Meteorological Droughts from 1987-2017 in Yabello and El-Woye Areas of Borana, Oromia Region, Ethiopia

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Abstract
Droughts originate from deficiency in precipitation over extended periods of time and affect approximately 60% of the world's population. They are the major obstacle to viable rain-fed agriculture. The study was undertaken to investigate the magnitude, frequency and trends of drought incidents in lowlands of the Borana Zone, southern Ethiopia from 1987 to 2017. Coefficient of variation, standard precipitation index, Mann–Kendal test, and Drought Index Calculator were used to analyse the rainfall data. The SPI for the main rainy season, short rainy season and annual period were computed. Accordingly, 1998, 2002, 2003, 2006, 2015 and 2016 were drought periods in the study area. During the 1987-2017 period, almost 50% of the period faced drought and the year 2006 saw the most severe and extreme drought episode in the study area with SPI value of -2.14 at El-Woye and -2.01 at Yabello. Except for the annual rainfall CV at Yabello, which is 21.2% medium variability, the short and main rainfall seasons CV of both Yabello and El-Woye as well as the annual rainfall of El-Woye showed high rainfall variability as the CV value is over 30%. However, all timescales, except the two-month timescale at El-Woye, were statistically insignificant ($p<0.05$). Tendencies of drought during the main rainy season were observed to increase while for that of the short rainy season the annual scale of the Borana area showed a decreasing trend. Therefore, stakeholders at local, regional and national levels are required to take proper adaptive and mitigating measures and forecasting systems to advance warning and proactive actions in favor of the communities and the environment and the region in particular and elsewhere at large. Continuous and persistent drought monitoring is essential to determine when droughts begin and end. Further studies in relation to using SPI as a standalone method of drought analysis and interpretation are recommended for further conformity to the scenario of the environment. Such studies are important to refine the existing knowledge for proper representation of the study area.

Keywords: Borana, drought, Drought Index Calculator, Mann–Kendall, Standardized Precipitation Index (SPI), trends

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1. Introduction

Drought is a deficiency of precipitation from expected or normal conditions that extends over a season or longer periods of time and where water is thus insufficient to meet the needs of human activities (NRC, 2007). Drought is generally characterised as a short-term meteorological occurrence, which stems from a shortage of rainfall for a long period of time compared with its average and normal conditions (Mondol *et al*., 2015). Furthermore, Wilhite (2002) described drought as a normal, recurring phenomenon of climate that practically occurs in all regions of the world.

Droughts, which originate from deficiency in precipitation over extended periods of time and affect approximately 60 per cent of the world‘s population, are the major constraints to viable rain-fed agriculture particularly in the ASALs (Huho and Mugalavai, 2010). The available estimates on drought impacts suggest that, during the period 1998–2017 following the flood, which affected a further 1.5 billion resulting in a huge toll to humanity, killed about 21,563 people (EM-DAT, 2018). There are four types of drought, namely meteorological, agricultural, hydrological and socio-economic droughts (Wilhite and Glantz, 1985; WMO, 2006).

Meteorological drought is deficiency of rainfall which can be observed immediately (Panu and Sharma, 2002). Meteorological drought is based on the degree of dryness or rainfall deficit and the length of the dry period (NOAA, 2019). According to Swain *et al*. (2018), meteorological drought occurs when there is a prolonged time with less than average precipitation. The magnitude and severity of meteorological drought impacting social and economic systems of any human society will be dependent on the underlying vulnerability and are exposed to the event as well as climate and weather patterns that determine the frequency and severity of the event (Wilhite *et al*., 2007).

In the Borana Lowland, prolonged and recurrent drought is the most typical event of climate change. Remarkably, drought cycles have been shortened that increase their risks (Oxfam, 2011). As a result, reproductive performance of livestock was reduced due to the fact that livestock mortality is increasing (Herrero *et al*., 2010). In Borana Zone, drought occurs every 1–2 years, compared to every 6–8 years in the past (Riche *et al*., 2009). This threatens the livestock production system, which recurrently erodes the size of livestock before full recovery is achieved (Ayana, 2007).

Over the past few decades there have been many studies with regard to drought which have been carried out in different parts of pastoralist areas and in the study area (Abera and Aklilu, *2012;* Paul, 2013; Opiyo *et al*., 2014; Dirriba and Jema, 2015; Argaw *et al*., 2015; Dirriba, 2016). Most of these studies have been devoted to analyzing the pastorals’ and agro-pastorals’ strategies for coping with impacts of the droughts. Paul (2013) also studied socio- economic impacts of droughts, coping strategies and government interventions in Marsabit County, Kenya. Moreover, Dirriba (2016) studied the impacts of droughts and conventional coping strategies of the Borana Community in Yabello and Dirre districts, Ethiopia, where the survey results showed that drought severely affected the livestock of the pastoralists. However, these studies failed to identify the extent of annual rainfall variability in the short season and main season as well as their trends and variations of drought in the study area for over three decades. Hence, the current study focused on assessing meteorological drought for the period 1987-2017 by including short and main rainy seasons as well as annual rainfall distribution using different indices and two meteorological stations in the Borana Lowlands, Oromia Region, Ethiopia.

