



Assessing the Impact of Climate Change on Drought Characteristics in the Central Rift Valley of Ethiopia

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Abstract

The understanding of past and future droughts is vital for the development and management of water resources at certain area. Thus, this study assessed climate change's impact on meteorological drought based on the Standardized Precipitation Index (SPI) in the Central Rift Valley of Ethiopia. Rainfall data of nine stations for the period of 1985-2019 (historical) were obtained from the Ethiopian National Meteorological Agency. Projected rainfall data of Representative Concentration Pathway (RCP) scenarios under HadGEM2-ES were obtained from the CORDEX-Africa database selected for the years 2020-2049 (near), 2050-20779 (mid), and 2080-2100 (far future). The computed SPI values were, then subjected to frequency, intensity and Mann-Kendall (MK) and Sen's slope-based trend analyses. Accordingly, based on SPI-3 values, 325 moderate, 141 severe, and 87 extreme drought events were identified in the historical period. Similarly, for the near future, 392 moderate, 171 severe and 95 extreme drought events were identified under RCP4.5, and 456 moderate, 184 severe, and 98 extreme drought events were identified under RCP8.5 scenarios for the far future. MK trend test showed about, 69% no trend and a 19% decreasing trend at 95% confidence level in the historical period. RCP 8.5 showed a significantly decreasing trend with the S-test of -158 and $Z = -1.98$ in near future and ($S\text{-test} = -122$, $Z = -2.3$) in the far future. But, RCP4.5 showed decreasing trend in the mid-future ($S\text{-test} = -178$, $Z = -2.1$). In general, the results showed that drought increased in intensity, severity and duration in the historical and future periods under RCP4.5 and RCP8.5 scenarios.

Keywords: Meteorological Drought; SPI; Drought Trend Analyses; Drought Frequency; Drought Intensity.

1. Introduction

Drought is a natural hazard characterized as having below normal precipitation as a result of numerous variables acting on multiple time scales (months to years) and it can vary spatially, drought can have impacts on various sectors, especially on hydrological conditions, agriculture and ecosystems (Homdee et al. 2016). Unlike most disasters, drought does not appear abruptly. It

slowly builds over time due to the changes in different environmental and climatological factors. It is one of the deadly disasters that has plagued almost every continent in general and in Ethiopia in particular (Khan and Gilani, 2021). The climate of Ethiopia is mainly controlled by the seasonal migration of the Inter-Tropical Convergence Zone ITCZ (NMSA, 2001) and the complex topography of the country. The variation of the average annual temperature and rainfall distribution as well as elevation differences can greatly influence the local microclimate (Gebre, 2015), while this difference may be partially influencing the variability and trends in regional rainfall. Current climate variability is already imposing a significant challenge on Ethiopia by deterring the struggle to reduce poverty and sustainable development effort. The World Bank (2010) ranked Ethiopia among the most vulnerable countries in the world to the negative effects of climate change; mainly due to its high dependence on rain-fed agriculture, low adaptive capacity, and a higher reliance on natural resources based on livelihood, among others (EPCC, 2015).

Drought can be categorized into four major categories (Wilhite and Glantz, 2005) related to precipitation (meteorological), soil moisture (agricultural), stream flow (hydrological), and socioeconomic droughts. Meteorological droughts are quite common, and they are primarily classified by the extent of dryness in a given location and the length of the dry period. Although agricultural drought is linked to a lack of water needed to support crops, the drought does not always coincide with meteorological drought. On the other hand, hydrological drought is limited to the level of streamflow that can meet the demand. A study by Wilhite and Glantz (2005) gives a detailed description of this specific drought phenomenon.

There are several methods to analyze drought in many parts of the world. Drought indices measure how much precipitation for a given period has deviated from historically established norms (Shefine, 2018). Some of the widely used drought indices include Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Standardized Precipitation Index (SPI), and Surface Water Supply Index (SWSI) (Svoboda and Fuchs, 2017). The indices chosen are determined by the dataset available and the accuracy required. The SPI and SPEI are similar to each other in the calculation, but use two different inputs (precipitation versus precipitation and temperature) and can be calculated for any time scale of interest. The SPEI was proposed based on the SPI by (Vicente Serrano et al., 2010). Based on the principle of water balance, the SPIE uses the difference between precipitation and potential evapotranspiration (PET) as the input condition to evaluate the dry and wet conditions of the area. Among them, both the SPI and SPEI have the characteristics of multiple timescales, which can represent various types of droughts and better reflect the variations in drought characteristics). Therefore, these indexes are widely used throughout the world. The SPI, setting the period every month, typically 1, 3, 6, 9, or 12 months, calculates the shortage of precipitation and defines drought intensity based on the SPI value (Mohammed et al., 2018). The SPI, as calculated for a different period, can be applied to various fields based on the length of the time units. The short accumulation period of SPI is used for agricultural purposes, while the SPI for relatively long accumulation periods is used for the supply and management of water resources. The calculated SPI enables the determination of the precipitation probability necessary for resolving the current meteorological drought (Salehnia et al., 2017).

Until recently, studies on the projections of extreme weather events, such as drought, have often been based upon a few general circulation models (GCMs), regional climate models (RCMs), and/or emission scenarios. The different concepts and methods of representing drought events applied in different studies make inter-comparing results from different analyses challenging

(IPCC, 2012). Existing studies have noted emerging issues related to possible changes in the drought situation over the East African region. Most studies show consistent results, with a likely increase in drought duration and moderate incidence, with fewer occurrences of extreme events across possible scenarios (i.e., RCP4.5 and 8.5) (Gidey et al.,2018; Haile et al., 2020). Examination of projected changes in drought frequency and severity depicts possible manifestations of severe to extreme drought occurrences that are expected to intensify during 2071–2100 (Haile et al.,2020a,2020b). For instance, using CMIP5 models, most studies projected an increase in drought episodes towards the end of the century by 16%, 36%, and54% under RCP 2.6, 4.5, and 8.5 scenarios, respectively (Haile et al.,2020b).

According to (Elias et al.,2019) water bodies especially lakes and associated wetlands of the Central Rift Valley of Ethiopia (CRV) have decreased by 11.57% between the years 1985-2015; the highest turn down, which is 8.89%, was recorded in the years 1995-2015. Therefore, understanding possible future changes in the climate and their impacts on droughts is essential for adaptation and mitigation planning. meteorological drought assessment aims to be useful in the decision-making process for drought monitoring and identifying appropriate site for specific adaptation and mitigation actions in order to prevent water stress.

A recent study noted that three-quarters of the total publications on drought over Africa between 1980 and 2020 focused on agricultural and hydrological droughts, while the remaining fraction was based on socioeconomic and meteorological studies (Adisa et al.,2019). In this thesis, the studies and discussions are based on meteorological drought and the impact of climate change on drought characteristics. This is because most agricultural activities that support over 80% of livelihoods across the African continent are regulated solely by weather and climate. Climate change can influence precipitation (meteorological) droughts through changes in atmospheric water-holding capacity, circulation patterns, and moisture supply (Ukkola et al.,2020).

Thus, this study focused on the assessment of past and projected meteorological drought by utilizing the historical precipitation data from Ethiopia’s National meteorological agency and HadGEM2-ES climate model output scenario under Africa CORDEX of the two RCPs; RCP 4.5 (Clarke *et al.*, 2007), and RCP 8.5 (Riahi *et al.*, 2007)) based on the value of SPI calculated by RStudio software.

2. Materials and Methods

2.1. Description of the Study area

This study was conducted in the Central Rift Valley (CRV) of Ethiopia. The area lies between 7°10' to 8°30'N and 38°15' to 39°25'E, with an area coverage of about one million hectares (Figure 1). The mean altitude of the area is about 1550m.a.s.l. The lithology of the area is dominated by basalt, ignimbrite, lava, gneiss, lapilli tuff, volcanic ash and pumice as well as riverine and lacustrine alluvium (Fitsum-, 2020). The climate of the Central Rift Valley area varies significantly along an altitudinal gradient, but generally arid and semi-arid climate characterizes with a mean annual rainfall of 900 mm (Mengesha et al., 2015). The area mostly experiences bimodal rainfall: with most of the rain (about 70%) occurring during the three summer months (June to August and sometimes up to September), while very short and unreliable rain occurs from April to May. The temperature of the area is relatively high with a mean monthly maximum and a monthly minimum of 30.5°C and 7.5°C (Temesgen et al., 2013).

