DROUGHT AND TREND ANALYSIS IN TRARZA REGION IN MAURITANIA

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

in Civil Engineering

by
Ely Yacoub Traore

July 2016
İZMİR

We approve the thesis of **Ely Yacoub Traore**

Examining Committee Members:

____

Prof. Dr. Gökmen TAYFUR
Department of Civil Engineering, Izmir Institute of Technology

____

Prof. Dr. Şebnem ELÇİ
Department of Civil Engineering, Izmir Institute of Technology

____

Asst. Prof. Dr. Ömer Levend AŞIKOĞLU
Department of Civil Engineering, Ege University

29 July 2016

____

Prof. Dr. Gökmen TAYFUR
Supervisor, Department of Civil Engineering,
Izmir Institute of Technology

Prof. Dr. Gökmen TAYFUR
Head of the Department of Civil Engineering

Prof. Dr. Bilge Karaçalı
Dean of the Graduate School of Engineering and Science

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my advisor Prof. Dr. Gökmen TAYFUR for his continuous support, guidance, and encouragement throughout this study, I also want to thank him for his patience, helpfulness and trust. I could not have imagined having a better advisor and mentor for my master study.

I would also like to express my special appreciation and thanks to the Presidency for Turks abroad and related communities for their financial support and for the opportunity given me to study in Turkey.

Finally, I must express my very profound gratitude to my family for their endless love, patience and encouragement during the course of my study. They have been my support throughout my entire life and I am so grateful to them all. This accomplishment would not have been possible without them. Thank you

ABSTRACT

DROUGHT AND TREND ANALYSIS IN TRARZA REGION IN MAURITANIA

Long-term precipitation and temperature historical records (monthly recorded for 44 years) in three stations (Boutilimit (station 1), Nouakchott (station 2), and Rosso (station 3)) are employed to investigate the drought characteristics and to investigate the temperature and precipitation trends during the period of 1970 to 2013 in Trarza region in Mauritania. Six Drought Indices (DIs), namely normal Standardized Precipitation Index (normal-SPI), log normal Standardized Precipitation Index (log-SPI), Standardized Precipitation Index using Gamma distribution (Gamma-SPI), Percent of Normal (PN), the China-Z index (CZI), and Deciles are used for the drought analysis. These methods are based on 1-, 3-, 6-, and 12 month time periods. The results showed that the log-SPI, the gamma-SPI, PN and Deciles were able to capture the historical extreme and severe droughts observed in early 1970s and early 1980s.

In the trend analysis, The Mann Kendall (MK test), Spearman's rho (SR test), Şen trend test were used for the trend identification in the time series and the Pettitt test for detecting the change point at the time series while the Thiel-sen Approach was used to estimate the magnitude of the slope in the precipitation and temperature time series. The results of trend analysis showed that the average temperature and the annual precipitation are both increasing by about 0.3^{o}C per decade and 3 mm per year, respectively.

Keywords: Drought, Trend, Trarza Region, Mauritania, SPI, CZI, PN, Deciles, Arid, Precipitation, Temperature

ÖZET

MORİTANYA’DAKİ TRARZA BÖLGESİ İÇİN KURAKLIK VE EĞİLİM ANALİZİ

Üç istasyon’dan (Boutilimit (istasyon 1), Nouakchott (istasyon 2) ve Rosso (istasyon 3)) elde edilen uzun süreli yağış ve sıcaklık kayıtları kullanılarak 1970’den 2013’e kadar olan süre için kuraklık ve eğilim analizleri Moritanya’daki Trarza bölgesi için yapılmıştır. Altı kuraklık indeksi (DIs); standart yağış indeksi (normal-SPI), log-normal standart yağış indeksi (log-SPI), gamma dağılımı kullanan standart yağış indeksi (gamma-SPI), Normal yüzde (PN), Çin-Z indeksi (CZI) ve Deciles kuraklık analizi için kullanılmıştır. Bu yöntemler 1-, 3-, 6-, ve 12 aylık zaman periyodu için kullanılmıştır. Sonuçlar göstermiştir ki; log-SPI, gamma-SPI, PN, ve Deciles yöntemleri 1970 ve 1980 başlarında gözlenmiş olan tarihi ekstrem ve şiddetli kuraklıkları tahmin edebilmişlerdir.

Mann Kendall (MK test), Spearman’s rho (SR test) ve Şen eğilim test yöntemleri yağış ve sıcaklık zaman serilerinin eğilimlerinin belirlenmesinde kullanılmıştır. Zaman serilerinde değişim noktasının belirlenmesinde Pettitt testi ve yağış ve sıcaklık zaman serilerinin eğimlerinin değerinin belirlenmesinde ise Thiel-sen yaklaşımı kullanılmıştır. Eğilim analiz sonuçları göstermiştir ki; ortalama yıllık sıcaklık 0.3 ^{o}C/10 yıl ve ortalama yıllık yağış 3 mm/10 yıl olarak artmıştır.

Anahtar kelimeler: Kuraklık, Eğilim, Trarza bölgesi, Moritanya, SPI, CZI, PN, Deciles, Kurak, Yağış, Sıcaklık

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATION

CZI: China-Z Index

DIs: Drought Indices

FAO: The Food and Agriculture Organization

FEMA: Federal Emergency Management Agency

MK: Mann Kendall

NMCC: National Meteorological Center of China

OFDA: Office of Foreign Disaster Assistance

PN: Percent of Normal

SPI: Standardized Precipitation Index

SR: Spearman's rho

UNCC: United Nations Convention on Combating Desertification and Drought

WMO: World Meteorological Organization

CHAPTER 1

INTRODUCTION

Drought almost occurs in all climatic zones, such as high as well as low rainfall areas and is generally related to the reduction in the amount of precipitation received over an extended period of time, such as a season or longer period. High temperatures; high winds; low relative humidity, have also an important role in the occurrence of drought. Although it is not possible to avoid drought, its effect on the environment and on people can be minimized based on drought preparedness and management. Success of drought preparedness and management depends on how well drought is defined and characteristics of drought are quantified (severity, intensity, duration….,). For this reason many drought indices have been developed for the analysis of the drought through its magnitude, duration, and intensity. Drought indices are generally derived from precipitation, because long-term precipitation records are often available. The drought analysis in this thesis is based on 44 years monthly rainfall records.

In 20th century the average air temperature has increased by 0.7^{o}C and it has affected precipitation and river discharge. This situation could have serious effects on the population as well as agriculture, environment, economy and industry (Yavuz & Erdoğan, 2012) . This recent hydrological regime changes brought into focus the search for effective trend identification analysis. Several trend detection tests developed by many researchers and have been used around the world. Based on historical annual precipitation and temperature records in this thesis the precipitation and temperature trends are investigated by different trend methods.

1. 1. Problem Statement

Some countries across the Sahel (in western Africa) at the end of the drought season heralded a period of steady rainfall. Not so in Mauritania, which is one of the Sahelian countries most affected by drought. In 1983-84, Mauritania was afflicted with its worst drought since the beginning of the 1970s when Mauritania experienced an extended severe drought (Spinage, 2012). Households are still struggling to cope with the effects of the drought, such as:

- Reducing farmers' crop yield, increasing the price of food on local market and making difficult water supply for the needs of people.
- Inducing massive movements of population to urban centers.
- Creating significant economic losses

Given the problems mentioned above, there is a clear demand to understand and assess historical drought in order to develop mitigation plan for the consequences of drought in the future.

1.2. Objectives of the Study

The main source of the groundwater in Mauritania is the Trarza aquifer, which covers about 40,000 km^2. The Senegal River is Mauritania's only permanent waterway, which makes the Trarza one the most populated regions in the country. 1086 km long Senegal River which is located between Mauritania and Senegal flows through a valley up to 19 km wide (https://en.wikipedia.org/wiki/Senegal_River). It is used for different purposes such as, irrigation, navigation, drinking, and hydro power generation. The water resources in Trarza region in Mauritania support a range of use including urban water supply and agricultural not only in the region but also in the surrounded regions in Mauritania. This fact highlights the importance of drought assessment and monitoring for the region. The aim of this thesis is to carry out the assessment of drought in Trarza region in Mauritania. The general objectives are the followings;

- identify suitable drought index(s) for Trarza region in Mauritania that can be employed for drought assessment within the region,
- identify the characteristics of drought such as frequency, magnitude and duration
- identify the trends in precipitation and temperature in the region during the period of 1970-2013,
- calculate the trend magnitude, and
- detect a single change-point in the precipitation and the temperature time series.

Analyses frameworks used in this study are presented in Figs. 1.1 and 1. 2

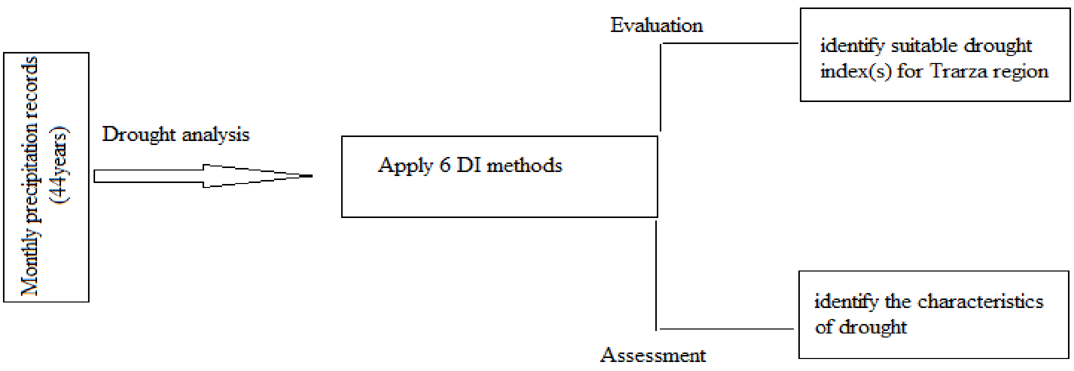

Figure 1.1. Drought analyses framework used in this study

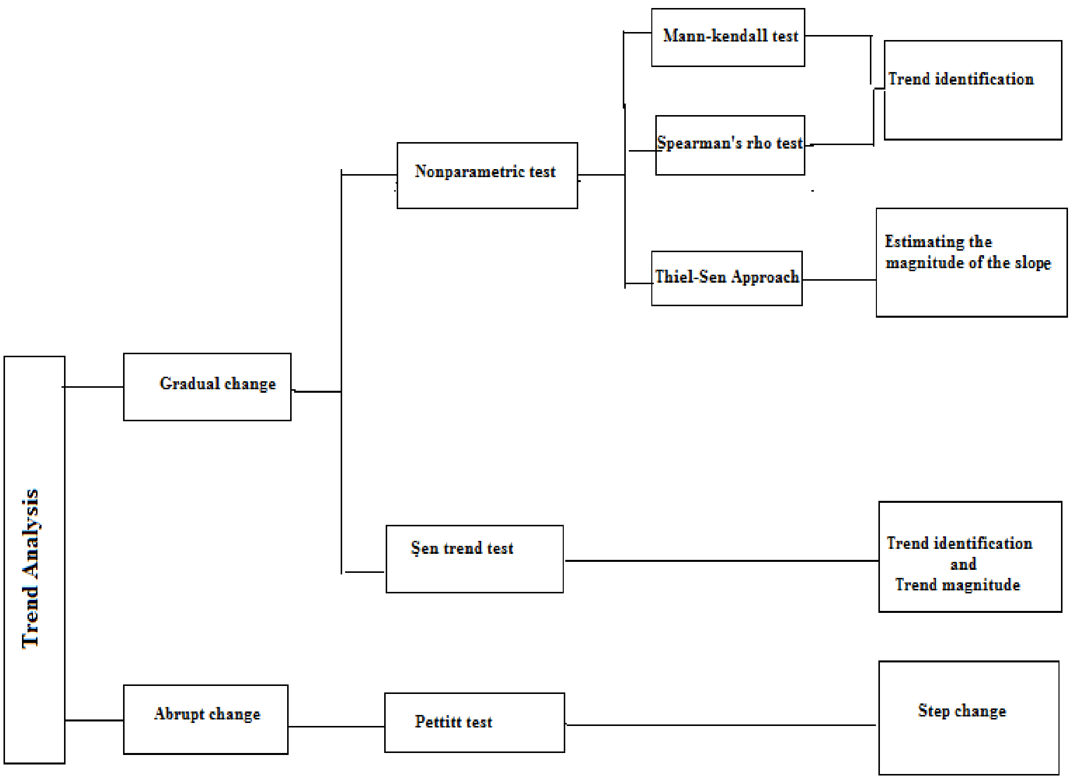

Figure 1.2. Trend analyses framework used in this study

1.4. Thesis Structure

This thesis is consisted of six chapters. The chapters are briefly explained in the following:

CHAPTER 1. INTRODUCTION. This chapter first introduces the needs for the drought and Trend analyses then shortly clarifies, the problem statement, the aim of the study then methodology in the thesis and finally structure the thesis.

CHAPTER 2. LITERATURE REVIEW. This chapter explains the background information of the study. The first part of this chapter describes the Droughts through its definitions, classification, characteristics, impacts and assessment then gives a short explanation for the methods used for drought analysis. The second part explains the background of trend analysis and the study done for the subject.

CHAPTER 3. DATA AND STUDY AREA. This begins with a brief description of water resource in Mauritania following by clarification of the region of the study. The data and its characteristics were presented at the end of this chapter.

CHAPTER 4. DROUGHT ANALYSIS. This chapter starts by the methods used to analyze the drought in the region and their applications. Then the results are described followed by discussion.

CHAPTER 5. TREND ANALYSIS. This chapter as well as chapter 4 consists of two parts: the annual temperature (maximum, minimum, average), and annual precipitation trends analyses by applying 5 trend identification tests. Then the results of this methods were discussed at the end.

CHAPTER 6. CONCLUSIONS AND FUTURE REVIEW. This chapter concludes the overall the two subjects, drought and trend analyses by summarizing their results, then highlights the importance of this thesis in the region of the study.

CHAPTER 2

LITURATURE REVIEW

2. 1. Review on Drought Literature

Drought is recognized as an environmental disaster and it has attracted the attention of environmentalists, ecologists, hydrologists, meteorologists, geologists and agricultural scientists. Compering to the other natural disasters, drought usually affects slowly in time, often accumulate over an extended period of time and may linger for years after termination so that makes it possible to build mitigation plan to reduce drought effects in an efficient way. Drought is available in extensive literature with respect to definitions, classifications, methods of analysis and management procedures.

2.1.1. Drought Definitions

When defining a drought it is important to distinguish between conceptual and operational definitions (Mishra & Singh, 2010). Conceptual definitions help to understand the concept of drought and its effects. For example; drought is a prolonged period of deficient precipitation. Conceptual definitions do not provide quantitative answers to 'when", "how long", "how severe" a drought is and are often used as a startup in scientific papers and reports. Operational definitions help to identify the onset, severity, and termination of drought periods. Generally operationally defined drought can be used to analyze drought frequency, severity, and duration for a given historical period.

Drought is viewed in different ways by different constituency of water users. Some of the commonly used definitions are: The World Meteorological Organization (WMO) (Mishra & Singh, 2010), states that drought comes from a deficiency of precipitation that results in a water shortage for some activities or some group. The UN Convention to Combat Drought and Desertification (General, 1994) defines 'drought is the naturally occurring phenomenon that exists when rainfall has been significantly less than normal recorded levels, causing serious hydrological imbalances that badly affect land resource production systems. The Food and Agriculture Organization (FAO) (Mishra & Singh, 2010) of the United Nations defines a drought as ‘the percentage of years when crops fail from the deficiency of moisture’. The encyclopedia of climate and weather (Schneider, 1996) describes a drought as ‘a prolonged period (a season, a year, or several years) of deficient rainfall relative to the statistical multi-year mean for a region’. Gumbel (1963) stated that ‘drought is the smallest annual value of daily streamflow’. Palmer (1965) defined drought as a significant deviation from the normal hydrologic conditions of an area’. However, drought definitions vary, depending on the variable which is used to describe the drought hazard. Hence, drought definitions can be classified into four categories which are discussed below.

2.1.2. Classifications of Drought

Droughts are generally classified into four categories (Mishra & Singh, 2010) which include:

1. Meteorological drought is described as a lack of rainfall over a region for a prolonged period of time often, accompanied by high temperature, high winds, and low humidity that make evapotranspiration increasing as shown in Figure 2.1. Meteorological drought is the first type of drought that people can report as a drought, because they study detailed and accurate daily records of rainfall and can relate them to the known characteristics of the soil in a particular region.

2. Hydrological drought is an extended periods of unusually low soil moisture which affect agriculture and plant growth and it is usually measured on the scale of a river drainage system.

3. Agricultural drought is the first economic sector which could be affected by drought. Low precipitation might affect stream flow, lake, reservoir levels, and makes their elevations decline to abnormal low levels.

4. Socioeconomic drought occurs when shortage of water begins to affect the health, well-being and quality of life of the people or when the drought starts to affect the supply of goods and services to a community.

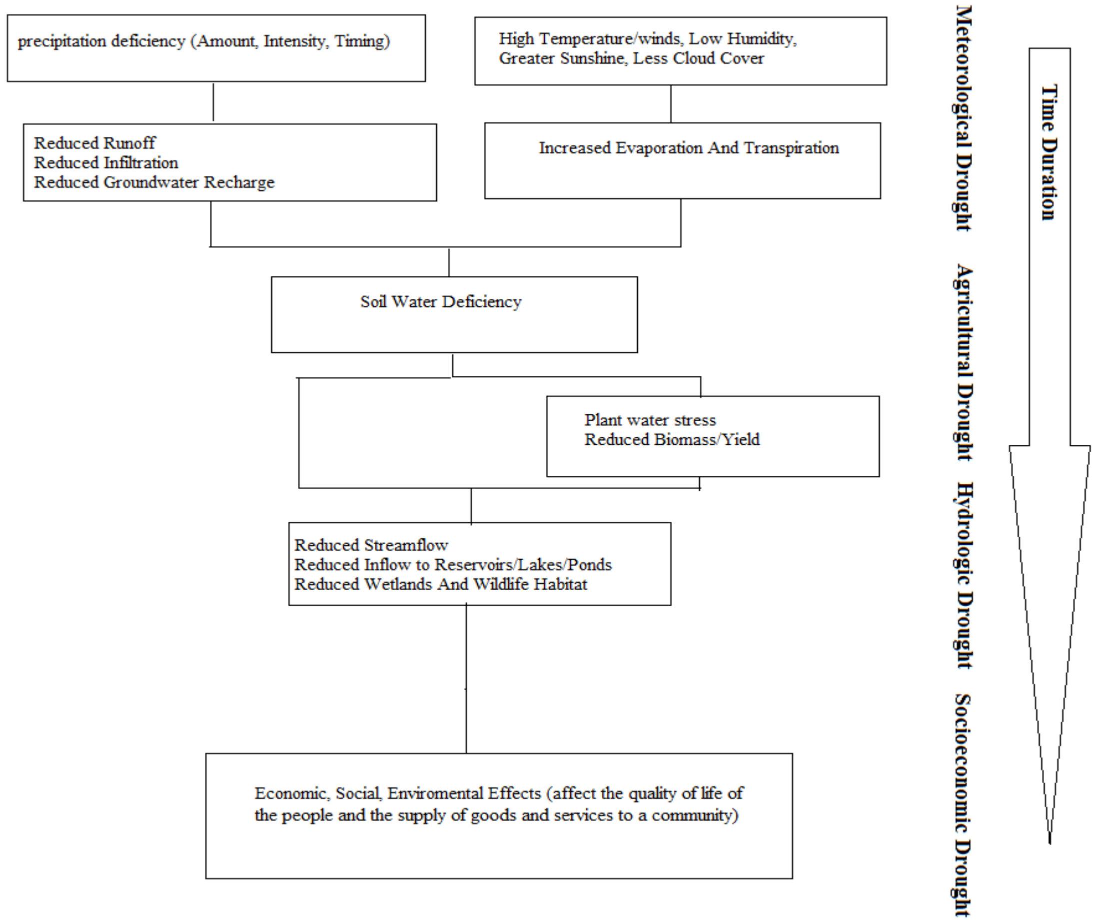

Figure 2.1 Development of drought

2.1.3. Impact of Drought

Mishra and Singh (2010) stated that drought ranks first among all natural hazards in terms of the number of people affected; the US Federal Emergency Management Agency (FEMA) estimated annual losses of drought at US$6-8 billion (Wilhite, 2000). The percentage of area affected by drought has doubled from 1970s to 2000s (Nagarajan, 2010). Since the late 1960s, the Sahel, a semiarid region in West Africa between the Sahara desert and the Guinea coast rainforest has experienced a drought of unprecedented severity in recorded history (Mishra & Singh, 2010). The drought has had a devastating impact on this ecologically vulnerable region and was a major impetus for the establishment of the United Nations Convention on Combating Desertification and Drought (UNCCD) (Zeng, 2003). For example, in subSaharan

Africa, The Office of Foreign Disaster Assistance (OFDA) reported that the droughts of the early to mid-1980s are reported to have adversely affected more than 40 million people (Wilhite, 1996). The 1991–1992 droughts in southern Africa affected 20 million people and resulted in a deficit of cereal supplies of more than 6.7 million tons (Wilhite, 2000).

