Meteorological Drought in Northwestern Escarpment of Ethiopian Rift Valley: Detection Seasonal and Spatial Trends

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Research

Keywords: Meteorological Drought, SPEI, Belg, Kiremt, Northwestern Escarpment of the Ethiopian Rift Valley, Livelihood Zones

DOI: https://doi.org/10.21203/rs.3.rs-125114/v1

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Abstract

Background

The Northwestern Escarpment of Ethiopian Rift Valley has been frequently affected by drought for decades in the major livelihood zones. This brought an adverse effect on the social and economic sectors because it affects significantly the smallholder farmers of the area. However, Most of these reviewed studies have limitations to show the evolutions, spatiotemporal drought frequencies, durations and severities in livelihood zone levels. Hence, the aim of this study was to monitor meteorological drought condition of the Alaje-Ofla (ALOF), Tserare Catchment (TC) and Raya Valley (RV) Livelihood Zones (LZ) from 1983 to 2016 using Standardized Precipitation Evapotranspiration Index (SPEI) at three months’ time scale. Both monthly Climate Hazards Group InfraRed Precipitations with Station data (CHIRPS) and Enhancing National Climate Service (ENACTS) temperature data (1983-2016) at moderate spatial resolution (i.e., 4 km-by-4km) were obtained from the National Meteorological Agency of Ethiopia.

Results

This study uncovers seasonally recurring droughts that vary in severity, frequencies, and durations within as well as between the livelihood zones. The results indicated that severe drought occurred in all livelihoods zone of the study area from 1983/4 to 1991, while in the ALOFLZ and TCLZ relatively high droughts were observed. The severity and frequency of droughts were increased during the Belg (small rain) season, but decreased in Kiremt (summer) from the period 1989 to 2016. Hence, the severity of drought both on humans and livestock was severe in the area, particularly before the year 2001, but neither catastrophic drought nor food security in TCLZ and RVLZ was observed after year 2001.

Conclusion

Studying drought with long recorded meteorological data from a large number and uniformly distributed meteorological grids in small scale livelihood zones had great implications to identify the real trends of spatiotemporal meteorological drought. This enabled the researchers to investigate the real drought frequencies, severity, and durations in small scale areas. This study can support to improve the existing drought monitoring system and to build resilience to drought at household level.

1. Background

Drought is a recurrent natural phenomenon occurs in most parts of the globe, even in the wet and humid regions (Dai, 2011; He et al., 2011; Masih et al., 2014; Tian, 2019; Zarei, 2019). It is one of the natural disasters that extensively damage the environment, and economy in several ways (e.g., agriculture, water resources, ecologies, human welfare and animal life) (Mavromatis, 2012; Lu et al., 2015; Tefera & Bello, 2019; Chen et al., 2020; Yacoub & Tayfur, 2020). According to the Emergency Events Database (EM-DAT) (2014), approximately 642 drought events were reported across the globe in the period 1900–2013. These events claimed the lives of 12 million people, and affected over 2 billion people. The total economic damages were also estimated nearly 135 billion USD. Masih et al. (2014) reported that there were about 291 drought events that affected more than 362,225,799 people during the period 1900 to 2013 in Africa. In Ethiopia, drought is a common occurrence and it has been, and still is, the main driving cause behind the country’s exposure for periodic famine (Webb & Braum, 1990; Kiros, 1991, Andargie, 2014). According to EM-DAT (2017), the degree of drought varies in intensity, spatial and temporal coverage in Ethiopia. From 1973-2016, about 26 mild-severe droughts have occurred in the northern Ethiopia ( Gebru & Beyene, 2012, EM-DAT, 2017), which overlays with the territories of the current study settings. Since 1965/1966 the country has been revisited with drought events at regular occurrences within ten-year intervals (Andargie, 2014). However, in recent years (since 2000), drought has been occurring within two to three years’ time intervals (Gidey, 2012, Gidey et al., 2018a,b).

As a land of multiple paradoxes, in Ethiopia the rural settings have been divided into pastoral, agro-pastoral and cropping livelihood zones and these three broad livelihood zones in turn sub-split into 175 livelihood zones based on economic geography (The Livelihoods Integration Unit, 2010). The three livelihood zones of the study areas include Raya Valley livelihood Zone (RVLZ), Alagie-Ofla livelihood Zone (ALOFLZ), and Tsirare Catchment Livelihood Zones (TCLZ) are among these livelihood zones. These three major livelihood zones (LZs) are among the most droughts prone and chronically food-insecure areas of the country (Andargie, 2014). Agriculture and livestock, which comprise the main livelihood system in the three LZs are frequently affected by drought. This costs thousands of human lives, and brought an adverse effect on the social and economic sectors because it affects significantly the smallholder farmers of the area (Abhra & Simhadri, 2015; Tefera & Bello, 2019). According to Gebru & Beyene (2012), the chronic nature of food insecurity leads to not only deprivation of access to immediate food demands, but also to the depletion of assets, which are expended and distress-sold for procuring food from the market or other sources.