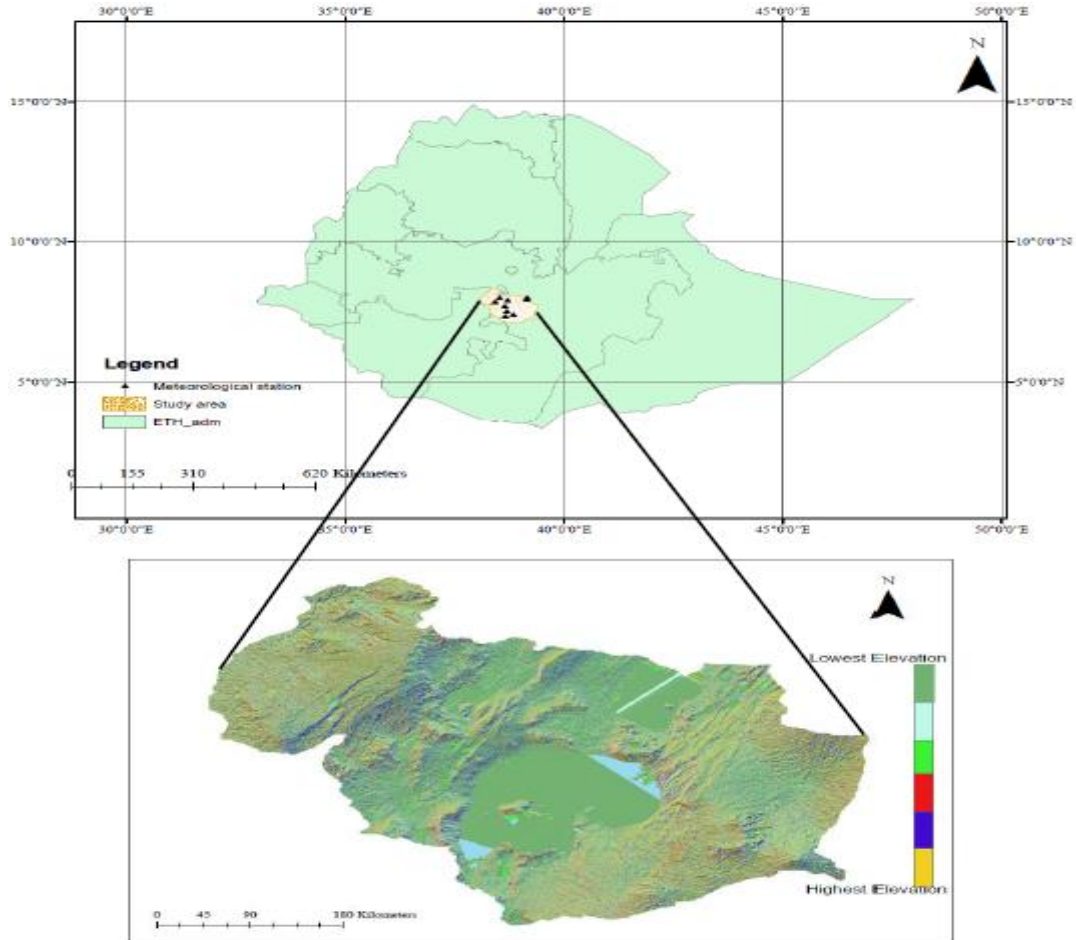


Figure 1. Location of the study area and distribution of meteorological stations in Central Rift Valley

2.2. Data Collection and Analysis

In this study, monthly rainfall data of years 1985-2019 of nine stations were obtained from Ethiopian National Meteorological Agency (NMA). In addition, downscaled daily rainfall data of the period 2020-2100 were obtained from HadGEM2-ES United Kingdom Met Office Hadley Center, UK's climate model of Coordinated Regional Climate Downscaling Experiment (CORDEX) under Africa database of CMIP5.

2.3. Description of Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) is one of the most widely used precipitation data-based meteorological drought indices. It was developed by McKee et al. (1993) to analyze and evaluate drought events. This method is based on only precipitation data. It is also known to be a simple index that allows checking not only drought periods, but also wet periods (Edwards and McKee 1997). According to Edwards and McKee (1997), this method is determined to compare precipitation within a certain period time to the long-term mean precipitation of a particular time step observed at the same site. Mathematically, it is given as:

$$SPI = \frac{X_i - \bar{X}}{\sigma} \quad \text{Equ...1}$$

Where SPI X_i is precipitation at time i , \bar{X} is mean precipitation of a particular time step and σ is standard deviation.

The mathematical computation of this index, for any time scale, at any study area is carried out using long-term precipitation data (longer than 30 years). The long-term precipitation data is fitted to Gamma Probability Density Function, which is then transformed into a normal distribution (Edwards and McKee 1997). The SPI can be calculated for any time scale and this is done by comparing the precipitation for the period of interest (usually 1 month, 3 months, 6 months, 9 months and 12 months) to the mean of the same period over the historical record.

Once the SPI 1, SPI 3, SPI 6 and SPI 12 values are determined at the selected stations, the values are further analyzed to characterize drought in a study area based on duration, intensity and trend. In this study, SPI was calculated using RStudio software for all meteorological station of Central Rift Valley for historical period (1985-2019) and projected years (2020 to 2100) under RCP4.5 and RCP8.5 scenarios. After determining all values of SPI, drought intensities were classified in five magnitude classes as given in Table 1.

Table 1. SPI drought classification (Anonymous, 2016 a)

| SPI | Drought Intensity Class |
|---------------|-------------------------|
| Above 0 | No drought |
| 0 to -0.99 | Near normal |
| -1 to -1.49 | Moderately dry |
| -1.5 to -1.99 | Severely dry |
| -2 and less | Extremely dry |

To assess the spatial extent of droughts in the study area, SPI3 time series values of each meteorological station have been interpolated as illustration by inverse distance weighted (IDW) method using the Spatial Analyst tool of ArcGIS. The interpolated maps are then, reclassified into different drought severity classes.

2.4. Characterizing Drought in terms of duration, severity and intensity

As stated by Spinoni et al. (2014), Drought Duration (DD) is determined as the number of months between the start and the end of drought. According to McKee et al. (1993), drought event starts when the SPI is continuously negative and reaches an intensity of -1.0 or less and it ends when the SPI becomes positive. Thus, these definitions were used to determine the maximum Drought Duration at every station under the considered SPIs in this study. Thompson (1999) defined Drought Magnitude (DM) as the cumulative values of drought index over a drought period. In this study, MD was determined as the sum of SPI values within the maximum DD. DM divided by DD gives the Average Drought Intensity (ADI).

2.5. The Mann-Kendall (MK) Trend Test

The Mann–Kendall (MK) (non-parametric) test was applied to detect an upward trend or downward (i.e., monotonic trends) in a series of climate data, which has been widely used for detection of trends in time series in Ethiopia ((Tekleab et al.,2013, Yilma and Zanke (2004); (Tabari et al., 2015; Gebremedhin et al., 2016)). It is the test to make correlation between a sequence of pairs of values. The testing of trends is made at a specific significance level α , which is usually taken at 0.05. For the time series x_1, \dots, x_n , the MK test statistic is calculated using the formula

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sgn}(x_j - x_i) \quad \text{Equ...2}$$

$$\text{sgn}(x_j - x_i) = \begin{cases} +1 & \text{if } (x_j - x_i) > 0 \\ 0 & \text{if } (x_j - x_i) = 0 \\ -1 & \text{if } (x_j - x_i) < 0 \end{cases}$$

The application of trend test is done to a time series x_i that is ranked from $i = 1, 2 \dots n-1$ and x_j , which is ranked from $j = i+1, 2 \dots n$.

The sample size $n \geq 10$, the mean and variance of S are given as follows:

$$\text{Var}(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^m t_i(i-1)(2i+5)}{18} \quad \text{Equ...3}$$

Where T_i is the number of data in the tied group and m is the number of groups of tied ranks. The test statistics Z is computed as:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{\text{VAR}(S)}} & \text{if } S < 0 \end{cases} \quad \text{Equ...4}$$

The standardized MK statistic Z follows the standard normal distribution. Positive values indicate an increasing trend and negative values indicate a decreasing trend. To test for either an increase or decrease monotonic trend at α level of significance, H_0 is rejected if $|Z| > Z_{1-\alpha/2}$. At the 5% significance level ($\alpha=0.05$), the null hypothesis is rejected if $|Z| > 1.96$.

3. Results and Discussion

3.1. Effect of Climate Change on Drought Characteristics

In order to assess the effects of drought on meteorological drought in the study area, first, SPI values of various periods were determined. Then, the SPI values were further analyzed to come up with drought duration, frequency and intensity.

