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ORIGINAL ARTICLE

Modeling the Spatio-Temporal Meteorological Drought Characteristics Using the Standardized Precipitation Index (SPI) in Raya and Its Environs, Northern Ethiopia

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Abstract
In Ethiopia, recurrent droughts were associated with El Niño phenomenon, particularly in the study area where the majority of smallholder farmers depend on rain-fed agriculture. The aim of this study was to model the spatio-temporal meteorological drought onset, offset, duration, magnitude, intensity, frequency, severity and spatial extent in Raya and its environs, Northern Ethiopia. Both the ground meteorological stations and TAMSAT (tropical applications of meteorology using satellite and ground-based observations) monthly rainfall data were gathered from the National Meteorological Agency of Ethiopia for the period 1983–2015. The Inverse Distance Weighting (IDW), a type of the deterministic interpolation method was applied to quantify the amount of seasonal rainfall by producing surface rainfall map. A Standardized Precipitation Index (SPI) at 3-month timescale was used to evaluate seasonal rainfall deficit and characterize meteorological drought. The results revealed that all sites obtained minimal and irregular rainfall, hence led to catastrophic droughts. Also, the findings showed that there was high rainfall variability across the study area that ranged from 28.14 to 42.32%. As a result, mild-to-severe meteorological drought phenomena were observed once in every 2–3 years. This incidence was found to be high in terms of spatial and temporal coverage during the last three decades. Therefore, this study may help to offer better insight for policymakers to establish drought mitigation and adaptation strategies.

Keywords Meteorological drought characteristics · Rainfall · SPI-3 · Raya · Ethiopia

1 Introduction

Drought has been caused by the decline of seasonal or annual rainfall in a long period (McKee et al. 1993; Peters et al. 2002). Wilhite (1996) reported that the extended periods of acute water shortage due to meteorological drought are increasing at an alarming rate in both developed and developing countries. Belal et al. (2014) stated that one-third of the world's population resides in water scarce areas, and nearly 1.1 billion people lack access to clean drinking water. Studies showed that people dwelling in areas with high water stresses projected to increase significantly from 300 million to 3 billion by the year 2025. In developing countries, e.g., Ethiopia, the impacts of drought are more devastating, leading to food shortages, population migration, and livestock mortality (Kogan et al. 2013). Abebe (2014) and Tabari et al. (2015) reported that water is a scarce resource in the northern highlands of Ethiopia due to high rainfall variability and recurrent drought. Besides, the area is characterized by dry or arid and semi-arid climatic conditions. As a result, the incidence of drought over the region has spatial and temporal variations and it becomes critical to monitor the relative drought occurrence levels and their distributions over a region at a time (Wang et al. 2001). Şen et al. (2017) reported that arid regions experience both high temperature and evapotranspiration. That is why drought occurred repeatedly in all agro-climatic zones of the study area such as lowlands, midlands, and highlands in the last three decades. World Bank (2006) reported that the challenge has gradually expanded from the north to the rest of the country

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and its intensity has deepened. However, its onset, offset, spatial extent, magnitude, intensity, duration, frequency, and severity differ both in spatial and temporal coverage. Svoboda et al. (2012) reported that this phenomenon might extend over a season or longer period, leading to inadequate rainfall to meet the demands of humans, vegetation and livestock. This may cause complex environmental issues and impacts, particularly on the economy and society (Shamsipour et al. 2011). For instance, in the year 2015, the study area experienced its worst drought because of El Niño resulting in failure of the main rains (July, August, and September) season in the most parts. The failure of two successive main rainy seasons, which feeds nearly 80–85% of the population, caused an increase in malnutrition rates due to food shortage and a high shortage of forages for livestock. World Bank (2006) indicated that food shortages during drought period drive people to strip natural resources (e.g., fuelwood, craft supplies, and wild foods). This led to a significant effect on the livelihood of the community that relied on rain-fed agriculture as well as the regional or national economic growth at large.

The incidence of meteorological drought has largely escalated because of the extended periods of rainfall deficiency (Wilhite 1996). Gidey et al. (2017) reported that the long-term rainfall condition of the study area was up to 558 mm and its distribution was irregular. As a result, the manifestations of meteorological drought became severe. Therefore, this natural hazard needs to be monitored scientifically to mitigate its negative impacts. Tabari et al. (2015) stated that there is a need to understand the previous drought events using a scientific method of assessing the condition rainfall variability in Ethiopia. Gidey et al. (2018) reported that several meteorological drought indices have been developed to measure the incidence of drought. Conversely, the Standardized Precipitation Index (SPI) was found to be important to evaluate the extent of rainfall deficit in a given period for two reasons: (1) it needs only rainfall data; (2) it can be applied worldwide on different timescales such as 1, 3, 6, 9, 12, and 24 months. The index also provides early warning information to formulate appropriate mitigation measures locally, regionally and contently. This may support policy improvement, decision-making and build up a drought resilience strategic framework in the economic development of the community. For example, selection of an appropriate timescale helps in in-depth assessment of the nature of drought such as frequency, magnitude, and duration (McKee et al. 1993). Studying of meteorological drought over a short timescale would have great significance to small and marginal farmers as well as decision-makers to introduce proper water resource management mechanisms in areas severely affected by drought like Raya and its environs, Ethiopia. The aim of this study was to model the spatio-temporal meteorological drought onset, offset, duration, magnitude, intensity, severity, frequency, and extent using the Standardized Precipitation Index (SPI) at 3-month timescale in Raya and its environs, Northern Ethiopia.