Ethiopia had adopted National Disaster Risk Management Policy and Strategy in 2013 to reduce disaster risks and potentials damages caused by disasters (Drechsler & Soer, 2016). However, the Woreda Disaster Risk Profile (WDRPs) have not been executed at the local level (Biru & Amanuel M. Dibaba, 2018). A number of aunts such as Kenawy et al., (2016) over Ethiopia, Mohammed, (2018) in North East Highland of

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Ethiopia and Gidey (2012 and 2008) in Tigray Regional State corroborated the presence of locally embedded characters of drought evolution, that needs detail spatial drought studies to provide evidences for policy makers to adopt appropriate local polices to cope up with the risks of drought. Since 2000, drought has become almost a normal phenomenon and most of the year, apart from the rainy seasons, the area is dominated with dry weather and revisited with severe droughts (Gidey, 2012; Gidey et al., 2018a, 2018c, 2018b; Tefera & Bello, 2019). In the three LZs, the agro-ecosystem is very sensitive for precipitation change. The changes or variability in precipitation amount and distribution have negative impacts on the environment as well as on the livelihood of the marginal households. In most cases, drought recurs before the affected area has recovered from the most recent drought event (Abhra & Simhadri, 2015).

Several studies related to drought have been conducted using SPEI in different parts of the globe. For instance, Abbasi et al. (2019) studied drought using SPEI and gene expression model from 1951-2009 for all time scales in Urmia, Iran. They found that the prediction accuracy was increased by increasing SPEI time scales, and it is better than indicators that only use precipitation data and it can be indicators of hydrological drought. Bae et al., (2018), found out the characteristics of drought based on SPEI using Thomthwaite and Penman-Monteith equations in South Korea from1981-2010 years. They found that SPEI using Penman-Monteith equations slightly shows severe drought than Thorn Thwaite equations. Diaz et al., (2020), study drought tracks using gird data from SPEI in India from 1901-2013, and they found the severity, duration, onset, and end positions track of the drought. Beharry et al., (2019) studied to build baseline scenarios of meteorological droughts using SPI Index for the southernmost Caribbean islands of Trinidad and Tobago from 1980-2014. Their result shows that there are variations of drought characteristics over a small island, the possible adverse effects on surface water reservoirs.

Similarly, few studies have been conducted in Tigray at regional and zonal scale, but not at livelihood zone levels. For instance, Gidey (2012) and Gidey et al. (2008 a,b) studied the effectiveness of food security policy in ensuring rural food security and poverty reduction in the Tigray region and assessment of the various drought conditions of the area. Anny et al. (2016) studied the relationship between rainfall variability and land cover changes as impacted by spatial-temporal rainfall variability along the Ethiopian Rift Valley escarpment. Gidey et al. (2018a,b,c,d) also analyzed the meteorological, and agricultural droughts onset, cessation, duration, frequency and spatial extent using an advanced approaches of geospatial technologies. Moreover, Abhra & Simhadri (2015) conducted a study on climate change and farmers’ perception, and factors affecting the perception of climate change in Southern Tigray. Tefera & Bello (2019) also studied the correlation between SPI and SPEI index for drought measurement in Tigray. These authors have used 12 grids for meteorological data analysis throughout the region.

Most of these reviewed studies have limitations to show the evolutions, spatiotemporal drought frequencies, durations and severities in livelihood zone levels. The study of drought conditions in zonal,regional, national or continental levels could generalize the situations of the vulnerable areas which need special focuses and local solutions based on the magnitude of their vulnerabilities. So far, there have been little or no intensive study that attempts to capture the frequencies, severity, durations, and spatial coverage of drought at a LZ level which will be data sources for the WDRPs. Most of the reviewed literatures indicate that metrological data were collected from few stations which were not proportional to their spatiality. Unrepresentative data could not demonstrate a full picture of results that vividly put the magnitude and intensities of droughts as well as the real spatial distributions and time series of these occurrences.

Therefore, to design the right strategies that help reducing the impacts of drought and to sustain the livelihood of the local communities and their environment, it needs detailed studies of drought evolutions, its tracks, and magnitudes at specified livelihood zones with intensive meteorological data. Hence, this study attempts to detect meteorological drought incidence using SPEI in Northwestern Escarpment of the Ethiopian Rift Valley. Studying the trends of spatiotemporal drought frequencies, durations, and severities at livelihood zones are important to show the real drought vulnerable area on local levels, which will be used as an input for policies and strategies in drought management and preparedness. Moreover, the outlook of the local drought occurrences in the historic context could facilitate in applying low-risk and long-term plans to develop strong livelihood systems which can withstand the impacts and strengthen the resilience for communities and to conserve and sustainably use their natural resources.

