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Spatiotemporal Analysis of Meteorological Drought Using Standardized Precipitation Index (SPI) in Gabiley Region, Somaliland

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Abstract

Drought is a common natural disaster worldwide, with varying durations, severity levels, and spatial extents. This study aimed to model the spatiotemporal variation of meteorological drought events in the Gabiley region of Somaliland. The study utilized primary data collected from the meteorological station in Gabiley and CHIRPS (Climate Hazards Group InfraRed Precipitation with Station) data to develop the standardized precipitation index (SPI) at a 3-month timescale. The results of the study revealed that the study area was characterized by drought and received inadequate precipitation, resulting in catastrophic droughts that negatively impacted the socioeconomic situation of the community. Mild-to-severe meteorological drought events occurred every two to three years, with the most severe droughts occurring in 1998, 2002, 2009, 2015, and 2017. Specifically, the year 2015 experienced the most severe meteorological drought in the region during the studied period. The predominant type of drought was a mild year in the study area. The SPI was found to potentially identify meteorological drought, making it a useful tool for policymakers as they develop drought adaptation and mitigation policies. This study provides valuable information that can benefit local authorities and policymakers in creating drought mitigation and adaptation strategies in the Gabiley region.

Keywords

Meteorological Drought, SPI, CHRIPS, Rainfall, Gabiley

1. Introduction

In most places of the world, droughts rank among the most severe types of natural disasters due to their diverse duration, intensity, frequency, and geographical scope (Shatanawi et al., 2013). Drought is difficult to define the onset and cessation time (Shatanawi et al., 2013). It's a slow onset, a recurrent incidence in arid and semiarid areas, and its impacts on agriculture, the environment, and socioeconomic remain for years after the cessation of the event (Gidey et al., 2018). Droughts have been caused by the failure of annual or seasonal precipitation over a long period, resulting in a water deficiency. (Belal et al., 2014; McKee et al., 1993) stated that the prolonged periods of acute water deficiency due to drought are rising at an alarming rate in world countries and one-third of the world's population lives in water-scarce areas, and approximately billions of people have access to insufficient clean drinking water.

The effect of meteorological drought is managed by the duration, frequency, magnitude, and spatial extent of the precipitation deficiency (Degefu & Bewket, 2015). The precipitation deficit at a specific time and space indicates drought magnitude. Drought magnitude is categorized as slight drought into extreme drought. Degefu & Bewket (2015) demonstrated that climate change is very likely to rise the severity of droughts in some parts of the world in the coming decades. To mitigate the impact of meteorological drought, many scholars developed drought indices that are applicable in various parts of the world (Balint et al., 2013; Sepulcre-Canto et al., 2012; Vicente-Serrano et al., 2010).

According to Gidey et al. (2018) several meteorological drought indices that are based on directly observed measurements of climatic variables including precipitation, temperature, and evapotranspiration have been established over time to assess the occurrence of meteorological drought. Based on the quality and amount of weather and climate data available, the study's objectives, computational ease, and the capacity to consistently disclose spatiotemporal changes in the incidence of meteorological drought, drought indices for monitoring should be developed (Morid et al., 2006). For observing meteorological drought events over a variety of time periods, the Standardized Precipitation Index (SPI) is a widely used index that is suitable for areas with low precipitation (Spinoni et al., 2014).

Severe droughts have affected agricultural, socioeconomic conditions and environmental conditions significantly across a variety of periods of time in semi-arid regions, including Somaliland. Droughts become more vulnerable and led to water scarcity, food shortages, population migration, and livestock mortality (Sepulcre-Canto et al., 2012; Vicente-Serrano et al., 2010). However, there are spatiotemporal variations in the incidence of drought throughout the region, it is essential to track the relative levels of drought occurrence and their distributions over a region at a time (Wang et al., 2001).

Gabiley, located in the west of Somaliland, is of particular interest due to its vital role in the economy of the country with its agricultural production in Somaliland. However, precipitation deficiency shows to be a significant constraint for the agricultural development in Gabiley. In fact, in the last years, many parts of Gabiley were mild to severe droughts which caused precipitation deficits (Abdulkadir, 2017). According to World Bank (2006), the main rainy season (April, May, and June) decreased in most areas due to El Nio in 2015, making it the worst drought in Gabiley historically. The insufficiency of seasonal precipitation bears substantial consequences on agricultural output, leading to food insecurity and socioeconomic implications for impoverished communities (Morton, 2007). The prevalence of meteorological droughts has significantly amplified as a result of extended dry periods, as reported by Wilhite (2000). In the examined region, the extended precipitation deficit has resulted in a long-term rainfall average of 550 mm and irregular precipitation patterns (Abdulkadir, 2017).

