TREND AND DROUGHT ANALYSIS OF THREE STATIONS IN THE PUNTLAND STATE OF SOMALIA

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İZMİR

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ABSTRACT

ANALYSIS OF TREND AND DROUGHT CONTION IN THREE STATION LOCATED IN PUNTLAND REGION OF SOMALIA

Long-term rainfall and temperature records were used to analyze drought features as well as temperature and precipitation trends in Somalia's north area from 1980 to 2020. Monthly records are being used at three locations (Bossaso (station 1), Qardho (station 2), and Garowe (station 3).Deciles, Discrepancy precipitation index, percent normal, Gamma, log normal, and normal-SPI were used to examine the Drought. The past extreme and severe droughts that occurred in the early 1980s and throughout the course of the last two decades are being detected using the log-SPI, gamma-SPI, PN, and Deciles

The Mann Kendall (MK) test, Spearman's rho (SR test), and the Şen trend test were used in the trend analysis to identify trends in time series, and the Pettitt test to detect change points in time series. In contrast, the Thiel-sen Approach was used to estimate the magnitude of the slope in the precipitation and temperature time series. The average temperature and annual precipitation are increasing by about 0.3C per decade and 3 mm per year, according to the trend analysis results.

Keywords: *Drought, Trend, Bossaso, Qardho and Garowe, Somalia, SPI, DPI, PN, Deciles, Precipitation, Temperatur, Arid.*

ÖZET

SOMALİ’NİN PUNTLAND BÖLGESİ İÇİN KURAKLIK VE EĞİLİM ANALİZİ

Üç istasyon’dan Bossaso (istasyon 1), Qardho (istasyon 2) ve Garowe (istasyon 3)) elde edilen uzun süreli yağış ve sıcaklık kayıtları kullanılarak 1980’den 2020’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), Discrepancy precipitation index (DPI) ve Deciles kuraklık analizi için kullanılmıştır. Bu yöntemler 1-, 3-, 6-, ve 12 aylık zaman periyodu için kullanılmıştır. Sonuçlara göre, log-SPI, gama-SPI, PN ve Deciles, 1980'lerin başlarında ve son yirmi yılda meydana gelen tarihi aşırı ve şiddetli kuraklıkları yakalayabilir.

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 0.36^0C /10 yıl ve ortalama yıllık yağış 3.15 mm/10 yıl olarak artmıştır.

Anahtar kelimeler: *Kuraklık, Eğilim, Puntland bölgesi, Somaliya, SPI, PDI, PN, Deciles, Kurak, Yağış, Sıcaklık*

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LIST OF ABBREVIATION

DIs: Drought Indices

FAO: The Food and Agriculture Organization

CZI: China-Z Index

MK: Mann Kendall

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

IRS: Remote sensing satellites

PSAWEN: Puntland State Agency for Water, Energy and Natural Resources

SWALIM :Somalia Water and Land Information Managemen

CHAPTER 1

INTRODUCTION

Drought is a natural disaster that occurs due to less precipitation than average over a lengthy period in a region, affecting natural environment functions and human activities (Sivakumar, 2005). Drought can happen in almost every part of the world, even in wet places (UNISDR, 2011; Vicente-Serrano et al., 2014). Drought is regarded as a natural hazard that leads to mass migration. Drought has killed more than 11 million people and harmed 2 billion people during the 19th century, far more than any other natural disaster (Chennat, 2013). Malnutrition and death are primarily caused by shortages of food and water as a result of Drought (Rahman et al., 2018). Drought has both immediate and long-term effects on the environment and the economy (Rahman et al., 2018; FAO, 2017). Drought events are a threat to all geographical locations. However, some areas are more susceptible to Drought than others. These include the Mediterranean and African countries, which have long-term climate abnormalities. In this context, Somalia has gone through extended droughts over previous 25 years, exacerbating the humanitarian situation. Several severe droughts have occurred in recent years, including 1964, 1969, 1974, 1987, 1988, 2000, 2001, 2004, 2008, 2011, 2016, and 2017.

A severe drought hit the entire East African region between July 2011 and mid-2012, described as the worst in 60 years. It had caused widespread devastation triggering a catastrophic food crisis in Somalia, Djibouti, Ethiopia, and Kenya, threatening the livelihoods of 9.5 million people in those countries. Affecting primarily southern Somalia and resulting in livestock deaths,reduced harvests, and decreased demand for la bour and household income; approximately onethird of the population, 3.7 million peopl e, were affected, with nearly 260,000 people dying. Somalia has been engulfed in civil war for nearly two decades, resulting in non-institutionalized governance (Said, Abdullahi Ali, 2019). Drought research is hampered by war, making it challenging to raise drought awareness (Said, Abdullahi Ali, 2019). Drought monitoring and early warning are critical instruments for managing crop losses, preventing famines, and lowering the danger of starvation. In Somalia, there is currently no national drought monitor in place. Therefore, determining the most appropriate meteorological drought index would help authorities develop a drought monitoring system for states and the entire country. This technique can give decision-makers in the region a clear picture of the drought risk and allow them to take preventative steps.

1.1. Problem Statement

Although Somalia has experienced severe droughts, the long-term spatial and temporal evaluation of drought occurrences is unknown. As a result, there is a lack of preparedness and misinformed drought management techniques. Many earlier studies in Somalia on drought incidences have concentrated on crisis management (Maxwell and Fitzpatrick, 2012; May Stadt and Ecker, 2014; Ou and Hao, 2018) rather than examining drought occurrence patterns and regional distribution. As a result of the abovementioned issues, there is an obvious need to better understand and assess historical Drought to build a strategy for mitigating drought-related impacts in the future.

1.2. Objectives

Droughts in Somalia's especially semi-arid Puntland state have resulted in thousands of people and livestock deaths and significant economic consequences for the agricultural sector due to the uneven temporal and spatial distribution of rainfall. Drought monitoring is an essential component of predicting and analyzing drought consequences, and there is no single index that can represent all aspects of meteorological Drought. This study aims to investigate and assess the duration and severity of meteorological droughts using different meteorological indices such as Percent of Normal Index (PNI), Deciles Drought Index (DDI) and Standardized Precipitation Index (normal-SPI, gamma-SPI, log-SPI), and Discrepancy Precipitation Index (DPI).

To evaluate the performance of drought indices in the Puntland State of Somalia.

The following are the main objectives:

1. To analyze the spatial and temporal variation of meteorological Drought.
2. To assess the hydrological drought occurrence for selected sub-basins of the study area
3. To predict the occurrence of Drought using time series analysis.
4. To suggest suitable drought mitigation measures

5. To detect a single change-point in the precipitation and the temperature time series.
6. Identify the trends in precipitation and temperature in the region during the period from 1980-2020

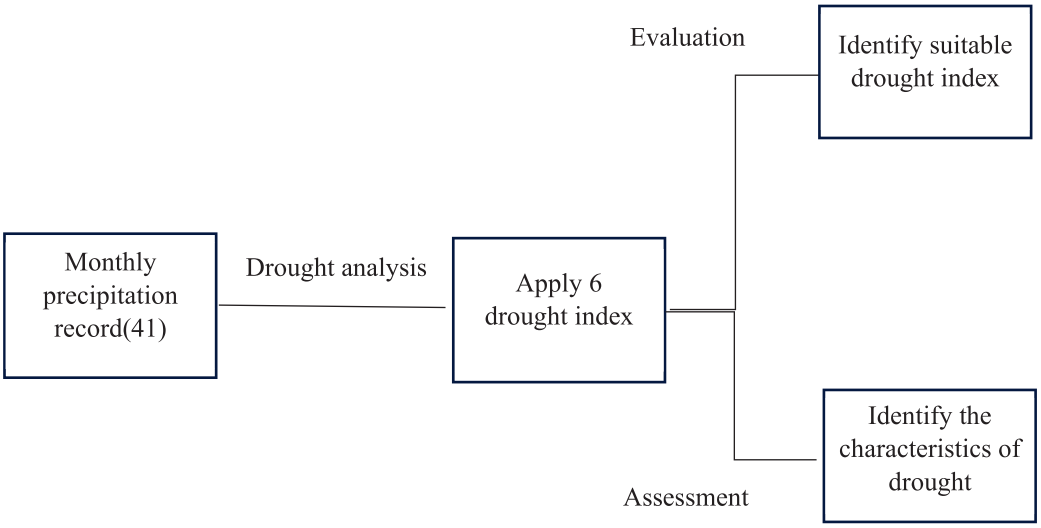

Figure 1.1. Drought analyses framework

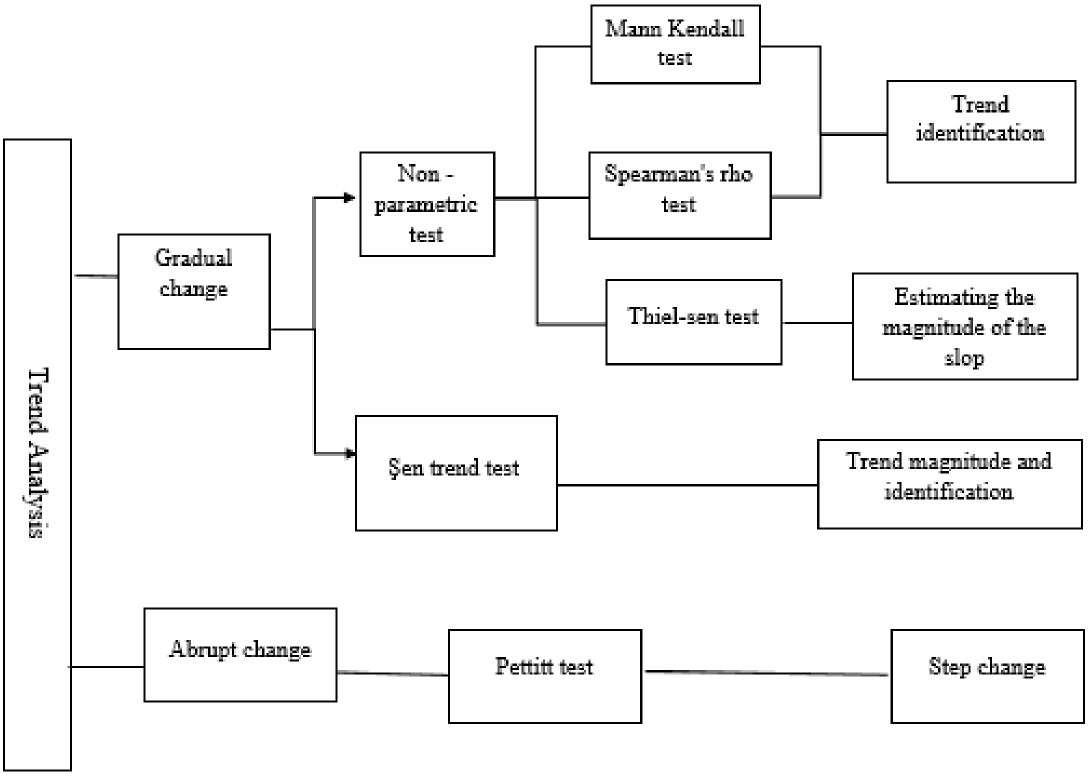

Figure 1.2. Trend analyses framework

CHAPTER 2

LITERATURE REVIEW

2.1. Overview of Drought

Drought results from a natural decline in precipitation. Low precipitation affects the environment and human activity, which are both impacted by the absence of precipitation. Seasons, years, or ten years, for example, are frequently associated with high temperatures, strong winds, and low humidity. Inadequate rainfall can reduce soil moisture or groundwater, decrease river flow, agricultural failure, and water scarcity. No one can identify when a drought began or end because the weather constantly changes, unlike other weather disasters like hurricanes. It is also challenging to analyze the first effects of the Drought because they do not appear immediately. As a result, detecting the onset of Drought can take weeks or even months.

Droughts can continue for several weeks, months, or years at a time, and in some locations, droughts can last for ten years or more in some regions. The longer a drought exists, the worse the consequences are for humans. Droughts have a wide range of consequences on individuals. They could influence people's access to safe drinking water, which is essential for everyone because water sources can dry up during a drought. If their region's water supply is depleted, people must find adequate water from other sources to survive. Water is also required for the plant to grow. Irrigation is only possible if there is sufficient water in surrounding rivers, lakes, and streams or if groundwater is available. These water sources decrease and may even dry up during a drought, leaving crops unable to irrigate and resulting in death. Droughts cause water and food insecurity in developing countries and worsen hunger and civil unrest problems.

2.2. Types of Drought

Drought is characterized as a lack of rainfall that causes a substantial hydrologic (water) imbalance, resulting in water shortages, agricultural damage, streamflow reduction, and groundwater and soil moisture depletion, among other effects. Drought is the planet's most physically dangerous hazard to agriculture (**Wilhite and Glantz, 1985).** Drought can be classified into four different methods as; meteorological, hydrological, agricultural, and socioeconomic (**Gokcekus, 2020).**

2.2.1. Meteorological Drought

Meteorological Drought is described as a lack of precipitation across a region for an extended period of time, typically accompanied by high temperatures, high winds, and low humidity, all of which cause evapotranspiration to increase. Meteorological Drought is the first kind of Drought that individuals can describe as a drought. Researchers study detailed and accurate daily rainfall records and relate them to known soil characteristics in a specific region **(Nalbantis, 2009)**.

2.2.2. Agriculture Drought

Agricultural Drought can be defined as the varying vulnerability of crops at different stages of development, from emergence through maturity **(Tate and Custard, 2002).** Agriculture Drought is the first economic sector that could be influenced by weather conditions (**Changnon, 1987).** Low recipitation may impact streamflow, lake, and reservoir levels and may cause their elevations to drop to abnormally low levels as a result.

2.2.3. Hydrological Drought

Hydrological Drought refers to the effects of periods of rainfall or snowfall shortages on surface or subsurface water supplies, including streamflow, reservoir, and groundwater **(Nalbantis, 2009).** Watershed or river basin scales are frequently used to define hydrological Drought's frequency and severity. Although all droughts begin with a lack of rainfall, hydrologists are primarily interested in how precipitation manifests itself in the hydrologic system. Hydrological droughts frequently occur concurrently with or later than meteorological and agricultural droughts. Precipitation shortfalls require time to express themselves in components of the hydrological system such as soil moisture, streamflow, groundwater, and reservoir levels. As a result, these effects are out of sync with those in other industries **(Tallaksen and van Lanen, 2004).**

Hydrological Drought is defined as long periods of low soil moisture that influence agricultural and plant growth and is usually monitored on a river drainage system scale.

2.2.4. Socioeconomic Drought

Socioeconomic Drought occurs when a lack of water negatively impacts people's health, well-being, and quality of life or when a lack of water negatively impacts the supply of goods and services to a community **(Tallaksen and Lanen, 2004).**

2.3. Causes of Drought in Somalia

According to **Mishra and Singh (2010**), the amount of rain that falls in a particular location varies from a year to the next. In northern Somalia research locations such as the Garowe parts of Qardho and Bossaso regions, researchers do research year after year, month after month, or as needed. According to experts, Drought in northern Somalia is mainly caused by natural conditions and human activity **(National of Meteorology, Somalia Government, 2013**).

The most common problems that cause Drought in Northern Somalia are lack of rainfall, and human activities.

2.3.1. Lack of Rainfall

A lack of or insufficient precipitation primarily causes Drought in northern Somalia. If the area does not receive rain for an extended period, a water shortage develops in that area, and it becomes dry, particularly for more than a season; this scenario results in dry conditions and a lack of water for crop growth in that area, which is classified as a drought. The exact opposite occurs when the location has pressure systems and less water vapor. Farmers plant crops in the hope of rain, but agricultural droughts occur when the rains do not fall and irrigation systems are not in place.

2.3.2. Human Activities

Human activities have a considerable impact on the management of the water cycle. Deforestation, overgrazing, over-cultivation harm the water cycle. Moreover, agriculture minimizes evaporation, stores water, attracts rainfall, and supplies significant atmospheric moisture through transpiration; tree and vegetation cover is vital for the water cycle. In this view, deforestation causes decreasing vegetation cover and removing trees increases evaporation, diminishing soil's ability to hold water, making it more vulnerable to desertification. The capacity of soil to hold water is located most of the time in Somalia's northern areas.

2.3.3. Flow of Surface Water

In various geographical regions around the research area, small lakes, rivers, and streams are the principal sources of downstream surface water. These surface water flows dry off downstream during scorching seasons or due to certain human activities, resulting in Drought.That means that water demand exceeds supply. Excessive irrigation systems and hydroelectric dams are just two examples of human activities that dramatically reduce the amount of water moving downstream to other locations.

2.3.4. Climate Change and Global Warming

Climate change, or human activity, has increased greenhouse gas emissions into the atmosphere, leading to a sustained rise in global average temperatures. As a result, evaporation and evapotranspiration rates have increased, and higher temperatures have resulted in wildfires and longer dry spells. As a result of global warming, drought conditions are becoming more common.

