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SPEI-based spatial and temporal evaluation of drought in Somalia

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ABSTRACT

Somalia is one of the most drought prone countries both in Africa and globally. Drought events usually develop gradually unnoticed, causing tremendous effects on both agriculture and environment. This study evaluated the spatio-temporal variations of drought occurrences in Somalia for the period between 1980 and 2015 as quantified by Standardized Precipitation Evapotranspiration Index (SPEI). The intensities, frequencies and trends of drought occurrences were analyzed using SPEI for the multiple timescales of 1-, 3-, 6-, 12-, and 24-month. The temporal variations in drought showed decreasing trends in severity and increasing trends in drought duration as the SPEI timescales increases. The major drought event as identified by SPEI 12 occurred during the period between May 2011 and January 2013 lasting for a period of 12 months with an intensity of −0.55. Furthermore, drought count was generally high in the southern parts of Somalia and entire country had suffered droughts ranging from moderately dry to severely dry conditions. An average drought duration of between 2 and 3 months was recorded for most (81%) of the locations. The results of this study could be used to support the water resources management, and to promote the realization of environmental protection and crop production in future.

1. Introduction

Drought has significant socioeconomic consequences globally, and its management is difficult due to its variable occurrence (Bachmair et al., 2016). It occurs in varying scales both in space and time globally (Dai, 2011; Gebremeskel Haile et al., 2020). In most cases, its consequences are felt when there is high water scarcity or when the provision of water for agricultural and human use is not sustainable (Clark et al., 2016). However, moderate droughts can as well have destructive effects on the vegetation structure and function and could eventually cause large scale changes to ecosystems (Ensham and Airfax, 2012). Droughts occur naturally (Mukherjee et al., 2018), but can be accelerated by human and climatic factors (Lott et al., 2013). Besides, climate change has accelerated drought frequency and severity across the globe. Dry lands are more susceptible to drought and since 41% of the global landmass is covered by dry lands, the potential for drought to have detrimental consequences is significant (Johnson and Mayrand, 2007). Drought alone has been associated with more than 50% of the 22 million deaths caused by natural disasters between 1900 and 2004 (Parry et al., 2004). The World Bank directly attributed over 800,000 deaths worldwide to the droughts which occurred between 1970 and 2017 (World Bank, 2018). This report further noted that drought is also responsible for the largest drop in Gross Domestic Product (GDP) and it accelerates conflict.

In Africa drought and desertification are key threats to sustainable development (Nyong and Adesina, 2007). This is because two-thirds of Africa is classified as deserts or drylands (12.933 million Km^2) and is highly susceptible to droughts and land degradation (UN Ecosoc, 2007). Desertification is both a cause and a consequence of poverty and resource depletion in Africa. This threatens economic growth, food security, and political stability in the region. In the Horn of Africa, drought and its detrimental consequences on the environment and natural resources continuously occur (Allen et al., 2010). This is due to changes in the climatic patterns, increased human population, inadequate institutional capacities, civil unrest and high poverty levels in the region (Abdulkadir, 2017). The summer of 2011 produced one of the worst droughts in the region, affecting Kenya, Somalia, Ethiopia, Eritrea and Djibouti (Ghebrezgabher et al., 2016). This resulted in reduced annual crop yields, high rates of animal mortality, and elevated food prices (Fredriksen, 2016). While all of the East African countries were affected by drought and the resulting declines in agricultural production, it was in Somalia that the drought led to famine. Ten million people faced severe food shortages with tens of thousands dying of malnutrition as a result of the 2011 drought accompanied by warfare (Nicholson, 2014).

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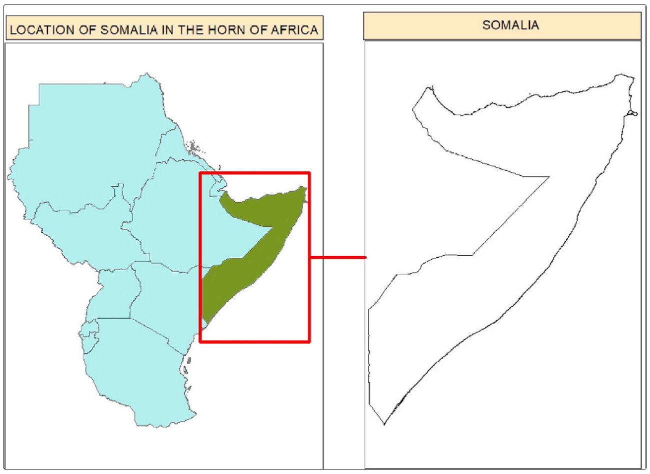

Fig. 1. Study area.

The 2016–2017 drought had immense environmental impacts. Approximately 68% of natural standing vegetation was lost during the one-year drought period (or 113,282 km^2), accounting for 18 percent of the total national landmass. In general, this drought caused damages and losses in the environment sector worth approximately USD 564.8 million (World Bank, 2018). The drought has also triggered excessive extraction of natural resources due to diminishing conventional livelihoods.

While there have been serious droughts in Somalia, the long-term spatial and temporal evaluation of drought occurrences remain unexplored. This has resulted in poor preparedness and uninformed strategies for drought management in the country. Many previous works on drought incidences in Somalia have focused on crisis management, (Maxwell and Fitzpatrick, 2012; Maystadt and Ecker, 2014; Ou and Hao, 2018), rather than evaluating the patterns of occurrence and regional distribution of drought. Others have evaluated drought impacts on forage availability (Vrieling et al., 2016) and drought risk mitigation in urbanizing areas of East Africa (Kalantari et al., 2018). Previous efforts to evaluate drought occurrences in Somalia have focused on specific parts or states of the country rather than the whole country, largely due to its spatial complexity. For example, Abdulkadir (2017) assessed the occurrence of drought in the state of Somaliland. Another study by Said et al. (2019) used a multi-index approach of meteorological drought indices such as Deciles Drought Index (DDI), Percent of Normal Index (PNI) and Standardized Precipitation Index (SPI) to investigate droughts across the Puntland state. These two studies covered only two of the six federal states in Somalia, and no known study has attempted to assess the countrywide pattern of drought incidences. Besides, these studies also made use of drought indices that do not capture the influence of climate change on drought patterns. To this end, there is a need for a critical investigation of long-term historical spatio-temporal patterns of droughts over the entire Somalia. This involves analysis of drought in terms of duration, frequency, severity, and intensity (Radmanesh Said et al., 2019).

Long term historical spatial and temporal analysis of drought events informs better drought impacts management planning and designing of mitigation measures based on previous trends, thus improving preparedness (Vicente-Serrano et al., 2012a,b). Understanding of the spatial and temporal characteristics of drought can help in determining vulnerability of water resources, vegetation and society to drought (Touchan et al., 2008). It also enhances understanding of the nature of drought under influence of climate change (Mishra and Singh, 2010). This further improves drought risk reduction, reviewing of existing efforts and designing of new measures to combat drought.