Therefore, mitigating the adverse impacts of meteorological drought needs to be monitored scientifically. As it only requires precipitation data and can be used globally on a variety of time scales, including 1, 3, 6, 9, and 12 months, the Standardized Precipitation Index (SPI) is used in this study to estimate the area of the precipitation deficit in each period. Furthermore, using a rainfall-based drought indicator like the SPI is a good strategy in areas like Somaliland where access to data is limited because of its simplicity and calculating ease. Therefore, this study's purpose is to monitor the spatiotemporal meteorological drought using the Standardized Precipitation Index (SPI) at a 3-month timescale in the Gabiley region, Somaliland.

2. Materials and Methods

2.1. Description of the Study Area

The study area is in the Gabiley region in the western part of Somaliland as shown (**Figure 1**). Geographically the study is situated from 43.02˚E to 43.9˚E longitude and from 9.01˚N to 10.02˚N latitude. The southern part has a border with Jijiga, Ethiopia. Gabiley has an estimated the number population of 146,527 UN Population Fund (2019). It has a total land area of about 4328 km^2 and has five villages namely: Arabsiyo, Agabar, Wajale, Kalabaydh, and Gabiley. These communities have a long history of cultivating crops that parallels that of the neighboring Ethiopian Somali region. Sources of livelihood for these communities include crop production, livestock, small business, and labor wages. In terms of production volume and area covered, cereal crops top the list of key food crops, and sheep and goats are the most important livestock to rear. The 37% is suitable for rainfed agriculture (Abdulkadir, 2017). The language spoken is Somali while their religion 100% has Islamic doctrine.

The altitude of the study area ranges from 361 m to 1715 m above sea level (**Figure 1**) similarly, the slope of the study area is classified as Flat at 75.5%, Gentle at 21.5%, and Steep at 3% is shown (**Figure 2**).

In terms of the slope, the majority of the Gabiley district is a flat slope in the