2. Materials And Methods

2.1. Study area

This study was conducted in the three livelihood zones of northwestern escarpment of the Ethiopian rift valley (Raya valley and its adjacent). It is located between 12° 20'°-12° 50'° N latitude and 39°10'°-39°53’41.7” E longitudes in north eastern Ethiopia. The topography of the area includes mountains, plateaus, valleys, and gorges. The area has mainly semi-arid and sub-humid climates characteristics and comprises Dry Kola (500–1500 m.a.s.l), Dry Woinadega (1500–2300 m.a.s.l), Dry Dega (2300–3200 m.a.s.l) and High Dega (wurch) (above 3200 m.a.s.l) agro-climatic zones (Humi & Zeleke, 2018). The study area covers 3809 KM². The RVLZ has Dry Woinadega and Dry Kola agro-climatic zones with an area of 1447 KM² and 386 KM², respectively. The ALOFLZ has Dry Dega and High Dega agro-climatic zones with a total areas of 1035 KM² and 52 KM², respectively. But TCLZ has only Dry Woinadega agro-climatic zone with 933.56 KM² area. The rainfall distribution of the
The study area is bimodal with abundant rainfall in July and August, and the second smaller rainy season from March to May. The study area receives an annual precipitation of 400-700 mm in the semi-arid, while the sub humid parts of the area receive between 700 to 1000 mm. The maximum average annual temperature ranged between 25.4 to 27.5 °C, while the minimum average annual temperature is between 12.5 to 14.5 °C. Furthermore, the smallholder farmers of the study area practiced a mixed agricultural production system (i.e., crop production and livestock rearing) (Abhia & Simhadri, 2015). Besides, sorghum, maize, wheat, barley, pulses, and teff are the predominant crop types grown in the kola and dry-woinadega agro-ecological zones both during the Kiremt (main rain) and Belg (small rain) seasons. Humi & Zeleke (2018) also reported that barley, wheat, legumes, teff, and pulses are grown in the dry-dega parts of the study area, and the High Dega (wurch) areas are cultivated barley and sometimes potatoes.

2.2. Data collection

In this study, both the monthly Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) and Enhancing National Climate Service (ENACTS) Maximum (Tmax) and minimum (Tmin) temperatures data (1983-2016) at moderate spatial resolution (i.e., 4km-by-4km) have been acquired from the National Meteorological Agency of Ethiopia. The collected data were free of zero missing values and used to compute drought frequency, duration, magnitude, and the spatial coverage.

2.3. Data processing, analysis and interpretation

The Standardized Precipitation Evapotranspiration Index (SPEI) which is one of the prominent meteorological drought indices was applied to analyze the condition of drought incidence at three months' time scale in the study area. SPEI has been widely used for drought measurements and water balance estimation across the globe (Shi et al., 2017). Vicente-Serrano et al., (2012) reported that the index combined Palmer Drought Severity Index (PDSI) to simplify the detection of meteorological drought incidence. For the calculation of the SPEI, the first step is to find the probability density function using gamma probability density function which best describes the distribution of the precipitation data over different time scales using the same computing procedure of the SPI (Zhang & Shen, 2019). However, the inputs required to calculate SPEI program are precipitation and Potential Evapotranspiration (PET). World Meteorological Organizations (WMO) recommends using the Penman-Monteith (MP) equation to calculate PET. However, Penman-Monteith (MP) equation requires long recording data of solar radiation, temperatures, wind speed, and relative humidity which are not easily available in meteorological stations in routinely measuring and long term records particularly in developing countries Bae et al., (2018). Therefore, if there is a limitation of data, Vicente-Serrano et al.,( 2014), are recommended Hargreaves (Hg) equations as first and Thornthwaite (Th) equations as the second alternatives to estimate PET in order to calculate SPEI using R packages. So that, to run the PET of this study, depending on the availability of the maximum and minimum temperatures, precipitations, longitude and latitudes data, the Hargreaves (Hg) equation was used.

\[ SPEI = P - PET \]  

Where P monthly average rainfall and PET monthly Potential Evapotranspiration. For further information on the SPEI tool visit at http://sac.csic.es/spei/index.html.

| Descriptions       | SPEI values |
|--------------------|-------------|
| Extremely wet      | >2          |
| Very wet           | 1.5 to 1.99 |
| Moderately wet     | 1.00 to 1.49|
| Mildly wet         | 0 to 0.99   |
| Mild drought       | 0 to -0.99  |
| Moderate drought   | -1.0 to -1.49|
| Severe drought     | -1.5 to -1.99|
| Extreme drought    | <-2         |

Table 1. Meteorological drought classification or interpretation by SPEI (Sources: WMO, 2012)

After analysis the magnitude and severity of the drought within the SPEI indexes the spatial and temporal trends of the drought further analyzed and mapped in ArcGIS. The Invers Weighting Methods (IDM) method was used to interpolate the spatial drought trends. The IDM is important tool for rainfall distributions and drought occurrences interpolation in heterogamous geographies (Mohammed, 2018). Since the
meteorological data were collected approximately 4km by 4km, Thiessen polygon were applied to calculate accurate areas of each grid points. Using each grid area, the spatial drought coverages were computed for the studying drought seasons of the study livelihood zones. The GraphPad Prism version 8.4.2 was used to see and to compare the drought spatial extension trends between the three LZs using simple linear regression.

