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Spatiotemporal Variability of Drought and its Relationships to ENSO and IOD Indices in Somaliland

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Abstract

Drought is one of Somaliland's most prevalent natural hazards, causing serious socioeconomic and environmental harm. This study investigated the spatial and temporal variability of drought and its relationships with El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) indices using the Standardized Evapotranspiration Index (SPEI) from 1981 to 2020. The Mann-Kendall trend test and Sen's slope estimator were used to assess the trends of annual and seasonal SPEI time series. The Empirical Orthogonal Function (EOF) was employed to examine the dominant modes of the SPEI series, and Pearson and partial correlation analyses were performed to investigate the associations between significant modes of drought variability and ENSO and IOD indices. The results demonstrated a statistically significant downward trend of SPEI (increasing drought) at 99% confidence level. The EOF analysis indicated two spatially distinct zones of drought variability in the west and east of the country. Drought variability had a statistically significant negative correlation with ENSO in the summer and winter seasons, and with IOD in the winter season and annual time series. The findings of this study will provide important information for drought risk assessment, mitigation, and predictability in Somaliland.

Keywords: Drought, Standardized Precipitation Index, ENSO, IOD, Somaliland.

Introduction

Drought is a periodic climate occurrence across the world that greatly affects the society, economy, and environment (Masih et al. 2014). Drought is distinct from other natural hazards due to its slow onset, lack of a broadly accepted definition, and non-structural and widespread impacts (Wilhite et al. 2014). Moreover, determining the beginning and end of a drought is challenging due to its creeping nature (Wilhite et al. 2014). However, the characterization of drought in terms of its severity, duration, location, and timing is similar to the characterization of other hazards (WMO and GWP 2016).

According to Masson-Delmotte et al. (2021), the intensity and frequency of agricultural and ecological droughts have increased over land areas since 1950 and are expected to continue increasing in the 21st century. On the continent of Africa, drought phenomena have become more widespread over the last few decades and are anticipated to worsen in the future. Masih et al. (2014) demonstrated that there had been a considerable increase in drought in terms of frequency, intensity, and geographical coverage over the whole continent of Africa during the last six decades. Several drought-related studies undertaken in East Africa indicate that drought frequencies and severity have increased in recent years, and in some cases, drought has prolonged two or more rainy seasons (Funk 2012, Hoell and Funk 2014, Nicholson 2016). The current drought in East Africa, which is the result of below-average precipitation for three consecutive rainy seasons (Turner et al. 2022), depicts the progression of droughts into multiple rainy seasons.

The El Niño Southern Oscillation (ENSO) is one of the primary causes of drought, and it has been noted that episodic dryness can occur almost anywhere in the world, including in Eastern and Southern Africa. Previous drought investigations across the continent of Africa produced similar conclusions. For instance, Masih et al. (2014) found that ENSO and SST are the primary factors driving drought across the African continent. Furthermore, several research findings revealed that the severe drought of 2010–2011 in East Africa was highly linked to La Niña, the cold phase of ENSO (Dutra et al. 2012, Lott et al. 2013). In addition, Hoell and Funk (2014) reported that Indo-Pacific SSTs have forced increasingly frequent droughts, spanning consecutive MAM and OND seasons across eastern Africa since the 1980s.

Recent increases in the frequencies and severity of drought in Somaliland have had negative impacts on the lives and livelihoods of Somaliland's people. As livestock is the backbone of the nation's economy, it is particularly vulnerable to droughts of increasing frequencies and severity. Somaliland has experienced 13 episodes of drought over the past six decades. The magnitude of the economic costs of drought in Somaliland is exemplified by the 2016–2017 extreme drought (Kew et al. 2021), which caused damages and losses estimated to exceed USD 874 million (Pape and Wollburg 2019). In addition, recurring droughts have had devastating impacts on pastoral livelihoods, resulting in a rise in poverty and family disruptions, which has cast doubt on the viability of pastoralism (Hartmann et al. 2010).

Despite the fact that drought is the most catastrophic natural hazard in the country (Abdulkadir 2017), a paucity of drought-related studies in the country has resulted in a deficiency of information for assessing drought risks and mitigation. Consequently, investigating and gaining a better understanding of historical spatiotemporal drought patterns is crucial for assessing drought risk and mitigation (Tian 2017) and is essential for building resilience to future droughts (Haile et al. 2020). In Somaliland, there was a scarcity of research examining the long-term spatial patterns and temporal evolution of drought, as well as its connections with ENSO and IOD. Therefore, this study aimed to bridge this knowledge gap, contribute to a better understanding of drought, and identify the potential sources of drought predictability in the country.

Materials and Methods

Study area

This research was undertaken in the Republic of Somaliland, which is not internationally recognized as a sovereign nation, but has been functioning as a de facto country since 1991. Somaliland is located between 08°00' North and 11°30' North and 42°30' East and 49°00' East (Figure 1). It is bordered to the west by Djibouti, to the south by Ethiopia, and to the east by Somalia. Somaliland has a coastline of up to 850 kilometres and a total area of 137,600 km^2. Somaliland has three major topographic zones: the coastal plains, coast ranges, and plateau (Hartmann et al. 2010).

The country's climate is warm and semi-arid. The annual average precipitation in Somaliland ranges from less than 50 mm by the coast to 500 mm inland along the Golis range, and at times surpasses 900 mm. The average daily temperature is between 25 °C and 35 °C (Hartmann et al. 2010). In Somaliland, precipitation is highly varied, as are seasonal temperatures.

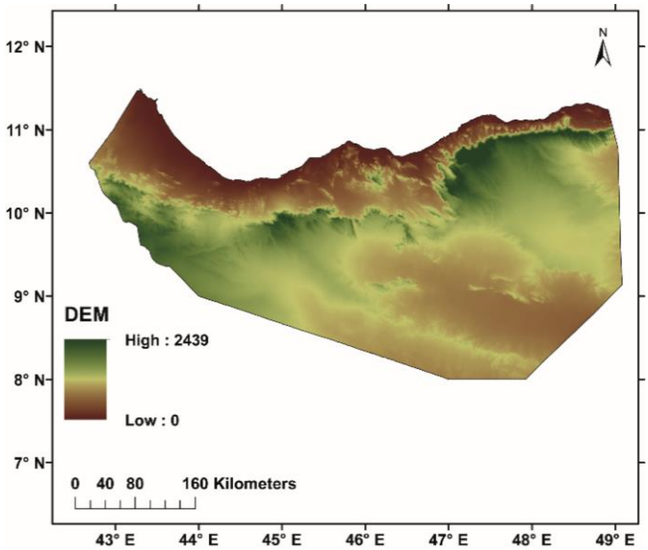

Figure 1: The map of Somaliland; the area of the study.