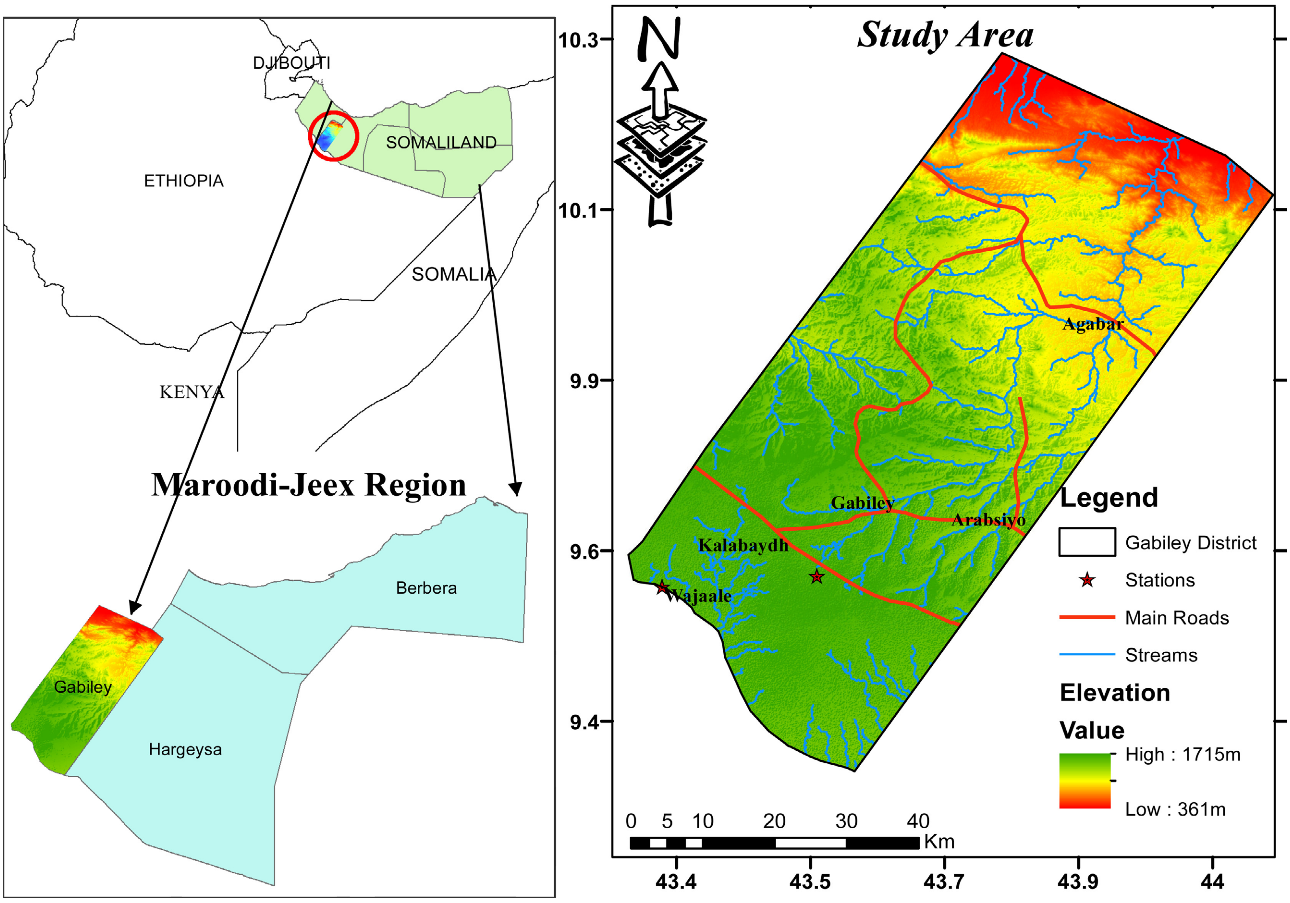

Figure 1. Location of the study area.

southwest while a small area is steep in the north. The climate zone of the Gabiley district is semi-arid (Moist) with a bimodal rainfall pattern: shorter fall (September-November) and longer spring (end of March-mid June), which leads to two harvest periods. Annual rainfall in the Gabiley district ranges from 292 mm to 568 mm and the average temperature ranges from 20˚C - 24˚C.

2.2. Data Sources

Monthly rainfall data for the period 1995-2020 were collected from the meteorological station in the Gabiley region, which is an essential input for analyzing meteorological drought occurrences and determining meteorological drought severity. However, missing values were observed in the monthly rainfall data due to malfunctions in the recording equipment and other associated issues. To address this challenge, monthly Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) precipitation data were employed at a 5 km by 5 km grid size. The CHIRPS product performs better in Africa (Funk et al., 2015) The CHIRPS satellite precipitation product, developed by the U.S. Geological Survey (USGS) and the Climate Hazards Group at the University of California, Santa Barbara (UCSB), has been found to perform better in Africa, including Somaliland (Dinku et al., 2018).