2 Materials and Methods

2.1 Study Area

The study area is found at 39°24′40″ and 40°25′20″ Easting and 12°7′20″ and 13°8′0″ Northing (Fig. 1) (Gidey et al. 2017). The area has 11 districts located in three agro-ecological zones such as lowland (e.g., Gulina, Yalo, Megale), midland (e.g., Alamata, Kobo, Hintalo Wejirat, Raya Azebo), and highlands (e.g., Gidan, Alaje, Ofla, and Endamehoni). Gidey et al. (2017) reported that the study area covers about 14,532 km^2. Ayenew et al. (2013) and Gidey et al. (2017) indicated that the rainfall status of the area is irregular and it receives up to 558 mm per annum. Gidey et al. (2017) stated that the maximum temperature (T_{max}) and minimum temperature (T_{min}) of the study area was about 30.5 and 15.9 °C, respectively, in 2015. During this period, the highest temperature was observed during the last three decades (Gidey et al. 2017). The maximum and minimum elevation value of the study area is 4129 and 324 m above sea level (m.a.s.l) (Fig. 1). The mean elevation value of the area is also 1762 m above sea level (m.a.s.l) (Gidey et al. 2017). Eutric cambisols is the major soil type and covers about 4667.1 km^2 (32.1%), while the dystric gleysols cover only small portions of the area, i.e., about 1.1 km^2 or 0.001%, respectively (Gidey et al. 2017).

2.2 Data Collection

2.2.1 Rainfall

Rainfall data are the most important inputs for assessing meteorological drought characteristics (Gidey et al. 2018). Table 1 shows the total number of meteorological stations used to collect the monthly rainfall data from the period 1983–2015. However, the rainfall data had some missing values due to malfunctioning of the recording instruments and other related problems. To resolve this challenge, the tropical applications of meteorology using satellite and ground-based observations (TAMSAT) monthly rainfall data at 4 km by 4 km grid size were collected from the National Meteorological Agency (NMA) of Ethiopia (Gidey et al. 2018). In this case, the satellite data were used as a proxy for observational gaps in weather stations (Kogan et al. 2013; Kogan and Guo 2016).

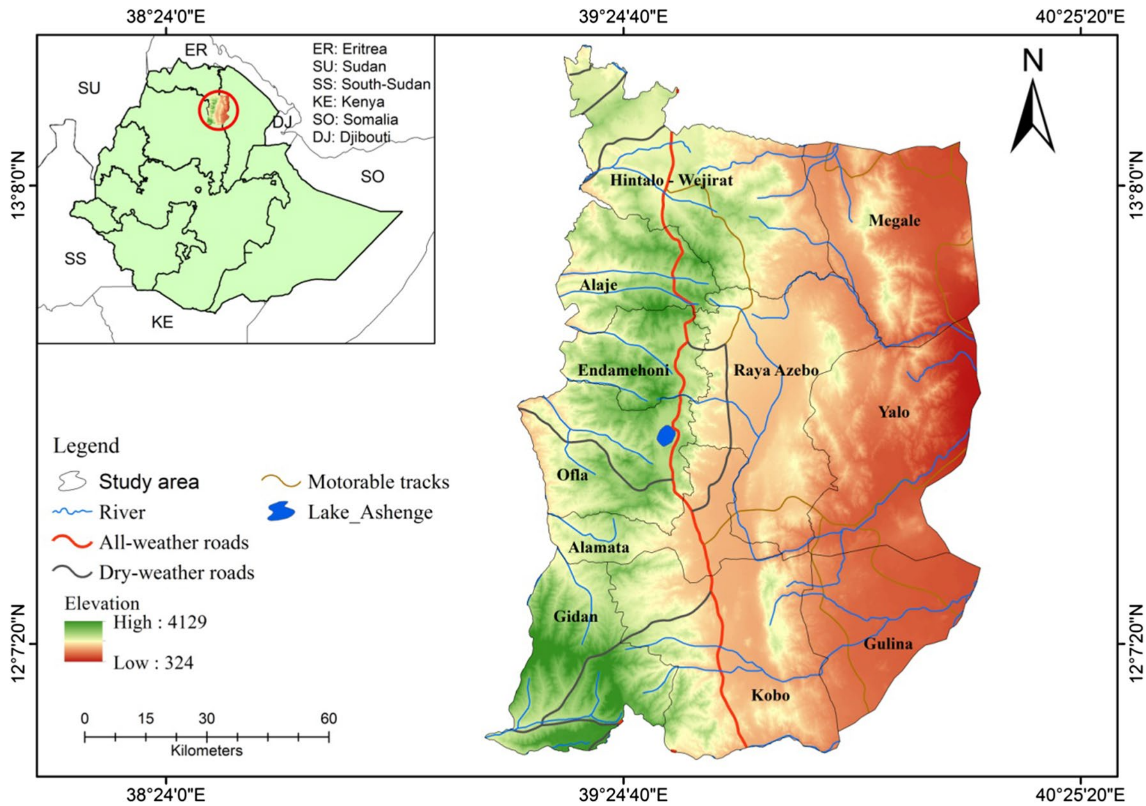

Fig. 1 Map of the study area (improved: Gidey et al. 2017)

Table 1 Spatial distribution of meteorological stations found in the study area (soure: Gidey et al. 2018)

S. no	Station	Location		
		Longitude (E)	Latitude (N)	Altitude (m.a.s.l)
1.	Adigudom	39.51	13.25	2100
2.	Adishehu	39.53	12.93	2465
3.	Alamata	39.71	12.42	1589
4.	Chercher	39.77	12.54	1781
5.	Debub	39.64	13.08	2536
6.	Erebti	39.99	13.25	877
7.	Hashenge	39.52	12.60	2480
8.	Kelawn	39.98	12.14	859
9.	Kobo	39.63	12.13	1470
10.	Korem	39.51	12.51	2450
11.	Mehoni	39.65	12.80	1590
12.	Maichew	39.53	12.78	2432
13.	Robet	39.62	12.01	1629
14.	Sanka	39.48	11.89	1989
15.	Tekulish	39.48	12.15	2181
16.	Waja	39.60	12.30	1458
17.	Yalo	39.88	12.36	869
18.	Zata	39.28	12.51	2334
19.	Zobel	39.75	12.17	1893

2.3 Data Processing and Analysis

2.3.1 Rainfall

The Inverse Distance Weighting (IDW) a type of the deterministic interpolation method was applied to analyze the seasonal of rainfall and produce a surface rainfall map by predicting the values of unmeasured stations based on the known gauge station values using ArcGIS 10.4.1 geostatistical tools (Gidey et al. 2018). This interpolation technique is widely accepted because of its flexibility and reliability. That is why various studies have reported that IDW is better if the gauge stations are well distributed. In this study, the interpolated rainfall data were used as input to assess the values of SPI in each district and determine the historical meteorological drought onset, offset, duration, magnitude, intensity, severity, frequency and spatial extent.