Data

Global SPEI dataset

The study utilized the most recent version of the Global SPEI database, SPEIbase v2.7. The SPEIbase is a global, long-term dataset based on monthly precipitation and potential evapotranspiration from the Climate Research Unit (CRU) of the University of East Anglia (Vicente-Serrano et al. 2010). The spatial resolution of the dataset is 0.50 x 0.50 degrees, and the temporal resolution is monthly. The dataset's description is found at https://spei.csic.es/database.html. Several prior studies examined drought in the Horn of Africa region using the SPEIbase (Haile et al. 2020).

Climate indices data

The NINO3.4 SST anomaly was employed to illustrate ENSO conditions in the study based on deviations from the three-month moving average of SSTs in the NINO3.4 zone, where positive NINO3.4 values indicate El Niño events and negative values indicate La Niña events (Tian 2017). This data was obtained from http://www.esrl.noaa.gov/psd/gcoswgsp/Timeseries/Nino34. The Dipole Mode Index (DMI) is derived from the difference between the western equatorial Indian Ocean (50°E–70°E and 10°S–10°N) and the south-eastern equatorial Indian Ocean in order to represent the Indian Ocean Dipole (IOD) (90°E–110°E and 10°S–0°N). The DMI data was retrieved from https://psl.noaa.gov/gcoswgsp/Timeseries/DMI.

Methodology

Standardized Precipitation and Evapotranspiration Index (SPEI)

The research employed the Standardized Precipitation Evapotranspiration Index (SPEI). The SPEI is a basic multiscale drought indicator that utilizes precipitation and temperature data to detect, monitor, and analyze droughts (Vicente-Serrano et al. 2010). A drought event is identified when the SPEI values are continuously negative and reach a value of -1.0 or less (Tan et al. 2015). In addition, the 12-month SPEI (SPEI-12) and the 3-month SPEI (SPEI-03) were used to study the distribution and variability of drought on annual and seasonal timescales, respectively. The SPEI combines the Palmer Drought Severity Index (PDSI) sensitivity in assessing evapotranspiration demand with the Standardized Precipitation Index (SPI) multi-temporal strength (Beguería et al. 2014). Its computation procedures are detailed in depth by Vicente-Serrano et al. (2010) and Beguería et al. (2014). Several researchers have already used the SPEI to examine drought in the Horn of Africa region (Tefera et al. 2020).

Empirical Orthogonal Function (EOF)

The EOF was used to analyze and extract the dominant modes of spatial and temporal drought variability over the study area. The EOF approach is utilized for the analysis of single field variability by identifying the spatial-temporal patterns of variability and providing the significance of each pattern (Björnsson and Venegas 1997). In this study, spatial patterns were referred to as EOFs and time series as Principal Components (PCs). EOF is described in depth by Björnsson and Venegas (1997). The EOF was widely utilized for spatial-temporal drought studies (Junaid and Qayoom 2021).

Mann-Kendall test

The drought trends were assessed using the Mann-Kendall test and Sen's slope estimator. The Mann-Kendall test is a nonparametric tool for detecting statistical trends. It is frequently employed to assess the significance of an increasing or decreasing trend in hydro-meteorological time series, such as a series of drought indices (Tan et al. 2015). Its benefits over other trend-testing techniques are that it does not require a normal distribution and is less susceptible to outliers (Liu et al. 2021). On the other hand, Sen's slope estimator is an easy nonparametric test that employs a linear model to identify the slope and is computed to indicate the trend of data variation (Yue et al. 2021). Previously, the Mann-Kendall test was utilized to evaluate drought in the Horn of Africa region (Tefera et al. 2020, Haile et al. 2020).

Correlation analysis

Pearson correlation**:** The study employed the Pearson correlation method to evaluate lead-lag correlations between SPEI, and ENSO and IOD with confidence levels of 95% and 99%. Pearson Correlation Coefficient (PCC) values vary from -1 to 1, with negative values denoting negative correlation and positive values denoting positive correlation. In addition, the connection is stronger when it approaches -1 or 1, and weaker when it approaches 0. Previous scholars analyzed the associations between drought and climatic indices in the Horn of Africa using Pearson correlation (Bayable and Gashaw 2021).

Partial correlation**:** In addition, the study employed partial correlation analysis. This is a linear correlation technique used to remove the influence of a third variable on the correlation between any two variables (Yang and Xing 2022). Therefore, partial correlation analysis was employed to eliminate the influence of IOD on drought, and a correlation between ENSO and drought was established. Additionally, the effect of ENSO was excluded, and the association between IOD and drought was established. Previously, a number of studies employed partial correlation to control the effects of other variables on drought while analyzing the relationships between drought and climatic indicators (Yang and Xing 2022).

Results and Discussion

Annual and seasonal spatial distribution of drought in Somaliland

The SPEI-12 and SPEI-03 values of 54 grid points were used to study the spatial distribution of drought on annual and seasonal timescales in Somaliland from 1981 to 2020. The grid points were interpolated over Somaliland by using Inverse Distance Weighting (IDW), as shown in Figures 2 and 3. The annual spatial distribution of drought represented by SPEI-12 values indicated that the northern part of the country, particularly the northwestern and northeastern regions, experienced drought during the study period, as shown in Figure 2. These are the country's coastal areas, where the rainfall is very low and the temperature is high. Generally, drought conditions decreased from the country's north (coast) to the south (inland), as indicated in Figure 2.

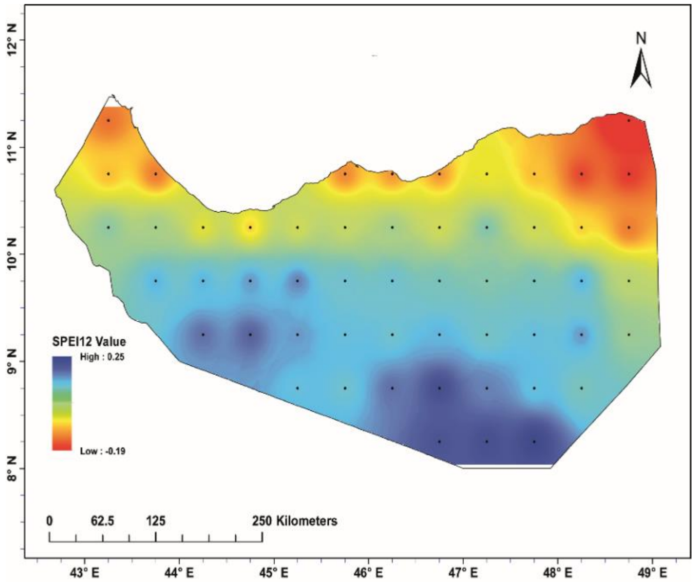

Figure 2: Annual spatial distribution of drought in Somaliland from 1981 to 2020.

