Drought Frequency, Severity, and Duration Monitoring Based on Climate Change in Southern and Southeastern Ethiopia

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Abstract. Ethiopia is highly vulnerable to the impact of climate change due to its low adaptive capacity and a higher dependence on rain-fed agriculture for livelihood. The aim of this paper was to identify the long-term climatic trends and the magnitude of those trends and to analyse drought duration, frequency, and severity in southern and south-eastern Ethiopia based on climatic data (1980-2017). This research is a quantitative research method. The southern and south-eastern of Ethiopia were purposely selected based on a frequent occurrence of drought in the country. Monthly data were obtained from National Meteorological Agency (NMA) of Ethiopia. Mann-Kendall (MK) Test coupled with Sen’s Slope Estimator was used to analyse the trend of climatic data and its magnitude, and Standardized Precipitation Evapotranspiration Index (SPEI) was used to analysis drought characteristics. SPEI of 1-, 3- and 6-month timescales were calculated to understand drought characteristics. The result of the MK test showed that annual rainfall trend had non-significant decrease at all station except at Gode. The trend of annual maximum and minimum temperature is insignificantly increasing. The calculated SPEI revealed drought is more frequent and severe from time to time in the study area. Results showed that the most frequent, severe and prolonged droughts occurred during 1999-2017 compared to 1980-1999. Climate change mitigation and proactive drought management approach is highly recommended in order to minimize the risk of drought.

1. Introduction
Droughts occur in all countries but the frequency, severity, and duration vary from country to country and region to region. Over-exploitation of natural resources, weather variability and climate change are mostly responsible for drought [1]. Intergovernmental Panel on Climate Change (IPCC) reported that extreme weather and climate events including droughts and floods have significant impacts on the economy, natural resources, livelihoods, and human health in Africa [2]. Unlike developed countries, least developed countries (LDCs) are more sufferers of the impact of climate change due to physical, social and economic factor [1]. In this regard, the effects of drought are more severe in sub-Saharan...
Africa, where rain-fed farming encompasses 95% of all agriculture [3, 4].

In Africa’s arid and semi-arid lands, droughts have been recorded over several hundred years and the droughts in the 1960s, 1970s, and 1980s, and most recently the Horn of Africa droughts in 2011 are the major one [5]. Ethiopia is extremely vulnerable to climate-related hazards, commonly drought and floods [6], due to its high reliance on natural resources, low adaptive capacity and a higher dependence on rain-fed agriculture for livelihood [7]. Drought is a repeated occurring a phenomenon in Ethiopia. Before 1970, drought hit the nation at least once in every 10 years but after then it has become more frequent. Recently it has occurred at least every two or three years at different levels of severity [8]. In addition to drought, major floods also happened in different parts of the country in 1988, 1993, 1994, 1995, 1996 and 2006 [9].

Based on topographic variation, Ethiopia has three mega climatic zones known as Kolla, Woinadega, and Dega. Kolla is warm semi-arid and less than 1500m above sea level; Woinadega is a cool semi-humid temperate zone with altitude 1500–2400m above sea level; and Dega is cool and humid zone, with an altitude greater than 2400m above sea level. Most of the regions which are categorized under Kolla climatic zone are drought-prone areas [8]. According to Ethiopian Panel on Climate Change [5], today, more than 50% of the chronic drought-affected people in Ethiopia are from the pastoral areas. Southern and South-eastern parts of Ethiopia are among drought-prone areas in the nation. These parts are also among the food insecure areas of the country and farming is practiced in the context of reliable rainfall and has frequently suffered from recurrent drought. The drought has caused a severe shortage of water, livestock deaths due to lack of pasture and animal diseases, and famine in Ethiopia [10, 11].

In southern Ethiopia, cattle numbers dropped by 37% after the drought of 1983 to 1985 and 42% in the early 1990s (Ethiopian Panel on Climate Change, 2015). In 2015/16, the drought endangered lives and livelihoods of 10.2 million people in southern and south-eastern lowland areas of the country [12].

Monitoring drought, which is defined as data collection, analysis, and reporting to develop information for decision makers on drought condition is very important to reduce drought risk and development of an early warning [3]. Drought monitoring is the basic activity for drought mitigation. For monitoring and analysis of drought, different indices have been developed. Most researches related to drought analysis and monitoring systems have been conducted using either the Palmer drought severity index (PDSI) [13] or standardized precipitation index (SPI) [14]. The PDSI is based on a soil water balance equation while SPI is based on a precipitation probabilistic approach. An enhanced drought index that is especially suited for studies of the effect of climate change on drought severity, standardized precipitation evapotranspiration index (SPEI) has been developed [15]. The SPEI is the most appropriate index for detecting, monitoring, and exploring the effects of global warming on drought [16]. As an input, SPEI is based on the difference between precipitation and potential evapotranspiration (P – ET0), rather than precipitation (P) while SPI is based on precipitation. Therefore, SPEI provides a more reliable measure of drought severity than only considering precipitation by comparing the difference between precipitation and evapotranspiration [15, 16].

