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Original Article

Drought Analysis in Somalia Using GIS - Based on Reconnaissance Drought Index (RDI) and Standardized Precipitation Index (SPI)

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ABSTRACT

As a result of climate change, Somalia has experienced severe droughts in recent decades because Somalia is a water-scarce country in East Africa with arid and semi-arid environments. In this study, drought in Somalia from 2010 to 2021 was investigated. For this purpose, the agroclimatological data consisting of precipitation, air temperature, and potential evapotranspiration (ETp) were obtained and calculated in DrinC software. The Reconnaissance Drought Index (RDI) and Standardized Precipitation Index (SPI) were used as meteorologically based to measure drought severity and analyse the variability of drought events in Somalia during the last decade. Most years experienced rainfall deficits and severe drought in the study area, but the worst years were 2010-2011 and 2016-2017. The results of the RDI and SPI variations showed that drought was most severe in 2016-2017 and 2010-2011, with the south-eastern region being the most severely affected. The results of this analysis should provide valuable guidance to future scientists, researchers, and national managers researching this topic.

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INTRODUCTION

Drought is one of the most complex natural disasters with serious consequences for human activities and the environment (Tigkas et al., 2013). Its cause and the extent of its development are difficult to determine (Aadhar & Mishra, 2017). Drought generally results in significant water shortages due to inadequate rainfall, high evaporation, exploitation of water resources, or a combination of all these factors (Sheffield & Wood, 2008). Lack of rainfall over a long period of time leads to drought (Fadhil, 2011). Drought can negatively affect soil moisture, groundwater, rivers, ecosystems, and human activities depending on the duration and severity of the precipitation deficiency (Smakhtin & Hughes, 2004; Al-Quraishi et al., 2021).

The effects of global warming are being felt in many parts of the world as temperatures have risen and precipitation has decreased (Yu et al., 2019). The consequences of this climate change could be more frequent and severe droughts in many countries (Al-Quraishi et al., 2020). Due to its arid or semi-arid environment, low annual rainfall, improper land use practices, overgrazing and deforestation, and heavy reliance on agriculture as a source of income, Somalia is highly sensitive to the effects of drought due to its impaired ability to withstand dry periods. In addition, half of the population lives off pasture, which depends on rainfall and temperature (Metz, 1992). Thus, drought occurs when the primary rainy season fails in a given year, resulting in a sharp decline in the pasture, vegetation, and agricultural production. The population is also displaced, starves, becomes unemployed, and migrates to other cities and neighbouring countries (UNCCD, 2020). According to Kundell (2008), Somalia experiences moderate droughts every three to four years and severe droughts every seven to nine years.

Monitoring and forecasting droughts are becoming increasingly important as the consequences of droughts become more severe. Indicators have been developed to detect and monitor the onset, duration, and intensity of droughts. These data can be used by decision-makers to minimize and mitigate drought-related impacts (Mishra & Singh, 2010). Drought calculations should consider the long-term average of the balance between precipitation and evapotranspiration (ET) in a region. The frequency, magnitude, intensity, and duration of a drought can be used to define it (Kapluhan, 2013).

Drought indices are useful for characterizing and monitoring droughts because they quantify the severity, duration, and frequency of climatic anomalies. This is accomplished by simplifying complicated meteorological functions. In addition, they provide easily understandable information on drought severity to a wider audience (Tsakiris et al., 2007).

The drought index is difficult to calculate because it takes time; alternatively, programs can be used that can calculate it faster and more correctly. DrinC is the most important of these programs. A primary goal of DrinC is to provide an easy-to-use tool for calculating various drought indices, including the Reconnaissance Drought Index (RDI) and the

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Standardized Precipitation Index (SPI). Few data are required to calculate the selected indices, and the results are easy to understand and apply for operational and strategic planning. For each case study, many alternatives to describe drought can be included in the calculation process, performed through a windows-based interface. DrinC is also used to calculate potential evapotranspiration (ETp) using temperature-based methods (Tigkas et al., 2013).

Studies by Pashiardis and Michaelides (2008); Borg (2009) have contributed significantly to our understanding of DrinC; however, none of the studies have adequately assessed the severity of droughts in Somalia. To fill this information gap, in this study, we aim to analyse and evaluate the frequency, duration, and severity of droughts that have affected Somalia over the past decades.