The seasonal spatial distribution of drought was also investigated using SPEI-03 values during the study period. Figures 3 (a) and 3 (c) indicate wet seasons (spring locally known as *gu* and autumn locally known as *deyr*), while Figures 3 (b) and 3 (d) indicate dry seasons (summer locally known as *xagaa* and winter locally known as *jiilaal*) in Somaliland. During the spring (*gu*), only the northeastern part of the country experienced drought in the study period, as shown in Figure 3 (a). Figure 3 (b) generally shows that the autumn (*deyr*) season exhibited a similar spatial distribution of drought to the annual distribution indicated in Figure 2. On the other hand, the dry seasons (summer and winter) in Figures 3 (b) and 3 (d) showed widespread drought conditions across the country except for small pockets in the eastern and southeastern parts of the country.

Temporal variations and trends of drought in annual and seasonal timescales

As Figure 4 shows, SPEI-12 started to decrease from 1989 on and showed negative values for the last two decades. This meant that the rising temperatures and declining long rains in Eastern Africa, as indicated by several studies (Nicholson 2017), led to water deficits in Somaliland, thus decreasing SPEI-12 values. Moreover, the results of the temporal evolution of SPEI-12 also showed two periods of long droughts, from 2000 to 2010 and from 2010 to 2018, with the lowest drought intensities being -1.12 in 2009 and -1.63 in 2015. This indicated that the country has generally been in a state of drier conditions since the year 2000, with increasing drought intensity.

The results of the assessment of the Mann-Kendall Trend test and Sen's slope estimator revealed a statistically significant downward trend in SPEI-12 (increasing drought) at 99% confidence level during the study period, as indicated in Figure 4. Furthermore, the magnitude of the downward trend was -0.0644 yr^{-1} on an annual basis. These findings are in line with the findings of Haile et al. (2020), who found that drought increased in the Greater Horn of Africa from 1964 to 2015, and that there was a change point in the SPEI series in 1989 over the region.

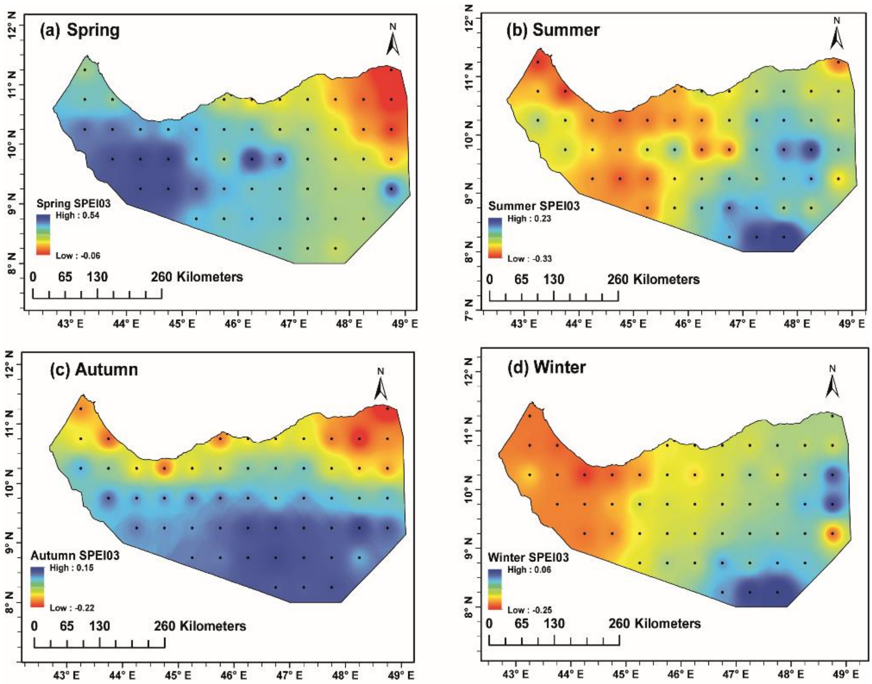

Figure 3: Seasonal spatial distribution of drought in (a) spring, (b) summer, (c) autumn, and (d) winter in Somaliland from 1981 to 2020.

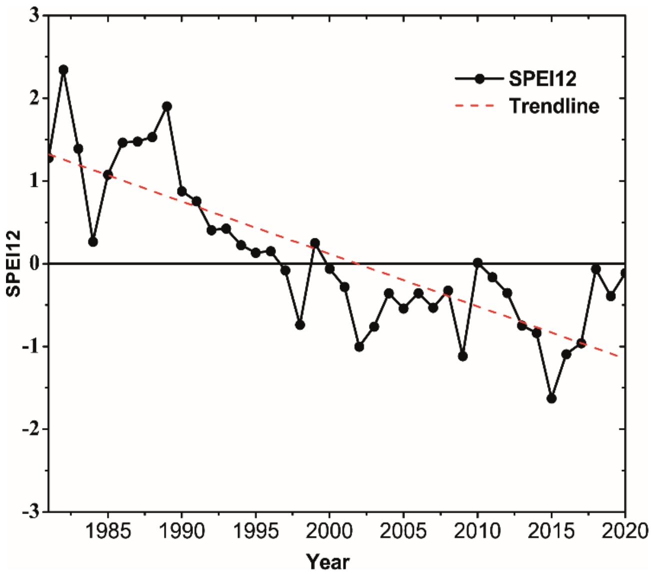

Figure 4: Average annual variations and trend of drought in Somaliland from 1981 to 2020.

The results of the seasonal investigation of SPEI-03 revealed that the spring (*gu*) season showed less intense droughts, as shown in Figure 5 (a), while the autumn (*deyr*) season indicated drier conditions from 2005 to 2017, with the occurrence of a severe drought in 2015 that reached a SPEI value of -1.92 and lasted up to 2017, as indicated in Figure 5 (c). The summer showed severe drought in 2002 and extreme drought in 2017 with SPEI values of -1.59 and -2.11, respectively, as shown in Figure 5 (b), while the winter seasons identified periods of severe winter drought in the years 1999, 2005, and 2015 with SPEI values of -1.79, -1.57, and -1.62, respectively, as indicated in Figure 5 (d). Generally, the autumn, summer, and winter seasons agreed that the drought of 2015–2017 was the most severe during the study period. This result is consistent with the findings of Kew et al. (2017), who concluded that the 2016–2017 drought was extreme in Somaliland since the return period of such an event is roughly 100 years.

Under a 99% confidence level, the assessment of the trends of the average SPEI-03 series for seasonal timescales revealed a statistically significant downward trend of SPEI-03 in all seasons. This showed that Somaliland's droughts have been getting worse over the last 40 years.

