Received 21 December 2016
Revised 15 April 2017
15 May 2017
Accepted 15 May 2017

Meteorological drought assessment in north east highlands of Ethiopia

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Abstract

Purpose – The purpose of this paper is to investigate the patterns and trends of drought incidence in north east highlands of Ethiopia using monthly rainfall record for the period 1984-2014.

Design/methodology/approach – Standard precipitation index and Mann – Kendal test were used to analyze drought incident and trends of drought occurrences, respectively. The spatial extent of droughts in the study area has been interpolated by inverse distance weighted method using the spatial analyst tool of ArcGIS.

Findings – Most of the studied stations experienced drought episodes in 1984, 1987/1988, 1992/1993, 1999, 2003/2004 and 2007/2008 which were among the worst drought years in the history of Ethiopia. The year 1984 was the most drastic and distinct-wide extreme drought episode in all studied stations. The Mann–Kendal test shows an increasing tendencies of drought at three-month (spring) timescale at all stations though significant ($p < 0.05$) only at Mekaneselam and decreasing tendencies at three-month (summer) and 12-month timescales at all stations. The frequency of total drought was the highest in central and north parts of the region in all study seasons.

Originality/value – This detail drought characterization can be used as bench mark to take comprehensive drought management measures such as early warning system, preparation and contingency planning, climate change adaptation programs.

Keywords Drought, Trends, SPI, Extremes, Mann–Kendall

Paper type Research paper

1. Introduction

Drought is a recurrent climate phenomenon which occurs in most parts of the world, with varying frequency, severity and duration (Wilhite, 1993; Shatanawi *et al.*, 2013). It is difficult to determine the onset and ending time of a drought. It develops slowly, and its impact may

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International Journal of Climate Change Strategies and Management
Vol. 10 No. 1, 2018
pp. 142-160
Emerald Publishing Limited
1756-8692
DOI 10.1108/IJCCSM-12-2016-0179

remain for years after termination of the event (Morid *et al.*, 2006). There is no universally accepted definition of drought that applies to all circumstances. Perhaps most definitions are based on the deficiency of rainfall resulting in water shortage for some activities related to use of water (Wilhite, 1993; Wilhite and Glantz, 1985). Morid *et al.* (2006), Karavitis (1999) and Szinell *et al.* (1998) defined drought as "the state of adverse and wide spread hydrological, environmental, social and economic impacts due to less than generally anticipated water quantities".

Droughts are one of the highest natural disasters globally having major impacts on environmental, economic and social conditions (Paulo *et al.*, 2012; Morid *et al.*, 2006). The impact of drought is governed by the magnitude, duration, frequency and spatial extent of the rainfall deficit (Degefu and Bewket, 2013; Zargar *et al.*, 2011). Magnitude refers to the amount of rainfall or water storage deficit at a particular place and specific time. Drought magnitude is categorized, in most commonly used indices, into mild, moderate, severe and extreme. Frequency/return period/is the average time between drought events and duration refers to the length of time that a given drought event stays. The spatial coverage refers to the areal extent of a specific area affected by a given drought incidence. Usually severe and extreme drought episodes cover wider areas, while mild and moderate drought episodes tend to affect localized areas (Degefu and Bewket, 2013).

Scientific literature has commonly classified droughts into four main categories as meteorological, agricultural, hydrological and socio-economic (Wilhite and Glantz, 1985; Tallaksen and Van Lanen, 2004; Mishra and Singh, 2010). For the purpose of this study, meteorological drought was adopted where rainfall is commonly used for drought analysis. Droughts over a region can be characterized using different indices, which all use rainfall either alone or in combination with other meteorological elements (Zargar *et al.*, 2011; Edossa *et al.*, 2010).

Although drought is a natural occurring recurrent extreme event (Wilhite, 1993; Shatanawi *et al.*, 2013), various empirical and modeling studies proved that climate change is very likely to increase the magnitude, frequency and duration of droughts over some parts of the world in the coming decades (IPCC II, 2014, Degefu and Bewket, 2013).

There were severe droughts which have had a substantial impact on the socio-economic and environmental condition of Ethiopia at different times and scales (Table I). For instance, although the recorded history of drought in Ethiopia dates back to 250 BC, its frequency has increased over the past few decades and still have been the hallmarks of the country (Meze-Hausken, 2000; Deressa *et al.*, 2010). From 1950s to1980s, droughts occurred on average once per decade, and recently, it occurred once every three years in Ethiopia (Block, 2008). On the other hand, World Bank (2006) reported that 16 drought events were experienced during 1980-2004 which makes Ethiopia the most drought-affected country. The year leading to June 2011 has been claimed to be the driest in 60 years in some regions of Somalia, Northern Kenya and Southern Ethiopia (USAID/FEWS 2011). Ethiopia faced one of the worst droughts the country has seen in decades with over 10.2 million people in need of food aid (UN OCHA, 2015). Triggered by El Niño, the rainy seasons in 2015 failed so that the drought brought significant impact by limiting agricultural production, straining livelihoods and exacerbating food insecurity among poor and vulnerable households.

From 1986 until 2013, a total of nine El Niño events had occurred. The magnitude of seven of the El Niño years (1986/1987, 1991/1992, 1994/1995, 2002/2003, 2004/2005, 2006/2007, 2009/2010) were either moderate or weak, while the magnitude of two of them (1987/1988 and 1997/1998) were strong (FAO, 2014). There is a remarkable correspondence between annual rainfall in Ethiopia and ENSO events (Haile, 1988).