MATERIALS AND METHODS

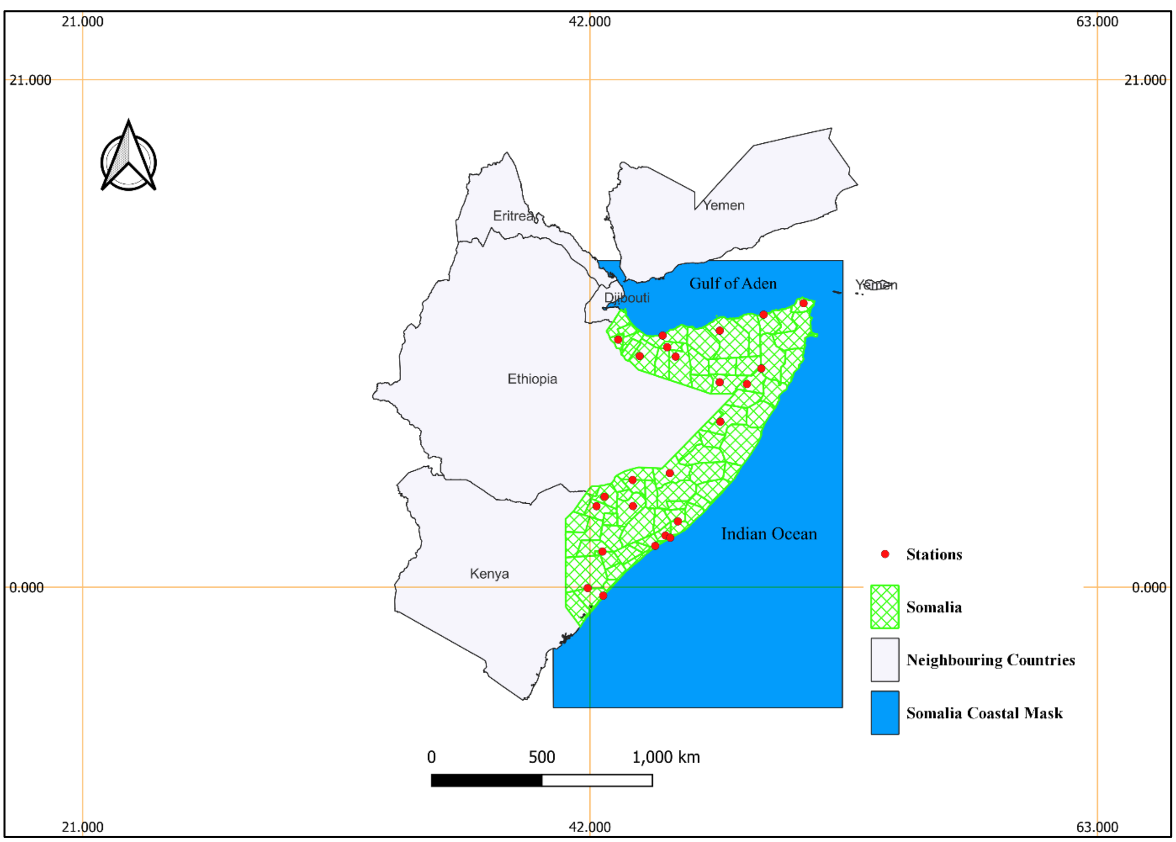
Study Area

This research was conducted in Somalia, in the horn of Africa (*Figure 1*), a region in East Africa. The research region is bounded by Ethiopia to the west and enclosed by the Red Sea, Gulf of Aden, and the Indian Ocean to the north and east, Kenya to the southwest, and Djibouti to the Northwest. Somalia has an area of 637103 km^2 and is divided into 18 regions.

Data Collection

Monthly precipitation (P), maximum temperature (T_{max}), and minimum temperature (T_{min}) records from 25 meteorological stations from 2010 to 2021 were downloaded from the National Aeronautics and Space Administration power data access viewer (NASA) (https://power.larc.nasa.gov/).

Figure 1: Study area location and spatial distribution of climate stations



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Drought Indices

Reconnaissance Drought Index (RDI)

The severity of a drought can be determined using the Reconnaissance Drought Index (RDI), with the standard version providing more accurate results (RDIst). For the input-output balance of a water system, the RDI was developed to solve the water deficit (Tsakiris and Vangelis, 2005; Tsakiris et al., 2007). Cumulative P (a measured determinant) and ET_p (an estimated determinant) form the basis of the RDI. However, the calculation method ET_p does not affect the RDI results (Vangelis et al., 2013). To calculate the baseline (k) RDI for the ith year, the following formula is used:

$$\propto_{k}^{(i)} \frac{\sum_{j=1}^{k} P_{ij}}{\sum_{j=1}^{k} ETp_{ij}}, \quad i=1(1) \quad N \quad and \quad j= \quad 1(1) \quad =k \tag{1}$$

Where N is the total number of years for which data are available, P_{ij} and $ET_{p\text{-}ij}$ are the precipitation and potential evapotranspiration for the jth month of the ith year. They were evaluated at different locations and time scales, and the values of k sufficiently follow the lognormal and gamma distributions (Tigkas, 2008; Tsakiris et al., 2008).