2.3.2 Assessment of Rainfall Variability

In this study, the coefficient of variation (CV) was applied to assess the rainfall variability as follows (Eqs. 1, 2):

$$\mathrm{CV} = \sigma/\bar{x}, \tag{1}$$

$$\mathrm{CV}(\%) = 100 \times \frac{\sigma}{\bar{x}}, \tag{2}$$

where CV(%) = coefficient of variation in %, σ = standard deviation, and $\bar{x}$ = mean of rainfall (1983–2015).

2.3.3 Meteorological Drought Monitoring Using SPI

In 2009, the World Meteorological Organization (WMO) has accepted the Standardized Precipitation Index (SPI) to be a universal meteorological drought index. It also emphasized that all National Meteorological and Hydrological Services found around the world should apply SPI to monitor meteorological droughts. Studies have indicated that SPI is applicable at any location based on the long-term rainfall data. The index is helpful for assessing the wetness and dryness conditions. In this study, the SPI algorithm developed by McKee et al. (1993) was applied to monitor meteorological drought. The index was evaluated by transforming the cumulative probability of rainfall data into the standard normal distribution (AghaKouchak et al. 2015; Rossi et al. 2007; McKee et al. 1993). McKee et al. (1993) reported that SPI values range between − 1 and 1. The negative SPI value shows periods of drought stress, while the positive value shows non-drought conditions. Mishra and Singh (2010) revealed that the strength of SPI is capability to quantify for different timescales. However, Bonaccorso et al. (2003) suggested that SPI on a short timescale like 3 or 6 months is appropriate for detecting drought events that affect agricultural practices, while the longer timescale, such as 12 or 24 months is more suitable for water resources management purposes. In this study, the SPI was calculated for 3 month timescale after the monthly rainfall data were arranged (Fig. 2). Studies showed that the long-term rainfall data are not normally distributed. As a result, it requires the estimation of gamma distribution parameters such as α and β, which would then transform into a normal distribution as follows (Eq. 3):

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} \mathrm{e}^{-x/\beta} \quad \text{for } x > 0, \tag{3}$$

where α = shape parameter, β = scale factor, x = the amount of rainfall, and Γ = gamma function.

SPI estimated based on the cumulative probability function as follows (Eq. 4):

$$G(x) = \int_0^x g(x)\mathrm{d}x = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} \int_0^x x^{\alpha-1} e^{-x/\beta} \mathrm{d}x, \tag{4}$$

where $G(x)$ = cumulative probability of the observed rainfall

US-NDMC (2016) indicated that if the actual rainfall becomes low probability of the cumulative probability function, then the area is under the prevalence of drought; otherwise, the situation reflects wet event. Furthermore, the gamma function is undefined for $x = 0$ and rainfall may have zero value (Gidey et al. 2018). In this study, the cumulative probability function was analyzed as follows (Eq. 5):

$$H(x) = q + (1 - q)G(x), \tag{5}$$

where q = probability of zero.

The fitted rainfall record was transformed into a normal distribution, so that mean SPI is zero and the standard deviation is one. To analyze SPI, the long-term mean seasonal rainfall data of the study area was computed by summing the whole record divided by the number of measurements in the last three decades (Eq. 6):

$$\bar{x} = \frac{1}{n} \times \sum_{i=1}^{n} x_i, \tag{6}$$

where $\bar{x}$ = mean value, n = number of observations in the data set or years, and x_i = the value of ith timescale being averaged.

The standard deviation was also computed to measure the spread of rainfall as follows (Eq. 7):

$$\sigma = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2}, \tag{7}$$

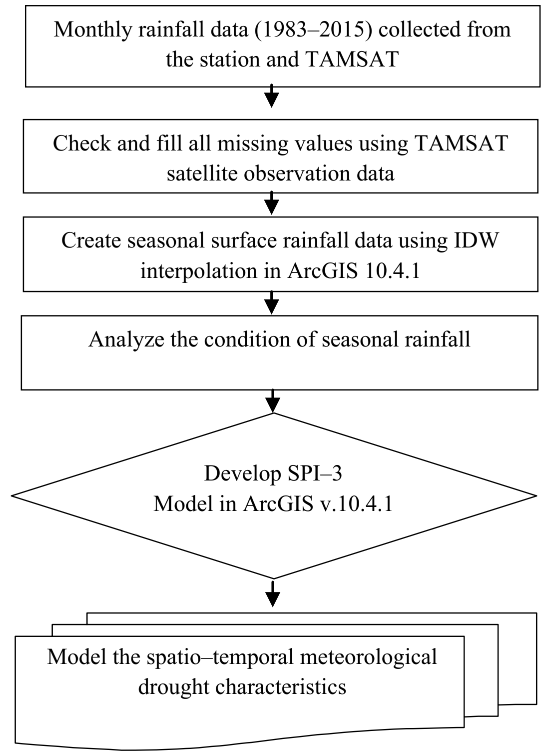

Fig. 2 Schematic diagrams of the spatio-temporal meteorological drought characteristics using SPI

where σ = standard deviation, x_i = each value of data sets, $\bar{x}$ = mean of the data sets, n = total number of observations, and $\sum$ = sum of all data sets.

A model was then established to quantify and interpret the values of SPI in the ArcGIS 10.4.1 as follows (Table 2) (Eq. 7):

$$\text{SPI} = \left(p_i - \bar{p}\right) / \sigma, \tag{8}$$

where p_i = current rainfall, $\bar{p}$ = long-term mean, and σ = the standard deviation of the long-term record.