Table I.
Major drought years and their effects in different regions of ethiopia for the last 50 years

Year	Region	Impacts
1964-1966	Tigray and Wollo	About 1.5 million people were affected and 300,000 livestock died
1972-1973	Tigray and Wollo	Death of about 200,000 people and 30% of livestock population in the area
1978-1979	Southern Ethiopia	1.4 million people were affected
1983-1984	All regions	8 million people affected, 1 million people died
1982	Northern Ethiopia	2 million people were affected
1987-1988	All regions	7 million people were affected
1991-1992	North, east & south Ethiopia	4 million people were affected
1993-1994	Tigray and Wollo	7.6 million people were affected
2000	All regions	About 10.5 million people were affected
2002-2003	All regions	About 13 million people were affected; 1.4 million livestock died
2006	Southern Ethiopia (Borena)	About 7.4 million people affected; 247,000 livestock died
2008	Southern Ethiopia (Borena)	About 26,000 livestock died
2008-2009	All regions	About 5 million people were affected
2011	South-central, southeastern, and eastern parts of Ethiopia	About 4.5 million were affected
2015-2016	Northern, Southern and Eastern Ethiopia	About 10.2 million people were affected

Sources: Compiled from Degefu (1987), Meze-Hausken (2000), FAO (2003), Segele and Lamb (2005), Amsalu and Adem (2009), Deressa *et al.* (2010), Famine Early Warning Systems Network (FEWS NET) (2011), Viste *et al.* (2012) and FDRE (2016)

The analysis and forecasting of extreme climatic events has become increasingly relevant to make planning effective. Although drought is becoming the most common and damaging natural hazard in Ethiopia, there were no as such detail studies conducted about its magnitude, frequency and spatial extent in different regions of Ethiopia (Degefu and Bewket, 2013). The same is true in this study area. Hence, to reduce the damages from drought, it is crucial to characterize drought. Drought characterization at regional and local scales has significant implications for drought management such as early warning system (farmers could be warned before the advent of drought as to when, what and where to cultivate and when to sell their animals as well as how to conserve water resources and food), preparation and contingency planning (the government is working toward reorganizing its resources *before* the impact of drought is felt, climate change adaptation programs (introduction of off-farm activities and drought resistant crop and animal varieties).

Different indices have been developed through time to quantify the magnitude of meteorological drought. Most of these indices are based on direct observed measurement of climatic variables such as rainfall, evapotranspiration and temperature (Steinemann *et al.*, 2005). Some of the widely used indices include the Palmer Drought Severity Index (PDSI) (Palmer, 1965), the Percent of Normal, and the Deciles approach (Gibbs and Maher, 1967), the Standard Precipitation Index (SPI) (McKee *et al.*, 1993) and Standard Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano *et al.*, 2010).

Each index has its own strength and weakness. For example, PDSI is considered as useful in monitoring drought at a regional scale and allows comparisons over relatively large zones (Steinemann *et al.*, 2005). It also uses water balance models to consider the effects of temperature and rainfall. However, it does not work well in mountainous areas where there are extremes in rainfall or runoff variables (Mpelasoka *et al.*, 2008; Ellis *et al.*, 2010).

Moreover PDSI requires large amount of climate and soil moisture data, and they are not simple to calculate (Degefu and Bewket, 2013; Morid *et al.*, 2006). A brief description of these and other indices was given in Morid *et al.* (2006).

The choice of indices for drought monitoring should be based on the quantity and quality of available climate data, purpose of the study, computational simplicity and its ability to consistently detect spatial and temporal variations of a drought event (Morid *et al.*, 2006). Keyantash and Dracup (2002) also indicated that drought indices must be statistically robust and easily calculated, and have a clear and comprehensible calculation procedure.

In this study, SPI, which is currently used widely for its multiple advantages, has been used. The SPI was proposed by McKee *et al.* (1993) and has been used frequently during the past two decades (Hirschi *et al.*, 2011; Vicente-Serrano *et al.*, 2015). The robustness of SPI over the other drought indices has been reported in many studies (Vicente-Serrano *et al.*, 2015; Viste *et al.*, 2012; WMO, 2012; Hirschi *et al.*, 2011; Hayes *et al.*, 1999; Guttman, 1998; Mpelasoka *et al.*, 2008). In addition to its simplicity and ease of calculation, in regions like Ethiopia, where the access to data is limited, there are good reasons for choosing a rainfall-based drought measure (SPI) (El Kenawy *et al.*, 2016; Degefu and Bewket, 2013; Viste *et al.*, 2012). Details of SPI computation can be accessed in the user guides of SPI (WMO 2012).

The objective of this paper is therefore to monitor the magnitude, duration, frequency, spatial variability and trends of drought incidence in South Wollo, north east highlands of Ethiopia.

2. Materials and methods

2.1 Description of the study area

South Wollo zone is located in the north east part of Ethiopia lying between 10°12′N and 11° 40′N and 38°30′E and 40°05′E. Its zonal capital, Dessie, is found 400 kms North of Addis Ababa. It is one of the drought-prone and aid-dependent areas in Amhara Regional State (Bewket and Conway, 2007). The study area covers a total area of 17053.45 km^2 with 18 rural and 2 urban districts.

South Wollo is characterized by diverse topographic features in which high mountainous and deeply incised canyons and gorges, valleys and plateaus with steep slopes dominate its most parts (Coltorti *et al.*, 2007). The elevation ranged from the dry plains at 1,000 m altitude in the east to the high peaks above 3,500 m altitude in the west. However high-land areas ranging between 1,500 and 3,500 m altitude are the dominating feature of South Wollo (Rosell and Holmer, 2007). Because of the diverse topography, the study area experiences different climatic conditions that range from hot and arid lowlands in the eastern part to cold and humid highlands in the western part.

The mean annual temperature varies from less than 5°C in the western highlands to 22°C in the eastern lowlands. The annual rainfall varies between less than 1,000 mm in the western part to more than 1,200 mm in the eastern part. Bimodal rainfall pattern with shorter spring (March-May) and longer summer (June-August) characterizes the study area which leads to two harvest periods. The spring season is very influential for mid to high latitude areas, whereas the mid lands to lowland areas mainly depend on the summer rain. Except a few pocket areas where small-scale irrigation is practiced, crop production is rainfed.