In Ethiopia, even though different indices have been used to analysis drought phenomenon, SPEI has not yet been used. Besides, many researchers have just analyse rainfall and temperature data to explain if the temperature of the country has changed or not without considering the effects of climate change on drought [17]. Regional and local information on drought and climate change is very important for monitoring and managing the impacts of drought and climate change. Drought monitoring provides important figures that support to lessen the consequences of drought, and it is useful for a drought management plan. However, drought monitoring has not been done in many parts of the country including this study area. Furthermore, scientific methods of study on drought frequency, duration and severity in the areas have not been well studied and documented even though it is the drought-prone and hence, these situations motivate the author to study and provide the vital information. So, in order to fill these gaps, this paper aims to monitor drought frequency, duration and severity by using multi-scalar drought index, SPEI.
2. Methodology

2.1 Description of Study Area and Data Acquisition

Ethiopia is a landlocked nation bordered to the north by Eritrea and Djibouti, to the South by Kenya, to the east by Somalia, and to the west by Sudan. The country has a temperate climate in the highlands and a tropical climate in the lowlands with a rainy season from mid-June to mid-September. It is characterised by extreme geographic diversity, and elevations ranging from 100m below sea level to 4,62m above sea level. This research took place in southern and south-eastern of Ethiopia which is presently experiencing severe drought. The southern parts included in this study in Arbaminch part of Southern Nations, Nationalities and Peoples’ region; Neghele, Yabello and Moyale from Oromia region, and the south-eastern are Gode and Kebr Dehar from Ethiopia’s Somali region. Figure 1 shows the map of the study area.

![Figure 1. Study area map](image-url)
National Meteorological Agency (NMA) of Ethiopia for the analysis. Long-term climatic trends and the magnitude of those trends were analyzed using the Mann-Kendall (MK) Test coupled with Sen’s Slope Estimator. Drought frequency, duration, and severity analysis were carried out using Standardized Precipitation Evapotranspiration Index (SPEI) based on climatic data from six weather stations (1980-2017). Table 1 shows the information of meteorology stations and the period of data used for the study; and Table 2 shows mean annual precipitations (PRCP) in mm and mean annual temperature (Tmean) in °C. Mean monthly precipitation of the study area are presented in Figure 2.

Table 1. Meteorology stations information and the period of data used for the study

| Name of stations | Latitude       | Longitude      | Elevation | Duration |
|------------------|----------------|----------------|------------|----------|
| Arbaminch        | 6.057167       | 37.55783       | 1207       | 1980-2017|
| Moyale           | 3.55           | 39.03333       | 1166       | 1980-2017|
| Neghele          | 5.416667       | 39.56667       | 1544       | 1980-2017|
| Yabello          | 6.883333       | 38.1           | 1729       | 1980-2017|
| Gode             | 5.9            | 43.58          | 290        | 1980-2015|
| Kebry Dehar      | 6.733333       | 44.3           | 505        | 1980-2015|

Table 2. Mean annual precipitations (PRCP) and mean annual temperature (Tmean)

| Year | PRCP | Tmean | PRCP | Tmean | PRCP | Tmean | PRCP | Tmean | PRCP | Tmean |
|------|------|-------|------|-------|------|-------|------|-------|------|-------|
| 1980 | 1042 | 24    | 660  | 22    | 901  | 20    | 733  | 21    | 40   | 29    |
| 1981 | 1328 | 23    | 892  | 22    | 1309 | 19    | 839  | 20    | 205  | 28    |
| 1982 | 1115 | 23    | 908  | 22    | 1030 | 20    | 899  | 20    | 196  | 29    |
| 1983 | 908  | 23    | 436  | 23    | 709  | 20    | 520  | 22    | 285  | 29    |
| 1984 | 798  | 23    | 473  | 23    | 552  | 19    | 568  | 21    | 71   | 28    |
| 1985 | 872  | 23    | 1024 | 23    | 658  | 19    | 885  | 20    | 248  | 28    |
| 1986 | 914  | 23    | 728  | 23    | 718  | 19    | 701  | 21    | 221  | 29    |
| 1987 | 707  | 24    | 572  | 23    | 836  | 20    | 578  | 20    | 127  | 28    |
| 1988 | 1064 | 24    | 803  | 22    | 539  | 21    | 535  | 20    | 157  | 28    |
| 1989 | 1026 | 23    | 511  | 22    | 701  | 19    | 799  | 19    | 221  | 28    |
| 1990 | 622  | 24    | 972  | 22    | 780  | 21    | 774  | 20    | 205  | 28    |
| 1991 | 757  | 24    | 352  | 22    | 473  | 20    | 419  | 20    | 181  | 28    |
| 1992 | 964  | 24    | 289  | 22    | 564  | 22    | 526  | 20    | 142  | 28    |
| 1993 | 874  | 24    | 409  | 22    | 669  | 21    | 648  | 20    | 140  | 28    |
| 1994 | 813  | 24    | 544  | 22    | 623  | 21    | 544  | 20    | 298  | 29    |
| 1995 | 895  | 24    | 325  | 23    | 739  | 21    | 597  | 20    | 195  | 29    |
| 1996 | 935  | 24    | 415  | 23    | 775  | 21    | 607  | 20    | 185  | 28    |
| 1997 | 1216 | 24    | 1092 | 23    | 624  | 21    | 833  | 20    | 535  | 29    |
| 1998 | 741  | 24    | 586  | 22    | 497  | 21    | 557  | 20    | 259  | 30    |
| 1999 | 733  | 24    | 289  | 22    | 359  | 21    | 372  | 20    | 197  | 29    |
| 2000 | 869  | 24    | 437  | 23    | 512  | 21    | 397  | 20    | 304  | 29    |
| 2001 | 1084 | 23    | 442  | 23    | 607  | 21    | 448  | 20    | 136  | 30    |
| 2002 | 809  | 24    | 596  | 22    | 692  | 21    | 755  | 20    | 226  | 30    |
| 2003 | 882  | 24    | 451  | 23    | 615  | 21    | 604  | 20    | 243  | 30    |
| 2004 | 758  | 24    | 564  | 22    | 663  | 21    | 874  | 20    | 249  | 29    |
| 2005 | 933  | 24    | 428  | 23    | 836  | 21    | 612  | 20    | 186  | 29    |
|      |      |       |      |       |      |       |      |       |      |       |
Table 1. Annual precipitation and mean temperature of study areas (2006-2017)

