, reads among others, “that, the State must respect, protect, promote and fulfil the social, economic, and environmental rights of everyone and strive to meet the basic needs of previously disadvantaged communities” (NEMA 1998). It should be noted that the definition includes water as part of the components that make up environment. The NEMA (1998) is very relevant, because during drought, the living and the non-living are negatively affected. This Act defines environment as “the surroundings within which humans exist and that are made up of (i) the land, water and atmosphere of the earth, (ii) micro-organisms, plant and animal life, (iii) any part or combination of (i) and (ii) and the interrelationships among and between them, and (iv) the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being” (NEMA 1998).

The definition of environment according to NEMA (1998) makes a relationship between the land, water and atmosphere. This study is about hydrological drought, and has a bearing on water. Water is a natural resource which supports animal life and ecosystem, absence of it disrupts the livelihood of life or ecosystem. The study is based in the Province of Free State where more agricultural activities are taking place. Not agricultural activities would be disrupted by hydrological drought, environment also stands to be negatively impacted, hence the preamble of this act is relevant thus far.

2.7.2.5 National Water Act

In the preamble of the National Water Act, Act 36 of 1998, the National Government, recognises that water is a “scarce and unevenly distributed national resource which occurs in many different forms, but are all part of a unitary inter-dependent cycle; that while water is a natural resource that belongs to all people, the discriminatory laws and practices of the past have prevented equal access to water, and use of water resources. The National Government, therefore, acknowledges overall responsibility for and authority over the nation’s water resources and their use, including the equitable allocation of water for beneficial use, the redistribution of water, and international water matters” (DWA 1998).

Water resources are the main targets of decreased precipitation; it is for this reason that, drought monitoring is essential, especially for early warning purposes. Even though the Water Act is silent on drought management, SPI is the form of drought index to assist in this regard.

2.8 SUMMARY

The reviewed studies reveal the extent of research work already available regarding drought in the context of the world. Drought impact in any shape and form illustrates the fact that drought has catastrophic effect on humans and the environment. The fact that, there is not enough documented drought data on African countries, illustrates the fact that there is still work that needs to be done. South Africa, like any other country in the world, and in Africa has had its fair share of drought impacts. The impacts of drought show itself in agriculture, as there is decreased agricultural yields over the years whenever there is reduced precipitation. The fact that, agricultural drought manifests itself as a result of meteorological drought, means that hydrological drought illustrates a decreased water supply at stream flow, surface and ground water level, as well as, the extent to which socio-economic drought manifests itself. The use of SPI is critical to determining the hydrological risk characteristics, in order to enable water-resource managers to plan effectively for success of water-resource projects, this include the farming community at large.

Other than using SPI to determine the extent of meteorological drought, the literature review further indicated that the SPI was never used to determine the severity, intensity, frequency of a hydrological drought. The current study focusses on the use of SPI to determine the hydrological drought risk characterisation by making use of the software package called DrinC. Furthermore, the literature review suggests that the concept of drought monitoring and prediction goes a long way into making reliable data available for decision-makers, such as water-resource managers to make informed decisions that would have more potential in advancing mitigation and adaptation methods. The research gap as indicated, informed the research design and data collection procedures discussed in the following chapter.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This chapter explains the methodology applied in this study. The aspects that will be looked into are research design and methodology, data collection, as well as data analysis. Research methodology is defined as a way to systematically solve research problems and there are various logical steps to be followed. Research is defined by Leedy (1997:3) as "the systematic process of collecting and analysing information (data) in order to increase our understanding of the phenomenon with which we are concerned or interested."

3.2 RESEARCH DESIGN AND METHODOLOGY

Research design relates to research methods, data collection techniques and the analysis of the collected data. Methodology on the other hand, is defined as the processes undertaken in order to explain the logic behind research methods, (Welman, Kruger and Mitchell 2005). Mahlangu (1987:3-4) defines 'research methodology' as "the study of the logic or rationale underlying the implementation of the scientific approach to the study of reality, a theory of correct scientific decisions". It is inferred from the definitions in this paragraph that the research has to follow a prescribed process in order for it to gain scientific status.

Mahlangu (1987) contributes to the definition of 'methods' and 'methodology'; a 'method' is defined as the techniques used for collecting data about the world around us, whereas 'methodology' is the logic of applying a scientific perspective to the study of events. This research follows a methodology in data collection and data analysis, as will be discussed below.

The research methodology chosen for this study is the quantitative method or approach. The difference between quantitative and qualitative approach is that, with qualitative approach, the data collected are in the form of words and sentences, and some of this information need to be converted into numbers for them to be used quantitatively, whilst, with the quantitative approach, the data collection is numerical in nature and can be mathematically computed. This is to allow for an in-depth understanding of the research problem as outlined in chapter 1. Creswell (2012) writes that in quantitative research, the researcher seeks to measure differences and the magnitude.

Quantitative approach have the advantage that they are cheaper to implement, are standardized so that comparisons can be easily made (Kabir 2016).

3.3 DATA COLLECTION

Data collection is defined as a "process of gathering and measuring information on variables of interest, in an established systematic fashion that enables one to answer stated research questions, test hypotheses, and evaluate outcomes" (Kabir 2016). For purposes of this research, secondary data was extracted from NASA online databases. Five meteorological stations were sampled and data for the period, 1923-2017, for each station was extracted.

Secondary data means information originally collected by one researcher and later accessed by another researcher for research purposes, in order to determine an answer to a current research question, (Smith 2008). Smith (2008) further argues that, this secondary data set come in quantitative format, meaning that the information consists of studied objects whose characteristics are coded in variables that have a range of possible values, derived from primary data. Smith (2008), however, adds that, secondary data can also be non-numeric in nature. In this instance, for purpose of this research, management information systems, NASA online databases, were used as data sources. Satellite precipitation data for drought monitoring was collected, due to the advantages it comes with, namely, (a) consistent and homogeneous data in a quasi-global scale and (b) coverage over areas with no other means of observations, such as, the use of rain gauges and weather radars, (Sorooshian et al. (2011). Among others, other advantages of satellite precipitation data include availability of information despite inability to access an area of interest due to topographical and geographical layout. The fact that it is less costly and time-saving for the researcher is also an advantage. The importance of using the emerging satellite data sets for drought monitoring, especially for validation and verification of model simulations, is further emphasised by Wardlow et al. (2012).

The researcher chose secondary data in this instance, firstly because it is relevant to the current research, also because of the advantages it comes with. Smith et al., (2011) explain some of the advantages of secondary data as - (i) easily accessible compared to primary data, (ii) available on different platforms that can be accessed by the researcher, (iii) very affordable, it requires little to no cost to acquire because it is sometimes freely available, (iv) the time spent on collecting secondary data is usually very little compared to that of primary data, (v) it makes it possible to carry out longitudinal studies without having to wait for a long time to draw conclusions, (vi) It helps to generate new insights into existing primary data. NASA online database is a freely available database from where the precipitation data was sourced. Time and cost were of great essence because, if it was not for the NASA online database, the researcher would not be in a position to access the precipitation records for 94 years period.

3.3.1 Data reliability and validity

What comes together with data reliability and validity is data quality. Hewson (2016) argues that using data that has been collected by a specialist team of experts not only maximises data quality, but also proves efficient in terms of time and cost. Hewson (2016) further argues that large data sets often contain a wealth of information which is not exhausted in relation to one particular research question.

Creswell (2012) reiterates the fact that, a goal of good research is to have measures or observations that are reliable. As already argued by Hewson (2016), data collected by specialist team of experts maximises quality; that in itself carries a weight of reliability for if the data is of maximum quality, the data stand to be reliable. When data is reliable, it is equally vital that the data is valid as well. Creswell (2012) further argues that validity is the development of sound evidence to demonstrate that the test interpretation of scores about the concept or construct that the test is assumed to measure, matches its proposed use. Data used in this research is from NASA online database, whereby specialist team of experts, as suggested by Hewson (2016), collects the data. Now that the data was collected by specialist team of experts, it can be inferred that the data is of maximum quality, hence, also reliable and valid. Sarojini, Stott and Black (2016) reiterate the fact that reliable and accurate estimates of precipitation are not only crucial for the study of climate variability but are also important for water resource management, agriculture, and weather, climate, and hydrological forecasting. Data reliability and validity are therefore vital for the findings of a research to be trusted. Trust is crucial as the recommendations of the research are bound to be implemented by one organisation or the other.

Homogeneity, in simple terms, means the state of being all the same or all of the same kind, however, statistically, data homogeneity means a dataset of all items in the sample are chosen because they have similarities in one way or the other. For example, people in a homogeneous sample might share the same gender and age. Now, in the context of the precipitation data used in this research, the data contains millimetres of rainfall data values, which differ from month to month, depending on the amount of rainfall, the data in this instance is bound to be different from month to month. The fact that the rainfall values differ from month to month does not take away the fact that the data is homogenous, simply because, the data comes from the same population. Chebana, Ouarda and Duong (2010) define 'homogenous' as all observations arising from the same population, implying that they have the same underlying distribution. Testing for homogeneity of a sample implies, therefore, the verification that the collected data do not represent a mix of several samples from different populations. Now that, the precipitation data from NASA online databases is used in this research, the data comprises of different rainfall values that are a measure of the amount of rainfall in millimetres that has fallen in a given month. It is important to note that the rainfall in this regard is the only variable that is being used.

Stationarity means the absence of significant change of series over time. Chebana et al. (2010) define 'stationarity' as the absence of significant increase or decrease of mean and/or scale throughout the observation period. This means that, if the variable, in the context of this research, precipitation data, is constant and shows no sign of increase or decrease, there would not be a trend change, and therefore the stationarity would prevail. The data would, therefore, be put on a trend analysis software to determine if there is a trend or not, whilst, at the same time, determining stationarity. Stationarity, homogeneous and trend have a relationship, in that a sample is homogenous if it comes from a strictly stationary process and conversely, therefore, on the abstract level, homogeneity of a time series corresponds to strict stationarity (Chebana et al. 2010).

Outlier, in simple terms means the data item which is detached from the rest of the data items. In the context of the data set, an outlier would be a value too high or too low in comparison to the rest of the values of the data set. Literature show that there are outlier detection methods, which are out there, which include Tukey's fences. Literature also show methods to work with outlier, which include either discarding or retention of outlier. In this instance, it would not be feasible for the data to be subjected to any test because every value of this precipitation data is vital. The values are all vital because the aim of the research is based on drought analysis, for one to get the ultimate results, all values should receive equal care and treatment.

3.4 DATA ANALYSIS

Mouton (2006:108) explains the aim of data analysis as "being that of understanding the various constitutive elements of the data by scrutinising the relationship between concepts, constructs or variables, in order to establish repeated themes". For the purpose of this research, secondary data extracted from NASA online database was used. Secondary data analysis is defined by Hewson (2006) as the further analysis of existing data sets with the aim of addressing a research question distinct from the one the data was meant for, or originally collected for, and generating novel interpretations and conclusions. The univariate precipitation data as extracted from NASA, would be fed into the Drought Indices Calculator (DrinC) Software Package. This would enable the researcher to analyse computed SPI values according to the chosen time scales.

3.4.1 Drought Indices Calculator Software Package

It is important to note that, Drought Indices Calculator (DrinC) is a software, which is capable of computing data for various drought indices. Now to contextualise this, the software was used to compute precipitation data from 1923 until 2017, in order to determine drought severity and duration using Standard Precipitation Index, (SPI), in the Free State Province. In this study, historical time series of daily precipitation from five (5) weather stations, covering the period 1923–2017, from Free State Province, South Africa, were extracted from NASA online database and analysed. Some meteorological stations are often unable to capture all data, making it difficult to have a continuous data time series of the selected time period of study, however, SPI drought index is able to compute even though some data are missing.

As already stated, the advantages of using SPI are premised on the principle of parsimony and the ability to quantify the magnitude, duration, and extent of droughts, independently, of the local climatic conditions. The parsimony principle here is based on the fact that only precipitation data is sought for computation purposes. McKee et al. (1993) explain that the SPI requires only one input variable, could be applied in a similar way to precipitation, snowpack, streamflow, reservoir storage, soil moisture, and ground water, recognizes a variety of time scales, and provides information on precipitation deficit, percent of average and probability. Morid, Smakhtin, and Moghaddasi (2006) reiterate the fact that SPI requires only precipitation as an input and has capability to monitor both dry conditions represented by negative values and wet conditions represented by positive values. The more negative the SPI value, the more severe the drought, however, if the positive values persist, it is a good sign that the drought is ending or has ended.

Now that, the SPI is the drought index of choice by virtue of it being used here as a tool to determine drought risk characteristics, it is important to note that, for one to determine drought severity and duration, SPI needs the support of other software for computing of data series; the software package, DrinC, was chosen for this purpose. Essentially, the researcher would like to determine hydrological drought risk characteristics using SPI, therefore, it would not be possible without first, determining the intensity, severity and drought duration in the Free State Province, hence, the use of the software, DrinC.

3.4.2 Data processing

Monthly precipitation data were extracted from five meteorological stations, collected via satellite and maintained by NASA for SPI calculations. The complete time series of precipitation for each station data were chosen from January 1923 to December 2017. NASA keeps strict control over data quality and missing data values were substituted with average values. The same data calculation method was used for each station within the Free State Province. The South African weather seasons are grouped accordingly as spring (September, October, November), summer (December, January, February), autumn (March, April, May), and winter (June, July, and August). The rainy season in South Africa is in summer, hence, less or no rain is received in winter, however, for DrinC software, data was arranged from October to September in accordance with the software specifications and for reliable results to be attained. The analysis was then conducted as per individual time scales of SPI-6, SPI-9 and SPI-12.