The use of remotely sensed data in assessment and monitoring of drought have gained popularity in the recent past. This is due to the low cost and repetitive nature of data acquisition, synoptic view and high reliability. A number of drought indices have been developed to this effect. These include the palmer drought severity index (PDSI), standardized precipitation index (SPI) and the standardized precipitation evapotranspiration index (SPEI). The PDSI is disadvantaged by the strong influence of calibration period, challenges in spatial comparability, and subjectivity in relating drought conditions to the index values (Chen et al., 2018). Its other disadvantage is that it has a fixed time scale and therefore cannot be used to assess types of droughts that occur at different time scales. On the other hand, while SPI is easy to calculate and operates over multiple time scales, it is based on monthly precipitation data, ignoring the mechanisms by which droughts develop. SPEI overcomes the disadvantages of both PDSI and SPI (Li et al., 2019). It is based on precipitation and temperature and therefore combines the sensitivity of the PDSI to changes in evaporation demand with the simplicity of calculation and the multi-temporal nature of the SPI.

This study used SPEI to evaluate the distribution of drought and drought characteristics in the whole of Somalia. Through this evaluation, the study aimed at generating information on the trends of drought occurrences over time and space which may be useful to both national and local governments, and other organizations in Somalia. However, the study was limited by the low security levels in Somalia that makes the country largely inaccessible. This has complicated possibilities for ground-truthing available information. Besides, the 1991 civil war in Somalia led to the collapse of hydro-meteorological monitoring network (Muchiri, 2007). The current stations established by Food and Agriculture Organization Somalia Water and Land Information Management (FAO SWALIM) from 2002 do not have uniform spatial distribution throughout the country and therefore cannot be useful in computing reference SPEI. To overcome such limitations Global SPEI database was selected as a source of data. Global SPEI database provides SPEI at a uniform spatial resolution of 0.5° and is also easily accessible.

2. Methods

2.1. Study area

The study was done in Somalia, the eastern-most African country covering a total area of 637,660 km^2 (Fig. 1). Its coastline is 3025 km in length and is the longest in Africa (Alwesabi, 2012). Somalia has a population of approximately 14.74 million people as estimated in July 2017 by the World Bank. Half of the population depends on pastoralism which is dependent on the timings and amounts of rainfall (Alwesabi, 2012). However, in the past three decades, there has been dramatic changes in the socio-economic aspects of pastoralism mainly as a result of the recurring droughts which in turn negatively impact availability of fodder, and thus adversely affecting livestock production.

Generally, hot weather is experienced throughout the year in Somalia. It has an average annual daytime temperature of 27 °C. This is among the world's highest mean annual temperatures. Due to the cold offshore currents, the coastal region is usually 5–10 °C cooler than the inland areas (Hadden and Lee, 2007). Somalia has two climatic zones, the semi-arid and the arid zones (Menkhaus, 2014). The semiarid zone receives moderate rainfall and is suitable for rain fed agriculture. This zone covers the northern mountains, southwest and northwest areas. The arid zone receives low precipitation and is used for pastoralism. It covers the central and northernmost regions of the country. There are two rainy and two dry seasons in Somalia. The main rainy season occurs from April to June and is followed by a dry season between July and September (Alwesabi, 2012). The short rainy season comes between October and November. This is followed by the second and main dry season, which extends from December to March.

Table 1
SPEI index values and the drought intensity.

SPEI VALUE	CLASS
More than 2.00	Extremely wet (humid)
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0.50 to 0.99	Slightly wet
−0.49 to 0.49	Near normal
−0.99 to −0.50	Mild dry
−1.49 to −1.00	Moderately dry
−1.99 to −1.50	Severely dry
Less than −2.00	Extremely dry (drought)

(Thornthwaite, 1948). The Thornthwaite have a disadvantage in over-estimation and under-estimation of potential evapotranspiration in places experiencing low temperatures. The Penman-Montheith method is considered a superior method (Ali et al., 2019) and therefore the SPEIbase is recommended for most uses including long-term climatological analysis. Somalia has a mean annual potential evapotranspiration of 2200 mm (Frenken, 2005).

The SPEI data is calculated at various time scales ranging from 1 to 48 months. This index is widely used for ecological, agricultural and hydrological applications (Vicente-Serrano et al., 2012a,b). At 1-, 3-, and 6-month time scales, drought is usually considered to be relevant for agriculture, at 12 months, for hydrology, and at 24 months for socio-economic impacts (Potop et al., 2014). According to Bae et al. (2018), SPEI can be classified into various categories as indicated in Table 1.

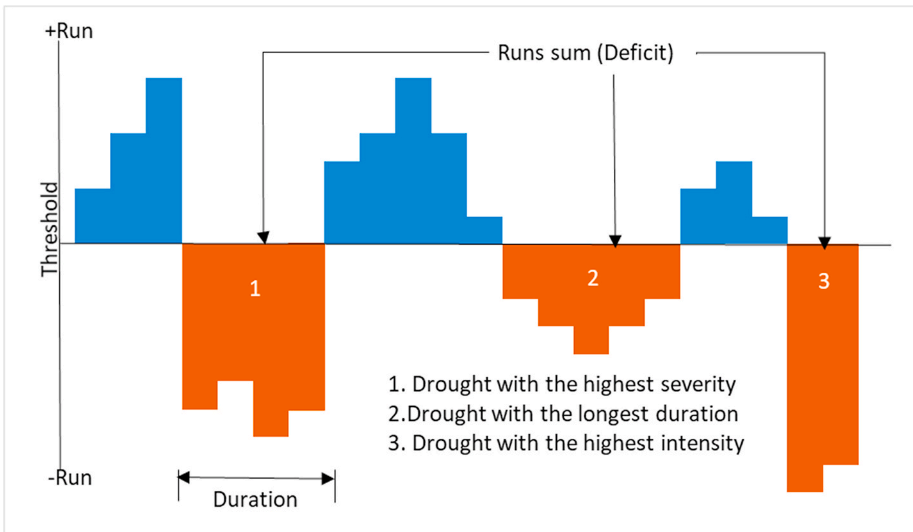

Fig. 2. Drought characteristics using run theory based on selected threshold level (Lee et al., 2017).

Table 2
Observed drought frequencies in Somalia for multiple time scales.