| Year | Arbaminch | Moyale | Neghele | Yabello | Gode | Kebry Dehar |
|------|-----------|--------|---------|---------|------|-----------|
| 2006 | 1128      | 24     | 1044    | 21      | 693  | 20         |
| 2007 | 1141      | 23     | 548     | 21      | 514  | 22         |
| 2008 | 851       | 24     | 448     | 22      | 777  | 22         |
| 2009 | 639       | 25     | 496     | 23      | 547  | 22         |
| 2010 | 1068      | 24     | 788     | 21      | 503  | 22         |
| 2011 | 887       | 24     | 532     | 23      | 640  | 22         |
| 2012 | 1080      | 24     | 428     | 22      | 524  | 22         |
| 2013 | 1061      | 24     | 799     | 23      | 769  | 22         |
| 2014 | 866       | 24     | 512     | 22      | 623  | 21         |
| 2015 | 1121      | 25     | 533     | 24      | 767  | 22         |
| 2016 | 787       | 24     | 377     | 24      | 619  | 22         |
| 2017 | 786       | 25     | 436     | 23      | 495  | 22         |

Figure 2. Monthly mean precipitations

2.2 Methods of Trend Analysis

2.2.1 Mann-Kendall (MK) Test.

Mann-Kendall (MK) test is the most frequently used non-parametric test for identifying trends in hydrologic and climatic data. It can be accompanied with Sen’s Slope estimator to determine the magnitude of the trend. The n time series values \(X_1, X_2, X_3, \ldots, X_n\) are replaced by their relative ranks \(R_1, R_2, R_3, \ldots, R_n\) (starting at 1 for the lowest up to n) \([18, 19]\).

The Mann-Kendall statistic \(S\) is given as:

\[
S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(x_j - x_k)
\]  

(1)

The application of trend test is done to a time series that is ranked from \(i = 1, 2, \ldots, n-1\) and \(x_i\), which is ranked from \(j = i+1, 2, \ldots, n\). Each of the data point \(x_i\) is taken as a reference point which is compared with the rest of the data points \(x_j\) so that,
\[ sgn(x_j - x_i) = \begin{cases} +1, & \text{if } x_j > x_i \\ 0, & \text{if } x_j = x_i \\ -1, & \text{if } x_j < x_i \end{cases} \] (2)

The variance statistic is given as
\[ Var(S) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(i-1)(2i+5)}{18} \] (3)
where \( n \) is the number of observation and \( t_i \) are the ties of the sample time series. The test statistics \( Z_c \) is as follows:
\[ Z_c = \begin{cases} \frac{S-1}{\sigma} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sigma} & \text{if } S < 0 \end{cases} \] (4)

A positive value of \( Z_c \) indicates that there is an increasing trend in time series and vice versa. The critical test statistic values for various significance levels for observations are 1.645, 1.96 and 2.57 at 90, 95 and 99 % probability levels. If \( Z_c \) appears greater than \( Z_{\alpha/2} \) where \( \alpha \) depicts the significance level, then the trend is considered significant. In this study, 95% significance level was used.

2.2.2 Sen’s Slope Estimator Test.
Sen’s estimator is used to predicting the magnitude of the trend [20] and it is given as follows:
\[ \beta = Median = \frac{\sum_{j=i}^{j} x_{j} - x_{i}}{j-i} \text{ for all } i \leq j \] (5)
In which 1\(< i \(< j \(< n \) and is the robust estimate of the trend magnitude. A positive value of \( \beta \) indicates an increasing trend, while a negative value of \( \beta \) indicates a decreasing trend.