2.1.4. Assessment of Drought

Assessment of droughts is a primary importance in the planning and management of water resources. In this light, there is the need to investigate droughts in the region historically, in terms of the causes and impacts during their occurrences. Consequently, understanding the different concepts of drought would help in developing models to for the droughts. Droughts, unlike other natural disasters creep in slowly and for this reason it is possible to build mitigation strategies to efficiently combat effects of droughts. Mitigation actions should be undertaken in three phases: prior, during and after droughts. This way, not only would the effects be reduced significantly but also at a minimal cost. In this reason several methods were developed to assess and monitor the drought event.

2.1.5. Drought Indices

A drought index is a single variable used for assessing the effect of a drought and defining different drought parameters, which include intensity, duration, severity and spatial extent. Drought indices are usually continuous functions of rainfall, temperature, streamflow, or other measurable variables. Rainfall data are widely used to calculate drought indices, because long-term rainfall records are often available. Brief descriptions on drought indices which are grouped according to the surface of information used in this thesis are reviewed below.

2.1.5.1. Standardized Precipitation Index (SPI)

The standardized precipitation index (SPI) for any location is calculated, based on the long-term precipitation record for a desired period. This long-term rainfall record is fitted to a probability distribution, which is then transformed into a normal distribution using an equal-probability transformation so that the mean SPI for the location and desired period is zero (McKee, Doesken, & Kleist, 1993) and as such, values above zero indicate wet periods and values below zero indicate dry periods.

In 1993 researchers at Colorado State University proposed the SPI to be a relatively simple for the purpose of defining and monitoring drought (M. J. Hayes, Svoboda, Wilhite, & Vanyarkho, 1999). The SPI has several characteristics that are improvement of how it is effective tool for drought monitoring, including its simplicity and temporal flexibility, which allow its application for water resources on all timescales (M. J. Hayes et al., 1999).

The use of different types of statistical distribution affects the SPI values as the SPI is based on the fitting of a distribution to precipitation series. Some of the commonly applied distributions include gamma distribution (Edwards, 1997) and Pearson Type III distribution (Guttman, 1999). Normal, log-normal, extreme value, and exponential distributions are widely applied to simulations of precipitation distributions (Lloyd‐Hughes & Saunders, 2002; Madsen, Mikkelsen, Rosbjerg, & Harremoës, 1998; Thom, 1966; Todorovic & Woolhiser, 1976).

China-Z Index (CZI) is other drought index has been introduced to the National Meteorological Center of China (NMCC) since the early 1990s using the same category of SPI. CZI is calculated assuming that precipitation data follow the Pearson Type III distribution (Ju, Yang, Chen, & Wang, 1997).

2.1.5.2. Percent of Normal (PN)

In this method the time scale of the analysis can vary from a single month to a year. The percent of normal (PN) is highly transparent, which makes it favorable for communicating drought levels to the public (Keyantash & Dracup, 2002). The use of PN implies a normal distribution which considered the mean and the median to be the same (M. Hayes, 2003), which is not necessarily true. Therefore, mitigating the risks of drought based on the departures from normal is not a useful decision-making tool when used alone (M. J. Hayes, 2006a).

2.1.5.3. Deciles

The method of deciles is based on dividing the distribution of monthly record precipitation into 10 parts or deciles. It was developed by Gibbs and Maher (1967) to avoid some of the weaknesses within the “percent of normal” approach. In calculating deciles, long-term monthly rainfall records were first ranked from highest to lowest to construct a cumulative frequency distribution (Barua, Ng, & Perera, 2010).

2.1.6. Drought Characteristics

When defining drought, the characteristics of drought should be defined. A drought event has the following main components as showed in Figure. 2.2. Drought initiation time (t_i): it indicates the beginning of a drought, in the other word it is the starting of the water shortage period. Drought termination time (t_e): it is the time when the drought is no longer persisting. Drought duration (D): it is expressed in period of time (years, months, weeks, etc.,) during which a drought parameter is continuously below the critical level. In other words, it is the time period between the beginning and termination of a drought. Drought severity (S); it indicates a cumulative deficiency of a drought parameter below the critical level. Drought intensity (I): it is the average value of a drought parameter below the critical level. It is measured as the drought severity divided by the duration. Interval time (L): it is the period between two drought events.

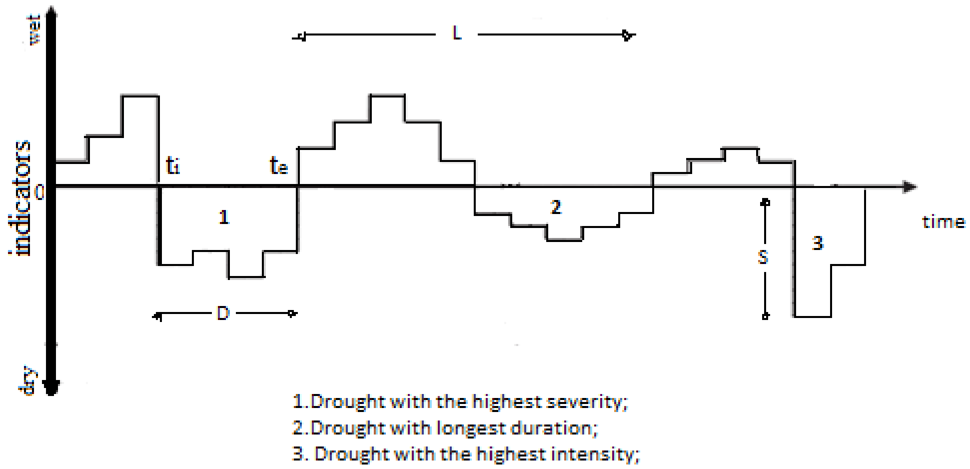

Figure 2. 2. Drought characteristics using the run theory for a given threshold level (source: Mishra & Singh, 2010)

DIs are mostly developed for a specific region, Morid, Smakhtin, and Moghaddasi (2006) mentioned that no index is ideal or universally suitable because of the inherent complexity of drought phenomena, the different hydro-climatic, and the catchment characteristic; After comparing and evaluating the performance of different DIs Barua et al. (2010) found that Aggregated Drought Index (ADI) was superior to other indexes for drought management within the Yarra River catchment in Australia. In Tehran, Morid et al. (2006) The Gamma SPI and Effective Drought Index (EDI) were found to be able to detect the onset of drought, its spatial and temporal variation consistently, and it recommended for operational drought monitoring in the region. In China the SPI was found to be an effective index for assessing drought conditions at different time scales and has suggested to be adopted for use in China (Yuan & Zhou, 2004), while Wu, Hayes, Weiss, and Hu (2001) proposed that CZI and normal SPI can be considered more appropriate tools for monitoring drought and floods than the Gamma SPI because they are easier to calculate. However the choice of indices to monitor the drought in a specific area should be based on the quantity of climate data available and on the ability of the index to consistently detect spatial and temporal variations during a drought event (Morid et al., 2006).

2.2. Review on Trend Analysis

The global climatic change has attracted the attention of many scientists in recent years. The studies of the effect of climate change are mostly monitored through the air temperature and precipitation trends change rather than hydrologic variables. Many studies have proved the evidences that the temperature and the precipitation increased in the recent year; New, Todd, Hulme, and Jones (2001) collected a precipitation data from a number of countries to identify the trends in precipitation and they concluded that the daily precipitation has increased during the twentieth century. A study by Jones, New, Parker, Martin, and Rigor (1999) on the surface air temperature and its changes over 150 years showed that the global temperature during the periods 1925-1944 and 1978–1997 rose by 0.37° and 0.32°C, respectively. Lettenmaier, Wood, and Wallis (1994) analyzed the hydro-climatological trends in the continental United States for the period of 1948-1988 and they found that increasing on trends have detected in half of the station for the march temperature as well as the precipitation which increases from September through December in 25 percent of the stations. S.-T. Chen, Kuo, and Yu (2009) investigated the historical trends of meteorological drought in Taiwan by means of long-term precipitation records, and they detected positive trend in the daily precipitation time series for dry days all over Taiwan.

The historical hydro-climatic such precipitation and temperature recorded data are generally used for planning and designing water resources projects. The changes in these meteorological variables in the recent years brought into focus the search for effective trend identification Tests to investigate and analyze the regime changes in the data time series for these variables. Many of these trend tests are classified into parametric and non-parametric methods. Parametric trends test are found to be more powerful than non-parametric ones (Shadmani, Marofi, & Roknian, 2012). However, paramedic trend test require data to be normally distributed. In comparison, non-parametric trend tests do not assume that the data has specific distribution. The non-parametric Mann Kendall (MK) and Spearman's tests are commonly used for detecting trend of hydro-meteorological variables (Garbrecht, Van Liew, & Brown, 2004; Gellens, 2000; Kahya & Kalaycı, 2004; Shadmani et al., 2012). The reason of using these two nonparametric rank-based statistical tests is their ability to identify the monotonic trends (upward and downward trends) in the time series data. The MK test is designed to deal with such data; non-normal data, missing values, seasonality, censoring (detection limits), and serial dependence (Hirsch & Slack, 1984). However the power of these methods has not been well documented. Yue, Pilon, and Cavadias (2002) investigated the power of these two tests and the results indicate that their power (decease or increase) depends on different variables including slope of the trend, sample size, pre-assigned significance level and the variation of the time series. Şen (2011) provided a new trend analysis method, which is able to identify the trend in the time series especially in terms of low, medium and high values of the data (Kisi & Ay, 2014). This method is valid whatever the sample size, serial correlation structure of the time, and non-normal probability distribution functions (Şen, 2011). many studies use the Theil-Sen approach which was provided by Hirsch, Slack, and Smith (1982) for estimating absolute values for slope (Z. Chen & Grasby, 2009; Gallego, García, Vaquero, & Mateos, 2006; Shadmani et al., 2012; Some'e, Ezani, & Tabari, 2012; Yue et al., 2002) . Furthermore, the Pettitt's test (1979) is used for detecting change points in the time series (Gebremicael, Mohamed, Betrie, van der Zaag, & Teferi, 2013; Mu, Zhang, McVicar, Chille, & Gau, 2007; Tomozeiu, Busuioc, Marletto, Zinoni, & Cacciamani, 2000; Zhang et al., 2008).

CHAPTER 3

DATA AND STUDY AREA

3.1. Study Area

Mauritania is located in western Africa and it is generally composed of the Sahara desert (arid zone) in the north and the Sahel (a semiarid zone) in the south (Fig. 3.1).

Figure 3.1. Mauritania Map

The Sahara extends over a large area and it is characterized by an absence of vegetation cover, water scarcity, and sporadic precipitation. The total (actual) renewable surface water resources in Mauritania are estimated at 11.1 km^3/year and the internal renewable surface water resources at 0.1 km^3/year. The hydrographic system is dominated by the Senegal River which runs along the southern border (Fig. 3.1.). In Mauritania, total groundwater resources are estimated at 3.7 km^3, which refers to the continuous aquifers only; however the yields of the alluvial groundwater in the wadis and the intermittent aquifer systems have not yet been quantified. The rainy season lasts only 3 months (July-September) with average annual rainfall being 99 mm, but this varies from less than 20 mm in the north to more than 500 mm in the south-east, and average minimum and maximum temperatures vary from 16°C in January to 36°C in June.

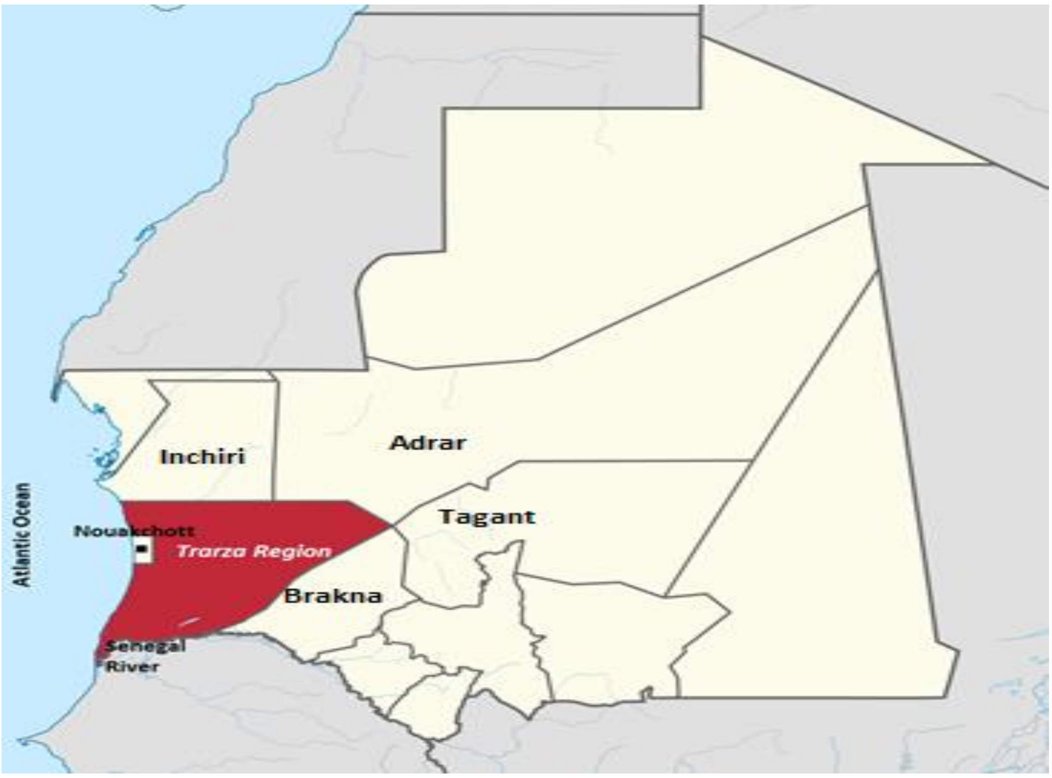

Figure 3.2. Trarza Region

Trarza is a region in southwest Mauritania, it borders the regions of Inchiri and Adrar to the north, Brakna to the east, and the country of Senegal to the south as is shown in the Figure 3.2. The water resources in Trarza region support a range of use in Mauritania including urban water supply and agricultural. It borders by the Senegal River which plays a very important role as main surface water source in Mauritania. Trarza has a huge reservoir (La nappe du Trarza) which becomes crucial during drought periods.

3.2. Data

With the arrival of the French in 1905, the meteorological observation began in Mauritania and the activity of observing the weather and climate continued to grow basically managed by a meteorological observation network consisting of 18 synoptic stations including 4 marine observations and more than 600 rainfall stations distributed all over the country. The network is still far from fulfilling the needs of the country and thus it must be compacted to ensure good coverage of the country which is about 1.03 million km^2, in size.

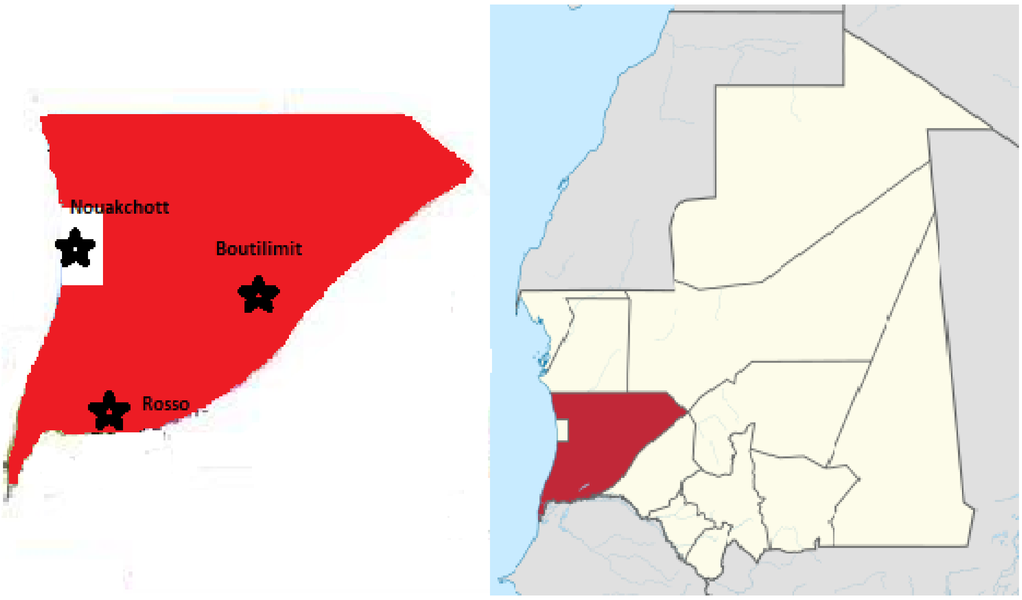

Figure 3.3. Rainfall Stations

The data used in this study for calculating DIs were collected from the National Office of Meteorology of Mauritania (Office National de la Météorologie). Three rainfall stations, namely Boutilimt (station #1), Nouakchott (station #2), and Rosso (station #3), as shown in Figure 3.3 were employed in this study. One station (Nouakchott) is outside the catchment area; however it was considered in this study since it is very close to the study area. Table 3.1 summarizes the latitude, longitude and altitude for each station.