3.1.1. Effects on Drought Frequency

The value of SPI-3 showed that 45 to 74 moderate, 17-38 severe and 9-27 extreme drought events were occurred during 1985-2019, and most of the extreme droughts recorded in Degaga station followed by Koshe, Ziway, Kulmsa, Arsi negele, Tora, Bulbula, Assela and Langano. The frequencies of moderate, severe and extreme drought conditions of the historical and projected periods under the RCP4.5 and 8.5 scenarios for both SPI3 and SPI6 are presented in the Table 2.

Based on standardized precipitation index value calculated for 9 meteorological stations results showed that (1991-1992), (2015-2016) and (2017-2018) were drought year and extremely, severely, and moderately drought condition were observed in this year for historical rainfall data Figure 2.

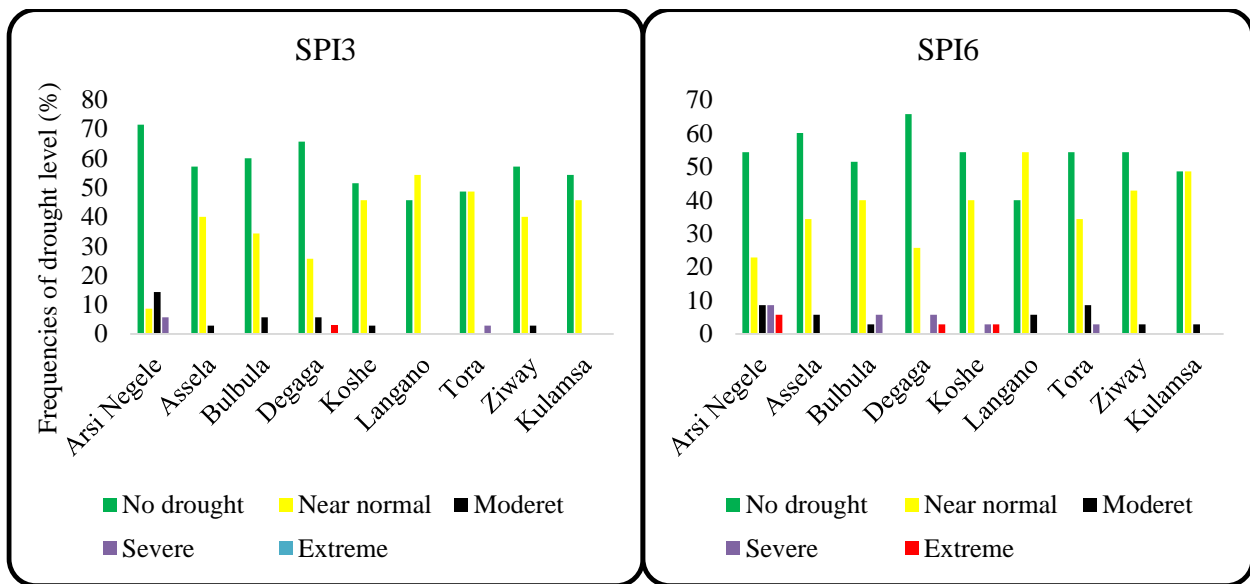


Figure 2. Frequencies of various levels of droughts (%) calculated at each station

The year 2015 had the worst droughts over Southern, central and western part of Central Rift Valley of Ethiopia. Similarly, Ethiopian Panel on Climate Change, (2015) support our findings by mentioning that drought in 2015 and 2011 is one of the most severe droughts in the Horn of Africa. The result showed that among the extreme droughts that happened at Southern, central and western part of study area, in 1989 was the most severe drought with peak negative SPI-3 value -3.8 in Ziway station; followed by extreme drought which occurred in Koshe with SPI-3 value -3.7.

Table 2. Drought frequency at various stations (%) of SPI 3 and SPI6 as determined for various periods

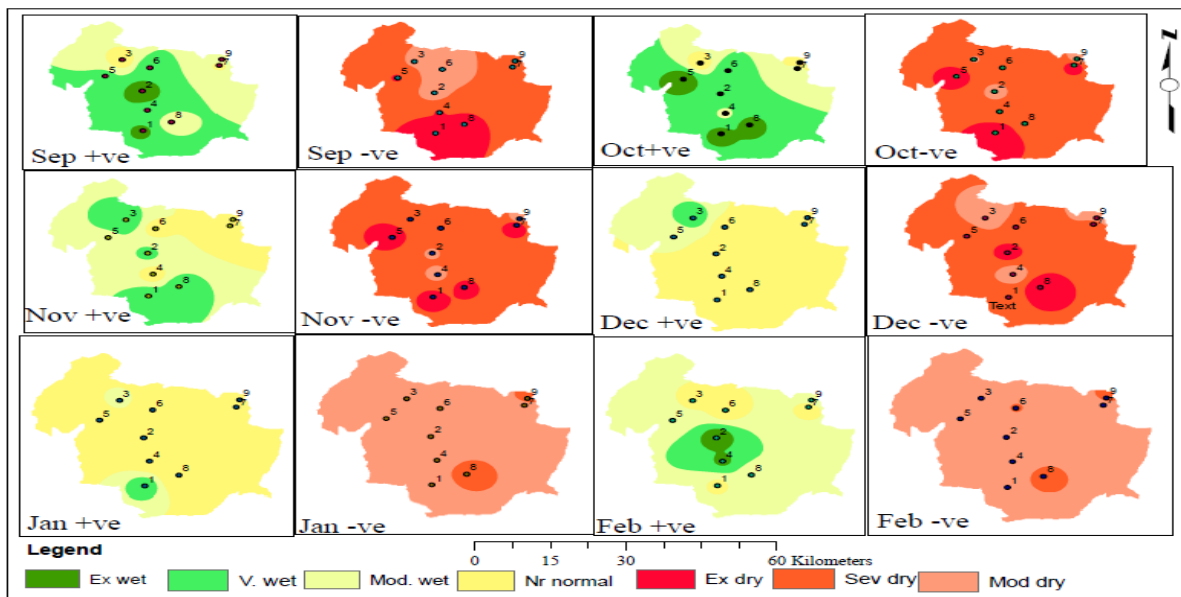
| SPI3 | | | | | | | | | | | | | | | | | | | | | | |
|---------|-------------------|------|------|-------------|------|------|------------|------|------|------------|------|------|-------------|------|------|------------|------|------|------------|------|------|--|
| Station | Historical period | | | RCP4.5 | | | | | | | | | RCP8.5 | | | | | | | | | |
| | | | | Near future | | | Mid future | | | Far Future | | | Near future | | | Mid future | | | Far Future | | | |
| | Mod. | Sev. | Ext. | Mod. | Sev. | Ext. | Mod. | Sev. | Ext. | Mod. | Sev. | Ext. | Mod. | Sev. | Ext. | Mod. | Sev. | Ext. | Mod. | Sev. | Ext. | |
| (1) | 58 | 31 | 11 | 52 | 35 | 13 | 52 | 37 | 11 | 50 | 34 | 14 | 50 | 37 | 13 | 57 | 30 | 13 | 52 | 32 | 16 | |
| (2) | 66 | 19 | 15 | 70 | 20 | 10 | 68 | 22 | 10 | 66 | 23 | 11 | 75 | 18 | 7 | 72 | 20 | 8 | 67 | 20 | 13 | |
| (3) | 57 | 22 | 21 | 60 | 30 | 10 | 55 | 32 | 13 | 51 | 33 | 16 | 51 | 32 | 17 | 54 | 34 | 12 | 55 | 33 | 12 | |
| (4) | 74 | 17 | 9 | 80 | 14 | 6 | 76 | 17 | 7 | 75 | 17 | 8 | 72 | 18 | 10 | 70 | 24 | 11 | 68 | 26 | 11 | |
| (5) | 66 | 18 | 16 | 68 | 20 | 12 | 65 | 22 | 13 | 64 | 23 | 13 | 62 | 24 | 14 | 61 | 25 | 14 | 58 | 27 | 15 | |
| (6) | 58 | 25 | 17 | 60 | 23 | 17 | 59 | 23 | 18 | 56 | 25 | 19 | 55 | 26 | 19 | 52 | 28 | 20 | 50 | 30 | 20 | |
| (7) | 63 | 25 | 12 | 65 | 24 | 11 | 65 | 25 | 10 | 62 | 27 | 11 | 62 | 25 | 13 | 60 | 28 | 12 | 60 | 27 | 13 | |
| (8) | 45 | 29 | 27 | 47 | 26 | 26 | 44 | 29 | 27 | 42 | 31 | 27 | 40 | 35 | 25 | 40 | 34 | 26 | 42 | 35 | 23 | |
| (9) | 48 | 38 | 14 | 52 | 36 | 12 | 52 | 37 | 11 | 50 | 37 | 13 | 50 | 36 | 14 | 48 | 37 | 15 | 48 | 35 | 17 | |
| SPI6 | | | | | | | | | | | | | | | | | | | | | | |
| (1) | 44 | 29 | 27 | 56 | 34 | 10 | 52 | 36 | 12 | 52 | 35 | 13 | 51 | 36 | 13 | 50 | 37 | 13 | 49 | 37 | 14 | |
| (2) | 70 | 17 | 13 | 68 | 19 | 13 | 67 | 20 | 13 | 65 | 22 | 13 | 62 | 24 | 14 | 60 | 26 | 14 | 60 | 25 | 15 | |
| (3) | 58 | 21 | 21 | 60 | 23 | 17 | 58 | 24 | 18 | 56 | 26 | 18 | 54 | 29 | 17 | 53 | 30 | 17 | 50 | 32 | 18 | |
| (4) | 71 | 18 | 11 | 72 | 18 | 10 | 70 | 20 | 10 | 68 | 21 | 11 | 65 | 23 | 12 | 65 | 24 | 11 | 62 | 26 | 12 | |
| (5) | 60 | 22 | 18 | 58 | 24 | 18 | 57 | 25 | 18 | 54 | 29 | 17 | 51 | 32 | 17 | 51 | 33 | 16 | 50 | 35 | 15 | |
| (6) | 60 | 24 | 16 | 60 | 27 | 13 | 58 | 29 | 13 | 53 | 35 | 12 | 51 | 37 | 11 | 50 | 38 | 11 | 49 | 38 | 12 | |
| (7) | 61 | 27 | 12 | 63 | 26 | 11 | 60 | 29 | 11 | 60 | 30 | 10 | 62 | 28 | 10 | 58 | 28 | 14 | 55 | 31 | 14 | |
| (8) | 46 | 26 | 28 | 47 | 28 | 25 | 42 | 33 | 25 | 44 | 33 | 23 | 46 | 35 | 18 | 45 | 36 | 18 | 44 | 40 | 16 | |
| (9) | 42 | 42 | 16 | 45 | 39 | 16 | 45 | 35 | 20 | 46 | 36 | 18 | 46 | 38 | 16 | 47 | 37 | 16 | 45 | 39 | 16 | |