2.3.5. A General Lack of Understanding About Adaptable Farming Techniques

Some farmers have failed to diversify their crops throughout time due to no fault of their own. These could be because they know how to cultivate the fundamentals, do not have access to a wide variety of seeds, or do not understand different farming procedures. When a farmer relies only on one crop, he or she becomes vulnerable to weather extremes.

According to **Gokcekus (2020), farmers** causes the ground to dry up, lose water, and change its environment. Natural phenomena include low precipitation and rainfall compared to other sections of the country, crop growth seasons vary from season to season and crop growing seasons are disrupted by rain and human activities, lack of understanding of the destruction of trees, planting new trees, ways of farming, and year exchanges of crop seeds, and primitive farming technology and there is no other alternative resource to farming in this region.

2.4. Effects of Drought in Northern Parts of Somalia

Drought has far-reaching consequences for the ecosystem and civilization (**Mishra and Singh 2010).** Water is used in practically all human activities, as well as in the lives of plants and animals. On this basis, prolonged water scarcity can have various direct and indirect effects on society because water, second only to breathable air, is one of the essential elements for human survival. As a result, when a drought is defined as insufficient water to satisfy present demands, situations can quickly become difficult or dangerous.Drought consequences in Somalia can be divided into four categories: Environmental, Economic, social, and political.

2.5. Assessments of Drought

Drought assessments are essential in the planning and management of water resources. Considering this, historical droughts in the region should be investigated in terms of causes and impacts during their occurrences. Droughts, unlike other natural disasters, develop slowly, making it feasible to develop drought mitigation methods that effectively mitigate their consequences. Drought mitigation should be done in three stages: before, during, and after the drought. Not only would the consequences be considerably decreased, but they would also be at a low cost. As a result, many approaches for assessing and monitoring the drought event are created.

2.5.1. Monitoring of Drought

Most countries have drought monitoring mechanisms based on ground-based information on drought-related parameters such as precipitation, weather, crop conditions, and water availability. Satellite Earth observations are a great complement to data collected in the field. Satellites are often needed to provide the overview, comprehensive coverage, and frequent information needed for spatial monitoring of drought conditions. The current status of remote sensing data for drought monitoring and early warning is based on rainfall, surface moisture, temperature, and vegetation monitoring **Tayfur (2021).**

Remote sensing satellites (IRS) have been employed to evaluate, interpret, validate, and integrate meteorological parameters. These data are used to evaluate ground impacts such as surface (soil) moisture and estimate precipitation intensity, amount, and coverage.

2.5.2. Drought Mitigation

Drought Mitigation refers to actions and programs undertaken before a drought to reduce long-term vulnerability to future droughts. It includes structural and non-structural measures (e.g., appropriate crops, dams, engineering projects) to limit Drought's adverse effects.In order to mitigate the effects of a drought, the following elements must include Prediction Monitoring Impact Assessment Response:

- Creating proper connections between early warning systems, disaster assistance, and emergency response
- Rapid assessment of ongoing drought emergencies is essential.
- Developing diagnostic tools for use in quick assessments

- Interagency diagnostic teams (pre-emergency) are being established and trained.
- Research is being conducted to determine the impact of drought relief efforts on societal vulnerability.

2.6. Drought Indices

A drought index is a single variable that is used to assess the impact of drought and define various drought parameters such as intensity, duration, severity, and spatial extent. Continuous rainfall, temperature, streamflow, or other measurable variables are commonly used as drought indices. Because long-term rainfall records are frequently available, rainfall data is widely used to calculate drought indices.

2.6.1. Standardized Precipitation Index (SPI)

This method is one of the most easily accessible and extensively used indices for weather drought severity estimation. The standardized precipitation index (SPI) for any location can be determined using long-term precipitation data for the given period. **(McKee, Doeskin, and Kleist, 1993).** They developed a method for fitting long-term rainfall data to a probability distribution and then translated it using an equal-probability transformation into a normal distribution. As a result, the mean SPI for the location and desired period is zero, with values greater than zero indicating wet periods and less than zero indicating dry periods.

2.6.2. Percent of Normal (PN)

The analysis time scale in this procedure might range from a month to a year. Because the percent of normal (PN) is a highly straightforward metric, making it is ideal for reporting drought levels to the general public **(Keyantash & Dracup, 2002).** The usage of PN assumes a normal distribution in which the mean and median are equal, which is not always the case **(Hayes, 2003).** As a result, minimizing drought risks only based on deviations from normal is not an effective decision-making tool **(Hayes, 2006a).**

2.6.3. Deciles

The deciles method divides the monthly record precipitation distribution into ten pieces. Gibbs and Maher (1967) created a percent of standard technique to circumvent some weaknesses in the "percent of normal" approach. Long-term monthly rainfall records are first ranked from highest to lowest to generate a cumulative frequency distribution, then used to calculate deciles **(Barua, Ng, & Perera, 2010).**

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2.6.4. Discrepancy Precipitation Index

Tayfur (2001) developed the Discrepancy Precipitation Index (DPI) to analyze and monitor meteorological Drought. The method does not apply a probability distribution to the precipitation data; instead, it is based on the mean value discrepancy. The D-score values are used to classify droughts, and drought categorization ranges are identical to those of the standard precipitation index (SPI). He used this method to the measurement of meteorological Drought at some sites worldwide, including those in dry climates (Mauritania), semi-arid climates (Afghanistan), and Mediterranean climates (Turkey). The most often used drought indices are the log-SPI and gamma-SPI. However, DPI can determine the magnitude of the difference in the precipitation data set **(Tayfur, 2021).** The Discrepancy Measure has introduced The Discrepancy Precipitation Index to record historical droughts as the DM of a precipitation series rises.

CHAPTER 3

STUDY AREA AND DATA

3.1. Somalia Location Geography and Climate

The Federal Republic of Somalia is an African country in East Africa. It is a peninsula in Africa's northeastern region bordered by three other African countries on three sides; Djibouti is located in northwest Somalia, Ethiopia is located on the western edge of the country, and Kenya is located in the southwestern (Figure 3.1). The total land area of 637 square kilometres. Somalia is surrounded by three bodies of water: the Gulf of Aden, the Indian Ocean, and the Guardafui Channel (show its location on the map!) (Figure 3.1).

Figure 2.1. Location of Somalia Map

Figure 2.2. Map of Somalia

The topography in Somalia can distinguish five distinct physio-geographic zones

i. Plains along the northern coast known as Guban.
ii. The northern Golis mountain range and the plateaus there
iii. the central coastal plains,
iv. the broad limestone-sandstone plateau that spans most of central and southern Somalia,
v. and the part of south flood plains which have the highest potential for agricultural production.

Somalia's climate has no significant seasonal variation due to its closeness to the equator. However, certain unpredictable rainstorms can occur from time to time. The average daily maximum temperature ranges from 25 to 40 °C. The average daily minimum temperatures vary from 15 °C to 20 °C, except for high altitudes along the eastern seaboard.

As seen in figure (3.3), Northeastern annual rainfall is less than 90 mm, approximately 200 to 300 mm long in the central highlands. However, the northwest and southwestern parts of the country receive much larger rain, averaging 410 to 510 mm per year

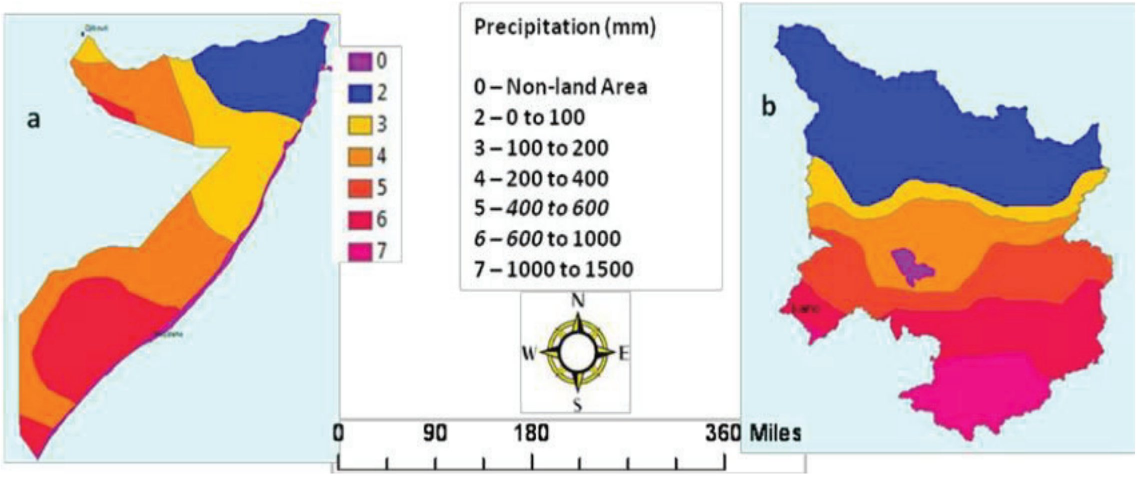


Figure 2.3. Mean annual precipitation (mm) 1980 to 2020

Rainfall is typically in the form of scattered showers or severe downpours, and it is highly unpredictable. In Somalia, there are four distinct seasons:

1) Jilal season, which lasts from December up to March, is the driest and most challenging time of the year,
2) Gu season, or primary rainy season, lasts from April until June and is the wettest
3) Period of the year. These rains, which originate in the southwest, revitalize the pasture area, particularly on the central plateau, the desert quickly changed into lush flora during this period.
4) Hagaa season is the second dry season, which lasts from July through September, and it is the driest period of the year.
5) Deyr season includes the second and shorter rainy season from October to November.

3.2. The Study Area

Puntland is a state in northeastern Somalia, bordering the Gulf of Aden to the North and the Indian Ocean to the southeast (Fig 3.4). Puntland has a population of about 2.4 million people and covers about one-third of the country's geographical area of 212,500 km^2. The state's climate is described as semi-arid with a warm climate. There are two rainy seasons: a) Gu, which begins in July and ends in September, and b) Deyr, which begins in October and ends in early December, with a poor rainfall distribution pattern of 27–250 mm annually. Only seven meteorological stations in the region have annual rainfall records. Qardo,Garow and Bosaso stations are the paramount importance.

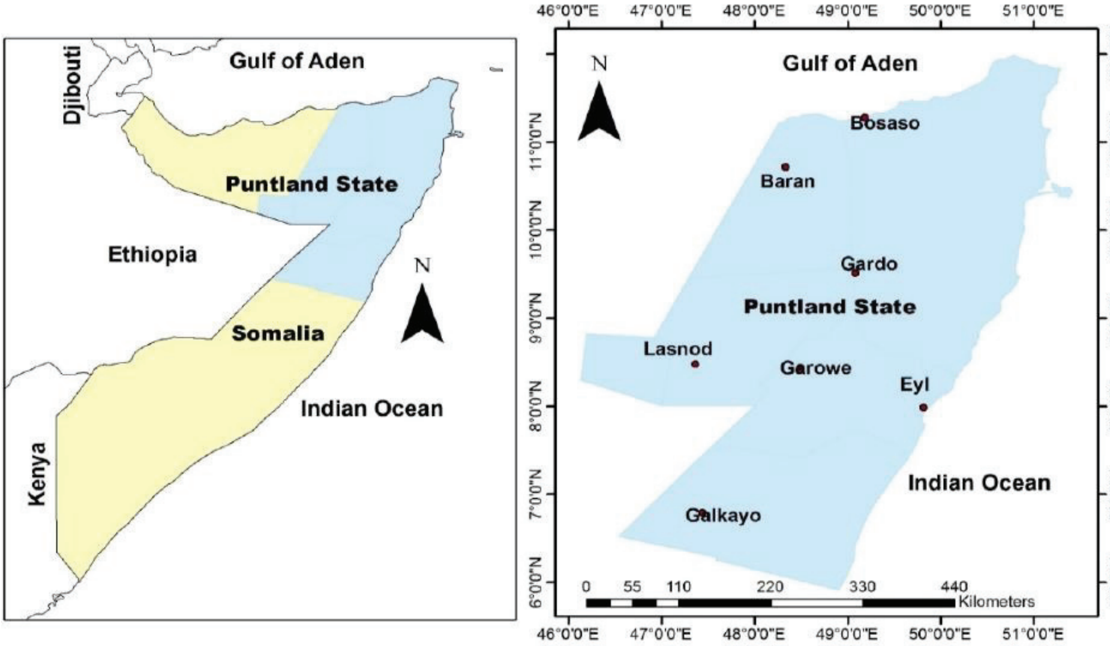


Figure 2.4. Study Area

Most of the Puntland territory is arid rangelands and is best suited for livestock grazing and not for crop production due to the general scarcity of water and the saline soils with high content of salt deposits. Regardless of where you live, water is one of the most critical factors in achieving sustainable development. Improving water security through the appropriate management of water resources is critical to advancing environmental, social, and economic development. Somalia's water resources are restricted in both quantity and quality, droughts Moreover, floods are becoming more frequent, further deteriorating the country's water security status.

Somalia has only two permanent rivers, Juba and Shabelle, which start in the Ethiopian highlands to the Indian Ocean and extend through the southern part of the country. Shabelle river is above 4,350 m mean sea level, 2,526 km long, with an average flow capacity of 75 m^3/s and a catchment area of 283,054 km^2 (Figures 3.2 and 3.5). The total length of the Juba River is 1,808 km, with an average flow capacity of 186 m^3/s and a catchment area of about 210,010 km^2 (Figures 3.2 and 3.6).

The two rivers have significant seasonal variations in inflows but do not completely dry out.

High flows are seen during wet seasons (April, June, September, and November). Rivers sometimes break and penetrate weak embankments and flood draining neighbouring lands, as river flow volumes in the dry season are significantly reduced. Water flows for only a few hours to days after the rainfall events, and there are no river gauging stations to measure the level of the rivers. There is no rivers in the northern and western parts of the country, and two rivers are located in the south of the country (see Figure 3.5 And figure 3.6).

Figure 2.5. Shabelle river is located in south Somalia

Figure 2.6. Juba River is located south of Somalia

Surface water is used for Domestic Demand; about 30% of Somali population (7.5 million) lives in the south of the country, and those populations use water from Juba and Shabelle rivers. Surface water is also used for Livestock Demand; water for livestock is an essential basis for the subsistence and development of the Somali population. Livestock is a primary source of nutrition and income. About 55% of the Somali population was directly engaged in livestock production (FAO/WB/EU 2004). Most livestock in Somalia is found near Juba and Shabelle basins, like grazing goats, sheep, cattle, and camels. Despite the infrastructural collapse in irrigated agriculture, 70% of the national cereal production is still in the Juba and Shabelle basins.

Except for those living along Juba and Shabelle rivers, all regions in Somalia rely on groundwater for domestic water, livestock, and small-scale agriculture. There is deficient, adequate rain and no perennial surface water in most parts of the country. Boreholes, shallow wells, and springs are Somalia's most common groundwater sources. Residents in rural and urban areas use groundwater to meet their domestic and livestock water demands and small-scale irrigation. The most common groundwater sources are shallow wells (manual drilling), wells, springs, subsurface dams, and infiltration galleries. The region uses important groundwater sources such as dug wells, boreholes, and springs.