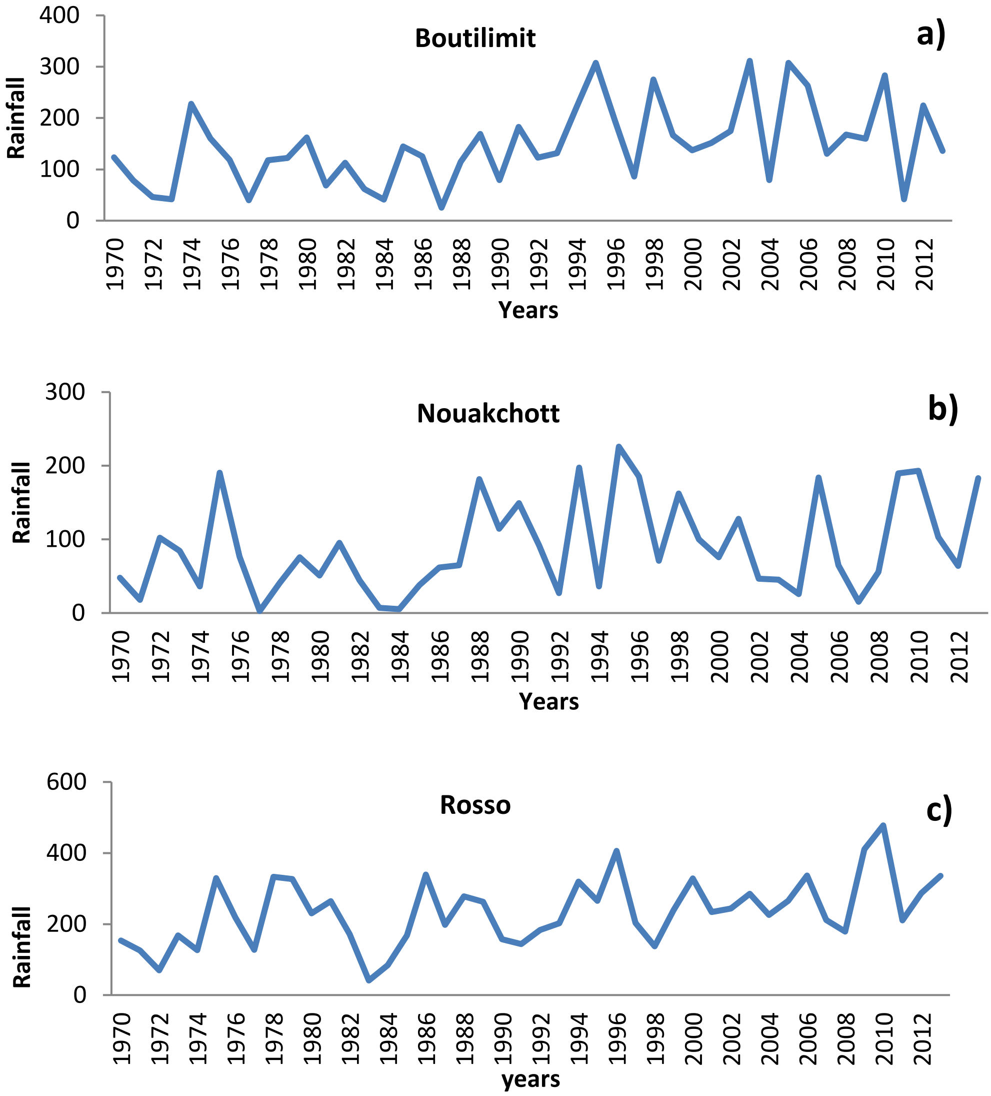

Figure 3.4. The rainfall in the 3 Stations (Boutilimit (a), Nouakchott (b) and Rosso (c))

The monthly precipitation (rainfall) and temperature data from 1970 to 2013 are used in this study. The employed rainfall data for each station are shown in Figure 3.4.

Table 3.1. Location of the Meteorological Stations

Station	Latitude (North)	Longitude (West)	Altitude (m)
Boutilimt (station #1)	17.54	14.69	48.59
Nouakchott (station #2)	18.07	15.95	4.44
Rosso (station #3)	16.51	15.8	6.26

As seen in figure 3.4, maximum annual rainfall reaches 311 mm in 2003 and 226 mm in 1995 in Stations 1 and 2, respectively while Station 3, which is located in the Senegal River Valley region where the rainfall is higher than other regions, behaves differently with maximum rainfall of 477.8 mm in 2010. Table 3.2 summarizes rainfall characteristics for each station.

Table 3.2. Annual Rainfall Characteristics

Rainfall characteristics	**Boutilimit**	**Nouakchott**	**Rosso**
Mean	146.22	89.97	234.12
Standard Error	11.69	9.55	14.19
Median	133.75	73.5	228.15
Mode	307.2	75.9	265.5
Standard Deviation	77.56	63.37	94.12
Sample Variance	6016.17	4016.02	8860.44
Kurtosis	0.27	0.83	0.0075
Skewness	0.57	0.62	0.30
Range	286.1	223.2	436.7
Minimum	25.3	2.7	41.1
Maximum	311.4	225.9	477.8
Confidence Level (95.0%)	23.58	19.26	28.61

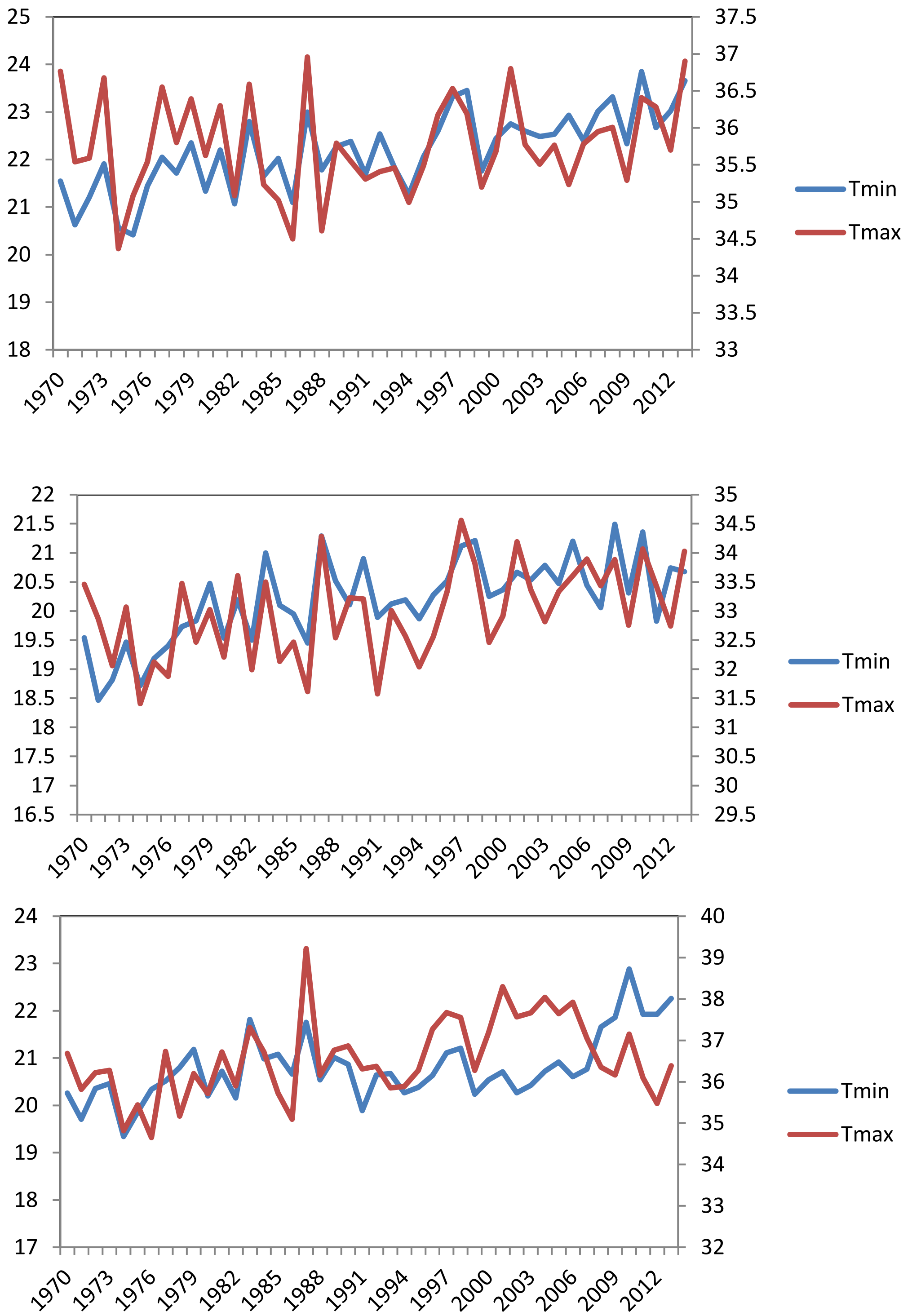

Figure 3.5. Annual maximum and minimum temperatures for the three stations Boutilimit (1), Nouakchott (2) and Rosso (1), respectively

Table 3.3. Characteristics of Annual temperatures (maximum, minimum, average) data for Boutilimit (1), Nouakchott (2) and Rosso (3)

Station	T-min (ºC)			T-max (ºC)			T-average (ºC)		
	min	**max**	**mean**	**min**	**max**	**mean**	**min**	**max**	**mean**
1	20.4 (1975)	23.8 (2010)	22.3	34.3 (1974)	36.95 (1987)	35.69	27.46 (1974)	30.28 (2013)	29.04
2	18.46 (1971)	21.49 (2008)	22.22	31.4 (1974)	34.55 (1997)	33.01	25.06 (1974)	27.83 (1997)	26.61
3	19.34 (1974)	22.88 (2010)	20.6	34.65 (1976)	39.21 (1987)	36.36	27.07 (1974)	30.48 (1987)	28.71

In this work, annual minimum temperature (T-min), maximum temperature (T-max) and average temperature (T-average) were collected from three stations namely Boutilimit (1), Nouakchott (2) and Rosso (3) during the period of 1970-2013. The characteristics of these data are presented in Fig 3.5 and Table 3.3. They showed that station 3 has the maximum temperature record with 39.21ºC in 1987 when it was the warmest year detected in the station 1 and 3 with average of 30.28 and 30.48ºC. The minimum temperature in this region was detected in 1971 in the station 2 with 18.46ºC, but 1974 is considered as the coldest year (during the period of the study) in the region where the average temperature showed its minimum values in the three stations, 27.46ºC, 25.06ºC and 27.07ºC for the stations 1, 2 and 3, respectively.

CHAPTER 4

DROUGHT ANALYSIS

4.1. Application

Based on monthly precipitation records for 44 years collected from 3 weather stations we applied different types of DIs for the purpose of drought assessment within the region for periods of 1, 3, 6, and 12 months. Since the rainy season is July-September, only this 3 months period was considered in the analysis for monthly and 3 months analysis. These methods were used to identify the characteristics of drought (frequency, magnitude and duration) and were also evaluated to identify suitable drought index(s) that can be employed for drought assessment in the region.

4.1.1. Standardized Precipitation Index (SPI)

The standardized precipitation index (SPI) for any location is calculated, based on the long-term precipitation record for a prolonged period of time. This long-term rainfall records are fitted to a probability distribution, which is then transformed to a normal distribution using an equal-probability transformation so that the mean SPI for the location and desired period is zero (McKee et al., 1993) and as such, values above zero indicate wet periods and values below zero indicate dry periods.

Table 4.1. SPI Drought Classifications
(Source: Barua et al., 2010)

SPI value (z-score)	Category
2.00 or more	Extremely wet
1.50 to 1.99	very wet
1.00 to 1.49	Moderately wet
0.99 to -0.99	Near normal
-1.00 to -1.49	Moderate drought
-1.5 to -1.99	Severe drought
-2 or less	Extreme drought

There are different types of statistical distribution can give different results when applied as the SPI is based on the fitting of a distribution to precipitation series. In this study we use three different types of statistical distribution; normal distribution, log-normal distribution and the gamma distribution. The drought classifications for the z-score (SPI) are summarized in Table 4.1.

4.1.1.1. Normal-SPI

It may be sometimes more effective, at the computational level, to standardize the data directly from a fitted normal distribution where possible. The normal-SPI is computed as follows (Cacciamani, Morgillo, Marchesi, & Pavan, 2007):

$$SPI = z = \frac{x - \hat{\mu}}{\hat{\sigma}} \tag{4.1}$$

where, z is the standardized value, and $\hat{\mu}$ and $\hat{\sigma}$ are the sample estimates of the population mean and standard deviation, respectively.

4.1.1.2. Log-normal SPI

In common with the gamma distribution, the log-normal distribution is positively skewed and non-negative. It has the benefit of its simplicity since it is just a logarithmic transformation of the data. Log-normal SPI is calculated as follows (Lloyd-Hughes & Saunders, 2002):

$$SPI = z = \frac{\ln(x) - \hat{\mu}}{\hat{\sigma}} \tag{4.2}$$

4.1.1.3. Gamma-SPI

In most cases, Gamma distribution is the best model for observational precipitation data. The density probability function for the Gamma distribution is expressed as (Sönmez, KÖmÜscÜ, Erkan, & Turgu, 2005):

$$f(x, \alpha, \beta) = \frac{1}{\beta^{\alpha}\,\Gamma(\alpha)} x^{\alpha-1} e^{x/\beta} \quad \text{for } x,\ \alpha,\ \beta > 0 \tag{4.3}$$

Where α and β are the shape and scale parameters, respectively. X is the rainfall amount and Γ(α) is the Gamma function defined by the integral (Gąsiorek & Musiał, 2015) :

$$\Gamma(x) = \lim_{n\to\infty} \prod_{v=0}^{n-1} \frac{n!\,n^{y-1}}{y+v} \equiv \int_0^{\infty} y^{\alpha-1}\, e^{-y} dy \tag{4.4}$$

The maximum likelihood method is used to estimate the optimal values of the parameters α and β by using Eqs (4.5-4.6) (Barua et al., 2010) as:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \tag{4.5}$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \tag{4.6}$$

for n number of observations (Barua et al., 2010),

$$A = ln(\bar{x}) - \frac{\sum ln(x)}{n} \tag{4.7}$$

The resulting parameters $\hat{\alpha}$ and $\hat{\beta}$ are then used to cumulative probability for nonzero rainfalls by using the Equ. 8 (Barua et al., 2010) as follows:

$$F(x) = \int_0^x f(x)dx = \frac{1}{\hat{\beta}^{\hat{\alpha}}\, \Gamma(\hat{\alpha})} \int_0^x x^{\hat{\alpha}-1}\, e^{-x/\hat{\beta}} dx \tag{4.8}$$

Equ.4.8 can also be expressed as (Barua et al., 2010):

$$F(x) = \frac{1}{\Gamma(\hat{\alpha})} \int_0^x t^{\hat{\alpha}-1}\, e^{-t} dx \tag{4.9}$$

where t = X/β̂. Since the gamma function is undefined for X = 0 and precipitation may contain zeros, the calculations of probability of zero and non-zero becomes (Lloyd-Hughes & Saunders, 2002)

$$H(x) = q + (1 - q)F(x) \tag{4.10}$$

where, q is the probability of zero rainfall when m is the number of zeros in a precipitation time series, then q is estimated by m/n. The cumulative probability, H(x) is then transformed to the standard standardized normal distribution so that the SPI mean (Z) and the variance become 0 and 1, respectively. Using an approximation provided by Abramowitz and Stegun (1965), which converts cumulative probability into the standard normal random variable, called z:

$$SPI = z = -(k - \frac{c_0 + c_1 k + c_2 k^2}{1 + d_1 k + d_2 k^2 + d_3 k^3})$$

$$\text{when } k = \sqrt{ln\left\{\frac{1}{[H(x)]^2}\right\}} \qquad \text{for } 0 < H(x) \leq 0.5 \tag{4.11}$$

$$SPI = z = +(k - \frac{c_0 + c_1 k + c_2 k^2}{1 + d_1 k + d_2 k^2 + d_3 k^3})$$

$$\text{when } k = \sqrt{ln\left\{\frac{1}{[1-H(x)]^2}\right\}} \qquad \text{for } 0.5 < H(x) \leq 1 \tag{4.12}$$

where, $c_0 = 2.515517, c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, and $d_3 = 0.001308$. The SPI threshold range that is used to define severity of the drought is presented in Table 4.1.

4.1.2. Percent of Normal

The Percent of Normal (PN) is a meteorological drought index, which is calculated by dividing actual precipitation by normal precipitation then multiplying by 100% (M. J. Hayes, 2006b). PN Drought classification is presented in Table 4.2.

Table 4.2. PN Drought Classifications
(Source: Barua et al., 2010)

Threshold range	Drought classification
180% or more of normal rainfall	Extremely wet
161% to 180% of normal rainfall	Very wet
121% to 160% of normal rainfall	Moderately wet
81% to 120% of normal rainfall	Near normal
41% to 80% of normal rainfall	Moderately drought
21% to 40% of normal rainfall	Severe drought
20% or less of normal rainfall	Extremely drought

4.1.3. China-Z Index (CZI)

The CZI is a drought index that was introduced to the National Meteorological Center of China (NMCC) in early 1990s. The CSI is calculated as (Ju et al., 1997):

$$z_i = \frac{6}{C_{si}}\left(\frac{C_{si}}{2}\varphi_i + 1\right)^{1/3} - \frac{6}{C_{si}} + \frac{C_{si}}{6} \tag{4.13}$$

$$C_{si} = \frac{\sum_{j=1}^{n}(x_{ij} - \bar{x}_i)}{n * {\sigma_i}^3} \tag{4.14}$$

$$\varphi_i = \frac{x_i - \bar{x}_i}{\sigma_i} \tag{4.15}$$

Where z_i is the CZI, i is the time scale interest, C_{si} is the coefficient of skewness and n is the total number of years in the record, φ_i is a standard deviation, x_i is a precipitation, $\bar{x}_i$ is the average and σ_i is the standard division.

4.1.5. Deciles

The method of deciles is based on dividing the distribution of monthly record precipitation into 10 parts (or deciles) (Barua et al., 2010).

Table 4.3. Deciles Drought Classifications

(Source: Barua et al., 2010; Gibbs and Maher, 1967)

Threshold range	Drought classification
Deciles 1-2 (lowest 20%)	Much below normal
Deciles 3-4 (next lowest 20%)	Below normal
Deciles 5-6 (middle 20%)	Near normal
Deciles 7-8 (next highest 20%)	Above normal
Deciles 9-10 (highest 20%)	Much above normal

In calculating deciles, long-term monthly rainfall records are first ranked from highest to lowest to construct a cumulative frequency distribution (Barua et al., 2010). The threshold ranges of deciles used to define drought conditions are presented in Table 4.3.