An RDI is determined for a hydrologic year using reference periods of 3, 6, 9, and 12 months. The RDI differs from previous drought indices in that it is developed for specific reference periods rather than as a "rolling" index of continuous duration.

Standardized Precipitation Index (SPI)

The SPI was developed by McKee et al. (1993) as a "versatile instrument in drought monitoring and analysis tool" and has been used ever since. A long-term precipitation record for the appropriate period is essential for the SPI calculation at each site. A probability distribution is fitted to this long-term data, which is then transformed into a normal distribution to test whether the mean SPI is zero (Edwards & McKee, 1997). A positive SPI means precipitation is above or below the median, and a negative number means the opposite. When the SPI is modified, wet and dry regions can be represented similarly. The SPI can measure the severity of not only drought periods but also wet periods. Thom (1958) discovered the gamma distribution, which he believed was well suited for climatological P data. The frequency or probability density function of the Gamma distribution is as follows:

$$g(x) = \frac{1}{\beta^{a}\,\tau(a)} x^{a-1} \varrho^{-x/\beta}, for\ x > 0 \tag{2}$$

Where x is the amount of P, a and β are the shape and dimension parameters, respectively, and gamma τ (a) is the gamma function. For each station and relevant time scale, the gamma parameters a and β are computed (1, 3, 6, 9, 12 months, etc.). A and β's maximum likelihood estimates are:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right), \beta = \frac{\bar{X}}{a}, \text{ Where } A = \ln(\overline{X}) - \frac{\sum \ln(x)}{n} \tag{3}$$

Based on n observations, the cumulative probability of observed precipitation events is calculated for the given location and month for the derived parameters. As precipitation distributions can contain zeros and gamma function for x = 0 is under, the cumulative probability is as follows;

$$H(X) = q + (1 - q)G(x) \tag{4}$$

Where G(x) is the cumulative probability of the incomplete gamma function, and q is the probability of no precipitation. If m is the total number of zeros in a time series of precipitation, m/n can be used to calculate q. The conventional normal random variable z with a mean of zero and a variance of one (Abramowitz & Stegun, 1965) is then transformed from the cumulative probability H(x) to give the SPI.

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The SPI identifies a situation as a drought event if the index continuously falls below 1.0. If the SPI is positive, the event is complete. The beginning, end, and severity of each month in which a drought event persists thus define the duration of the event. To calculate the severity of the drought, the SPI is summed for each event month (Hayes et al., 2007).

Table 1: Classification of drought conditions according to the RDI and SPI

SPI values	Classification
2.0+	Extremely Wet
1.5 to 1.99	Very Wet
1.0 to 1.49	Moderately Wet
-0.99 to 0.99	Near Normal
-1.0 to -1.49	Moderately Dry
-1.5 to -1.99	Severely Dry
-2 and less	Extremely Dry

Source: (Barua et al., 2010).

DrinC Software Interface

DrinC is a graphical user interface (GUI) program for Microsoft Windows. Simplicity, comprehensiveness, and user-friendliness were emphasized in creating the software package. Several additional options are available for each function in the software's main menu. As can be seen in *Table 2*, each index requires a different set of input data to be calculated. It is possible to import data directly from MS Excel files through a manual or automatic process. There is the option of using monthly or annual data and real (up to 150 years) or synthetic data (up to 1500 years) series. It is also possible to convert insufficient precipitation data into suitable precipitation data. (Tigkas, 2008; Tsakiris et al., 2008).

Table 2: Required input data for each index.

Index	Required input data
RDI	P and ETp (or temperature)
SPI	P

***ET$_p$* Calculation**

DrinC supports Hargreaves and Samani's temperature-based calculation of ETp. Data on the minimum and maximum temperatures are needed for this procedure.

Drought Indices Calculation

When calculating drought indices using an adaptive method (Tsakiris et al., 2007), the user can select the parameters that best fit the needs or objectives of the particular study. It is also possible to calculate drought indices sequentially for each month and provide results either per month or per period to directly compare the severity of different droughts throughout the year. DrinC uses the primary reference period for the hydrologic year (October to September). Consequently, the essential time steps are monthly, three months, six months, and one year, and the default calculation period begins in October.