Note; - Arsi Negele(1), Bulbul(2), Koshe(3), Langano(4), Tora(5) Ziway(6), Assela(7), Degaga(8), Kulmsa(9)

Since SPI can be calculated at different time scales, it often serves as indicator of different drought types. 3-month SPI of September-February was used in the present work to quantify

severity of drought for selected drought and wet years. In Figure 3, ARC-GIS used in order to interpolate SPI3 value to determine the spatial pattern of meteorological drought (Monthly variation of Standard precipitation index (SPI3)) for the months of September, October, November, December, January and February. As shown in Figure 3, Arsi Negele station in 2004 and Bulbula in 2012 shows that extremely wet condition. Also, in the same month at Langanu, Tora and Ziway in 2010, 1993 and 2016 respectively there was very wet (green color) condition is observed.

The cream/shade of yellow/ color on the map represents the moderately wet condition for Kulmsa and Degaga meteorological station in 1990 and 1988 respectively. Yellow color on map at koshe and Assela stations indicates that there was near normal conditions in these area in 2016 and 2001 respectively. Whereas, in drought years of September months Arsi Negele, Langanu, Tora and Degaga meteorological stations showed the situation of extreme drought (red color) condition in 2015, 1991, 2015, 2017 respectively. The orange rust color on map represents that severely dry condition in drought years of September months for Assela and kulmsa meteorological station in 1991 and 2015. In January and February major part of study shows moderately dry (Peach Melba – Orange) condition except in Dagaga ana kulmsa station which shows severely dry condition.

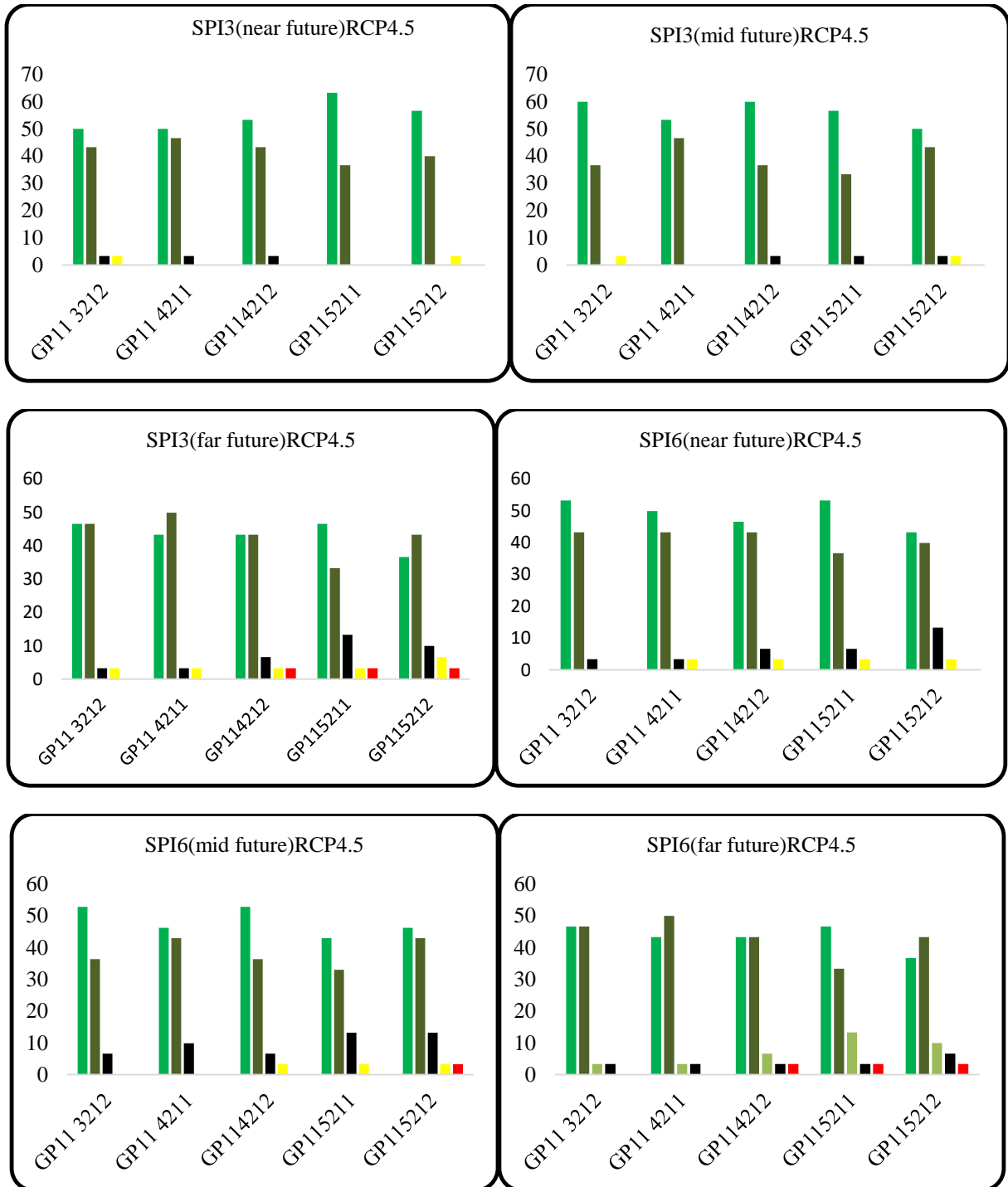


Note: -Nr normal = near normal, mod wet = moderately wet, v. wet = very wet, ex wet = extremely wet, sev dry = severely dry, Ex. dry = extremely dry and Mod. dry = moderately dry. ArsiNegele(1), Bulbula(2), Koshe(3), Langanu(4), Tora(5), Ziway(6), Assela(7), Dagaga(8) and Kulamsa(9) non drought year(+ve), drought year(-ve).

Figure 3. Variation of Standard precipitation index (SPI3) values over selected drought and non-drought years from 1985-2019

For projected climatic data in near future (2022, 2029 and 2046) in mid future (2058, 2065 and 2061, 2068) and in far future (2099, 2085 and 2099,2083) which were among the drought years for both RCP4.5 and RCP8.5 respectively. Monthly series of SPI3 and SPI6 have been computed. Figure 4 shows, examples of SPI3 and SPI6 series for projected precipitation

data for each of the three analyzed periods that represent the near future, mid future and far future for both RCP4.5 and RCP8.5 scenario.