3.4.3 Calculation of SPI

SPI was developed for drought events to be monitored at different time scales of 3, 6, 12, 24 months or more. To calculate SPI, at least 20 to 30 years of monthly precipitation data is required, even more than 30 years is ideal, hence, the using of data from 1923 to 2017 for the purpose of this research. The period of focus, therefore, was 94 years, and the SPI for time scale of 6-, 9- and 12-months was calculated, herewith, referred to as SPI-6, SPI-9 and SPI-12. According to Spinoni, et al. (2014) and Tan et al. (2015), duration of a drought event equals the number of months between the start of drought and the month it ends, whilst severity is calculated as the absolute value of the sum of all SPI values during a drought event (see equation 3.1). Intensity of a drought event on the other hand, refers to severity divided by duration (see equation 3.2). The larger the severity value, the more severe the drought is. Drought frequency is determined by the number of drought events divided by total number of years for the study period, per meteorological station, multiplied by 100% (see equation 3.3).

$$Se=\sum_{ji}^{m} Indexj \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 3.1}$$

$$DIe=Se/m \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 3.2}$$

where **e** is a drought event; **j** is a month; **Indexj** is the SPI value in month **j**; **m**, **Se** and **DIe** are the duration, severity, and intensity of a drought event **e**, respectively.

$$Fs=ns/Ns(100\%) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Eqn 3.3}$$

where **ns** is number of drought events, **Ns** is total number of years for the study period, and **s** is a station

3.4.4 Mann Kendall (M-K)

Of the three approaches to detect and assess trends as identified by Clement and Thas (2009), the non-parametric method, based on the Mann–Kendall test is applied for this research. Mann-Kendall test (Mann 1945 and Kendall 1975) is one method amongst others which is preferred by various researchers, (Kundu et al. 2015). The choice for the use of this test is also premised on the fact that it is widely accepted in hydrology as proclaimed by Khaliq et al. (2009) and also mainly because it is one of the two trend-analytic tools recommended by the WMO, (Adeloye and Montaseri 2002). According to Zhang et al. (2006), Mann Kendall test also known as (M–K) trend test, is a non-parametric statistical test; it is used frequently to evaluate significance in a monotonic increasing or decreasing trend in hydro-meteorological time-series including a series of drought indices, in this case, SPI. Kulkarni and von Storch (1995) conducted a test which illustrated that Mann-Kendall test, does reject the null hypothesis of no trends. A Mann Kendal test was conducted in this research to determine if there is a trend or not. Duhan and Pandey (2013) argue that Mann-Kendall test does not need datasets to follow normal distribution and show homogeneity in variance; transformations are not basically required if data already follows normal distribution, in skewed distribution greater power is achieved.

3.5. ETHICAL CONSIDERATIONS

The researcher understands the importance of ethical considerations; however, the data used is freely available. Notwithstanding the fact that the data is freely available, the researcher understands among other things, confidentiality and privacy aspects regarding ethical clearance. In this regard, the researcher did not rely on any primary data, there were, therefore, no special permissions from any authorities, institutions or any other interested parties that were required. The researcher relied primarily on secondary data and for this reason, only ethical clearance from the University of Free State was sought, clearance was granted with the following number: UFS-HSD2020/0742/306. On the other hand, full referencing of sources was used in order to avoid plagiarism.

3.6. SUMMARY

This chapter illustrated how the research was conducted. It provided a discussion of the research design, data collection methods and analysis, and ethical considerations of the study. The research approaches, such as quantitative approach were discussed, giving various definitions and their advantages. Data collection was discussed and it was shown that secondary data was the central source for this research. The researcher discussed the stages of research as outlined in research methodology literature. The researcher opted for quantitative method so that a comprehensive understanding of the research phenomenon is adequately provided. The use of this method gave the researcher an opportunity to collect secondary data as per the requirements of the research questions, as well as to follow a systematic approach in obtaining empirical findings, as documented in the next chapter.

CHAPTER 4: DATA ANALYSIS

4.1 INTRODUCTION

Creswell (2012) explains that data analysis pertains to analysing and interpreting the data that involves drawing conclusions about it; representing it in tables, figures, and pictures to summarize it; and explaining the conclusions in words to provide answers to your research questions. This chapter therefore presents data analysis, and details of the findings of the research. The data is explained with the help of figures, tables and frequencies so that the findings are interpreted and recorded. Secondary data for the five sampled meteorological stations was extracted from NASA online databases. Data was found to be of acceptable quality as argued by Hewson (2016). Data was then tested for homogeneity by making use of Pettitt's test. Microsoft Excel was used to record and analyse data then the data was imported into DrinC software package for further analysis. As Mouton (1993: 170-173) explains, "presentation of the researcher's case should be logically, objectively, persuasively and concisely constructed". The researcher therefore opted to present the analysis in the sequential format which followed the order of rainfall chart representing raw data, descriptive statistics of rainfall which was extrapolated from the raw data, homogeneity test for all stations, trend test for rainfall of all the stations, plot of SPI for all stations, return periods as well as severity.

4.2 SECONDARY DATA

The figures below represents plots for the rainfall secondary data, which was extracted from NASA online database. The rainfall data was recorded on Microsoft Excel software so that charts could be created in order for researcher to make meaningful interpretation of the data.

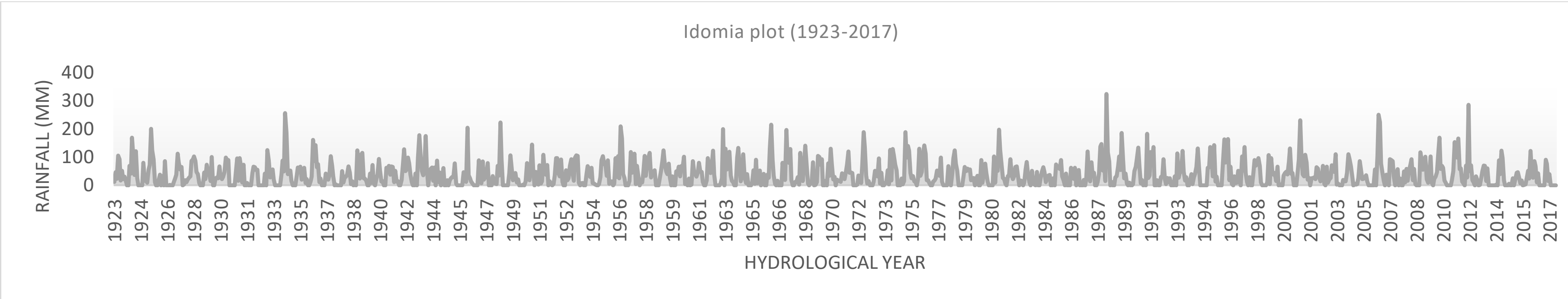

Figure 4.1 illustrates the rainfall patterns at Idomia weather station.

Rainfall pattern at this station has always been at a low, ranging below 12.2mm, with 12.2mm recorded in 1923 and the highest recorded being 256.2mm in 1934. The rainfall pattern remained at a low with just a few mm above or below 200 mm value. The highest recorded at this station was 324mm in 1988 meaning that, the rainfall recorded at this station has never reached 400mm value.

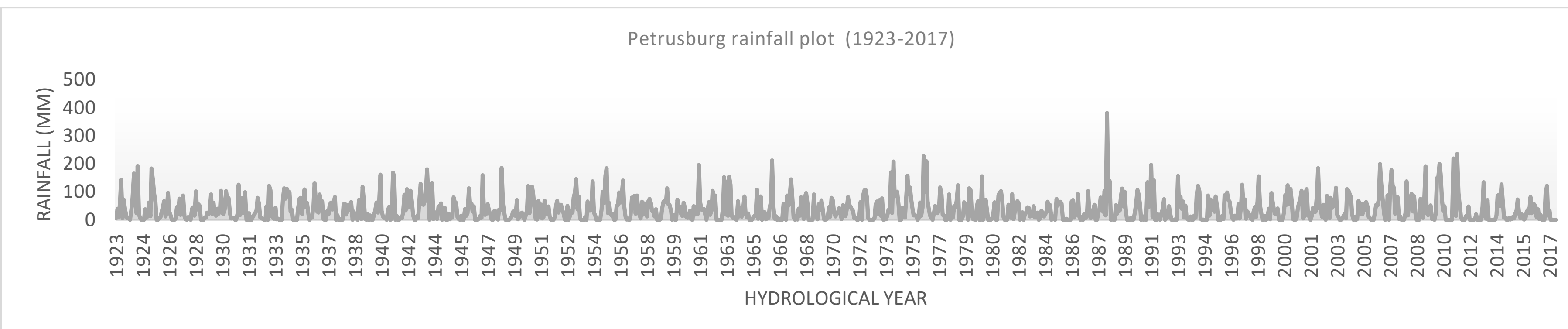

Figure 4.2 illustrates the rainfall pattern at Petrusburg weather station.

At this station, the rainfall pattern, as compared to Idomia, has also been low, ranging between 0mm to 227mm, which was recorded in 1976. The highest recorded rainfall at this station was 381mm, which was recorded in 1988. This precedes a decreased value of 235 in 2011; the values decreased even further implying that, the rainfall patterns never reached 400mm at this station, just the same as Idomia station.

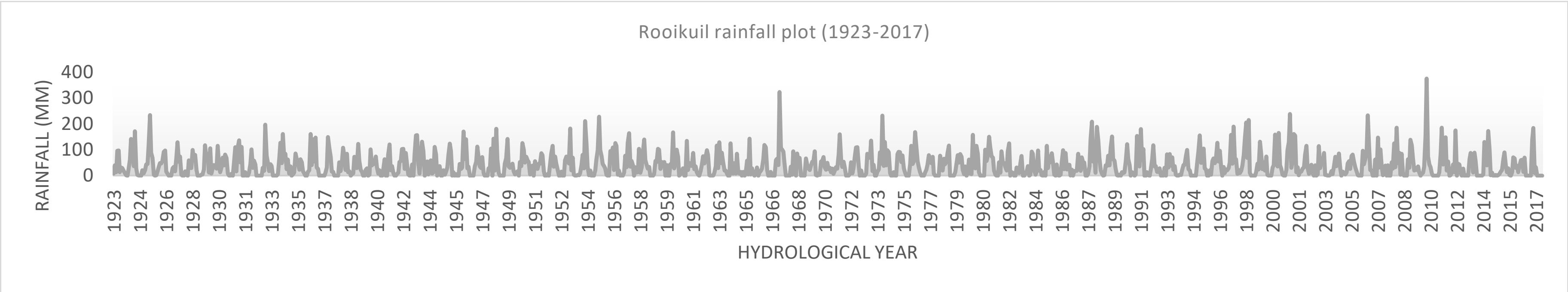

Figure 4.3 illustrates rainfall pattern at Rooibult weather station.

Rainfall patterns has ranged between 0mm and 200mm most of the time. Rainfall exceeding 200mm was recorded at least on ten occasions with the value of 233.2mm recorded in 1967 and the highest recorded value of 375mm recorded in 2010.

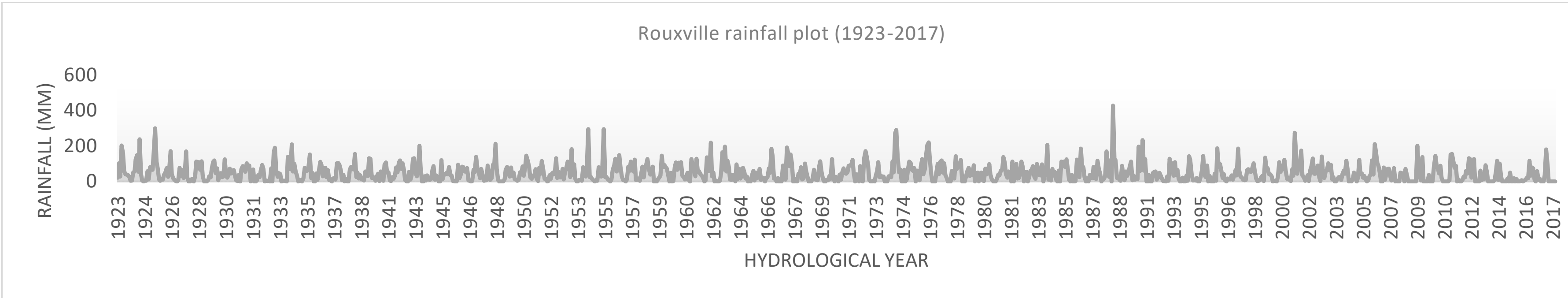

Figure 4.4 illustrates rainfall patterns at Rouxville weather station.

At this station, the rainfall has exceeded 200mm mark at least on sixteen occasions. 299mm was recorded in 1925, 295mm was recorded in 1954 as well as in 1955. A record 427.5mm was recorded in 1988.

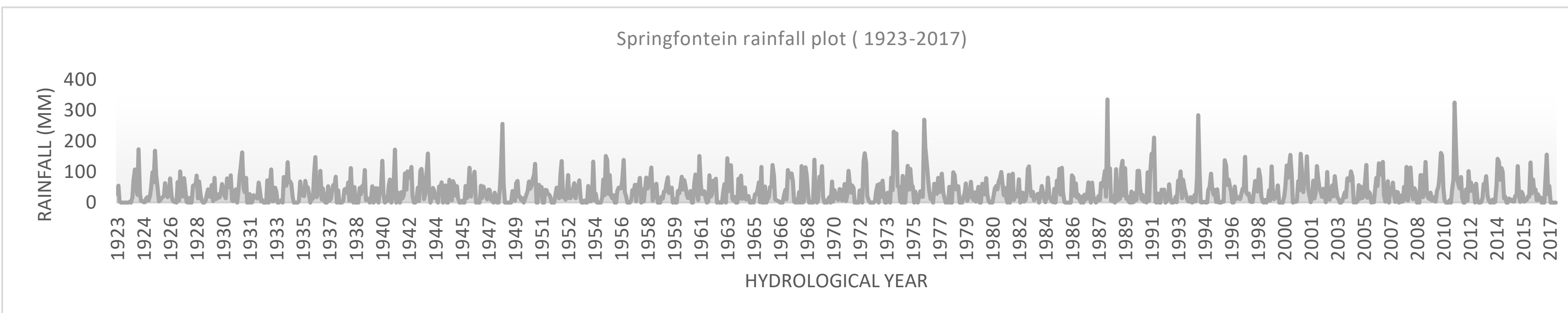

Figure 4.5 illustrates rainfall patterns at Springfontein weather station.

The rainfall pattern at this station has always ranged between 0mm and just below 200mm, there is, however, a record where the rainfall exceeded 200mm mark on seven occasions. Year 1948 has seen rainfall record of 256.4mm, in 1974 225.5mm, in 1970 270mm, in 1988 335.3mm, in 1991 211.1mm, 1994 284.5mm, and 325.3mm in 2011. It is seen again that, the highest record at this station is 335.3mm in 1988.

It can be seen that, the majority of the stations have recorded the highest value in 1988 except for just one station, Rooibult. This station recorded 323.5mm in 1967 and the highest recorded was 375mm in 2010. All the stations has recorded rainfall lower than 400mm confirming that, South Africa receives lower rainfall compared to global average which is 860mm. The implication of the reduced rainfall is that, the situation has a potential of developing into drought, progressing through drought stages into hydrological drought. The impacts of hydrological drought are such that, the water resources are unable to recharge or take too long to recharge exacerbating the hydrological drought situation in this regard.

4.2.1 Descriptive Statistics

Descriptive statistics summarise raw data and make a deductible and meaningful interpretable analyses to enable a decision maker to have insight of the past.