Time scale	Drought frequencies (%)					
	Wet	Mild	Moderate	Severe	Extreme	χ^2 test *P* value
SPEI 1	47.8	46.6	5.4	0.2	0	<0.001
SPEI 3	51.7	42.2	6.1	0.0	0	<0.001
SPEI 6	48.5	47.5	3.7	0.2	0	<0.001
SPEI 12	51.7	45.3	2.9	0	0	<0.001
SPEI 24	49.0	49.3	1.7	0	0	<0.001
χ^2 test *P* value	0.892^{ns}	0.643^{ns}	0.189^{ns}	1.000^{ns}	*	

χ^2 test, Chi-square (two-tailed test); significant at probability level $p \leq 0.001$; ns = not significant at $p \leq 0.001$; ****p*** value for extreme drought was not determined.

2.2. Datasets

This study adopted SPEI retrieved from the Global SPEI database[1] for the period between 1980 and 2015.The Global SPEI database (SPEIbase) provides long-term, concrete information on drought conditions globally. These indices have a spatial resolution of 0.5-degree and a temporal resolution of one month (Beguería et al., 2010). Based on the 0.5-degrees resolution, data for 194 geographical locations were retrieved for Somalia. The SPEIbase database is based on the FAO-56 Penman--Monteith (Zotarelli et al., 2010) method of estimating potential evapotranspiration which is more superior to the Thornthwaite method

Standardized Precipitation Index (SPI) is a multi-scaler probabilistic index that measures deficiencies in precipitation during dry and wet periods and thus allows monitoring of drought conditions at various timescales (McKee et al., 1993). SPI calculation was done using long-term monthly precipitation data fitted to gamma probability distribution function. The precipitation data used were obtained from Climate Hazards Group Infrared Precipitation with Station Data (CHIRPS) database. The values were then used to determine temporal drought properties for comparison with SPEI based properties. Based upon the SPI classification (McKee et al., 1993), value range for various drought categories are similar to those of SPEI.

2.3. Analysis of drought conditions and frequencies

Drought conditions vary from one drought event to another. Drought conditions can be worsened by water scarcity that results mainly from global climatic changes (Paper, 2009). A drought event can be defined as a prolonged period with a SPEI value of −1 or less which starts when the SPEI drops to a value below 0 and is said to end when the SPEI gets to a positive value preceded by a value of −1.0 or less (McKee et al., 1993). Drought characterization is done in three dimensions: drought duration, severity and intensity (Lee et al., 2017). This study made use of 36 years monthly SPEI values for multiple time scales of 1-, 3-, 6-, 12- and 24-month derived from the SPEIbase. Chi-square test was performed to determine whether drought categories as identified by SPEI at various timescales were significantly different.

Runs theory, proposed by Yevjevich (1967) was applied to analyze drought characteristics based on SPEI, and drought characterization was

[1] https://spei.csic.es/database.html.

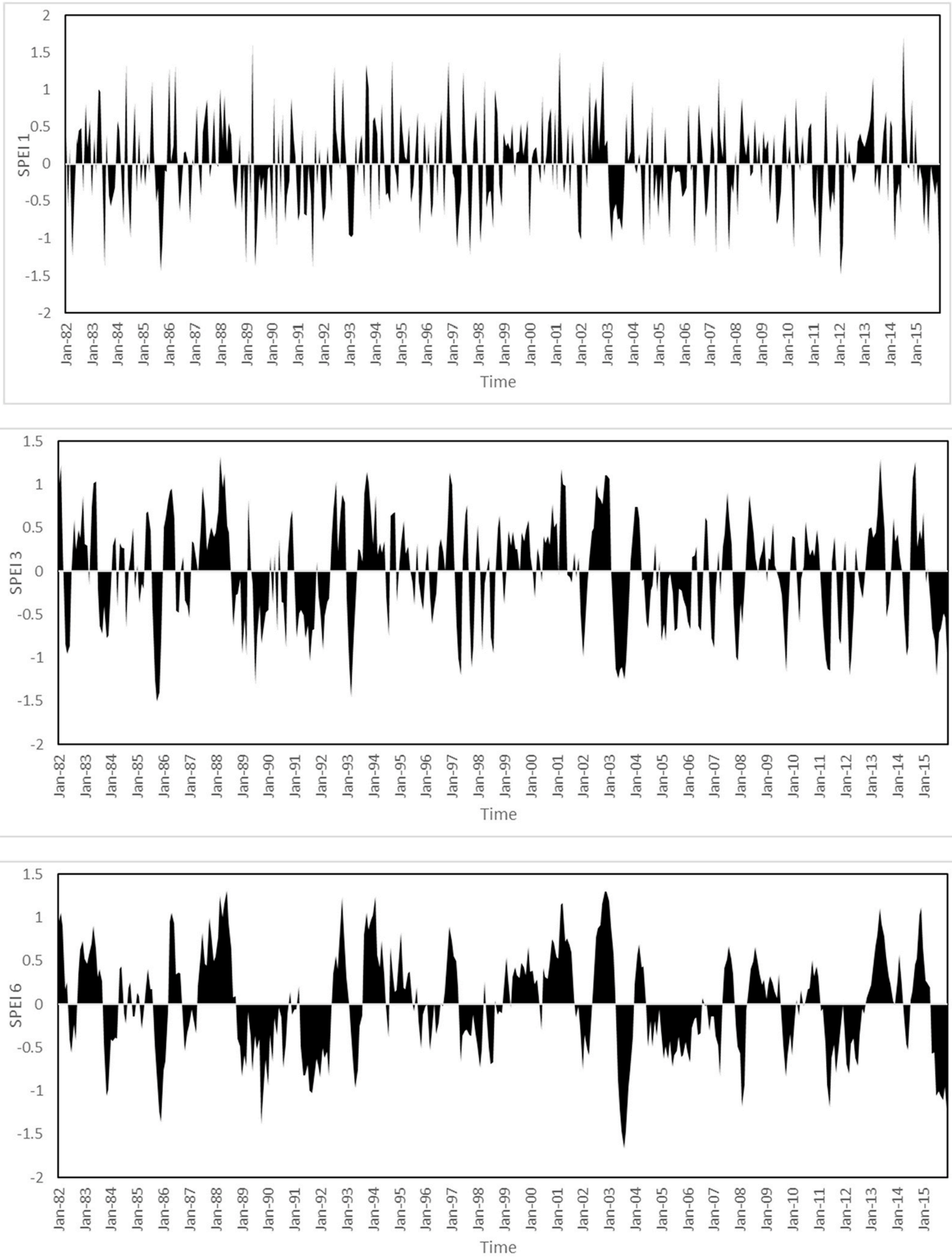

Fig. 3. (A) Variation of SPEI 1 with time.

based on the statistical parameters of drought duration and severity at different truncation levels. Based on this theory, drought duration, severity and intensity are defined in reference to the truncation levels. Drought severity is the sum of drought parameters below the truncation level while drought duration is the number of months or years during which the drought parameter is continuously below the truncation level. Drought intensity is drought severity divided by respective drought duration. Thus, drought duration is expressed as period during which a drought parameter is continuously below the critical level, i.e., the number of months between the commencement of drought and the end month (Spinoni et al., 2014). An illustration of drought characteristics for a given threshold level is shown in Fig. 2.