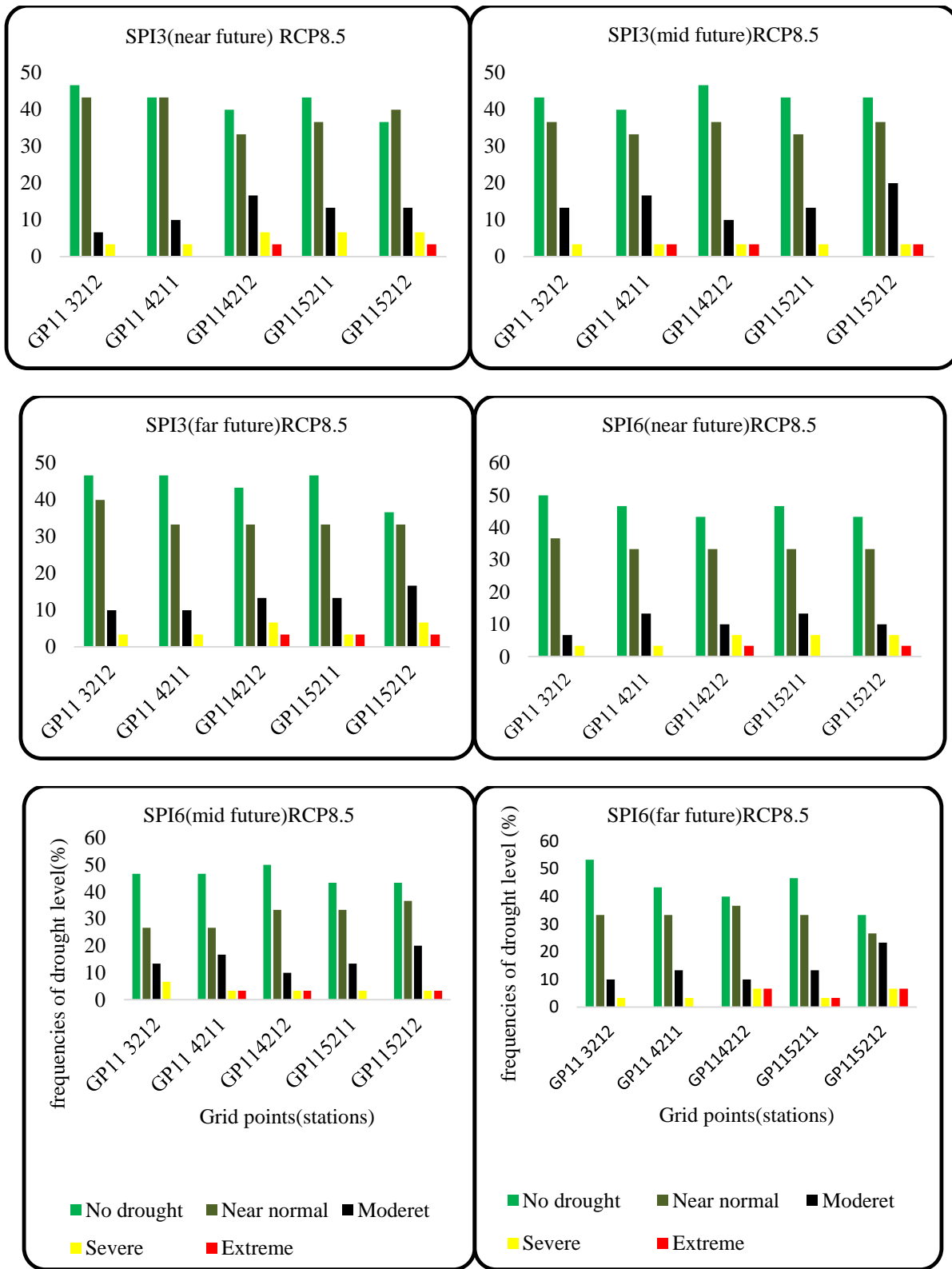
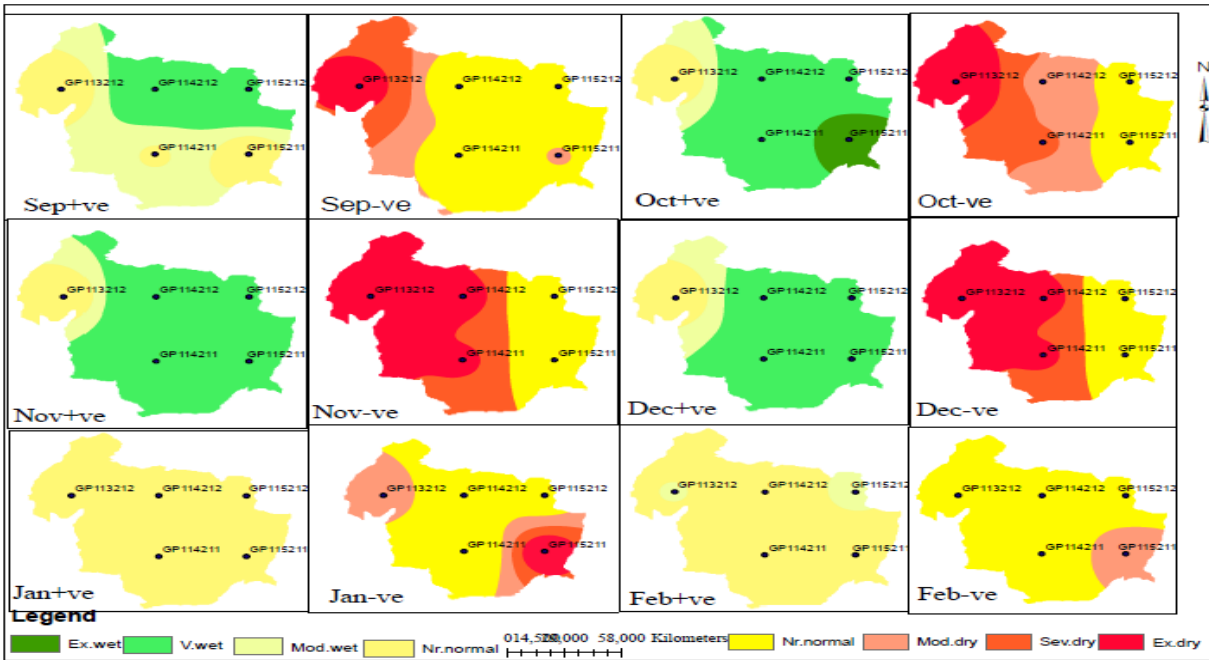
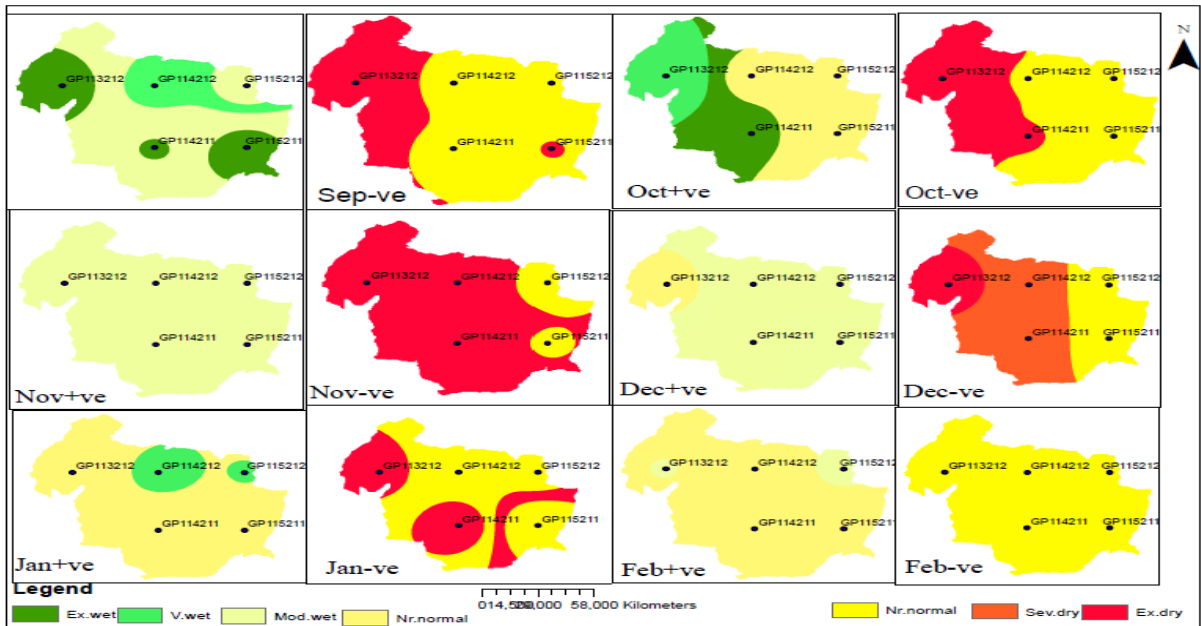


Figure 4. Frequencies of various levels of projected droughts (%) calculated at various stations

To show the spatial extent of droughts in the study area, SPI3 time series values of each meteorological station have been interpolated by Inverse Distance Weighted (IDW) method using the Spatial Analyst tool of ArcGIS and results shown in Figure 5 for both RCP4.5 and RCP8.5.



a.) RCP4.5



b.) RCP8.5

Figure 5. Three-month variation of Standard precipitation index (SPI3) values over drought and non-drought years under emission scenario of both RCP 4.5 and RCP8.5 from (2020 - 2100)

3.1.2. Effects on Drought Severity and Duration

Table 3 is provided to depict the characteristics of SPI in terms of drought duration and severity for each station and for various projections.