Table 4.1: Descriptive statistics of rainfall

Statistic	Idomia	Petrusburg	Rooibult	Rouxville	Springfontein
Nbr. of observations	1141	1141	1141	1141	1141
Minimum	0.000	0.000	0.000	0.000	0.000
Maximum	100.000	100.000	100.000	100.000	100.000
Range	100.000	100.000	100.000	100.000	100.000
1st Quartile	0.118	0.787	0.933	1.637	1.193
Median	8.187	5.812	7.493	7.719	6.994
3rd Quartile	19.552	15.324	16.933	16.854	16.485
Mean	12.427	9.887	11.201	11.073	11.150
Variance (n-1)	194.510	134.230	158.603	141.478	164.212
Standard deviation (n-1)	13.947	11.586	12.594	11.894	12.815
Variation coefficient (n-1)	1.122	1.172	1.124	1.074	1.149

Descriptive statistic was applied to the data as shown in table 4.1 above. It can be seen that, observations were made across all five stations. The minimum and maximum rainfall across all stations was recorded. The mean refers to the average rainfall received at each station and only 20% of the stations shows a relatively higher average rainfall received as compared to the other four stations. The other stations received more or less same average rainfall except for 20% which has received an average rainfall that is relatively lower compared to the others. It can be concluded that the majority of the stations have been starved of rainfall with each station receiving an average of less than 12.427mm of rainfall.

The variation coefficient therefore measures relative variability as the ratio of the standard deviation to the average or the mean. Variation in this regard refers to change in rainfall per individual station over the time scale. The variation coefficient of rainfall in this context is acceptable if it is not too much to cause drought or floods. It can be seen that, the variation coefficient for 20% of the stations is relatively lower as compared to the other stations. This is an indication that, the rainfall pattern at his station did not change drastically overtime to cause severe and extreme drought. Even though it can be accepted that drought has occurred depending on the minimal amount of rainfall received, it can also be said that the change in rainfall pattern has been consistent. The 80% of the stations shows a higher variation of rainfall received as compared to the 20%, implying that, high possibility of drought has taken place as an indication of drought risk in the province.

4.2.2 Homogeneity Test

The data was subjected to homogeneity test in order to determine the consistence of data over the years despite the change in the tools used to collect data. The possibility of data being corrupted by equipment failure or change in the data collection mechanism is high, but the homogeneity test has a capability to test if the change was significant or not. The table below illustrate the results of the homogeneity tests conducted.

Table 4.2 Pettitt's test (rainfall): Homogeneity test

Parameter	Idomia	Petrusburg	Rooibult	Rouxville	Springfontein
K	15988	21352	14480	41791	19887
t	2012	2010	2010	1991	1974
p-value (Two-tailed)	0.711	0.675	0.786	0.577	0.757
alpha	0.05	0.05	0.05	0.05	0.05

Table 4.2 above illustrate the Pettitt's test results. The results represents the homogeneity tests that were conducted for the rainfall data for all five stations. The ***t*** illustrates the time the change in data occurred. The ***p*** illustrates the percentage level the change occurred. The alpha represents the benchmark upon which the change is measured, meaning that if the change is above or below the benchmark, the change has significance or non-significance to influence the unreliability or the reliability of data. The homogeneity test is very critical and it is therefore a determinant factor to cause the researcher to carry on with the research or to abandon the research, that is if the data is reliable or not. The researcher conducted a homogeneity test and found that, the change of data

happened in 2012, it does not matter what caused the change. What is important in this instance is to determine if the change was significant to warrant the data reliable or not. To determine if the data is reliable the ***p*** value needs to be above the alpha value. Alpha value is also referred to as significance level. The change took place in 100% of the stations. Was the change significant to render the data unreliable or not? The two tailed ***p*** value was found to be above the significance level (0.05) in 100% of the meteorological stations. If the ***p*** value is found to be below the significance level, the change would then be significant enough to render the data unreliable. The data passed the homogeneity test and it is therefore homogeneous. The change that took place was insignificant and therefore, the researcher is good to proceed with the research.

4.2.3 Trend Test

Trend test in this regard relates to the decreasing or increasing amount of rainfall measured per meteorological station. This is determined by the comparison of every data value preceding it in a data series. The presence of trend is illustrated by the sign value either increasing consistently or decreasing consistently. In the context of this research, the increasing trend would mean the movement of copious rainfall and the decreasing trend would mean the movement towards less rain. The table below represents the results of the trend test that was conducted.

Table 4.3: Mann-Kendall trend test / Two-tailed test (rainfall)

Parameter	Idomia	Petrusburg	Rooibult	Rouxville	Springfontein
Kendall's tau	-0.004	-0.018	-0.009	-0.071	0.022
S	-2256.000	-11330.000	-5428.000	-43646.000	14164.000
Var (S)	162162805	163265905	163125345	154021197	163719394
p-value (Two-tailed)	0.859	0.375	0.671	0.000	0.268
alpha	0.05	0.05	0.05	0.05	0.05

Mann –Kendall trend test was conducted in order for the researcher to find if there was a trend of rainfall decreasing or increasing. Table 4.3 above presents the results of the test. The measurement here is benchmarked by the alpha value; alpha value is also referred to as the significant level. The benchmark is therefore fixed at value of 0.05. The measure of whether there is a trend or not is compared against the benchmark represented by the ***p*** value. If the ***p*** value is above the significant level, there is no trend, and if the ***p*** value is below the significant level, there is trend. Kendal's tau in this regard, indicates whether the trend is increasing or decreasing. The negative Kendall's tau value represents the decreasing trend whilst the positive value represents the increasing trend.

It is seen that the majority (80%) of the stations relative to 20% experienced a decreasing trend, even though this decreasing trend is not significant. For the decreasing trend to be significant, whilst the Kendal's tau has a negative value, the ***p*** value on the other hand, should have a value less than the significant value. Now, it is seen that, 60% of the stations, i.e., the Idomia, Petrusburg, and Rooibult have negative Kendall's tau values except for Springfontein, which has a positive Kendall's tau value. It is however important to note that, even though the ***p*** values are above significant level, all three stations with the negative Kendall's tau value do not have a significant decreasing rainfall trend. Springfontein station has a decreasing trend even though it has a positive Kendall's tau value and a ***p*** value above the significant level.

Rouxville, making up 20% of the stations experienced a decreasing rainfall trend because the ***p*** value is lower than the significant value, whilst at the same time the Kendall's tau has a negative value. The decreasing rainfall trend in this instance is significant, meaning that, the rainfall at this station has a decreasing trend. This is a worrying factor because the decreasing rainfall means that the water supply is diminishing and that the water resources are taking too long to recharge. The decreased rainfall is of high detriment to the water resource managers and any other end user such as the farmers, industry and for household use. The decreasing rainfall trend also mean that, the agricultural activities in this town are disrupted and calls for mechanical means of water supply to be implemented. The mechanical irrigation systems are costly for the farming community. Mechanical irrigation system would mean that water has to be piped from neighbouring towns or provinces. Boreholes would also come handy in this regard and also at a cost. This is so that the human, the crops, environment and livestock can get sufficient water supply for survival and improvement of quality of live as well as of the agricultural products, failure which, the impacts of hydrological drought would be felt

4.3 DATA ANALYSIS

4.3.1 Hydrological Drought and Standard Precipitation Index

It has already been shown that SPI is a drought index that is used to measure the level of dryness and wetness. In the study, SPI is used to determine the hydrological drought risk characteristics but first the level of hydrological drought has to be determined. SPI can be used to measure the extend of drought from as low as one month up to twenty-four months. However, for one to measure the extend of hydrological drought, at least three months times scale is calculated. For this research, the researcher used the time scales of six, nine and twelve months to measure the extend of drought in the Free State Province of South Africa. For these SPI calculations to be made, rainfall data from five sampled meteorological stations was extracted from NASA online databases. Microsoft Excel was used to sort and analyse the data after which the data was imported into the DrinC software to determine the SPI. The figures below illustrate the level of drought as calculated by making use of DrinC software on the time scales of SPI-6, SPI-9 and SPI-12.

4.3.1.1 Standard Precipitation Index (SPI-6)

The figures below represents the SPI-6 calculations that were conducted using DrinC software. SPI-6 are the calculations of the drought occurrences by making use of the six (6) month's rainfall data. The figure presents the SPI class characterisation depicting the level of hydrological drought as measured from the five sampled meteorological stations. The level of wetness and of dryness is a measure of moving out of drought and into drought symbolising the end or beginning of drought respectively. The end or beginning of drought is measured by the SPI classification whereby the ≥2 SPI value illustrate the level of wetness and contrarily, the SPI -1.99**-,** -1.5 and ≤2 depicts the severity and extremity of drought respectively. This means that if the SPI move beyond negative value, the drought is coming in and if the SPI value moves further in to negative, the drought progresses into mild, moderate, severe and extreme stages.

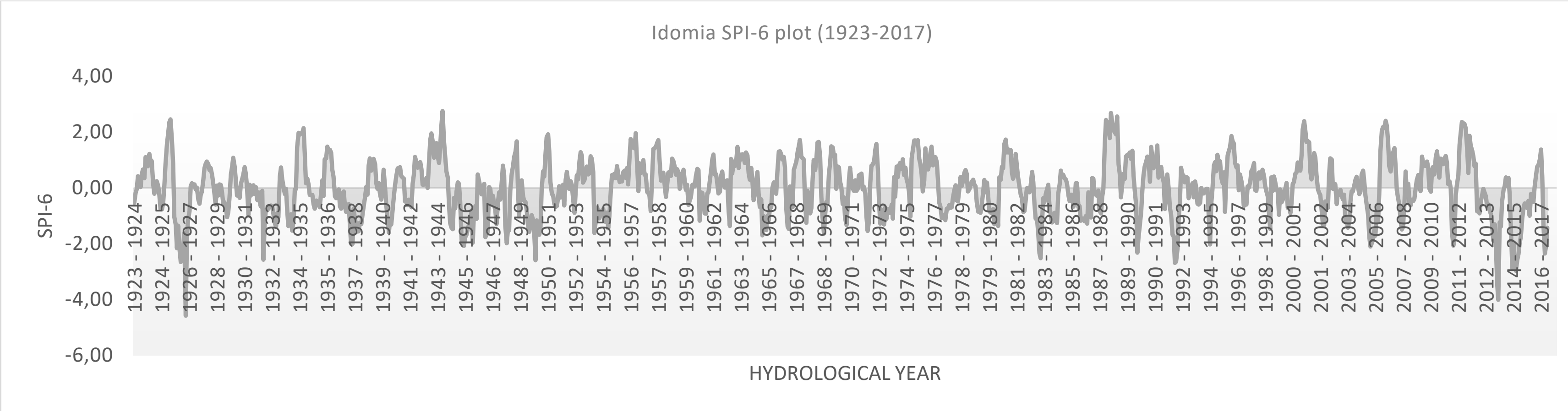

Figure 4.6 shows the SPI-6 for Idomia station.

The station shows the occurrences of drought over the years from the year 1923 with the SPI values going lower than ≤2 on more than ten occasions. The station has seen the SPI values going even further below ≤4 in 1926-1927 as well as in 2013-2014. The drought episode lingered in 2013-2014, 2015-2016 and in 2017-2017, of which the drought episode of 2015-2016 saw a provincial disaster declared in the Free State Province.

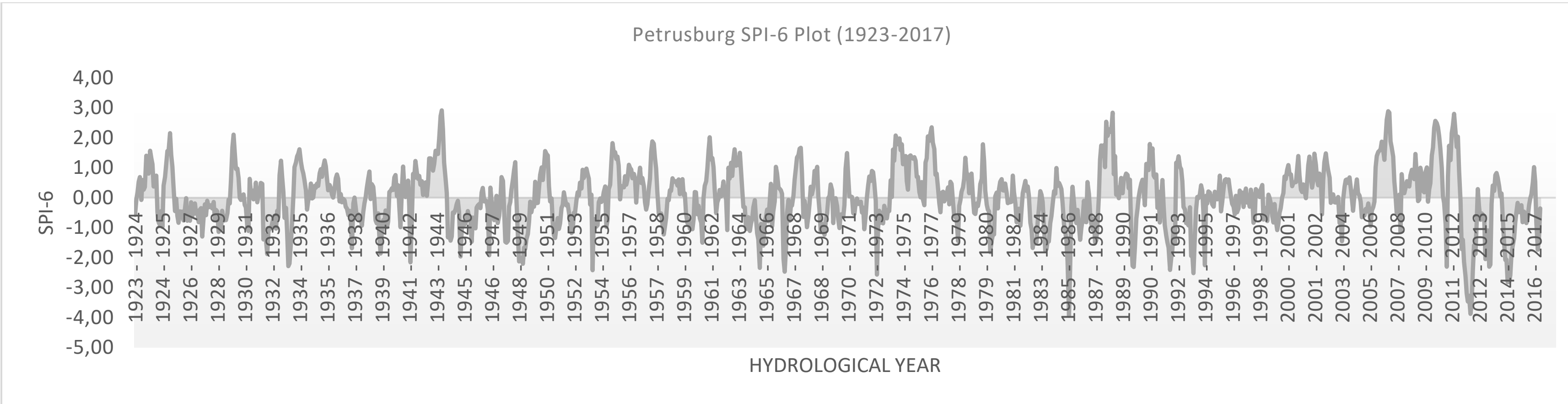

Figure 4.7 shows the SPI-6 for Petrusburg.

The station shows the persistent drought episodes with the SPI values going below ≤2 on about fifteen occasions. The highest value for a drought episode is shown to be just below ≤4 at -3.94 in 1985-1986. The station also shows the drought episode that took place in 2012-2013 which shows the SPI value just below ≤4 at -3.88. This drought episode preceded the drought episode of 2014-2015 as well as 2016-2017.

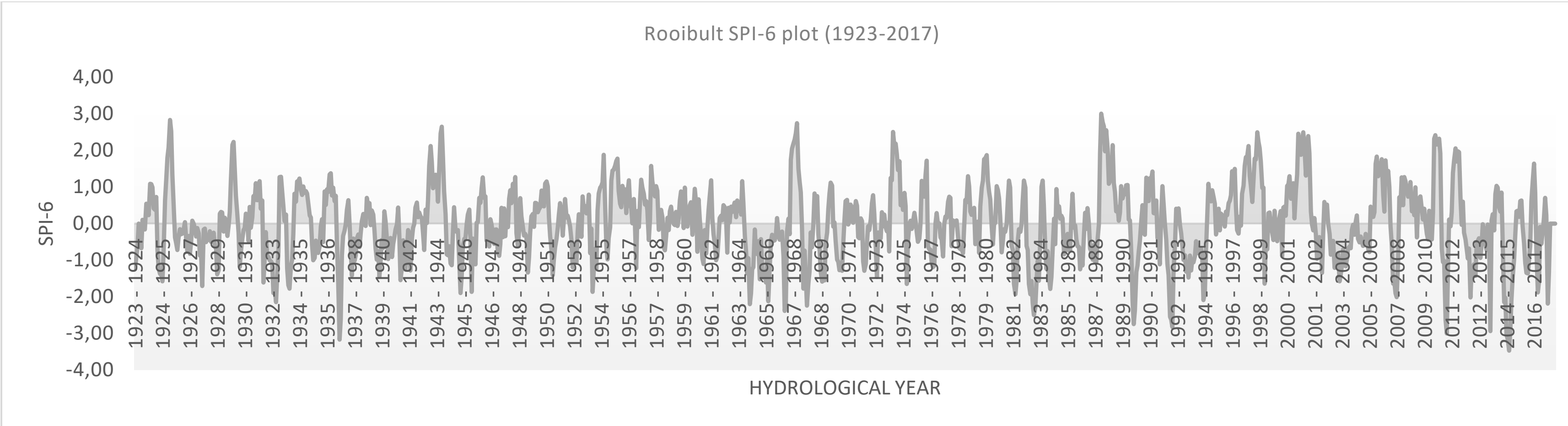

Figure 4.8 shows the SPI-6 for Rooibult.