2.4. Interpolation methods

Interpolation methods were used in analyzing both short-term and long-term distribution of SPEI. Interpolation have been used in the recent past in a number of studies (Kilibarda et al., 2015; Suparta and Rahman, 2016) to assess climate change time series. In this study, time series of annual and seasonal SPEI were subjected to interpolation. Spatial interpolation is a procedure of estimating weather or climatic condition of an unobserved area from points spread over an observed area (Ghebrezgabher et al., 2016). However, the accuracy of spatial interpolation depends on the quality of the data available for the observed area. Other factors that determines the accuracy of spatial interpolation includes the distance from the sea, atmospheric haze and

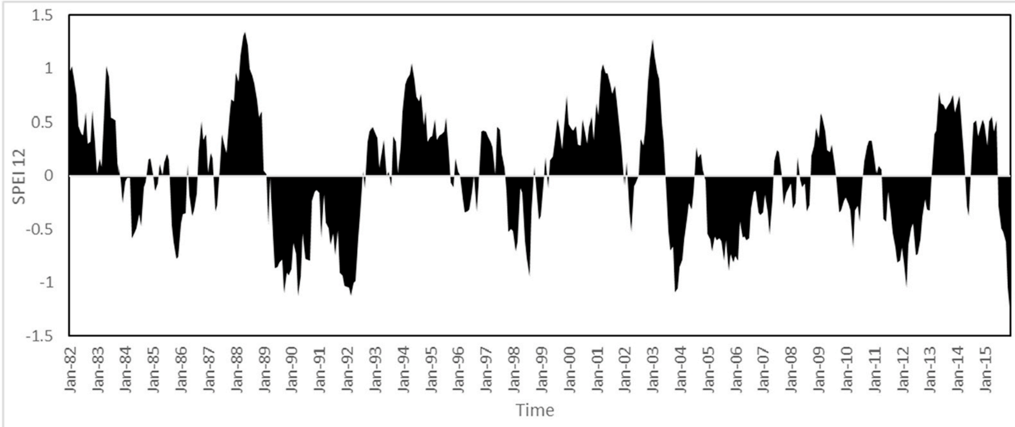

Fig. 3. (*continued*).

circulation, and the topography of the area (Irmak et al., 2010). Therefore, underestimation or overestimation is a limitation to spatial interpolation (Gottschalk et al., 2015; Plouffe et al., 2015). A number of interpolation techniques are available in ArcGIS including the Inverse Distance Weighting (IDW), Kriging, Spline and Natural Neighbor. In this study Inverse Distance Weighting (IDW) was preferably selected over other interpolation methods for its suitability to evenly distributed data (Azpurua & dos Ramos, 2010). This method is deterministic whereby values of unmeasured points are estimated by linear combination of values at nearby measured points. Inverse Distance Weighting has been used previously in similar studies such as Angel et al. (2019) and Vu et al. (2018).

3. Results and discussion

3.1. Temporal drought characteristics

3.1.1. Observed drought occurrence

Table 2 presents frequencies of drought occurrences at different time scales for various drought categories. Wet conditions are less persistent for the 1-month SPEI compared to the other timescales. However wet periods are more persistent in a 3- and 12-month timescale while drought periods are more than wet periods for the remaining timescales. Generally, there were statistically significant differences ($p < 0.001$) in the categories of drought as identified by SPEI at various timescales. On the contrary, there were no statistically significant differences ($p > 0.001$) in SPEI at different timescales in identifying drought in various categories.

The results further indicate a decreasing trend in the frequency of moderately severe droughts except for 1-month SPEI. This implies that the 1-month SPEI could not be useful in evaluating drought trends in the region. This is further explained by the ever-drying conditions in Somalia (being a semi-arid country) that results in frequent precipitation deficits.

3.1.2. Variation of drought duration, intensity and frequency with time

SPEI values enable users to analyze distribution of drought both in time and space. In this study 1-Month, 3-Month, 6-Month and 12-Month timescales were chosen for drought evaluation. Fig. 3 (a to d) clearly depicts variability of drought sequence, duration and severity. Fig. 3(a) shows that drought events are more frequent with shorter durations for 1-month SPEI compared to the 3-, 6-, and 12-month SPEI. Generally, as the record time increases, drought duration increases while the drought frequency and intensity declines. Radmanesh et al. (2019) also found a decreasing trend in frequency of the wet and dry periods with increase in SPEI timescales. This implies that the increase in timescale have a smoothing effect on individual drought severity and an increasing effect on drought duration. These results agrees with those of Haile et al. (2020) who observed an overall smoothing effect in drought occurring across the Greater Horn of Africa over a 52 yr period for SPEI-1, SPEI-3, SPEI-6, and SPEI-12. Results further shows that the most intense drought (SPEI = −1.09) based on SPEI 6 occurred between May to December 2003. For the 12-month SPEI, the most intense drought (SPEI = −0.72) occurred between July to December 2015. In contrast, the maximum drought duration for the 6-month and 12-month SPEI were found to be 26 months and 41 months respectively. This therefore means that drought detection varies with the timescales in which the SPEI data is recorded. Using SPEI, drought events were successfully identified. For example, SPEI 12 successfully identified the May 2011 to January 2013 (duration of 21 months with an intensity of −0.55) drought that have been featured in other studies (Anderson et al., 2012; Dutra et al., 2013). Droughts with high severity occurred during 1973–1974, 1984–1985, 1989–1993 and 2010–2011. These drought events were found to have large scale impacts in the Horn of Africa on the environment and society (Haile et al., 2019). The 1984–1985 and 1989–1993 drought events were previously found to have affected the entire African continent (Masih et al., 2014). The 1984 drought was previously found to have affected the entire Horn of Africa presenting serious environmental problems (Ghebrezgabher et al., 2016).

Fig. 4 (a) to 4 (d) shows temporal trends of drought based on the Standardized Precipitation Index (SPI) at various timescales (1-month, 3-month, 6-month and 12-month). Drought showed similar trends to those identified by SPEI. However, the wet and dry conditions did not necessarily occur at the same time even if the indices are calculated at similar timescales. For example, SPEI 6 shows dry conditions in the year 2003 whereas SPI 6 shows wet conditions on the same year. This is could be attributed to the fact that SPI is based on precipitation only, whereas the SPEI is based on both precipitation and potential evapotranspiration (PET). To determine correlation between SPI and SPEI, a Pearson's correlation was calculated for the 1-, 3-, 6-, and 12-month indices. The correlation coefficient decreased with increase in timescale with the coefficients ranging between 0.66 and 0.71. Other studies have also found high correlation between SPI and SPEI (Vicente-Serrano et al., 2010; Jiang et al., 2015).