Table 3. Characteristics of SPI in terms of drought duration and severity for each station

| Station | SPI Time Scale | Maximum Value | | RCP 4.5 | | | | | | RCP 4.5 | | | | | |
|---------|----------------|---------------|-----|-------------|-----|------------|-----|------------|-----|-------------|-----|------------|-----|------------|-----|
| | | Historical | | Near Future | | Mid Future | | Far Future | | Near Future | | Mid Future | | Far Future | |
| | | DD | DS | DD | DS | DD | DS | DD | DS | DD | DS | DD | DS | DD | DS |
| (1) | SPI3 | 11 | -23 | 9 | -19 | 11 | -24 | 12 | -24 | 10 | -22 | 12 | -22 | 12 | -22 |
| | SPI6 | 12 | -26 | 11 | -22 | 12 | -22 | 9 | -14 | 11 | -21 | 10 | -21 | 11 | -23 |
| (2) | SPI3 | 10 | -16 | 11 | -19 | 12 | -19 | 11 | -14 | 12 | -25 | 10 | -17 | 11 | -24 |
| | SPI6 | 10 | -19 | 7 | -15 | 8 | -14 | 10 | -17 | 9 | -18 | 11 | -19 | 10 | -20 |
| (3) | SPI3 | 6 | -14 | 4 | -10 | 6 | -8 | 9 | -10 | 8 | -14 | 10 | -15 | 11 | -19 |
| | SPI6 | 7 | -11 | 5 | -9 | 4 | -6 | 10 | -18 | 10 | -15 | 9 | -17 | 10 | -19 |
| (4) | SPI3 | 5 | -11 | 6 | -13 | 5 | -7 | 9 | -12 | 7 | -9 | 8 | -12 | 11 | -23 |
| | SPI6 | 6 | -12 | 8 | -14 | 10 | -17 | 7 | -7 | 7 | -10 | 9 | -13 | 9 | -17 |
| (5) | SPI3 | 11 | -21 | 9 | -17 | 11 | -20 | 12 | -16 | 8 | -11 | 7 | -9 | 11 | -22 |
| | SPI6 | 9 | -20 | 9 | -22 | 5 | -6 | 8 | -8 | 11 | -14 | 10 | -11 | 10 | -21 |
| (6) | SPI3 | 4 | -5. | 5 | -7 | 7 | -11 | 10 | -22 | 10 | -18 | 12 | -20 | 9 | -16 |
| | SPI6 | 6 | -11 | 7 | -14 | 8 | -9 | 9 | -14 | 6 | -10 | 7 | -11 | 8 | -11 |
| (7) | SPI3 | 4 | -9 | 6 | -8 | 5 | -7 | 7 | -9 | 4 | -7 | 6 | -8 | 7 | -9 |
| | SPI6 | 6 | -13 | 7 | -17 | 6 | -11 | 9 | -10 | 5 | -8 | 7 | -9 | 10 | -11 |
| (8) | SPI3 | 12 | -28 | 10 | -19 | 9 | -12 | 12 | -26 | 6 | -8 | 8 | -10 | 8 | -9 |
| | SPI6 | 12 | -25 | 10 | -22 | 11 | -25 | 8 | -15 | 10 | -17 | 9 | -10 | 8 | -12 |
| (9) | SPI3 | 5 | -10 | 4 | -8 | 5 | -10 | 9 | -13 | 7 | -9 | 9 | -13 | 10 | -17 |
| | SPI6 | 6 | -14 | 7 | -15 | 8 | -11 | 11 | -19 | 6 | -7 | 5 | -8 | 8 | -14 |

Note; - Arsi Negele(1), Bulbul(2), Koshe(3), Langano(4), Tora(5) Ziway(6), Assela(7), Degaga(8), Kulmsa(9), Drought duration(DD),Drought severity (DS)

In this study, drought characteristics (duration and severity) were analyzed using standardized precipitation index (SPI). The SPI series were computed for 9 meteorological stations in Central Rift Valley of Ethiopia from January 1985 to December 2019 at 3 and 6-month time scale to study the characteristics of drought. Results of SPI-3 and SPI-6 calculation, obtained maximum duration and severity of each station, these values were presented under Table 3 for each meteorological station, Feb-Dec/2015 and Jan-Dec/2015 or very short until short duration for Arsi Negele station, Sep-Dec/1991 and Apr-Sep/1999 for Assela station, Mar-Dec/2015 and Mar-Dec/2015 for Bulbula station, Jan-Dec/2017 and Jan-Dec/2018 for Dagaga station, Feb-Jul/2008 and Jul-Dec/2017 for Koshe station, Jan-May/2008 and Jan-Jun/2008 for Kulmsa station, Jun-Oct/1991 and Jul-Dec/1991 for Langan station, Feb-Dec/2015 and Mar-Dec/2015 for Tora station, at selected SPI3 and SPI6 time series respectively.

Table 4 and 5 also denotes drought duration (DD), maximum drought duration (MDD) as well as the Average drought Intensity (ADI) at every station under the considered SPIs in this study.

Table 4. Maximum drought duration (DD_m), corresponding drought magnitude (DM) and the Average Drought Intensity (ADI) at various stations of SPI 3 as determined for various periods.

| SPI3 | | | | | | | | | | | | | | | | | | | | | | | |
|---------|-------------------|----|-----|-----------------|----|-----|-----------------|----|-----|-----------------|----|-----|-----------------|----|-----|-----------------|----|-----|-----------------|----|-----|--|--|
| Station | Historical Period | | | RCP4.5 | | | | | | | | | RCP8.5 | | | | | | | | | | |
| | | | | Near future | | | Mid future | | | Far Future | | | Near future | | | Mid future | | | Far Future | | | | |
| | DD _m | DM | ADI | DD _m | DM | ADI | DD _m | DM | ADI | DD _m | DM | ADI | DD _m | DM | ADI | DD _m | DM | ADI | DD _m | DM | ADI | | |
| (1) | 11 | 8 | 0.7 | 9 | 7 | 0.8 | 11 | 8 | 0.7 | 12 | 11 | 0.9 | 10 | 11 | 1.1 | 12 | 14 | 1.2 | 12 | 13 | 1.1 | | |
| (2) | 10 | 8 | 0.8 | 11 | 10 | 0.9 | 12 | 11 | 0.9 | 11 | 11 | 1 | 12 | 12 | 1 | 10 | 11 | 1.1 | 11 | 13 | 1.2 | | |
| (3) | 6 | 7 | 1.2 | 4 | 5 | 1.3 | 6 | 8 | 1.3 | 9 | 12 | 1.3 | 8 | 13 | 1.6 | 10 | 10 | 1 | 11 | 12 | 1.1 | | |
| (4) | 5 | 2 | 0.4 | 6 | 4 | 0.7 | 5 | 4 | 0.8 | 9 | 9 | 1 | 7 | 8 | 1.1 | 8 | 10 | 1.3 | 11 | 11 | 1 | | |
| (5) | 11 | 9 | 0.8 | 9 | 7 | 0.8 | 11 | 10 | 0.9 | 12 | 11 | 0.9 | 8 | 8 | 1 | 7 | 9 | 1.3 | 11 | 12 | 1.1 | | |
| (6) | 4 | 5 | 1.3 | 5 | 7 | 1.4 | 7 | 10 | 1.4 | 10 | 14 | 1.4 | 10 | 15 | 1.5 | 12 | 14 | 1.2 | 9 | 11 | 1.2 | | |
| (7) | 4 | 2 | 0.5 | 6 | 5 | 0.8 | 5 | 4 | 0.8 | 7 | 7 | 1 | 4 | 5 | 1.3 | 6 | 5 | 0.8 | 7 | 10 | 1.4 | | |
| (8) | 12 | 14 | 1.2 | 10 | 13 | 1.3 | 9 | 14 | 1.6 | 12 | 16 | 1.3 | 6 | 9 | 1.5 | 8 | 13 | 1.6 | 8 | 13 | 1.6 | | |
| (9) | 5 | 3 | 0.6 | 4 | 2 | 0.5 | 5 | 4 | 0.8 | 9 | 8 | 0.9 | 7 | 7 | 1 | 9 | 10 | 1.1 | 10 | 10 | 1 | | |