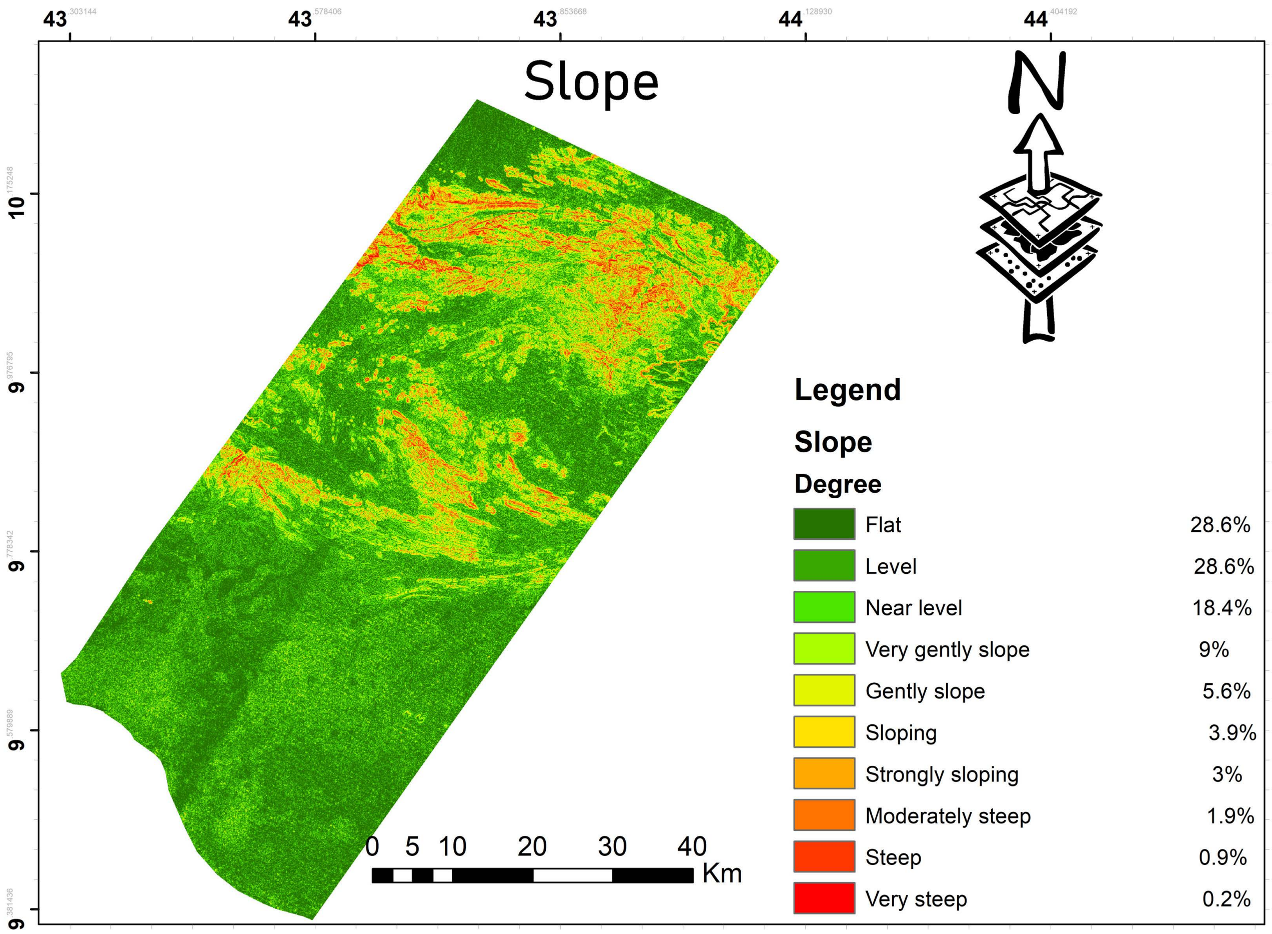

Figure 2. Slope of the area study (digital elevation model, 2018).

Although monthly CHIRPS data have been shown to be significantly more accurate in estimating East African rainfall, this research used CHIRPS data due to its higher spatial resolution and higher accuracy in the Gabiley region. A monthly time series of CHIRPS rainfall was acquired for the period 1995-2020. In this study, satellite rainfall data were used as a substitute for observational gaps at weather stations to illustrate the spatiotemporal variation of meteorological drought.

2.3. Standardized Precipitation Index (SPI)

According to the World Meteorological Organization, the Standardized Precipitation Index (SPI) indicates global weather droughts, as well as recommending that all National Meteorological Services throughout the world monitor meteorological droughts using the Standardized Precipitation Index (SPI). SPI is used to measure meteorological droughts, primarily resulting from inadequate precipitation (Liu et al., 2021). The Standardized Precipitation Index (SPI) algorithm, developed by McKee et al. (1993), was used in this study to quantify precipitation shortages at various timescales (McKee et al., 1993). In order to examine the Spatio-temporal pattern of meteorological drought events, the standardized Precipitation Index (SPI) was calculated by McKee et al. (1993). A Standardized Precipitation Index, which can be used to monitor droughts on a monthly or even long-term basis, represents the likelihood that precipitation will occur over a specific period. It is computed from CHIRPS historical spatial data utilizing monthly, seasonal, and annual precipitation data sets. The monthly rainfall data in Gabiley were arranged, and the SPI was calculated over a 3-month timescale (**Figure 3**). The use of a 3-month timescale for the SPI calculation in the present study is supported by previous research that has shown it to be a suitable timescale and is widely accepted as a standard timescale for monitoring meteorological droughts in various regions worldwide. For example, a study by Gidey et al. (2018) found that the 3-month SPI was effective in detecting meteorological droughts in Ethiopia, while McKee et al. (1993) recommended using a 3-month timescale for the calculation of the SPI in their original paper on the index. Therefore, the 3-month SPI was deemed appropriate for the study area and the objectives of the present work.

According to McKee et al. (1993), the Standardized Precipitation Index (SPI) values vary from −1 to 1 (**Table 1**). When drought stress is present, the SPI value is negative, while drought has ended, or the area is wet when the SPI value is positive, based on Equation (1).

$$\text{SPI} = \left(X_i - X_m\right)/\sigma \tag{1}$$

where X_i is the Current Rainfall, X_m is the long-term mean and σ is the standard deviation of the long-term precipitation record.