The drought episodes at this station has been persistent over the years with values below ≤2 showing on more than ten occasions. Low SPI value denoting drought was -3.17 in the years 1936-1937. The lowest value of -3.47 was however in the years 2014-2015 signalling the severe to extreme drought episode in consistent with the other stations, Idomia and Petrusburg. It is worth noting that, the lower the SPI value the more the drought progresses into severe and ultimately into extreme drought.

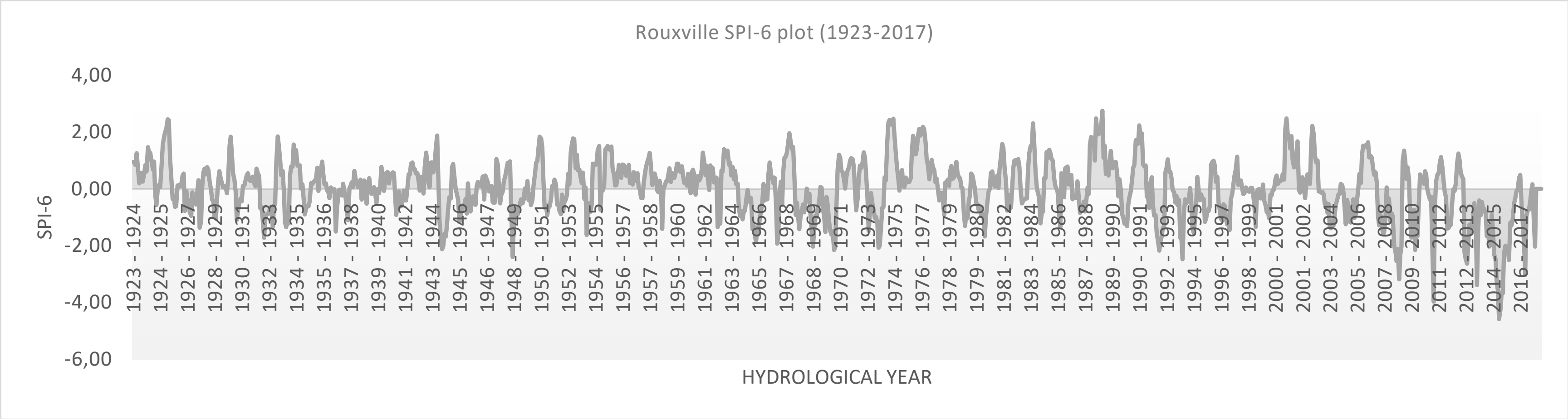

Figure 4.9 shows the SPI-6 for Rouxville.

Just like with the other stations as discussed above, this station has also seen the episodes of drought over the years, even though the drought events were not as severe as the ones reflected in the other stations. The station has however seen the record low SPI values which denote the severity of drought in years 2008-2009, with the SPI value of -3.17, -3.97 in the years 2010-2011 and the record lowest of -4.59 recorded in the years 2015-2016 which is consistent with other stations as discussed above.

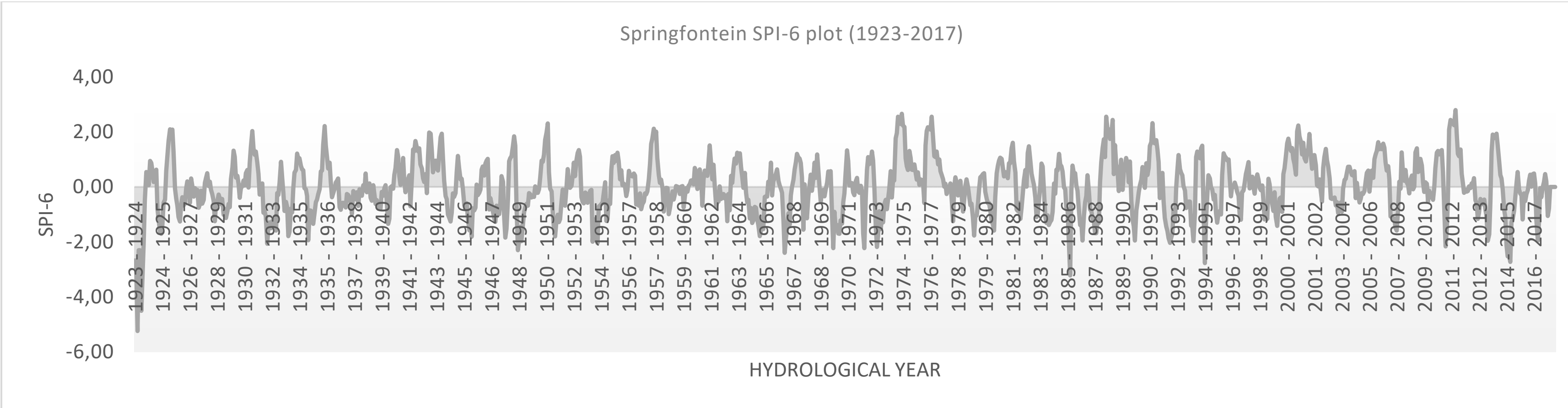

Figure 4.10 shows the SPI for Springfontein.

This station shows the extreme drought episode, which happened in the years 1923-1924 where a lowest SPI value of -5.27, was recorded. The station has also seen multiple episodes of drought over the years with the values lower than ≤2, with the lower value of -3.22 happening in 1985-1986. This station is also consistent with other stations to record drought episode in the years 2015-2016.

Majority of the stations show the persistence of hydrological drought with stations recording SPI-6 value of 0.00 and lower throughout the study period. Consistent with the drought declaration in the province in the years 2015-2016, by measure of SPI-6, all five stations confirms the prevalence of drought episodes in the Free State Province.

4.3.1.2 Standard Precipitation Index (SPI-9)

Figures 4.11-4.15 below represents the SPI-9 calculations that were conducted using DrinC software. These sections deals with the SPI calculations calculated out of nine months rainfall data form the sampled five stations.

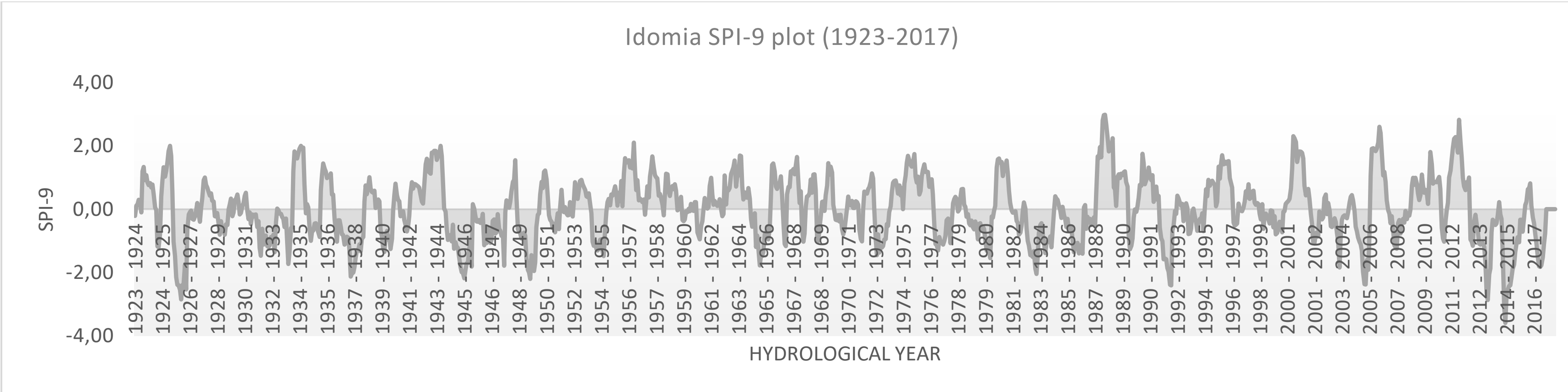

Figure 4.11 above represents SPI-9 for Idomia station.

The drought at this station has been persistent over the years, with the SPI values below -3.00 only in the years 1925-1926 as well as in the years 2014-2015 where a value of -359 was registered.

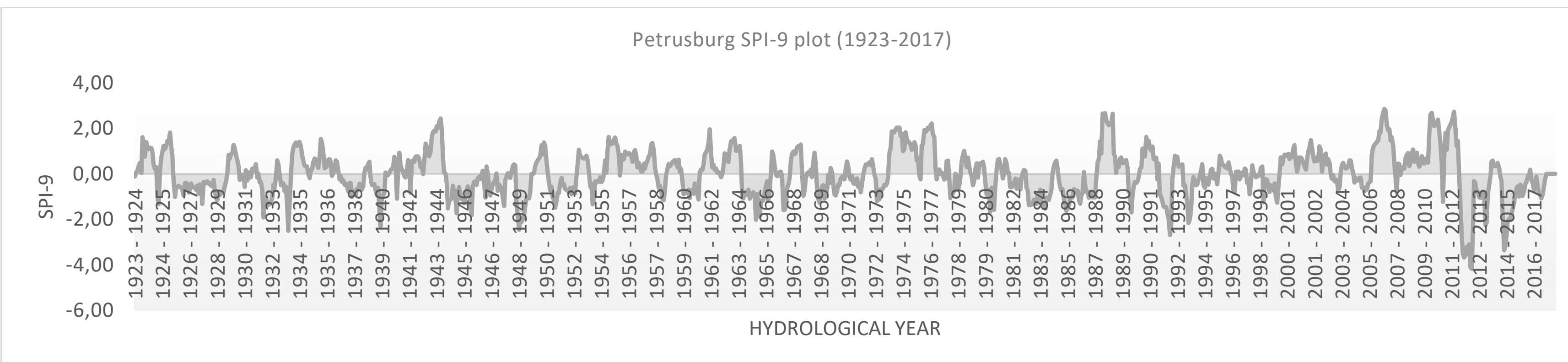

Figure 4.12   represents SPI-9 for Petrusburg station.

The SPI at this station illustrates the episodes of drought that happened over the years. The SPI values here shows drought occurrences, with the values between 0.00 and -1.00 over the years and between -1.00 and -2.00. This station is also recorded drought episode in the years 2012-2013 of -4.10.

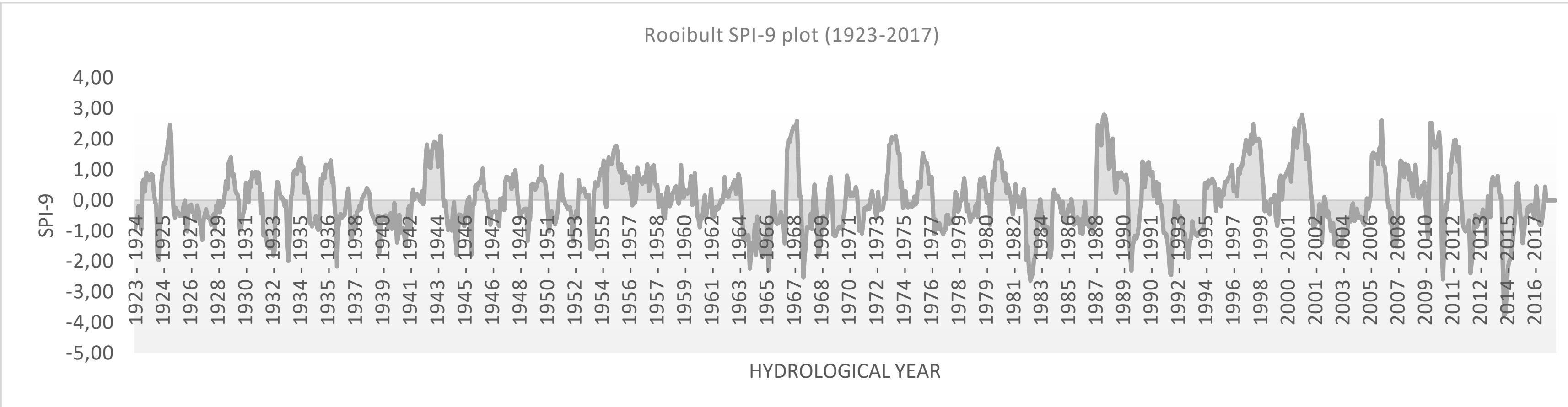

Figure 4.13 represents SPI-9 at Rooibult station.

This station has also recorded drought episodes over the years with the SPI-9 value of -3.71 recorded in 2 years 2014-2015.

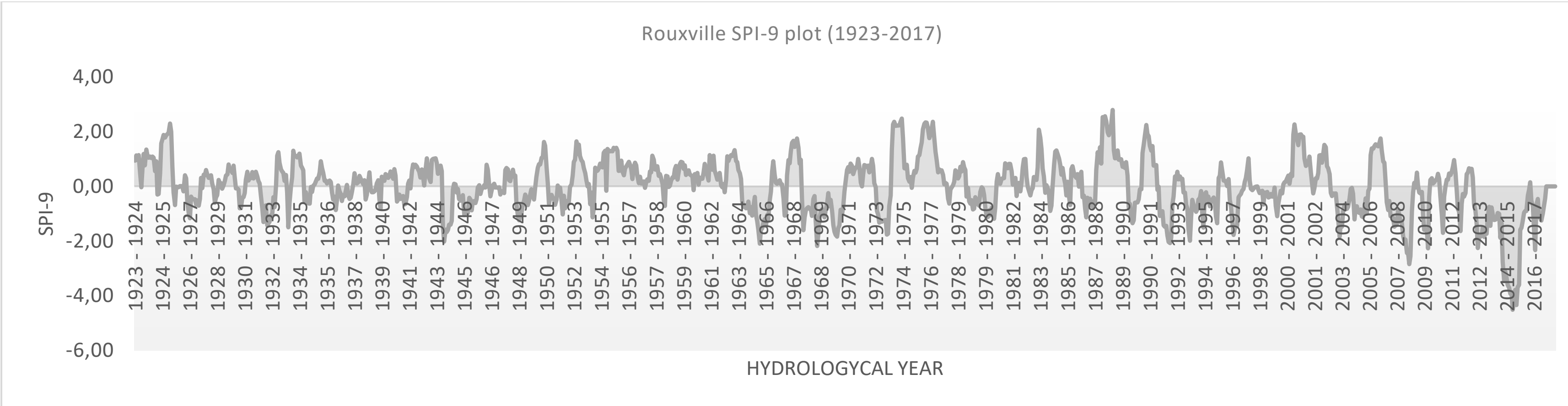

Figure 4.14 represents SPI-9 at Rouxville station.