Table 5. Maximum drought duration (DD_m), corresponding drought magnitude (DM) and the Average Drought Intensity (ADI) at various stations of SPI6 as determined for various periods.

| SPI6 | | | | | | | | | | | | | | | | | | | | | |
|---------|-------------------|----|-----|-----------------|----|-----|-----------------|----|-----|-----------------|----|------|-----------------|----|-----|-----------------|----|-----|-----------------|----|-----|
| Station | Historical Period | | | RCP4.5 | | | | | | | | | RCP8.5 | | | | | | | | |
| | | | | Near future | | | Mid future | | | Far Future | | | Near future | | | Mid future | | | Far Future | | |
| | DD _m | DM | ADI | DD _m | DM | ADI | DD _m | DM | ADI | DD _m | DM | ADiI | DD _m | DM | ADI | DD _m | DM | ADI | DD _m | DM | ADI |
| (1) | 12 | 9 | 0.8 | 11 | 7 | 0.6 | 12 | 11 | 0.9 | 9 | 9 | 1 | 11 | 12 | 1.1 | 10 | 12 | 1.2 | 11 | 12 | 1.1 |
| (2) | 10 | 7 | 0.7 | 7 | 8 | 1.1 | 8 | 10 | 1.3 | 10 | 11 | 1.1 | 9 | 11 | 1.2 | 11 | 14 | 1.3 | 10 | 12 | 1.2 |
| (3) | 7 | 6 | 0.9 | 5 | 4 | 0.8 | 4 | 4 | 1 | 10 | 9 | 0.9 | 10 | 10 | 1 | 9 | 9 | 1 | 10 | 11 | 1.1 |
| (4) | 6 | 4 | 0.7 | 8 | 7 | 0.9 | 10 | 9 | 0.9 | 7 | 7 | 1 | 7 | 8 | 1.1 | 9 | 10 | 1.1 | 9 | 11 | 1.2 |
| (5) | 9 | 7 | 0.8 | 9 | 8 | 0.9 | 5 | 4 | 0.8 | 8 | 8 | 1 | 11 | 9 | 0.8 | 10 | 14 | 1.4 | 10 | 13 | 1.3 |
| (6) | 6 | 4 | 0.7 | 7 | 5 | 0.7 | 8 | 7 | 0.9 | 9 | 10 | 1.1 | 6 | 4 | 0.7 | 7 | 8 | 1.1 | 8 | 10 | 1.3 |
| (7) | 6 | 3 | 0.5 | 7 | 6 | 0.9 | 6 | 4 | 0.7 | 9 | 8 | 0.9 | 5 | 2 | 0.4 | 7 | 6 | 0.9 | 10 | 12 | 1.2 |
| (8) | 12 | 13 | 1.1 | 10 | 12 | 1.2 | 11 | 14 | 1.3 | 8 | 12 | 1.5 | 10 | 12 | 1.2 | 9 | 15 | 1.7 | 8 | 13 | 1.6 |
| (9) | 6 | 3 | 0.5 | 7 | 6 | 0.9 | 5 | 4 | 0.8 | 11 | 12 | 1.1 | 6 | 6 | 1 | 5 | 7 | 1.4 | 8 | 8 | 1 |

3.2. Non-Parametric Trend (Mann-Kendall test)

3.2.1. MK Test for Historical Meteorological Drought

MK trend test on observed period monthly rainfall result reveals that no trend, insignificantly decreasing trend over certain meteorological station and increasing trend too Table 6. Positive Z-test value shows an increasing trend while a negative Z-test value showed a decreasing trend based on threshold Z value for 5% significance level. This value or $Z_{1-\alpha/2}$ value is 1.96 from the standard normal table or z table for 95% confidence level (Belay *et al.*, 2021). In other case hypotheses, H_0 which says the nature of the monotonically increasing or decreasing trend is not significant (no trend) this happens when the absolute value of Z- test less than 5% significance level of threshold value. According to the MK test result for each meteorological station, monthly share of rainfall exhibited about 66.67% no trend, 25% negative trend, 8.33% not significant decreasing trend in rainfall amounts at Bulbula, 33.33% no trend, 50% decreasing trend,

8.33% not significant decreasing and increasing too at Arsi Negele, 100 no trend at Assela,, 50% no trend, 25% decreasing trend and 25% not significant decreasing at Degaga, 66.67% no trend, 16.66% decreasing trend and 8.33 not significant decreasing trend at Koshe,75% no trend,8.33% decreasing trend and 8.33% not significant decreasing and increasing trends at Kulmsa, 91.67% no trend and 8.33 not significant decreasing at Langano meteorological station.

Table 6. Mann Kendall test output for monthly, seasonal and annual time series data (From 1985-2019)

| Variable | S - Test | Z - Test | Sen Slope | VAR(S) | Remark |
|-----------------|-----------------|-----------------|------------------|---------------|---------------|
| January | -4 | -1.646 | 0* | 4246 | N.t@90% |
| February | -51 | -2.54 | -0.053 | 4164.33 | D.t@95% |
| March | -102 | -2.12 | -0.049 | 4165.33 | N.t@95% |
| April | -38 | -1.13 | -0.034 | 4165.33 | n.t@95% |
| May | -21 | -1.47 | -0.019 | 4165.33 | n.t@95% |
| Jun | -59 | -0.82 | -0.026 | 4165.33 | n.t@95% |
| July | -35 | -2.09 | -0.042 | 4165.33 | D.t@95% |
| August | -38 | -0.76 | -0.029* | 4165.33 | I.t@95% |
| September | -79 | -2.08 | -0.042 | 4164.33 | D.t@95% |
| October | -44 | -2.12 | -0.060 | 4165.33 | D.t@95% |
| November | -6 | 2.38 | 0.000* | 3947.67 | N.t @95% |
| December | -66 | -1.93 | 0.000* | 3600.33 | N.t 90% |
| Belg(autumn) | -85 | -2.06 | -0.054 | 4165.33 | D.t@95% |
| winter(bega) | -134 | -2.06 | -.061 | 4165.33 | D.t@95% |
| summer(keremt) | -62 | -0.95 | -0.053 | 4165.33 | n.t@95% |
| Annual | -66 | -2.01 | -0.040 | 4165.33 | D.t@95% |

Note: * mean not significant at 95% level; N.t, mean no trend at 95%; D.t mean decreasing trend at 95

3.2.2. MK test for Projected Meteorological Drought

According to the Z-values the trend test statistics taken on annual mean rainfall of RCP4.5 comparatively shows insignificantly increasing trend but RCP 8.5 shows significantly decreasing trend with the S-test value of -158 and with the Z-value is $|Z| > 1.96$ for 95% confidence level for near future projected climatic data. The tabular illustration of two future RCPs trends of long year means annual rain fall were shown in the Table 7.

Table 7. MK trend test results of rainfall under two near future and mid future

| Statistics | RCP from 4.5 | | | RCP 8.5 | | |
|--------------|-----------------|-------------|-------------|-------------|-----------------|-----------------|
| | Near Future | Mid Future | Far Future | Near Future | Mid Future | Far Future |
| Z-test | +0.72 | -1.67 | -2.1 | -1.98 | -0.77 | +0.66 |
| Significancy | Not significant | Significant | Significant | Significant | Not significant | Not significant |
| S-test | 56 | -102 | -178 | -158 | -88 | +88 |

4. Conclusion

As results of 3-month SPI showed that in the Central Rift Valley of Ethiopia from January 1985 to December 2019, (1991-1992), (2015-2016), (2017-2018) and 2019 were drought year for historical rainfall data. The value of SPI-3 showed that 325 moderates, 141 sever and 87 extremely dry condition. Drought events occurred during 1985-2019, and most of the droughts recorded in Arsi Negele station followed by Tora, Assela, Degaga, Kulmsa, Ziway, Koshe, Bulbula and Langano meteorological station.

The average monthly share of rainfall in CRV showed about, 69% no trend, 19% decreasing trend in historical period. According to the Z-values the trend test statistics taken on annual mean rainfall of RCP 8.5 shows significantly decreasing trend with the S-test of -158, Z-test of -1.98 and with the Z-value $|Z| > 1.96$ at near future, (S-test= -122, Z=-2.3) at far future for 95% confidence level. But RCP4.5 shows decreasing trend at mid future (S-test=-106, Z= -1.67) for $|Z| > 1.64$ at 90% confidence level. For projected climatic data in near future (2022, 2029 and 2046) in future (2058, 2065 and 2061, 2068) and in far future (2099, 2085 and 2099, 2083) which were among the drought years for both RCP4.5 and RCP8.5 respectively.