3.3. Data

The National Office of Meteorology of Somalia provided the data used in this study to calculate the Drought Indices (Dis). In this investigation, three rainfall stations were used: Bossaso (station 1), Qardho (station 2), and Garowe (station 3), as indicated in Figure 3.7

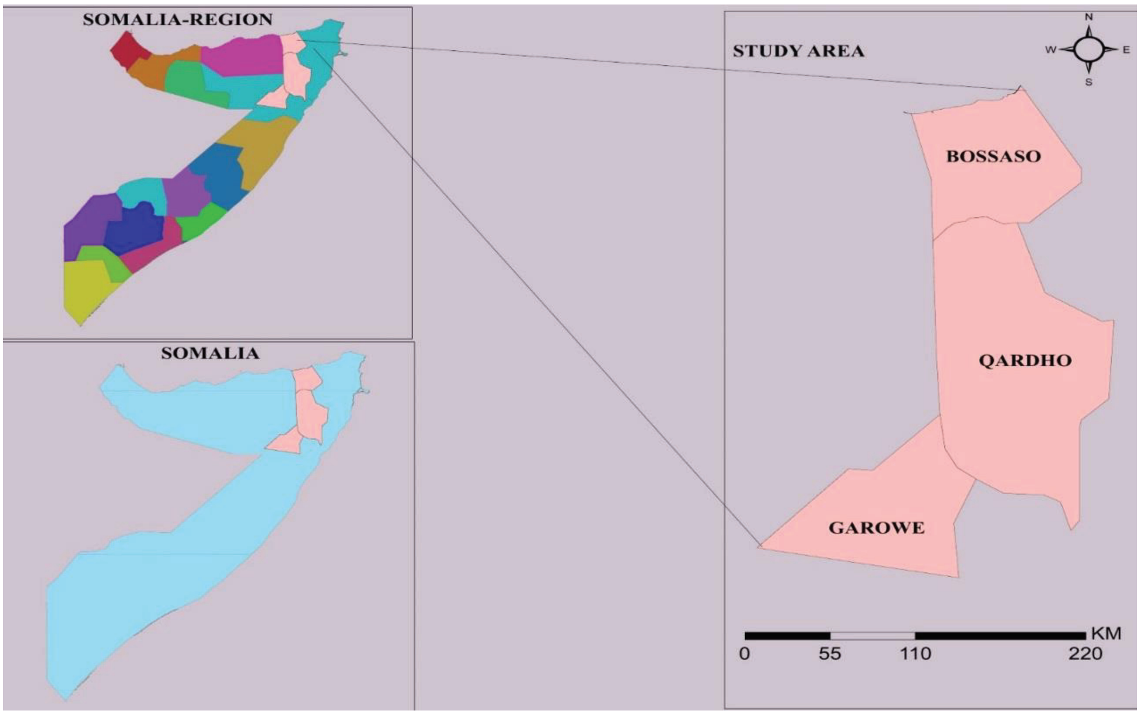


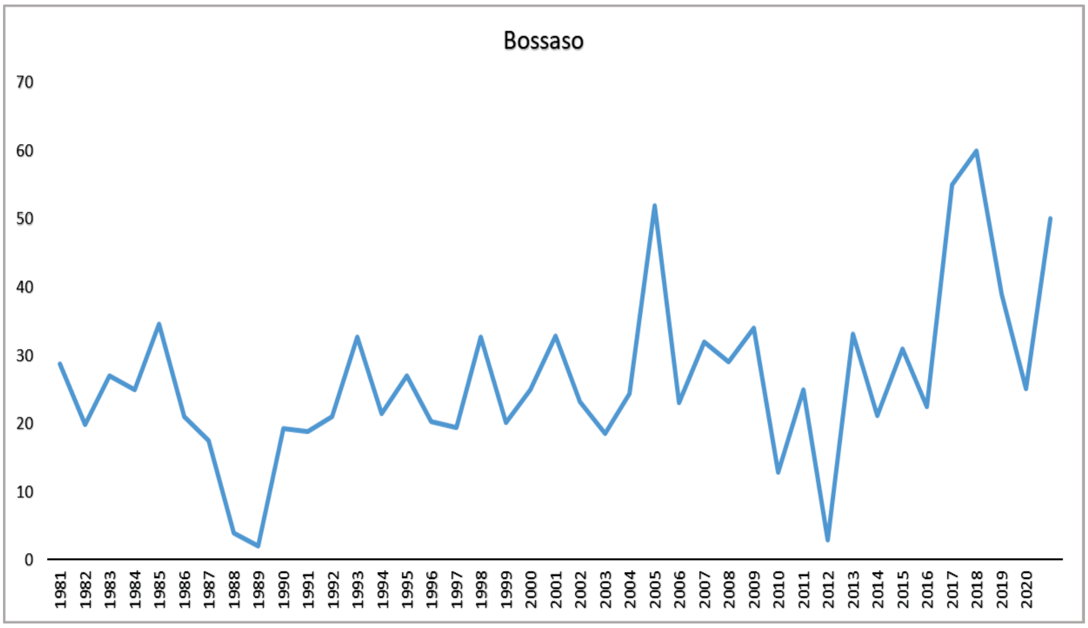
Figure 2.7. Stations of study Area

Although one station (Garowe) is outside the catchment area, it was included in this analysis due to its proximity to the study region. Each station's latitude, longitude, and altitude are summarized in Table 3.1.

Table 2.1. Location of Meteorological stations in Puntland

Station	Names	Elevation (m)	Latitude	Longitude	Mean annual rainfall (mm)
1	Bossaso (station 1)	15	11.28	49.19	27
2	Qardho (station 2)	725	9.51	49.09	221.4
3	Garowe (station 3)	465	8.41	48.48	183

Data on monthly precipitation (rainfall) and temperature are used in this study, covering the period from1980 to 2020. Figure 3.8 shows annual rainfall data from the three stations.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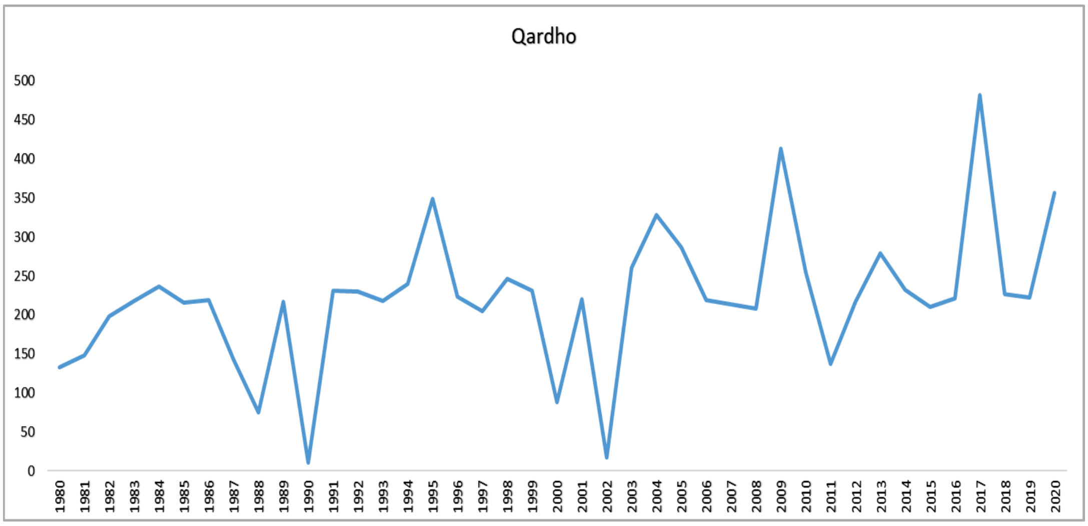
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1999
2000
2001
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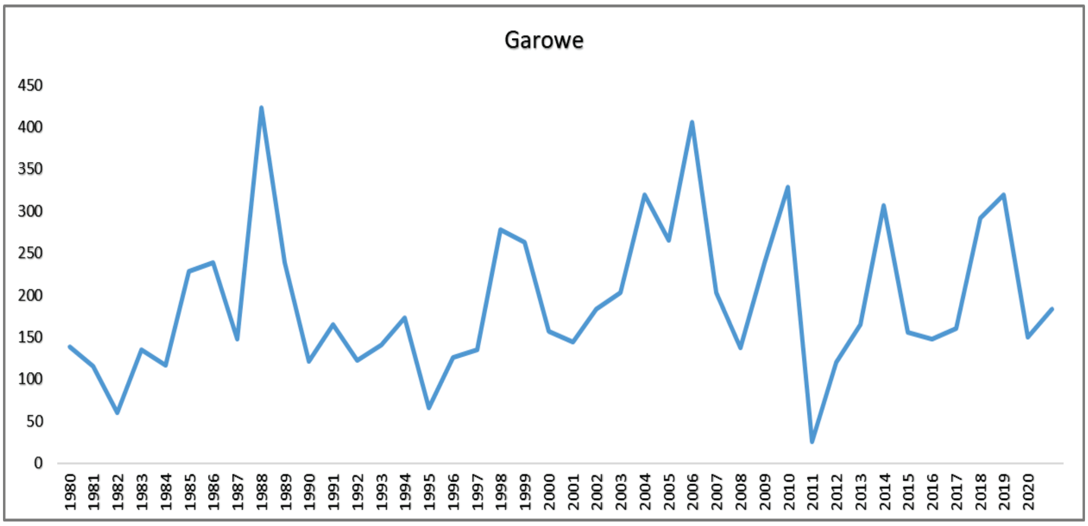
2020


Garowe
450
400
350
300
250
200
150
100
50
0
1980
1981
1982
1983
1984
1985
1986
1987
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2011
2012
2013
2014
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2016
2017
2018
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2020

Figure 2.8. Annual precipitation data for the three stations for the period of 1980-2020

Stations 1 and 2 receive 221.4 mm and 27 mm of annual rainfall, respectively, according to Figure 3.8, whereas Station 3, located in the Nugal region, receives 183 mm of rainfall. Table 3.2 presents the summary of the rainfall characteristics for each site.

Table 2.2. Rainfall characteristics for Bossaso station.

Bossaso	
Mean	26.44028455
Standard Error	1.925017
Median	24.98416667
Mode	25
Standard Deviation	12.32612301
Sample Variance	151.9333085
Kurtosis	1.392953408
Skewness	0.699022182
Range	58
Minimum	2
Maximum	60
Sum	1084.051667
Count	41
Confidence Level (95.0%)	3.890604485

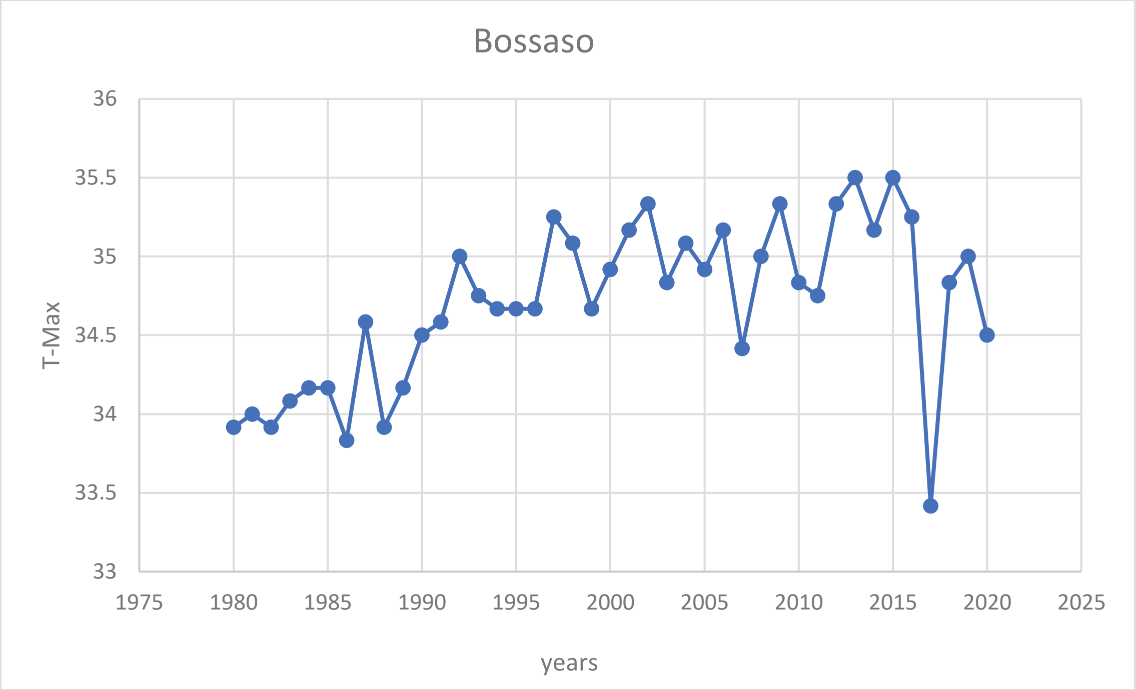
Qardh	
Mean	221.3984047
Standard Error	13.85675384
Median	220.5166667
Mode	#N/A
Standard Deviation	88.72651634
Sample Variance	7872.394701
Kurtosis	2.076769206
Skewness	0.209217187
Range	470.875
Minimum	10.91666667
Maximum	481.7916667
Sum	9077.334591
Count	41

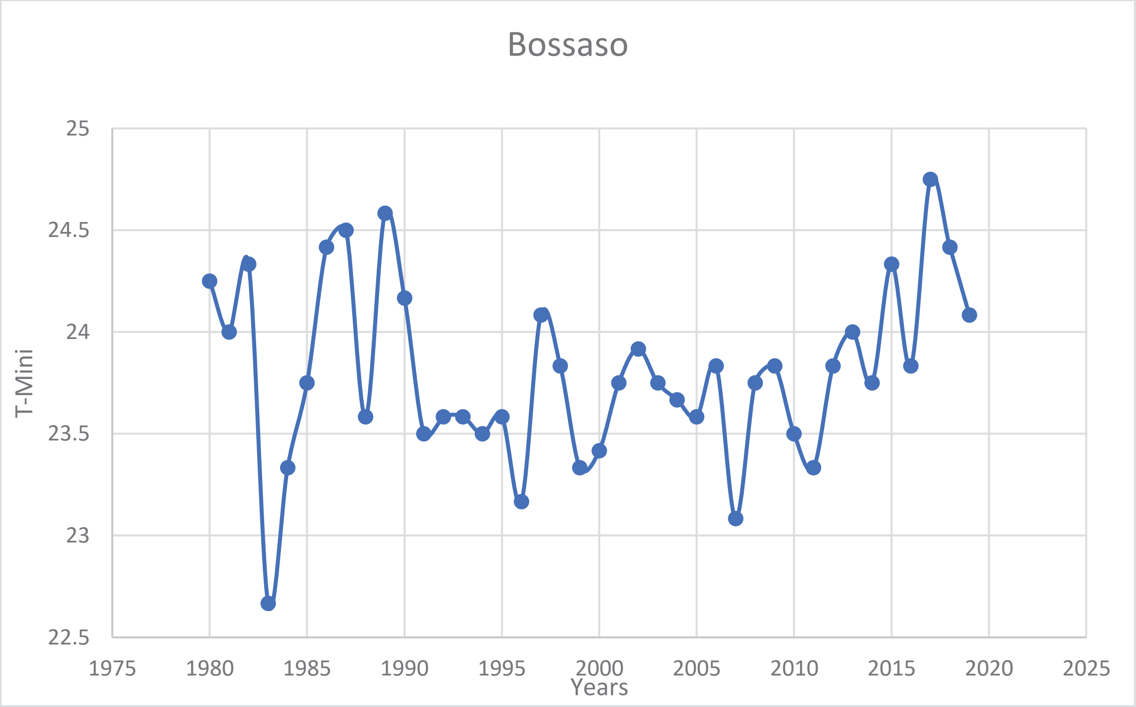
Confidence Level (95.0%)	28.00554417

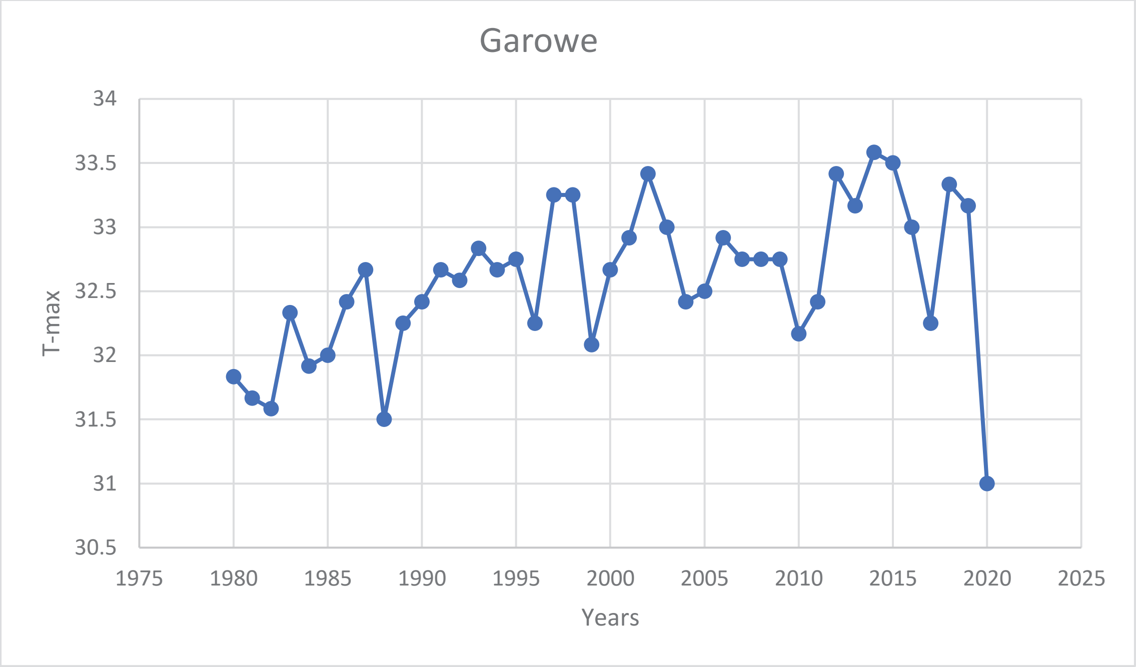
Garowe	
Mean	183.1286
Standard Error	13.54202
Median	166.0167
Mode	#N/A
Standard Deviation	86.71125
Sample Variance	7518.84
Kurtosis	0.686519
Skewness	0.189167
Range	404.251
Minimum	2.1
Maximum	406.351
Sum	7508.272
Count	41
Confidence Level (95.0%)	27.36945

Temperature data were obtained from three locations, namely Bossaso (1), Qardho (2), and Garowe (3), for the period 1980-2020. The lowest temperature (T_{min}), maximum temperature (T_{max}), and average temperature (T_{ave}) were all measured annually at each station.