2.2.3 Autocorrelation.
According to some studies, it is very important to test serial correlation because the presence of a positive or negative autocorrelation affects trend detection. If significant autocorrelation exists in time series, pre-whitening the series is necessary before applying the Mann-Kendall test to remove serial correlation from the series [26]. The serial correlation coefficient was calculated as:
\[ r_1 = \frac{1}{n-1} \sum_{i=1}^{n-1} (x_i - \bar{X})(x_{i+1} - \bar{X}) \] (6)

No significant serial correlation was judged present if the value of fell inside the bounds given by:
\[ -1 - 1.645\sqrt{(n-2)} \leq r_1 \leq 1 + 1.645\sqrt{(n-2)} \] (7)

If, however, significant serial correlation was detected, then a pre-whitened series \( x^* \) was created for subsequent analysis from:
\[ x^*_i = x_{i+1} - r_1 x_i \] (8)

2.2.4 SPEI Value Calculation
SPEI is a simple multi-scalar drought index that combines precipitation and temperature data. It was first suggested as an enhanced drought index that is especially suitable for studies of the effect of global warming on drought severity by [15]. The calculation of SPEI is based on the original SPI calculation procedure. However, the SPEI uses the monthly (or weekly) difference between precipitation and potential evapotranspiration (PET) while the SPI is calculated using monthly (or weekly) precipitation as the input data. SPEI is at different timescales, and in this research, 1-, 3- and 6-month time scales were calculated.

The steps of computation of the SPEI based on Vicente-Serrano et al. [15] are as follows:
2.2.5 Estimation of the potential evapotranspiration (PET). The first step in calculating SPEI is an estimation of the potential evapotranspiration via the Thornthwaite method. Thornthwaite method is the simplest approach for calculating PET because it requires only monthly average temperature and station’s latitude as input data [21]. Following Thornthwaite method, the monthly PET (mm) is obtained by

\[ PET = 10K \left( \frac{10T}{I} \right)^m \]  

(9)

Where \( T \) is the monthly-mean temperature (°C); \( I \) is a heat index, which is calculated as the sum of 12 monthly index values \( i \), the latter being derived from mean monthly temperature using the formula

\[ i = \left( \frac{T}{5} \right)^{1.514} \]  

(10)

m is a coefficient depending on \( I \): \( m = 6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.79 \times 10^{-2} I + 0.492 \); and \( K \) is a correction coefficient computed as a function of the latitude and month,

\[ K = \left( \frac{N}{12} \right) \left( \frac{NDM}{30} \right) \]  

(11)

Here NDM is the number of days of the month and \( N \) is the maximum number of sun hours, which is calculated using

\[ N = \left( \frac{24}{\pi} \right) \omega_s \]  

(12)

where \( \omega_s \) is the hourly angle of sun rising, which is calculated using

\[ \omega_s = \arccos (-\tan \varphi \tan \delta) \]  

(13)

where \( \varphi \) is latitude in radians and \( \delta \) is the solar declination in radians, calculated using

\[ \delta = 0.4093 \left( \frac{2\pi J}{365} - 1.405 \right) \]  

(14)

where \( J \) is the average Julian day of the month.

2.2.6 Calculating the difference between the precipitation \( P \) and PET.
The second step in computing SPEI is calculating the difference between the precipitation \( P \) and PET. The difference between the precipitation \( P \) and PET for the month \( i \) is calculated using

\[ D_i = P_i - PET_i \]  

(15)

which provides the water surplus or deficit for the analysed month (month \( i \)). Following the same procedure as that for the SPI, the calculated \( D_i \) values are aggregated at different time scales. The difference \( D_{i,j}^k \) in a given month \( j \) and year \( I \) depends on the chosen time scale \( k \). For example, the accumulated difference for 1 month in a particular year \( I \) with a 12-month time scale is calculated using:

\[
\begin{align*}
X_{i,j}^k &= \sum_{l=13-k+1}^{12} D_{i-1,l} + \sum_{l=1}^{j} D_{i,l}, \text{ if } j < k \\
X_{i,j}^k &= \sum_{l=j-k+1}^{j} D_{i,l}, \text{ if } j \geq k
\end{align*}
\]  

(16)

where \( D_{i,l} \) is the \( P \)-PET difference in the first month of year \( i \), in millimetres. Normalize the water balance into a log-logistic probability distribution to obtain the SPEI index series. For calculation of the SPI on different time scales, the probability distribution of the gamma family is used (the two-parameter gamma or three-parameter Pearson III distributions), because the frequencies of precipitation accumulated at different timescales are well modelled using these statistical distributions. Although the SPI can be calculated using two-parameter distribution, such as the gamma distribution, the distribution of the three-parameters needed to calculate the SPEI. In the distribution of two-parameter, the variable \( x \) has a lower limit of zero (\( 0 < x < \infty \)), while the distribution of the three-parameters, \( x \) can take values in the range (\( \gamma > x < \infty \)), where \( \gamma \) is the parameter origin of the distribution; consequently, \( x \) can have a negative value, which is common in \( D \) series.
Frequency estimator \((F_i)\) is calculated as the following approach of Hosking [22]
\[
F_i = \frac{i - 0.35}{N}
\]
(17)
where \(i\) is the range of observations arranged in increasing order and \(N\) is the number of data points.