The value of SPI-3 showed that 392 moderate drought, 171 severe and 95 extreme droughts for RCP4.5 and 456 moderate, 184 severe and 98 extreme number of drought events occurred for RCP8.5.

Funding

No Funding has been received.

Competing Interests

The authors declare no competing interests.

Concerns to Publish

All the authors concern to the publication of this article.

References

- Abdourahamane, Z. S. and Acar, R. (2018). Analysis of meteorological drought variability in Niger and its connection with climate indices, *Hydrological Sciences Journal*, 63(8), 1203–1218. doi: 10.1080/02626667.2018.1489542
- Aksoy, H. et al. (2018) ‘SPI-based Drought Severity-Duration-Frequency Analysis SPI-based Drought Severity-Duration-Frequency Analysis’, (September).
- Anonymous .(2016a). Handbook of Drought Indicators and Indices. – World Meteorological Organization (WMO), Global Water Partnership (GWP), The National Drought Mitigation Center (NDMC).
- Arnell, N.W. & Reynard, N.S. (1996). The Effects of Cc Due to Global Warming on River Flows in Great Britain. *Journal of Hydrology*. 183 (3-4), 397-424. [https://doi.org/10.1016/0022-1694\(95\)02950-8](https://doi.org/10.1016/0022-1694(95)02950-8)
- Belay, A. et al. (2021). Analysis of Climate Variability and Trends in Southern Ethiopia, *Climate*, 9(6), p. 96. doi: 10.3390/cli9060096.
- Belayneh, A., Adamowski, J., Khalil, B. (2016). Short-term SPI drought forecasting in the Awash River Basin in Ethiopia using wavelet transforms and machine learning methods. – *Sustainable Water Resources Management* 2(1): 87-101.
- Bobadoye, A. et al. (2019). Assessment of Meteorological drought using Standardized Precipitation Index (SPI) in Kajiado County, Keny, *Journal of Forestry Research and Management*, 16(1), 154–163.
- Buttafuoco, G., Caloiero, C. (2014): Drought events at different timescales in southern Italy (Calabria). – *Journal of Maps* 10(4): 529-537.
- Elias, E., Seifu, W., Tesfaye, B., & Girmay, W. (2019). Impact of land use/cover changes on lake ecosystem of Ethiopia Central Rift Valley.
- Ethiopian Panel on climate change (EPCC) (2015). First Assessment Report, Summary of Reports for Policy Makers, Published by the Ethiopian Academy of Sciences
- Fitsum. (2020). Wetland Management in the Central Rift Valley of Ethiopia.
- Gebremedhin, K., Shetty, A., Nandagiri, L., 2016. Analysis of variability and trends in rainfall over northern Ethiopia. *Arab J Geosci*. 9 (451) <https://doi.org/10.1007/s12517-016-2471-1>
- Gebre SL, Ludwig F (2015). Hydrological Response to Climate Change of the Upper Blue Nile River Basin: Based on IPCC Fifth Assessment Report (AR5). *Journal of Climatology Weather Forecasting* 3:121. <https://doi.org/10.4172/2332-2594.1000121>

- Gidey, E., Dikinya, O., Sebego, R., Segosebe, E., & Zenebe, A. (2018). Predictions of future meteorological drought hazard (*2070) under the representative concentration path (RCP) 4.5 climate change scenarios in Raya, Northern Ethiopia. *Model Earth System and Environment*, 4, 475–488. <https://doi.org/10.1007/s40808-018-0453-x>.
- Guttman, N.B. (1999). Accepting the standardized precipitation index: a calculation algorithm, *Jawra Journal of the American Water Resources Association*, 35: 311-322.
- Haile, G. G., Tang, Q., Hosseini-Moghari, S. M., Liu, X., Gebremicael, T. G., Leng, G., Kebede, A., Xu, X., & Yun, X. (2020b). Projected impacts of climate change on drought patterns over East Africa. *Earth's Future*, 8(7), e2020EF001502.
- Homdee T., Pongput K., Kanae S., (2016). A comparative performance analysis of three standardized climatic drought indices in the Chi River basin, Thailand, *Agric. Nat. Res. (ANRES)* 50(3): 211–219.
- IPCC (2012). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*, in: A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate.
- Mckee, T.B.; Doesken, N.J.; Kleist, J. (1993). The Relationship of Drought Frequency and Duration to Time Scales, *Preprints*. pp. 179–184.
- Mengesha, G., Elphick, C. S., Field, C. R., Bekele A., & Mamo, Y. (2015). Abundance and temporal patterns in wetland birds in and around Lake Ziway, Ethiopia. *Journal of Biodiversity Management Forestry*, 4(1), 1-9, doi:10.4172/2327-4417.100013.
- Mishra, A. K. and Desai, V. R. (2006). Drought forecasting using feed-forward recursive neural network, *Ecological Modelling*, 198: 127–138. doi: 10.1016/j.ecolmodel.
- Mohammed, Y. et al. (2018). Meteorological drought assessment in northeast highlands of Ethiopia *International Journal of Climate Change Strategies and Management*, 10(1): 142–160. DOI: 10.1108/IJCCSM-12-2016-0179.
- NMSA (2001). *Initial National Communication of Ethiopia to the United Nations Framework Convention on Climate Change (UNFCCC)*. National Meteorological Services Agency, Addis Ababa, Ethiopia.
- Salehnia, N. et al. (2017). Estimation of meteorological drought indices based on AgMERRA precipitation data and station-observed precipitation data', *Journal of Arid Land*, 9(6), pp. 797–809. DOI: 10.1007/s40333-017-0070-y.
- Shefine, B. G. (2018) 'Analysis of Meteorological Drought Using SPI and Large Scale Climate Variability (ENSO)-A case study in North Shewa Zone, Amhara Regional State, Ethiopia', *Hydrological Current Research*, 9(307), 2. doi: 10.4172/2157-7587.1000307.
- Svoboda, M. and Fuchs, B. (2017) *Handbook of Drought Indicators and Indices**. doi: 10.1201/9781315265551-12.

- Thomas B. McKee, N. J. D. and J. K. (1993) ‘Analysis of Standardized Precipitation Index (SPI) data for drought assessment’, *Water (Switzerland)*, 26(2), 1–72. doi: 10.1088/1755-1315/5.
- Tabari, H., Meron, T.T., Willems, P., 2015. Statistical assessment of precipitation trends in the upper Blue Nile River basin. *Stoch. Environ. Res. Risk Assess.*<https://doi.org/10.1007/s00477-015-1046-0>.
- Tekleab. S, Mohamed. M, Uhlenbrook. S, 2013. Hydro-climatic trends in the Abay/Upper Blue Nile basin, Ethiopia. *Physics and Chemistry of the Earth* 61–62 (2013) 32–42.
- Temesgen, H., Nyssen, J., Zeneber, A., Haregeweyen, N., Kindu, M., Lemenih, M., & Haile M. (2013). Ecological succession and land use changes in a lake retreat area (Main Ethiopian Rift Valley). *Journal of Arid Environments*, 91: 53-60.
- Teutschbein, C., Seibert, J., 2010. Regional climate models for hydrological impact studies at the watershed scale: A review of recent modeling strategies. *Geography Compass* 4, 834 -860.
- Teutschbein, C., Seibert, J., 2012. Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods. *Journal of Hydrology* 456- 457, 12-29.
- Thomas B. McKee, N. J. D. and J. K. (1993). Analysis of Standardized Precipitation Index (SPI) data for drought assessment, *Water (Switzerland)*, 26(2):1–72. doi: 10.1088/1755-1315/5.
- Ukkola, A. M., De Kauwe, M. G., Roderick, M. L., Abramowitz, G., & Pitman, A. J. (2020). Robust future changes in meteorological drought in CMIP6 projections despite uncertainty in precipitation *Geophysical Research Letters*, 47(11), e2020GL087820
- Vicente-Serrano SM, Beguería S, López-Moreno JI, Angulo M, El Kenawy A. (2010). A new global 0.5 gridded dataset (1901-2006) of a multiscalar drought index: comparison with current drought index datasets based on the Palmer Drought Severity Index.
- Yilma and Zanke, (2004). S. Yilma, U. Zanke Recent changes in rainfall and rainy days in Ethiopia. *Int. J. Climatol.*, 24 (2004), 973-983, 10.1002/joc.1