2. Materials and Methods

2.1. Description of Study Area

The study was conducted in Yabello and El-Woye districts of Borana zone in Oromia regional state. Borana zone is located in southern Ethiopia between 3° 36'-6° 38' N and 36° 43'- 41° 40' E, 570 kilometers away from Addis Ababa, the capital of Ethiopia (Figure 1). The study area experiences a bi-modal monsoon rainfall type, where 60% of the 300-900mm annual rainfall occurs during March to May (g*anna*[*]) and 40% between September and October (*hagaya*[**]) (Zemenu, 2009). The same source further indicates that the average annual temperature of the area is 24.5^{0}C. The corresponding amounts of maximum and minimum temperatures are 26.83^{0}C and 20.4^{0}C, respectively.

The livelihood of 60% of the population depends on pastoralism, while the livelihood of the remaining 40% of the population relies on agro-pastoralism. The pastoralists and agro-pastoralists in Borana are the owners of rich and respected cultural heritage and customary institutions, in which they are involved in local administration, make rules and regulations of social relationship and resource management. Nevertheless, the indigenous knowledge and customary institutions to manage the resources have been adversely challenged by different external political factors and natural phenomena like droughts (BoZA, 2013).

[*]*ganna*= main rainy season; [**]*hagaya*= short rainy season

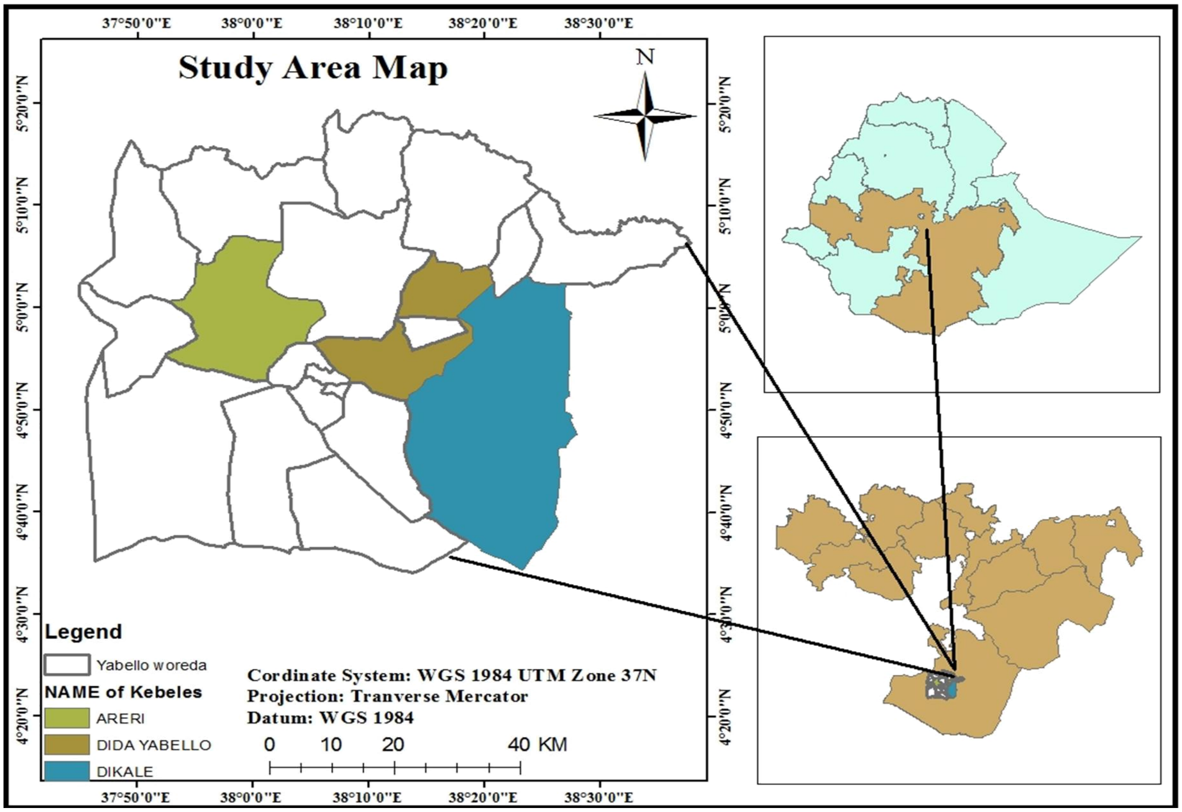

Figure 1: Location map of the study area

2.2. Research Design, Data Sources, and Methods of Analysis

The study used mixed methods research, particularly the concurrent triangulation approach as research design. The purpose of mixed methods research is to build on the synergy and strength that exists between quantitative and qualitative research methods to understand a phenomenon more fully than is possible using either quantitative or qualitative methods alone (Gay *et al*., 2012).

Rrainfall data of Yabello and El-Woye stations of Borana area for the period 1987-2017 were obtained from Ethiopian National Meteorological Agency (NMA) and used in the computations related to meteorological drought. The data of the two stations of Borana area are used to minimize or avoid the effects of spatio-temporal variations of rainfall due to gaps in the data as well as for the complementation and maintenance of quality of the meteorological data in the Borana area. Data were generated following the first order Markov chain model using INSTAT plus (v3. 6) Software (Stern *et al*., 2006) to fill the missing values. Drought Index Calculator (DrinC) was used to analyze the SPI (Tigkas *et al*., 2014).