As the topography is very rugged, soil erosion was a critical problem in the study area. It is highly degraded and deforested in terms of indigenous trees but does have considerable eucalyptus plantations. Alpine species unique to extreme highland areas are found in western highland parts of the study area. Local people in the area are engaged in subsistence agriculture for their livelihood. Unlike other areas of East Africa where highlands generally are the most food secure parts of a country, the opposite often is the case in Ethiopia. In fact, the crowded, steep-sloped highlands above 2,000 metres including large parts of South Wollo, are among the country's most famine-prone areas (Little *et al.*, 2006) (Figure 1).

2.2 Data source

Monthly rainfall data from six stations for the period (1984-2014) were obtained from Ethiopian National Meteorological Agency (NMA) and used as an input variable to calculate meteorological drought. Initially, we collected rainfall data from 10 stations found in the study area. However, due to their missing data and shorter length of records, we only selected the six stations.

2.3 Standard Precipitation Index computation

SPI was designed to quantify the rainfall deficit for multiple timescales in the studied stations. The SPI is a z-score and represents the drought event departure from the mean, expressed in standard deviation units. SPI is a normalized index in time and space. This feature allows comparisons of SPI values among different locations.

Although SPI can be calculated from 1 month up to 72 months, 1-24 months is the best practical range of application (Guttman, 1999; WMO, 2012). We, therefore, computed the SPI values at two time-scales, i.e. 3 months (SPI-3) and 12 months or annual (SPI-12). The SPI-3 was used to assess droughts during spring (belg) and summer (kiremt) seasons which represent the shorter and longer rain seasons, respectively, and SPI-12 was used to assess the annual drought. Positive SPI values indicated greater than mean rainfall and negative values indicated less than mean rainfall.

For each month of the calendar year, new data series were created, with the elements equal to corresponding rainfall moving sums (Degefu and Bewket, 2013). Then, the SPI value provides a comparison of the rainfall over a specific period with the rainfall totals

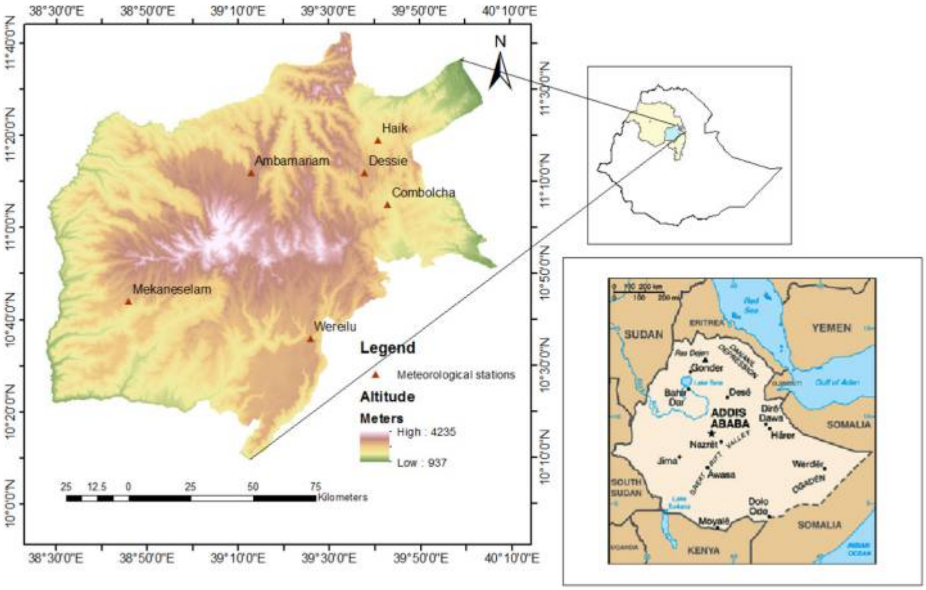


Figure 1.
Location map of South Wollo and meteorological stations used in this study

from the same period for all the years included in the historical record (Shahid, 2008). It is essentially a seasonally normalized, backwards-looking moving average of precipitation. For example, the three-month SPI calculated for August 2005 used the total rainfall of June-July-August 2005 and compared with the June-August rainfall totals of all the years considered in the study. Similarly, the 12-month SPI for December 2005 used the rainfall total for January 2005 to December 2005.

Conceptually, SPI is equivalent to the *Z*-score used in statistics, and it is calculated as:

$$SPI_{ij} = \frac{X_{ij} - \mu_{ij}}{\alpha_{ij}}$$

where SPI_{ij} is the SPI of the ith month at the jth timescale, X_{ij} is rainfall total for the ith month at the jth time scale, $\boldsymbol{\mu}_{ij}$ and α_{ij} are the long-term mean and standard deviation associated with the ith month at the jth time scale, respectively.

In this study, SPI values were produced for each month of the year using SPI_SL.6.exe program developed by Colorado Climate Center (available at http://ulysses.atmos.colostate.edu/SPI.html).

This program classified drought events in four magnitude classes, i.e. if SPI ranges between 0 and −0.99, it is mild drought; −1.00 and −1.49, it is moderate drought; −1.50 and −1.99, it is severe drought; and extreme drought if SPI is −2.00 or less (McKee *et al.*, 1993; WMO, 2012). Each drought event has a duration defined by its beginning and end.

2.4 Methods for smoothing time series data and trend detection

The rank-based nonparametric Mann–Kendall (MK) test (Mann, 1945; Kendall, 1975) has been commonly used to assess the significance of monotonic trends in hydro-meteorological time series. Another rank-based nonparametric test, the Spearman's rho (SR) test (Lehmann, 1975; Sneyers, 1990), has sometimes been applied to detect trends in hydrological data. The study of Yue *et al.* (2002) and Viste *et al.* (2012) noted that these two tests have almost the same power to identify trends in time series. In comparison to the parametric *t* test, the common use of the nonparametric tests is mainly due to the consideration that they are more suitable for the situations of non-normal data, incomplete data, and missing data problems, which frequently occur in hydro-meteorological studies. MK test simply calculates whether the variable is increasing or decreasing with time (Collins, 2009).