3.2. Spatial evaluation of drought

Drought identification was done for all stations using the runs theory. For geographic locations, drought characteristics including count and severity were determined. A total of 14,820 drought occurrences were extracted. On average there are about 76 drought occurrences for each geographic location with a mean duration of 2.53 months and a mean severity of −1.42. Fig. 5 (a) shows the spatial distribution of SPEI locations in Somalia. Fig. 5(b) and (c) and 5 (d) shows spatial

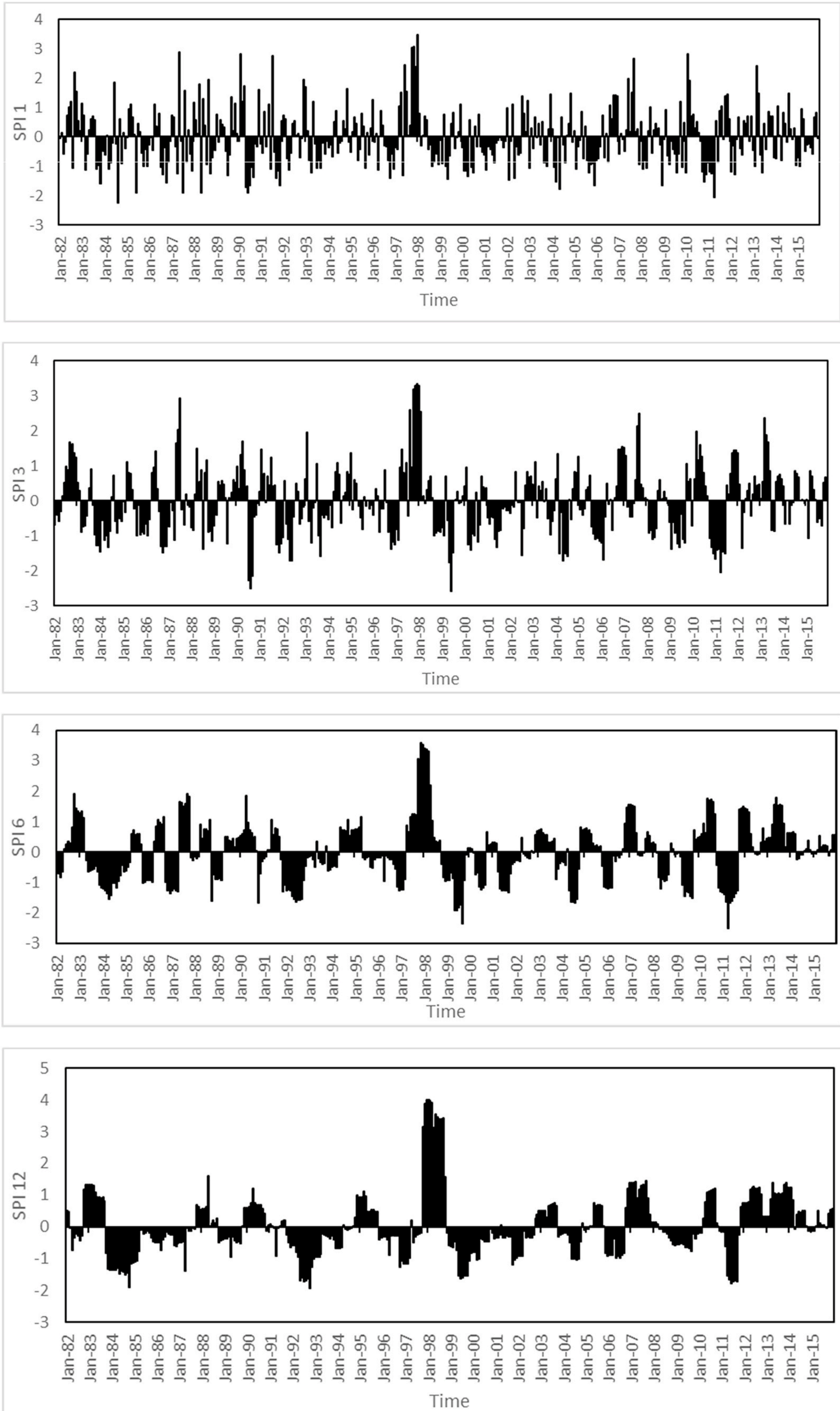

Fig. 4. (A) Variation of SPI 1 with time.