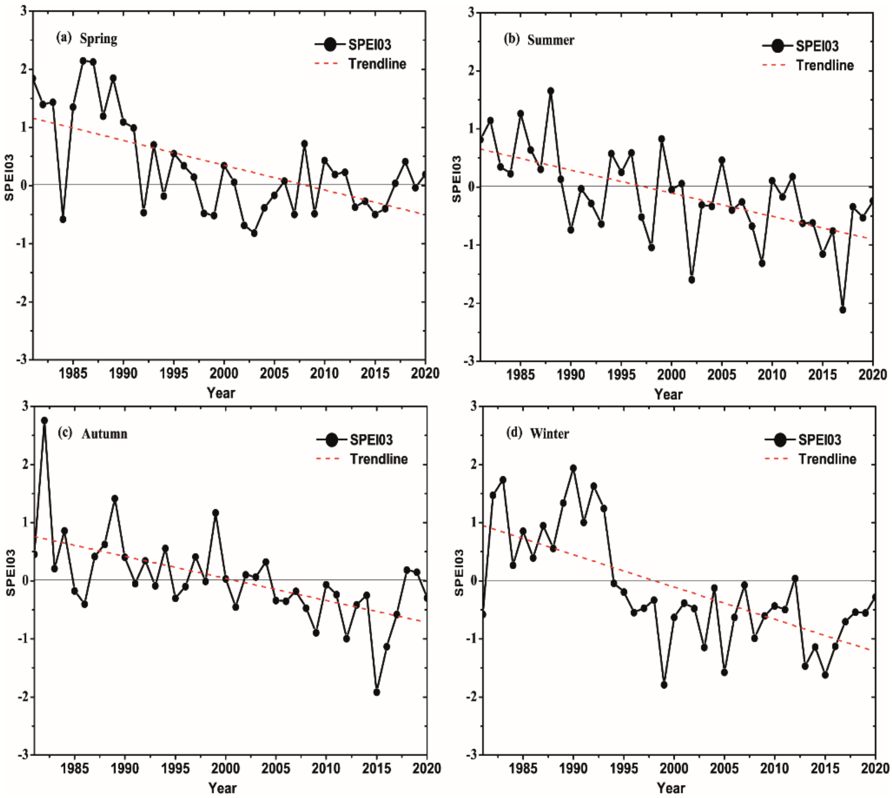

Figure 5: Average temporal variations and trends of (a) spring, (b) summer, (c) autumn and (d) winter drought in Somaliland from 1981 to 2020.

Moreover, the results of the slope of the downward trends of SPEI-03 showed seasonal decreasing values of -0.0432 yr^{-1} in spring, -0.0367 yr^{-1} in summer, -0.0306 yr^{-1} in autumn, and -0.0521 yr^{-1} in winter. This indicated that the change in trends was greatest in winter, followed by spring and summer, while the smallest trend change was observed in the autumn season. The results of the increased seasonal drought in spring, summer, and winter are consistent with those of Haile et al. (2020), who found similar results for the Greater Horn of Africa region. However, the results of the autumn season were different from that of Haile et al. (2020), who found a decreasing drought in the autumn season in the region.

EOF analysis for spatial and temporal variabilities of drought

An EOF analysis was applied to each grid point of the SPEI-12 series to extract the annual dominant modes of spatial patterns and the temporal evolution of drought in

Somaliland from 1981 to 2020. As shown in Figures 6 (a) and (b), EOF-1 accounted for 85.66% of the variance, while EOF-2 accounted for 9.38% of the variance. The cumulative variance explained by EOF-1 and EOF-2 was 95.04%. This indicated that these two first EOF modes well explained the variance in the SPEI-12 series in Somaliland during the study period. The spatial patterns of EOF-1 showed a positive loading throughout the country, while EOF-2 revealed a negative and positive spatial distribution, with negative loadings in the west and positive loadings in the east of the country. The results of EOF-2 revealed two spatially distinct regions of drought variability in the west and east of the country during the study period.

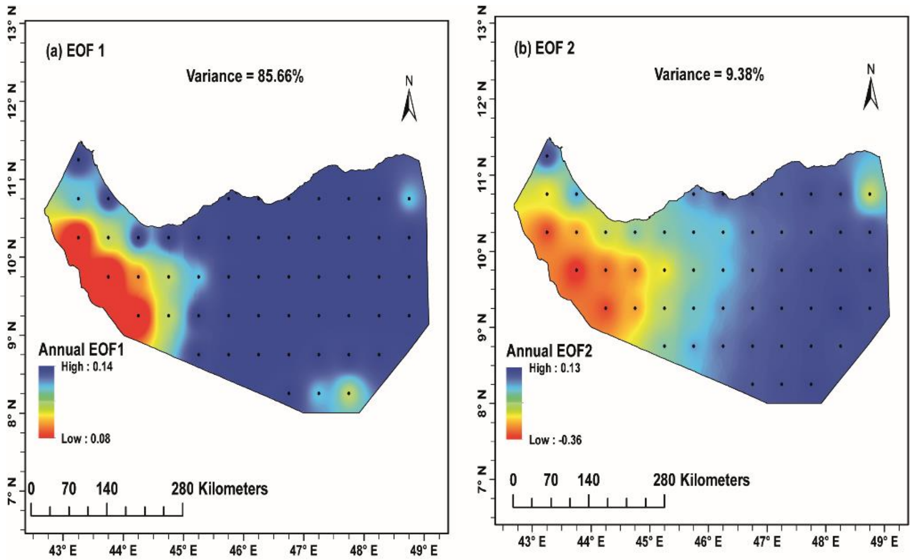

Figure 6: Patterns of the first EOFs for SPEI-12 series (a) EOF-1 and (b) EOF-2.

The first corresponding principal component (PC-1) generally exhibited a decreasing temporal pattern from the year 1989 on and a statistically significant downward trend at 99% confidence level during the study period, as shown in Figure 7 (a). This demonstrated good physical significance and is in agreement with the results in Figure 4. Furthermore, the results showed that Somaliland has been getting drier over the past 20 years, with 2015 being the driest year. Figure 7(b) shows that the second corresponding principal component (PC-2) had positive and negative temporal changes that did not show a statistically significant downward trend.

An EOF analysis was also performed on the SPEI-03 series to examine drought's dominant spatial and temporal variabilities on seasonal time scales from 1981 to 2020 in Somaliland. Figures 8 (a) and (b) show that EOF-1 and EOF-2 of the spring season returned explained variances of 83.61% and 9.91%, respectively, with a total explained variance of 93.52%. This meant that the first two EOFs accurately revealed the spatial and temporal variations of drought in Somaliland during the study period. EOF-1 had positive loadings throughout the country, while EOF-2 showed negative and positive loadings in the east and west of the country,respectively. The results revealed two spatially contrasting regions of drought variability in the eastern and western regions of the country.