2.3.4 Analysis of Drought Duration (L), Magnitude (M), Intensity (I), and Frequency

Gidey et al. (2018) indicated that drought duration could be expressed by evaluating the number of repeated drought events. In this study, the drought duration was investigated based on the number of successive drought incidence days or periods. Drought magnitude is also explained by the summation of rainfall deficits over a particular period. The magnitude of drought was assessed based on McKee et al. (1993) as follows (Eq. 9):

$$M = -\left(\sum_{j=1}^{x} SPI_{ij}\right), \tag{9}$$

where M = drought magnitude, x = number of drought months, j = drought months, and SPI_{ij} = SPI value in ith timescale and jth year.

The intensity of drought in the study area from the period 1983–2015 was also statistically analyzed as follows (Eq. 10):

$$I_j = M_j / L_j, \tag{10}$$

where I_j = intensity, M_j = drought magnitude, and L_j = drought duration.

Table 2 Classification of meteorological drought by SPI (source: McKee et al. 1993; Paulo and Pereira 2006; Rossi et al. 2007)

SPI	Drought classification	
	Severity	Symbol
≥ 2	Extremely wet	EW
1.5 to 1.99	Very wet	VW
1.0 to 1.49	Moderately wet	MW
0.99 to 0	Mildly wet	MiW
0 to − 0.99	Mild drought	MiD
− 1.0 to − 1.49	Moderate drought	MD
− 1.5 to − 1.99	Severe drought	SD
≤ − 2.0	Extreme drought	ED

Furthermore, the frequency of drought incidence was assessed to measure the regularity of drought events or return period as follows (Eq. 11):

$$f = (N/T) \times 100, \tag{11}$$

where f = percentage of drought relative frequency, N = number of drought epochs, and T = total number of observed years (in this case it is 33 years).

3 Results and Discussion

3.1 Seasonal Rainfall Variability

Analysis of the seasonal rainfall variability in the arid and semi-arid regions (e.g., the study area) provides good insight to deal with the seasonal droughts in detail (Gidey et al. 2018). Figure 3 presents the seasonal rainfall condition at each district for the period 1983–2015. The results show that all districts received low and irregular rainfall, leading to disastrous droughts. This study observed that during the last 33 years, the maximum and minimum recorded rainfall was 605, 46 mm in the districts of Hintalo Wejirat and Ofla, respectively. The years 1984, 1987, and 2015 were observed as the worst and/or driest period in the area. Conway (2000) noticed that this driest year recorded was due to low rainfall events. Similarly, this study found that during the years 1983, 1984, 1985, 1987, 1989, 1990, 1991, 1993, 1997, 2002, 2004, 2008, 2009, 2014, and 2015, the areas received a maximum of 382 and minimum of less than 212 mm, respectively (Fig. 3).

Furthermore, this study observed that there is very high rainfall variability that ranged between 28.14 and 42.32% in the study area. Table 3 clearly shows that the variability of rainfall in the area was different from district to district. For example, in the district of Ofla, a higher rainfall variation which was estimated at 42.32% was observed. However, lower rate of variability (28.14%) than the other parts of the study area was also observed in the district of Hintalo Wejirat (Table 3). World Bank (2006) reported that rainfall variability may drastically affect the recharge of groundwater in some areas resulting in failure of wells. As a result, the incidences of meteorological drought impact could be severe and affect the production and productivity level of the rainfed agriculture in the area. The ultimate influencing factors of rainfall variability in Northern Ethiopia in general and the study area in particular were due to El Niño–Southern Oscillation events, which are associated with lower than average rainfall (Conway 2000). Alemayehu and Bewket (2016) showed that the frequent droughts in the area during the last 30 years were due to the limited rainfall arising from the El Niño event. Abebe (2014) also observed the occurrences of drought in the northern Ethiopian highlands caused by high

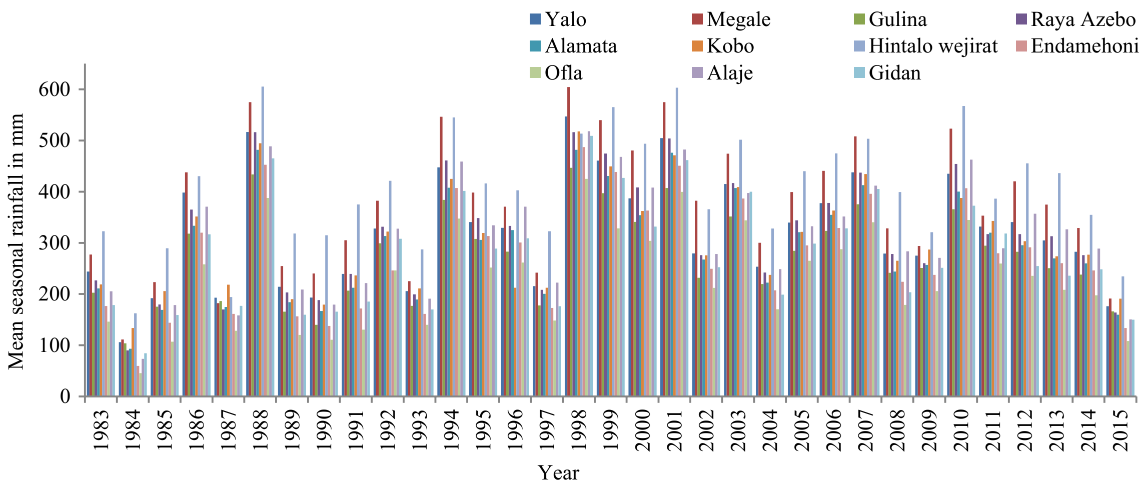

Fig. 3 Mean seasonal rainfall in the study area from 1983 to 2015

Table 3 Seasonal rainfall variability in the study area over the period 1983–2015