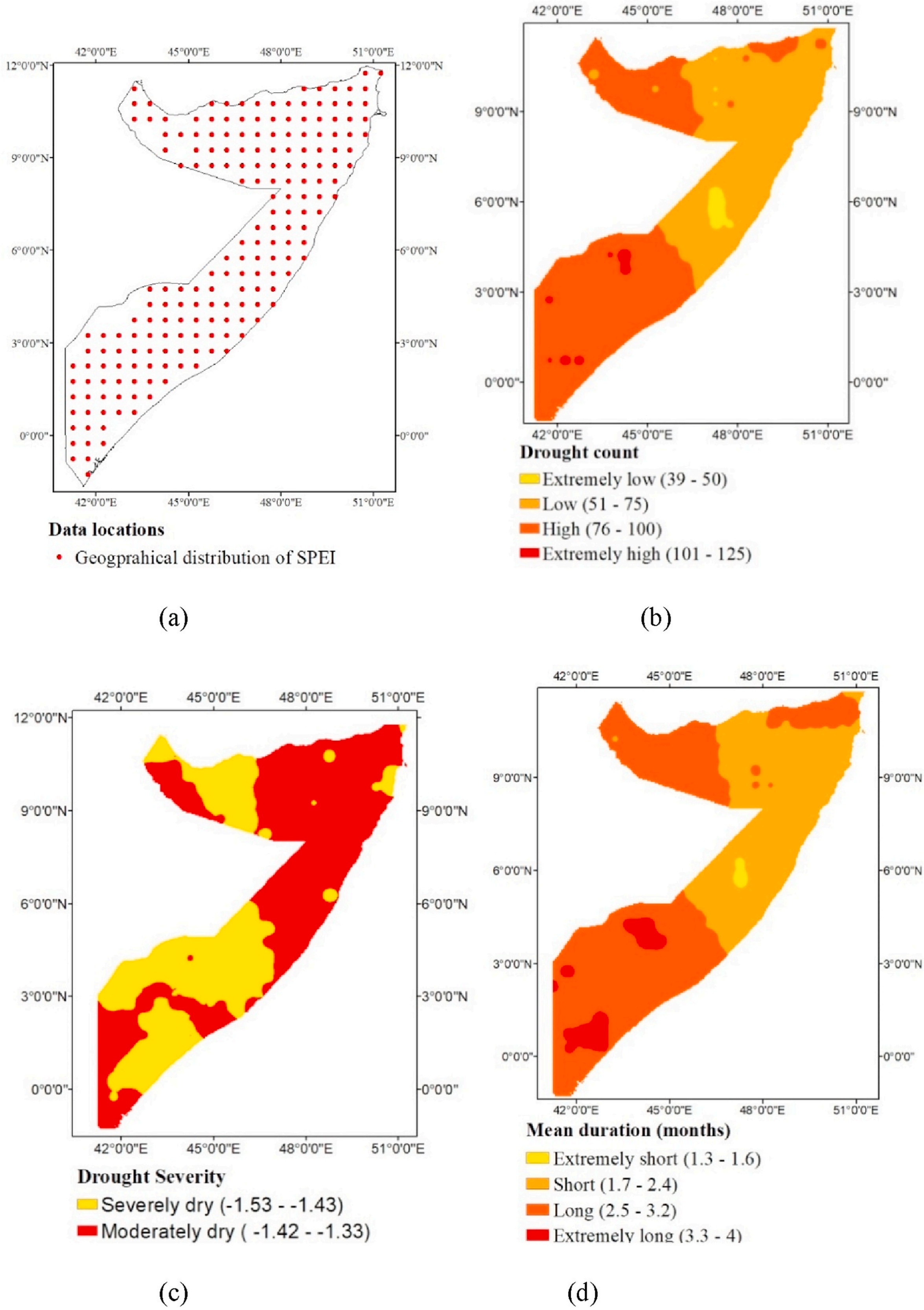

Fig. 5. Spatial distribution of drought characteristics over Somalia: (a) SPEI locations, (b) drought count, (c) drought severity and (d) drought duration.

distribution of drought characteristics in terms of drought count, mean duration and mean severity respectively. Fig. 5 (b) shows remarkable variations of drought count in space; The northern parts of Somalia recorded high (76–100) drought occurrences while the central parts have counts ranging from low (51–75) to extremely low (39–50). However, the southern parts presented between high (71–100) and extremely high (100–125) drought counts.

Drought severity is almost uniformly distributed throughout the country as shown in Fig. 5 (c); Drought ranges between moderately dry (−1.42 to −1.33) to severely dry (−1.53 to −1.43) conditions. Fig. 5 (d) shows spatial variation of mean duration; A small section of the central parts of Somalia experienced extremely short drought duration (1.3–1.6 months). North West and south west Somalia experienced between long (2.5–3.2 months) and extremely long droughts (3.3–4.0 months). However, the larger part of central Somalia experienced short (1.7–2.4 months) drought durations. A negative relationship between drought count and drought duration can be deduced from these results as shown in Fig. 5(b) and (d).

It is evident that there are a lot of differences in drought characteristics regionally within the country. The North West and South West parts are more prone to have high frequencies of droughts with short duration. Drought prevention and management in these areas should therefore focus efforts on short and moderate droughts to reduce the impacts of these droughts on crops. The central parts are more prone to low frequencies of droughts which last for long durations. In these places, drought prevention and management should focus on minimizing their impacts on water availability within the country.

4. Conclusion

Drought is one of the most destructive natural phenomena in the Horn of Africa and Somalia has always been the unfortunate recipient of their detrimental consequences. These droughts often develop gradually and unnoticed. This necessitates drought characterization in terms of frequency, severity and duration for informed drought management by the relevant governmental and non-governmental agencies. In this study, SPEI at the 1-, 3-, 6- and 12-month timescales were used to evaluate temporal characteristics of drought for the period between 1980 and 2015. SPEI 3 was however selected for spatial evaluation of drought distribution. Results presented in this study are in line with findings reported in other studies, and enhance the knowledge and understanding of drought phenomena in Somalia. Based on the results, following conclusions can be made:

1. SPEI was successfully used to identify and characterize historical drought events. Based on SPEI 12, three major drought events occurred during the study period. The longest drought occurred from March 1989 to July 1992, lasting for a period of 41months. The other two occurred from December 2004 to May 2007 and from May 2011 to January 2013 lasting for 30 months and 21 months respectively.
2. The SPEI-based drought evaluation in Somalia reveals no specific spatial and temporal pattern of drought events. However, higher frequencies and severity of drought events were observed in recent years. This is likely to have detrimental impacts on water availability and crop productivity in the country. It can also result in destructive effects on the environment and a negative impact on both social and economic sectors.

These results being the first in the country are useful to policy and decision makers in furthering the understanding of drought and for future preparedness.

Author contribution

All the authors contributed efforts towards the accomplishment of this work. Sylus K. Musei conceived and designed the study, retrieved and analyzed the data and wrote the original draft of the manuscript. Justin M. Nyaga assisted in interpretation of the results whereas Zeila A. managed literature searches and verified that the objectives of the study were met. The draft manuscript was revised and final copy read and approved by all.

CRediT author contribution statement

Sylus Kipngeno Musei: All the authors are credited for having contributed significantly to the success of this work. **Justin Muhoro Nyaga:** All the authors are credited for having contributed significantly to the success of this work. **Abdi Zeila Dubow:** All the authors are credited for having contributed significantly to the success of this work.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Abdulkadir, G., 2017. Assessment of drought recurrence in Somaliland : causes , impacts and climatology. Weather Forecast. 5 (2), 1–12. https://doi.org/10.4172/2332-2594.1000204.

Ali, Z., Hussain, I., Faisal, M., Almanjahie, I.M., Ahmad, I., Khan, D.M., Qamar, S., 2019. A probabilistic weighted joint aggregative drought index (PWJADI) criterion for drought monitoring systems. Tellus Dyn. Meteorol. Oceanogr. 71 (1), 1588584.

Allen, C.D., Macalady, A.K., Chenchouni, H., Bachelet, D., McDowell, N., Vennetier, M., Cobb, N., 2010. A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. For. Ecol. Manag. 259 (4), 660–684. https://doi.org/10.1016/j.foreco.2009.09.001.

Alwesabi, M.S., 2012. MODIS NDVI Satellite Data for Assessing Drought in Somalia during the Period 2000-2011, 257.

Anderson, W.B., Zaitchik, B.F., Hain, C.R., Anderson, M.C., Yilmaz, M.T., Mecikalski, J., Schultz, L., 2012. Towards an integrated soil moisture drought monitor for East Africa. Hydrol. Earth Syst. Sci. 16 (8), 2893–2913. https://doi.org/10.5194/hess-16-2893-2012.