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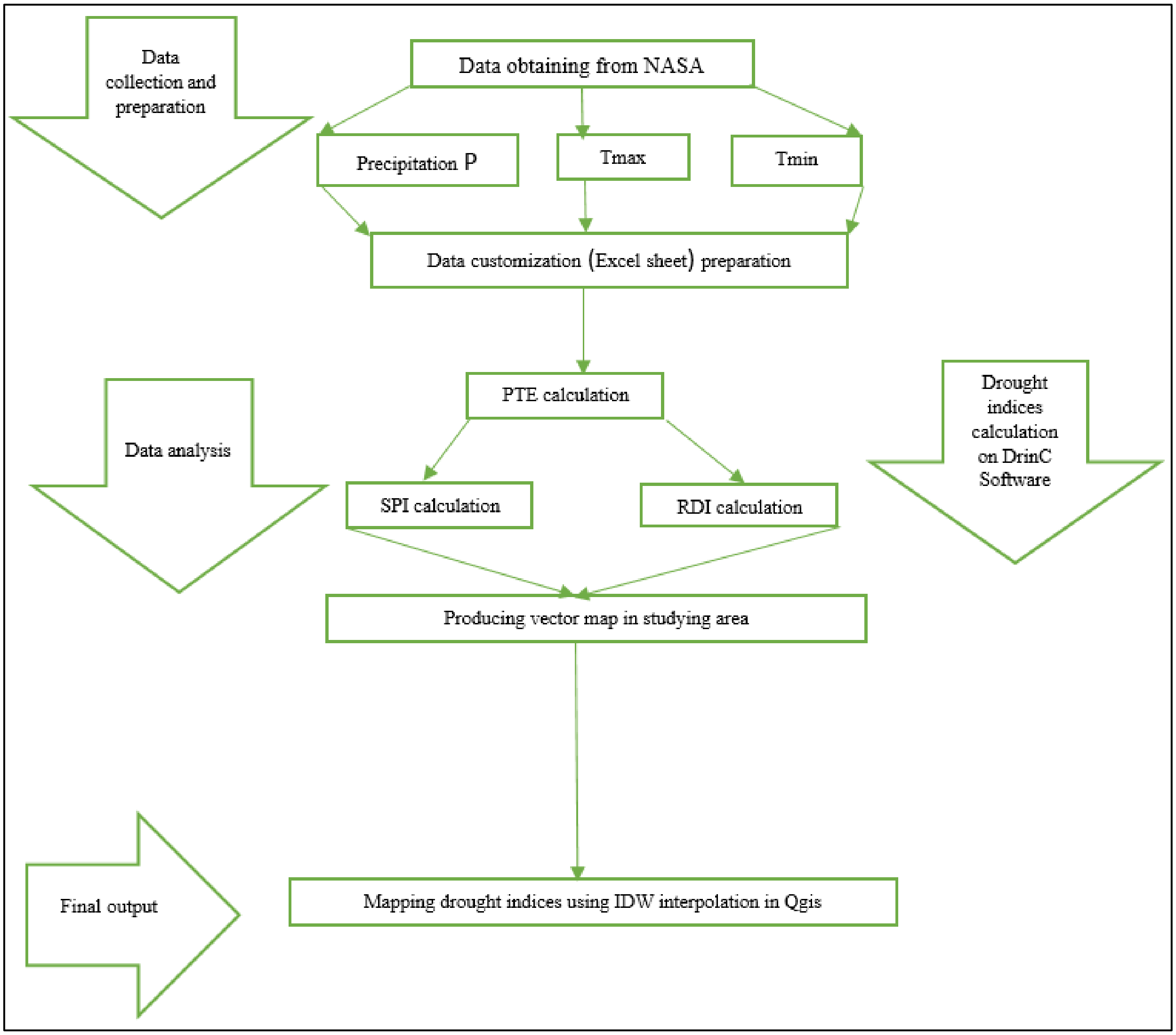
Figure 2: Flowchart of the methodology



RESULTS

RDI and SPI Variation

The results presented in *Table 3* and *Figure 3* & *4* show that 2010-2011 and 2016-2017 were the year is most affected by drought, according to RDI and SPI. Compared to other years, drought was significantly worse in these years. The worst drought occurred in 2016-2017.

In 2016-2017, the average RDI and SPI were -1.12 and -1.131, respectively. The spatiotemporal distribution of RDI and SPI in Somalia from 2010 to 2021 is shown in *Figure 3* & *4*. While the north-eastern and southern regions of Somalia were affected by the 2017-2019 drought events, the 2016-2017 drought event exhibited significant regional diversity at the spatial scale. There was a significant correlation between RDI and SPI and average rainfall in most of Somalia during the study period from 2010 to 2021.