At this station, of all the drought episodes that occurred over the years, the station recorded the biggest drought, a measure of -4.51 in the years 2014-2016.

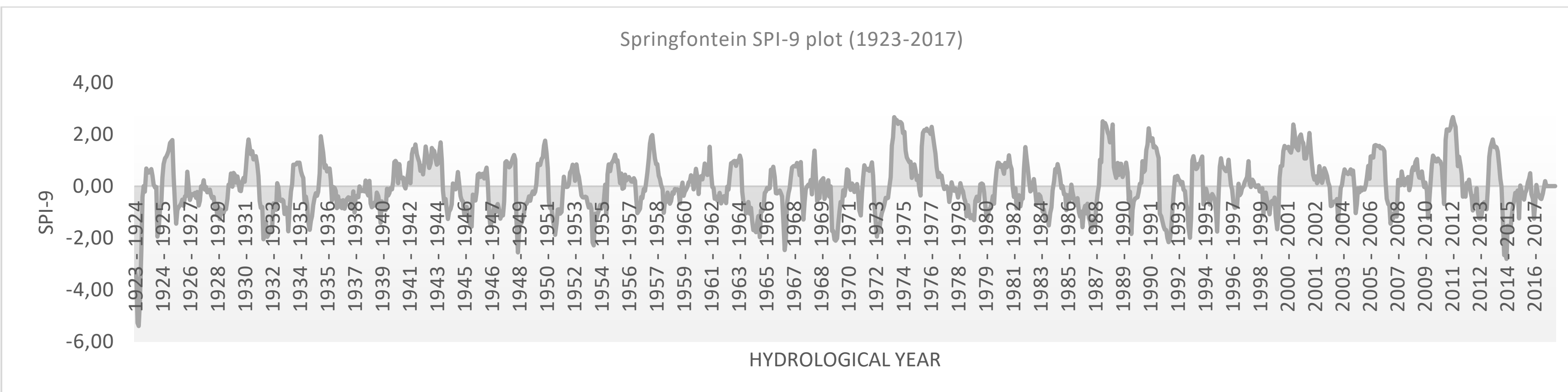

Figure 4.15 represents SPI-9 at Springfontein station.

The drought episodes at this station has been persistent over the years covered by this study, however, the extreme drought of SPI-9 value of -5.39 was recorded in the years 1923-1924. Consistent with the SPI values of the other stations, this station also recorded a drought episode of about -3.00 1n the years 2014-2015.

Majority of the stations show the persistence of hydrological drought with stations recording SPI-9 value of 0.00 and lower throughout the study period. Consistent with the drought declaration in the province in the years 2015-2016, by measure of SPI-9, all five stations confirms the prevalence of drought episodes in the Free State Province.

4.3.1.3 Standard Precipitation Index (SPI-12)

The figures below represents the SPI-12 calculations that were conducted using DrinC software. SPI-12 implies that, the calculations of the drought occurrences were made by making use of the twelve (12) month's rainfall data. The figure presents the SPI-12 class characterisation depicting the level of hydrological drought as measured from the five (5) sampled meteorological stations.

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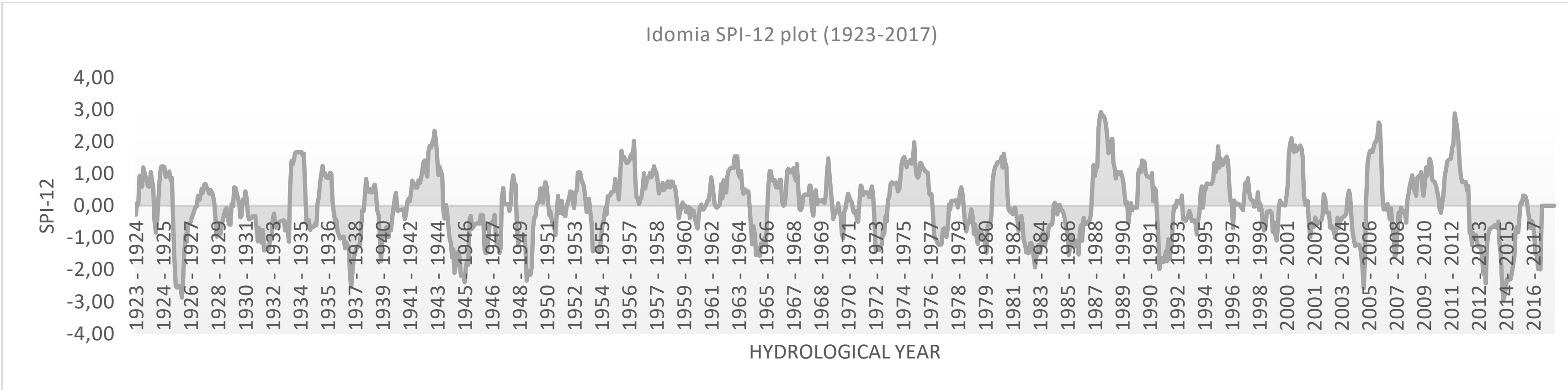

Figure 4.16 represents the SPI-12 from Idomia station.

This station has recorded a multiple drought episodes over the years from 1923 to 2017. The SPI-12 values are shown to be below ≤ 3.00 and below -1.00 depicting the level of hydrological drought in this regard. It is important once again to note that, the SPI-12 value of -3.00 illustrate the extreme drought episode that has taken place. SPI-12 value of -2.94 is seen for the years 2014-2015 preceding another episode of the SPI-12 value of -1.99 in the year 2017-2017.

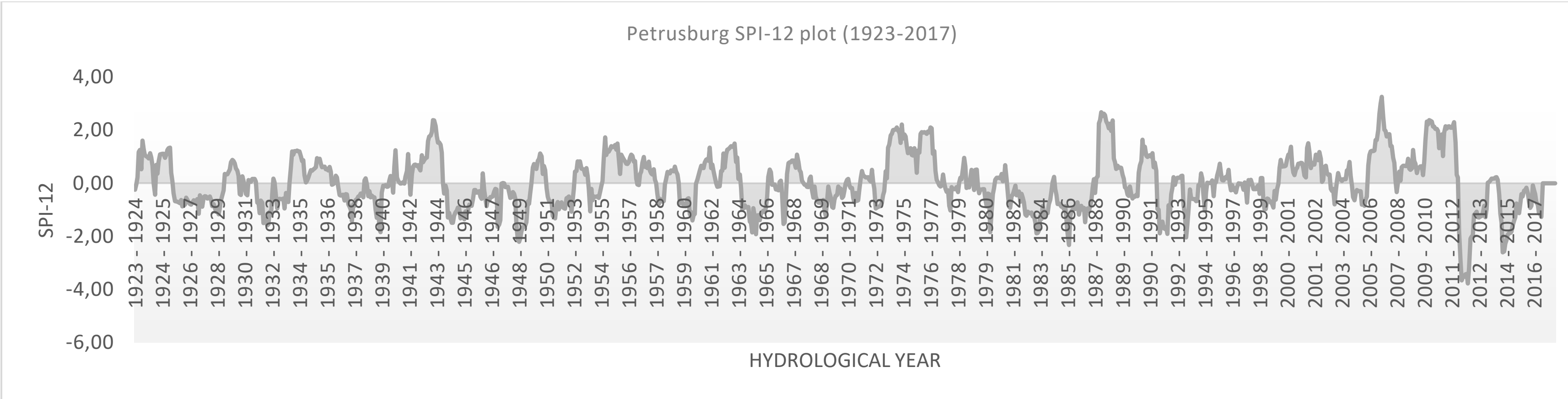

Figure 4.17 represents the SPI-12 from Petrusburg station.

This station has seen the episodes of drought depicted by SPI-12 values between 0.00 and -2.00. Drought episode of an SPI-12 value of -3.77 was recorded in the year 2012-2013. The year 2012-2013 are the years preceding the drought years of 2015-2016 whereby a provincial drought disaster was declared in the Free State Province.

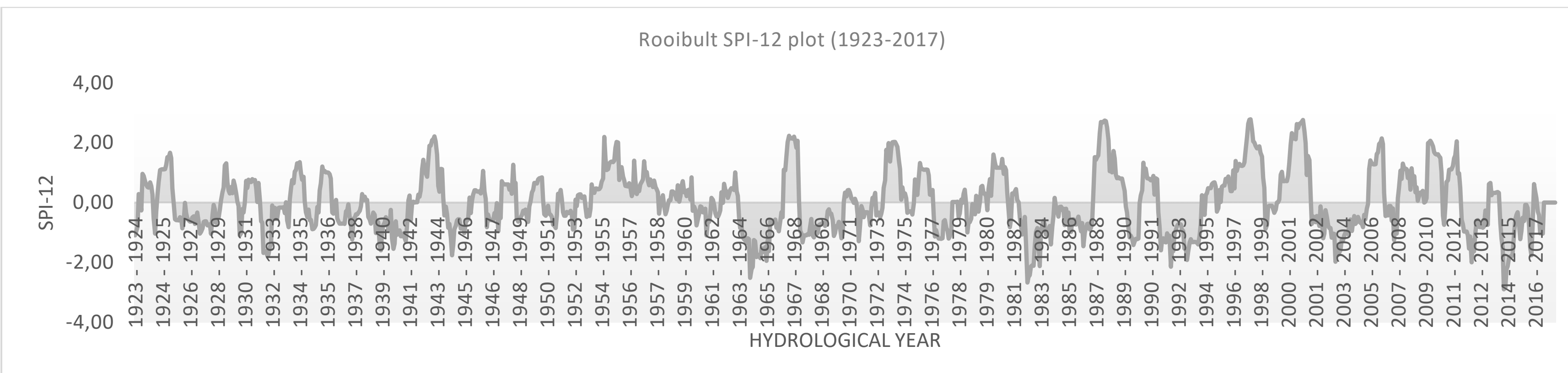

Figure 4.18 represents the SPI-12 for the Rooibult station.

Just like other stations, this station has also recorded drought episodes that have occurred over the years. The SPI-12 values recorded varies between 0.00 and -2.00. There has been few instances where the SPI-12 values went way below -2.00 whereby a value of -3.00 was recorded in the years of 2014-2015.

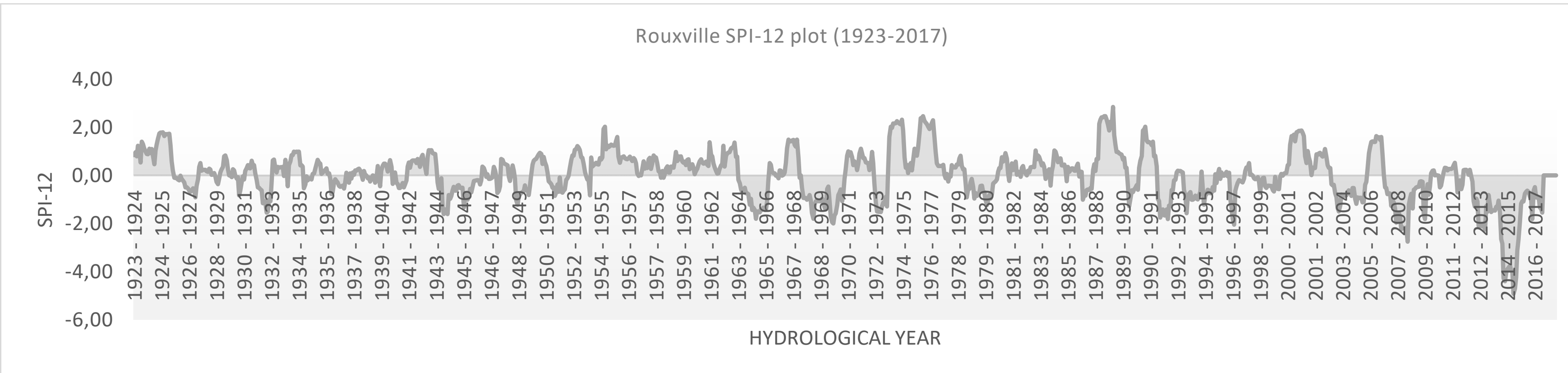

Figure 4.19 represents the SPI-12 for the Rouxville stations.

This station also presents multiple drought episodes which are denoted by the SPI-12 values between 0.00 and -2.00. Again, this station recorded the SPI-12 value of -4.92 in the years of 20145-2016, illustrating the extreme drought episode which has occurred.

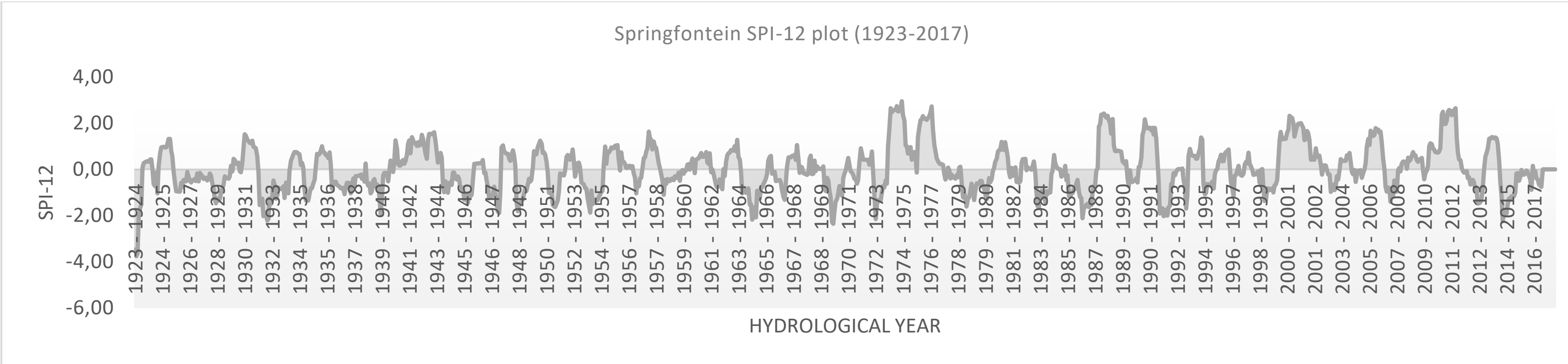

Figure 4.20 represents the SPI-12 for Springfontein station.

This station has recorded a big drought episode measured at SPI-12 value of -3.65 back in 1923-1924. There has been multiple drought episodes which preceded the 1923-1924, with the SPI-12 values varying between 0.00 and -2.00 over the years. The values went below -2.00 on more than five occurrences, whereby in the years 2015-2016, it is shown that the station recorded a -2.14 SPI-12 value.