Angel, L., Manuela, M., Rodrigues, R., Ceris, S., Superior, I., Ist, T., Ul, L., 2019. Journal of Hydrology : regional studies spatio-temporal variability of droughts over past 80 years in Madeira Island. J. Hydrol.: Reg. Stud. 25 (1), 100623 https://doi.org/10.1016/j.ejrh.2019.100623.

Azpurua, M., dos Ramos, K., 2010. A comparison of spatial interpolation methods for estimation of average electromagnetic field magnitude. Progress In Electromagnetics Research M 14 (September), 135–145. https://doi.org/10.2528/PIERM10083103.

Bachmair, S., Stahl, K., Collins, K., Hannaford, J., Acreman, M., Svoboda, M., Overton, I. C., 2016. Drought indicators revisited: the need for a wider consideration of environment and society. Wiley Interdisciplinary Reviews: Water 3 (4), 516–536. https://doi.org/10.1002/wat2.1154.

Bae, S., Lee, S.H., Yoo, S.H., Kim, T., 2018. Analysis of drought intensity and trends using the modified SPEI in South Korea from 1981 to 2010. Water (Switzerland) 10 (3). https://doi.org/10.3390/w10030327.

Beguería, S., Vicente-Serrano, S.M., Angulo-Martínez, M., 2010. A multiscalar global drought dataset: the SPEI base: a new gridded product for the analysis of drought variability and impacts. Bull. Am. Meteorol. Soc. 91 (10), 1351–1356. https://doi.org/10.1175/2010BAMS2988.1.

Chen, S., Zhang, L., Liu, X., Guo, M., She, D., 2018. The use of SPEI and TVDI to assess temporal-spatial variations in drought conditions in the Middle and lower reaches of the Yangtze river basin, China. Advances in Meteorology. https://doi.org/10.1155/2018/9362041. *2018*.

Clark, J.S., Iverson, L., Woodall, C.W., Allen, C.D., Bell, D.M., Bragg, D.O.N.C., Jackson, S.T., 2016. The impacts of increasing drought on forest dynamics , structure , and biodiversity in the United States, 2329-2352. https://doi.org/10.1111/gcb.13160.

Dai, A., 2011. Drought under global warming: a review. Wiley Interdisciplinary Reviews: Climate Change 2 (1), 45–65. https://doi.org/10.1002/wcc.81.

Dutra, E., Magnusson, L., Wetterhall, F., Cloke, H.L., Balsamo, G., Boussetta, S., Pappenberger, F., 2013. The 2010-2011 drought in the Horn of Africa in ECMWF reanalysis and seasonal forecast products. Int. J. Climatol. 33 (7), 1720–1729. https://doi.org/10.1002/joc.3545.