SPI Computation

The SPI is a z-score and represents the drought event departure from the mean, expressed in standard deviation units. Standard Precipitation Index is used to identify the meteorological drought or deficit of precipitation for multiple timescales in the stations studied (McKee *et al*., 1993). The SPI value provides a comparison of the rainfall over a specific period with the rainfall totals from the same period for all the years included in the historical record (Shahid, 2008; Yimer *et al*., 2017). To calculate the SPI, a long-term precipitation record at the desired station is first fitted to a probability distribution (e.g. gamma distribution), which is then transformed into a normal distribution so that the mean SPI is zero (McKee *et al*., 1993; Edwards and McKee, 1997). It is expressed mathematically as follows:

$$SPI_{ij} = \frac{Xij - \mu ij}{\delta ij}$$

Where SPI_{ij} is the SPI of the i^{th} month at the j^{th} timescale, X_{ij} is rainfall total for the i^{th} month at the j^{th} timescale, μ_{ij} and a_{ij} are the long-term mean and standard deviation associated with the i^{th} month at the j^{th} timescale, respectively.

Table 1: SPI based drought severity class

Index Value	Class SPI	Value	Drought severity class
SPI ≥2.0	Extremely wet		
1.5≤SPI<2.0	Very wet	Above 0	No drought
1.0≤SPI≤1.5	Moderately wet		
-1.0<SPI<1.0	Nearly normal	0.0 to -0.99	Slight drought
-1.5<SPI≤-1.0	Moderate dry	-1.0 to -1.49	Moderate drought
-2.0<SPI≤-1.5	Severely dry	-1.5 to -1.99	Severe drought
SPI≤-2.0	Extremely dry	-2 and less	Extreme drought

Source: Adapted from Mondol *et al*. (2015) and McKee *et al*. (1993)

Drought Index Calculator (DrinC) which was developed by the Laboratory of Reclamation Works and Water Resources Management, National Technical University of Athens was used to analyze Standard Precipitation Index (SPI) (Tigkas *et al*., 2014). McKee *et al*. (1993) first defined the index and the criteria for drought classifications by SPI values. In the present research, the modified classification of Mondol *et al*. (2015) is used (Table 1).

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). The SPI values were computed at three timescales including 2 months (SPI-2), 3 months (SPI-3) and 12 months or annual (SPI-12) as used by Yimer *et al*. (2017) and also recommended in WMO (2012). SPI-3 was used by Almedeij (2014) to assess drought characteristics in Kuwait.

Specifically, SPI-2, SPI-3 and SPI-12 were used to assess meteorological droughts and related water shortages in the main rainy (*ganna)* season (March-May), short rainy (*hagaya*) season and the annual, respectively, in Borana area. A drought occurs when the SPI is consecutively negative and its value reaches an intensity of -1 or less and ends when the SPI becomes positive. For each month of the calendar year, new data series were created, with the elements equal to the corresponding rainfall moving sums (Degefu and Bewket, 2013).

Trend detection and analysis

The study employed Mann-Kendall's (MK) test for rainfall trend analysis. Mann-Kendall's test checks the hypothesis of no trend versus the alternative hypothesis of an increasing or decreasing trend (Collins, 2009). The study of Yue *et al*. (2002) and Koricha *et al*. (2012) noted that these tests have to identify trends in time series.

$$S = \sum_{i-1}^{N-1} \sum_{J=I+1}^{N} \text{sgn}\,(xj - xi)$$

Where, S is the Mann-Kendal's test statistics; *x*i and *x*j are the sequential data values of the time series in the years *i* and *j* (*j* >*i*) and *N* is the length of the time series.

$$\text{Sign}\,(xj - xi) = \begin{Bmatrix} +1, \text{if}\,(xj - xi) > 0 \\ 0, \text{if}\,(xj - xi) = 0 \\ -1 \ \text{if}\,(xj - xi) < 0 \end{Bmatrix}$$

The variance of *S*, for the situation where there may be ties (that is equal values) in the *x* values, is given by:

$$Var(S)=\frac{1}{18}\left[N(N-1)(2N+5)-\sum_{i=1}^{M}t((t_i-1)(2t_i+5))\right]$$

Where, *m* is the number of tied groups in the data set and *ti* is the number of data points in the *ith* tied group. For n larger than 10, ZMK approximates the standard normal distribution (Partal and Kahya, 2006; Yenigun *et al.,* 2008) and computed as follows:

$$Z_{MK}=\begin{cases}\frac{S-1}{\sqrt{Var(S)}} & if\ S>0\\ 0 & if\ S=0\\ \frac{S+1}{\sqrt{Var(S)}} & if\ S<0\end{cases}$$

The presence of a statistically significant trend is evaluated using the Z_{MK} value. In a two-sided test for trend, the null hypothesis (H_o) should be accepted at a given level of significance. Z1-α/2 is the critical value of Z_{MK} from the standard normal table. For example, for 5% significance level, the value of Z1-α/2 is 1.96.