Majority of the stations show the persistence of hydrological drought with stations recording SPI-12 value of 0.00 and lower throughout the study period. Consistent with the drought declaration in the province in the years 2015-2016, by measure of SPI-12, all five stations confirms the prevalence of drought episodes in the Free State Province.

4.3.1.4 Summary

All the SPI-12 figures have shown the drought episodes at different levels. It is important to note that, calculation of SPI-12, SPI-9 and -6, measure the extend of hydrological drought where the surface water is depleted affecting the stream flow, lakes and sub-surface water. At this level of drought, the situation is dire in that a lot more economic and agricultural activities, environment as well as livelihoods are impacted. Borehole water is not adequate at this level and as a result, artificial irrigation is not adequate, farm animals would not have sufficient water and so will all other end users of water. Human life would be disrupted and so will the environment and agricultural activities. This is the time where hydrological drought progresses into socio economic drought.

4.3.2 SPI Drought frequency

This section looks into how often the drought episodes were repeated over the years from 1923 until 2017, the study period. The analysis follows the sequence of the SPI time scales, starting from SPI-6, -9 and -12 per meteorological station.

4.3.2.1 SPI-6 Drought frequency analysis

This is drought frequency measured from every six months data set for a period between 1923 and 2017.

Table 4.4: SPI-6 Drought frequency

		Idomia	Petrusburg	Rooibult	Rouxville	Springfontein
SPI values	**Class**	**SPI_6**	**SPI_6**	**SPI_6**	**SPI_6**	**SPI_6**
-0.99 to 0	Mild drought	379,00	417,00	413,00	375,00	398,00
-1.49 to -1.00	Moderate drought	107,00	75,00	98,00	83,00	103,00
-1,99 to -1,5	Severe drought	39,00	29,00	37,00	33,00	43,00
≤ -2	Extreme drought	31,00	1106,00	31,00	39,00	24,00

Table 4.4 above illustrates the SPI-6 drought frequency across the sampled meteorological stations. For Idomia station, it is shown that drought has occurred 557 times between 1923 and 2017. During this time period, it is seen that, drought has taken place on multiple occasions and at

different levels. It is however important to note that severe and extreme drought has 70 occurrences. Across all five stations, drought has occurred a multiple times, however, the most devastating episodes are severe and extreme droughts which have had **1412** occurrences in total. This is the indication that, as per SPI-6 measured biannually between 1923 and 2017, the episodes of hydrological drought has taken place more that it is desired, seeing that, the Free State Province is the farming hub and a major agricultural grain producer in the Republic of South Africa, persistence of hydrological drought poses a risk. The persistence of drought episodes, therefore threatens the environment as well as the livelihood of the populace.

4.3.2.2 SPI-9 Drought frequency

This section talks about drought frequencies measured from every nine months data set for a period between 1923 and 2017.

Table 4.5: SPI-9 Drought frequency

		Idomia	Petrusburg	Rooibult	Rouxville	Springfontein
SPI values	**Class**	**SPI_9**	**SPI_9**	**SPI_9**	**SPI_9**	**SPI_9**
-0.99 to 0	Mild drought	393,00	423,00	438,00	372,00	441,00
-1.49 to -1.00	Moderate drought	112,00	97,00	88,00	91,00	94,00
-1,99 to -1,5	Severe drought	39,00	27,00	44,00	41,00	39,00
≤ -2	Extreme drought	28,00	24,00	20,00	26,00	20,00

Table 4.5 illustrate drought frequency for SPI-9 across all five meteorological stations. It can be seen from the table that drought episodes have taken place multiple times as recoded by Idomia station. Severe to extreme drought had 67 occurrences over the years. All five stations have had multi-drought occurrences recorded; however, severe to extreme drought episodes have 308 repeated occurrences over the years between 1923 and 2017.

4.3.2.2 SPI-12 Drought frequency

This section talks about drought frequencies measured from every twelve months data set for a period between 1923 and 2017. This is a simple illustration of how many drought occurrences have taken place repeatedly measured per twelve monthly dataset from the five meteorological stations. The table below presents the SPI-12 drought frequencies.

Table 4.6: SPI-12 Drought frequency

SPI values	Class	Idomia	Petrusburg	Rooibult	Rouxville	Springfontein
		SPI_12	SPI_12	SPI_12	SPI_12	SPI_12
-0.99 to 0	Mild drought	382,00	432,00	428,00	369,00	425,00
-1.49 to - 1.00	Moderate drought	107,00	95,00	114,00	84,00	112,00
-1,99 to-1,5	Severe drought	41,00	34,00	37,00	33,00	39,00
≤ -2	Extreme drought	31,00	19,00	15,00	28,00	17,00

Table 4.6 above illustrates SPI-12 for five stations. It is seen from this table once again that drought had multiple occurrences across all stations. Idomia station alone has had 72 occurrences of drought episodes over the years, 1923 to 2017 recorded. All stations recorded multiple droughts, it is once again important to note that, severe to extreme drought has occurred across all stations with the total of 294 episodes recorded.

Majority of the stations have recorded drought episodes measured with datasets of six, nine and twelve months calculated to determine SPI-6,-9, and -12 over the years from 1923 to 2017, drought have occurred multiple times. Severe to extreme drought calculated per SPI across all stations have occurred total 2014 times. This is a significant number of severe to extreme drought events to have taken place. SPI-6, -9 and -12 calculates hydrological drought, meaning that all five stations have recorded hydrological drought which have had 2014 occurrences.

4.3.3 Drought severity analysis

This section discusses the drought severity measure per SPI. SPI-6, -9 and -12 will therefore be discussed and analysed individually as per figures below.

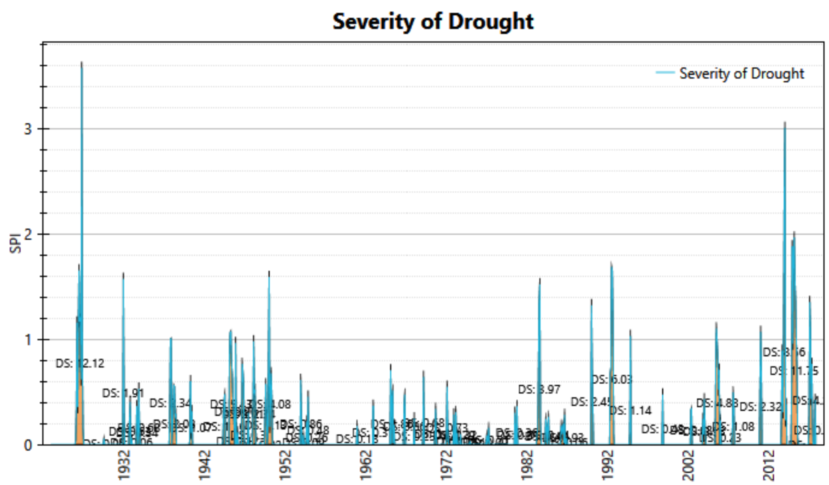

Figure 21: Idomia SPI-6 drought severity

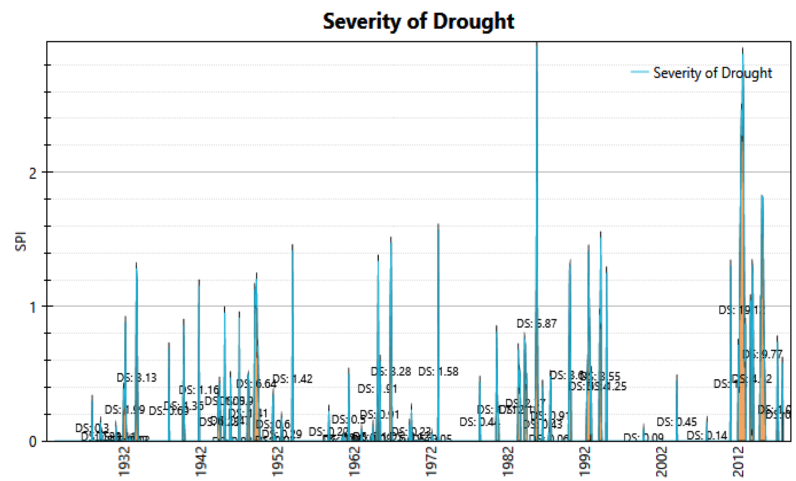

Figure 22: Petrusburg SPI-6 drought severity

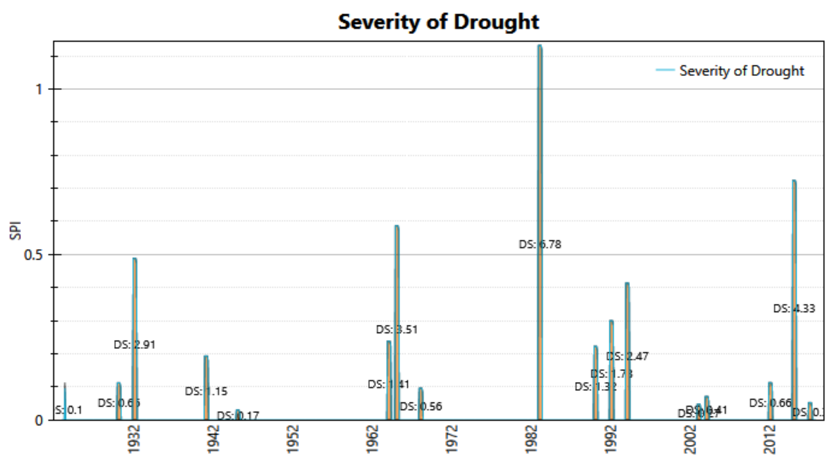

Figure 23: Rooibult SPI-6 drought severity

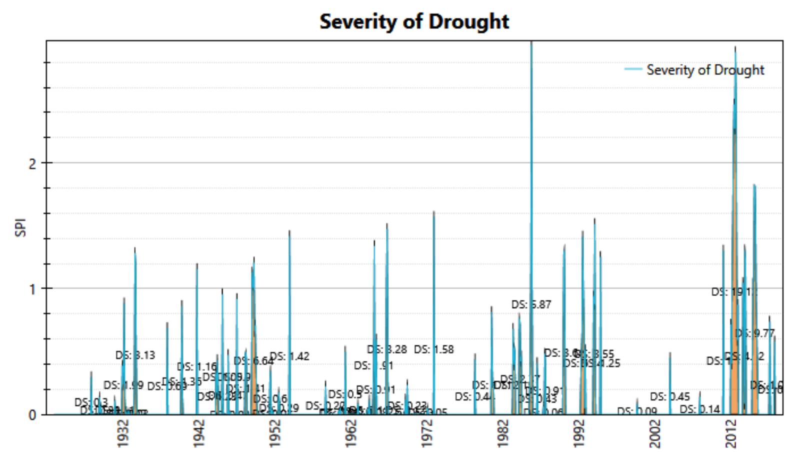

Figure 24: Rouxville SPI-6 drought severity

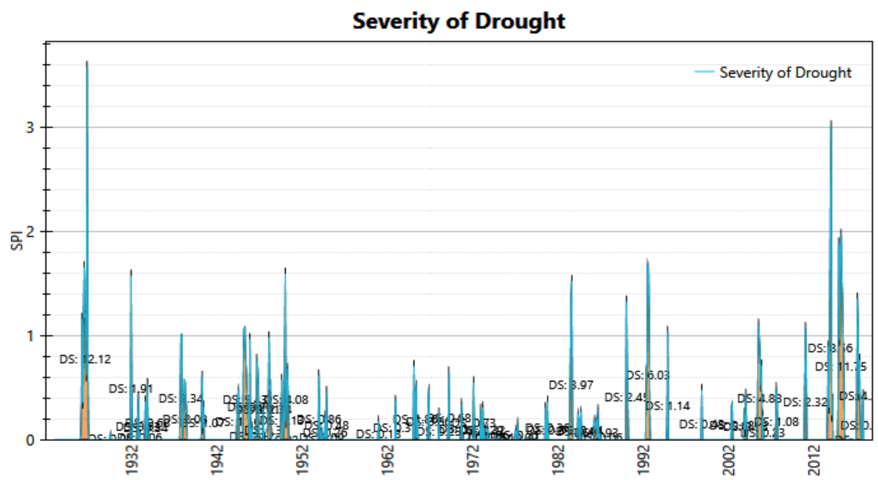

Figure 25: Springfontein SPI-6 drought severity

4.3.3.1 SPI-6 Drought severity

For this SPI, the majority of the stations have shown the drought severity at different years during the study period. Figures 4.21-4.25 represents SPI-6 drought severity over the years from 1923 to 2017 for the five meteorological stations. It is seen that severe hydrological drought events took place in the years 1925-1926. Another severe drought event took place in the years 2013-2014 as well as 2014-2015. The majority of the stations are in accord with figures 4.11-4.15, particularly figure 4.11 where it is shown that the SPI-6 hydrological drought value recorded was as low as ≤ 4 same period.

It is important to note that, across all the stations, the majority of the severe drought events were recorded in the last quarter of the study period, implying that, even though drought events have occurred in the first quarter and throughout the study period, the persistence of the severe drought is seen in the last quarter. The fact that, the last quarter is showing to have had multiple events of severe drought, is consistent with the fact that the Free State Province was declared a drought disaster in the last quarter of the study period. Equally important, is for the water resource managers and users, to take note of the drought events in the province, the frequency and the severity so that proactive measures can be put in place in order to avoid a catastrophic situation as a result of the impacts of hydrological drought.