4.2. Results

4.2.1. DIs Results for Boutilimit (Station 1)

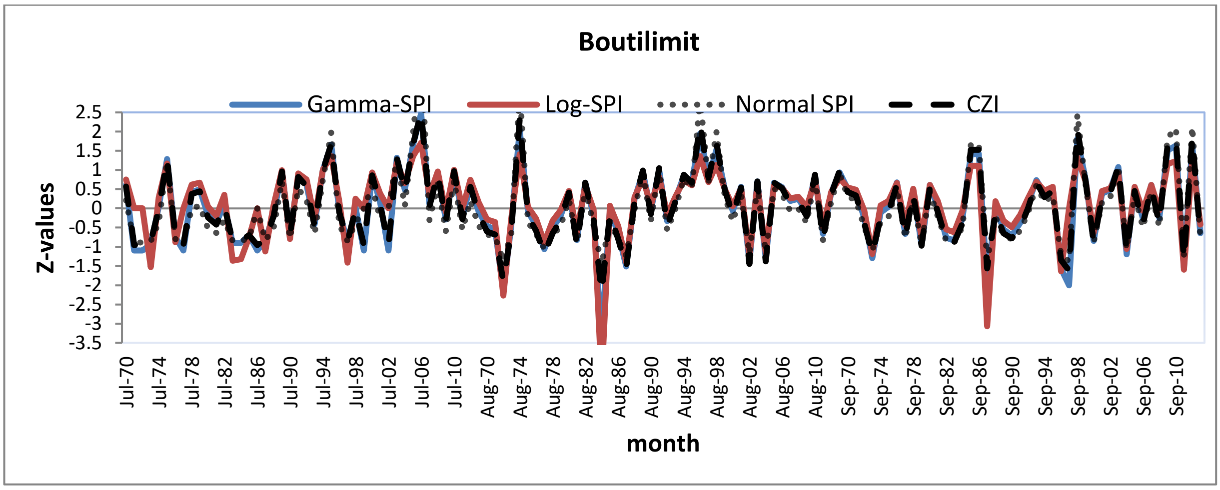

Figure 4.1. SPI and CZI results for monthly period for Boutilimit (Station 1)

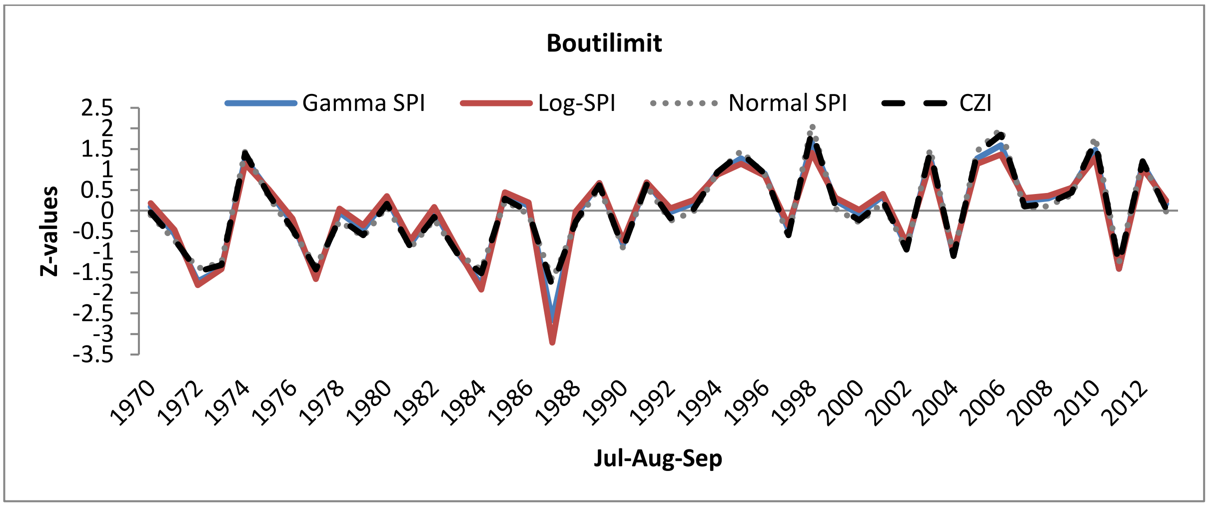

Figure 4.2. SPI and CZI results for 3-months period for Boutilimit (Station 1)

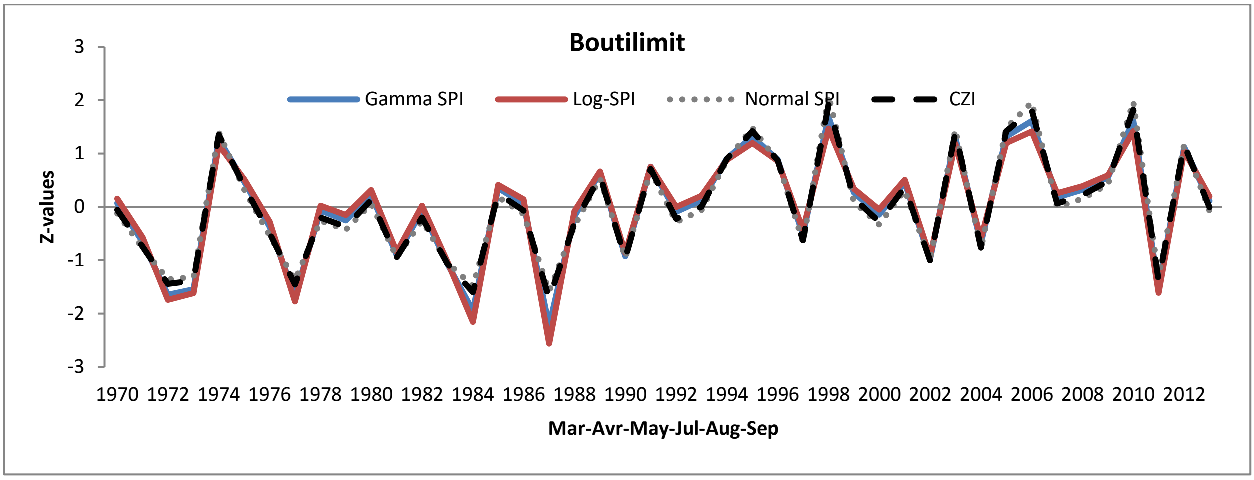

Figure 4.3. SPI and CZI results for 6-months period for Boutilimit (Station 1)

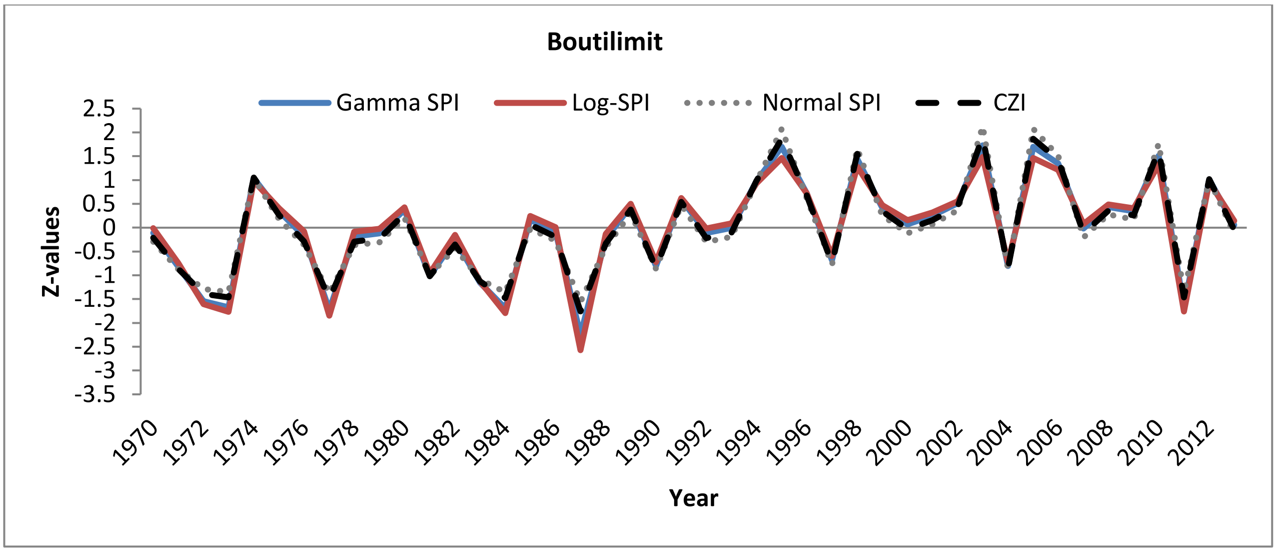

Figure 4.4. SPI and CZI results for 12-months period for Boutilimit (Station 1)

Figures 4.1- 4.4 present SPI and CZI results for periods of 1, 3, 6, and 12 months, respectively while Table 4.4 summarizes the deciles results. Figure 4.1 presents monthly period DI results for station 1. All DI methods produced almost the same results. The CZI and the gamma-SPI methods made more similar predictions for one-month period. These methods tend to make less drought and more wet conditions. The log-SPI makes extreme drought predictions, like the ones in 1984 and in 1987 (Figs 4.1-1.3). In the case of 3-months period, all the methods produced the same predictions. Here, the log-SPI and the gamma-SPI showed more similar performance in terms of prediction of the severe drought condition in 1987 (Fig 4.2). The normal-SPI and the

CZI tend to make wet and less drought conditions (Fig 4. 2). These similar results are obtained for the case of 6-months period (Fig 4.3) and the annual (12 months period) drought predictions (Fig 4.4). According to Fig 4.4, in 1972-1973, 1977, 1984, and 1987 there occurred severe/extreme drought conditions in Boutilimit station.

Figures 4.1-4.4 show that extreme drought was detected in 1987 while distinct drought events occurred in the years 1973, 1977, 1984, and 2011. The long dry periods were detected from 1970 to 1974 and 1982 to 1985.

Table 4.4. Deciles result for Boutilimit (Station 1)

Annuals Rainfall Values (mm)	Classification
43.1 - 78.9	Much below normal
114.3 - 123.1	Below normal
133.8 - 157.9	Near normal
167.8 - 205.2	Above normal
271.5 - 311.4	Much above normal

According to deciles results in Table 4.4, when annual rainfall is less than 133.8 mm drought conditions occur. Severe drought conditions would occur when annual rainfall is less than 80 mm (Table 4.4.).

4.2.2. DIs Results for Nouakchott (Station 2)

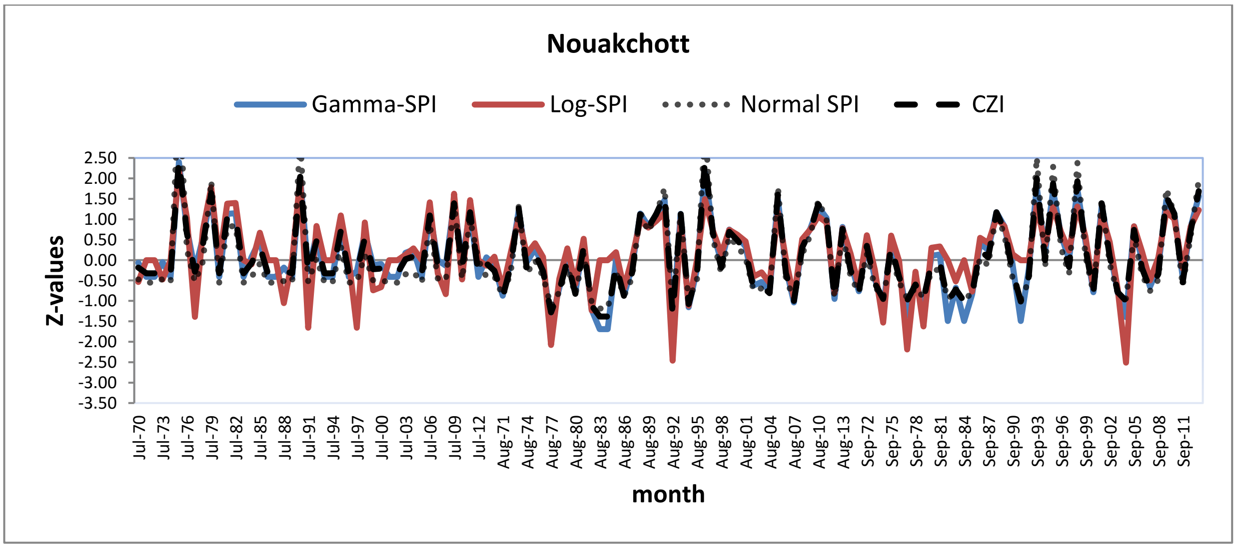

Figure 4.5. SPI results for monthly period for Nouakchott (Station 2)

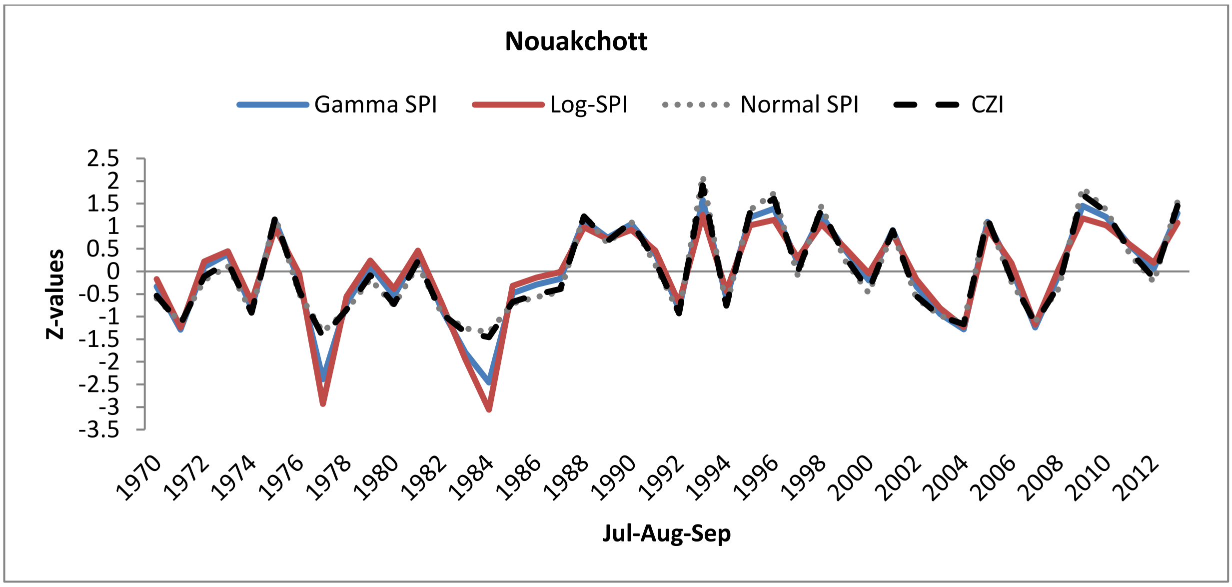

Figure 4.6. SPI results for 3-months period for Nouakchott (Station 2)

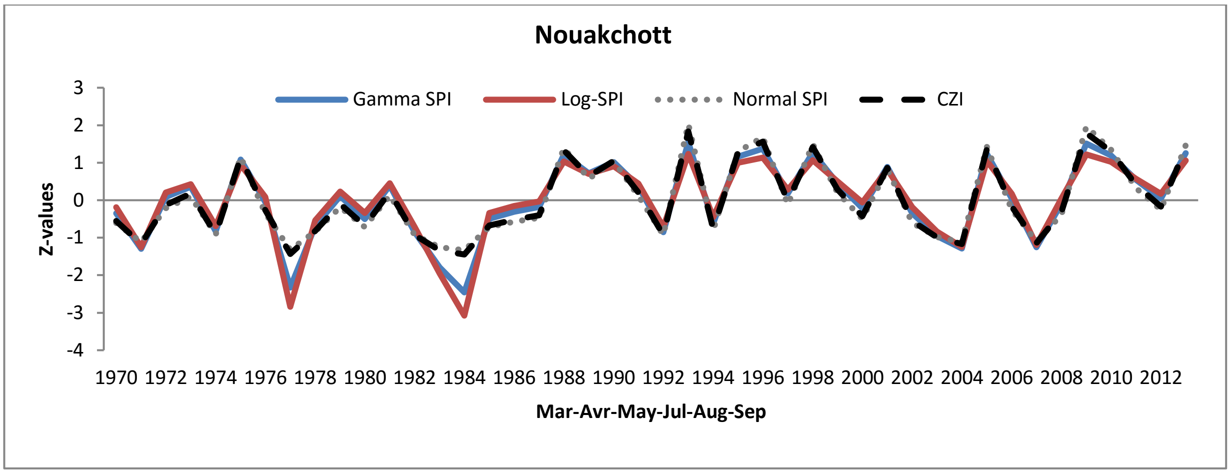

Figure 4.7. SPI results for 6-months period for Nouakchott (Station 2)

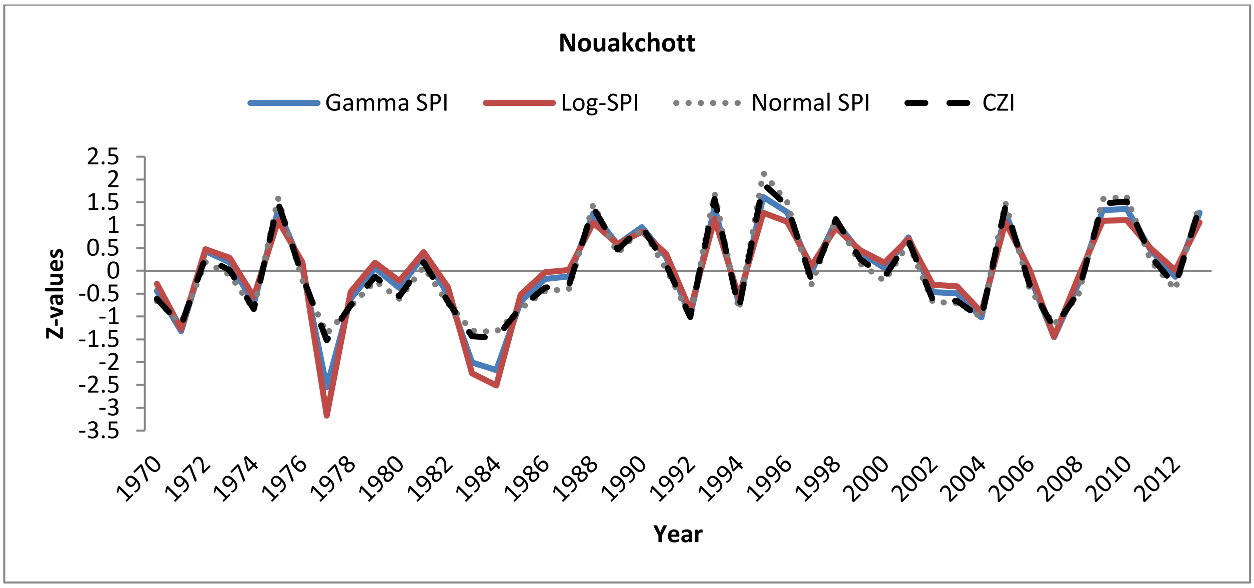

Figure 4.8. SPI and CZI results for 12-months period for Nouakchott (Station 2)

Figures 4.5-4.8 present the SPI and CZI results for periods of 1, 3, 6, and 12 months, respectively while Table 4.5 summarizes the decile results for Nouakchott station. For monthly period, the CZI and the gamma-SPI show similar behavior while the log-SPI tend to produce severe drought predictions (Fig 4.4). The results of DIs for 3-, 6-, and 12-months periods are similar. The normal-SPI and the CZI make fewer drought predictions while the gamma-SPI and the log-SPI make severe drought predictions, such as the ones in 1977 and 1984 (Figs 4.6-4.8).

Figures 4.5-4.8 show that drought appeared more frequently and intensity in this station, compared to the other stations during 44 years. Years; 1977 and 1987 were the worse in term of intensity (extremely droughts), however drought occurred by different intensity in the years; 1971, 1974, 1992, 1994, 2004 and 2007. The driest periods detected by DIs were the periods of 1970-1972, 1982-1986, and 2002-2005.

Table 4.5. Deciles result for Nouakchott (Station 2)

Annuals Rainfall Values (mm)	Classification
20.3 - 37.1	Much below normal
46.7 - 62.7	Below normal
73.5 - 90.5	Near normal
104.3 - 170.2	Above normal
188.3 - 225.9	Much above normal

According to Table 4.5, in station of Nouakchott, less than 73.5 mm/year rainfall is considered as drought according. Less than 63 mm/year and less than 37 mm/year rainfall are considered severe and extreme drought conditions, respectively (Table 4.5).