The probability density function of three parameters log-logistic distributed variable is expressed as
\[
f(x) = \frac{\beta}{\alpha} \left(\frac{x - \gamma}{\alpha}\right)^{\beta-1} \left[1 + \left(\frac{x - \gamma}{\alpha}\right)^{\beta}\right]^{-2}
\]
(18)
where \(\alpha, \beta,\) and \(\gamma\) are scale, shape, and origin parameters, respectively, for \(D\) values in the range \((\gamma > D < \infty)\).

The parameters of the Pearson III distribution can be obtained following [23]:
\[
\begin{align*}
\beta &= \frac{2w_1 - w_0}{6w_1 - w_0 - 6w_2} \\
\alpha &= \frac{\alpha}{\tau(\beta)} \left(\frac{1 + \frac{1}{\beta}}{\tau(1 - \frac{1}{\beta})}\right) \\
\gamma &= w_0 - \alpha \tau \left(\frac{1 + \frac{1}{\beta}}{\beta}\right) \tau \left(\frac{1 - \frac{1}{\beta}}{\beta}\right)
\end{align*}
\]
(19)
where \(\tau(\beta)\) is the gamma function of \(\beta\).

The probability distribution function of the D series, according to the log-logistic distribution, is given by
\[
F(x) = \left[1 + \left(\frac{x - \gamma}{\alpha}\right)^{\beta}\right]^{-1}
\]
(20)
With \(F(x)\) the SPEI can easily be obtained as the standardized values of \(F(x)\). Following the classical approximation of Abramowitz and Stegun [25]:
\[
SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3}
\]
(21)
Where \(W = \sqrt{-2\ln(P)}\) for \(P \leq 0.5\)
and \(P\) is the probability of exceeding a determined \(D\) value, \(P = 1 - F(x)\). If \(P > 0.5\), then \(P\) is replaced by \(1 - P\) and the sign of the resultant SPEI is reversed. The constants are \(C_0 = 2.515517, C_1 = 0.802853, C_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269,\) and \(d_3 = 0.001308\).

However, for the calculation of SPEI in this study, the software developed by Berguer et al. [16] was used, and it was applied using R package SPEI version 1.6 (http://cran.r-project.org/web/packages/SPEI). The package calculates PET using Thornthwaite, Penman-Monteith, or Hargreaves method. However, in this study, PET was calculated using Thornthwaite.

2.2.7 Drought Frequency, Duration and Severity
SPEI uses both precipitation and evapotranspiration to quantify drought frequency, duration, and severity. The climatic water balance, the difference between precipitation and reference evapotranspiration \((P - ET0)\), compares the available water \((P)\) with the atmospheric evaporative demand \((ET0)\), and therefore SPEI provides a more reliable measure of drought severity than when compared to calculating only precipitation [16]. A drought index is used to assess the effect of drought and to determine drought characteristics like duration, frequency, and severity. In this study, SPEI drought index was used to determine drought characteristics. Table 3 describes the categories of wet and dry in SPI [14] which is also used in SPEI [16].
Table 3. Categorization of wetness and dryness grade by the SPEI

| SPEI value     | Categories          |
|---------------|---------------------|
| More than 2   | Extremely wetness   |
| 1.50 to 1.99  | Severe wetness      |
| 1.0 to 1.49   | Moderate wetness    |
| −1.0 to 1.0   | Near normal         |
| −1.49 to −1.0 | Moderate drought    |
| −1.99 to −1.5 | Severe drought      |
| Less than −2  | Extremely drought   |

The same with SPI value, positive SPEI values indicate surplus water, related to precipitation above normal average, while negative values indicate water deficit or precipitation below normal average [26]. Figure 3, is used to determine drought characteristics (frequency, duration, and severity). The negative and positive values of SPEI are considered as the drought and non-drought event respectively. The drought starts when the SPI first falls below zero and ends when SPI value is positive [14]. A drought event is considered when the values of SPEI fall below zero, a period with negative SPEI values. Defining threshold value is crucial in order to determine the length of drought duration and magnitude of drought severity. The duration (D) of drought is the length of period in which the SPEI value is continuously negative. It starts from the SPEI values is equal to -1 and ends when the SPEI values turn out to be positive. The drought severity (S) is the cumulated SPEI values within the drought duration, which is defined by

\[ S = -\sum_{i=1}^{D} SPEI_i \]  

and intensity of drought is the ratio of severity of drought to its duration[27].