The 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). The significance level of the slope was estimated using Sen's method. Sen's slope (Q) estimates methods that account for seasonality of the precipitation data. This method uses a simple non-parametric procedure developed by Sen (1968) to estimate the slope. The nonparametric tests are used to detect trends but don't quantify the size of the trend or change. Hence, magnitude of the observed trend can be estimated with Sen's slope estimator when significant (Paulo *et al*., 2012).

Coefficient of variation

The rainfall variability for Yabello and El-Woye meteorological stations was calculated using the CV to evaluate the inter-annual variability of seasonal and annual rainfall and is computed as:

$$CV=\frac{\delta}{\dot{x}}$$

Where, CV= coefficient of variations, δ = standard deviation and ẋ= mean. The CV<20% indicates low variability, CV between 20% and 30% indicate moderate rainfall variability, CV>30% indicates high rainfall variability, CV>40% very high and CV>70% indicates extremely high inter-annual variability of rainfall as used by (Hadju *et al.,* 2013; Belay, 2014; Eshetu, *et al*., 2016).

3. Results And Discussion

3.1. Magnitude And Frequencies Of Drought

3.1.1. Main rainy season (*Ganna*)

The total number of drought events with slight, moderate, severe and extreme severe computed at 3-month timescale (March-May) in the main rainfall season accounted for 50% in Yabello and 53.3% in El-Woye stations (Figures 2 and 3). However, they had varied magnitude classes as can be seen from the SPI results. Severe droughts were recorded in 1999, 2000, 2008 and 2011 in Yabello station which ranges from -0.15 to -1.53, while severe droughts were recorded in El-Woye in 1996 and 1992, with SPI values of -1.59 and -1.85, respectively. Extreme severe drought was recorded in the year 2006 only in Yabello with SPI value -2.11, whereas it was not observed at El-Woye (Figure 3). This is in line with the recent finding of Habtamu (2019). Hence, continuous and persistent drought monitoring is essential to determine when droughts begin and end as it is a good indicator for such climatic regions (WMO 2012).