To illustrate the severity and spatial extent of the meteorological drought in the Gabiley at 3-month time scales, a model for measuring and interpreting the Standardized Precipitation Index (SPI) values was created in ArcGIS 10.8 to

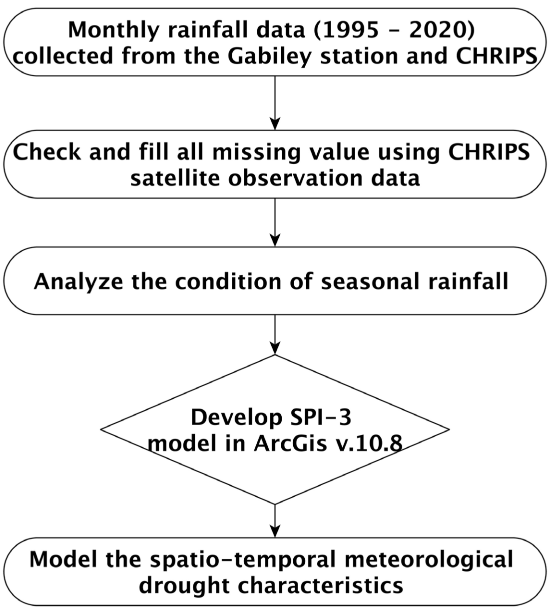

Figure 3. Schematic diagrams of the Spatio-temporal meteorological drought using SPI.

Table 1. Classification of meteorological drought by SPI (source: McKee et al., 1993).

SPI value	Drought Category
<−2.00	Extreme drought
−1.99 to −1.50	Severe drought
−1.49 to −1.00	Moderate drought
−0.99 to −0.50	Mild drought
−0.49 to 0.49	Near normal
0.50 to 0.99	Mild wet
1.00 to 1.49	Moderate wet
1.50 to 1.99	Severe wet
>2.00	Extreme wet

measure and interpret SPI values.

The SPI algorithm has been widely used to analyze meteorological droughts across the globe, including in Africa (Gidey et al., 2018; Uwimbabazi et al., 2022). In this study, the SPI was calculated over a 3-month timescale to examine the spatio-temporal pattern of meteorological drought events in Gabiley, using the CHIRPS precipitation data.

3. Results and Discussion

The results of the study revealed notable spatiotemporal variations in meteorological drought conditions at 3-month SPI interfaces in Gabiley from 1995 to 2020. The findings indicate that the region is susceptible to frequent drought occurrences, and communities that rely on rain-fed agriculture are particularly vulnerable. It was observed that different drought events occurred every two to three years on average during the 1995-2020 period.

3.1. Annual Rainfall

Figure 4 displays the annual rainfall distribution in Gabiley for the period 1995-2020. The investigation revealed that the highest amount of rainfall received in Gabiley was 568 mm, and the lowest amount of rainfall was 306 mm in the last 26 years. The driest years in Gabiley were 1998, 2009, 2015, and 2017. The Gu season, comprising April, May, and June, accounted for the most significant proportion of the annual rainfall.

The CHIRPS data indicated a substantial correlation with the ground station data, and there were no significant outliers. This study utilized CHIRPS data to compute SPI, explaining its significant association with rainfall observations. The scatter plot of ground and satellite products and the correlation of the fitness line (0.898) are depicted in **Figure 5**.

3.2. Meteorological Drought Monitoring Using (SPI)

In this study, the Standardized Precipitation Index (SPI) was employed to analyze

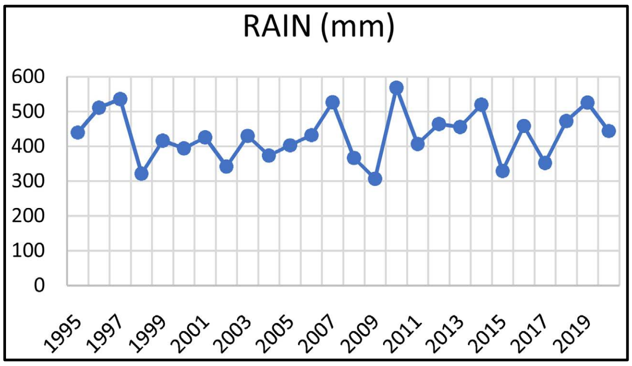

Figure 4. Annual time series rainfall distribution.