Figure 3.9 and Table 3.3 show the features of the collected data. As seen, Station 1 had the highest temperature record with 35.7 °C in 2014, the warmest year observed in Stations 1 and 3, with average temperatures of 20 and 24 °C, respectively. However, 1982 is considered to be the coldest year (within the duration of the study) in the region, with average temperatures reaching their lowest levels at 16 °C, 19 °C, and 23.56 °C, respectively, at Stations 1, 2, and 3.


Bossaso
T-Max
36
35.5
35
34.5
34
33.5
33
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
years


Bossaso
T-Mini
25
24.5
24
23.5
23
22.5
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
Years


Garowe
T-max
34
33.5
33
32.5
32
31.5
31
30.5
1975
1980
1985
1990
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2005
2010
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2020
2025
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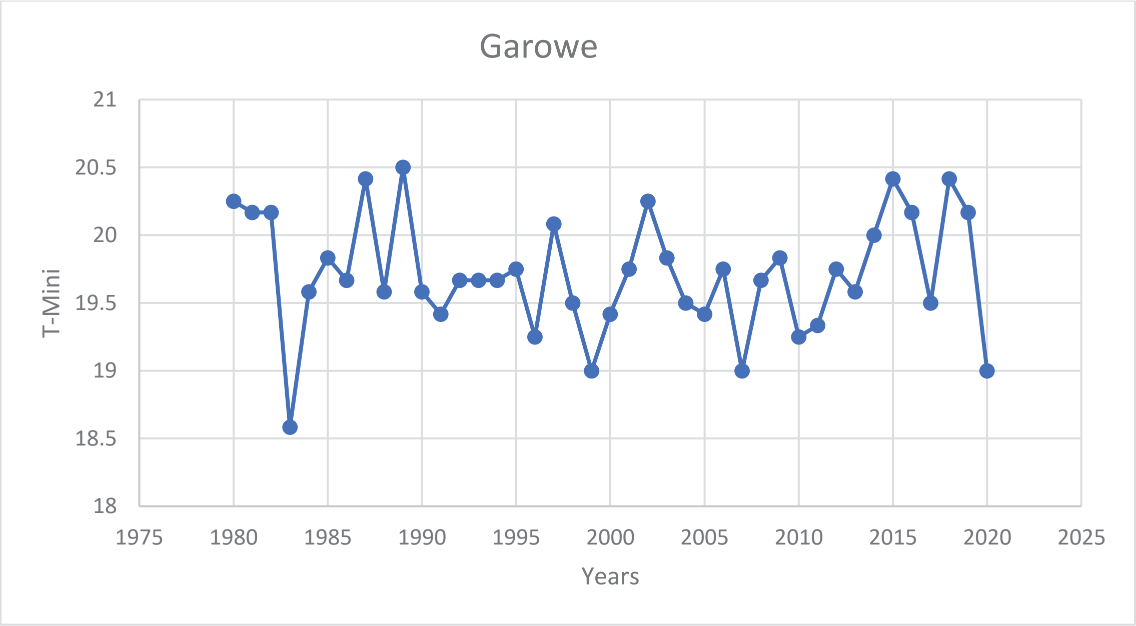
Garowe
T-Mini
21
20.5
20
19.5
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18.5
18
1975
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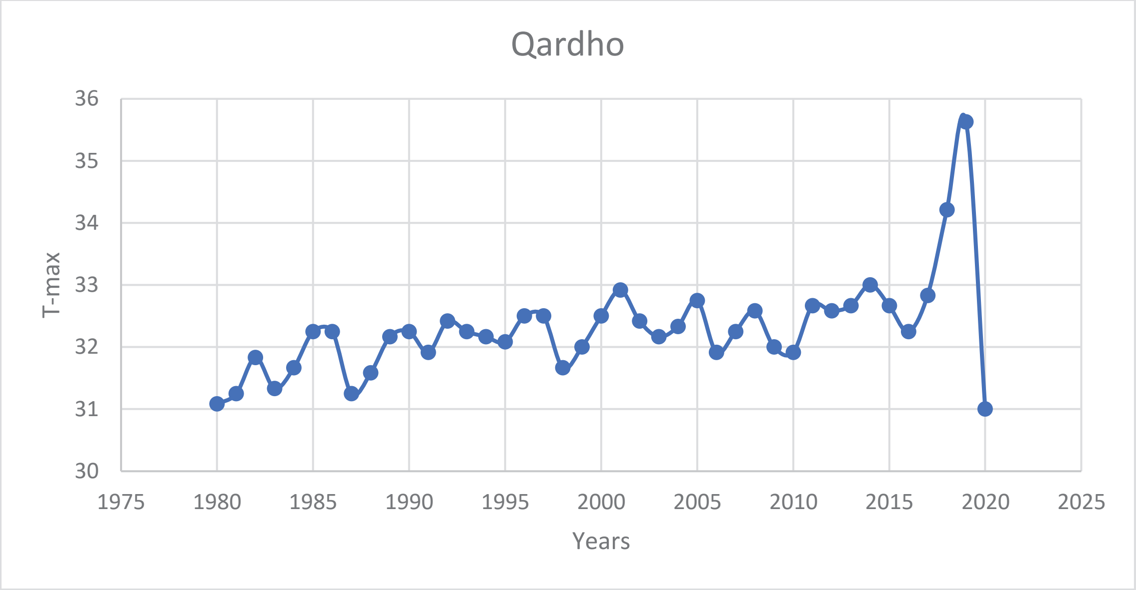
Years



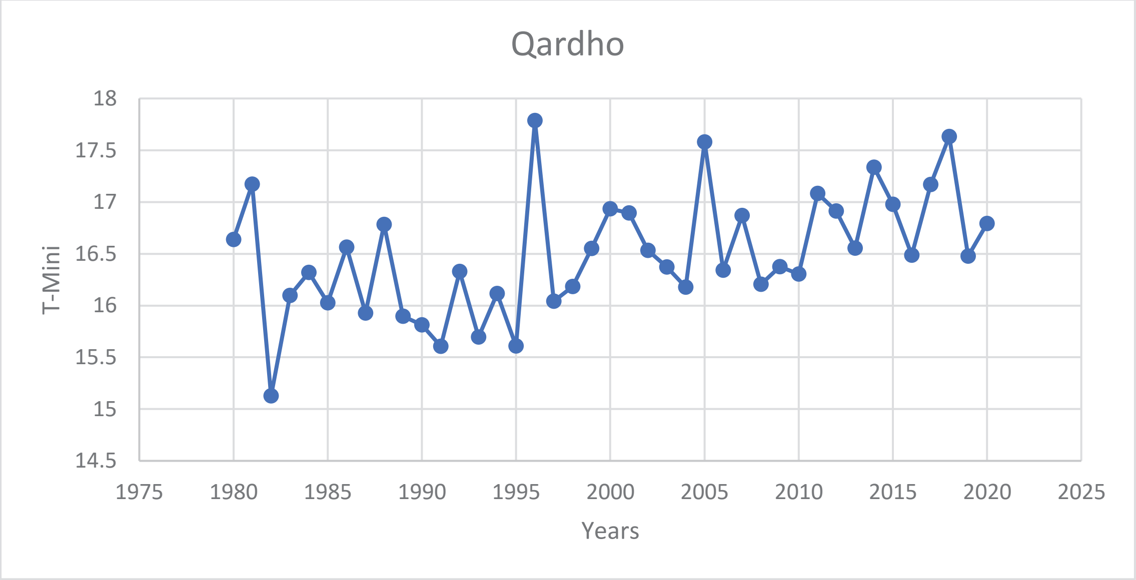


Figure 2.9. Max and Min temperatures at the three stations for the period of 1980-2020

Table 2.3. Characteristics of annual temperature data for three stations

	T-max		**T-min**			**T-average**			
Station 1	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
	33.083	35.417	34.709	21	25.25	23.56	27.5	29.792	29.135
	(2018)	(2014)		(1983)	(2018)		(1983)	(2016)	
Station 2	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
	31	35.63	32.306	15.13	17.79	16.5	23.644	25.37	24.566
	(2020)	(1997)		(1982)	(1996)		(1983)	(2015)	
Station 3	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
	31.500	33.833	32.632	15.83	21.25	19.74	23.875	28.03	25.716
	(1982)	(2015)		(1987)	(2003)		(1987)	(2019)	

CHAPTER 4

DROUGHT ANALYSIS

4.1. Methodology

The Standardized Precipitation Index (log-SPI, normal-SPI, and gamma-SPI), Deciles Index (DI), Discrepancy precipitation index (DPI), and Percent of Normal Precipitation Index (PNPI) are used in this study to detect meteorological Drought in three weather stations in the Puntland State of Somalia. The data used in this study comes from 41 years of monthly precipitation data from three stations in the Puntland State of Somalia. Detailed explanations of each method are provided below to demonstrate its capabilities and characteristics of each one.

4.1.1. Standardized Precipitation Index (SPI)

This method is one of the most detailed and extensively used indexes for evaluating the severity of meteorological Drought. A long-term precipitation series for a given duration, such as one, three, six, or twelve months (Shiau, J. T., 2006), is used to calculate the index established by (Mckee TB., Doesken NJ., and Kleist J., 1993). The long-term data is fitted to a gamma probability distribution, which is then transformed into a normal distribution with a zero mean and unit variance (Batisani, N., 2011), which is then transformed back into a gamma probability distribution. Table 4.1.1 depicts the drought classification for the z-score (SPI) index based on the drought classification. The negative SPI numbers suggest dry periods, while positive SPI values indicate wet periods. The Gamma Distribution SPI, Log-normal SPI, and Normal SPI are three frequently used SPI distributions employed in this study (Cacciamani,2007). The Gamma Distribution SPI, Log-normal SPI, and Normal SPI are also used.

Table 3.1. Drought classification for SPI values (Source:Barua et al. 2010)

SPI value(z-score)	Drought Classification
2.00 or	more Extremely wet
1.50 to 1.99	Very wet
1.00 to1.49	Moderately wet
0.99 to -0.99	Near normal
-1.00 to -1.49	Moderate drought
-1.50 to -1.99	Severe drought
-2.00 or less	Extreme drought

4.1.2 Normal-SPI

Instead of the gamma distribution, the normal-SPI uses the normal probability distribution (Yacoub, E. and Tayfur, G., 2016).In terms of mathematics, it is straightforward to compute, and in this example, the SPI index can be expressed as follows:

$$SPI = z = \frac{x-\hat{\mu}}{\hat{\sigma}} \tag{4.1.2}$$

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

4.1.3. Log-normal SPI

Like the gamma distribution, the log-normal distribution is positively skewed and non-negative. Because it is essentially a logarithmic modification of the data, it has the advantage of simplicity. (Lloyd Hughes & Saunders, 2002) The log-normal SPI is determined as follows:

$$SPI = z = \frac{\ln{(x)}-\hat{\mu}}{\hat{\sigma}} \tag{4.1.3}$$

4.2. Percent of Normal Index (PNI)

The PNPI is a drought measure that compares actual precipitation to average precipitation when evaluating meteorological data. It is typically used to calculate the long-term mean precipitation when at least a 30-year average is taken into account (Yacoub, E. and Tayfur, G., 2016). The Percent of Normal (PN) is a meteorological drought statistic computed by dividing actual precipitation by average precipitation and multiplying the result by 100 per cent to get the percentage of normal (M. J. Hayes, 2006b). The drought index is generally considered 100 per cent monthly, seasonally, and annually, with less than 100 per cent of PNPI values indicating dry periods. However, various places may have different findings for the same PNPI. As a result, applying it alone is not a good idea (Mohammad Musa Alami, Ehsanullah Hayat, Gokmen Tayfur, 2017). Table 4.2 shows the drought index classification for the PNPI values.

Table 3.2. *PNI* drought classification (Barua et al., 2010)

Class	*PNI* (%)
Wet	≥ 100
Normal	80 to 110
Moderately dry	55 to 80
Severely dry	40 to 55
Extremely dry	≤ 40

4.3. Discrepancy Precipitation Index (DPI)

Tayfur (2021) developed the Discrepancy Precipitation Index (DPI) to analyze and monitor meteorological Drought. The method does not apply a probability distribution to the precipitation data; instead, it is based on the mean value discrepancy. The D-score values are used to classify droughts, and drought categorization ranges are identical to the standard precipitation index (SPI).The suggested DIs is based on the discrepancy of rainfall data concerning the mean value. It is mathematically expressed by Eq.1

$$DPI = D_i = \log\left(\frac{P_i}{\bar{P}}\right) \tag{4.3}$$

$$\bar{P} = \frac{1}{N}\sum_{i=1}^{N} P_i \mathrm{i} = 1,2,3,\cdots,\mathrm{N} \tag{4.3.1}$$

where *Di* is called the discrepancy value (D-score) for the ith precipitation, *Pi* is the precipitation in data series, and *P is* the mean value of the precipitation data series- typically considered to be a 30-year mean (Willeke et al., 1994, Hayes, 2006)-defined by Eq. (2). According to Eq.(1), D =0 when *Pi* is equal to *Pand,* D is positive when *Pi >P* and D is negative when *Pi < P.*

The drought classification is categorized according to D-score values, as presented in Table 4.3 (Tayfur 2021).

Table 3.3. Discrepancy precipitation index

D-score (DPI value)	Category	Remark
0.0 to -0.19	Near normal	about 36% more or less than the mean value
-0.20 to -0.39	Moderate Drought	about 37–59% less than the mean valu
-0.40 to -0.59	Severe Drought	about 60–74% less than the mean value
-0.60 or less	Extreme Drought	about 75% or more less than the mean value

4.4. Drought Indices (DI)

(Gibbs and Maher 1967) proposed a technique for drought monitoring that involved dividing monthly rainfall data into deciles. Fortunately, it is a straightforward and straightforward calculation. DDI is a simple tool that takes simply rainfall data and is commonly used in Australia. To generate a cumulative frequency distribution using the DDI approach, long-term total monthly precipitation records were ranked from highest to lowest using the highest to the lowest ranking method. Afterwards, the distribution was separated into ten equal deciles, represented in Table 4.4.

Table 3.4. DDI classifications(Barua et al., 2010; Gibbs and Maher, 1967)

Value	*PNI* (%)
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

4.4.1. Gamma-SPI

Gamma-SPI is the most widely applied observational model for precipitation data. It involves fitting a gamma probability density function to a given time series of precipitation (Angelidis, P., Maris, F., Kotsovinos, N. and Hrissanthou, V., 2012)

Its probability density function defines it as:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{\frac{\pi}{\beta}} \text{ for } x > 0 \qquad (4.1.4.1)$$

Where β α and 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) :

$$\Gamma(\alpha) = \int_0^\infty \gamma^{\alpha-1} e^{-y} dy \qquad (4.1.4.2)$$

α and β parameters can be estimated as follows [4.1.4.2]:

$$\Gamma(\alpha) = \int_0^{\infty} \gamma^{\alpha-1} e^{-y} dy \; \alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right), \beta = \frac{\bar{x}}{\alpha}, \text{ with } A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \qquad (4.1.4.3)$$

In Eq. (5), n is the number of observations. After estimating a and þ coefficients, the probability density function is integrated concerning x, which yields the following expression G(x) for the cumulative probability:

$$G(x) = \int_0^{x} g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^{x} x^{\alpha-1} e^{-x/\beta} dx \qquad (4.1.4.4)$$

Substituting t for x/β in Eq. (4.1.4.3):

$$G(x) = \frac{1}{\Gamma(\alpha)} \int_0^{x} t^{\alpha-1} e^{-t} dt \qquad (4.1.4.5)$$

As the gamma function is not defined for x=0, for the possibility of zero values, the cumulative probability

$$H(x) = q + (1-q)G(x) \qquad (4.1.4.6)$$

In the case of zero precipitation probability (q), the cumulative probability distribution is transformed into the standard normal distribution, yielding the SPI (standard precipitation index). Using the approximate conversion supplied by [37], the following is the result:

for $0 < H(x) < 0.5$ (4.1.4.7)

$$z = SPI = -\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \qquad (4.1.4.8)$$

for $0.5 < H(x) < 1.0$

$$z = SPI = +\left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \qquad (4.1.4.9)$$

4.5. Results

We used different forms of DIs for drought evaluation throughout the region for periods of 1, 3, 6, and 12 months based on monthly precipitation records for 41 years obtained from three weather stations. Because the rainy season is July, August, and September, only these three months were included in the monthly and three-month analyses. These methods were used to determine the features of Drought (frequency, magnitude, and duration) and to analyze which drought index(s) may be used to evaluate Drought in the region.