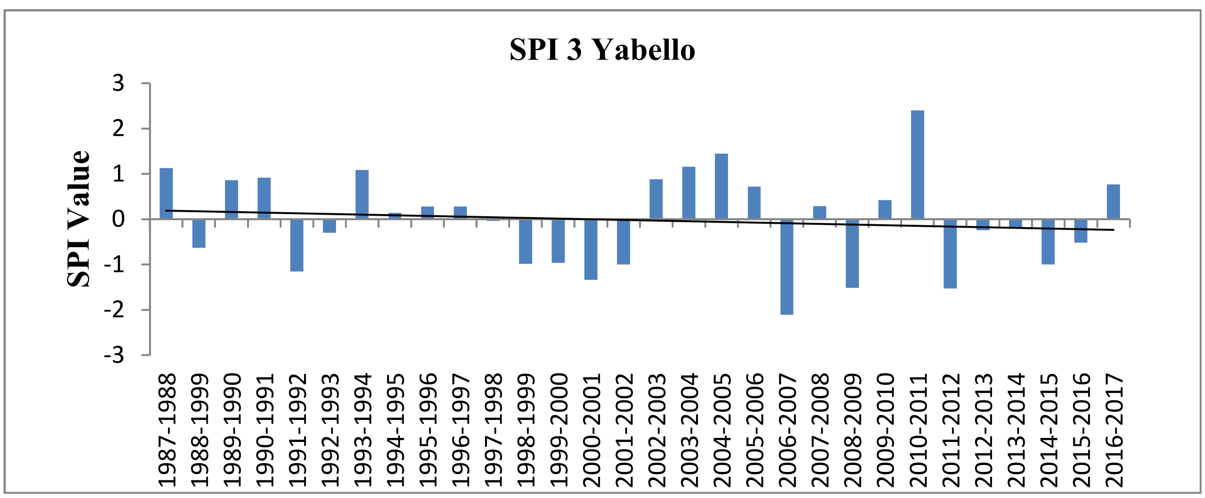

Figure 2: Three-month timescale of SPI at Yabello Station

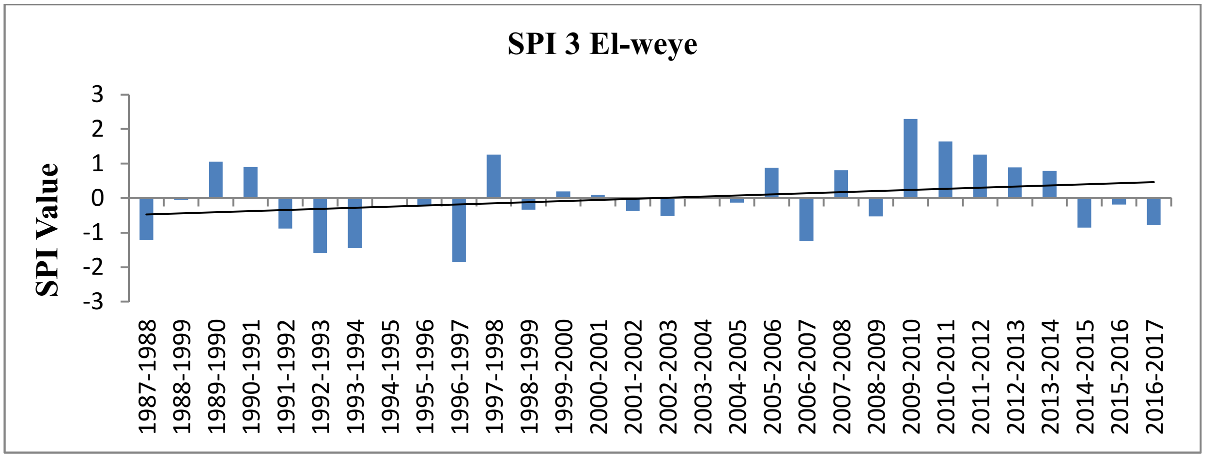

Figure 3: Three-month timescale SPI at El-Woye Station

The analysis of 3-month timescale (March-May) showed that 1988, 1991, 1992, 1998, 2001, 2008, 2014, 2015, and 2016 were drought years in both studied areas. Generally, the drought magnitude of the 3-month timescale varied from slight to extreme severe in the studied areas. As the main source of water for the study area is rainfall, any change in rainfall amount and distribution can lead to serious production deficit and undermine the delicate balance between pasture and livestock on which pastoral and agro-pastoral livelihood depends (Elias, 2009; Hagos *et al*., 2009). The main rainy season (March, April, May) rainfall contributed the highest percentages of 52.2% and 48.3% of rainfall to annual rainfall at Yabello and El-Woye respectively. So, failure of this season can make pastoral communities highly vulnerable to drought impacts.

3.1.2. Short rainy season (*Hagayyaa*)

The total number of drought events at the two-month timescale (September and October) in the entire period of analysis was found between 16 months at Yabello and 15 months at El-Woye stations, respectively (Figures 4 and 5). Yabello had an extreme severe drought with SPI value -2.28 at this timescale in the 2015 drought year. Severe droughts occurred in 1993, 2002 and 2006 whose values range from -1.55 to -1.76 at El-Woye station, whereas in Yabello station a severe drought occurred in 1992 with SPI values of -1.68.