4.2.3. DIs results for Rosso (Station3)

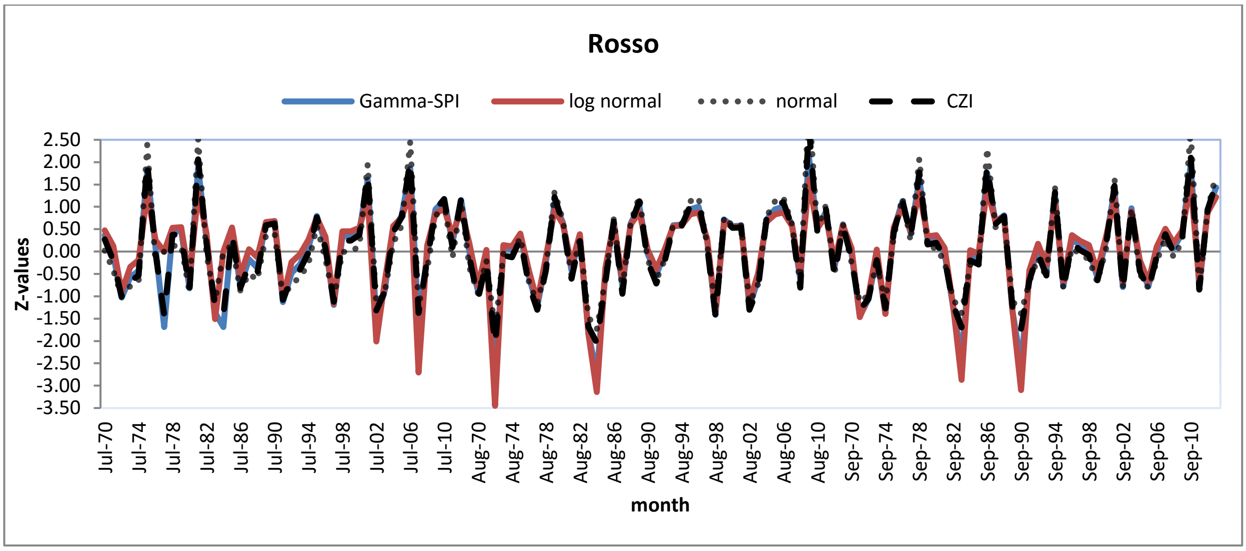

Figure 4.9. SPI results for monthly period for Rosso (Station 3)

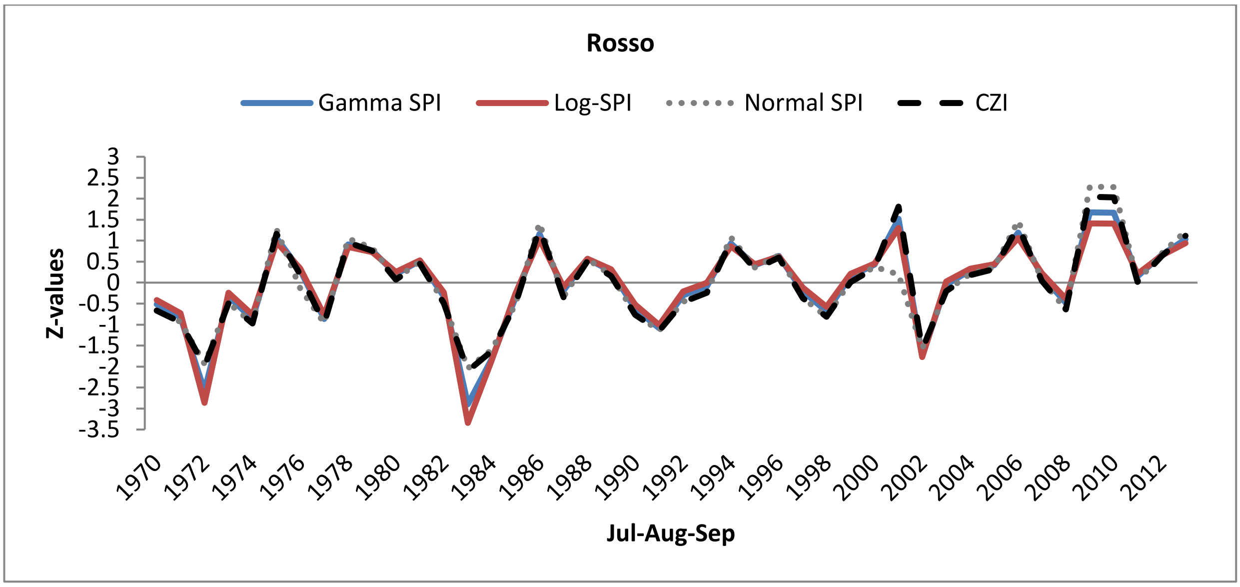

Figure 4.10. SPI results for 3-months period for Rosso (Station 3)

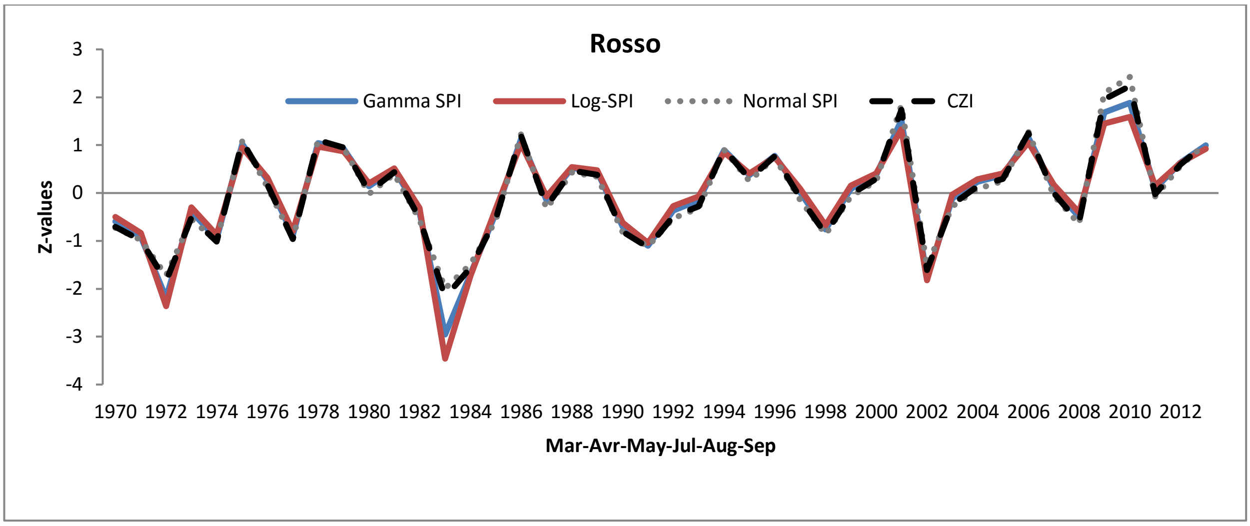

Figure 4.11. SPI results for 6-months period for Rosso (Station 3)

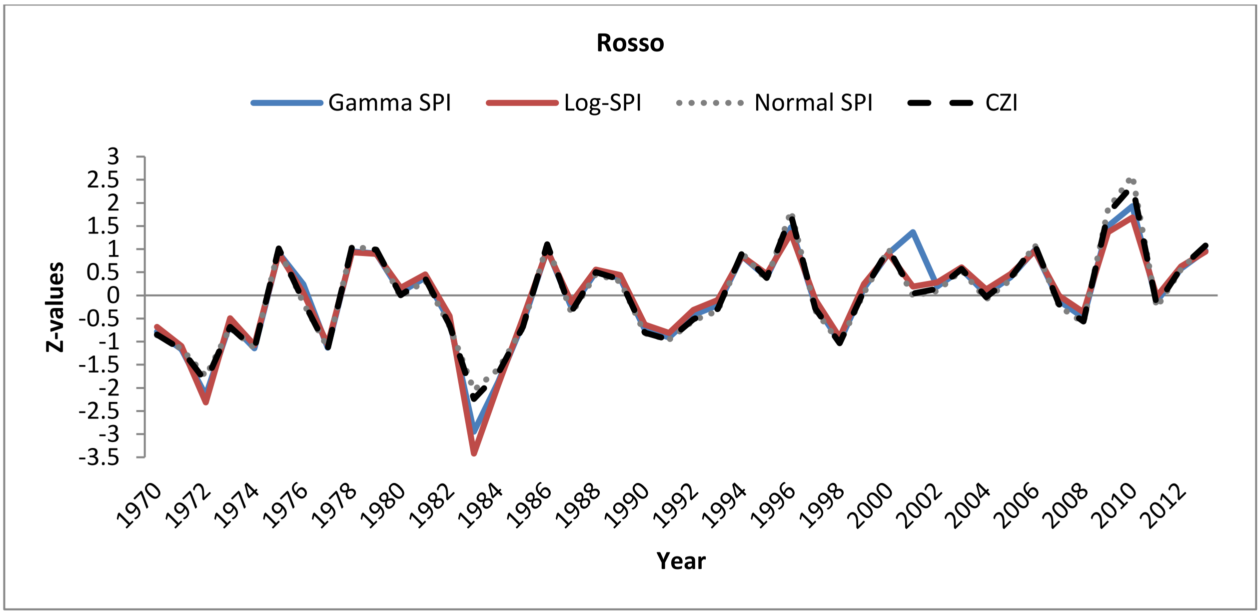

Figure 4.12. SPI and CZI results for 12-months period for Rosso (Station 3)

Figures 4.9-4.12 present SPI and CZI results for periods of 1, 3, 6, and 12 months, respectively while Table 8 summarizes the deciles results. The CZI and the gamma-SPI tend to predict more wet and fewer drought conditions and the log-SPI predicts more severe drought conditions such as the ones in August 1971, August 1984, September 1984 and September 1990, in a monthly period analysis (Fig 4.9). In the three-month period analysis, the gamma-SPI and log-SPI made more drought condition predications such as the ones in 1972, 1983 and 2002 while the normal-SPI and the CZI predicts more wet conditions such as the one in 2009-2010 period (Fig 4.10). The similar result is obtained in the case of 6-month and 12-month periods as well (Figs 4.11-4.12).

Figures 4.9-4.12 show that the most effected years by drought are 1972 and 1983 (extremely drought) and drought has also been detected with different intensity in the years 1974, 1977, 1998. The longest dry periods were detected in 1970-1975 and 1982-1985.

Table 4.6. Deciles result for Rosso (Station 3)

Annuals Rainfall values (mm)	Classification
127.2 - 155.6	Much below normal
177.9- 204.5	Below normal
234.8 -264.0	Near normal
285.2 - 328.8	Above normal
338.3 - 477.8	Much above normal

As shown in Table 4.6, less than 243.8 mm/year rainfall is considered as drought condition. This becomes severe and extreme drought condition when annual rainfall is less than 205 mm and 155 mm, respectively (Table 4.6).

4.3. Discussions of Results

Table 4.7 summarizes the predicted moderate, severe, and extreme drought years by the DI methods for the three stations. PN method results are also presented in Table 4.7 and figs B.1, B.2, B.3, B.4, and B.5. According to Table 4.7 , PN, the log-SPI, and the gamma-SPI methods captures 1987 as the year of extreme drought, 1972, 1973, 1977, 1984, and 2011 as the years of severe drought and 1983 as the year of moderate drought for Boutilimit station. According to the normal-SPI and the CZI methods, 1987 was the severe drought year for the station 1. The years 1972, 1973, 1977, 1981, 1983, 1984, and 2011 were the moderate drought years for the station 1. These results indicate that the normal-SPI and the CZI tend to make one-step underprediction of the degree of the drought. Also, the results indicate that the PN method tends to increase the number of moderate drought years for the three stations (Table 4.7). Owing to the ability of Deciles to classify drought into different categories when compared with other methods, a range of Deciles 1-2 (lowest 20%) was considered a severe and extreme drought.

1977, 1983 and 1984 were predicted as the extreme drought years for the station 2 by the PN and log-SPI and gamma-SPI methods. By the same methods, 2004 was predicted as the severe drought year for station 2 (Nouakchott). For Rosso station, all the methods indicate that 1983 was the year of extreme drought, 1972, 1984 were the severe drought years and 1971, 1974, and 1977 were the years of moderate drought in the station 3 (Table 4.7). The normal-SPI and the CZI methods indicated no extreme and severe drought cases for the station 2, unlike the other 4 DI methods (Table 4.7).

Table 4.7. Characteristics of Historical Droughts as detected by PN, Gamma-SPI, Log-SPI, CZI, Normal-SPI and Deciles

Methods	Drought Intensity	Station1 (Boutilimit)	Station2 (Nouakchott)	Station3 (Rosso)
	Extreme	1987	1971 1977 1983 1984 2007	1983
PN	Severe	1972 1973 1977 1984 2011	1992 2004	1972 1984
	Moderate	1971 1981 1982 1983 1988 1990 1997 2004	1970 1974 1978 1980 1982 1985 1986 1987 1994 1997 2002 2003 2006 2008 2012	1970 1971 1973 1974 1977 1982 1985 1990 1992 1997 1998 2008
	Extreme	1987	1977 1983 1984	1983 1972
Log-SPI, Gamma-SPI	Severe	1972 1973 1977 1984 2011	1971 2004 2007	1984
	Moderate	1981 1983	1974 1978 1982 1985 1992 1994	1971 1974 1977
	Extreme	………….	……….	1983
Normal-SPI, CZI	Severe	1987	…………	1972 1984
	Moderate	1972 1973 1977 1981 1983 1984 2011	1971 1977 1983 1984 2004 2007	1971 1974 1977 1998
Deciles	Extreme and Severe	1970 1972 1973 1977 1981 1983 1987 2011	1971 1974 1977 1983 1984 1992 2004 2007	1970 1971 1972 1974 1977 1983 1984 1991 1998

Table 4.8 summarizes the probability of the drought reoccurrence according to the gamma-SPI results. As seen in Table 4.8, 4.7 severe/extreme drought years might be experienced in stations 1 and 2 in every 44 years. That means, one in every 7 year period, there could be a severe drought year in these stations according to Table 4.8, while the stations 1 and 3 might experience fewer drought years than the station 2.

Table 4.8. The probability of drought recurrence by Gamma-SPI, Log-SPI and

Station	category	Number of times on 44 years	Severity of event
1	Moderate drought	2	1 in 22 years
	Severe drought	5	5 in 44 years
	Extremely drought	1	1 in 44 years
2	Moderate drought	6	6 in 44 years
	Severe drought	3	3 in 44 years
	Extremely drought	3	3 in 44 years
3	Moderate drought	3	3 in 44 years
	Severe drought	1	1 in 44 years
	Extremely drought	2	1 in 22 years

Table 4.9 summarizes the common years that have experienced drought predicted by the PN method. As seen in Table 11, stations 1 and 3 have experienced almost the same occurrences of droughts, unlike station 2; PN has detected 14 drought years in 44 for the stations 1 and 3, and 22 drought years in 44 years for the station 2. PN has predicted more moderate drought years after 1997 in station 2 than the other stations (Table 4.7).

Table 4.9. The relations between the stations by PN

Stations	1,2,3	1,2	1,3	2,3
Common	1971	1971	1971	1970
drought years	1982	1977	1972	1971
	1983	1982	1973	1974
	1984	1983	1982	1982
	1997	1984	1983	1983
		1987	1984	1984
		1997	1990	1985
		2004	1997	1992
				1997
				2008

The results in Tables 4.7 and 4.9 show that the drought is detected in the seventies and eighties more than the 1990s. Drought has less frequency in the 2000s, where it appeared at a rate of 1 in 10 years in the region. In 2010s the drought was seen again in 2011 (detected in station 1 by all methods). According to the PN results Table 4.9, Trarza region has experienced drought for 3 years consecutively from 1982, 1983 and 1984, which is considered the worse period for the region.

In Mauritania, the recorded long droughts in 1910s, the 1940s, the 1960s, the 1970s and the 1980s have had dramatic environmental and societal effects, such as famine and dislocation (https://en.wikipedia.org/wiki/Sahel_drought). As seen in Table 4.7, for all the stations, PN, Deciles, the log-SPI and the gamma-SPI were able to capture these (the early 1970s and 1980s) extreme drought periods successfully. This result implies that these methods can be employed for drought analysis in this region.

CHPTERE 5

TREND ANALYSIS

5.1. Application

Trend analysis is considered as one of the most important issues in global climate change problems. The main purpose of trend analysis in this study is to provide a view for meteorological (precipitation and temperature) variables in the past and the future time's changes. In this context, 44 years meteorological records were used to investigate trend in precipitation and temperature time series. The Mann Kendall (MK test), the Spearman's rho (SR test), the Şen trend test were used for the trend identification in the time series and the Pettitt test (Pettitt, 1979) for detecting the change point at the time series while the Thiel-sen approach was used to estimate the magnitude of the slope in the precipitation and temperature time series. The trend analyses framework that is used in this thesis is outlined in Fig 1.2.

5.1.1 Mann-Kendall Test (MK test):

The MK test is used for the trend identification for a given time series data. The main purpose of MK test is to statistically investigate if there is a monotonic upward or downward trend of the variable of interest over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) in time. In this test, the null hypothesis H_0 and the alternative hypothesis H_a *r*espectively refer to non-existence and existence of trend. The MK test is calculated (Kisi & Ay, 2014) as:

$$\mathrm{sgn}(x_i - x_j) = \begin{cases} 1; \ \mathrm{IF}\ x_j > x_i \\ 0; \ \mathrm{IF}\ x_j = xi \\ -1; \ \mathrm{IF}\ x_j < xi \end{cases} \quad (5.1)$$

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_i - x_j) \quad (5.2)$$

where x_i and x_j respectively indicate the data values at times i and j, and n is the length of the data set. If S value is positive it means the variable consistently increases through time, while negative value S indicates a decreasing trend. Equation (5.3) is used in cases where n is larger than 0.

$$\mathrm{Var(S)} = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i-1)(2t_i+5)}{18} \quad (5.3)$$

where, p indicates the number of tied groups, t_i is the number of data points in the pth group. After the variance of time is provided in the Eq 5.3, the standard Z can be expressed by Equ. 5.4 as follows (Kisi & Ay, 2014)

$$Z = \begin{cases} \frac{S-1}{\sqrt{\mathrm{Var(S)}}} & \text{IF } S > 0 \\ 0; & \text{IF } S = 0 \\ \frac{S+1}{\sqrt{\mathrm{Var(S)}}}; & \text{IF } S < 0 \end{cases} \quad (5.4)$$

The calculated Z value is compared with standard normal distribution table with two tailed confidence levels. When $|Z| > Z_{1-\alpha/2}$ then H_o is rejected and H_a is accepted which means there is a significant trend. Otherwise, H_0 is accepted and H_a is rejected which means the trend is not statistically significant. 5% significant level which refers to $Z_{1-\alpha/2} = 1.96$ (from the standard normal table) was used for the M-K method in this study.

5.1.2. Spearman's rho Test (SR test)

Similar to MK, rank-based nonparametric statistical SR test is commonly used to assess the significance of monotonic trends in hydro- meteorological data time series, this method detects the existence and non- existence of trend in the data time series, and also it can identify if there is increase or decreases in trend. In this test, the null hypothesis H_o means that the given data are independent and identically distributed through the time, while the alternative hypothesis H_o indicates the existing of the trend. The SR test statistic D and the standardized test statistic Z_{SR} are calculated by Eqs. 5.5 and 5.6, as follows (Shadmani et al., 2012)

$$D = \frac{6\sum_{i=0}^{n}(R(X_i)-i)^2}{n(n^2-1)} \tag{5.5}$$

$$Z_{SR} = D\sqrt{\frac{n-2}{1-D^2}} \tag{5.6}$$

where $R(X_i)$ is the rank of i-the observation X_i in the sample size (n). In this test, H_o is rejected and H_a is accepted if $|Z_{SR}|> 2.08$ for the 5% significance level. Positive values of Z_{SR} indicate the trend decrease, while the negative values indicate trend decrease.

5.1.3 Şen (2012) Trend Detection Test

This method is basically based on dividing the time series of the data into to equal halves, rank them from the highest to the lowest and then plotting against each other in which the first sub-series (X_i) is located on the X-axis, and the other sub-series (X_j) is located on the Y-axis based on the Cartesian coordinate system as shown in Fig 5.1.