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Table 3: Characteristics of RDI and SPI in the study area from 2010 to 2021

Year	RDI				SPI			
	Max	**Min**	**Mean**	**SD**	**Max**	**Min**	**Mean**	**SD**
2010-11	-0.19	-1.68	-0.98	0.44	-0.23	-1.72	-0.99	0.45
2011-12	2.30	-1.38	0.50	1.20	2.27	-1.41	0.50	1.19
2012-13	1.05	-1.18	0.16	0.59	0.97	-1.19	0.14	0.58
2013-14	0.74	-1.23	-0.03	0.61	0.77	-1.24	-0.01	0.63
2014-15	1.77	-1.09	0.49	0.75	1.78	-1.11	0.50	0.75
2015-16	1.63	-1.04	0.76	0.70	1.65	-1.01	0.79	0.69
2016-17	0.04	-2.52	-1.12	0.61	0.05	-2.54	-1.13	0.62
2017-18	1.40	-2.55	-0.55	0.98	1.44	-2.56	-0.54	1.01
2018-19	-0.04	-2.29	-0.90	0.46	0.06	-2.29	-0.88	0.47
2019-20	2.20	-1.17	0.86	0.95	2.17	-1.17	0.88	0.95
2020-21	3.53	-1.01	1.20	1.14	3.53	-1.01	1.20	1.14

The calculated RDI and SPI values for Somalia from 2010 to 2021 are shown in *Figure 5*. The results show an inconsistent cycle of dry and wet periods throughout the study period. With significant variations among meteorological stations, droughts were observed in the hydrological years 2010-2011, 2011-2012, 2012-2013, 2013-2014, 2015-2016, 2016-2017, 2017-2018, 2018-2019, 2019-2020, and 2020-2021.

Droughts typically start at the beginning of the rainy season as a result of delayed or reduced rainfall. However, the country experienced the worst drought between 2016 and 2017 (*Figure 3* & *4*). In addition, moderate to severe droughts occurred in 2016-17, 2010-2011, 2018-2019, and 2017-2018, with average RDI values of -1.12, -0.98, -0.90, and -0.55, and SPI values of -1.13, -0.99, -0.88, and -0.54, respectively (*Table 3*; *Figure 3* & *4*).

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Figure 3: Spatiotemporal variations of RDI in the study area from 2010 to 2021