For the three stations, Qardho, Bossaso and Garowe, annual precipitation values of the Standardized Precipitation Index (Normal-SPI, Log-SPI, and Gamma-SPI), the Percent of Normal (PNPI), the Deciles Index (DI), and Discrepancy precipitation index were calculated, as detailed further below.

4.5.1 These Results for Bossaso (Station 1)

The SPI and DPI findings for the periods of 1, 3, 6, and 12 months are presented in Figures 4.1-4.4, respectively, while Table 4.5 provides a summary of the decile results for the Bossaso station. Drought index results for station 1 are shown in Figure 4.1 for three months. For three months, all of the methods generated the same results. In this case, the log-SPI and the gamma-SPI performed similarly in predicting the severe Drought in 2011. (Fig 4.2). The normal SPI produces wetter and less drought-prone conditions (Fig 4. 2). These similar results were obtained for drought predictions over six months (Fig. 4.3) and an annual period (12 months) (Fig 4.4).

The data presented in Figures 4.1 through 4.4 demonstrate that the extreme Drought was identified in 2011, while separate drought events took place in 1988, 1989, 2009. Long dry spells were observed between the years 1986 and 1989, as well as between 2009 and 2011

Table 3.5. Deciles result for Bossaso (Station 1)

Annuals Rainfall Values (mm)	Classification
13.8 - 9.6	Much below normal
20.7 - 22.3	Below normal
25 - 27	Near normal
31.4 - 33.7	Above normal
48.1 - 60	Much above normal

According to the Deciles approach, Drought occurs when annual precipitation is less than 24.98 mm. As shown in Table 4.5, precipitation less than 22.29 mm/year and 10 mm/year are severe and extreme drought indicators, respectively.

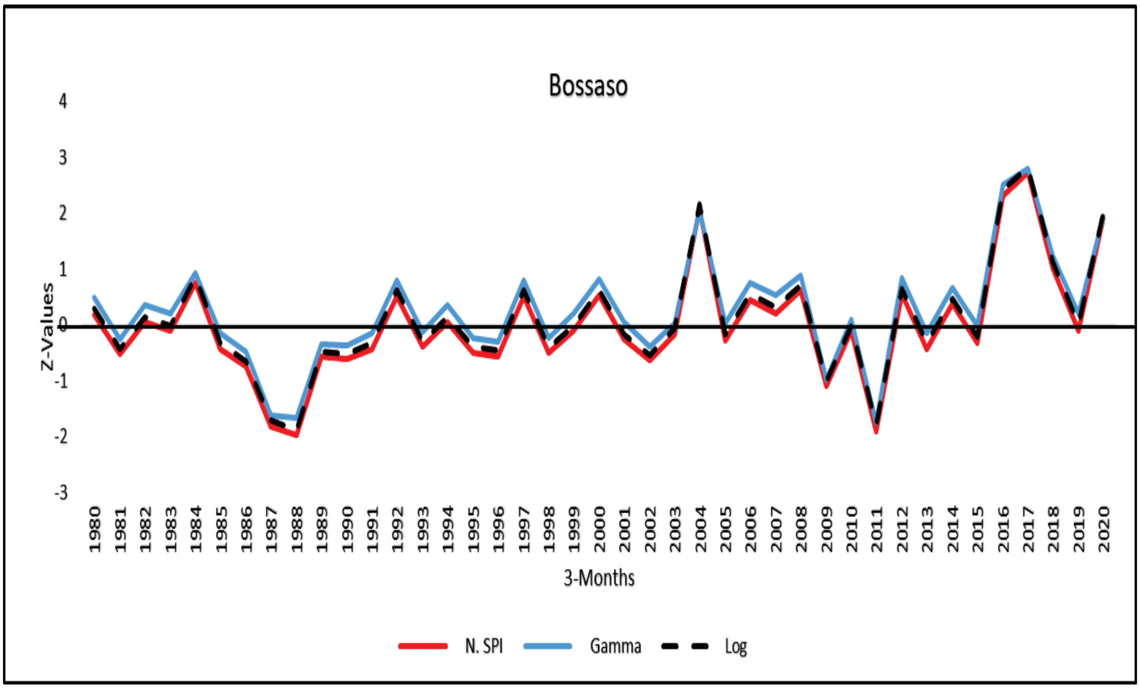


Figure 3.1. SPI results for 3-months period for Bossaso (Station 1)

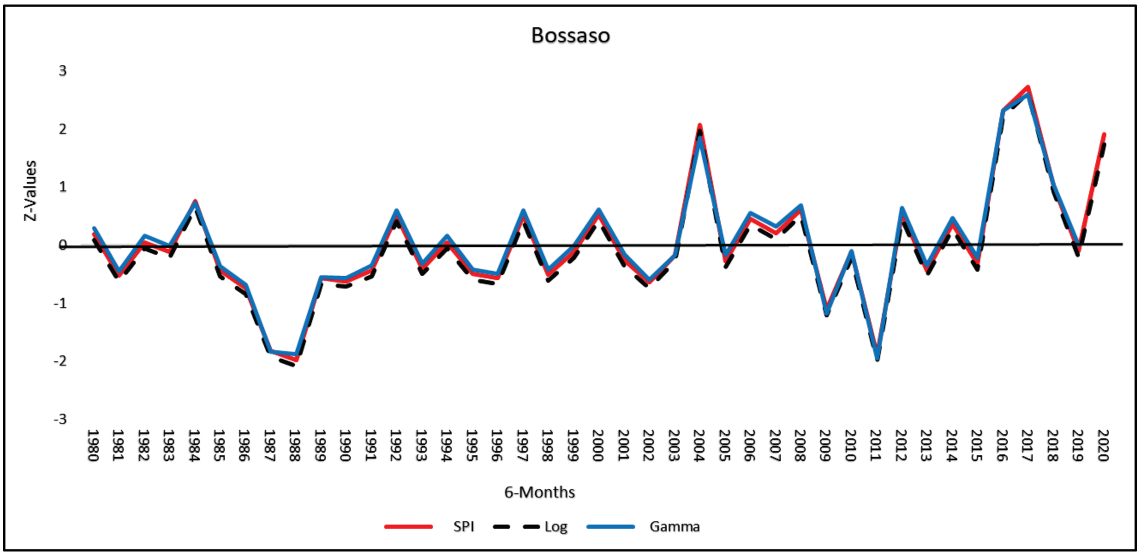


Figure 3.2. SPI results for 6-months period for Bossaso (Station 1)

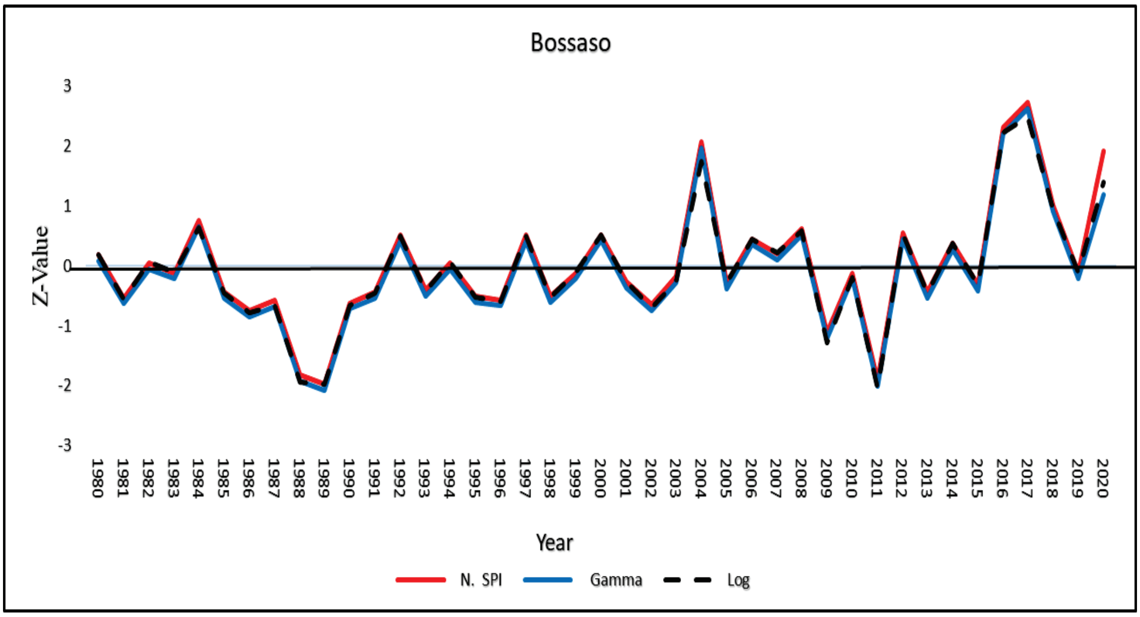


Figure 3.3. SPI results for 12-months period for Bossaso (Station 1)

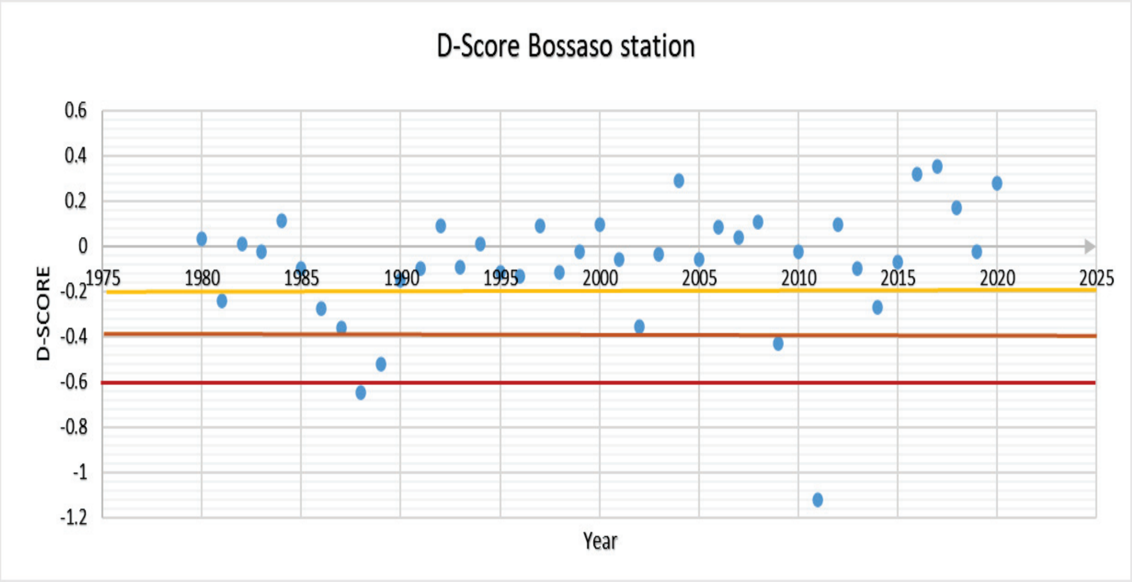


Figure 3.4. DPI results for 12-months period for Bossaso (Station 1)

4.5.2. These Results for Qardho (Station 2)

Figure 4.5-4.8 shows the results of the Normal-SPI, Log-SPI, Gamma-SPI,DPI Measurement. Deciles findings are shown in Table 4.6.As can be seen, the extreme Drought occurred in 2011 and 2008, as indicated by the Normal-SPI, Log-SPI, Gamma-SPI, and DPI. Normal-SPI and DPI both show moderate droughts, but they fall short of capturing severe droughts. In the years 2002 and 2004, the Log-SPI and Gamma-SPI captured severe Drought. Droughts in 1981, 2004, 2005, and 2010 were moderated, according to the Log-SPI and DPI. The years 2005 and 2010 were identified as moderate drought years by the Log-SPI and Gamma-SPI.

The data presented in Figures 4.1 through 4.4 demonstrate that the extreme Drought was identified in 2011, while separate drought events took place in 1988, 1989, 2009. Long dry spells were observed between the years 1986 and 1989, as well as between 2009 and 2011

Table 3.6. Deciles result for Qardho (Station 2)

Annuals Rainfall Values (mm)	Classification
96.9-168.3	Much below normal
212.6-217.3	Below normal
220.5-227.1	Near normal
234.3-258	Above normal
344.6-481.8	Much above normal

Drought conditions occur when yearly rainfall is less than 220 mm, according to deciles values in Table 4.6. When annual rainfall falls below 210 mm, severe drought conditions develop.

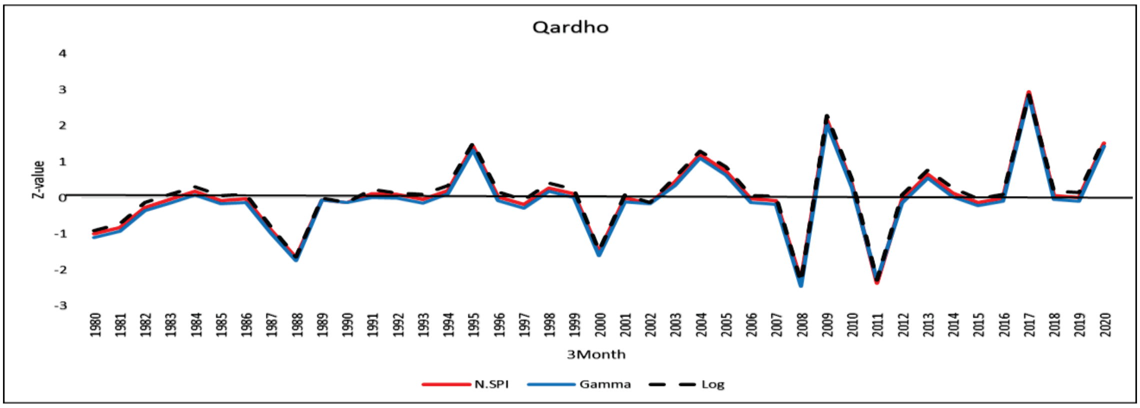


Figure 3.5. SPI results for 3-months period for Qardho (Station 2)

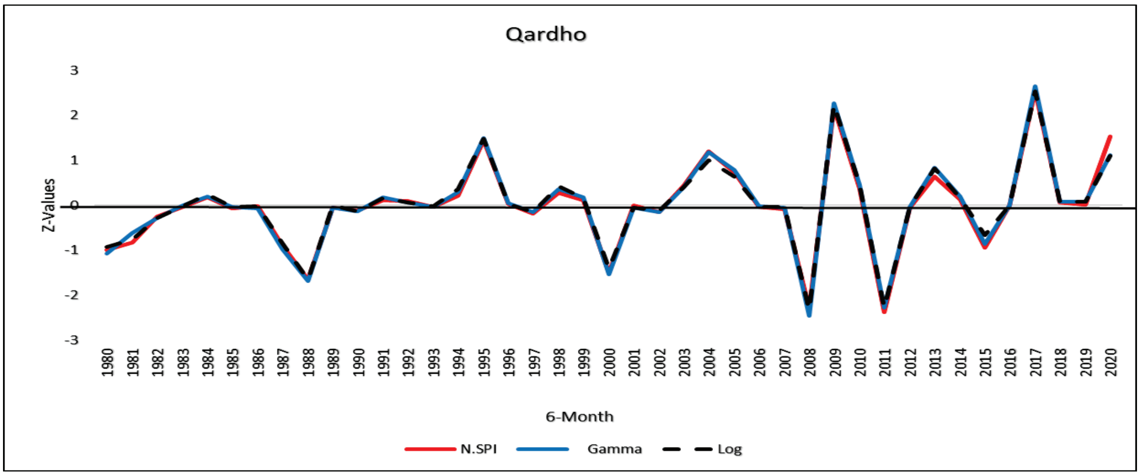


Figure 3.6. SPI results for 6-months period for Qardho (Station 2)

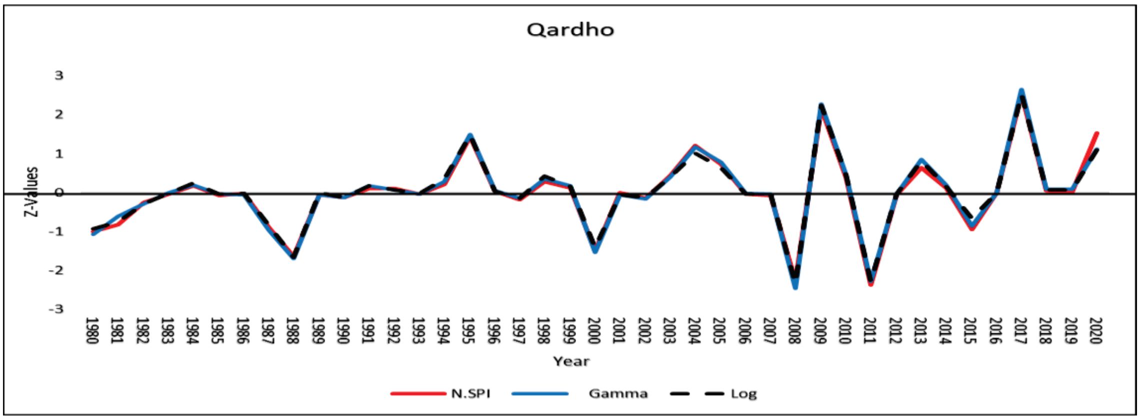


Figure 3.7. SPI results for 12-months period for Qardho (Station 2)