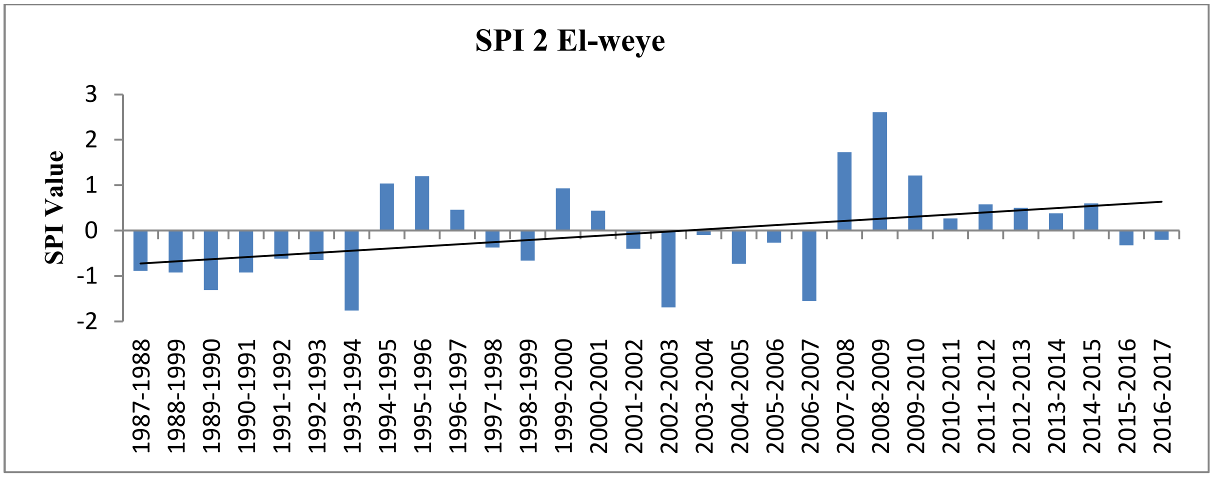

Figure 4: Two-month timescale SPI-2 at El-Woye Station

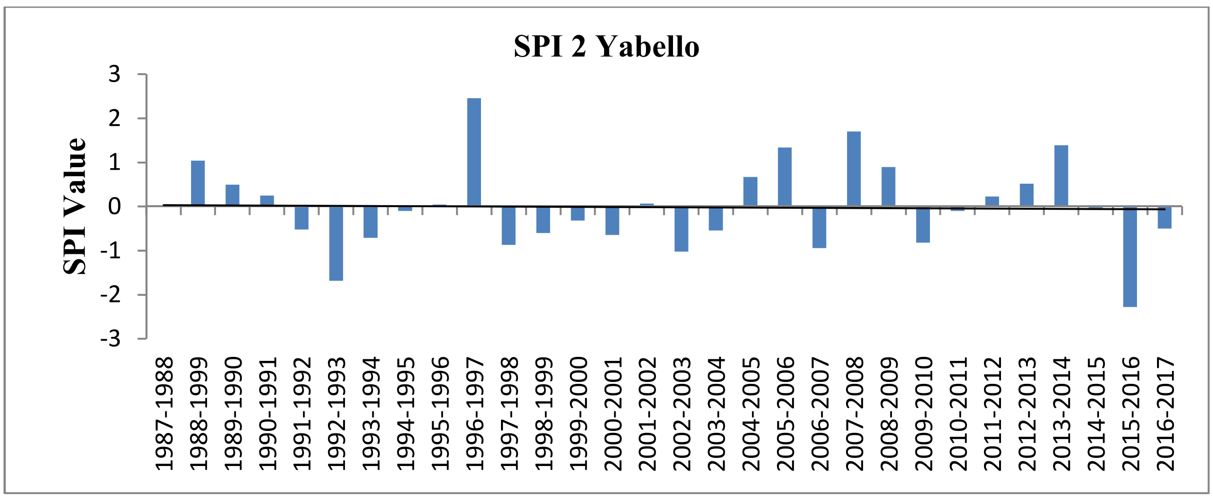

Figure 5: Two-month timescale SPI-2 at Yabello Station

3.1.3. Annual drought

The total number of drought years at 12-month timescale (January-December) was found 15 at Yabello and 16 at El-Woye, which constitutes 50% and 53.3% of the total number of drought incidents in the study period, respectively (Figures 6 and 7). At this timescale, the most severe droughts were recorded at Yabello in 2006 and 1999 with SPI values of -2.01 and -2.04, respectively, whereas in El-Woye an extreme severe drought was recorded in 2006 with SPI value of -2.14. This implies that in 2006 both areas underwent extreme severe drought events, which had large effects on the pastoralists and agro-pastoralists. This is supported by other studies (Temesgen *et al.,* 2009; Getachew, 2018) who stated in their studies that 7.4 million people were affected; 247,000 heads of cattle died in Borana lowlands, Tigray, Amhara, Afar and Somali regions in the 2006 drought.