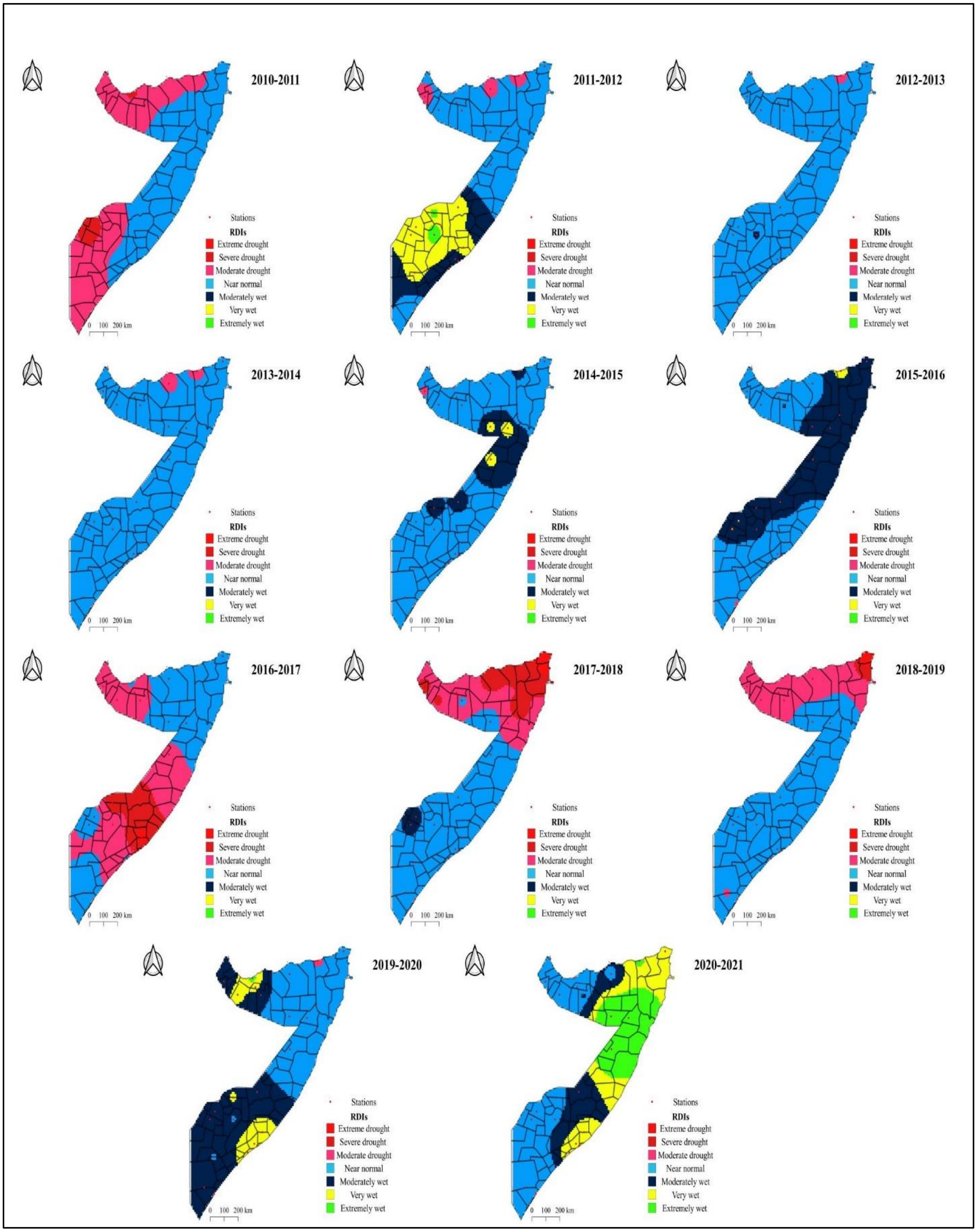

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Figure 4: Spatiotemporal variations of SPI in the study area from 2010 to 2021