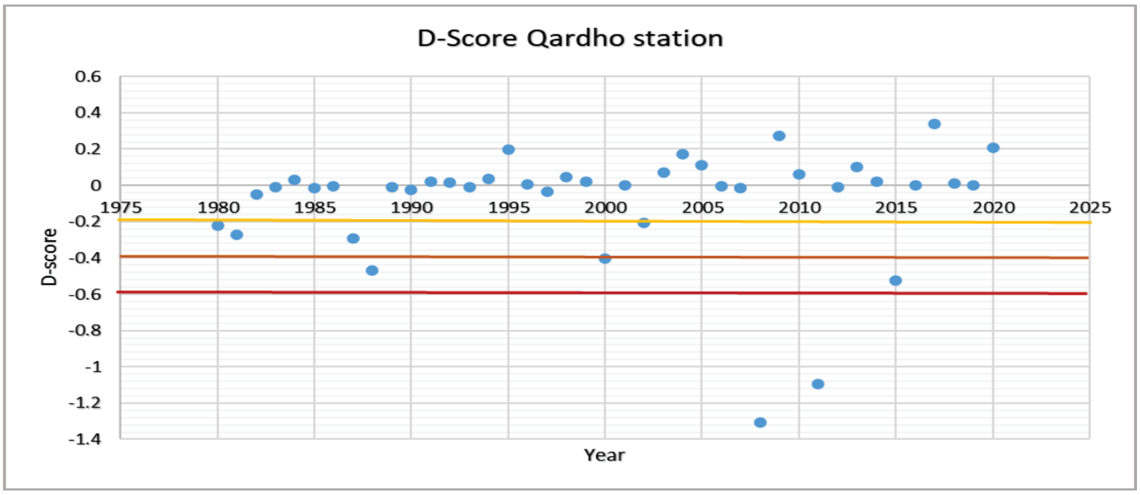


Figure 3.8. DPI results for 12-months period for Qardho (Station 2)

4.5.3. These Results for Garowe (Station 3)

The SPI,PN and DPI results are presented in Figures 4.9-4.12 for periods of 1, 3, 6, and 12 months, respectively, while Table 4.5 summarises the decile results for the Garowe station. For extreme, severe, and moderate drought intensities, the Normal-SPI, Log-SPI, Gamma-SPI, and DPI all show the same results at this station. According to the results of the four methods mentioned, the extreme Drought occurred in 2011 and 2012, severe Drought in 2015 and 2016, and moderate Drought in 1986,1987,1995,1996, and 2001.

Table 3.7. Deciles result for Garowe (Station 3)

Annuals Rainfall Values (mm)	Classification
43.7 - 136.2	Much below normal
151 - 161.4	Below normal
166 - 183.7	Near normal
208 - 243.4	Above normal
318.8 - 406.4	Much above normal

Drought conditions occur when yearly rainfall is less than 166 mm, according to deciles values in Table 4.7. When annual rainfall falls below 162 mm,and 136 This becomes severe and extreme drought condition are develop respectively.

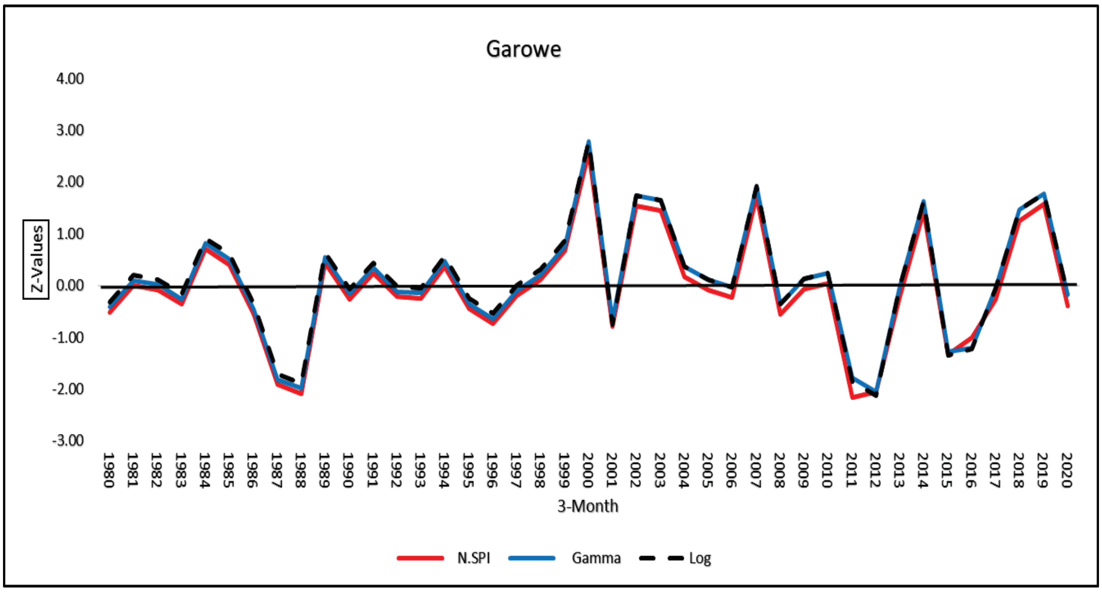


Figure 3.9. SPI results for 3-months period for Garowe (Station 3)

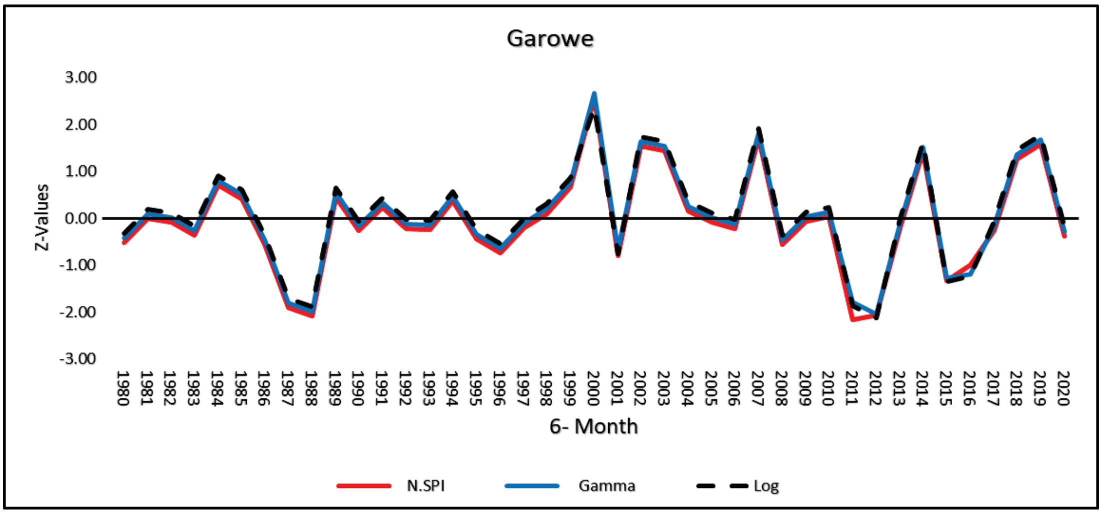


Figure 3.10. SPI results for 6-months period for Garowe (Station 3)

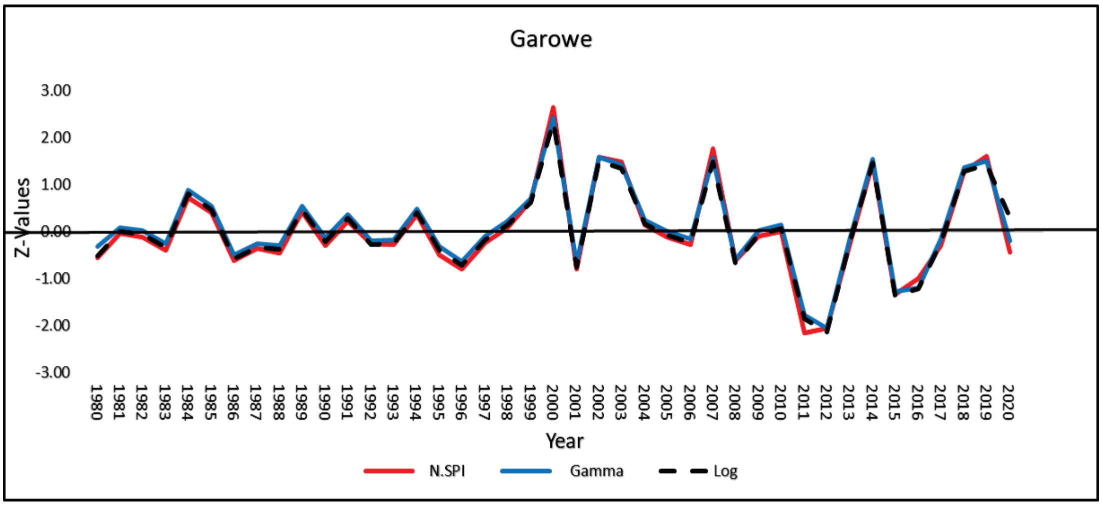


Figure 3.11. SPI results for 12-months period for Garowe (Station 3)

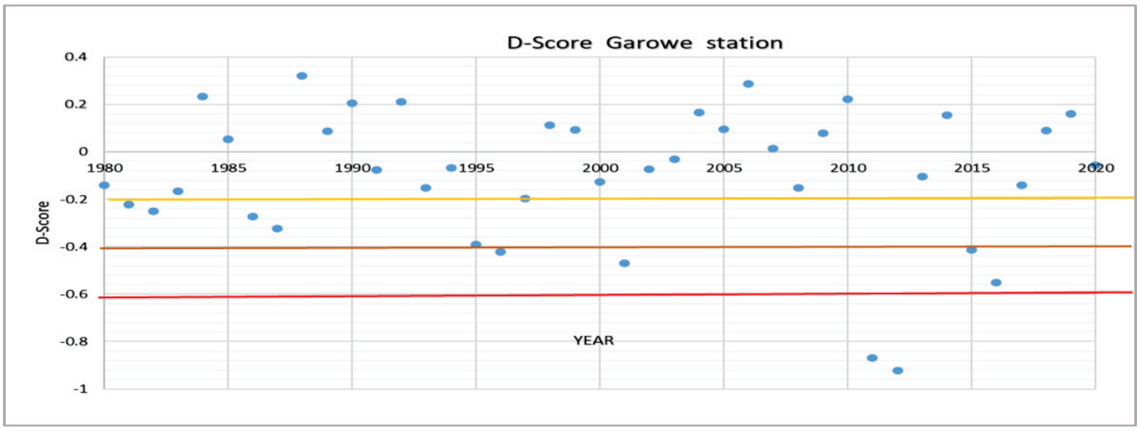


Figure 3.12. DPI results for 12-months period for Garowe (Station 3)

4.5.4. Discussions of Results

The drought intensities for the three stations are summarized in Table 4.8. The extreme, severe, and moderate drought intensities are indicated for normal-SPI, log-SPI, gamma-SPI, DPI and PN methods. The deciles approach does not include moderate drought intensities because this method only reveals extreme and severe droughts. 2011 was an extreme drought year for station one.1988,1989 was a severe drought year for station 1 according to the normal-SPI and DPI methodologies. The moderate drought years for station 1 were 1981, 1986, 1987, 2002 and 2009. According to these results, the normal-SPI and the DPI have a tendency to make underpredictions by one step regarding the severity of the Drought.

as the years of extreme Drought, the PN, log-SPI, and gamma-SPI methods predicted 2011 and 2008 as extreme drought years for station 2. Using the same methods, station two was predicted to have a severe drought year in 2015 and 2000 (Qardho). In the Garowe station, all methods indicate that 2011 and 2012 were extreme drought years, 2015 and 2016 were severe drought years, and 1986, 1987, 1995,1996 and 2001 were moderate drought years (Table 4.8).

The Drought Index techniques anticipate moderate, severe, and extreme drought years for the three locations, as shown in Table 4.8.

Table 3.8. Summary of indicated historical Drought by six DI methods

Methods	Drough intensity	Bossaso (S1)	Qardho (S2)	Garowe (S3)
Normal-SPI	Extreme	2011	2011 2008	2011 2012
	Severe	1988 1889	2015 2000	2015 2016
	Moderate	1981 1986 1987 2002 2009	1988 1987	1986 1987 1995 1996 2001
Log-SPI, Gamma-SPI	Extreme	2011	2011 2008	2011 2012
	Severe	1988 1889	2015 2000	2015 2016
	Moderate	2009 1986 1987	1988 1987	1986 1987 1995

		1981 2002		1996 2001
PN	Extreme	2011	2011 2008	2011 2012
	Severe	1988 1889	2015 2000	2015 2016
	Moderate	2009 1986 1987 1981 2002	1988 1987	1986 1987 1995 1996 2001
DPI	Extreme	2011	2011 2008	2011 2012
	Severe	1988 1889 2009	2015 2000 1988	1996 2001 2015 2016
	Moderate	1981 1986 1987 2002 2014	1980 1981 1987 2002	1982 1986 1987 1995 1996 2001
Deciles	Extreme and Severe	2011 1988 1889	2011 2008 2015 2000	2011 2012 2015 2016

CHAPTER 5

TREND ANALYSIS

5.1. Application Trend Analysis

Trend analysis is a technique for determining whether or not hydro-meteorological data is trending. It is necessary to identify the change in climate factors in order to analyze potential changes in water supplies. To analyze a major decline or increase in trend for a hydro-meteorological time series, specific approaches should be applied (Helsel and Hirsch 1992).

On the other hand, these methods should be chosen over non-parametric methods, which do not have the data set necessary to fit any distribution.

The main goal of trend analysis in this study is to view past and future changes in meteorological (precipitation and temperature) variables. The trend in precipitation and temperature time series was investigated using 41 years of meteorological records.

In order to identify trends in the time series, the Mann Kendall (MK) test, Spearman's rho (SR test), and the Şen trend test were used, as well as the Pettitt test (Pettitt, 1979) for detecting the change point in the time series. It was decided to utilize the Thiel-Sen technique to assess how much the slope in the precipitation and temperature time series had increased.

5.1.1. Spearman's Rho Test (SR test)

It is useful in environmental forensic investigations to employ Spearman's rank correlation coefficient for exploratory data analysis because it is a simple instrument. This method determines whether or not there is a trend in a data time series by analyzing the data and whether or not the trend is increasing or decreasing for the data series. In this test, the null hypothesis Ho implies that the presented data are independently and identically distributed across time. In contrast, the alternative hypothesis Ho shows a trend during the period under consideration. SR test statistics D and Z_{SR} are obtained using Eqs. 5.1 and 5.2, respectively, as shown in the following table (Shadmani et al., 2012).

$$D = \frac{6\sum_{i=0}^{n}(R(X_i)-i)^2}{n(n^2-1)} \tag{5.1}$$

$$Z_{SR} = D\sqrt{\frac{n-2}{1-D^2}} \tag{5.2}$$

Where R(Xi) is the rank of i-the observation Xi in the sample size (n). In this Test, Ho is rejected, and Ha is accepted if | Z_{SR} |> 2.08 for the 5% significance level. Positive values of Z_{SR} indicate the trending decrease, while the negative values indicate a trend decrease.