MK test, used by many researchers for trend detection due to its robustness for non-normally distributed data, was applied in this study to assess trends in the time series data (Kendall, 1975; Mann, 1945). However, the MK test requires the time series data to be serially independent (Petrow and Merz, 2009). The standard *p*-values obtained from it are based on an assumption of independence between observations. The presence of a significant positive serial correlation tends to overestimate the significance of the trend (Petrow and Merz. 2009; Yue *et al.*, 2002). Thus, the time series data should be tested for serial correlation and should be corrected if there is any significant autocorrelation (Petrow and Merz, 2009; Burn *et al.*, 2010) before subjected the data to the MK trend test. To improve the performance of the test (MK), the most widely used procedure of the trend-free pre-whitening (TFPW) method can be applied to remove serial correlation from the time series, and hence to eliminate the effect of serial correlation on the MK test (Yue *et al.*, 2002, 2003; Petrow and Merz, 2009). In this study, we found serial correlation of six out of eighteen time scales. However, only Ambamariam and Wereilu at 12-month timescale showed significant autocorrelation (p = 0.59 and 0.55), respectively. TFPW method was applied to remove the autocorrelation of these two stations following the works of Petrow and Merz (2009), Yue *et al.* (2002). Finally, we run the MK test. For detailed MK test statistics, see Kendall (1975) and Mann (1945) and the MK test manual prepared by Finnish Meteorological Institute (2002).

2.5 Mapping spatial distribution of drought incidences

The output from the SPI program is used as an input to ArcGIS to generate drought severity maps for the study area at 3 and 12-month time scales. To assess the spatial extent of droughts in the study area, SPI time series values of each meteorological station have been interpolated by Inverse Distance Weighted (IDW) method using the Spatial Analyst tool of ArcGIS. The IDW method gives better representation for interpolation of rainfall distribution over heterogeneous topographic terrain (Tagel *et al.*, 2011).

3. Results

The results of the study are discussed under three sub-topics:

(1) frequency and magnitude of drought events;

(2) trends of occurrences of drought events;

(3) spatial patterns of drought events.

3.1 Magnitude and frequency of drought events

Rainfall is bimodal in the study area (Figure 2). The contribution of summer (long rain period) rainfall to the average annual rainfall across stations was very high ranging from 65.7 per cent at Ambamariam to 53.56 per cent at Dessie. The number of drought months with different magnitude classes at short and long timescales (3 and 12-months) is shown on Figure 3. Drought months for 3 months (belg and kiremt rainfall) and 12 months (annual rainfall) were calculated using SPI. Drought frequency, in this study, was measured by the number of years which experienced negative SPI values in the total time series of 30 years.

3.1.1 Spring season. The total number of drought events with mild, moderate, severe and extreme intensities computed at three-month timescale (March-May) was accounted for 46 per cent in spring season in all stations except Combolcha and Ambamariam (not shown here). However, they had varied magnitude classes. Extreme magnitude droughts occurred for 2 months at Ambamariam, Combolcha and Dessie. As the analysis of three-month timescale (March-May) showed, the year 1988, 1999, 2004 and 2007-2009 were drought years across all studied stations. Except Haik and Wereilu which had severe drought magnitude,

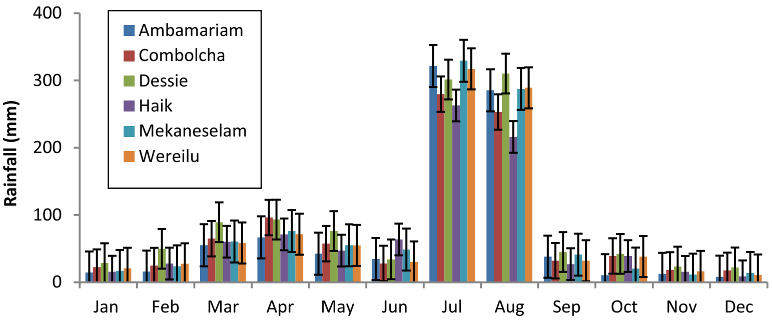
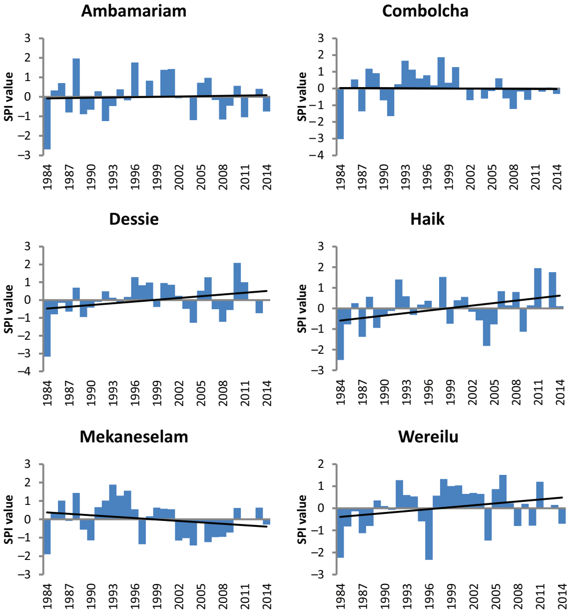


Figure 2.
Bimodal rainfall distribution of the study area

Annual



Summer

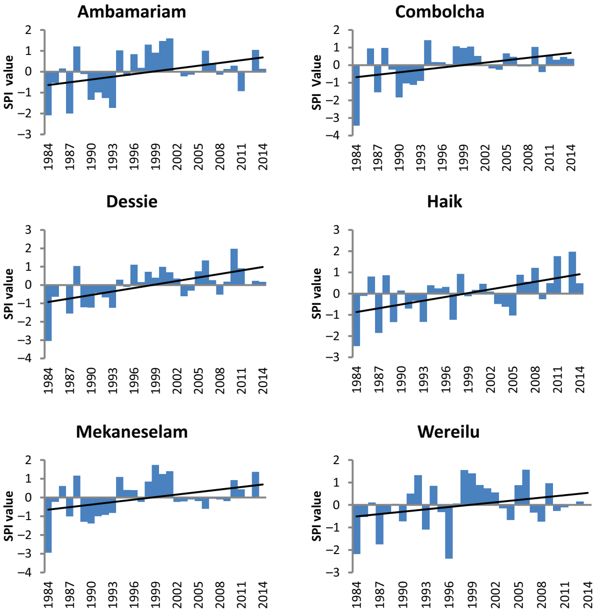


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Figure 3.
Magnitude and frequency of SPI values at annual, summer and spring time scales