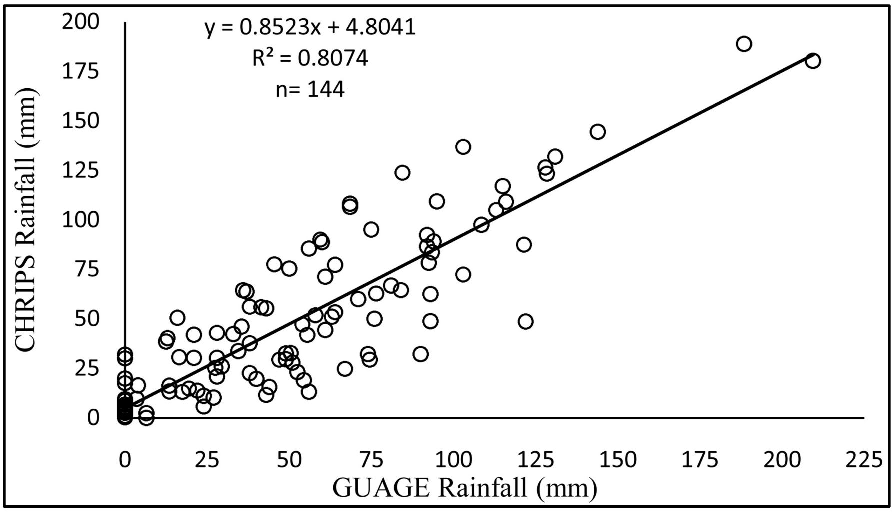

Figure 5. Linear correlation of Gauge station with the CHIRPS Rainfall.

the spatial-temporal pattern of meteorological drought in Gabiley, using rainfall data from 1995 to 2020 at a three-month time scale. The SPI values varied from year to year, and negative values indicated drought occurrences while positive values indicated the end of the drought in **Figure 6**. The results showed that severe droughts occurred in the years 1998, 2002, 2009, 2015, and 2017, with precipitation deficits and the worst dry seasons, and in 2011 and 2020 were moderate droughts in Gabiley. In contrast, the years 1996, 2001, 2007, and 2010 were wet periods and were free of drought incidents. The study also revealed that mild droughts were the most dominant drought category in the study area during the analyzed period.

The spatial patterns of SPI for drought years and wet years are analyzed and reclassified in **Figure 7** to demonstrate spatial trends in drought.

This study examined the spatial-temporal patterns of meteorological drought in the Gabiley region of Somaliland using the Standardized Precipitation Index [SPI] at a three-month time scale from 1995 to 2020. The findings revealed that the Gabiley region is prone to frequent droughts, which have severe consequences on agriculture, food security, and livelihoods. The Standardized Precipitation Index [SPI] shows that the year 2015 was recognized as a more severe

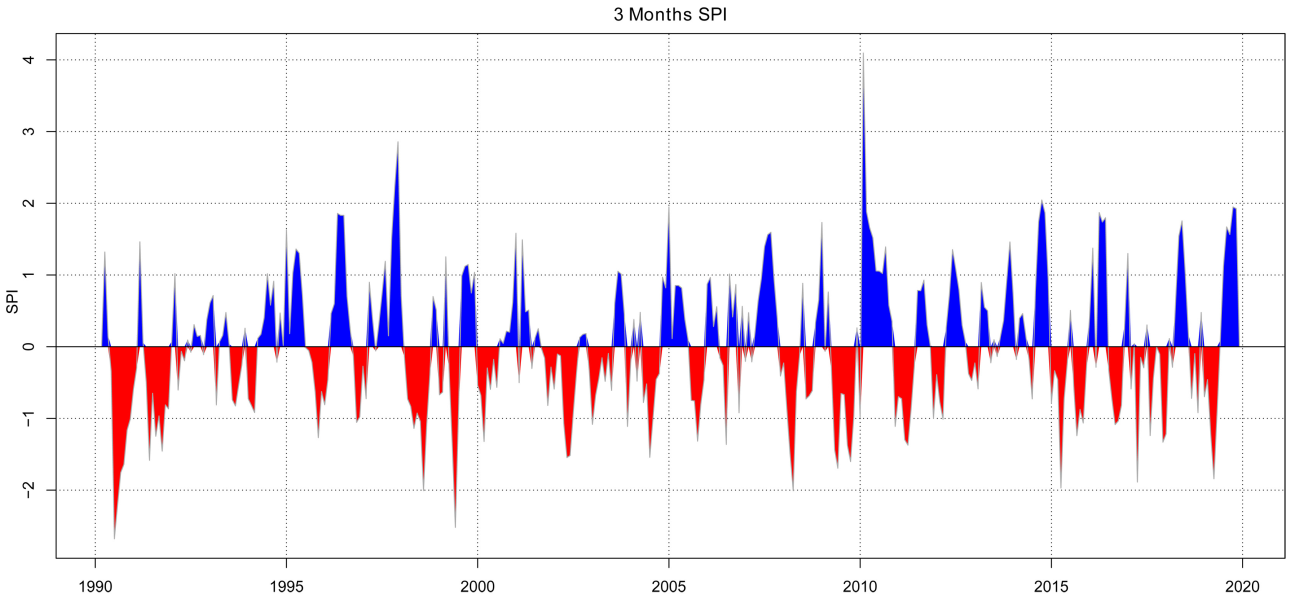

Figure 6. Meteorological drought condition in the Gabiley based on SPI-3.