5.1.2. Mann-Kendall Test

For a given time series of data, the MK test identifies trends. The fundamental goal of the MK test is to determine whether the variable of interest has a monotonic rising or decreasing trend over time. The term "monotonic upward (downward) trend" refers to a variable that continuously rises (falls) across time. The null hypothesis H0 and the alternative hypothesis Ha relate to the non-existence and existence of a trend, respectively, in this test. (Yacoub, E., & Tayfur, G. 2019). The MK test is calculated as follows:

$$\operatorname{sgn}\left(x_i - x_j\right) = \begin{cases} 1;\ \text{IF}\ x_j > x_i \\ 0;\ \text{IF}\ x_j = xi \\ -1;\ \text{IF}\ x_j < xi \end{cases} \tag{5.3}$$

$$\mathrm{S} = \sum_{\mathrm{i}=1}^{\mathrm{n}-1} \sum_{\mathrm{j}=\mathrm{i}+1}^{\mathrm{n}} \operatorname{sgn}\left(\mathrm{x}_\mathrm{i} - \mathrm{x}_\mathrm{j}\right) \tag{5.4}$$

Where xi and xj respectively indicate the data values at times i and j, and n is the length of the data set. If the S value is positive, the variable consistently increases through time, while the negative value S indicates a decreasing trend. Equation (5.5) is used in cases where n is larger than 0.

$$\mathrm{Var}\ (S) = \frac{n(n-1)(2n+5)-\sum_{i=1}^{p} t_i(t_i-1)(2t_i+5)}{18} \tag{5.5}$$

Where p indicates the number of tied groups, ti is the number of data points in the path group. After the variance of time is provided in Eq 5.5, the standard Z can be expressed by Equ. 5.6 as follows (Yacoub, E., & Tayfur, G. 2019).

$$\mathrm{Z} = \begin{cases} \frac{\mathrm{S}-1}{\sqrt{\mathrm{Var\ (S)}}} & \mathrm{IFS} > 0 \\ 0; & \mathrm{IFS} = 0 \\ \frac{\mathrm{S}+1}{\sqrt{\mathrm{Var\ (S)}}}; & \mathrm{IFS} < 0 \end{cases} \tag{5.6}$$

The calculated Z value is compared with the standard regular distribution table with two tailed confidence levels. When |Z|>Z1−α/2, Ho is rejected, and Ha is accepted, which means there is a significant trend. Otherwise, H0 is accepted, and Ha is rejected, which means the trend is not statistically significant. 5% significant level, which refers to Z1−α/2=1.96 (from the standard regular table), was used for the M-K method in this study.

5.1.3. Şen (2012) Trend Detection Test

Sen's slope method, introduced by (Şen, Z. 2012)is used to determine the trend's linear slope. According to the Cartesian coordinate system, this method is based on dividing the data's time series into two equal halves, rating them from highest to lowest, and then plotting them against each other with the first sub-series (Xi) on the X-axis and the second sub-series (Xj) on the Y-axis, as shown in Fig. 5.1.

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

5.1.4. Thiel-Sen Approach

After the identified trend tests, this method is utilized to calculate the magnitude of the slope. To explain the Thiel-sen technique mathematically, we can use Eq. 5.7 (Shadmani et al., 2012):

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

Where Xi and Xj denote the time series' sequential data values in the years I and j. β The estimated size of the trend slope in the data time series is calculated.

5.1.5. Pettitt's Test

Pettitt's test is a non-parametric sign test based on the Mann–Whitney two-sample test (rank-based) and has a test statistic of the form. The Pettitt method frequently finds a single change-point in a hydro-meteorological series with ambiguous data. Let t be the time of the transition point for a given time series (X1, X2,..., Xn) of length n. By dividing the time series at time t, the samples X1, X2,..., Xt and Xt+1, Xt+2,..., Xn can be obtained. Ut (S.-T. Chen et al., 2009) is a test statistic that can be represented as

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

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

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

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

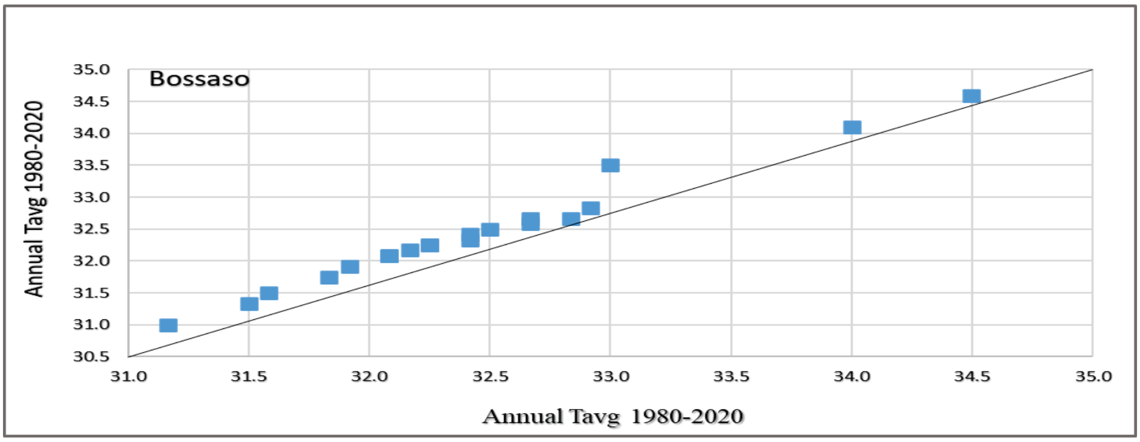
When the approximated probability exceeds (1-α), the change point considered to be a statistically significant level of α.

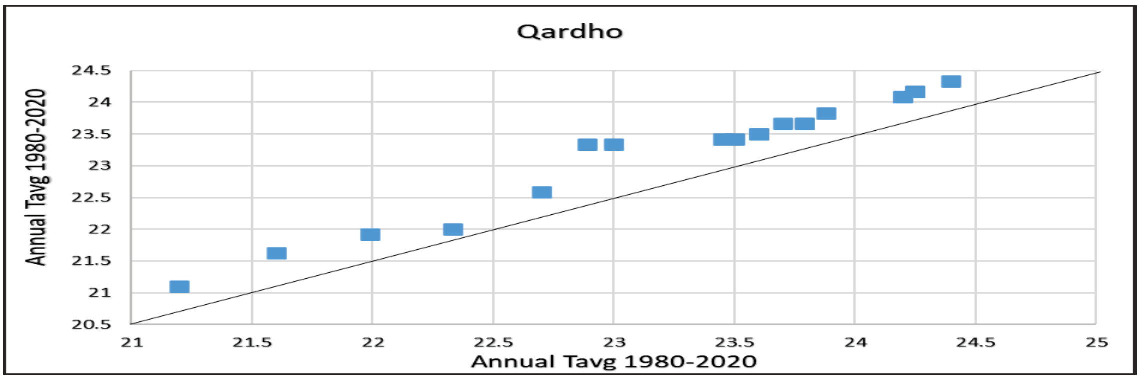
5.2. Results

5.2.1. Temperature Trends

The Mann-Kendall, Spearman's rho, Şen, Pettitt, and linear regression were used to investigate maximum, minimum, and average annual temperature trends. MK, Şen, and SR tests were used to identify trends in temperature time series, while Pettitt's test was used to detect change points. For the three study stations, almost all records show an increasing trend (Table 5.1, Figs 5.1, 5.2, 5.3).

The MK and SR tests produce the same results for the three stations; they found significant trends in the minimum and the average temperature in all of the stations, and they found significant trends in the maximum temperature at Stations 1 and 3, but they found no trend in the maximum temperature records at Station 2. These findings are displayed in Table 5.1. After the trends were identified using the MK and SR tests, the Thiel-sen method was used to estimate the magnitude of the slope (change per unit time), and the results showed that the annual average temperature increased at a rate of 0.2, 0.3, and 0.4 degrees Celsius per decade in the Bossaso, Qardho, and Garowe stations, respectively (Table 5.1). Pettitt's test for the results in all stations found that there were sudden shifts, also known as jumps, in the annual temperature's maximum, minimum, and average values (Table 5.1). The year 2000 marks the beginning of the sudden change that is observed





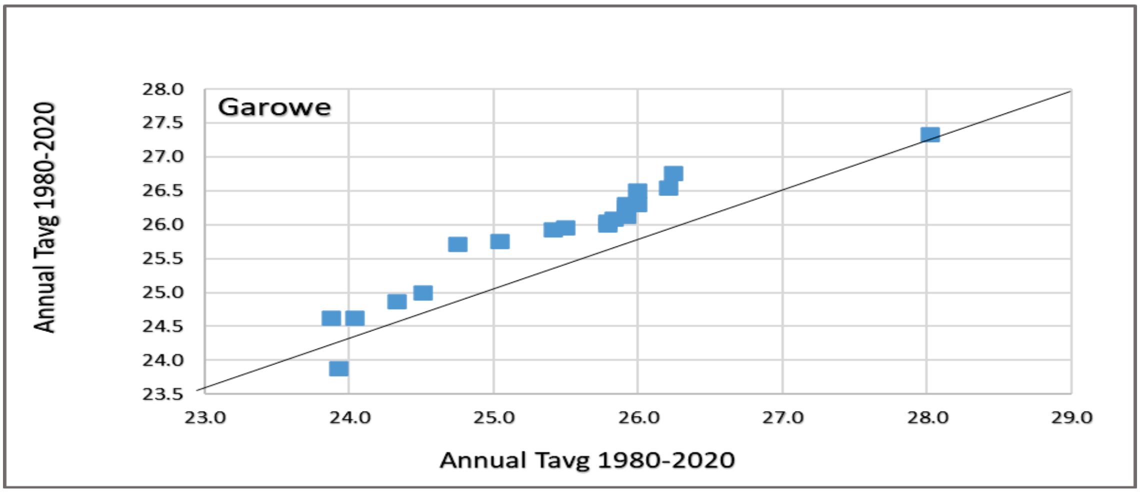
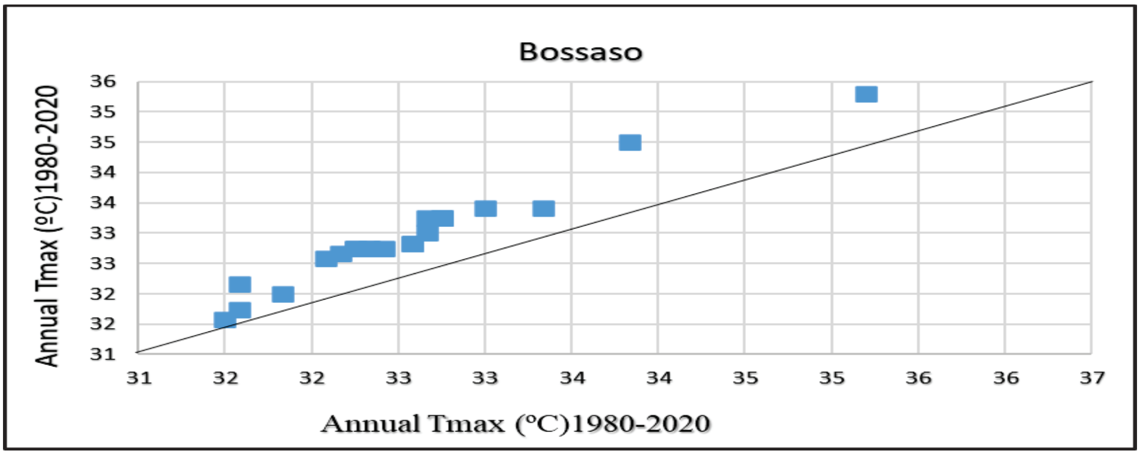
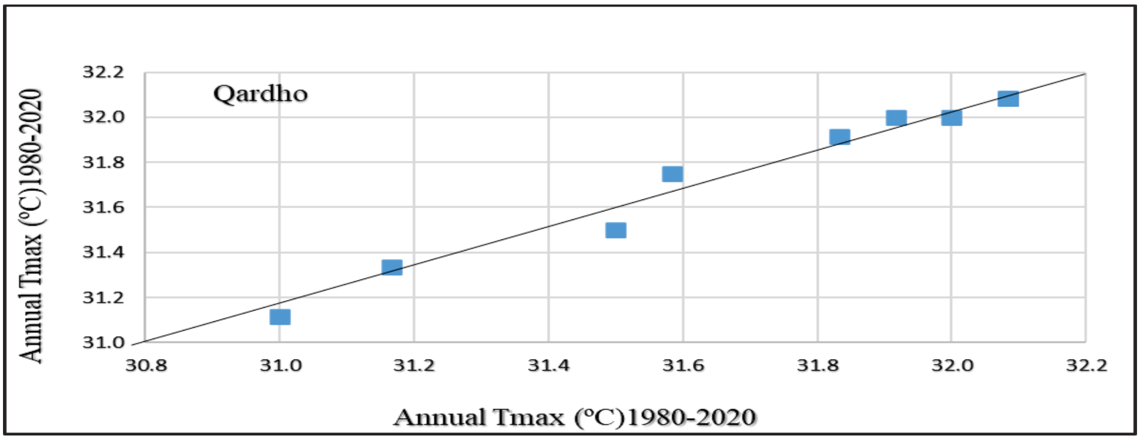


Figure 4.1. Annual Average temperature expressed as Tavg (ºC)) of Bossaso (S1), Qardho (S2) and Garowe (S3) stations, as determined by the Şen trend test





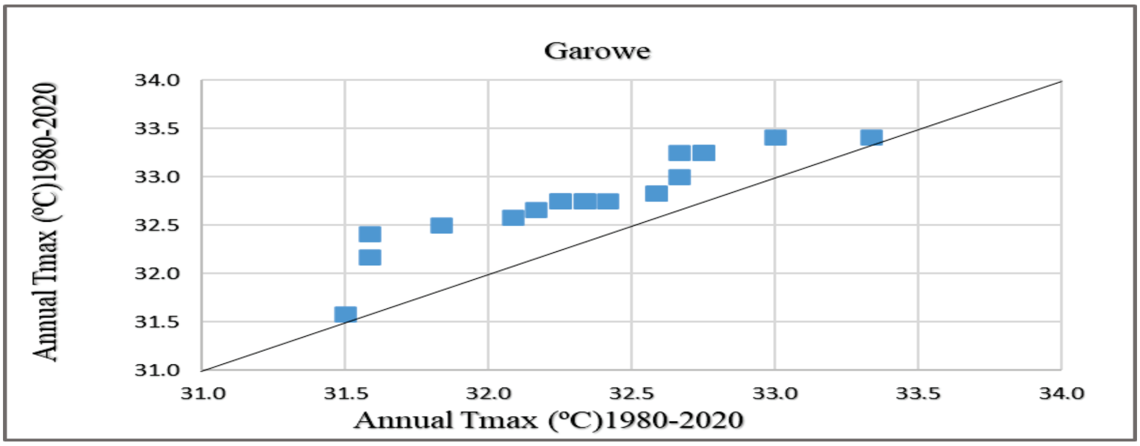
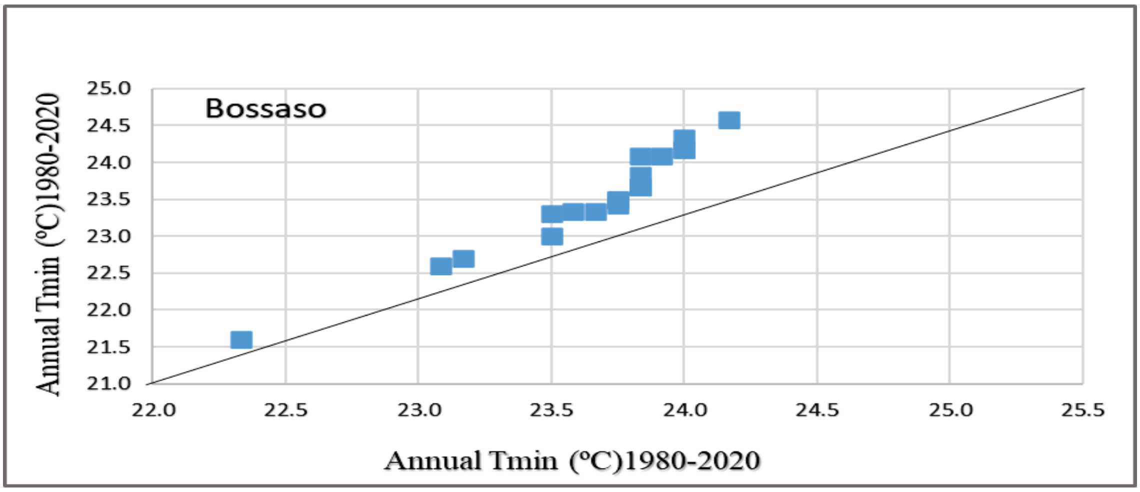
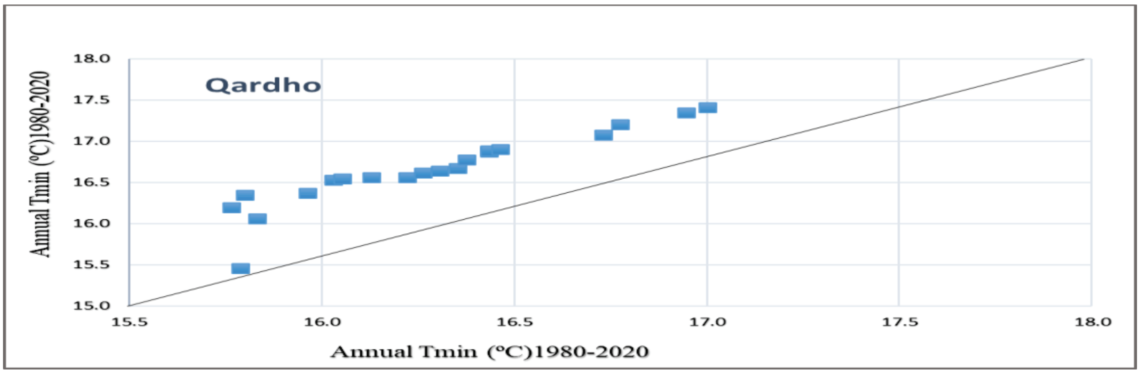


Figure 4.2. Annual maximum temperature expressed as Tmax (ºC)) of Bossaso (S1), Qardho (S2) and Garowe (S3) stations, as determined by the Şen trend test.