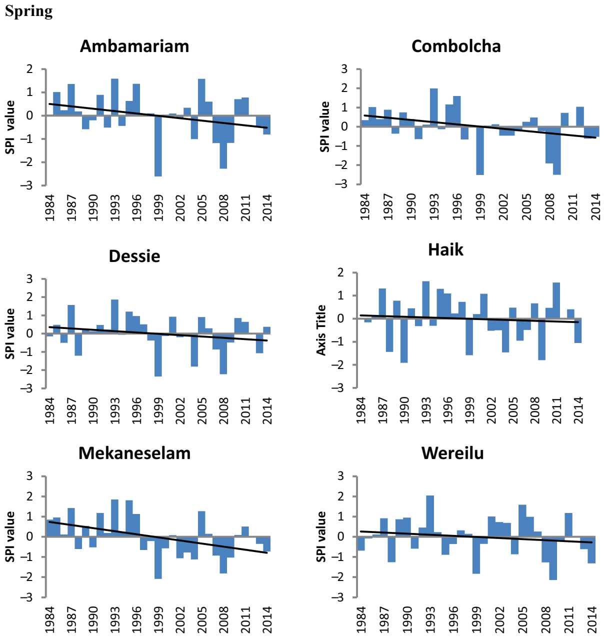


Figure 3.

extreme drought was recorded in 1999 in all stations ranging from −2.09 to −2.61. In the remaining drought years, the drought magnitude varied from mild to extreme in which Ambamariam and Dessie had extreme drought in 2008 and Combolcha and Wereilu experienced extreme drought in 2009.

3.1.2 Summer season. The total number of drought events at the three-month timescale (June-August) in the entire period of analysis was found between 12 months at Dessie and 18 months at Mekaneselam, respectively. In addition to 1984 drought year, Ambamariam had extreme (SPI value −2) drought at this timescale (June-August) in 1987 and Wereilu with SPI value of −2.39 in 1996. The worst drought was recorded in 1984 which had substantial impact on the region. Even though its magnitude varied, drought occurred across the study area at this timescale in 1984, 1987, 1992-1993, 2004 and 2008. The frequency of occurrences of drought at this season was the highest at Mekaneselam (60 per cent) and the lowest at Dessie (53 per cent) implying that Mekaneselam experienced one drought episode in almost every two to three years.

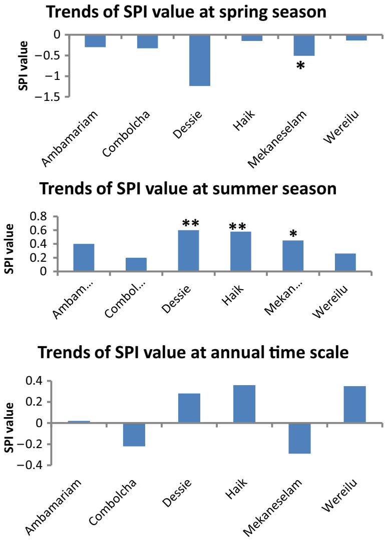
3.1.3 Annual drought. The total number of drought months at 12 month timescale (January-December) was found between 12 at Wereilu and 16 at Ambamariam which constitutes 40 and 53 per cent of the total number of drought incidences in the study period, respectively. At this time scale, the highest frequency of extreme drought was recorded at Wereilu in 1984 and 1996 with SPI value of −2.24 and −2.33, respectively. The year 1984 was the worst drought across the region with SPI value ranging from −1.9 to −3.17. Although there was varying degree of severity, drought was recorded across the study region in 1984, 1987, 2004 and 2008-2009. The total number of moderate droughts at 12 month timescale was the highest at Ambamariam and Mekaneselam with 4 and 6 months, respectively. This study confirms that the frequency of occurrences of droughts at summer was highest at Ambamariam.

There is a remarkable correspondence between rainfall in Ethiopia and ENSO events (Haile, 1988). When past ENSO events are compared with drought and famine periods in Ethiopia, they show a remarkable association. Recent documented droughts of Ethiopia in 1987-1988, 1991-1992, 1993-1994, 2002-2003, 2008-2009, 2011, 2015-2016 were all strong El Nino years (UN OCHA, 2015; FAO, 2014). This suggests that Ethiopian intense and extended drought periods either coincide or follow El Nino events. In recent years, the meteorological droughts are increasing especially in spring (belg) season (Figure 3) in the study region, and they have strong correlation with the El Nino events. Forecasting the occurrences of El Nino events will provide insights to estimate drought occurrences and plan adaptation strategies to minimize the associated risks.

3.2 Trends of drought occurrences

Trends of drought occurrences for 3 months (spring and summer) and 12 months (annual) timescales were shown in Figure 4. SPI values of May, August and December were considered to represent the drought conditions from March-May (spring season), June-August (summer season) and January-December (annual rainfall), respectively.

The computed SPI values for 3 months timescale during spring revealed that the occurrence of negative rainfall anomalies or frequent droughts were observed in the 1980s and 2000s and positive rainfall anomalies in the 1990s at most of the meteorological stations. The SPI value for 3 months timescale during summer showed increasing trends, which indicates declining of occurrences of droughts from time to time across the study stations. The SPI value for 12 months (annual) timescale showed negative rainfall anomalies at 1980s, the beginning of 1990s and after the mid of 2000s, while positive rainfall anomalies were observed at the end of 1990s and beginning of 2000s in the studied period.