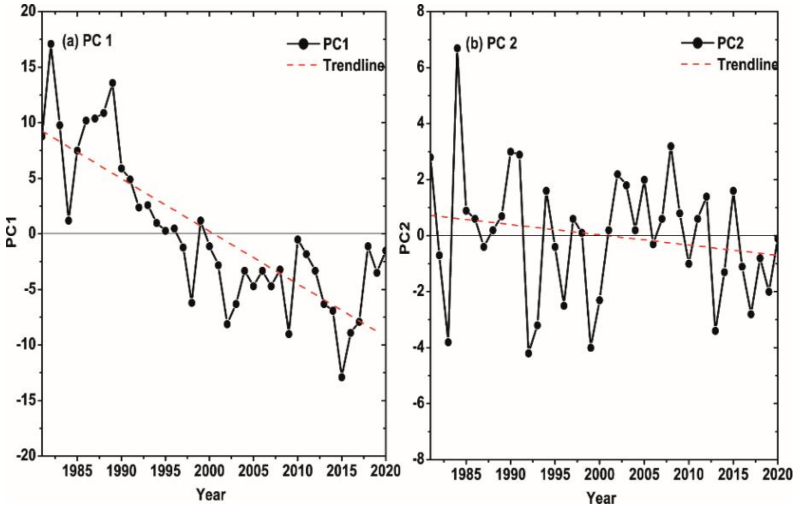

Figure 7: Principal components of the first two EOFs for SPEI-12 series (a) PC-1 and (b) PC-2.

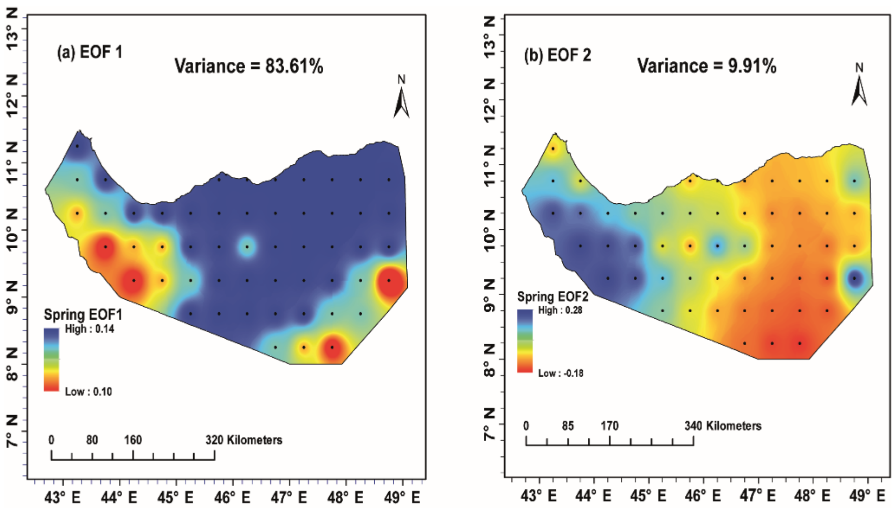

Figure 8: Patterns of the first EOFs for SPEI-03 values for the spring season (a) EOF-1 and (b) EOF-2.

The PC-1 of EOF-1 showed a statistically significant downward trend in drought variability at a 95% confidence level during the study period, as shown in Figure 9 (a). This meant that drought increased in the spring season across Somaliland during the study period, and the country has been in a drier spring season for the last three decades. Several studies, such as Nicholson (2017) showed that the long rainy season (MAM) in Eastern Africa has been getting shorter over time. This dry situation is probably because of this. In addition, PC-2 of EOF-2 indicated alternating positive and negative values with a statistically non-significant upward trend in drought variability in Somaliland, as shown in Figure 9 (b).

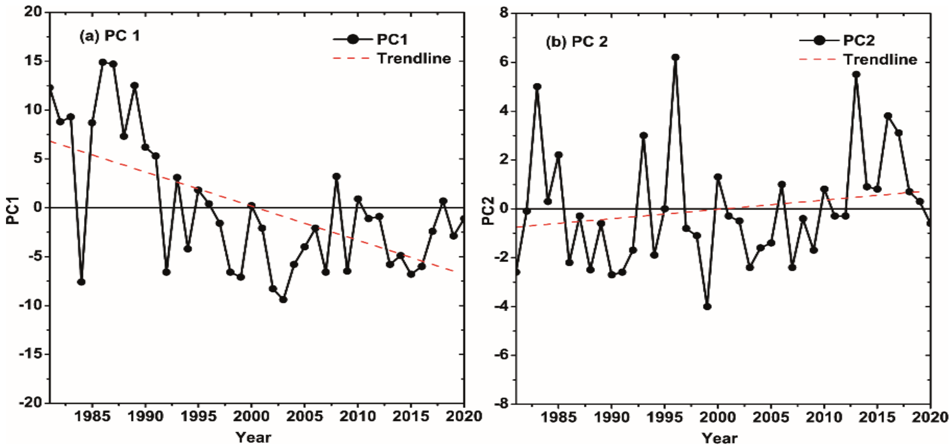

Figure 9: Principal components of the first two EOFs for SPEI-03 values for the spring season (a) PC-1 and (b) PC-2.

The explained variances of EOF-1 and EOF-2 for the summer season were 75.48% and 15.01%, respectively, as shown in Figures 10 (a) and (b). The cumulative explained variance of EOF-1 and EOF-2 was 90.49%. This meant that these two EOFs well captured the drought variability in the summer season. EOF-1 returned positive loadings throughout the country, while EOF-2 showed negative loadings in the western parts of the country and positive loadings with small negative pockets in the eastern parts. This meant that there were two spatially distinct regions of drought variability in the east and west of the country in the summer season.

The corresponding PC-1 of EOF-1 showed a statistically significant downward trend in drought variability at a 99% confidence level in the summer season, as shown in Figure 11 (a). The results revealed that, generally, the country has experienced drier summers for the last two decades. This is in line with the result shown in Figure 5 (b). In the summer season, PC-2 of EOF-2 showed a statistically significant downward trend in drought variability at a 95% confidence level, as shown in Figure 11(b). This result generally revealed that drier summer conditions have existed for the last two decades in the country's eastern regions.

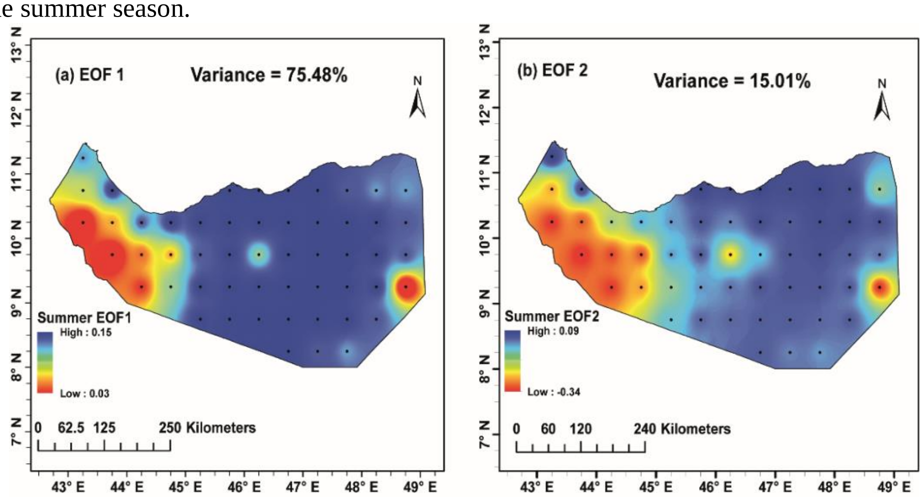

Figure 10: Patterns of the first EOFs for SPEI03 values for the summer season (a) EOF1 and (b) EOF2.