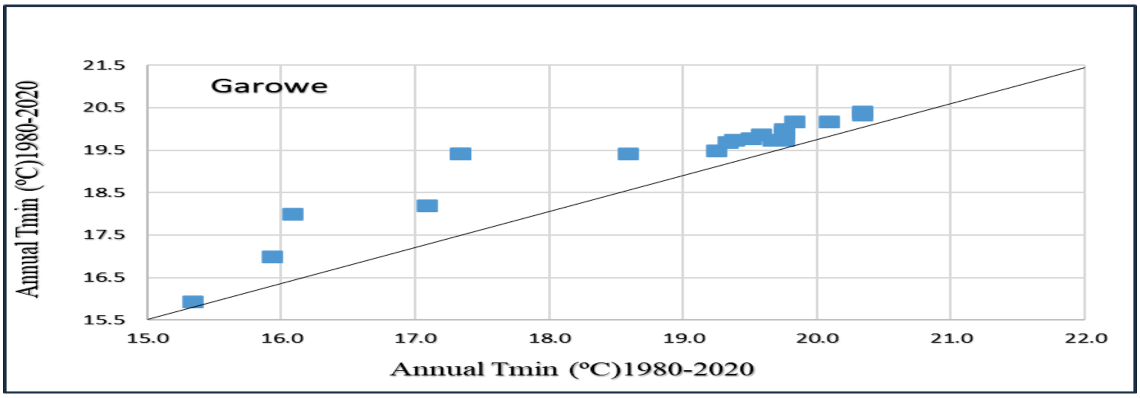


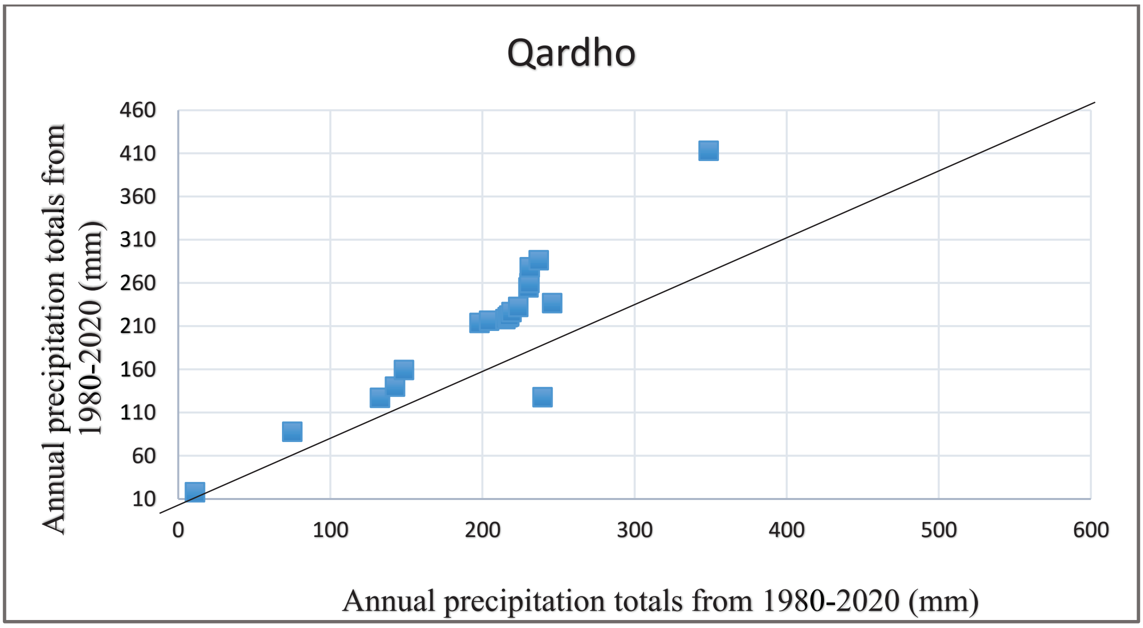
Figure 4.3. Annual minimum temperature, expressed as Tmin (ºC)),for the Bossaso (S1), Qardho,(S2) and Garowe (S3) stations, as determined by the Şen trend test

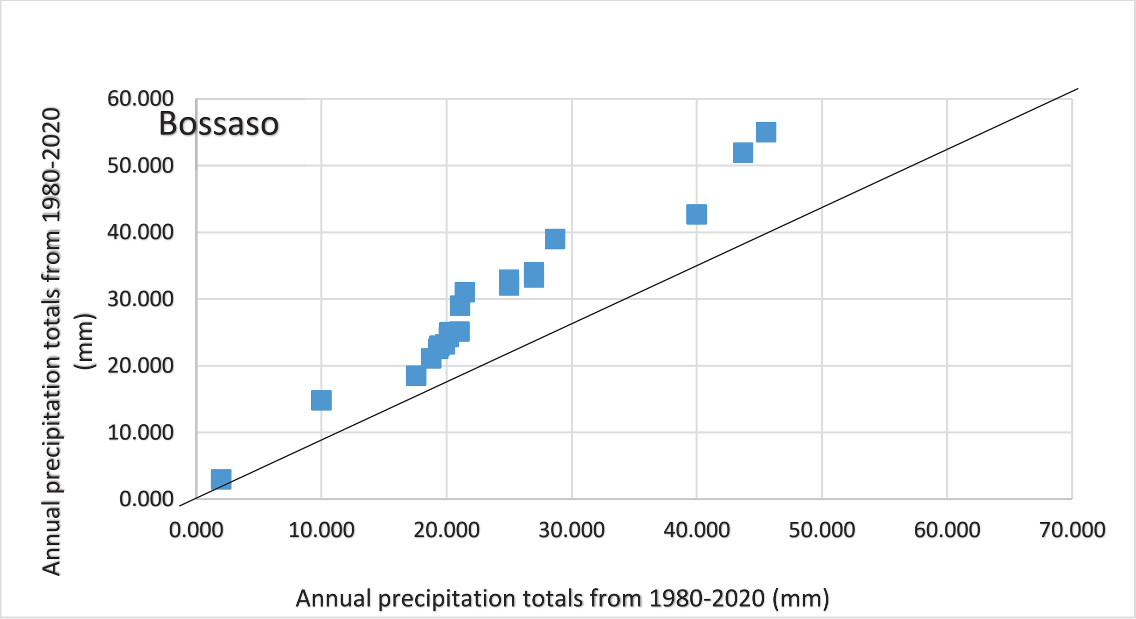
Table 4.1. Shows the results of the MK, SR, Thiel-sen, and Petites tests on Temperature analysis

Stations	Annual Temperature (ºC)	SR (Z_{SR})	MK (Z)	Trend	β(rate of increase) per decade (ºC)	Pettitt's test (changepoint)
Bossaso (station 1)	Tmax	2.6	2.45	Yes(+)	0.2	2000
	Tavg	5.27	4.22	Yes(+)	0.3	2000
	Tmin	6.11	5.17	Yes(+)	0.4	2000
Qardho (station 2)	Tmax	1.89	1.34	N0 (-)	_-	-
	Tavg	6.02	4.77	Yes(+)	0.2	2000
	Tmin	7.24	5.47	Yes(+)	0.3	2000
Garowe (station 3)	Tmax	2.71	2.52	Yes(+)	0.2	2000
	Tavg	5.67	4.5	Yes(+)	0.4	2000
	Tmin	5.15	4.29	Yes(+)	0.54	2000

5.2.2. Precipitation Trend

The annual precipitation time series was analyzed using the three rain gauge stations of Bossaso, Qardho, and Garowe. When it came to detecting precipitation trends, MK and SR both came up with the same result: significant trends (increasing) were absorbed in the Stations of Garowe and Qardho, but no trend was seen in the Station of Bossaso. The annual precipitation increase in Garowe and Qardho stations was found to be (+) 5.41 and (+) 3.67 mm per year, respectively, using the Theil sen's method figure (5.5) and (Table 5.2). shows the results. In the years 1998 and 1997, two change points were discovered in the Garowe and Qardho stations, respectively.





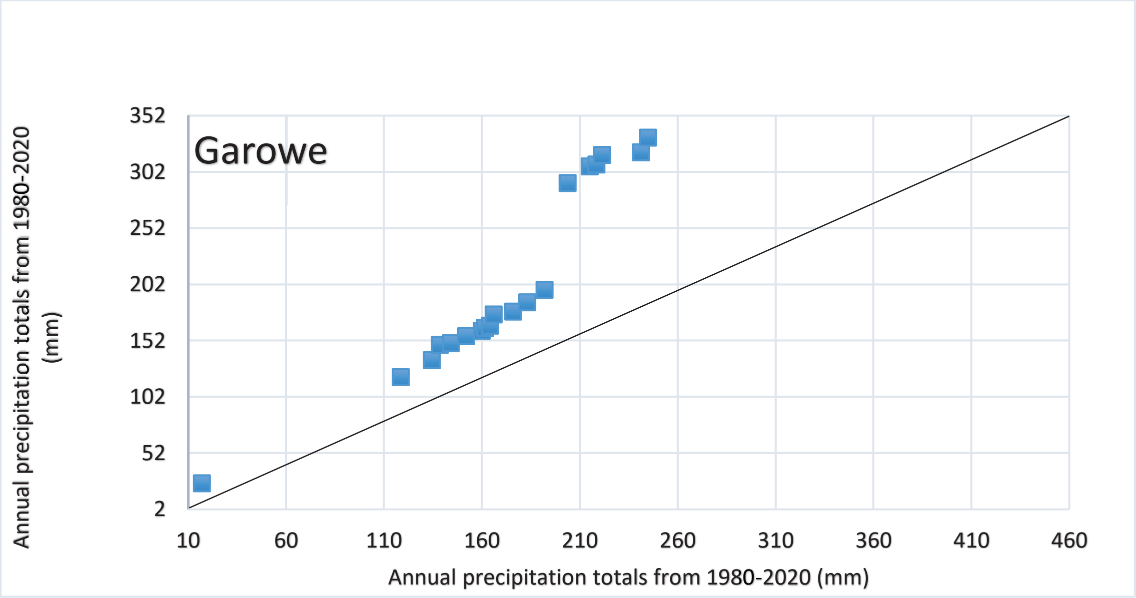


Figure 4.4. Annual rainfall by Şen trend test at Bossaso(S2), Qardho (S1), and Garowe (S3) stations.

Table 4.2. Shows the results of the MK, SR, Thiel-sen, and Petites tests on precipitation

Stations	SR (Z_{SR})	MK (Z)	Trend	β (rate of increase) per year in mm)	Pettitt's test (change point time)
Bossaso	3.43	3.12	*Yes (+)*	3.67	2000
Qardho	1.84	1.62	*NO (-)*	0.86	1998
Garowe	3.42	2.86	*Yes (+)*	5.41	1997

The Şen trend test, unlike the MK and SR tests, shows a trend in all stations where it shows a significant trend (increasing) for all values (high, medium, and low) in the same trend magnitude (slope). The low and high values in Bossaso and Qardho have weaker trend magnitude than the medium values, which have a significant trend magnitude, whereas the high values in Garowe have a stronger magnitude than the medium and low values (Fig 5.5).

5.3. Results Discussion

Temperature and precipitation trends for the North region were analyzed using various types of trend detection methods from 1980 to 2020. During the study period, there were positive trends in precipitation and temperature, according to the findings. Although all stations are experiencing slight increases in precipitation and temperature, they differ in terms of trend direction changes (slope and jumps).

The annual regional temperature time series analysis results show that temperature changes from 1980 to 2020 reflect overall warming in the region. The annual average temperature in Bossaso, Qardho, and Garowe stations increased by 0.3, 0.2, and 0.4C per decade, respectively. As shown in Table 5.1, the minimum temperatures impact the average temperature more than the maximum temperatures, with maximum values increasing at rates of 0.2 and 0.2C per decade for the stations of Bossaso, and Garowe, respectively, and no trend in the maximum temperature for the station of Qardho.

While all stations have significant positive trends in minimum temperatures, the magnitudes of the increasing trend for the stations Bossaso, Qardho, and Garowe were found to be 0.4, 0.3, and 0.54 degrees Celsius per decade, respectively. The Şen trend test revealed that the low temperatures (maximum, minimum, and average) increased more during the study period than the medium and high temperatures (1980-2021). The abrupt change in annual temperatures (maximum, minimum, and average) was detected for all stations in 2000, indicating that the region experienced a significant shift in trend direction in that year. The magnitudes were calculated for 1980-2000 and 2000-2020, and the results revealed that the average temperature rose in the first period (1980-2000) in stations 2 and 3. In contrast to stations 2 and 3, station 1 showed an increase in temperature in the last period (2000-2020) when compared to the rise in the first period (Table 5.1).

MK and SR tests on the annual precipitation time series revealed that two stations (Qardho and Garowe) have significant positive trends, while the Bossaso station has no trend. The Şen test, on the other hand, yielded different results by detecting a positive trend in the Bossaso station, but only in terms of the medium precipitation values from 1980 to 2020. The most significant positive was detected in station 3 of Garowe with a magnitude value of 5.41 mm per year, while precipitation in the station of Bossaso increased by 3.67 mm per year, according to Thiel-Sen results. In 1998, for the station of Qardho, and in 1997, for the station of Garowe, abrupt changes in annual precipitation were detected

CHAPTER 6

CONCLUSIONS RECOMMENDATION

This study investigated the performances of 6 Drought indices methods for assessing Drought and five trend tests for precipitation and temperature trends analysis in the region using historical and temperature and rainfall data collected from three stations in the Puntland region of Somalia from 1980 to 2020. The following are the conclusions reached:

1) A severe drought hit the entire East African region between July 2011 and mid-2012, described as the worst in 60 years. It had caused widespread devastation triggering a catastrophic food crisis in Somalia, Djibouti, Ethiopia, and Kenya, threatening the livelihoods of 9.5 million people in those countries.
2) Somalia has gone through extended droughts over the previous 25 years, exacerbating the humanitarian situation.
3) Several severe droughts have occurred in recent years, including 1964, 1969, 1974, 1987, 1988, 2000, 2001, 2004, 2008, 2011, 2016, and 2017.
4) Severe Drought is likely in Garowe, Bossaso, and Qardho stations when precipitation is less than162mm/year, 25 mm/year, and 220 mm/year, respectively.
5) For the drought analysis within the Puntland regions, drought indices produced nearly the same results.
6) The log-SPI and gamma-SPI produce similar results in the 3-, 6-, and 12-month drought analyses, predicting more severe drought conditions, whereas the normal-SPI and DPI methods predict more wet cases and fewer drought cases for all stations.
7) Temperature and precipitation trends for the North region were analyzed using various trend detection methods from 1980 to 2020. During the study period, there were positive trends in precipitation and temperature, according to the findings. Although all stations are experiencing slight increases in

precipitation and temperature, they differ in trend direction changes (slope and jumps).

8) The annual average temperature in Bossaso, Qardho, and Garowe stations increased by 0.3, 0.2, and 0.4^{0}C per decade, respectively.
9) The abrupt change in annual temperatures (maximum, minimum, and average) was detected for all stations in 2000, indicating that the region experienced a significant shift in trend direction in that year.
10) The precipitation time series has a positive trend detected in 2 stations (at the rate of 5.41 mm per year in Bossaso and 3.67 mm per year in Garowe), while no trend is detected in the other one (Qardho).

RECOMMENDATION

- Normal-SPI, gamma-SPI, and PN indicated less and moderate drought conditions, whereas log-SPI, DPI, and deciles accurately captured historical extreme and severe drought periods; thus, these methods are recommended for use as drought assessment tools in this region.
- Drought monitoring and early warning are critical instruments for managing crop losses, preventing famines, and lowering the danger of famine. In Somalia, there is currently no national drought monitor in place. Therefore, determining the most appropriate meteorological drought index would help authorities develop a drought monitoring system for states and the entire country.
- This technique can give decision-makers in the region a clear picture of the drought risk and allow them to take preventative steps.
- It is suggested that more research be done to assess and evaluate meteorological drought indices across the country.
- In order to reach justifiable and viable conclusions, it is critical to continue recording meteorological observations such as precipitation, temperature, humidity, wind speed, radiation, and so on.

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