Notes: *Significant at $p < 0.05$ level; **significant at $p < 0.01$ level

Figure 4.
The Mann–Kendall’s trend test for spring, summer and annual time scales

The MK trend test showed decreasing changes in SPI values in all stations suggesting increasing tendency of drought incidence at the three-month timescales during spring (Figure 4) However, significant trend ($p < 0.05$) was observed only at Mekaneselam station. On the other hand, the SPI values at the three-month timescale during summer showed increasing changes across stations, however, significant at Dessie, Haik and Mekaneselam ($p < 0.05$). Similar increasing trend of drought was also observed at 12-month timescale in all stations except Combolcha and Mekaneselam. However, the changes were not significant.

The trend analysis shows that there was no statistical evidence of any positive or negative trend of meteorological drought severity and frequency for the study area except Mekaneselam at the three-month timescale during spring and Dessie, Haik and Mekaneselam at the three-month timescale during summer. Although trends at all time-scales were not statistically significant, increasing tendencies of drought were observed during spring season and decreasing tendencies of drought during summer and annual scale in the study region.

3.3 Spatial patterns of drought occurrences

This study examined patterns of drought across the study region using time series (1984-2014) standardized precipitation index (SPI). The spatial patterns of drought at different time steps (three- and 12-months) were depicted in Figures 5(a)-(d) to 8(e1)-(e3). The

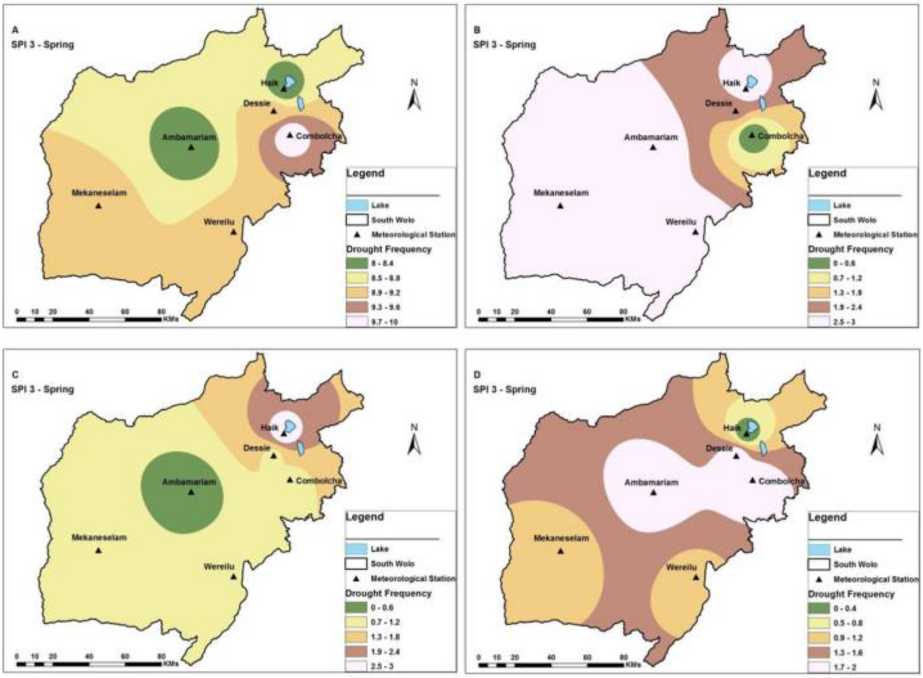
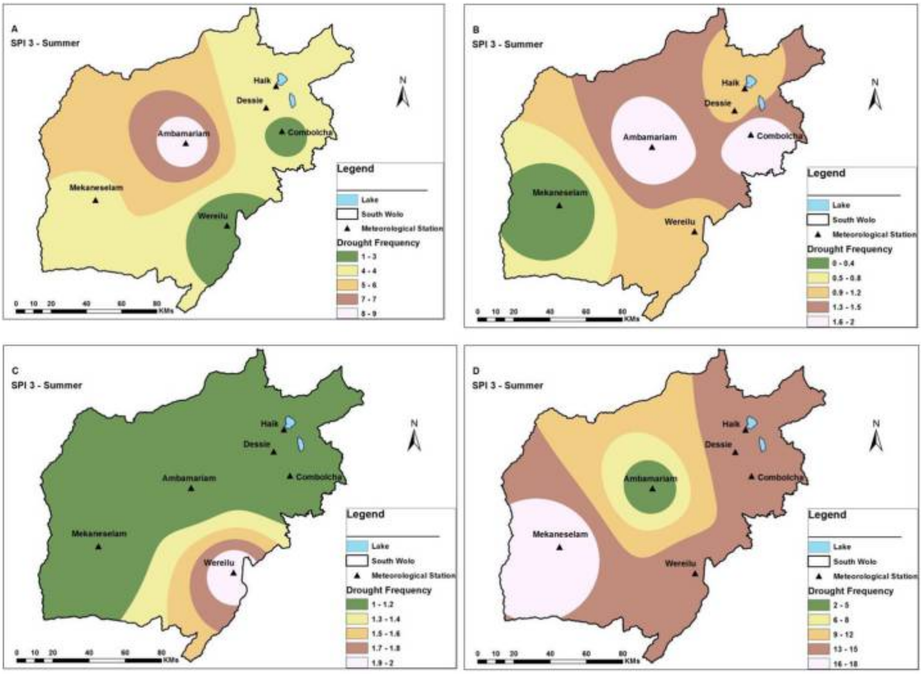


Figure 5.
Spatial distribution of drought events at the three-month time scale in spring (March-May) season in South Wollo, north east highlands of Ethiopia: (A) mild drought, (B) moderate drought, (C) severe drought, (D) extreme drought

Source: Derived using SPI method



Source: Derived using SPI method

Figure 6. Spatial distribution of drought events at the three-month time scale in summer (June-August) season in South Wollo, north east highlands of Ethiopia: (A) mild drought, (B) moderate drought, (C) severe drought, (D) extreme drought

frequencies of drought for different magnitude classes and timescales show complex and local scale spatial patterns.