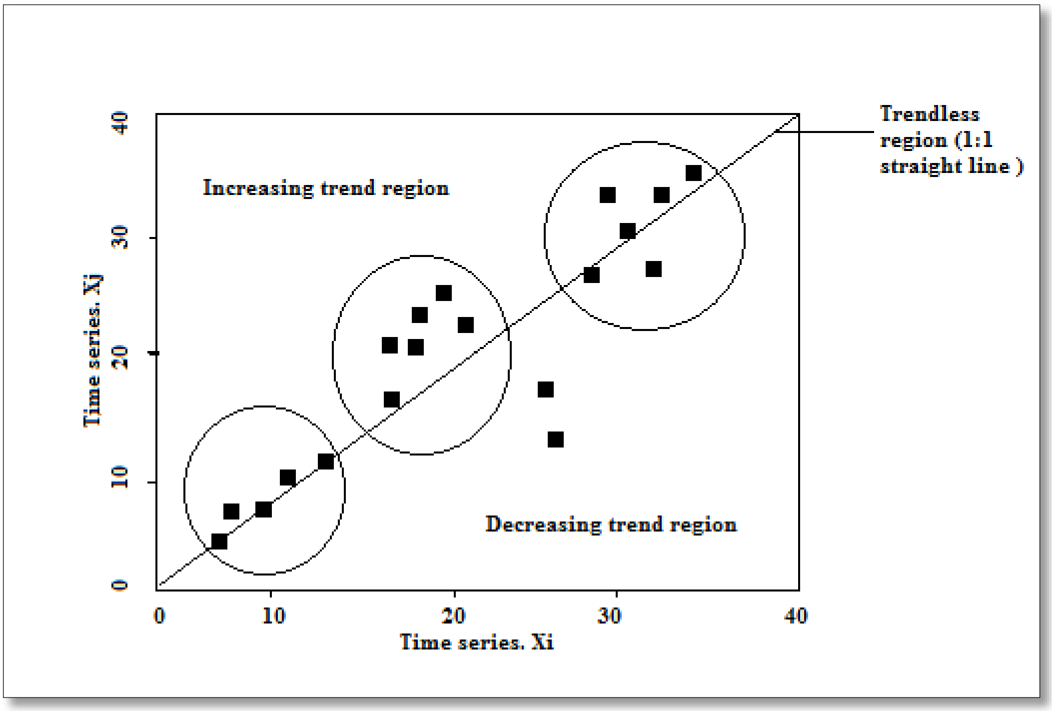

Figure 5.1. Illustration of decreasing, increasing and trendless regions (Source: Şen, 2011)

When the data are collected on the 1:1 (45˚) straight line it means there is no trend, when the data are in the below triangular area of the 1:1 straight line it means there is decreasing trend in the time series and when the data are in the upper triangular area of the 1:1 straight line, it means there is increasing trend in the time series. The high, medium and low values of the given data can be graphically evaluated in this approach.

5.1.4 Thiel-Sen Approach

This method is used to calculate the magnitude of the slope after the identified trend tests. The Thiel-sen approach can be expressed by the Eq. 5.7 (Shadmani et al., 2012):

$$\beta = \text{Median}\left(\frac{x_j - x_i}{j - i}\right) \quad (5.7)$$

where, X_i and X_j indicate the sequential data values of the time series in the years i and j. The calculated β is the estimated magnitude of the trend slope in the time series of the data.

5.1.5. Pettitt's Test

The Pettitt's approach is commonly used to detect a single change-point hydro-meteorological series with contentious data. For a given time series $\{X_1, X_2, \dots, X_n\}$ with a length n, let t be the time of the change point. The samples, $\{X_1, X_2, \dots, X_t\}$ and $\{X_{t+1}, X_{t+2}, \dots, X_n\}$, can be derived by dividing the time series at the time t. The test statistic U_t (S.-T. Chen et al., 2009) can be expressed by

$$U_t = \sum_{i=1}^{t} \sum_{j=i+1}^{n} \mathrm{sgn}(x_i - x_j) \tag{5.8}$$

$$\mathrm{sgn}(x) = \begin{cases} 1; & \text{IF } x > 0 \\ 0; & \text{IF } x = 0 \\ -1; & \text{IF } x < 0 \end{cases} \tag{5.9}$$

The maximum $|U_t|$ at time t can be considered to be the most significant change point. The approximated significance change probability P(t) for change point can be expressed by (S.-T. Chen et al., 2009)

$$P(t) = 1 - \exp\left(\frac{-6{U_t}^2}{n^3+n^2}\right) \tag{5.10}$$

When the approximated probability exceeds (1-α), the change point considered to be statistically significant level of α.

5.2. Results

5.5.1. Temperature Trends

Maximum, minimum and average annual temperature trends were investigated using different trend tests namely, MK test, SR test, Şen test , Pettitt's test and linear regression. MK, Şen test and SR tests were used for the trend identifying in temperature time series while Pettitt's test for detecting change point in the time series. Almost all records show increasing of trend for the three study stations (Table 5.1. Figs 5.2, 5.3, 5.4).

The MK and the SR tests show the same results for the three stations where they showed significant trends in the minimum and the average temperature in the all stations and maximum temperature significant trends were observed in Station 1 and 3 while no trend was observed in maximum temperature records in Station 2 as showed in Table 5.1. After the trends were identified by the MK and the SR tests, the Thiel-sen approach was applied to estimate the magnitude of the slope (change per unit time) and it showed that the annual average temperature increased in Boutilimit, Nouakchott and Rosso stations at the rate of 0.2, 0.3, and 0.3ºC per decade (Table 5.1). Abrupt changes (Jumps) in the annual temperature (maximum, minimum and average) were detected by Pettitt's test for the results in all stations (Table 5.1). 1995 was the year when abrupt change is detected.

Table 5.1. Temperature analysis results detected by the MK, SR, Thiel-sen and the Pettitt's testes

Station	Annual Temperature (°C)	MK (Z)	SR (Z_{SR})	Trend	β (rate of increases per decade by °C)	Pettitt's test (change point)	β (rate per decade by °C) in 1970-1995	β (rate per decade by °C) in 1995-2013
1	**Tmax**	0.43	0.744	No	-	-	-	-
	Tmin	4.70	7.26	Yes (+)	0.4	1995	0.33	0.43
	Tavg	2.92	3.72	Yes (+)	0.2	1995	0.01	0.3
2	**Tmax**	2.45	3.12	Yes (+)	0.2	1995	0.1	0.14
	Tmin	4.46	5.80	Yes (+)	0.4	1995	0.53	0.05
	Tavg	3.69	5.07	Yes (+)	0.3	1995	0.2	0.08
3	**Tmax**	2.63	3.02	Yes (+)	0.3	1995	0.07	0.6
	Tmin	3.24	4.06	Yes (+)	0.3	1995	0.17	0.98
	Tavg	3.87	5.44	Yes (+)	0.3	1995	0.14	0.06

The Şen trend test was used to investigate the existing of trend especially in terms of evaluation of low, medium and high values of the temperature data (maximum, minimum and average). The results show significant trends (increasing) for the low values in the all stations compering to the high and the medium values which are closer to the 1:1 line (Figures 5.2, 5.3, 5.4). Maximum temperatures recorded in Station 1 show different results where the medium values have almost no trend, trend decrease for the high values and increasing of trend for the low values (Figure 5.3).

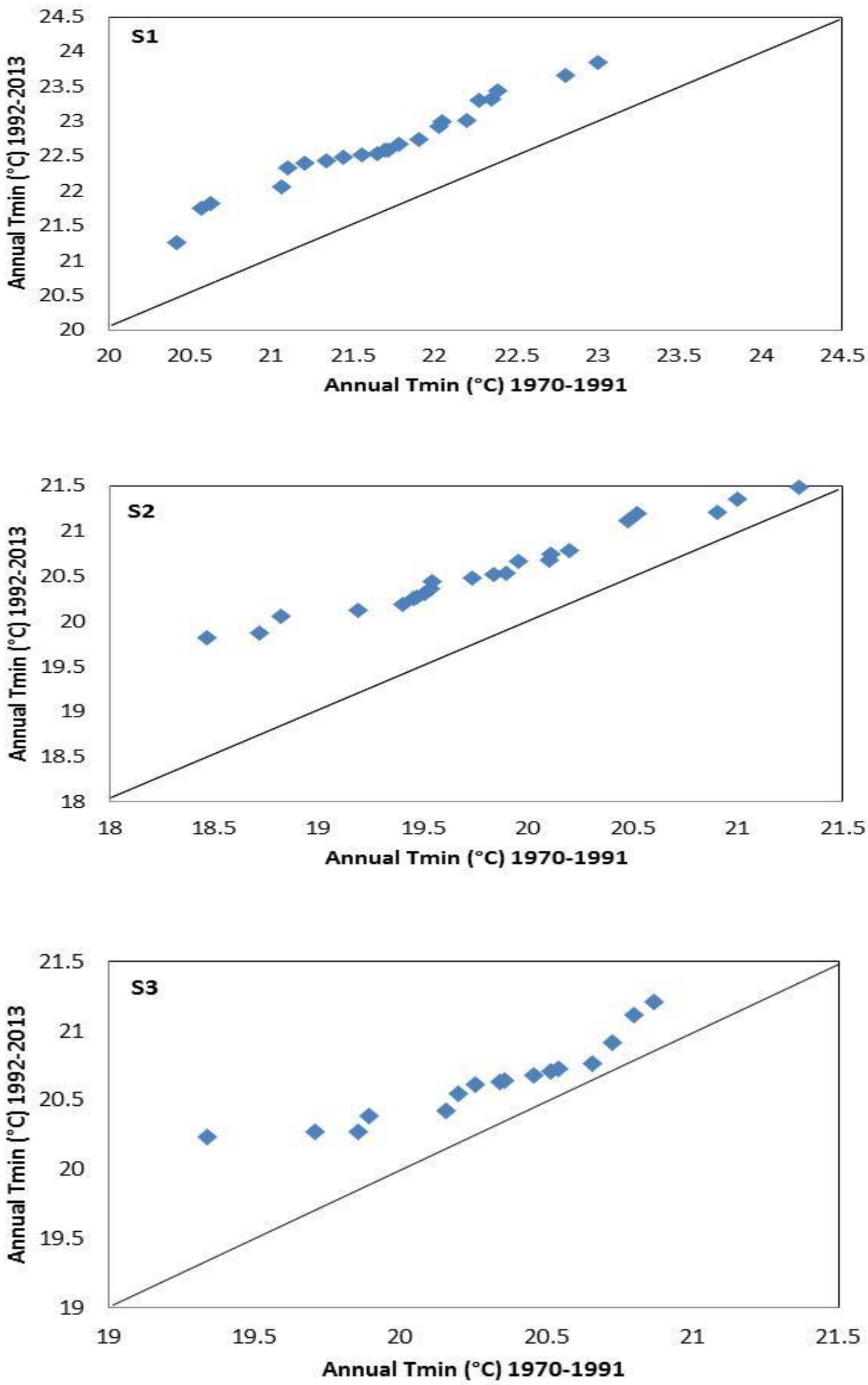

Figure 5.2. Annual minimum temperature (Tmin (ºC)) of Boutilimit (S1), Nouakchott (S2) and Rosso (S3) stations by Şen trend test

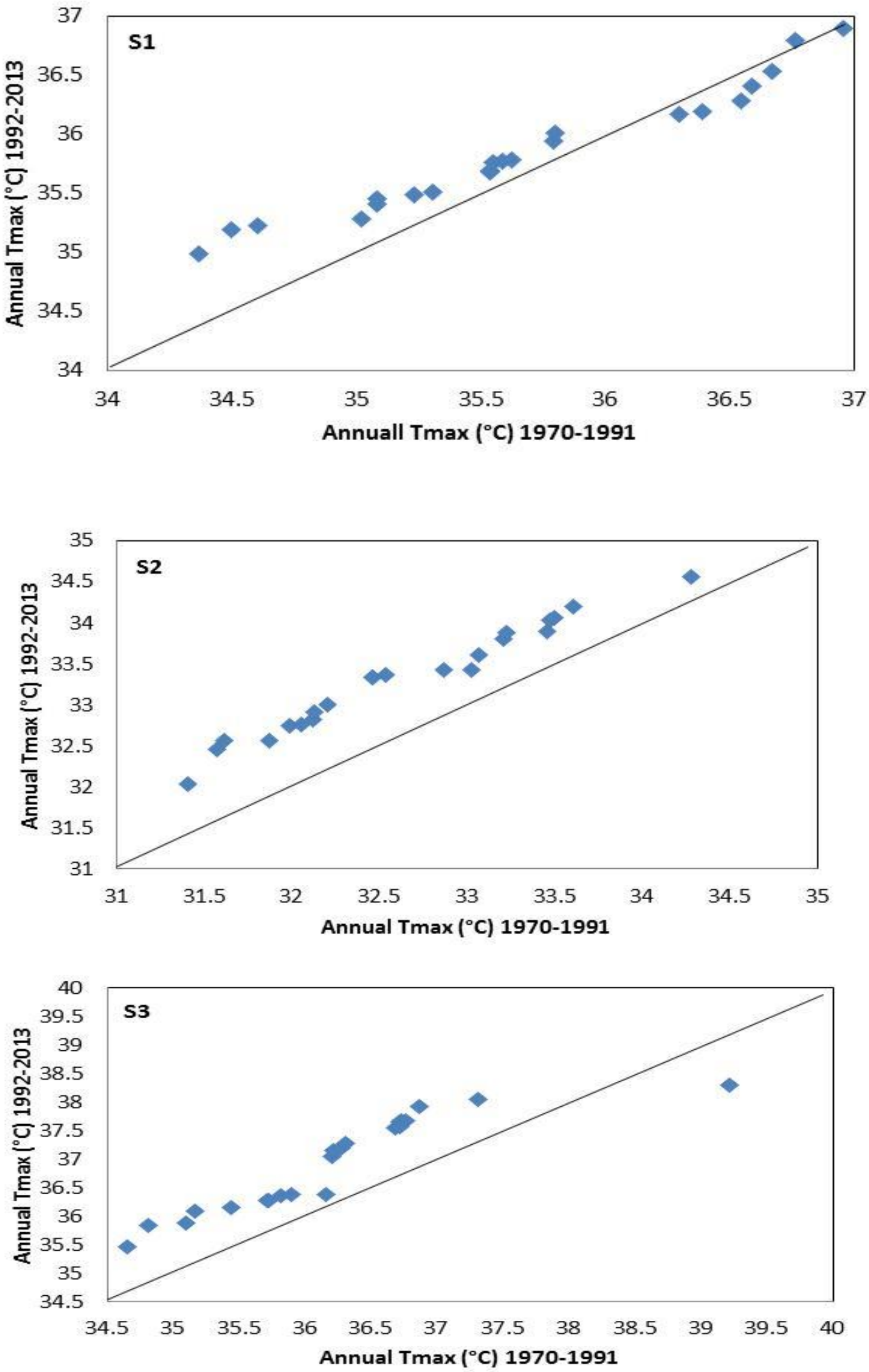

Figure 5.3. Annual maximum temperature (Tmax (ºC)) of Boutilimit (S1), Nouakchott (S2) and Rosso (S3) stations by Şen trend test

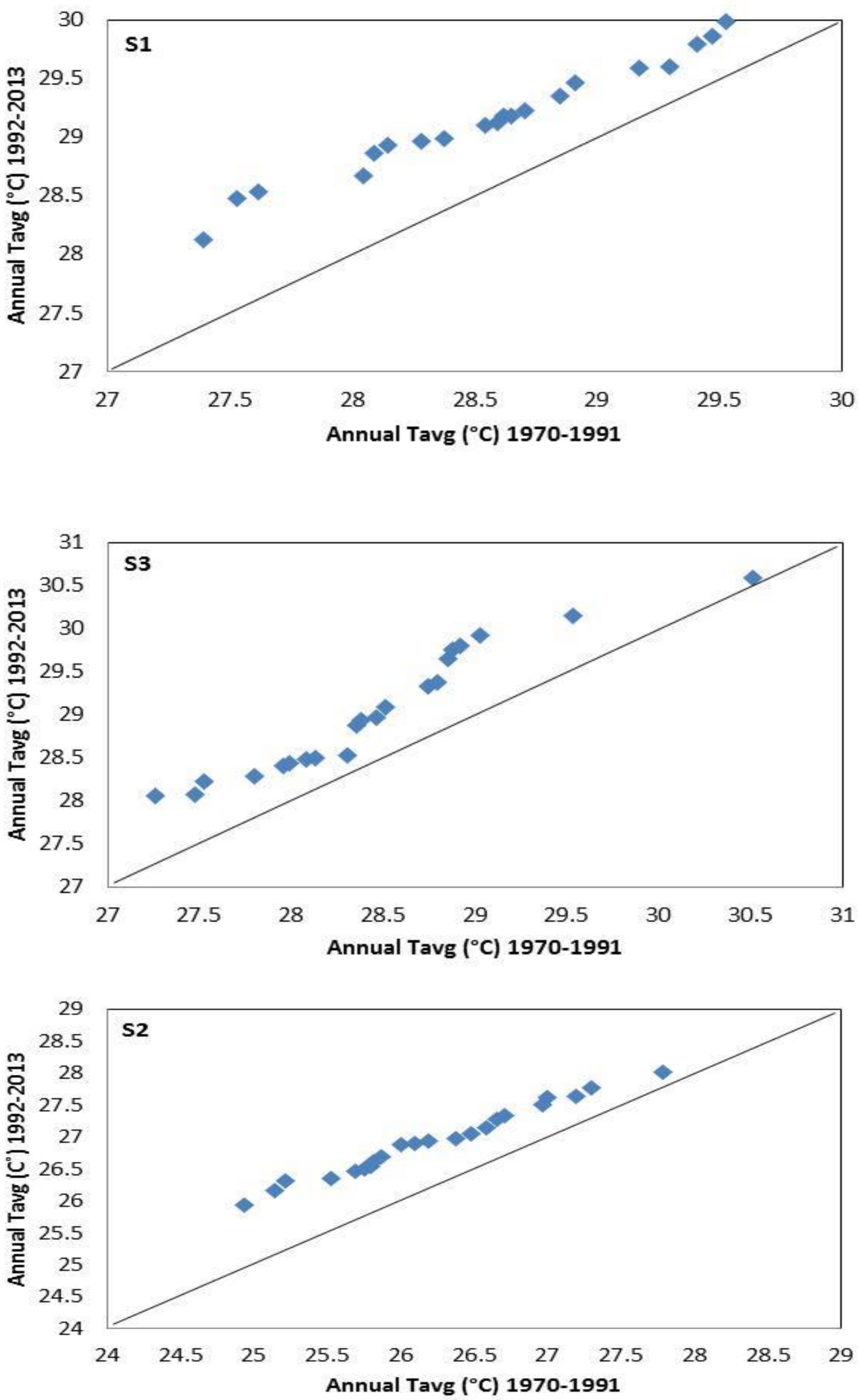

Figure 5.4. Annual Average temperature (Tavg (ºC)) of Boutilimit (S1), Nouakchott (S2) and Rosso (S3) stations by Şen trend test

5.2.2. Precipitation Trend

The three raingauge stations of Boutilimit, Nouakchott, and Rosso were used for analyzing the annual precipitation time series. MK and SP showed the same result for detecting precipitation trend where it was found that significant trends (increasing) were absorbed in the Stations of Boutilimit and Rosso while no trend was seen in the Station of Rosso. Using the Theil sen's method, the annual precipitation increase was found in Boutilimit and Rosso stations to be at the rate of (+) 3.35 and (+) 2.93 mm per year (Table 5.2). As shown in the Table 5.2 change points in the Boutilimit and Rosso stations were found at the year 1988 and 1993, respectively.

Table 5.2. Precipitation analysis results detected by the MK, SR, Thiel-sen and the Pettitt's testes

Station	MK (Z)	SR ($\mathbf{Z_{SR}}$)	Trend	β (rate of increases per year in mm)	Pettitt's test (change point time)
Boutilimt(#1)	3.12	3.43	Yes (+)	2.93	1988
Nouakchott (#2)	1.62	1.84	no	-	-
Rosso (#3)	2.86	3.42	Yes (+)	3.35	1993

Different to the MK and the SR tests, the Şen trend test shows trend in the all station where it shows significant trend (increasing) for the all values (high, medium and low) in the same trend magnitude (slope). In the stations Boutilimit and Nouakchott, the low and the high values have weaker trend magnitude than the medium values which have significant trend magnitude, while the high values in the station of Rosso have stronger magnitude than the medium and the low values (Fig 5.5).