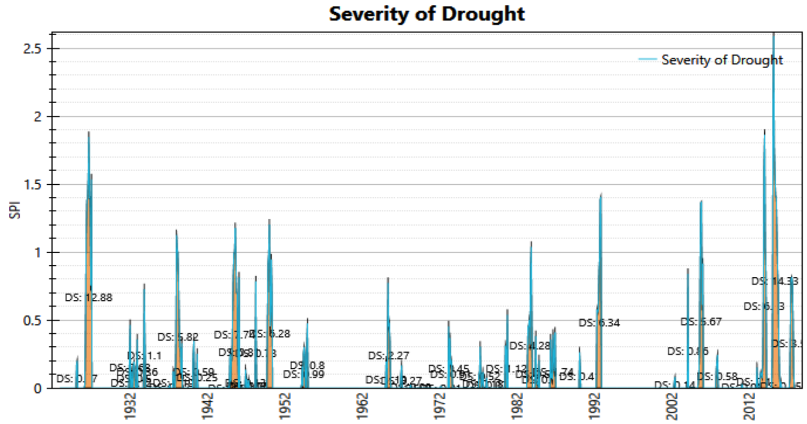

Figure 26: Idomia SPI-9 drought severity

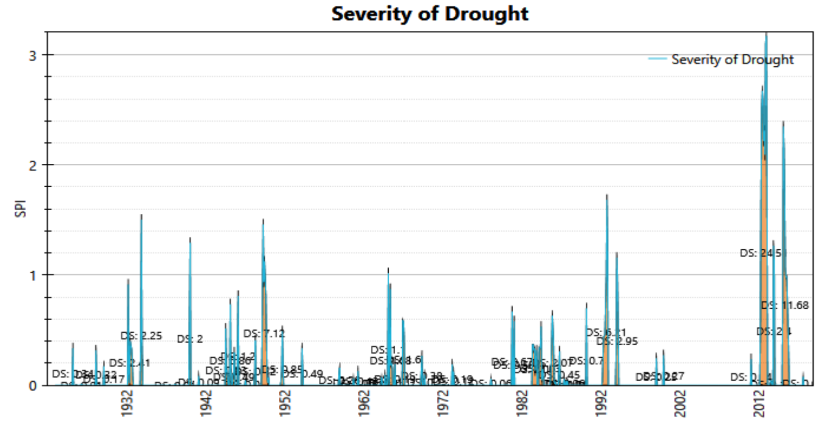

Figure 27: Petrusburg SPI-9 drought severity

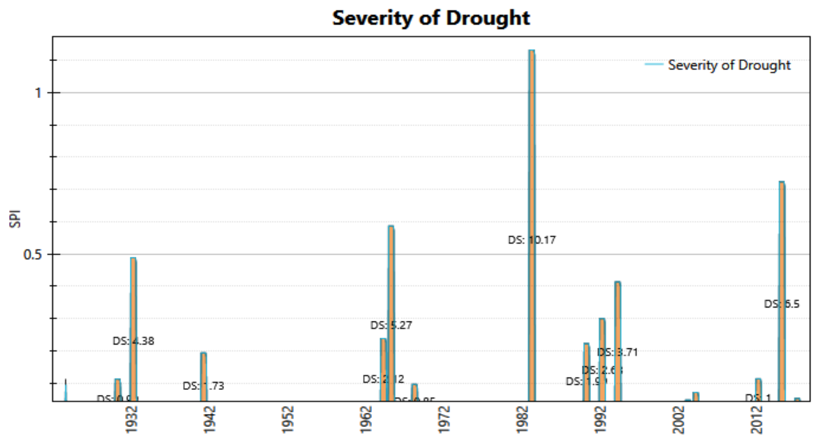

Figure 28: Rooibult SPI-9 drought severity

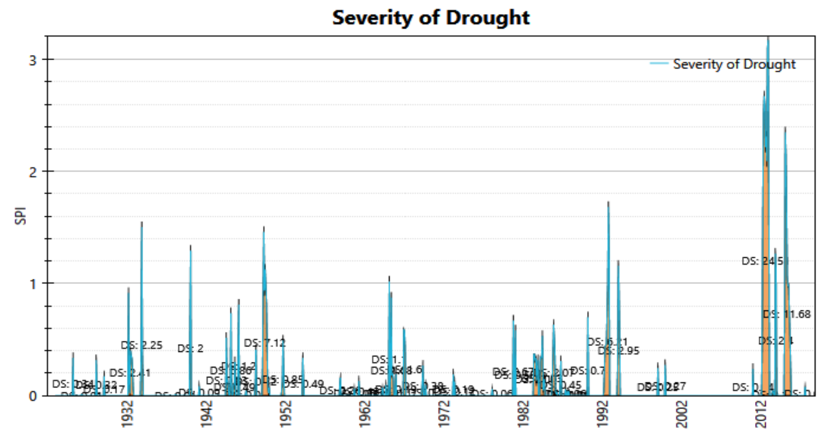

Figure 29: Rouxville SPI drought severity

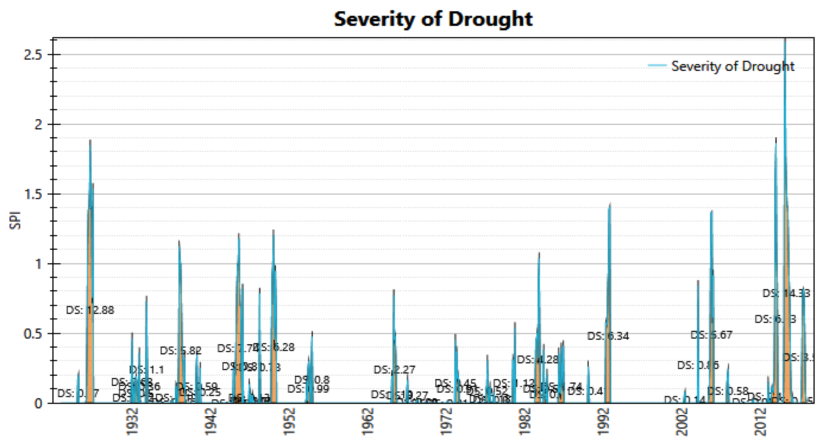

Figure 30: Springfontein SPI-9 drought severity

4.3.3.2 SPI-9 Drought severity

The figures above represents SPI-9 drought severity in the years 1923 to 2017 for the five meteorological stations.

Figure 4.26-4.30 presents the drought severity for all station. It can be seen that the majority of the stations show that drought had severe and extreme occurrences multiple times of which extreme drought events happened on about seven occasions. Consistent with SPI-6 drought severity, the majority of the stations illustrates that, severe to extreme drought events have taken place in the first and the last quarter of the study period. It is also seen that, 40% of the stations had recorded drought events consistent with the recoded SPI-9 values as low as -4.59 and -5.39.

Severe to extreme drought events have occurred on many occasions and in consistent with the drought frequencies on table 4.5.

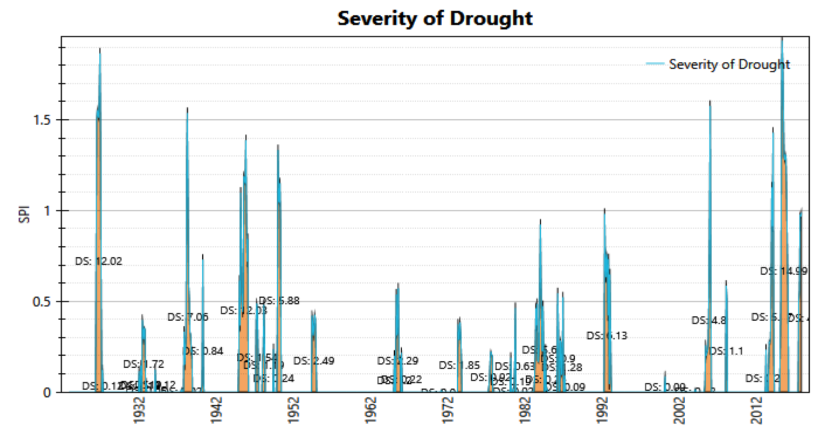

Figure 31: Idomia SPI-12 drought severity

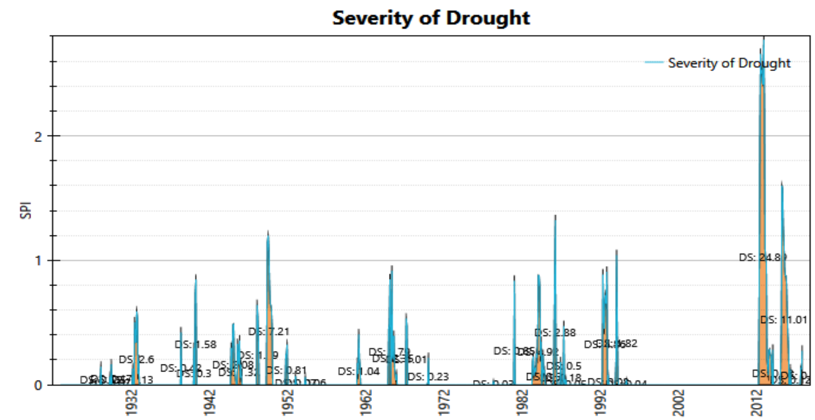

Figure 32: Petrusburg SPI-12 drought severity

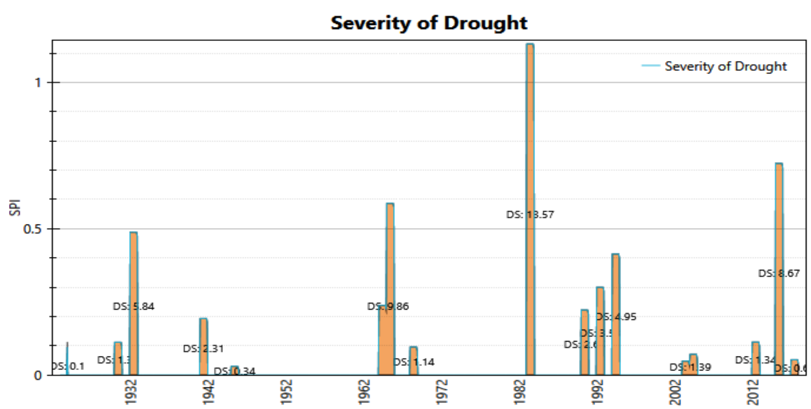

Figure 33: Rooibult SPI-12 drought severity

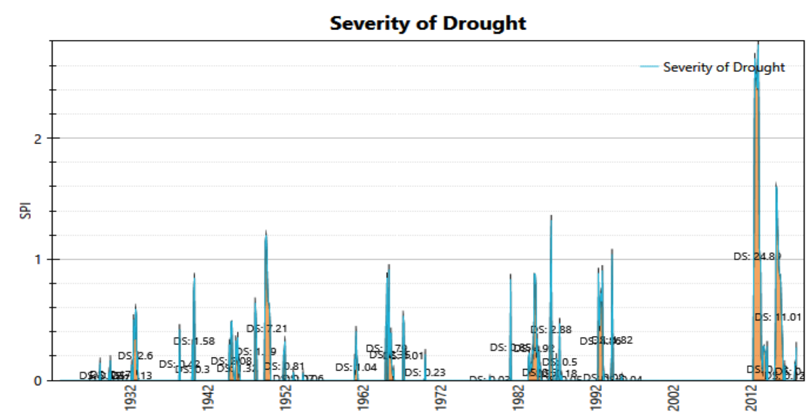

Figure 34: Rouxville SPI-12 drought severity

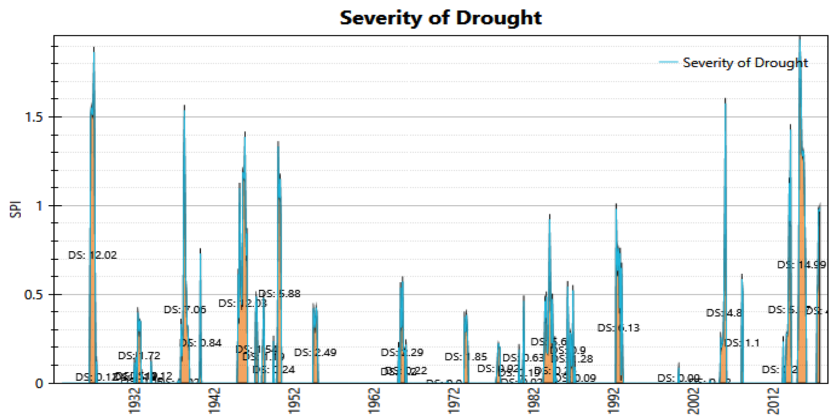

Figure 35: Springfontein SPI-12 drought severity

4.3.3.3 SPI-12 Drought severity

The figures above represents SPI-12 drought severity over the years from 1923 to 2017 for the five meteorological stations.

Figures 4.31-4.35 presents the SPI-12 drought severity for all stations whereby it is shown that throughout the study period, the majority of the stations have recorded multiple severe to extreme drought events occurrences. Extreme drought events had occurred in the first and last quarter of the study period. This is also consistent with drought level illustrated in figures 4.16-4.20 where SPI-12 values as low as -2.87, -3.77 and -4.99 were recorded. The fact that, the severe to extreme drought occurrences happened in the first and last quarter of the study period is consistent with SPI-6 and-9 drought severity events.

4.4. SUMMARY

The chapter presented data analysis and research results that are in a form of discussion and interpretation of figures and tables. Figures of raw data illustrative of the amount of rain recorded per hydrological stations were presented and discussed. Descriptive Statistics of raw data was discussed as well and the data reliability test that entailed the homogeneity test whereby the data was found to be homogeneous. Data analysis followed the discussion of SPI values across the five sampled meteorological stations illustrating levels of hydrological drought. Drought frequencies and severities were also discussed demonstrating how many times drought happened as well as how severe or extreme it was. The following chapter presents the conclusions of this study, the findings as well as the recommendations thereof.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

The definition of hydrological drought implies that, the occurrence of water levels below average in the lakes, reservoirs, rivers, the streams and groundwater might result in agricultural drought impacts as well as none agricultural impacts including tourism, recreation, urban water consumption, energy production and ecosystem conservation. This chapter presents the findings of data analysis in chapter four and also confirms the objectives in chapter one. The recommendations presented are based on the findings. The findings of this work goes a long way into laying a basis to assist the municipalities with information so that the relevant decision makers can make informed decisions related to service delivery, especially regarding water supply to the communities because the province is predominantly rural. Agribusiness will be assisted mainly because the quality of agricultural products also lies in the good supply of adequate water for agricultural purposes, therefore supply chain organisations would be informed of the areas in the province where they would find quality agricultural products. The farming communities are also expected to benefit tremendously largely because agricultural activities needs copious amount of water especially for irrigation purposes. In general, water resource managers will benefit by way of having an insight into hydrological drought levels, the return periods as well as severity in the province in order for them to plan the use of water accordingly. The use of water is found to be in such a manner that the water resources are supposed to be allowed to recharge in order to avoid depletion in one way or the other.

5.2 FINDINGS

The findings are presented and are in line with the objectives of the study as presented in chapter one, literature review in chapter two as well as data analysis in chapter four. It is apparent from literature review that, drought have a direct impact on human life and environment. The drought impacts are felt significantly in the loss of agricultural crops, other agricultural commodities as well as direct and indirect loss of human and animal life, disruption of ecosystem as a result of drought impacts, internationally, regionally as well as locally. Agricultural products supports life, the study area in this regard has experienced a drop in agricultural yields such as grain and loss of livestock as a result of drought.

5.2.1 Rainfall

The rainfall from the five meteorological stations were analysed and it is obvious from the chart in figure 4.1 that the rainfall has always been at its low in the Free State Province. The province has never received rainfall in excess of 400mm during the study period, except for once at Rouxville station where a rainfall of 427mm was recorded in the year 1988. This is in consistent with the fact that South Africa is a semi-arid country. This country receives less rain annually relative to global average 860mm of rainfall.

5.2.2 Trend of rainfall

Rainfall trend across all meteorological stations was measured by means of Kendal-Mann. The rainfall trend across all the meteorological stations indicates a slight change of either increasing or slightly decreasing. The rainfall had largely remained at below 400mm for the rest of the study period with slight increase and decrease from time to time, sometimes to no rain at all. This is in consistent with existing literature that argues the aridity of the South Saharan Africa, and South Africa as a semi-arid country.