historical drought than other drought events in comparison with other historical droughts, and the drought occurred within a spatial area of 4056 km^2 shown (**Table 2**).

The severe droughts that occurred in 2015 led to acute food shortages, the death of thousands of livestock, and the undernourishment of many children. Lack of rainfall was identified as the primary cause of drought in the region, exacerbated by the absence of effective drought mitigation policies and measures.

Furthermore, the impact of drought in Gabiley has been severe in terms of social, economic, and environmental consequences. Drought has led to the displacement of people and migration to neighboring regions in search of water and pasture, leading to overcrowding and competition over scarce resources. The disruption of agricultural activities has resulted in the loss of income and livelihoods, leading to poverty and unemployment. Moreover, drought has also contributed to the degradation of natural resources and the environment, as people resort to unsustainable practices such as overgrazing and deforestation in search of resources. Therefore, the impact of drought in Gabiley has been multifaceted, affecting various aspects of society and the environment. The findings of this study emphasize the need for effective drought management strategies and policies that can mitigate the impact of drought and enhance the resilience of communities to cope with future drought events.

The results of this study on meteorological drought monitoring using SPI-3 in Gabiley, Somaliland, are consistent with several recent studies on drought monitoring in other parts of Africa using the same approach. For instance, Abdullahi (2014) analyzed drought in Gabiley and found that droughts occurred regularly and had severe impacts on the region's agriculture and livelihoods. Similarly, Abdulkadir (2017) examined the spatiotemporal trends and variability of