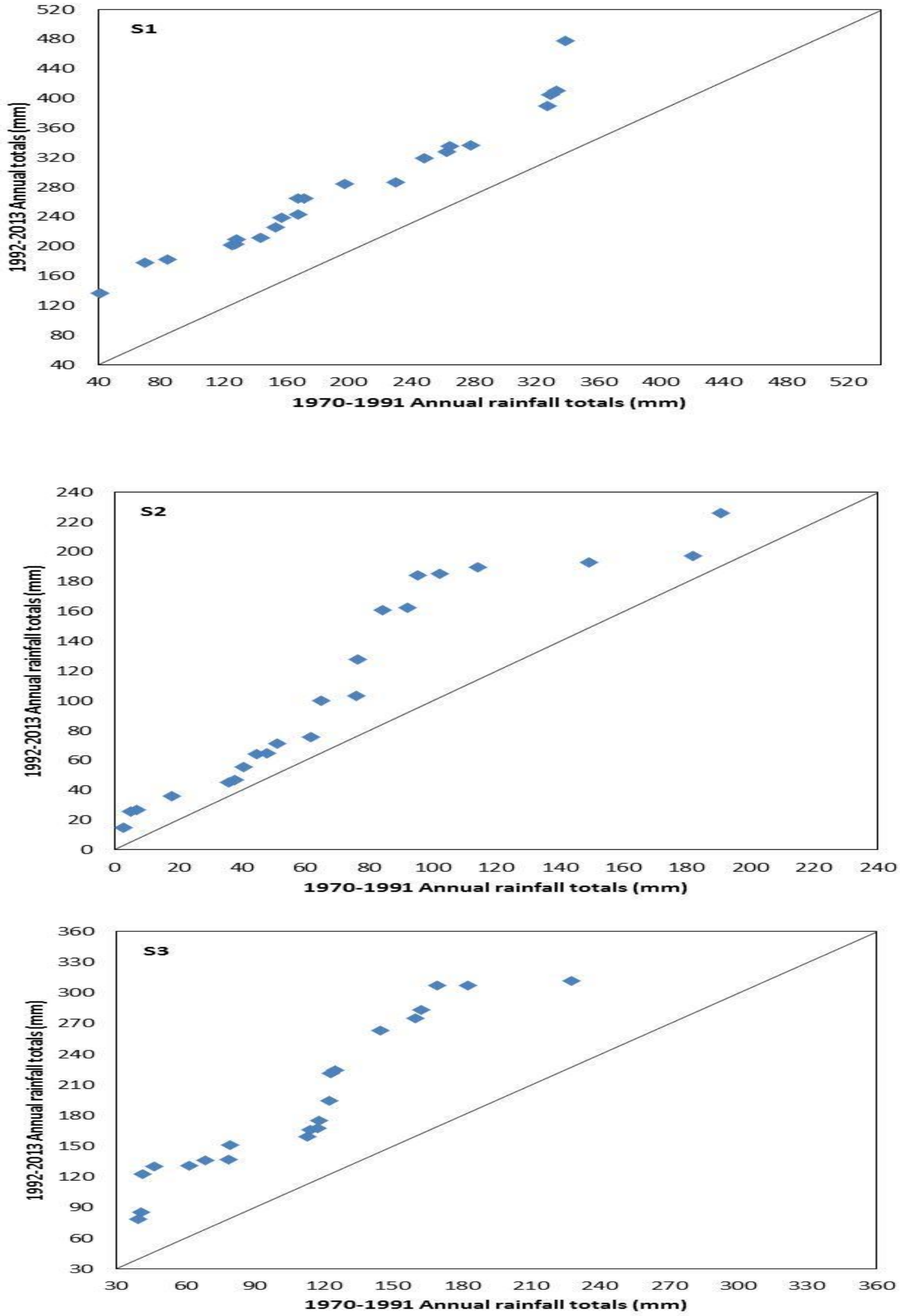

Figure 5.5. Annual rainfall of Boutilimit (S1), Nouakchott (S2) and Rosso (S3) stations by Şen trend test

5.4. Discussion of Results

Trend in temperature and precipitation during the period 1970-2014 was analyzed in Trarza region using different type of trend detection methods. The methods showed that there are significant positive trends on precipitation and temperature during the period of study. Although the stations have slight precipitation and temperature increasing trends, they defer in terms of trend direction changes (slope and jumps).

The results of the annual regional temperature time series analysis indicate that the changes in temperature over the 1970–2013 reflect warming for the region as a whole. The annual average temperature increased at the rate of 0.2, 0.3, and 0.3ºC per decade in Boutilimit, Nouakchott and Rosso stations, respectively. This increase on the average temperature is affected by the minimum temperatures more than the maximum ones as seen in the Table 5.1 where the maximum values increased at the rate of 0.2 and 0.3ºC per decade for the station of Nouakchott and the station of Rosso, respectively, and no trend in the maximum temperature has been detected in the station of Boutilimit. While the minimum temperatures have significant positive trends detected in the all stations, the magnitudes of the increasing trend for the minimum temperatures for the stations Boutilimit, Nouakchott and Rosso were found to be 0.2, 0.4 and 0.3ºC per decade, respectively. The Şen trend test showed that the low values of temperatures (maximum, minimum and average) have increased more the medium and the high values during the period of the study (1970-2013). The abrupt change in the annual temperatures (maximum, minimum and average) was detected in 1995 for the whole stations and that means the region had significant jump on the trend direction in that year. We calculated the magnitudes in the two periods: 1970-1995 and 1995-2013, the results showed that the rise of the average temperature in the first period (1970-1995) in the stations 2 and 3. In contrast to the stations 2 and 3, in station 1 the increase of the temperature was detected in the last period (1995-2013) in comparison to the rise in the first period (Table 5.1).

Analyzing annual precipitation time series by MK and SR tests showed that 2 stations (Boutilimit and Rosso) have significant positive trends while no trend was detected in the station of Nouakchott. However, the Şen test showed different results by detecting positive trend in the station of Nouakchott, but in terms of the medium values of precipitation during the period of 1970 to 2013. The results of the Thiel-Sen showed that the most significant positive was detected in station 3 of Rosso with magnitude value of 3.35 mm per year while the precipitation in the station of Boutilimit has increased 2.93 mm per year. The abrupt changes in the annual precipitation were detected in 1988 for the station of Boutilimit and in 1993 for the station of Rosso.

CHAPTERE 6

CONCLUSIONS AND FUTURE VIEW

Based on historical precipitations and temperatures recorded for the period 1970 to 2013 collected from 3 stations in region of Trarza in Mauritania, this study investigated the performances of 6 DI methods for assessing drought and 5 trend tests for precipitation and temperature trends analysis in the region . The following conclusions are drawn:

1. DIs produced almost the same results for the drought analysis within the Trarza region.
2. Trarza region had experienced prolonged and severe drought during the periods of 1970 to 1974 and 1982 to 1985.
3. More droughts are detected in the seventies and eighties than in 1990s.
4. Twelve drought years might be experienced in station 2 and six in stations 1 and 3 in every 44 years. In other words, Nouakchott station can experience drought in every 4 years, while the other stations can experience it in every 7 years.
5. When the rainfall is less than 123 mm/year, 63 mm/year, and 205 mm/year, it is likely that severe drought would occur in Boutilimit, Nouakchott, and Rosso stations, respectively.
6. In the monthly period drought analysis; the CZI and the gamma-SPI methods makes similar predictions and the log-SPI makes extreme drought predictions for all the stations.
7. In the 3-, 6-, and 12-month period drought analysis; the log-SPI and the gamma-SPI produce similar results, predicting more severe drought conditions while the normal-SPI and the CZI methods predict more wet case and fewer drought cases, for all the stations.
8. PN method tends to make fewer severe but more moderate drought conditions,
9. Deciles, PN, the log-SPI and the gamma-SPI were able to capture historical extreme and severe drought periods (1970s and 1980s) successfully. This result implies that these methods can be employed for drought analysis in this region.

10. The annual average temperature time series analysis indicates that the changes in temperature over the 1970–2013 reflect warming for the region as a whole.
11. The annual temperature is increasing about 0.2-0.4^{o}C per decade.
12. The abrupt change in temperature was detected in 1995 for the whole region.
13. The precipitation time series has positive trend detected in 2 stations (at the rate of 3.35 mm per year in Boutilimit and 2.93 mm per year in Rosso) while no trend is detected in the other one (Noukchott).

The water resources in Trarza are consists of groundwater and surface water. The source of the groundwater is the Trarza aquifer covering about 40,000 km^2. This aquifer plays a very important role as the main ground source of water for Mauritania. The Senegal River is Mauritania's only permanent waterway which is used for irrigation, navigation, drinking, and hydro power generation. The water resources in Trarza region support a range of use including urban water supply and agricultural not only in the region but also in the surrounded regions in Mauritania. Thus, the assessment and monitoring of drought and analyzing the meteorological trend in this region are crucial for Mauritania.

REFERENCES

[1] Abramowitz, M., & Stegun, I. A. (1965). Handbook of math. functions. *NBS Applied Math Series, 50*, 487.

[2] Barua, S., Ng, A., & Perera, B. (2010). Comparative evaluation of drought indexes: Case study on the Yarra River catchment in Australia. *Journal of Water Resources Planning and Management, 137*(2), 215-226.

[3] Cacciamani, C., Morgillo, A., Marchesi, S., & Pavan, V. (2007). Monitoring and forecasting drought on a regional scale: Emilia-Romagna region *Methods and tools for drought analysis and management* (pp. 29-48): Springer.

[4] Chen, S.-T., Kuo, C.-C., & Yu, P.-S. (2009). Historical trends and variability of meteorological droughts in Taiwan/Tendances historiques et variabilité des sécheresses météorologiques à Taiwan. *Hydrological sciences journal, 54*(3), 430-441.

[5] Chen, Z., & Grasby, S. E. (2009). Impact of decadal and century-scale oscillations on hydroclimate trend analyses. *Journal of Hydrology, 365*(1), 122-133.

[6] Edwards, D. C. (1997). Characteristics of 20th century drought in the United States at multiple time scales: DTIC Document.

[7] Gallego, M., García, J., Vaquero, J., & Mateos, V. (2006). Changes in frequency and intensity of daily precipitation over the Iberian Peninsula. *Journal of Geophysical Research: Atmospheres, 111*(D24).

[8] Garbrecht, J., Van Liew, M., & Brown, G.-O. (2004). Trends in precipitation, streamflow, and evapotranspiration in the Great Plains of the United States. *Journal of Hydrologic Engineering, 9*(5), 360-367.

[9] Gąsiorek, E., & Musiał, E. (2015). EVALUATION OF THE PRECISION OF STANDARDIZED PRECIPITATION INDEX (SPI) BASED ON YEARS 1954–1995 IN ŁÓDŹ. *Journal of Ecological Engineering, 16*(4), 49-53.

[10] Gebremicael, T., Mohamed, Y., Betrie, G., van der Zaag, P., & Teferi, E. (2013). Trend analysis of runoff and sediment fluxes in the Upper Blue Nile basin: A combined analysis of statistical tests, physically-based models and landuse maps. *Journal of Hydrology, 482*, 57-68.

[11] Gellens, D. (2000). Trend and Correlation Analysis of k-Day Extreme Precipitationover Belgium. *Theoretical and applied climatology, 66*(1-2), 117-129.

[12] General, U. S. (1994). United Nations convention to combat drought and desertification in countries experiencing serious droughts and/or desertification, particularly in Africa. *Particularly in Africa*.

[13] Gibbs and Maher, W. J., 1915-. (1967). *Rainfall deciles as drought indicators / by W. J. Gibbs and J. V. Maher.* Melbourne : Bureau of Meteorology, 1967.: Gibbs and Maher.

[14] Gumbel, E. (1963). Statistical forecast of droughts. *Hydrological sciences journal, 8*(1), 5-23.

[15] Guttman, N. B. (1999). Accepting the standardized precipitation index: A calculation algorithm1: Wiley Online Library.

[16] Hayes, M. (2003). Drought indices. National Drought Mitigation Center.

[17] Hayes, M. J. (2006a). *Drought indices*: Wiley Online Library.

[18] Hayes, M. J. (2006b). What is drought? Drought indices. *National Drought Mitigation Center.(Online).< http://drought. unl. edu/whatis/indices. htm*.

[19] Hayes, M. J., Svoboda, M. D., Wilhite, D. A., & Vanyarkho, O. V. (1999). Monitoring the 1996 drought using the standardized precipitation index. *Bulletin of the American Meteorological Society, 80*(3), 429-438.

[20] Hirsch, R. M., & Slack, J. R. (1984). A nonparametric trend test for seasonal data with serial dependence. *Water Resources Research, 20*(6), 727-732.

[21] Hirsch, R. M., Slack, J. R., & Smith, R. A. (1982). Techniques of trend analysis for monthly water quality data. *Water Resources Research, 18*(1), 107-121.

[22] Jones, P. D., New, M., Parker, D. E., Martin, S., & Rigor, I. G. (1999). Surface air temperature and its changes over the past 150 years. *Reviews of Geophysics, 37*(2), 173-199.

[23] Ju, X., Yang, X., Chen, L.-J., & Wang, Y. (1997). Research on determination of station indexes and division of regional flood/drought grades in China. *QJ Appl. Meteorol, 8*(1), 26-32.

[24] Kahya, E., & Kalaycı, S. (2004). Trend analysis of streamflow in Turkey. *Journal of Hydrology, 289*(1), 128-144.

[25] Keyantash, J., & Dracup, J. A. (2002). The quantification of drought: an evaluation of drought indices. *Bulletin of the American Meteorological Society, 83*(8), 1167.

[26] Kisi, O., & Ay, M. (2014). Comparison of Mann–Kendall and innovative trend method for water quality parameters of the Kizilirmak River, Turkey. *Journal of Hydrology, 513*, 362-375.

[27] Lettenmaier, D. P., Wood, E. F., & Wallis, J. R. (1994). Hydro-climatological trends in the continental United States, 1948-88. *Journal of Climate, 7*(4), 586-607.

[28] Lloyd-Hughes, B., & Saunders, M. A. (2002). A drought climatology for Europe. *International journal of climatology, 22*(13), 1571-1592.

[29] Madsen, H., Mikkelsen, P. S., Rosbjerg, D., & Harremoës, P. (1998). Estimation of regional intensity-duration-frequency curves for extreme precipitation. *Water Science and Technology, 37*(11), 29-36.

[30] McKee, T. B., Doesken, N. J., & Kleist, J. (1993). *The relationship of drought frequency and duration to time scales.* Paper presented at the Proceedings of the 8th Conference on Applied Climatology.

[31] Mishra, A. K., & Singh, V. P. (2010). A review of drought concepts. *Journal of Hydrology, 391*(1), 202-216.

[32] Morid, S., Smakhtin, V., & Moghaddasi, M. (2006). Comparison of seven meteorological indices for drought monitoring in Iran. *International journal of climatology, 26*(7), 971-985.

[33] Mu, X., Zhang, L., McVicar, T. R., Chille, B., & Gau, P. (2007). Analysis of the impact of conservation measures on stream flow regime in catchments of the Loess Plateau, China. *Hydrological Processes, 21*(16), 2124-2134.

[34] Nagarajan, R. (2010). *Drought assessment*: Springer Science & Business Media.

[35] New, M., Todd, M., Hulme, M., & Jones, P. (2001). Precipitation measurements and trends in the twentieth century. *International journal of climatology, 21*(15), 1889-1922.

[36] Palmer, W. C. (1965). *Meteorological drought* (Vol. 30): US Department of Commerce, Weather Bureau Washington, DC, USA.

[37] Pettitt, A. (1979). A non-parametric approach to the change-point problem. *Applied statistics*, 126-135.

[38] Schneider, S. H. (1996). *Encyclopedia of climate and weather* (Vol. 678): Oxford University Press New York.

[39] Şen, Z. (2011). Innovative trend analysis methodology. *Journal of Hydrologic Engineering, 17*(9), 1042-1046.

[40] Shadmani, M., Marofi, S., & Roknian, M. (2012). Trend analysis in reference evapotranspiration using Mann-Kendall and Spearman's Rho tests in arid regions of Iran. *Water resources management, 26*(1), 211-224.

[41] Some'e, B. S., Ezani, A., & Tabari, H. (2012). Spatiotemporal trends and change point of precipitation in Iran. *Atmospheric research, 113,* 1-12.

[42] Sönmez, F. K., KÖmÜscÜ, A. Ü., Erkan, A., & Turgu, E. (2005). An analysis of spatial and temporal dimension of drought vulnerability in Turkey using the standardized precipitation index. *Natural Hazards, 35*(2), 243-264.

[43] Spinage, C. (2012). *African ecology: benchmarks and historical perspectives*: Springer Science & Business Media.

[44] Thom, H. C. S. (1966). Some methods of climatological analysis.

[45] Todorovic, P., & Woolhiser, D. (1976). Stochastic Structures of the Local Pattern of Precipitation. *Stochastic Approaches to Water Resources, 2*.

[46] Tomozeiu, R., Busuioc, A., Marletto, V., Zinoni, F., & Cacciamani, C. (2000). Detection of changes in the summer precipitation time series of the region Emilia-Romagna, Italy. *Theoretical and applied climatology, 67*(3-4), 193-200.

[47] Wilhite, D. A. (1996). A methodology for drought preparedness. *Natural Hazards, 13*(3), 229-252.

[48] Wilhite, D. A. (2000). Drought as a natural hazard: concepts and definitions.

[49] Wu, H., Hayes, M. J., Weiss, A., & Hu, Q. (2001). An evaluation of the Standardized Precipitation Index, the China-Z Index and the statistical Z-Score. *International journal of climatology, 21*(6), 745-758.

[50] Yavuz, H., & Erdoğan, S. (2012). Spatial analysis of monthly and annual precipitation trends in Turkey. *Water resources management, 26*(3), 609-621.

[51] Yuan, W.-P., & Zhou, G.-S. (2004). Comparison between standardized precipitation index and Z-index in China. *Acta Phytoecologica Sinica, 4*.

[52] Yue, S., Pilon, P., & Cavadias, G. (2002). Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology, 259*(1), 254-271.

[53] Zeng, N. (2003). Drought in the Sahel. *Science, 302*(5647), 999-1000.

[54] Zhang, S., Lu, X. X., Higgitt, D. L., Chen, C.-T. A., Han, J., & Sun, H. (2008). Recent changes of water discharge and sediment load in the Zhujiang (Pearl River) Basin, China. *Global and Planetary Change, 60*(3), 365-380.