![Figure 3. Definition of drought characteristics [27]](image)

3. Result and Discussion

3.1 Precipitation Trend Analysis

The MK test and Sen's Slope Estimator were used to detect trends of time series precipitation and temperature data from 1980 to 2017 in Southern and South-eastern Ethiopia. Prior to trend analysis, the autocorrelation was done and pre-whitening applied to remove serial correlation from the series. The trend analysis has been done monthly, seasonally, and annually. The summarised results of the MK test for trend analysis precipitation are presented in Table 4. The results of MK test for monthly precipitation data revealed a statistically significant decreasing trend for the month of February at Arbaminch and
July at Yabello Station whereas there is significant trend increase detected in July at Arbaminch station. In the remaining months, a non-significant decreasing and increasing trend was observed. On the seasonal time scale, the significant decreasing trend was identified at the Moyale station in a winter season. Statistically, non-significant decreasing trend was detected at all stations except at Gode station in spring, one of the main rainy seasons of the region. However, in autumn, another main rainy season, an insignificant increasing trend was observed at all stations except in Kebry Dehar station. In the remaining seasons, non-significant decreasing and increasing trend was detected. The trend of annual rainfall had shown non-significant decrease at all stations except at Gode (which has a non-significant trend increase)

Table 4. Results of the MK test for monthly, seasonal and annual rainfall over the period 1980–2017

| Time Series | Arbaminch | Moyale  | Neghele | Yabello | Gode | Kebry Dehar |
|------------|-----------|---------|---------|---------|------|-------------|
| MK test    | Sen’s slope | MK test | Sen’s slope | MK test | Sen’s slope | MK test | Sen’s slope | MK test | Sen’s slope | MK test | Sen’s slope |
| January    | -132      | -0.55   | -34      | 0.00    | 89    | 0.00        | -132     | -0.32     | -28      | 0.00   | 80          | 0.00 |
| February   | -164*     | -0.90   | -112     | -0.19   | -54   | 0.00        | -95      | -0.31     | -33      | 0.00   | 32          | 0.00 |
| March      | -2        | -0.03   | -45      | -0.28   | -3    | -0.01       | -32      | -0.37     | 27       | 0.00   | 134         | 0.12 |
| April      | -71       | -1.47   | -110     | -2.38   | -142  | -3.2        | -88      | -1.54     | 136      | 1.16   | -117        | -1.54 |
| May        | -24       | -0.30   | -72      | -0.78   | -80   | -1.12       | -50      | -0.64     | -12      | -0.10  | -34         | -0.22 |
| June       | 202*      | 1.22    | -75      | -0.17   | 133   | 0.10        | -136     | -0.52     | -85      | 0.00   | 59          | 0.00 |
| July       | -134      | -0.30   | -32      | -0.01   | -48   | -0.05       | -195*    | -0.52     | 63       | 0.00   | 57          | 0.00 |
| August     | -27       | -0.10   | 98       | 0.05    | 114   | 0.09        | -86      | -0.15     | -66      | 0.00   | 87          | 0.00 |
| September  | 73        | 0.77    | 65       | 0.14    | -61   | -0.33       | -103     | -0.52     | -121     | 0.00   | 11          | 0.00 |
| October    | 34        | 0.38    | 14       | 0.19    | 7     | 0.04        | 79       | 0.71      | 127      | 0.84   | 2           | 0.00 |
| November   | 21        | 0.1     | 42       | 0.48    | 96    | 0.77        | 137      | 0.95      | 101      | 0.5    | 23          | 0.12 |
| December   | -47       | -0.63   | -65      | -0.18   | -103  | -0.12       | 11       | 0.00      | 40       | 0.00   | 42          | 0.00 |
| Spring     | -68       | -1.35   | -116     | -3.42   | -109  | -2.49       | -86      | -1.79     | 38       | 0.68   | -92         | -1.19 |
| Summer     | 144       | 1.44    | -38      | -0.14   | 56    | 0.18        | -100     | -0.71     | 13       | 0.00   | 51          | 0.04 |
| Autumn     | 100       | 2.51    | 26       | 0.85    | 22    | 0.30        | 72       | 1.16      | 120      | 1.27   | -2          | -0.04 |
| Winter     | -150      | -2      | -155*    | -0.83   | -76   | -0.35       | -86      | -0.81     | 1        | 0.00   | 1           | 0.00 |
| Annual     | -2        | -0.14   | -72      | -3.05   | -74   | -2.45       | -44      | -1.56     | 66       | 1.18   | -14         | -0.32 |

Statistically significant trends at the 5% significance level

In Ethiopia, the rainy season occurs at different periods. In southern and south-eastern Ethiopia, rain comes twice a year, during spring and autumn. During the study period, fluctuations of monthly, seasonal, and annual precipitation happened, which is an indication of climate change. Similar to the result, Mulugeta et al. [28] observed that mean annual total rainfall (1981–2009) had been fluctuating in Ethiopia. In addition, Fact sheet [29] reported that between the mid-1970s and late 2000s, seasonal rainfall decreased by 15–20% across parts of southern and south-eastern Ethiopia. However, a different result was reported by Beriga et.al [30], who has conducted the study in Arbaminch town during the period of 1987-2014. According to Beriga et.al, the trend of annual precipitation was non-significantly increasing at 95% confidence level during the period of 1995-2014.