5.2.3 Frequency of drought and return periods

Hydrological drought frequency was calculated from the data across all the meteorological stations, in terms of SPI-6, -9 and -12. The results of the calculations show that drought have frequented the province more at every time scale. At SPI-6, severe to extreme hydrological drought have had 1412 occurrences, with the Petrusburg meteorological station alone recording 1106 extreme drought occurrences. This is a massive number of drought occurrences and it amounts to an average of 31 extreme drought occurrences every 31 days during the study period. The 3-months, 6-months, 9-mongths, 12-months and more are time scales measure on SPI illustrative of the hydrological drought. SPI-9 shows 308 severe to extreme drought occurrences. Drought frequencies for SPI-12 shows that there were 294 severe to extreme drought occurrences over the study period.

Now that, all three time scales have shown repeated episodes of severe to extreme hydrological drought, it is apparent that the Free State Province had experienced hydrological drought during the study period.

5.2.4 Standard Precipitation Index classification

SPI was calculated to measure the extend of drought in the Free State Province. For hydrological drought, a measure of higher temporal scales is needed. Temporal scales of six, nine and twelve months were used in order to accurately measure the hydrological drought in the province. The results were compared against the SPI classification that determines if there is drought or not. The SPI measures the level of wetness and of dryness. The positive SPI value measures wetness and the negative value measures level of dryness. The number of times the level of dryness which measures hydrological drought and the extend of it, is illustrated on frequency tables, tables 4.4, 4.5 and 4.6 respectively. SPI-6 is a measure of hydrological drought measured from a 6-month time scale of data. The SPI-6 values for Idomia meteorological station, see table 4.4, is illustrative of drought showing the occurrence of mild, severe to extreme drought which took place 556 times. Petrusburg station recorded total drought total of 1627 times. For Rooibult station, drought happened a total of 579 times. Rouxville station has recorded 530 drought events and Springfontein recorded total of 568 drought events.

Table 4.5 presents SPI-9 hydrological drought and the number of times the SPI values were recorded illustrative of how many hydrological drought events took place during the study period. All stations have recorded varied drought levels over the years, however severe to extreme hydrological drought had 67 occurrences, for Idomia, 51 for Petrusburg, 64 for Rooibult, 67 for Rouxville and 59 Springfontein stations.

Table 4.6 presents SPI-12 values and number of times hydrological drought events took place across all five meteorological stations. All stations have recorded varied levels of drought from mild to extreme, however, severe to extreme hydrological drought have made 72 occurrences at Idomia stations, 53 Petrusburg, 52 for Rooibult, 61 for Rouxville and 56 occurrences for Springfontein.

5.2.5 Drought Severity

Hydrological drought presented itself at different levels from mild to extreme drought. Severe to extreme drought is seen to have occurred multiple times when measured across the three chosen time scales of SPI-6, -9 and -12. Figures 4.21-25, 4.26-30 and 4.31-35 show the SPI hydrological drought severity. The figures show that the province of Free State has experienced severe and extreme drought on various occasions as measured across all five meteorological stations. It is inferred that, because all five metrological stations have recorded multiple severe drought episodes and extreme at times when compared with tables 4.4, 4.5 and 4.6, the province is therefore prone to severe and extreme hydrological drought.

5.3 RECOMMENDATIONS

The aims of this study were to analyse rainfall pattern trends, to identify the hydrological drought and return periods, to determine the intensity and duration of hydrological drought as well providing an early warning tool for water users in the form of the final report of this research. The data analysis confirms the minimum rainfall in the study area. The province is frequented by hydrological drought and it has previously seen the reduced agricultural yields as well as death of livestock due to water shortage. Notwithstanding the fact that the province is regarded as a breadbasket, the hydrological drought is prevalent in the study area and with high severity because the province was even declared a drought disaster in the 2015/2016 hydrological years. The following recommendations are suggested in this regard.

5.3.1 Boreholes for water supply

Free State Province is vastly rural and has large farming land where agricultural activities are taking place. There are other economic activities taking place in the province such as mining and other manufacturing industries that use copious water. Water is not only for industry use but also for human consumption in order to support life. It is therefore equally important that all economic sectors and government sector make informed decisions of water supply in order for water to be adequately conserved and put to good use. In a drought prone province, the use of boreholes is important but care should be taken in order for the boreholes to be strategically placed/drilled and constructed. Adequate water management strategies would go a long way in ensuring that ground water is used sparingly. The boreholes would be largely beneficial if they are used interchangeably in order to allow the stream flows to recharge. The water resource managers from private sector as well as at government level, national, provincial or municipal should therefore make use of Hydro-Geologists in order to advice as to where the boreholes needs to be located rather than just randomly drilling. As envisaged in the Phase 2 Groundwater Resources Assessment (GRA2) project report, Global Positioning System (GPS) coordinates database should be kept and maintained. The local authority should have access to this database of the Global Positioning System (GPS) coordinates depicting all possible accessible ground water resources in order to make recommendations to the communities whenever boreholes are needed to be drilled for home consumption. Communities should be encouraged to consult with municipalities before initiating any borehole drilling in this regard. The same approach should be encouraged to be undertaken by small scale farming community. Irrigation for commercial farming make use of large quantities of ground water, although mining and other industry uses 15% and so is other economic sector and any other economic activity. Communal borehole drilling is encouraged whereby a group of households should share one borehole and a network of piping is used to distribute water directly to the individual household and business formations. Shared responsibility is encouraged in this regard.

5.3.2 Rain water harvesting

The fact that the province is prone to hydrological drought does not out rule flooding during rainy season. The use of water harvesting methods is encouraged for all water users. Water-resource management principles should take cognisance of the fact that surface water, rainwater and storm water harvesting is of great importance for economic, social and environmental use. The use of harvested water would allow water resources to recharge and prolong depletion. Although National Water Act, Act 36 of 1998 mandates for water resource management, the Act does not have legislative authority over rainwater harvesting. Storm-water management purpose is essentially to redirect and channel storm water back to the rivers and wetlands; the planning therefore does not encourage reuse in this regard. During wet seasons, the rainwater should be collected for domestic use such as food garden irrigation as well as small scale farming irrigation among others. Building designers should be encouraged to make room for rainwater harvesting in the structural design thereby encompassing rainwater collection, and redirecting same into the domestic garden irrigation system, among others. The water should also be spared for irrigation at the later stage when there is no rainfall rather than using consumable water for such. It is noted that this rainwater collection is not enforceable through any legislation and that building regulations only enforces fire water installations. It is recommended that the building designers and architects be encouraged to rationally design and include rainwater collection as well as storage in their designs in order to make it fashionable until it is legislated and made compulsory. The rainwater harvesting will go a long way in rural setup where piped and running water is not yet installed. Care should be taken not to use the harvested water for human consumption without having it treated first. Rainwater harvesting, even though it is argued that the practice is deteriorating in recent years, is practiced in India, (Dinesh, Ghosh, Patel, Singh and Ravindranath 2006) as much as it is in other parts of South Africa as well as in other countries in the world.

5.3.3 Agricultural products

Agricultural products pertains to agricultural yields such as but not limited to field crops, vegetables, fruits, livestock, horticultural products, milk and eggs. Agricultural products are directly linked to pre and post production and as such, production level is dependent on the classification of South Africa's farming sector, relative to the sequence as provided by Mahaliyanaarachchi, Wijeratne and Bandara (2006), see figure 5.1 below.

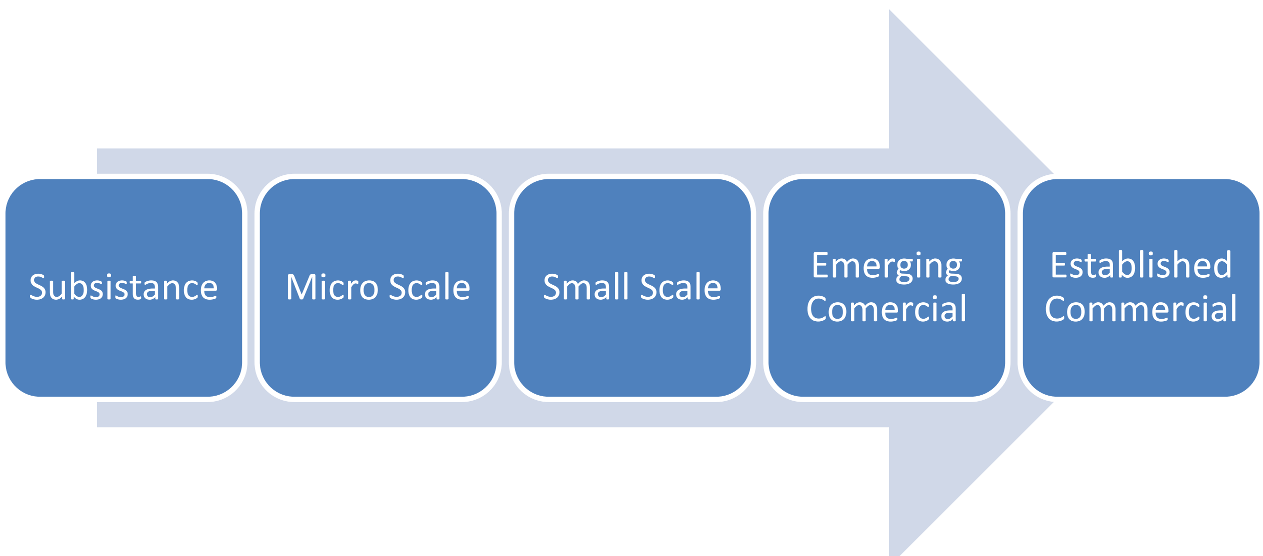

Figure 5.1: Classification of South Africa's farming sector

Source: Adapted from Mahaliyanaarachchi et al. (2006)

The agricultural products as in the figure 5.1 will vary and especially due to availability and unavailability of resources especially irrigation systems. Irrigation systems are a mechanical way of watering agricultural fields and might be costly to be afforded by subsistence, micro scale as well as small scale farmers. The hydrological drought in the province has shown prevalence, this in itself have negative implications to the agricultural products in terms of quality. Subsistence farmers depends mainly on rainwater and reuses water for irrigation whenever possible. The same applies to all other farming classifications as in figure 5.1. Rouxville meteorological station have shown that a lot of rainfall was recorded during the study period. Meaning that, agricultural products in any form in the vicinity of Rouxville are of good quality and therefore are of good nutritional value. Consumption of organic food is encouraged for benefits of good health. It is recommended for agribusiness to source their agricultural products from the farming community in Rouxville area because of the good rainfall taking place there.

5.3.4 Early warning system

The results and findings of this research illustrate that, there is a prevalence of hydrological drought in the Free State Province. The finding of this research therefore serves as a fore warning to the water resource managers, municipalities and their entities, communities, and any other decision maker. This report does not replace the automatic early warning systems that are in place but compliments and confirms the prevalence of hydrological drought thereof. The fact that the hydrological drought can be detected with a 3-months rainfall data computed using SPI, means that drought monitoring can predicted at early stages of development in order for mitigating action to be taken before widespread impacts are felt. This study used minimum of 6-month rainfall data, however, literature reveal that, even 3-month data can be used to detect the creeping drought. UNIDR (2017) defines Early Warning System as an “integrated system of hazard monitoring, forecasting and prediction, disaster risk assessment, communication and preparedness activities systems and processes that enables individuals, communities, governments, businesses and others to take timely action to reduce disaster risks in advance of hazardous events”. Early detection means that, the water resource managers, municipalities, farmers, communities and any other user of water would be in a good position to develop mitigating strategies earlier than later. It is the duty of government, and especially at the local level, to assist the poor communities who are unable to cope with impacts of drought in this regard.

5.3.5 Water use awareness campaigns in the community

Awareness campaigns regarding water use should be encouraged in light of water harvesting and leaks management. Water harvesting is not legislated and therefore is not enforceable by law. One of the possible ways is to encourage the local authorities to embark on awareness campaigns where communities and business are made aware of the drought impacts and the importance of water harvesting as a means of sparing water and allowing ground water resources to recharge in the process. The campaigns should include water leak management whereby communities should be encouraged to fix the damaged water pipes and to report with immediate effect, to the local authorities any water leak that they might come across. Disaster management volunteers may be used in this regard, as well as the EPWP. Platforms such as ward based and street committee gatherings, schools as well as churches can be used. Radio, television and social media are easily accessible by community members; they also should be used for awareness campaigns.

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APPENDIX A: ETHICAL CLEARANCE

UNIVERSITY OF THE FREE STATE
UNIVERSITEIT VAN DIE VRYSTAAT
YUNIVESITHI YA FREISTATA

UFS
UV

GENERAL/HUMAN RESEARCH ETHICS COMMITTEE (GHREC)

15-Jul-2020

Dear Mr Mampshe Nkgudi

Application Approved

Research Project Title:
Analysis of hydrological drought risk characteristics using Standardised Precipitation Index in the Free State Province

Ethical Clearance number:
UFS-HSD2020/0742/306

We are pleased to inform you that your application for ethical clearance has been approved. Your ethical clearance is valid for twelve (12) months from the date of issue. We request that any changes that may take place during the course of your study/research project be submitted to the ethics office to ensure ethical transparency. furthermore, you are requested to submit the final report of your study/research project to the ethics office. Should you require more time to complete this research, please apply for an extension. Thank you for submitting your proposal for ethical clearance; we wish you the best of luck and success with your research.

Yours sincerely

Dr Adri Du Plessis
Chairperson: General/Human Research Ethics Committee

AdPlessis

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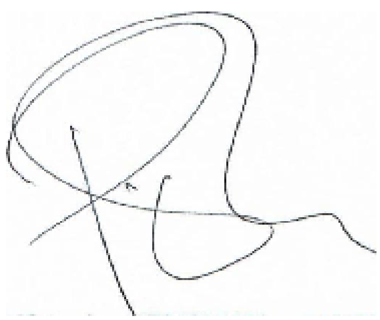
APPENDIX B: EDITOR'S NOTE

9 June, 2020

This is to certify that I, Dr P Kaburise, of the English Department, University of Venda, have proofread the research report, titled - **ANALYSIS OF HYDROLOGICAL DROUGHT RISK CHARACTERISTICS USING STANDARDISED PRECIPITATION INDEX IN THE FREE STATE PROVINCE** - by Mampshe Sunnyboy Nkgudi (student number: 2017548922). I have indicated some amendments which the student has undertaken to effect, before the final report is submitted.



Dr P Kaburise (0794927451/ 0637348805; phyllis.kaburise@gmail.com)

Dr P Kaburise: BA (Hons) University of Ghana (Legon, Ghana); MEd University of East Anglia (Cambridge/East Anglia, United Kingdom); Cert. English Second Language Teaching, (Wellington, New Zealand); PhD University of Pretoria (South Africa)