Figures 12 (a), (b), and (c) show that EOF-1, EOF-2, and EOF-3 had explained variances of 67.22%, 19.02%, and 8.01%, respectively, and a cumulative explained variance of 94.25%. EOF 1 and the majority of EOF 3 values showed positive loadings throughout the country, while EOF 2 indicated positive loadings in the western and negative loadings in the eastern parts of the country. The results of EOF 2 showed two spatially different regions of drought variability in the east and west of the country.

At 99% confidence level, the corresponding PC-1 and PC-3 indicated a statistically significant decreasing trend of drought variability in the autumn season, as shown in Figures 13 (a) and (c), respectively. The results generally indicated drier autumn conditions in the country for the last two decades. During the study period, PC-2 also showed a statistically significant trend of increasing drought variability in the country, as shown in Figure 13(b) at a 95% confidence level.

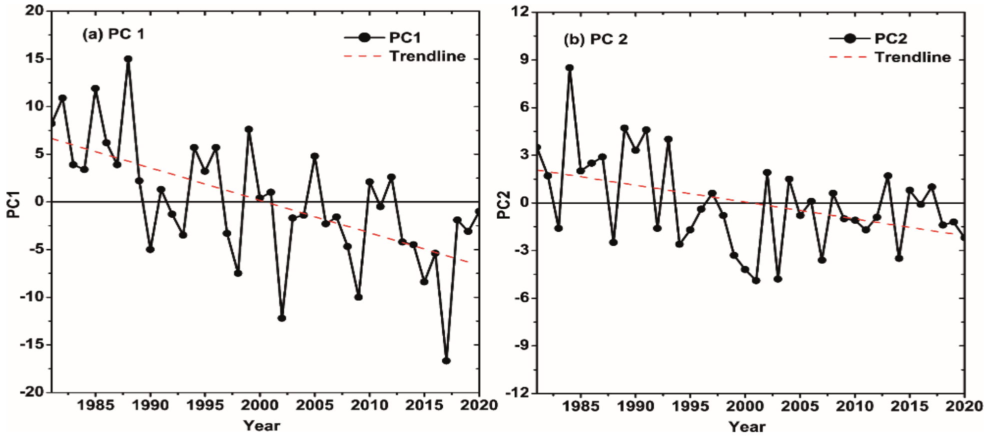

Figure 11: Principal components of the first two EOFs for SPEI-03 values for the summer season (a) PC-1 and (b) PC-2.

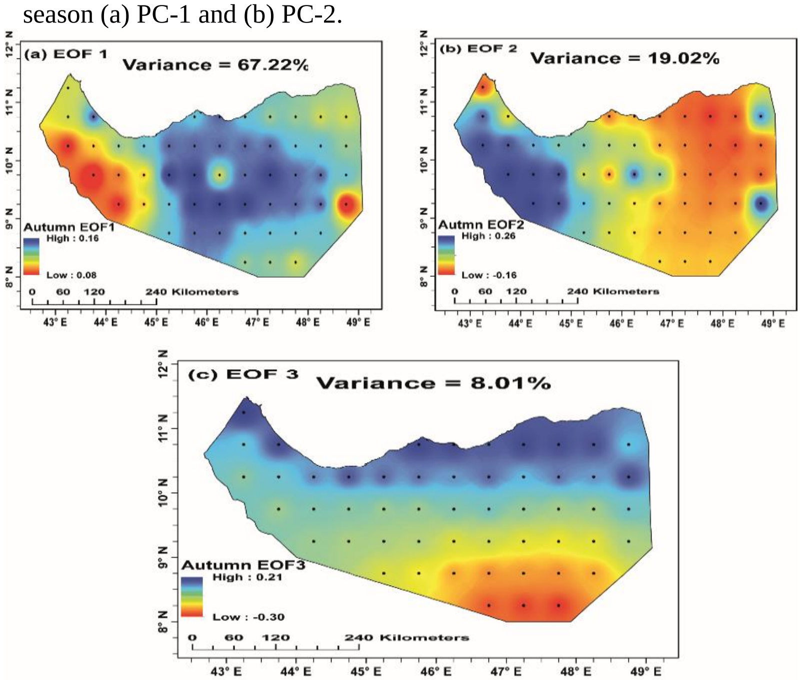

Figure 12: Patterns of the first EOFs for SPEI-03 values for the autumn season (a) EOF-1, (b) EOF-2 and (c) EOF-3.

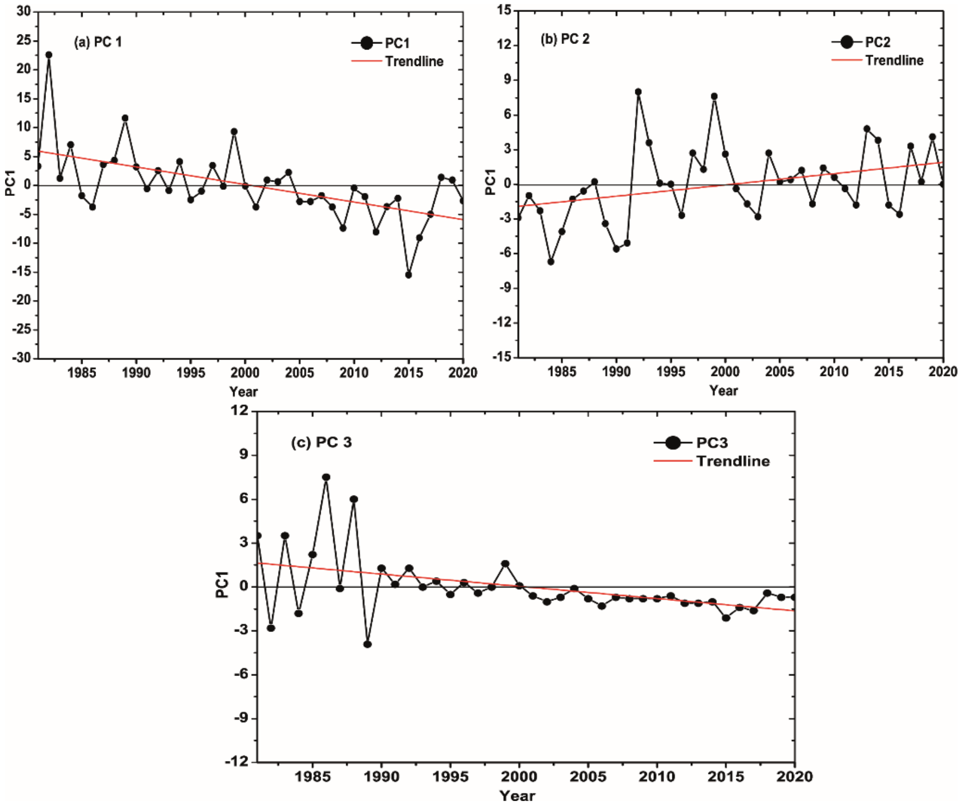

Figure 13: Principal components of the first two EOFs for SPEI-03 values for the autumn season (a) PC-1, (b) PC-2 and (c) PC-3.