District	Rainfall (mm)					
	Min	Max	Mean	SD	CV	CV %
Yalo	106.00	546.87	320.90	109.79	0.34	34.21
Megale	11.53	604.22	372.41	128.51	0.35	34.51
Gulina	103.83	446.56	273.61	90.21	0.33	32.97
Raya Azebo	90.19	516.08	316.29	114.29	0.36	36.13
Alamata	93.27	481.60	294.02	104.00	0.35	35.37
Hintalo Wejirat	162.37	605.25	401.16	112.89	0.28	28.14
Kobo	133.67	517.89	306.08	100.80	0.33	32.93
Endamehoni	59.62	486.99	274.67	111.18	0.40	40.18
Ofla	45.67	424.88	231.64	98.03	0.42	42.32
Alaje	73.37	517.95	312.62	113.59	0.36	36.34
Gidan	84.29	508.84	278.57	107.80	0.39	38.70

rainfall variability in both spatial distributions and timing. Livada and Assimakopoulos (2007) also found that the root cause of drought that occurred in Greece was due to the lack of adequate rainfall. This study also found that the drought incidence was attributable to the irregular behavior of monsoon rainfall, unreliable distribution and the effect of the Danakil depression, which is one of the driest, hottest and lowest places on the earth.

3.2 Meteorological Drought Conditions in the Study Area

The Standardized Precipitation Index (SPI-3) model indicated that the spatio-temporal meteorological drought incidence varied from year to year (Figs. 4, 5a–k). This probably occurred when the SPI-3 result was negative and ended when it is positive. Hence, this study found that the years 1986, 1992, 1995, 1996, 2000, 2005, 2011, and 2012 were moderately wet epochs in all districts in the last 33 years. Similarly, the years 1988, 1994, 1998, 1999, 2001, 2003, 2006, 2007, and 2010 were wet periods (Fig. 5a–k). The year 1998 was wet across all districts. As a result, the areas were free of drought incidence. However, drought intermittently struck the districts during the 1983, 1984, 1985, 1987, 1989, 1990, 1991, 1993, 1997, 2002, 2004, 2008, 2009, 2014, and 2015 period (Fig. 5a–k).

3.3 Historical Meteorological Drought Onset (O), Offset (E), Duration (L), Magnitude (M), and Intensity (I)

Tables 4, 5, and 6 show that the onset, offset, duration, magnitude, and intensity of meteorological drought in the study area during the period 1983–2015. The results indicated that drought struck extensively for a maximum of 3 years between the periods 1983–1985, 1989–1991 and 2013–2015, respectively (Tables 4, 5, 6). For example, in the lowland area (Table 4), the onset, offset, duration of

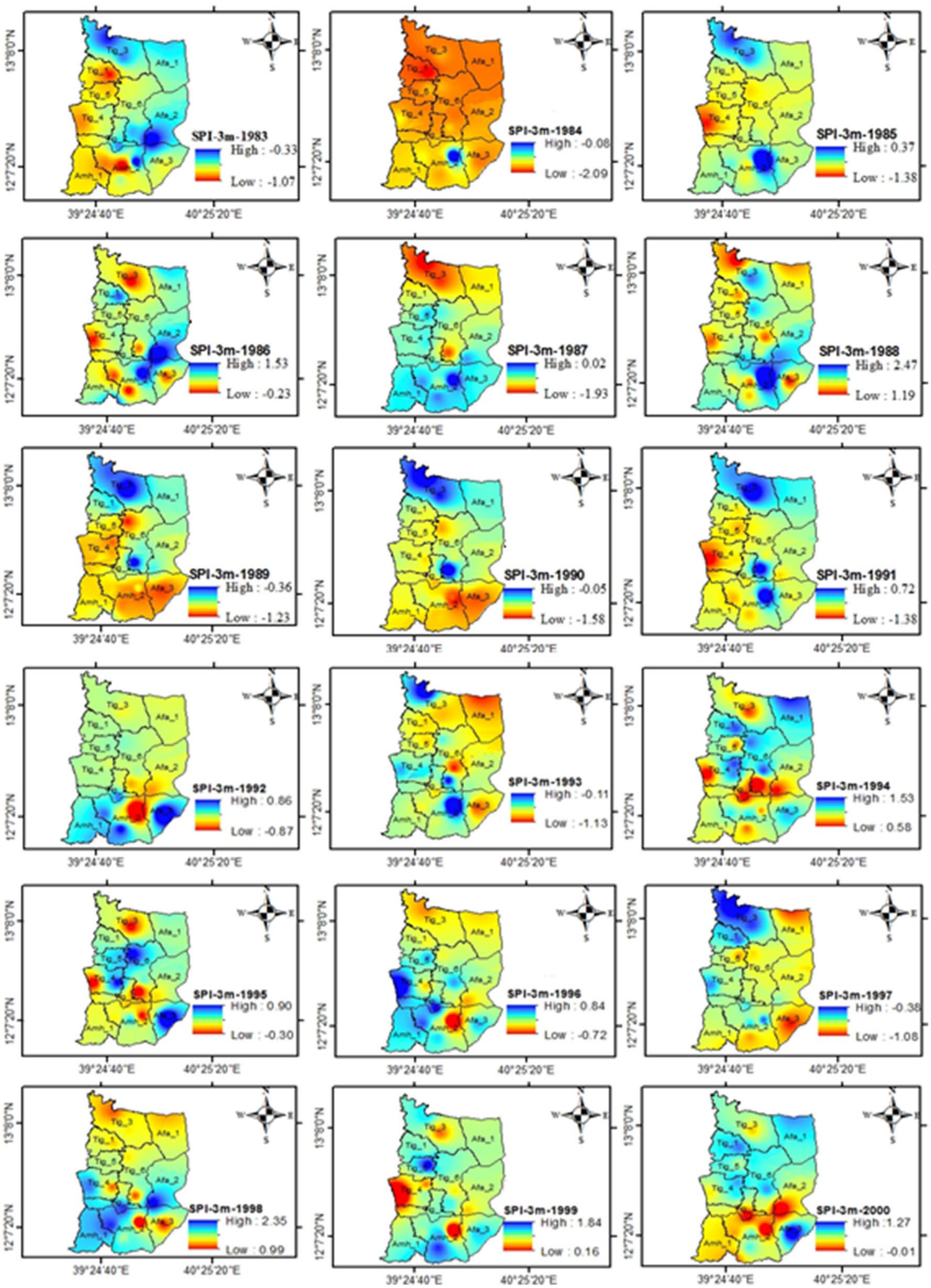

Fig. 4 A spatio-temporal meteorological drought condition in the study area over the period 1983–2015. Note*: Afa_1: Megale, Afa_2: Yalo, Afa_3: Gulina, Tig_1: Alaje, Tig_2: Alamata, Tig_3: Hintalo Wejirat, Tig_4: Ofla, Tig_5: Endamehoni, Tig_6: Raya Azebo, Amh_1: Gidan, Amh_2: Kobo