[55] https://en.wikipedia.org/wiki/Senegal_River

[56] https://en.wikipedia.org/wiki/Sahel_drought

APPENDIX A. DECILES RESULTS

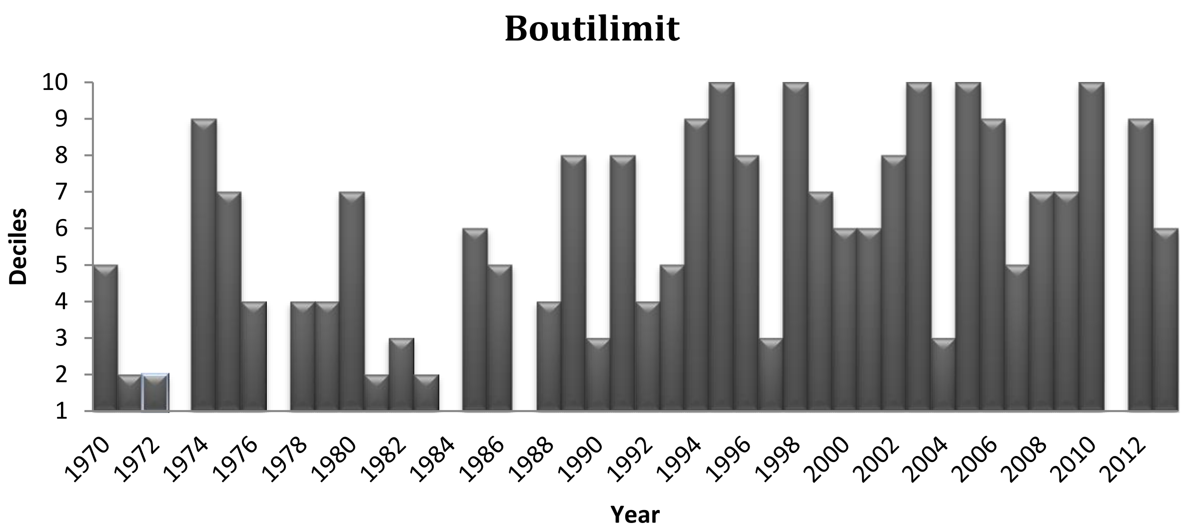

Figure A.1. Deciles results for the Station of Boutilimit (Station 1)

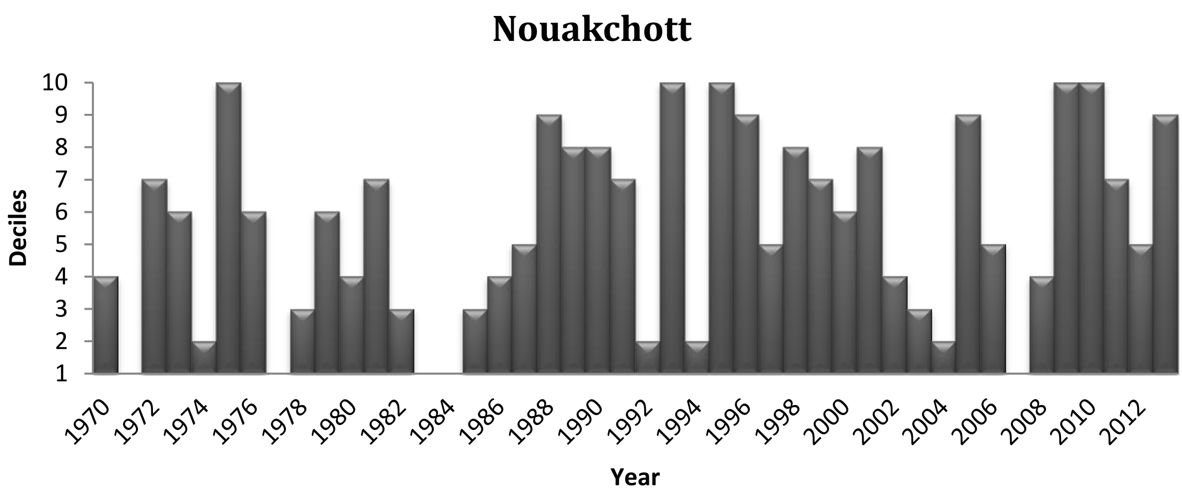

Figure A.2. Deciles result for the Station of Nouakchott (Station 2)

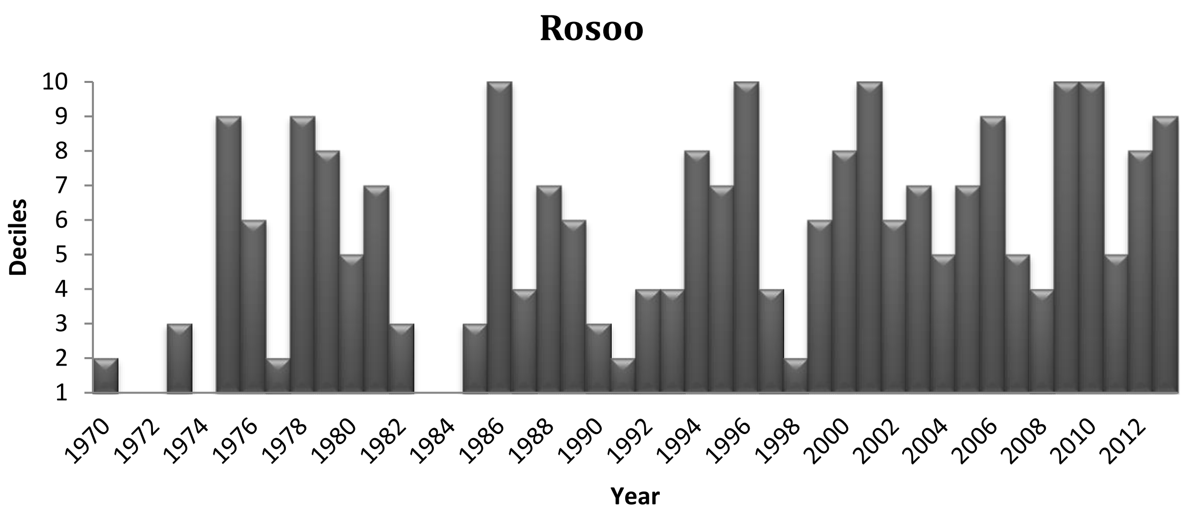

Figure A.3. Deciles results for the station of Rosso (Station 3)

APPENDIX B. PN RESULTS

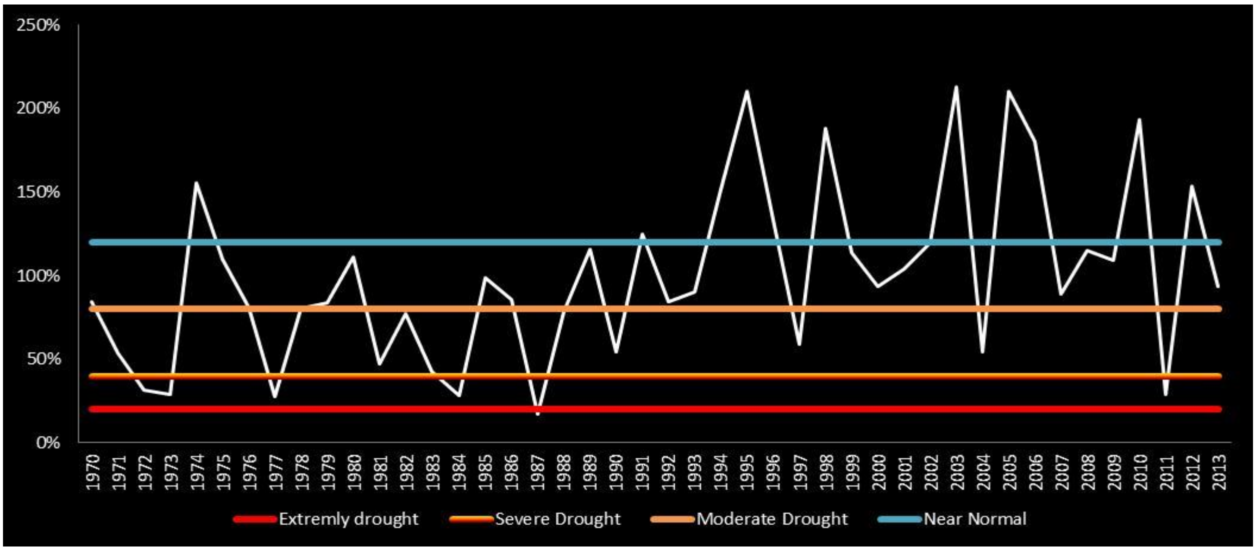

Figure B.1. Annual PN results for the station of Boutilimit (Station 1)

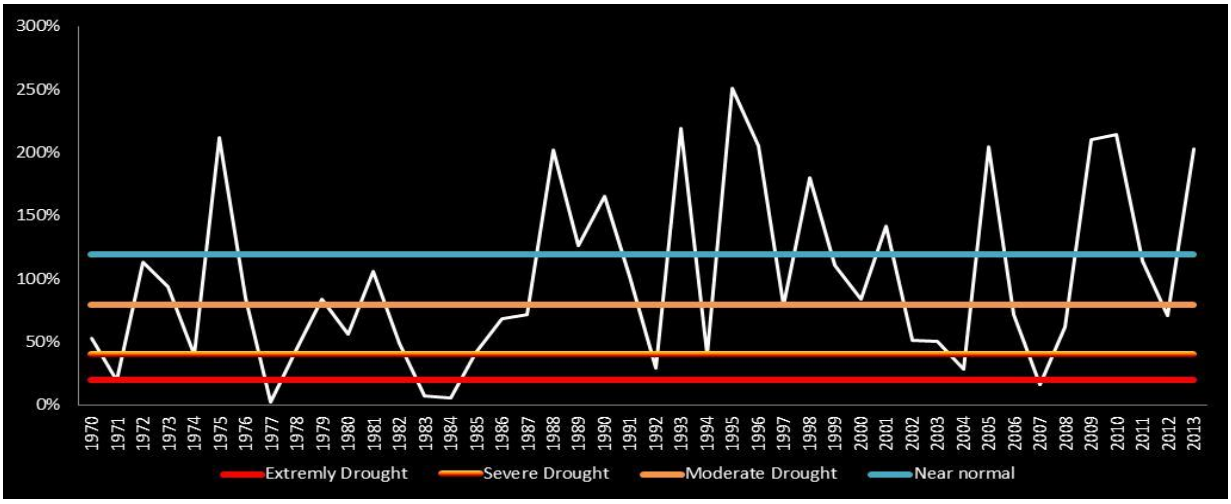

Figure B.2. Annual PN results for the station of Nouakchott (Station 2)

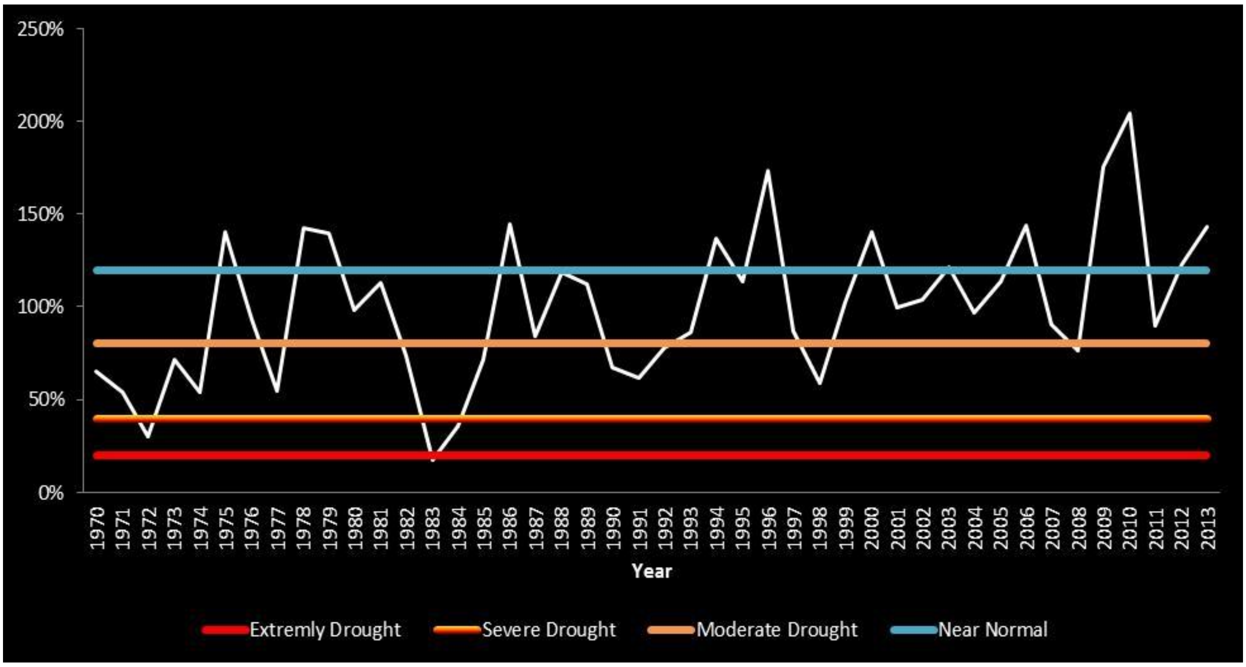

Figure B.3. Annual PN results for the station of Rosso (Station 3)

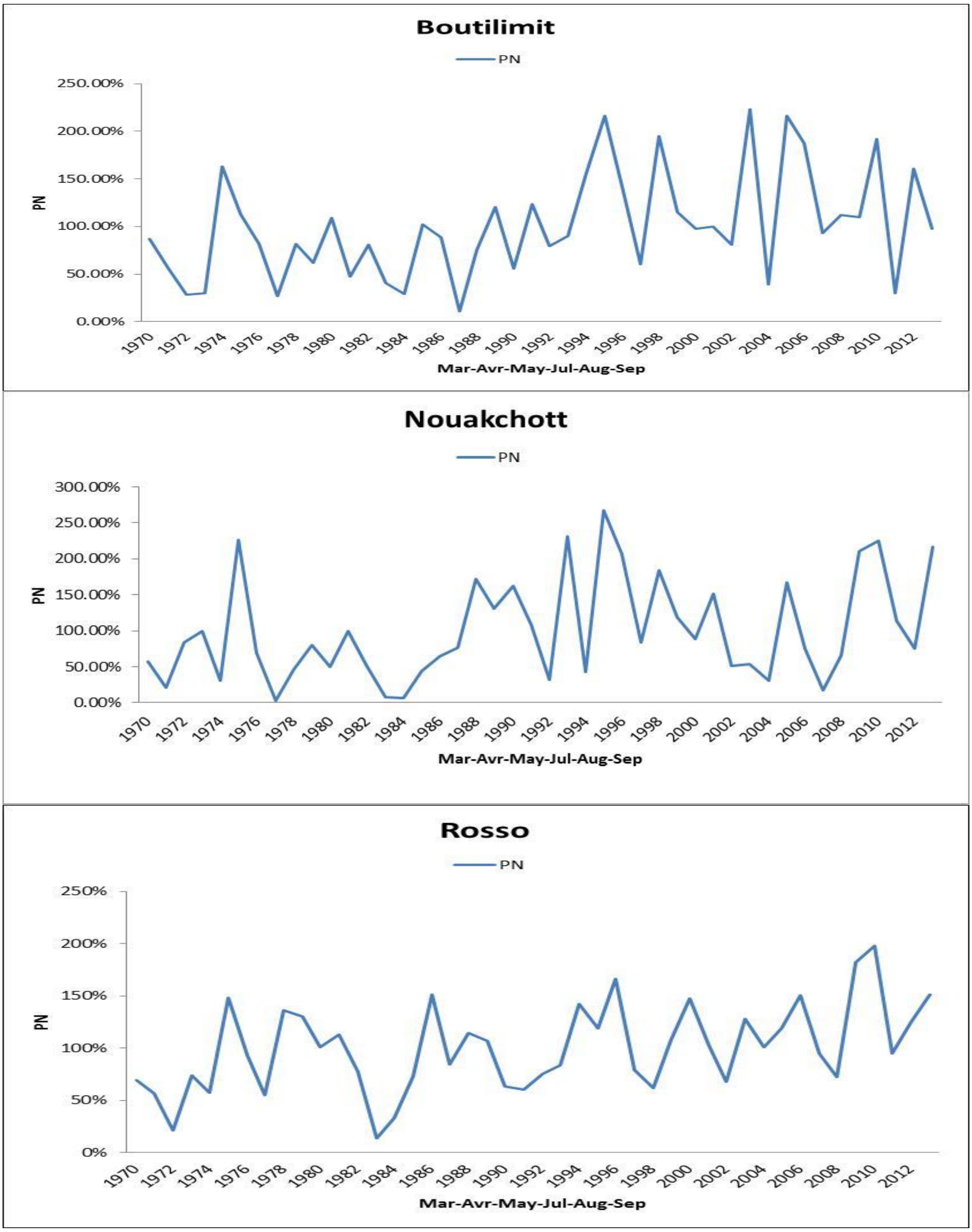

Figure B.4. 6 months PN results for the Stations Boutilimit, Nouakchott and Rosso, respectively

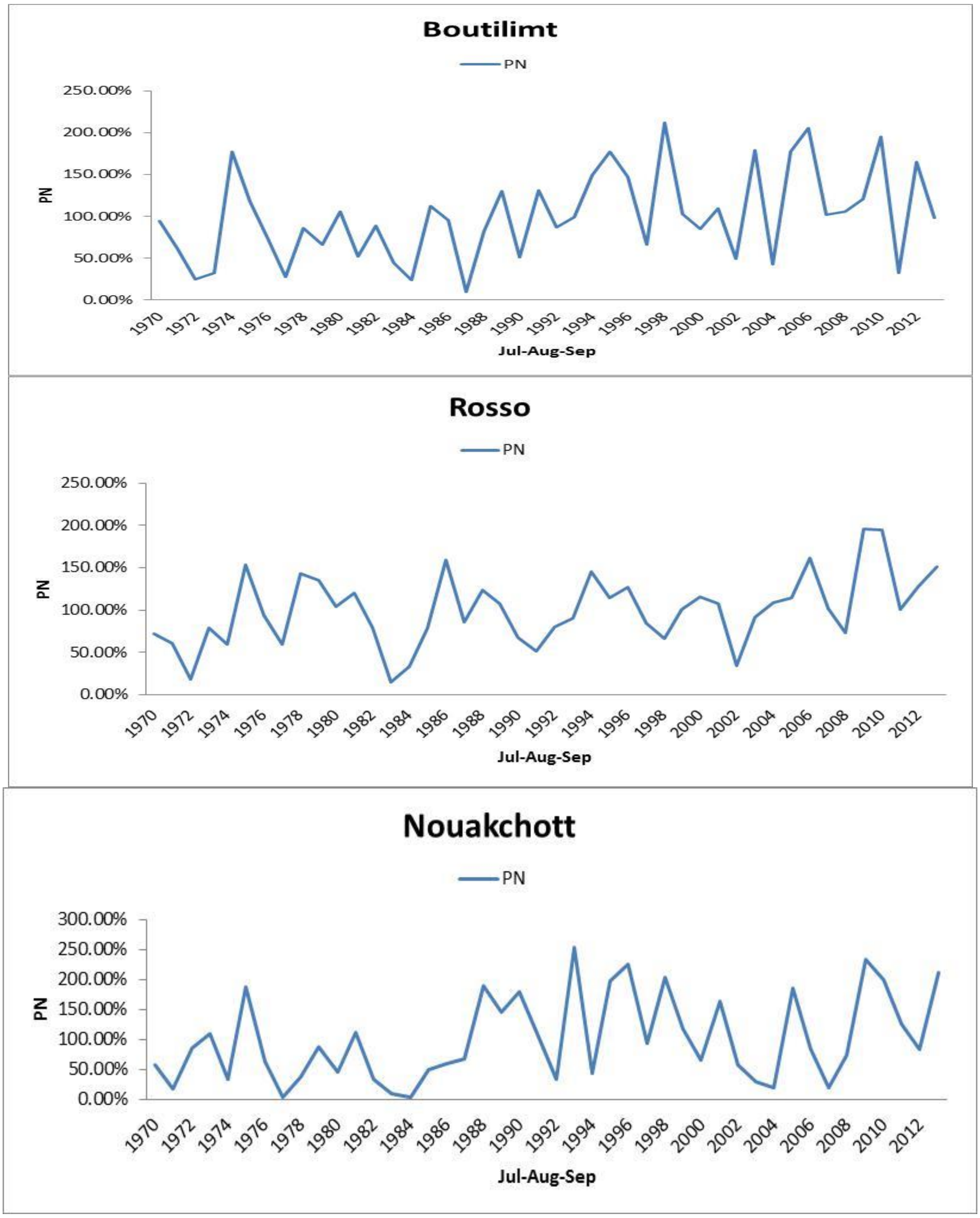

Figure B.5. 3 months PN results for the Stations Boutilimit, Nouakchott and Rosso, respectively