The explained variances of winter EOF-1 and EOF-2 were 88.87% and 6.98%, respectively, and their cumulative explained variance was 95.85%, as shown in Figures 14 (a) and (b). EOF-1 showed positive loadings throughout the country, while EOF-2 showed negative loadings in the west and positive ones in the east. EOF-2 results identified two spatially distinct regions of drought variability in the west and east of the country.

At 99% confidence level, the corresponding PC-1 indicated a statistically significant downward trend for the winter season, as shown in Figure 15(a). The result showed that drier winter conditions have dominated in Somaliland for the last two and a half decades. The result was consistent with that of Figure 5 (d). Moreover, the PC-2 indicated a statistically significant downward trend in the winter season, as shown in Figure 15 (b) at a 95% confidence level.

Correlation between drought variability and ENSO and IOD indices in Somaliland

ENSO and IOD are the dominant drivers of climate variability in East Africa. Hoell and Funk (2014) linked the increased frequency of droughts in East Africa in recent decades to Indo-Pacific SST. Using the time series (PCs) of the dominant modes of the EOFs extracted from SPEI-12 and SPEI-03 and the Nino3.4 and Dipole Mode Index (DMI) indices, lead-lag correlation analysis was conducted to examine the relationships between drought variability and ENSO and IOD indices on annual and seasonal timescales.

The summer PC-1 had a statistically significant negative correlation with the AMJ, MJJ, and JJA seasons of the Nino3.4 index, with the MJJ season indicating the highest correlation coefficient of -0.41 as shown in Table 1. This meant that El Nino, the warm phase of ENSO, was associated with drier summers in Somaliland from 1981 to 2020. This result is consistent with the findings of Gobie and Miheretu (2021), who found that El Nino was linked with less summer rainfall in northeastern Ethiopia. On the other hand, winter PC-2 had a mixed correlation with the Nino3.4 index, with a statistically significant negative correlation with the Nino3.4 index's JFM, FMA, NDJ, and DJF seasons and a statistically significant positive correlation with the Nino3.4 index's JAS, ASO, SON, and OND seasons, as shown in Table 1.

On the other hand, the JFM, FMA, and MAM seasons of the DMI showed a statistically significant negative correlation with both SPEI-12 PC-1 and winter PC-1, as shown in Table 1. Furthermore, the DMI season with the highest correlation coefficient was the JFM, which had a correlation coefficient of -0.4333 with winter PC-1.

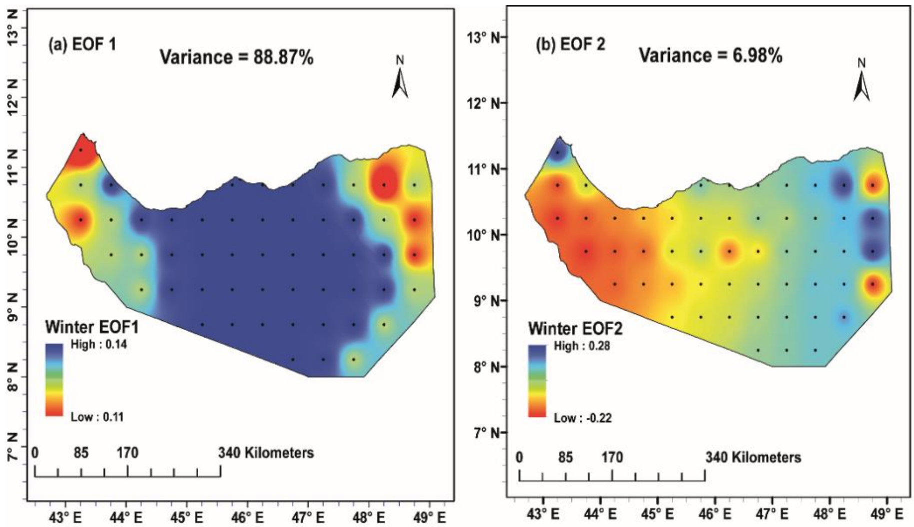

Figure 14: Patterns of the first EOFs for SPEI-03 values for the winter season (a) EOF-1 and (b) EOF-2.

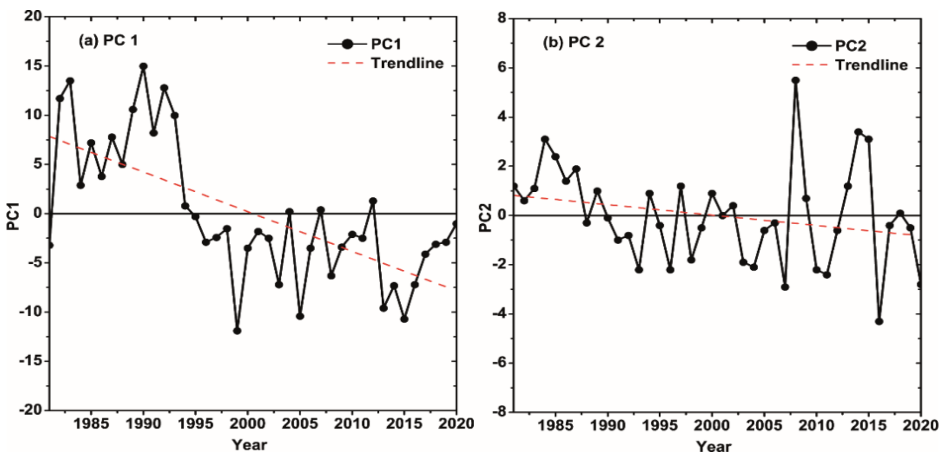

Figure 15: Principal components of the first two EOFs for SPEI-03 values for the winter season (a) PC-1 and (b) PC-2.