Except small pocket areas with severe droughts in eastern stations, the other stations were prone to moderate drought magnitude during spring. Extreme drought magnitude was also occurred at Ambamariam, Combolcha and Dessie in the same season. During summer, the western stations (Ambamariam, Mekaneselam and Wereilu) were highly exposed to high frequency of mild and moderate droughts, whereas eastern stations were less exposed to droughts. At annual timescale, extensive areas in the north east part of the region (Ambamariam, Combolcha and Dessie) also experienced high frequency of drought. Generally, the total frequency of drought was the highest at Mekaneselam at spring and summer and at Ambamariam at annual time scale.

4. Discussions

In this study, we presented a brief drought analysis at annual and seasonal time steps using SPI. We assessed the magnitude, frequency, trend, spatial pattern and probability of drought events over South Wollo from 1984 to 2014 at 3- and 12-month time scales. As the study area experiences bimodal rainfall (spring and summer) occurring between March to May and June to August respectively, we computed the SPI at three-month timescale for both seasons.

Results indicate that occurrences of drought in South Wollo showed temporal variation. The total number of drought events was higher in summer season than spring at Ambamariam, Combolcha and Mekaneselam. Summer is the main rainy season in the study

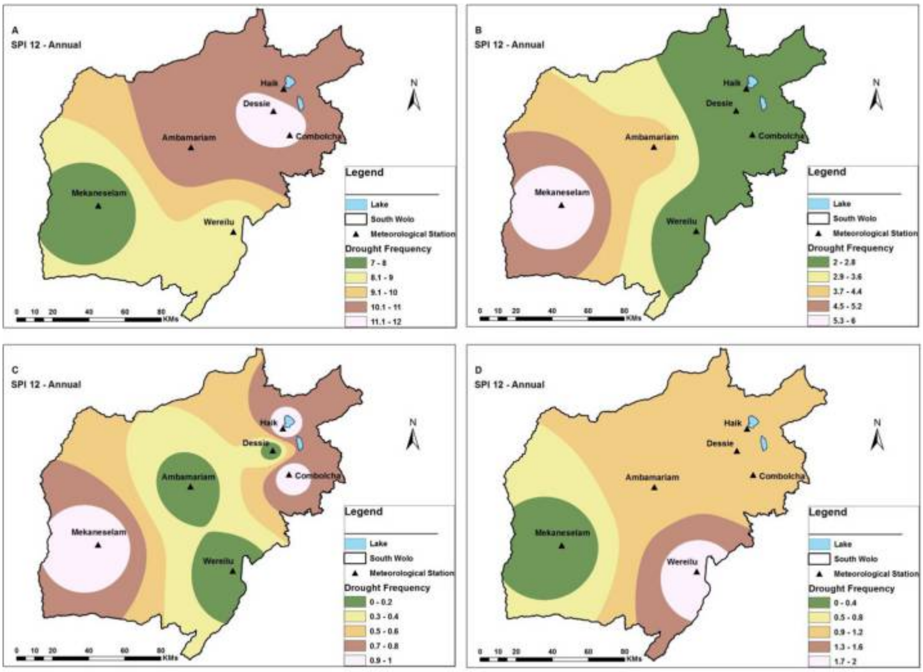


Figure 7.
Spatial distribution of drought events at 12-month time scale in South Wollo, north east highlands of Ethiopia: (A) mild drought, (B) moderate drought, (C) severe drought, (D) extreme drought

Source: Derived using SPI method from monthly rainfall data

area, contributing to more than 70 per cent of the annual rainfall (Viste *et al.*, 2012). Failing to rain at this season means failure of 85-95 per cent of the Ethiopian food crop which is produced in this season (Degefu, 1987).

Most of the studied stations experienced extreme magnitude droughts. The year 1984 was the most drastic and distinct-wide drought episode. All stations experienced extreme magnitude drought ranging from −2.18 to −3.44 at 3-month (summer) and from −1.9 to −3.03 at 12-month (annual) timescales. Except Wereilu and Haik (which had severe magnitude), extreme magnitude droughts were also observed at all stations in 1999 during spring season. This finding agrees with the findings of Viste *et al.* (2012) who found driest conditions all over Ethiopia during spring season in 1999. Additional extreme magnitude drought also occurred during spring at Ambamariam and Dessie in 2008 with SPI values of −2.28 and −2.22, respectively. There were also extreme magnitude droughts at Combolcha and Wereilu during spring season in 2009 with SPI value of −2.5 and −2.14, respectively. At the three-month timescale during summer, Ambamariam and Wereilu experienced extreme magnitude droughts in 1987 and 1996 with SPI values of −2. and −2.39, respectively.

The frequency of occurrences of drought was the highest (60 and 53 per cent) at Mekaneselam and Ambamariam at 3 month during summer and 12-month annual timescale, respectively. This shows that Mekaneselam and Ambamariam were frequently stricken by drought compared to other studied stations in South Wollo.

The occurrences of extreme magnitude droughts have important implications on rainfed agriculture (Ellis *et al.*, 2010; Morid *et al.*, 2006). The impacts of 1984 drought greatly expanded food insecurity, malnutrition, devastated livelihoods and caused for the loss of