3.2 Temperature Trend Analysis

Similar to precipitation, the trend analysis has been done for all months of the year, four seasons, and annual maximum and minimum temperature. The result revealed a statistically significant increasing trend of maximum temperature which was observed at all stations. The only significant decreasing trend was detected in October at Moyale and in November at Yabello station. In addition to maximum temperature, significant increasing trends of monthly minimum temperature were identified. The significant decreasing trends of monthly minimum temperature were observed in June at Kebry Dehar and in January at Yabello station. However, in the few months, a non-significant decreasing and
increasing trend of both minimum and maximum temperature was observed. Results of MK tests and Sen’s Slope Estimator for seasonal and annual maximum temperature (Tmax) and minimum temperature (Tmin) over the period 1980–2017 are presented in Table 5. As summarised in Table 3, MK trend test result revealed that maximum and minimum temperatures have been increasing through time non-significantly in all seasons even though there are significantly increasing and decreasing trends in all seasons. On the annual time scale, the significant increasing trends of maximum temperature were detected at Kebery Dehar and Neghele and minimum temperature at Gode and Moyale station. In the remaining station, the trend of annual minimum and maximum temperature showed a non-significant increasing trend (except at Kebery Dehar Station for the minimum temperature)

Table 5 MK test and Sen’s Slope for seasonal and annual Tmin and Tmax over the period 1980–2010

| Station  | Test | Time series |
|----------|------|-------------|
|          |      | spring      | summer      | Autumn      | Winter      | Annual      |
|          | Tmax | Tmin        | Tmax        | Tmin        | Tmax        | Tmin        | Tmax        | Tmin        |
| Arbaminch| MK   | 125         | 140         | 280         | 115         | 149         | 115         | 158         | -86         | 150         | 58          |
|          | Slope| 0.03        | 0.02        | 0.05        | 0.01        | 0.02        | 0.01        | 0.03        | -0.01       | 0.02        | 0.01        |
| Gode     | MK   | 105         | 105         | 181         | 168*        | 111         | 207         | 48          | -22         | 117         | 187*        |
|          | Slope| 0.03        | 0.04        | 0.03        | 0.02        | 0.03        | 0.03        | 0.01        | 0.00        | 0.02        | 0.03        |
| Kebery Dehar | MK | 214*       | -188*       | 262*        | 1           | 164*        | 37         | 224*        | -18         | 236*        | -39         |
|          | Slope| 0.04        | -0.03       | 0.06        | 0.00        | 0.03        | 0.00        | 0.03        | -0.0        | 0.04        | 0.00        |
| Moyale   | MK   | 18          | 133         | -26         | 133         | -72         | 199*        | 72          | 184*        | 37          | 299*        |
|          | Slope| 0.00        | 0.03        | -0.00       | 0.03        | -0.02       | 0.03        | 0.02        | 0.04        | 0.01        | 0.05        |
| Neghele  | MK   | 283*        | 217*        | 281*        | 232*        | 259*        | 180*        | 235*        | 50          | 269*        | 119         |
|          | Slope| 0.05        | 0.04        | 0.07        | 0.04        | 0.03        | 0.01        | 0.03        | 0.01        | 0.03        | 0.03        |
| Yabello  | MK   | -21         | 181*        | 5           | 131         | -106        | 123         | -32         | -192*       | 36          | 136         |
|          | Slope| 0.00        | 0.02        | 0.00        | 0.01        | -0.02       | 0.01        | -0.01       | -0.02       | 0.00        | 0.01        |

*Statistically significant trends at the 5% significance level
Monthly, seasonal and annual maximum and minimum temperatures have been increasing in most of the stations. Similar results are detected by Beriga et.al [30], who have conducted the study in Arbaminch town by using climate data from 1987-2014. Suryabhagavan [11] also said that maximum temperature has increased over 45% of the weather stations, while minimum temperature has increased at 53% of the weather stations in Ethiopia including southern and south-eastern parts of the country. Suryabhagavan also revealed maximum temperature has been increasing within the seasons in Ethiopia during the period of 1983–2012. An increase in temperature is among the indicators of global climate change [7].

3.3 Drought characteristics Analysis
In this study, drought characteristics (duration, severity, and frequency) were analysed using multiscale drought index, SPEI. The SPEI series were computed for 6 meteorological stations in Southern and South-eastern of Ethiopia from January 1980 to December 2017 in 4 stations and from January 1980 to December 2015 in 2 stations at 1-, 3- and 6-month time scale to study the characteristics of drought at short and medium ranges. The 3- and 6- months SPEI is used to identify seasonal drought events that affect agricultural practices due to rainfall shortage during the main rainy season. The 3-month SPEI is used to identify seasonal drought events and the 6-month SPEI indicates medium-term drought event.

Figure 4 shows drought events occurred at different time scale during the study period. The value of SPEI-1 showed that 62 to 81 drought events occurred during 1980-2017, and most of the droughts recorded in Yabello station followed by Arbaminch. In addition, during this year, 64 to 84 and 65 to 90 drought events were recorded in three months and six months’ time scale respectively. SPEI-3 value indicated that most of the drought events occurred in Arbaminch while SPEI-6 showed most drought
events recorded in Moyale meteorology station.

The result shows that in some stations, the short-time scale (SPEI-1) droughts are more frequent than the long-time scales (SPEI-3, SPEI-6). However, in some stations, long-time scales are more frequent than short-time scale. This shows that drought characteristics are changed when timescale is changed. The maximum duration of SPEI-1 drought was recorded in Kebry Dehar station in 2010 and 2012 which stayed for six continuous months. The maximum duration of SPEI-3 drought was recorded in Arbaminch station in 2009 which stayed for 8 continuous months where the maximum duration of SPEI-6 was recorded in Kebry Dehar station in 2011 which stayed for 12 continuous months. Table 6 shows that the duration, severity, and frequency of drought has increased since 1999.