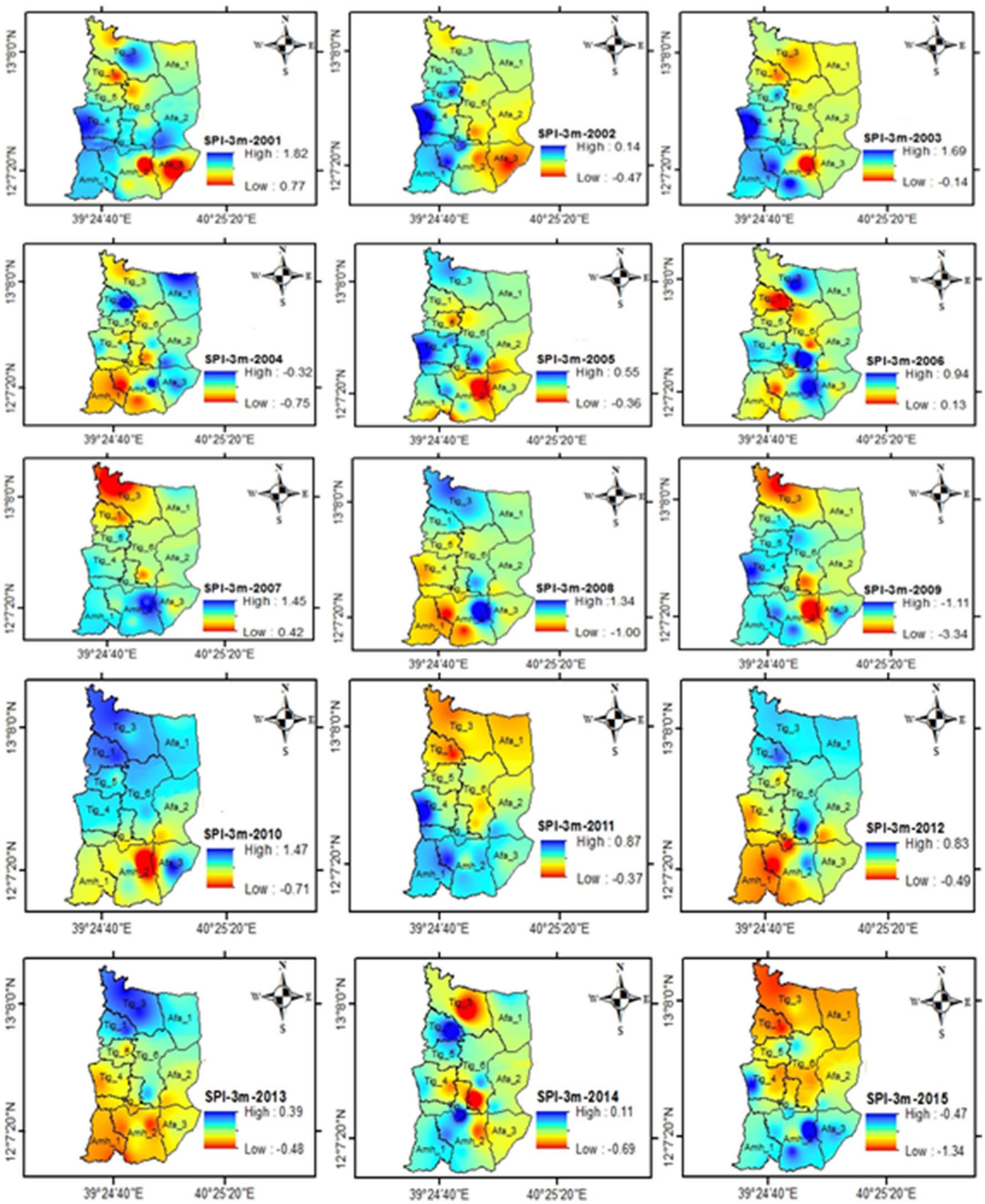

Fig. 4 (continued)

meteorological drought were 1–3 years throughout the study period. Similarly, the mid- and highlands also experienced comparable shocks (Tables 5, 6). There is no difference in the duration of drought periods. During this study period, significant impacts on the livestock, livestock products, and humans were observed throughout all agro-ecological zones. Particularly, the 1983–1985 droughts claimed the lives of thousands of smallholder farmers because the impact continued for consecutive 3 years. Characterizing the major properties of meteorological drought may give in-depth information for implementing better monitoring, adaptation and mitigation strategies.