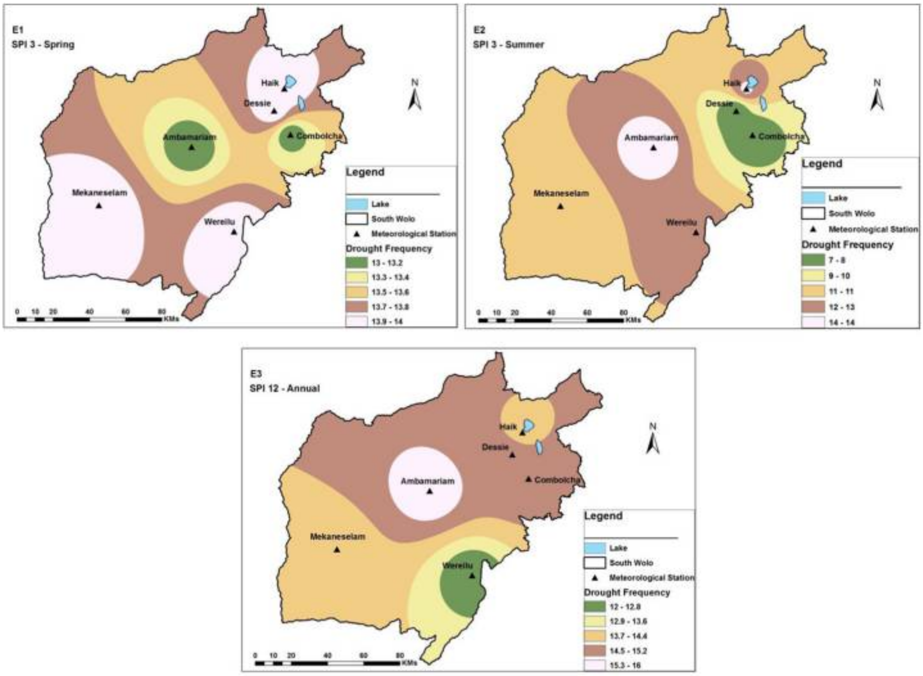


Figure 8.
Spatial distribution of total drought events in, seasons and at annual timescales in South Wollo, north east highlands of Ethiopia: (E1) spring (March-May); (E2) summer (June-August); (E3) annual drought

Source: Derived using SPI method from monthly rainfall data

millions of life in the region. This was also true all over Ethiopia. This finding agrees with previous research findings of (El Kenawy *et al.*, 2016; Mosaad, 2015; Bayissa *et al.*, 2015; Degefu and Bewket, 2013; Viste *et al.*, 2012; Tagel *et al.*, 2011; Edossa *et al.*, 2010; Bewket and Conway, 2007) who reported extreme drought in different parts of the country in the same period. Segele and Lamb (2005) also extensively demonstrated the severity of the 1984 drought over Ethiopia, particularly during the summer season.

The analysis revealed that in 1996 the SPI values at 3-month (June-August) and 12-month timescales at Wereilu and in 1987 at 3-month (June-August) at Ambamariam were unique to other stations which showed extreme droughts with SPI value of −2.39 and −2.33 at Wereilu, respectively, and −2.0 at Ambamariam. The analysis implies that drought magnitude can vary largely over space and this exceptional extreme drought shows a local character, where small area was affected, while others had less severe drought magnitude or even no drought. This finding is supported by the study of El Kenawy *et al.* (2016) who found similar drought occurrences in studying the changes in the frequency and severity of hydrological droughts over Ethiopia from 1960 to 2013.

The most striking characteristic of a drought is the change in its frequency as the time scale changes (Umran, 1999). On shorter time scales, droughts became more frequent but their duration was short. The opposite is true for longer time scales. Their frequency becomes less but remains for longer time. At the three-month scale, drought frequency increased but its duration decreased. This means that drought became more frequent at shorter time scales but stayed for shorter periods (Degefu and Bewket, 2013; Edossa *et al.*, 2010; Umran, 1999).

Generally, the temporal SPI analysis shows that most of the stations measured extreme, severe, moderate and mild drought episodes in the years 1984, 1987/1988, 1992/1993, 1999, 2003/2004 and 2007/08. Indeed, these years were among the worst drought years in the history of Ethiopia which agrees with previous findings of (Viste *et al.*, 2012, Tagel *et al.*, 2011 and Edossa *et al.*, 2010). The drought years identified by this SPI analysis for South Wollo are known for their substantial damage in terms of life and economic losses like other parts of Ethiopia which agrees with the findings of (Bayissa *et al.*, 2015; Tagel *et al.*, 2011). It is very important to remind that SPI used the monthly rainfall to analyze the drought episode in this study. However, the monthly rainfall data did not reflect the daily rainfall characteristics, such as the beginning and end time of dry spells which have a great implication on the effect of droughts especially for agricultural activities.

The MK test results indicate that SPI values were ranging from −0.14 to −0.51 Z-unit per decade at the three-month timescales during spring season suggesting increasing drought episodes. However, it was significant only at Mekaneselam ($p < 0.05$). On the other hand, the SPI values were increasing at the three-month (June-August) at all stations albeit the trends were statistically significant at Dessie, Haik and Mekaneselam. Generally, significant increasing tendencies of drought were observed during spring season and decreasing tendencies of drought during summer and annual scale in the study region.

5. Conclusions

In this study, a brief drought analysis was presented using SPI. It is a very important tool for quantifying drought and comparing its characteristics over time and space. We used SPI, in this study, to examine the magnitude and frequency, trend, patterns and probability of drought occurrences. Here, droughts occurrences were analyzed both at 3- and 12-month time scales, and the number of droughts at six stations are presented in Figure 3. Though almost all stations in the study region suffer from drought, it is important to consider that all of the stations did not experience well-defined drought episode during the same periods. In other words, temporal distribution and frequency of droughts varied markedly among each station.

Extreme droughts were more pronounced in stations where their altitude is above 3,000 masl during spring and in stations having altitude of less than 3,000 masl during summer. Similarly, stations found in western part of the study region were exposed to high frequency of severe and extreme droughts at annual timescale. The drought years in the study region identified by this SPI analysis were among the worst drought years in the history of Ethiopia. The year 1984, for example, was the most drastic and distinct-wide drought episode. Almost all stations experienced extreme magnitude drought at 3-month (summer) and 12-month timescales in the specified year.

Generally, the entire study area can be considered as drought prone area. Increasing tendencies of drought were observed during spring and decreasing tendencies at summer and annual timescales. The patterns of drought events in the study area are highly localized. Special attention (local-scale planning) should be given, while decision makers plan to effectively manage drought. The findings of this study have implications for drought management, early warning system, preparedness and contingency planning and climate change adaptation. In real sense, drought is a climatic event that cannot be prevented very easily, but interventions and preparedness to drought can help to cope with drought by developing more resilient ecosystems, improving resilience to recover from drought and taking various adaptation strategies like water harvesting, making irrigation system more efficient and a geographical shift of agricultural system.

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