Table 6. Summary of SPEI with longest duration and severity

| Station Name     | Time scale | Year | Duration (in months) | Severity   |
|------------------|------------|------|----------------------|------------|
| Kebry Dehar      | SPEI-1     | 2010 | 8                    | -18.8039   |
|                  |            | 2011 | 8                    | -14.8045   |
|                  | SPEI-3     | 2010 | 8                    | -16.9496   |
|                  |            | 2011 | 8                    | -14.8045   |
|                  | SPEI-6     | 2011 | 12                   | -25.9773   |
| Arbaminch        | SPEI-1     | 2009 | 6                    | -10.3321   |
|                  |            | 2009 | 8                    | -14.0805   |
|                  | SPEI-3     | 2009 | 8                    | -14.2936   |
|                  |            | 2011 | 8                    | -14.0735   |
|                  | SPEI-6     | 2011 | 12                   | -25.9773   |
| Gode             | SPEI-1     | 2001 | 5                    | -6.89994   |
|                  |            | 2002 | 5                    | -9.38491   |
|                  | SPEI-3     | 2003 | 7                    | -12.1451   |
|                  |            | 2011 | 11                   | -16.107    |
| Moyale           | SPEI-1     | 2016 | 7                    | -12.7163   |
|                  |            | 2016 | 7                    | -18.3317   |
|                  | SPEI-3     | 1999 | 8                    | -11.4268   |
|                  |            | 2011 | 7                    | -11.1971   |
|                  | SPEI-6     | 2011 | 8                    | -14.2167   |
|                  |            | 2011 | 9                    | -16.0411   |
|                  |            | 2017 | 9                    | -14.6475   |
| Neghele          | SPEI-1     | 1999 | 7                    | -7.40851   |
|                  | SPEI-3     | 1999 | 7                    | -10.1333   |
|                  | SPEI-6     | 1999 | 10                   | -14.1293   |

Figure 4. Drought events at 1-, 3- and 6-month time scale
The year 2011 had the worst droughts over Southern and South-eastern Ethiopia. Similarly, Ethiopian Panel on Climate Change [5] mentioned that drought in 2011 is one of the most severe droughts in the Horn of Africa. The result showed that among the extreme droughts that happened in Southern and South-eastern Ethiopia, 2016 drought was the most severe drought with peak negative SPEI-3 value $-4.4$ in Moyale; followed by extreme drought which occurred in Kebry Dehar in 2010 with SPEI-1 value $-3.814$. According to Actalliance [12], 2016 drought was very severe and affected 10.2 million people in southern and south-eastern lowland areas of the country. The result also revealed that during the period of 1980-1999, drought events were less frequent and severe compared to 1999-2017. The droughts occurred from 1999-2017 were more frequent, severe and stayed for a longer time. Similar to this finding, Gebrehiwot et al. [8] reported that before 1970, drought hit the nation at least once in every 10 years but after then it has becoming more frequent, and recently occurring every two or three years at different levels of severity. Understanding historical trends of climate elements and characteristics of drought have important role planning of water resource management and climate change mitigation to avoid the potential damage of future drought. It is also very important for urban water management. Therefore, climate change mitigation, which is reduction of drivers of climate change and proactive approach of drought management, the measure taken based planed strategy before occurrence of drought are a crucial solution. The SPEI-6 graphs of all stations were presented in Figure 5.

![Figure 5. SPEI-6 graph of Arbaminch, Yabello, Moyale, Neghele, Gode and Kebry Dehar, respectively](image)

4. Conclusion
In this paper the long-term climatic trends and the magnitude of those trends were identified by using Mann-Kendall (MK) Test coupled with Sen’s Slope Estimator; and drought characteristics were analysed by using Standardized Precipitation Evapotranspiration Index (SPEI) based on climatic data (1980-2017). The result of the MK test showed that the trend of annual rainfall had shown non-significant decrease in southern and south-eastern Ethiopia. A statistically non-significant decreasing trend of monthly and seasonal rainfall was detected over time in some months and seasons. The annual
maximum and minimum temperatures have been increasing through time in the study area. SPEI was computed at 1-, 3- and 6-month time scale in order to know the characteristics of drought. The result showed that drought characteristics are changed when timescale is changed. The calculated SPEI revealed that drought is more frequent and severe from time to time in the study area. Results showed that the most frequent, severe and prolonged droughts occurred in 1999-2017 compared to 1980-1999. Drought of 2016 was the most severe with peak negative SPEI-3 value −4.4 in Moyale, Southern and South-eastern Ethiopia. The longest duration of SPEI-6 was recorded in Kebry Dehar station in 2011 which stayed for 12 continuous months. The year 2011 had the worst droughts over Southern and South-eastern Ethiopia. Climate change mitigation and proactive drought management approach is highly recommended in order to minimize the risk of drought.

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