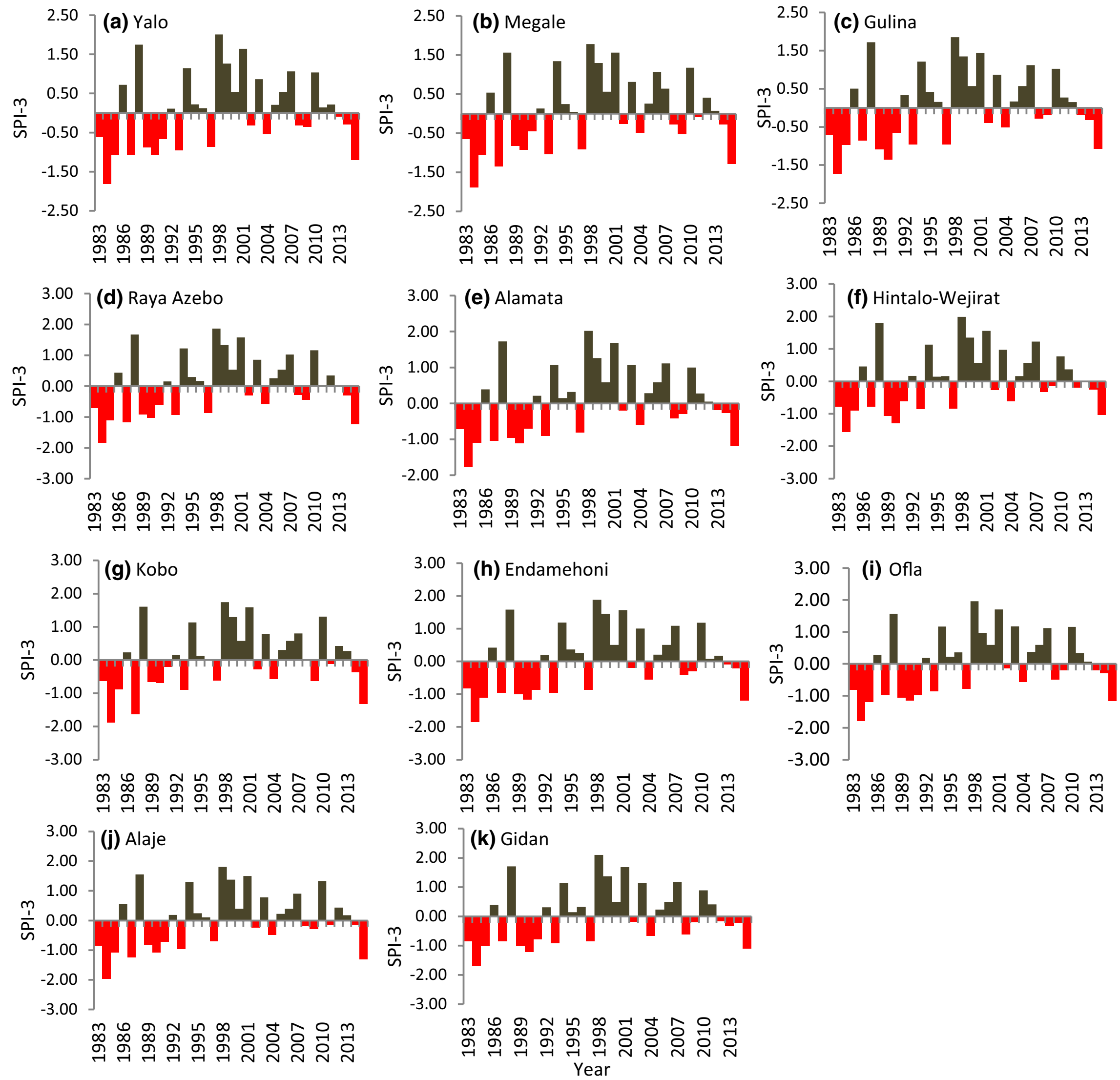

Fig. 5 **a–k** Meteorological drought condition in the study area based on SPI–3

Table 4 Historical meteorological drought onset (O), offset (E), duration (L), magnitude (M), and intensity (I) in lowlands of the study area

O	E	Yalo			Gulina			Megale		
		L	*M*	*I*	*L*	*M*	*I*	*L*	*M*	*I*
1983	1985	3	−3.50	−1.17	3	−3.39	−1.13	3	−3.59	−1.20
1987	1987	1	−1.06	−1.06	1	−0.86	−0.86	1	−1.35	−1.35
1989	1991	3	−2.60	−0.87	3	−3.08	−1.03	3	−2.19	−0.73
1993	1993	1	−0.95	−0.95	1	−0.96	−0.96	1	−1.03	−1.03
1997	1997	1	−0.87	−0.87	1	−0.95	−0.95	1	−0.91	−0.91
2002	2002	1	−0.31	−0.31	1	−0.39	−0.39	1	−0.26	−0.26
2004	2004	1	−0.54	−0.54	1	−0.51	−0.51	1	−0.48	−0.48
2008	2009	2	−0.66	−0.33	2	−0.47	−0.24	2	−0.80	−0.40
2013	2015	3	−1.59	−0.53	3	−1.57	−0.52	1	−0.09	−0.09
		–	–	–	–	–	–	2	−1.56	−0.78

3.4 Meteorological Drought Frequency, Severity, and Spatial Extent in the Study Area

Based on Fig. 5a–k, the severity, frequency, and spatial extent of the meteorological drought event are presented in Table 7. The result shows that meteorological drought is a regular incidence in all districts of the study area. The frequency in dry spells, as well as drought incidence, exacerbates crop failure and food insecurity and poverty (Awulachew et al. 2007). However, in the last 33 years, the study

Table 5 Historical meteorological drought onset (O), offset (E), duration (L), magnitude (M), and intensity (I) in the midlands of the study area

O	*E*	Raya Azebo			Hintalo-Wejirat			Kobo			Alamata		
		L	*M*	*I*	*L*	*M*	*I*	*L*	*M*	*I*	*L*	*M*	*I*
1983	1985	3	−0.37	−0.12	3	−3.39	−1.13	3	−3.23	−1.08	3	−3.58	−1.19
1987	1987	1	−1.17	−1.17	1	−1.63	−1.63	1	−0.78	−0.78	1	−1.04	−1.04
1989	1991	3	−2.55	−0.85	3	−1.55	−0.52	3	−2.95	−0.98	3	−2.78	−0.93
1993	1993	1	−0.94	−0.94	1	−0.90	−0.90	1	−0.85	−0.85	1	−0.90	−0.90
1997	1997	1	−0.86	−0.86	1	−0.62	−0.62	1	−0.85	−0.85	1	−0.81	−0.81
2002	2002	1	−0.30	−0.30	1	−0.28	−0.28	1	−0.26	−0.26	1	−0.20	−0.20
2004	2004	1	−0.58	−0.58	1	−0.58	−0.58	1	−0.61	−0.61	1	−0.60	−0.60
2008	2009	2	−0.72	−0.36	2	−0.65	−0.33	1	−0.47	−0.47	2	−0.71	−0.36
2014	2015	2	−1.53	−0.77	1	−0.12	−0.12	1	−0.19	−0.19	3	−1.62	−0.54
			–	–	2	−1.68	−0.84	2	−1.29	−0.65			