Ecosoc, U.N., 2007. Africa review report on drought and desertification. Fifth Meeting of the Africa Committee on Sustainable Development (ACSD-5) (November), 71. Addis Ababa 22-25 October 2007.
Ensham, R.J.F., Airfax, R.J.F., 2012. Potential aboveground biomass in drought-prone forest used for rangeland pastoralism, 22, pp. 894–908, 3.
Fredriksen, A., 2016. Crisis in ' a normal bad year ': spaces of humanitarian emergency , the Integrated Food Security Phase Classification scale and the Somali famine of 2011. https://doi.org/10.1177/0308518X15597446.
Frenken, K. (Ed.), 2005. Irrigation in Africa in Figures: AQUASTAT Survey, 2005, 29. Food & Agriculture Org.
Ghebrezgabher, M.G., Yang, T., Yang, X., 2016. Long-term trend of climate change and drought assessment in the Horn of Africa, 2016 Advances in Meteorology. https://doi.org/10.1155/2016/8057641.
Gottschalk, L., Krasovskaia, I., Dominguez, E., Caicedo, F., Velasco, A., 2015. Interpolation of monthly runoff along rivers applying empirical orthogonal functions: Application to the Upper Magdalena River, Colombia. J. Hydrol. 528, 177–191. https://doi.org/10.1016/j.jhydrol.2015.06.029.
Hadden, B.R.L., Lee, R., 2007. The Geology of Somalia : a Selected Bibliography of Somalian Geology , Geography and Earth Science . 7701 Telegraph Road UNCLASSIFIED/UNLIMITED Bibliography of Liberian Earth Science. (February).
Haile, G.G., Tang, Q., Sun, S., Huang, Z., Zhang, X., Liu, X., 2019. Droughts in East Africa: causes, impacts and resilience. Earth Sci. Rev. 193, 146–161.
Haile, G.G., Tang, Q., Leng, G., Jia, G., Wang, J., Cai, D., Sun, S., Baniya, B., Zhang, Q., 2020. Long-term spatiotemporal variation of drought patterns over the Greater Horn of Africa. Sci. Total Environ. 704, 135299. https://doi.org/10.1016/j.scitotenv.2019.135299.
Irmak, A., Ranade, P.K., Marx, D., Irmak, S., Hubbard, K.G., Meyer, G.E., Martin, D.L., 2010. S i c v n 53 (6), 1759–1771.
Jiang, R., et al., 2015. Use of four drought indices for evaluating drought characteristics under climate change in Shaanxi, China: 1951–2012. Nat. Hazards 75 (3), 2885–2903. https://doi.org/10.1007/s11069-014-1468-x.
Johnson, P.M., Mayrand, K., 2007. Governing Global Desertification 31, 93–95.
Kalantari, Z., Ferreira, C.S.S., Keesstra, S., Destouni, G., 2018. Nature-based solutions for flood-drought risk mitigation in vulnerable urbanizing parts of East-Africa. Current Opinion in Environmental Science & Health 5, 73–78.
Kilibarda, M., Tadić, M.P., Hengl, T., Luković, J., Bajat, B., 2015. Global geographic and feature space coverage of temperature data in the context of spatio-temporal interpolation. Spatial Statistics 14, 22–38. https://doi.org/10.1016/j.spasta.2015.04.005.
Lee, S.H., Yoo, S.H., Choi, J.Y., Bae, S., 2017. Assessment of the impact of climate change on drought characteristics in the Hwanghae Plain, North Korea using time series SPI and SPEI: 1981–2100. Water (Switzerland) 9 (8). https://doi.org/10.3390/w9080579.
Li, Y., Xie, Z., Qin, Y., Xia, H., Zheng, Z., Zhang, L., 2019. Drought under Global Warming and Climate Change : an Empirical Study of the Loess Plateau, 1–15. https://doi.org/10.3390/su11051281.
Lott, F.C., Christidis, N., Stott, P.A., 2013. Can the 2011 East African drought be attributed to human-induced climate change? Geophys. Res. Lett. 40 (6), 1177–1181. https://doi.org/10.1002/grl.50235.
Masih, I., Maskey, S., Mussá, F.E.F., Trambauer, P., 2014. A review of droughts on the African continent: a geospatial and long-term perspective. Hydrol. Earth Syst. Sci. 18 (9), 3635.
Maxwell, D., Fitzpatrick, M., 2012. The 2011 Somalia famine: context, causes, and complications. Global Food Security 1 (1), 5–12. https://doi.org/10.1016/j.gfs.2012.07.002.
Maystadt, J.F., Ecker, O., 2014. Extreme weather and civil war: Does drought fuel conflict in Somalia through livestock price shocks? Am. J. Agric. Econ. 96 (4), 1157–1182. https://doi.org/10.1093/ajae/aau010.
McKee, T.B., Doesken, N.J., Kleist, J., 1993. The relationship of drought frequency and duration to time scales. In: Proceedings of the 8th Conference on Applied Climatology, 17. American Meteorological Society Boston, MA, pp. 179–183, 22.
Menkhaus, K., 2014. Calm between the storms? Patterns of political violence in Somalia, 1950–1980. Journal of Eastern African Studies 8 (4), 558–572. https://doi.org/10.1080/17531055.2014.949404.
Mishra Ashok, K., Singh Vijay, P., 2010. A review of drought concepts [J]. J. Hydrol. 391 (1), 202–216.
Muchiri, P.W., 2007. Inventory of Hydro-Meteorological Data of Somalia. SWALIM Technical Reports.
Mukherjee, S., Mishra, A., Trenberth, K.E., 2018. Climate change and drought: a perspective on drought indices. Current Climate Change Reports 4 (2), 145–163. https://doi.org/10.1007/s40641-018-0098-x.
Nicholson, S.E., 2014. A detailed look at the recent drought situation in the Greater Horn of Africa. J. Arid Environ. 103, 71–79. https://doi.org/10.1016/j.jaridenv.2013.12.003.
Nyong, A., Development, A., Group, B., Adesina, F., 2007. *The Value of Indigenous Knowledge in Climate Change Mitigation and Adaptation Strategies in the African Sahel*. (June). https://doi.org/10.1007/s11027-007-9099-0.
Ou, C., Hao, X., 2018. Agriculture drought and food security monitoring over the horn of Africa (HOA) from space. 2018 7th International Conference on Agro-Geoinformatics, 2018 Agro-Geoinformatics 1–4. https://doi.org/10.1109/Agro-Geoinformatics.2018.8476128.
Paper, O., 2009. Application of relative drought indices in assessing climate-change impacts on drought conditions in Czechia, 155–171. https://doi.org/10.1007/s00704-008-0020-x.
Parry, M.L., Rosenzweig, C., Iglesias, A., Livermore, M., Fischer, G., 2004. Effects of climate change on global food production under SRES emissions and socio-economic scenarios, 14, 53–67. https://doi.org/10.1016/j.gloenvcha.2003.10.008.
Plouffe, C.C.F., Robertson, C., Chandrapala, L., 2015. Comparing interpolation techniques for monthly rainfall mapping using multiple evaluation criteria and auxiliary data sources: a case study of Sri Lanka. Environ. Model. Software 67, 57–71. https://doi.org/10.1016/j.envsoft.2015.01.011.
Potop, V., Boroneanţ, C., Možný, M., Štěpánek, P., Skalák, P., 2014. Observed spatiotemporal characteristics of drought on various time scales over the Czech Republic. Theor. Appl. Climatol. 115 (3–4), 563–581. https://doi.org/10.1007/s00704-013-0908-y.
Radmanesh Said, A.A., Cetin, M., Yurtal, R., 2019. Drought assessment and monitoring using some drought indicators in the semi-arid Puntland state of Somalia. Fresenius Environ. Bull. 28 (11A), 8765–8772.
Spinoni, J., Naumann, G., Carrao, H., Barbosa, P., Vogt, J., 2014. World drought frequency, duration, and severity for 1951-2010. Int. J. Climatol. 34 (8), 2792–2804. https://doi.org/10.1002/joc.3875.
Suparta, W., Rahman, R., 2016. Spatial interpolation of GPS PWV and meteorological variables over the west coast of Peninsular Malaysia during 2013 Klang valley flash flood. Atmos. Res. 168, 205–219. https://doi.org/10.1016/j.atmosres.2015.09.023.
Thornthwaite, C.W., 1948. An approach toward a rational classification of climate. Geograph. Rev. 38, 55–94. https://doi.org/10.2307/210739.
Touchan, R., Anchukaitis, K.J., Meko, D.M., Attalah, S., Baisan, C., Aloui, A., 2008. Long term context for recent drought in northwestern Africa. Geophys. Res. Lett. 35 (13).
Vicente-Serrano, S.M., Beguería, S., López-Moreno, J.I., 2010. A multiscalar drought index sensitive to global warming: the standardized precipitation evapotranspiration index. J. Clim. 23 (7), 1696–1718. https://doi.org/10.1175/2009JCLI2909.1.
Vicente-Serrano, S.M., Beguería, S., Gimeno, L., Eklundh, L., Giuliani, G., Weston, D., et al., 2012a. Challenges for drought mitigation in Africa: the potential use of geospatial data and drought information systems. Appl. Geogr. 34, 471–486.
Vicente-Serrano, S.M., Beguería, S., Lorenzo-Lacruz, J., Camarero, J.J., López-Moreno, J. I., Azorin-Molina, C., Sanchez-Lorenzo, A., 2012b. Performance of drought indices for ecological, agricultural, and hydrological applications. Earth Interact. 16 (10) https://doi.org/10.1175/2012EI000434.1.
Vrieling, A., Meroni, M., Mude, A.G., Chantarat, S., Ummenhofer, C.C., de Bie, K.C., 2016. Early assessment of seasonal forage availability for mitigating the impact of drought on East African pastoralists. Remote sensing of environment 174, 44–55.
Vu, T.M., Raghavan, S.V., Liong, S., Mishra, A.K., 2018. Uncertainties of Gridded Precipitation Observations in Characterizing Spatio-Temporal Drought and Wetness over, 2081, pp. 2067–2081. https://doi.org/10.1002/joc.5317. October 2017.
World Bank, 2018. Somalia Drought Impact & Needs Assessment, vol. I. United Nations Development Programme, p. 18.
Yevjevich, V., 1967. An Objective Approach to Definitions and Investigations of Continental Hydrologic Drought S an Objective Approach to Definitions and Investigations of Continental Hydrologic Droughts. Hydrology Papers. Colorado state university, Fort Collins, Colorado.
Zotarelli, L., Dukes, M.D., Romero, C.C., Migliaccio, K.W., Morgan, K.T., 2010. Step by Step Calculation of the Penman-Monteith Evapotranspiration (FAO-56 Method). Institute of Food and Agricultural Sciences. University of Florida.