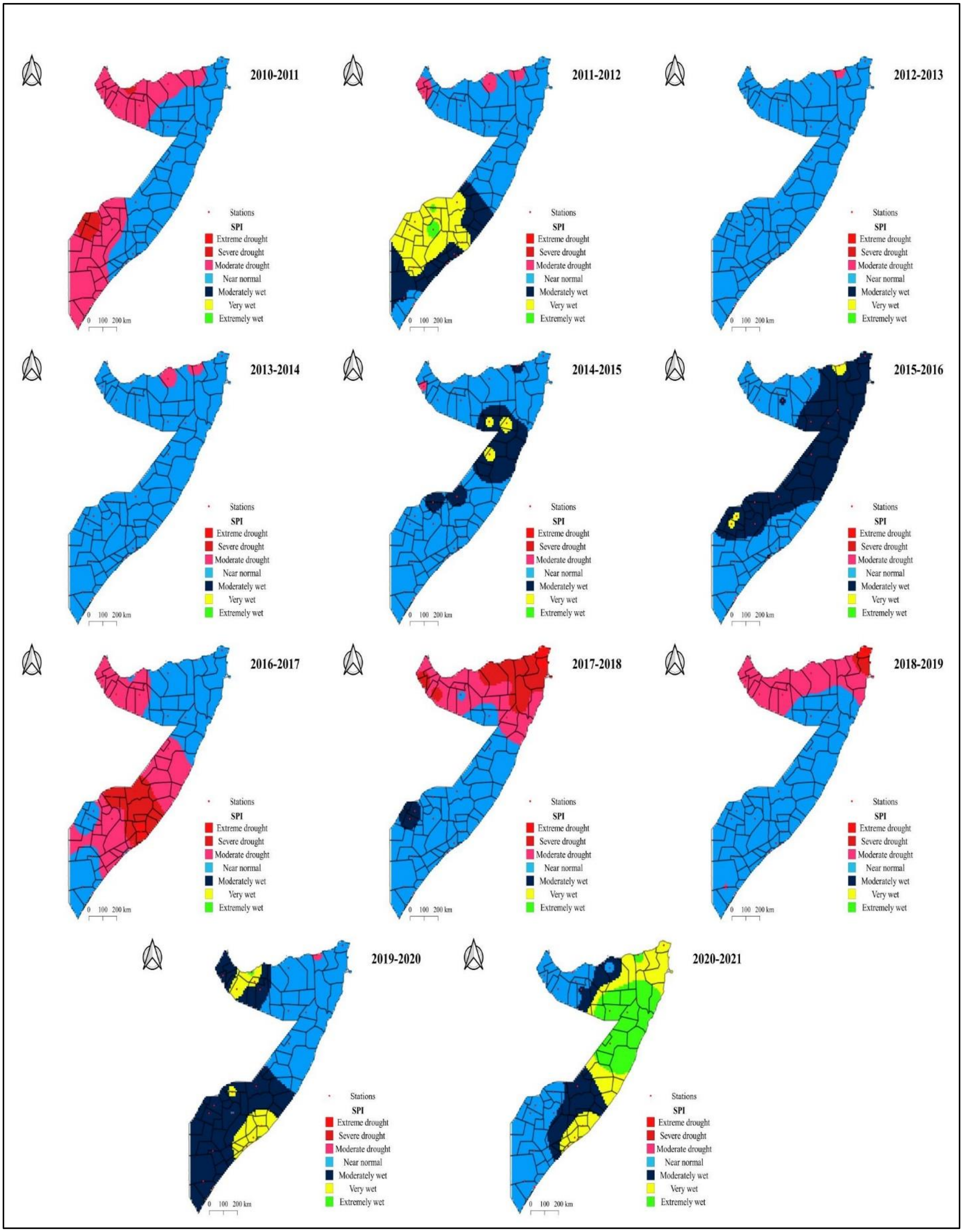

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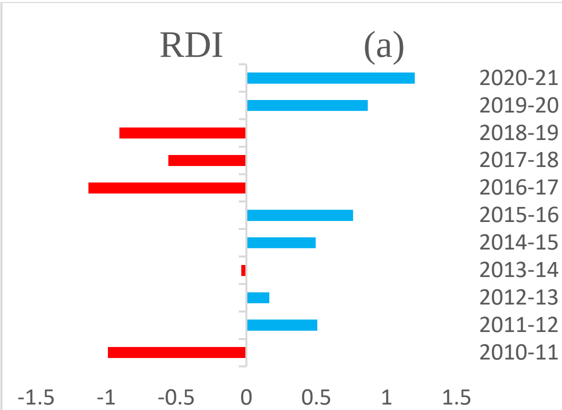
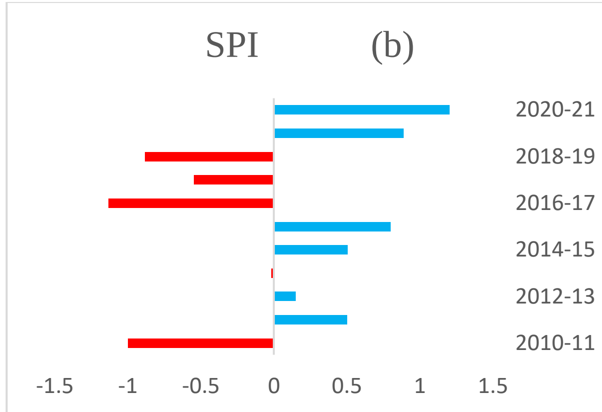
Figure 5: RDI values of the years (a) and SPI value of the years (b) in Somalia for all Stations





Throughout the country, RDI and SPI values were almost the same. The map shows that extreme, severe, and moderate droughts occurred in 2016-2017, 2010-2011, 2018-2019, and 2017-2018. In 2016-2017, the driest year in the last decade, severe drought was observed in the central and southern regions of the country and moderate drought in the north-western and southwestern regions. Drought was near normal in the rest of the country, the northwest, part of the southwest, and areas along the Jubba River (*Figure 3* & *4*).

After years of moderate to severe drought, the southern and central regions were found to have returned to near-normal conditions in 2017-2018. However, the country's north-western region had a distribution of extreme and moderate drought from near normal (*Figure 3* & *4*). The fact that rainfall typically comes from the Indian Ocean led to this condition. The same distribution as in 2017-2018, but it grew in a considerable part of the northwest to near normal in 2018-2019.

While the Garbahara, Luuq (southwest and Juba), and Berbera (northwest) regions experienced severe drought in 2010-2011, the northwest, southwest, and Juba regions experienced only mild drought. In terms of temperatures, Luuq, Berbera, and Garabaharay are considered the warmest areas in the country (*Figure 3* & *4*).

Bosaso (northwest), which experienced moderate drought nationwide in 2012-2013 and 2013-2014, was distributed almost normally. Compared to previous years, the state recovered from drought in 2014-2015 and was close to average. Compared to the five years prior to 2014-2015, Garowe, Galkacyo, Lasanod (Northwest), Xudur (southwest), and Balad-Wayne (central) were the first stations to transition from drought to humidity fully. In most states, 2015-2016, the humidity was reduced to intermediate levels and is close to a normal distribution (*Figure 3* & *4*).

Jawhar, Mogadishu, Afgooye, and Marka stations in the country's south were humid and very humid in 2018-2019 after three years of drought, as shown in the map distribution (*Figure 3* & *4*). The Shabelle River in these stations was responsible for this, the evaporation occurring from river causing humid air to atmosphere.However this occasion is valid the areas near to the river rather whole region . Like the south, very humid and moderately humid distribution was also observed in the hilly northwest. Conditions are typically near normal in the northeast and central parts of the country (*Figure 3* & *4*). The years 2020-2021, which were the wettest of the past decade, showed that the northeast, most of the south, and the northwest were very humid or highly humid, while the other regions were distributed about as they should have been.

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Calculating RDI and SPI is a very effective method for studying drought patterns and monitoring and evaluation. We found drought impacts on the country were strong in 2016-2017, 2010-2011, 2017-2018, and 2018-2019 based on RDI and SPI values (*Table 3*; *Figure 3* & *4*).