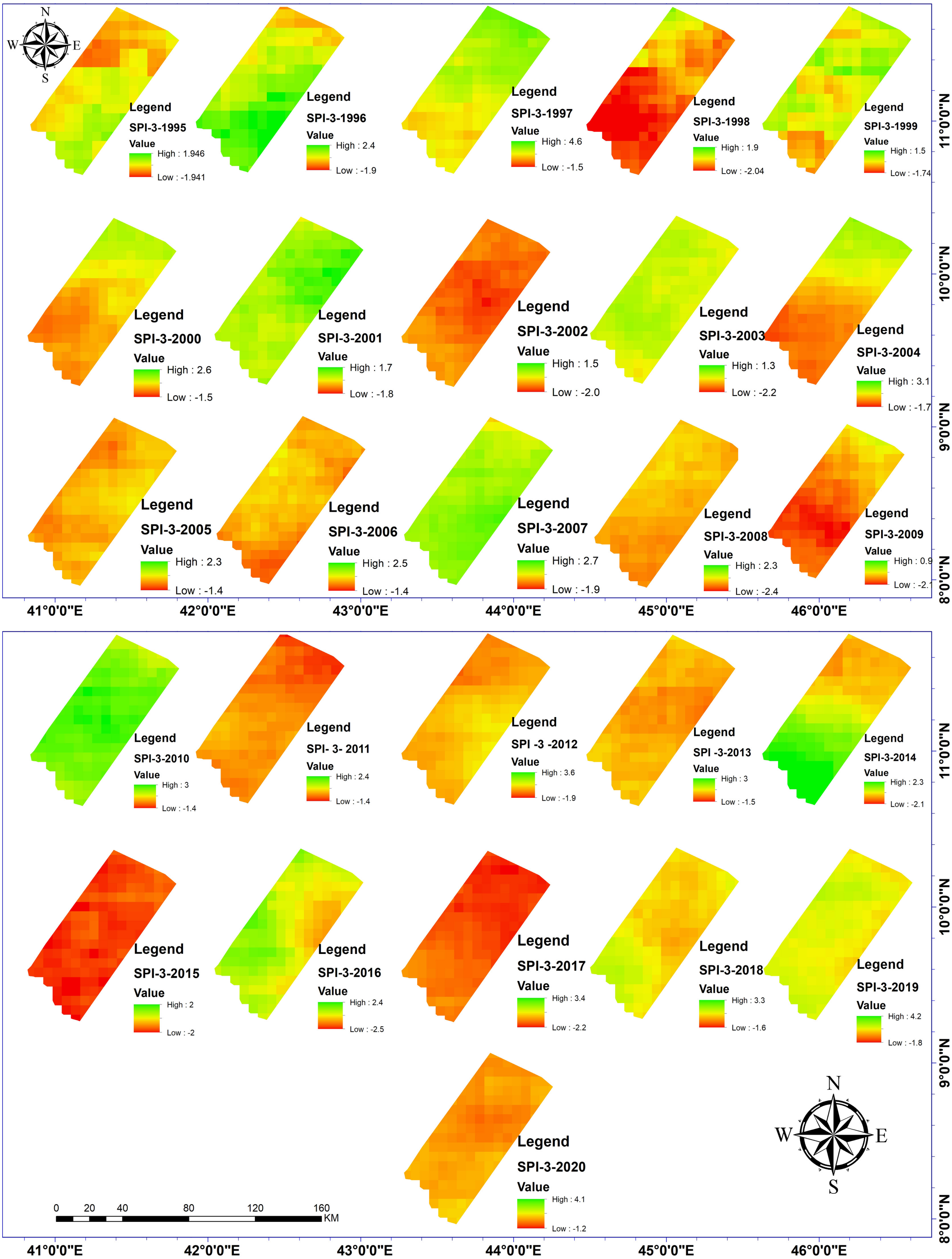

Figure 7. A Spatio-temporal meteorological drought condition in the Gabiley from 1995 to 2020.

Table 2. Drought years and spatial extent in gabiley region.

Drought Years	Area Affected (square kilometers)
1998	3102
2002	3452
2009	3071
2011	2700
2015	4056
2017	3996
2020	2411

droughts over Somaliland using SPI and found that the region experienced frequent and severe droughts. Previous studies using SPI-3 in African countries have also highlighted the adverse impacts of drought on agriculture, food security, and water resources. For instance, Kalisa et al. (2020) conducted a spatiotemporal analysis of drought and return periods from 1920 to 2016 in the East African region. The researchers assessed meteorological droughts using precipitation data from the Climate Research Unit (CRU) using the Standardized Precipitation Index (SPI). Over the study period, significant variations in drought magnitudes were observed throughout the region, as well as an increase in drought severity. Similarly, in Ethiopia, Shalishe et al. (2022) found that the severity of drought increased over the years, with SPI-3 values indicating that more than 80% of the country was affected by drought. Drought has had severe impacts on the country's water resources and food security, resulting in increased poverty and malnutrition. Gidey et al. (2018) analyzed drought patterns in Ethiopia using SPI-3 and found that the country experienced recurrent droughts, particularly in the eastern and southern regions. Onyango (2014) used SPI-3 to analyze drought patterns in Kenya and found that the country experienced frequent and severe droughts, particularly in the northern and northeastern regions. Overall, the results of this study on meteorological drought monitoring using SPI-3 in Gabiley, Somaliland, are consistent with recent studies in other parts of Africa. The findings suggest that meteorological droughts are a recurrent and severe problem in the regions, with significant impacts on agriculture, food security, and livelihoods, particularly in regions that are heavily dependent on rain-fed agriculture or natural water sources.

4. Conclusion

This study highlights the significant impact of meteorological drought on the Gabiley region between 1995 and 2020. The use of the Standardized Precipitation Index (SPI) provided valuable insights into the severity and spatial extent of meteorological drought in the region. The findings reveal that the study area experienced frequent and severe droughts over the last 26 years, with the years 1998, 2002, 2009, 2015, and 2017 being the most severe. The severity and spatial extent of meteorological droughts have changed significantly over the study period. The results indicate that the SPI is an effective index for monitoring meteorological droughts, both locally and globally. The ongoing severe drought in the research area is expected to persist, calling for enhanced monitoring, mitigation, and adaptation strategies to alleviate the negative impacts on communities and agriculture. The study findings could provide policymakers to develop policies and programs that support sustainable development, improve preparedness and response measures, and increase the availability of water resources. By working together with communities and other stakeholders, policymakers can help reduce the impact of drought on agriculture, food security, and livelihoods and ultimately save lives. For instance, the study findings may be used to promote rainwater harvesting as a viable and sustainable water management practice, which can significantly reduce the vulnerability of communities to drought and improve their resilience to climate change.

Conflicts of Interest

The authors of this paper hereby declare that there are no conflicts of interest that may influence the publication of this manuscript.

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