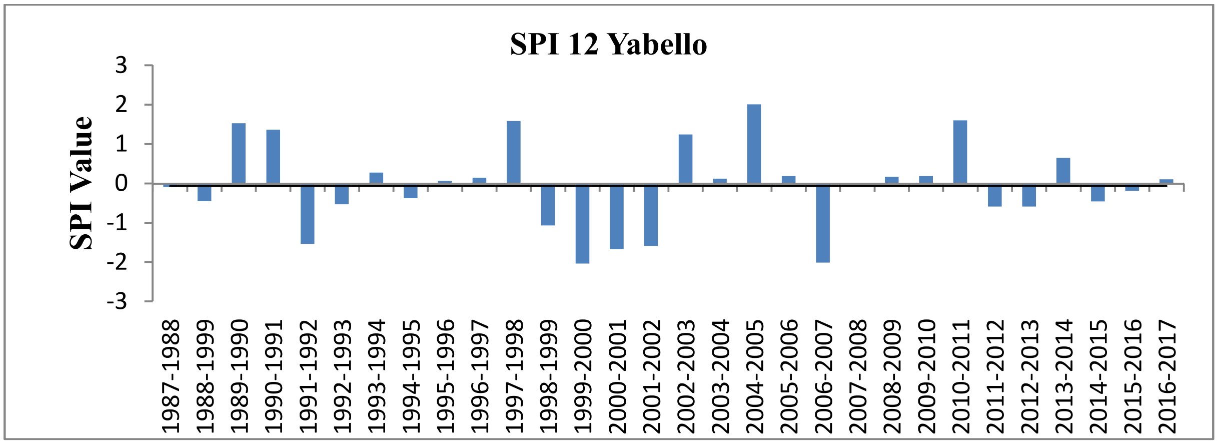

Figure 6: Twelve-month (annual) timescale SPI at Yabello Station

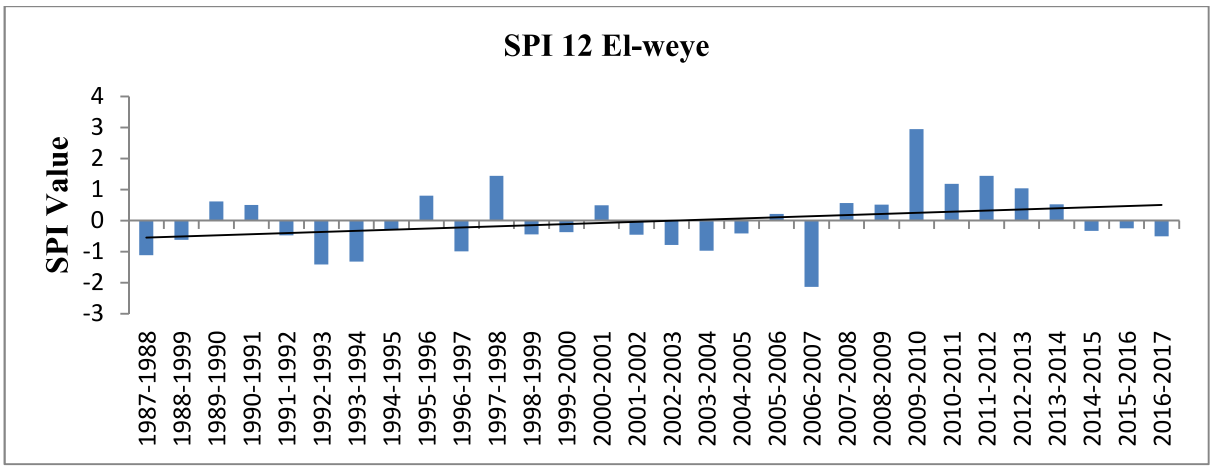

Figure 7: Twelve-month timescale SPI at El-Woye Station

The analysis of the 12-month timescale drought was recorded across the study areas in 1987, 1988, 1991, 1992, 1994, 1998, 1999, 2001, 2006, 2014 and 2015 although there was variation in the degree of severity. The total number of moderate droughts at 12-month timescale was 13 months at El-Woye and 9 months at Yabello. Generally, the rainfall pattern in the studied stations exhibited certain characteristics that a drought year is followed by another two or three dry years vis-à-vis the wet years. These findings are in agreement with that of Girma *et al.* (2013) and Girma *et al.* (2016). However, it is commented by Kumar *et al.* (2009) that the SPI values are overestimated for low rainfall levels and underestimated for high rainfall levels in some districts in India, particularly in the low rainfall district. Hence, using SPI as a standalone indicator needs to be interpreted with caution, for drought intensity assessment particularly in low rainfall districts are more vulnerable to droughts. Despite this fact, the sensitivity of SPI for the quality and reliability of data used to fit the distribution 30 to 50 years data is recommended by the USA (Keyantash and Dracup 2002) that makes the findings of this study acceptable as it used the data within the range of the recommendation.

3.2. Trends Of Drought Occurrences

Trends of drought occurrences for 2-month (Short rainy season), 3-month (Main rainy season) and 12-month (annual) timescales were shown in Figures 8 and 9. The trends of all of the SPI values seem similar with no significant variations among them. However, the trends of the two stations are slightly not in agreement with each other. As stated by Lin *et al*. (2020), the linear trend can be stated by its upward and/or downward positions compared to the mean. Accordingly, the linear trends in the late 1980s, late 1990s, and after 2007 showed opposite direction of movement compared to the mean in the case of both Yabello and El-Woye areas though the overall linear trend of SPI-2, SPI-3 and SPI-12 did not change significantly (Figure 7 and Figure 8).