The RDI and SPI values indicate that the country was severely affected by drought in 2016-2017, 2010-2011, 2017-2018, and 2018-2019 (*Table 3*, *Figure 5*). Although Somalia has abundant water resources, they are generally believed to be finite and fluctuate with the seasons. According to the United Nations Office for the Coordination of Humanitarian Affairs (OCHA), Somalia is experiencing severe drought due to insufficient rains in November 2016 and February 2017. Six years after a famine that claimed the lives of a quarter of a million people, the country is on the brink of another famine. Crops and livestock have been destroyed by water shortages and insufficient rainfall in the hardest-hit areas, leaving half the population (6.2 million people) homeless. About 3 million of these people struggle to eat enough food every day.

DISCUSSION

During the 2016-2017 dry season, the southern and western parts of the study area had the highest RDI and SPI values, while the north-eastern region consistently had more developed vegetation and near-normal drought conditions (*Figure 3* & *4*).

In different parts of Somalia, annual precipitation mean values decreased significantly in 2010-2011, 2016-2017, 2017-2018, and 2018-2019 (*Table 3*). The correlation coefficients show more drought episodes in Somalia during the growing seasons due to low rainfall and high temperatures. The onset and severity of drought in the ten years studied can be determined from the subsequent spatiotemporal variations of RDI and SPI. According to the results of RDI and SPI fluctuations in *Table 3* and *Figure 3* & *4*, Somalia experienced drought episodes mainly in 2016-2017, 2017-2018, 2018-2019, and 2010-2011. The results of the above studies are consistent with those from the southwest (2016-2017 and 2010-2011) and the north (2017-2018, 2018-2019, and 2010-2011), which found that the worst drought characterized the years between 2010 and 2021 since records began. The SPI variation results showed that the south-eastern region was most affected by the 2016-2017 and 2010-2011 droughts. In 2017-2018 and 2018-2019, the western and southern regions of Somalia were affected by moderate to severe drought (*Table 1*). Compared to previous hydrologic years, hydrologic years 2014-2015, 2015-2016, and 2020-2021 were wet (*Figure 3* & *4*).

Consistent with the McKee et al. (1993) study, drought occurs only when the SPI is negative, not when it is positive. But there were two times when the drought was really bad: from 2016 to 2017, from 2017 to 2018, and from 2010 to 2011 (*Figure 3* & *4*). Since the precipitation deficits persisted for at least the 2016-2019 and 2010-2011 periods, these two droughts can be considered long-term droughts.

According to RDI and SPI data, drought is always accompanied by low rainfall. Alwesabi (2012) assessed the drought in Somalia using MODIS NDVI -satellite data, and the NDVI data were mainly able to identify the exceptionally intense droughts of 2010-2011. It was found that the 2010-2011 drought was the worst as it lasted longer than any other drought in the entire study period (about 12 months). The Deciles Drought Index (DDI), Percent of Normal Index (PNI), and Standardized Precipitation Index (SPI) were used in the study by Said et al. (2019) to examine the droughts in the Somali state of Puntland. These indices successfully identified the four droughts recorded in the area in 2008, 2011, 2016, and 2017. According to Abdulkadir (2017), Somaliland was experiencing severe drought due to widespread failures in the growing season and record low vegetation in 2016. This is due to general rainfall failure during the 2016 Deyr season. This study found that 2010-2011

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and 2016-2017 were the worst drought years based on RDI and SPI values.

CONCLUSIONS

This study examined drought in Somalia over an 11-year period (2010-2021). Each year, climate data were collected for the same season (Oct.-Sep.), and PET was estimated using DrinC software. Two common spectral indices, RDI and SPI, were examined over a year to determine drought. Due to lower rainfall in Somalia, 2016-2017 and 2010-2011 were characterized by more severe drought. Given the frequent occurrence of droughts, it is critical to meet the water needs of the study area by using other available water resources such as groundwater and surface water from Somalia's two main rivers (Shabelle and Juba).

The results of the study also showed that southwestern Somalia was the most affected by drought in the years (2016-2017 and 2010-2011) and northern Somalia was the most affected by drought in the years (2017-2018, 2018-2019, and 2010-2011) compared to other years between 2010 and 2021. The results of RDI and SPI variations showed that drought was most severe in 2016-2017 and 2010-2011, with the south-eastern region being the most affected. In 2017-2018 and 2018-2019, drought was moderate to severe in the western and southern parts of Somalia. Compared to other hydrological years, 2014-2015, 2015-2016, and 2020-2021 hydrological years were wet.

The frequency of droughts and the causes of droughts still need to be researched in more detail. It is also important to study drought for only one year to calculate how it affects socioeconomic resources, water bodies, forests, sustainability, and agricultural production. This study was conducted over a one-year period. SPI and RDI have therefore combined their studies over a shorter period of time (seasonal or even monthly) to show how drought affects agriculture and lifestyles. For future studies of this type, we suggest the use of the Google Earth Engine.

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