Table 1: Correlation coefficients between drought variability and ENSO and IOD indices, and p-values in Somaliland

	Summer PC1		**Winter PC2**			**SPEI-12 PC1**		**Winter PC1**	
NINO3.4	r	p	r	p	DMI	r	p	r	p
DJF	-0.0839	0.6068	-0.4134	0.0080**	DJF	-0.2757	0.0851	-0.2048	0.2049
NDJ	-0.0645	0.6927	-0.4105	0.0085**	NDJ	-0.2846	0.0751	-0.1172	0.4715
OND	-0.2240	0.1647	0.3163	0.0467*	OND	-0.1748	0.2807	-0.1636	0.3131
SON	-0.2241	0.1644	0.3474	0.0281*	SON	-0.1434	0.3775	-0.1191	0.4642
ASO	-0.2303	0.1527	0.3541	0.0250*	ASO	-0.1424	0.3807	-0.1147	0.4810
JAS	-0.2869	0.0726	0.3230	0.0421*	JAS	-0.1076	0.5086	-0.0706	0.6651
JJA	-0.3527	0.0256*	0.2292	0.1548	JJA	-0.1575	0.3318	-0.1320	0.4170
MJJ	-0.4102	0.0086**	0.0886	0.5867	MJJ	-0.1795	0.2678	-0.1507	0.3532
AMJ	-0.3837	0.0145*	-0.0935	0.5662	AMJ	-0.2740	0.0871	-0.2948	0.0648
MAM	-0.2767	0.0839	-0.2511	0.1181	MAM	-0.3324	0.0361*	-0.3957	0.0115*
FMA	-0.1865	0.2493	-0.3602	0.0224*	FMA	-0.3432	0.0301*	-0.4333	0.0052**
JFM	-0.1109	0.4958	-0.3946	0.0117*	JFM	-0.2995	0.0604	-0.3522	0.0258*

Note: r refers to the correlation coefficient, and p refers to the significance level. *indicates significant correlation at 0.05 level, and ** indicates significant correlation at 0.01 level.

The partial correlation analysis was conducted to further investigate the correlation of summer PC-1 and winter PC-2 with the Nino3.4 index alone and the correlation of SPEI-12 PC-1 and winter PC-1 with the DMI alone. After removing the effects of DMI on drought variability in Somaliland, the correlation coefficient between summer PC-1 and the JJA, MJJ, and AMJ seasons of Nino3.4 slightly decreased but still remained statistically significant, as shown in Table 2. Furthermore, the correlation coefficient between winter PC-2 and the NDJ, OND, SON, and JAS seasons of Nino3.4 decreased to statistically non-significant values. Moreover, the correlation coefficient between winter PC-2 and the DJF and ASO seasons of Nino3.4 slightly decreased, and the correlation coefficient between winter PC-2 and the FMA and JFM seasons of Nino3.4 increased from a low to a moderate correlation coefficient. This result meant that Nino3.4 had a generally negative correlation with winter PC-2.

Table 2: Partial correlation coefficients between drought variability and ENSO and IOD indices, and their respective values in Somaliland

	Summer_PC1		**Winter_PC2**			**SPEI-12_PC1**		**Winter_PC1**	
NINO3.4	r	p	r	p	DMI	r	p	r	p
DJF	-0.0119	0.9428	-0.3306	0.0398*	DJF	-0.2686	0.0982	-0.2732	0.0924
NDJ	0.0540	0.7441	-0.2624	0.1065	NDJ	-0.2760	0.0889	-0.2025	0.2163
OND	-0.0822	0.6188	0.2499	0.1249	OND	-0.1883	0.2509	-0.2326	0.1542
SON	-0.1028	0.5334	0.3112	0.0538	SON	-0.1368	0.4063	-0.1555	0.3445
ASO	-0.1407	0.3927	0.3293	0.0406*	ASO	-0.1295	0.4321	-0.1505	0.3605
JAS	-0.2463	0.1307	0.3009	0.0626	JAS	-0.0653	0.6930	-0.0954	0.5634
JJA	-0.3160	0.0500*	0.2103	0.1989	JJA	-0.1082	0.5122	-0.1754	0.2854
MJJ	-0.3661	0.0219*	0.0699	0.6723	MJJ	-0.1343	0.4149	-0.2204	0.1776
AMJ	-0.3467	0.0306*	-0.0901	0.5853	AMJ	-0.2489	0.1266	-0.3585	0.0250*
MAM	-0.2910	0.0723	-0.2550	0.1172	MAM	-0.3359	0.0366*	-0.4018	0.0112*
FMA	-0.2361	0.1479	-0.4145	0.0087**	FMA	-0.3587	0.0249*	0.1736	0.2905
JFM	-0.1231	0.4554	-0.4312	0.0061**	JFM	-0.3018	0.0619	-0.3540	0.0270*

Note: r refers to the correlation coefficient, and p refers to the significance level. *indicates significant correlation at 0.05 level, and ** indicates significant correlation at 0.01 level.

When removing the effect of Nino3.4 on drought variability, the correlation coefficient between SPEI-12 PC-1 and MAM, FMA, and JFM seasons of DMI, and the correlation coefficient between winter PC-1 and MAM and JFM seasons of DMI remained more or less the same. Winter PC-1 and FMA season correlation decreased from negatively moderate to positively non-statistically significant low correlation, whereas winter PC-1 and DMI AMJ season correlation increased and became statistically significant at the 95% confidence level.

Conclusion

Investigating spatial-temporal patterns of drought variability and its relationships with climate indices such as ENSO and IOD provides critical information for a better understanding of the drought phenomenon, which is essential for drought risk assessment and mitigation. This study was undertaken in Somaliland, where drought-related literature is scarce. Using SPEI, EOF analysis, and correlation, this study examined the distribution, trends, and variability of drought as well as its relationships with ENSO and IOD indicators on annual and seasonal timescales in Somaliland from 1981 to 2020.

There was a general decrease in the SPEI-12 pattern since 1989 and a statistically significant downward trend of SPEI-12 (increasing drought) under a 99% confidence level with a magnitude of -0.0644 yr-1 during the study period. During the study period, all four seasons showed a statistically significant downward trend in SPEI-03 (increasing drought), with a trend change of -0.0432 yr-1 in spring, -0.0367 yr-1 in summer, -0.0306 yr-1 in autumn, and -0.0521 yr-1 in winter. EOF's analysis of SPEI-12 and SPEI-03 showed that drought conditions differed between the country's west and east during the study period. All the corresponding principal components (PCs) indicated statistically significant decreasing trends (increasing drought), except spring PC-2 and autumn PC-2.

In general, all time series analyses demonstrated that the country has been experiencing drier conditions for the past two decades. Moreover, the correlation analysis generally revealed a statistically significant negative correlation between summer PC-1 and winter PC-2 and the Nino3.4 index, whereas SPEI-12 PC-1 and winter PC-1 showed a statistically significant negative correlation with DMI. Drought variability had a statistically significant negative correlation with ENSO in the summer and winter seasons and with IOD in the winter season and annual time series. The results of this study can be used as a useful information source for drought risk assessment, mitigation, and predictability in Somaliland.

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Declaration of Conflict of Interest

The authors declare no conflict of interest in the publication of this paper.

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