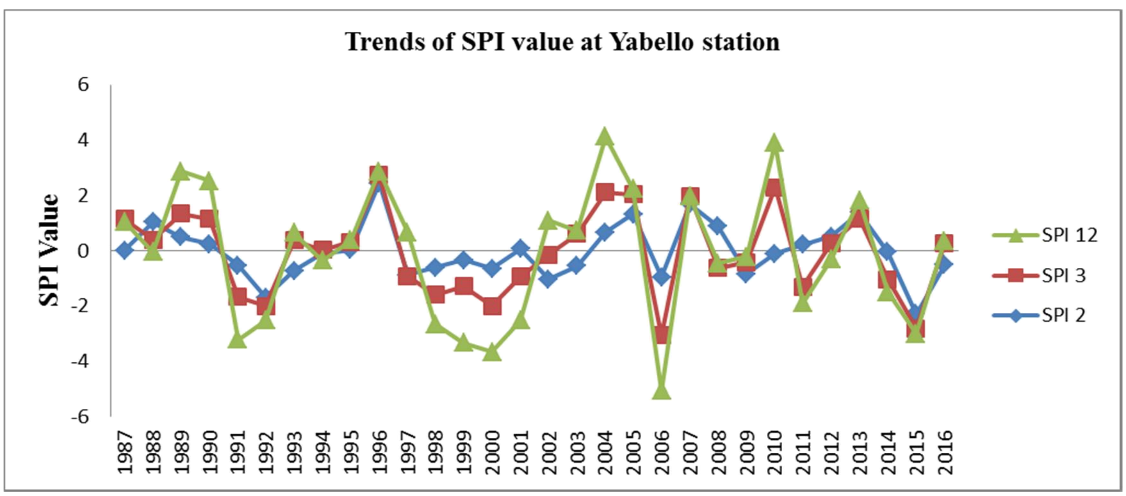

Figure 8: Trends of SPI values (at 2-, 3- and 12-month) at Yabello Station

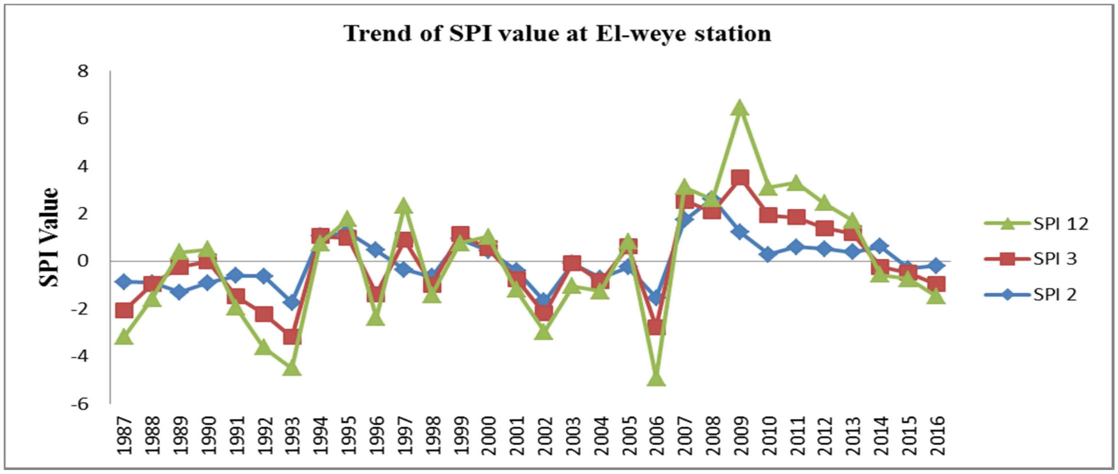

Figure 9: Trends of SPI values (at 2-, 3- and 12-month) at El-Woye Station

The MK test showed decreasing changes in SPI values in Yabello, which implies an increasing tendency of drought incidents at main rainy season, while El-Woye showed an increasing trend that implies declining of the tendency of drought incidents (Table 2). On the other hand, SPI-2 and SPI-12 values showed increasing trends at both stations. The linear trend analysis showed no statistical significance ($p < 0.05$) of any positive or negative trend of meteorological drought severity and frequency for both stations except at SPI-2 at El-Woye Station. It was slightly negative for the SPI-3 value when it comes to the Yabello area. Generally, detection of linear trends using nonparametric methods showed increasing tendencies of drought during the main rainy season and decreasing tendencies of drought during the short rainy season and annual scale in the study region. The area is frequently affected by drought as is also confirmed by Habtamu (2014).

Table 2: SPI MK trends for Yabello and El-Woye stations

Stations	SPI- 2 months			SPI-3 months			SPI- 12 months		
	Trend	**P-value**	**Sen Slope**	**Trend**	**P-value**	**Sen's Slope**	**Trend**	**P-value**	**Sen's Slope**
Yabello	0.05	0.98	0.008	-0.10	0.4	-0.02	0.01	0.94	0.002
El-Woye	0.28*	0.03	0.048	0.12	0.32	0.03	0.23	0.07	0.04

*=significant at p< 0.05

3.3. Rainfall Variability

The coefficient of variation of the seasonal and annual rainfall of the stations is presented in Table 19. The result indicated that rainfall variability at Yabello was CV=21.2%, while El-Woye station had CV=53%. The region has moderate and very high rainfall variability respectively. The main rainy season (March, April, May) rainfall contributed the highest percentages of 52.2% and 48.3% of rainfall to annual rainfall at Yabello and El-Woye, respectively, and the short rainy season (September and October) also contributed 21.4% and 24.7% at Yabello and El-Woye stations, respectively. This result agreed with the findings of Koricha *et al*. (2012) and Eshetu *et al.* (2016), who reported that main seasons made the highest contribution to annual rainfall.

The coefficient of variation range of the main rainfall season was 32.6% at Yabello Station which shows high variability, while it was 71.2% at El-Woye Station which implies very high variability in the study area (Table 2). This shows that during the main rainy season, the rainfall is highly variable, and it is in line with other studies in Ethiopia (Wassie and Fikadu 2014). The analysis of coefficient of variation for the short season (September and October) at Yabello Station was 48.3% which shows very high variability and 94.4% at El-Woye Station which is extremely variable. This shows that variability in both areas is higher than the main seasonal rainfall which agreed with the findings of many other studies (Gebre *et al.,* 2013; Belay, 2014; Girma, *et al*., 2016). The short rainy season rainfall at both stations shows the highest variation of rainfall distribution with the highest coefficient of variation, followed by the main rainy season and annual rainfall, respectively.

This finding is consistent with Desalegn *et al*. *(*2018) where greater rainfall variability is experienced during the small rainy season than the main rainy season and annual rainfall. Generally, the study site experiences moderate to extremely high inter-annual rainfall variability. As reported by Woldeamlak (2007) and Desalegn (2014), extreme high and low rainfall values within the study period could influence the rainfall trend. So both seasonal and annual rainfall distribution variability negatively affect the socio economic activities of the pastoralist and agro-pastoralist communities that mostly depend on rain-fed agriculture.

Table 1: Annual, main, and short season rainfall variability for Yabello and El-Woye Stations

Station	Annual			Main Rainfall Season				Short Rainfall Season			
	Mean	SD	CV	Mean	SD	%	CV	Mean	SD	%	CV
Yabello	597	126.94	21.2	311.6	101.6	52.2	32.6	128	62.13	21.4	48.3
El-Woye	514.3	272.7	53.0	247.2	176.1	48.3	71.2	127.6	120.5	24.7	94.4

4. Conclusion

This study investigated the frequency, magnitude and trends of droughts over lowlands of Borana during the short and main rainy seasons and annual rainfall for the period 1987-2017. The study was able to identify the major drought years within the study period and their severity. The assessment of meteorological drought showed the occurrence of slight to extremely severe droughts in the historical drought episodes in the stations studied.

The meteorological data results revealed that greater rainfall variability is experienced during the small rainy season followed by the main rainy season and annual rainfall in the Borana area, which in turn calls for proper mitigating and adaptive strategies as well as integrated forecasting and early warning systems to enhance the resilience of vulnerable communities. Continuous and persistent drought monitoring is essential to determine when droughts begin and end. Further studies are recommended for refinements of the results using advanced devices of drought integrated with local community-based resilience to study the frequent and intense meteorological droughts in the Borana area in particular and larger spatio-temporal dimensions.

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