Table 6 Historical meteorological drought onset (O), offset (E), duration (L), magnitude (M), and intensity (I) in the highlands of the study area

O	*E*	Endamehoni			Ofla			Alaje			Gidan		
		L	*M*	*I*	*L*	*M*	*I*	*L*	*M*	*I*	*L*	*M*	*I*
1983	1985	3	−3.79	−1.26	3	−3.80	−1.27	3	−3.90	−1.30	3	−3.53	−1.18
1987	1987	1	−0.96	−0.96	1	−0.98	−0.98	1	−1.25	−1.25	1	−0.85	−0.85
1989	1991	3	−3.04	−1.01	3	−3.18	−1.06	3	−2.60	−0.87	3	−3.00	−1.00
1993	1993	1	−0.96	−0.96	1	−0.86	−0.86	1	−0.97	−0.97	1	−0.91	−0.91
1997	1997	1	−0.86	−0.86	1	−0.78	−0.78	1	−0.71	−0.71	1	−0.86	−0.86
2002	2002	1	−0.19	−0.19	1	−0.14	−0.14	1	−0.23	−0.23	1	−0.18	−0.18
2004	2004	1	−0.56	−0.56	1	−0.56	−0.56	1	−0.48	−0.48	1	−0.66	−0.66
2008	2009	2	−0.71	−0.36	2	−0.69	−0.35	2	−0.48	−0.24	2	−0.80	−0.40
2013	2015	3	−1.52	−0.51	3	−1.65	−0.55	1	−0.14	−0.14	4	−1.79	−0.45
								2	−1.46	−0.73			

Table 7 Frequency, severity, and spatial extent of meteorological drought incidence from 1983 to 2015

District	Spatial extent (km^2)	Drought frequency and severity							
		Extreme drought (ED)		Severe drought (SD)		Moderate drought (MD)		Mild drought (MiD)	
		≤−2	%	−1.5 to −1.99	%	−1.0 to −1.49	%	0 to −0.99	%
Yalo	1716.5	0	0	1	3	4	12	10	30
Megale	1543.5	0	0	1	3	4	12	11	33
Gulina	1149.7	0	0	1	3	3	12	11	33
Raya Azebo	1782.7	0	0	1	3	4	12	10	30
Alamata	725.5	0	0	1	3	4	12	11	33
Hintalo-Wejirat	1933.1	0	0	2	7	3	9	12	36.4
Kobo	1942.7	0	0	1	3	1	3	12	36.4
Endamehoni	634.8	0	0	1	3	4	12	11	33
Ofla	1101.3	0	0	1	3	4	12	11	33
Alaje	773.2	0	0	1	3	4	12	11	33
Gidan	1229.2	0	0	1	3	4	12	12	36.4

areas were not hit by extreme drought (ED) and extreme wet (EW) conditions. The SPI-3 result indicates that the year 1984 was identified as a severe drought period than the 2015 drought event that covering nearly 14,532 km^2 spatially (Table 7). During this period, millions of people and livestock were faced with acute food shortages. This drought event was bad because it claimed the lives of thousands of humans and animals. Thousands of children were also left malnourished, and migrated in large numbers to neighboring countries such as Sudan (Assefaw 1993). This study also shows that the primary cause of drought in this period was the shortfall of the main rainy season. Besides, the poor drought mitigation policies and measures undertaken by the ruling military government (the so-called 'D*erg'*) aggravated the impact of drought on people and livestock. Further, the study found that one severe drought occurred in all districts of the study area except in Hintalo Wejirat. Four moderate droughts also hit all districts except Gulina, Hintalo Wejirat, and Kobo (Table 7). In the entire areas, about 10–12 mild droughts were observed. Hence, the frequency of drought events in the study area was found to occur once in every 2–3 years.

4 Conclusions

In this research, the spatio-temporal meteorological drought onset, offset, duration, magnitude, intensity, frequency, severity, and spatial extent are examined using the Standardized Precipitation Index (SPI) at 3-month timescale. The long-term analysis of rainfall indicated that all sites received minimal and irregular rainfall, leading to climate extremes such as droughts. The study area experienced very high rainfall variability ranging between 28.14 and 42.32% in the study area. The SPI-3 month timescale model reveals that the study area was stricken by mild-to-severe drought once in every 2–3 years. This drought regularity is observed at a higher rate than the previous decades. This study, therefore, realized that meteorological drought is a regular incidence in all districts of the study area. However, neither extreme drought (ED) nor extreme wet (EW) conditions were found. The year 1984 identified as a severe drought period in all parts of the study area covered nearly 14532 km^2 spatial extent. Similarly, the study found that four moderate droughts hit all districts except Gulina, Kobo, and Hintalo Wejirat, while in the entire areas about 10–12 mild droughts incidence was observed. This study found that SPI is the most crucial drought index for both local and global meteorological drought-related studies. Drought is severe in the study area and it is anticipated to continue in the future due to shortages of adequate rainfall. This study could provide better insight for policymakers on regional drought monitoring and early warning system to improve the existing monitoring, mitigation and adaptation strategies and the ongoing water harvesting activities in order to reduce the impact of climate extremes and drought. Further, it will support to enhance the livelihood of smallholder farmers through implementing drought-tolerant crop varieties in quality and quantity, substantial irrigation practices, and climate-based crop insurance schemes.

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Compliance with ethical standards

Conflict of interests On behalf of all authors, the corresponding author states that there is no conflict of interest.

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