3. Results And Discussion

3.1. Results

3.1.1. Drought characteristic in the study area

Studying the spatiotemporal trends of drought is important to carry out the analysis of the impacts of drought. The long and short rainy seasons in the study area are Kiremt (June to August or September) and Belg (March to May) respectively. Both seasons are the main rain sources to cultivate short as well as long cycle growth crops. Rain feed agricultural activities and productivities of the study area depends on the two seasonal precipitations. Small precipitation change in one or both seasons can have consequences of crop failure and forage problems in the study area. Shortage of precipitations for continuous months particularly during the consecutive rainy seasons has great impacts on rain feed agriculture systems. If there is a period of months to years of prolonged dry weather conditions due to precipitation departure in a certain region, meteorological drought may occur and these may have high impacts on water resources, agricultural activities, meteorological cycles, ecosystem processes, and social affairs. Consequently, the focus of this spatiotemporal drought study was emphasized on short (the Belg and Kiremt), combined (March-August) rainy season drought trends.

For the temporal drought trend results, charts and Figure were presented and for the spatial drought trends, the researcher preferred to put tables, graphs and maps for each LZs. Summary of spatial coverage for SPEI value for Belg and Kiremt seasons for the measured time scales from 1983 to 2016 were presented in Table 2 and Table 3, respectively. The colors of the maps below in Figure 4 for Belg season and Figure 7 for Kiremt season indicated the magnitude of the drought or wet seasons in SPEI3. The red and green colors represented the drought and wet season respectively. The blue color in the red and green maps presented for the highest or the lowest SPEI value for the drought and wet seasons respectively. But since the colors presented to show the range of SPEI3 magnitude at a grid level, the red or the green colors does not mean 100% drought or wet season; rather they indicated the extents of spatial drought or wet season coverage in the livelihood zones. Since the SPEI values were stated in ranges using IDW it was influenced with neighborhood grid points SPEI3 values. For the detail of the highest and lowest value of SPEI3 in each maps see in Figure 4 for Belg and Figure 7 for Kiremt. The area coverages of drought magnitude for the scales for each year's see below in Table2 for Belg and in Table3 for the Kiremt seasons.

3.1.2. Drought condition during the Belg season

From 1983 to 2016 in Belg 18 mild, moderate, severe, and extreme seasonal temporal droughts were recorded. From these seasonal drought years, 1990, 1991, 1999, 2000, 2003, 2004, 2008, 2009, and 2013 were recorded from moderate to extreme seasonal droughts in SPEI3. The frequencies of seasonal drought for Belg had increased since 1998 in all livelihood zones. The SPEI3 temporal drought trends clearly indicated in Figure 2. As seen in the chart, the longest persistent drought years for this season were occurred for seven years from 1998 to 2004 and followed by five drought seasons from 2012 to 2016. From 1983 to 1999 there were high severity and short frequencies of Belg drought. Within the past thirty-four years (1983-2016), the 1999 were recorded as the severe in temporal Belg drought in SPEI3 in all livelihood zones. The magnitude was ranged from -1.71 in TCLZ to -1.88 SPEI values in RVLZ.

From 1983 to 1999, there were ten moderate up to severity wet Belg seasons in all livelihood zones but, with slight differences with the livelihood zones and the indexes. From the years of 2000 to 2016 there were four wet Belg seasons in all livelihood zones and both indexes. The years of 1994 and 1997 were recorded as the highest wet Belg season in SPEI3 values for the three LZs. The recorded SPEI value of the year 1996 for ALOLZ and TCLZ were 2.00. Further, the years of 1993 and 1987 were recorded as the second and third highest wet Belgs in SPEI3 values respectively. The longest persistent wet seasons for SPEI3 values were recorded from 1985 - 1987 and 1995 - 1997.

Below the spatial drought map in Figure 4 indicated, in the years of 1984, 1990, 1991, 1999, 2009 and 2013 ALOLZ were recorded severe to extremely severe drought Belg seasons with SPEI3 magnitude of -2.24, -1.51, -2.02, and -2.33, -1.84, and -1.53 respectively. Further more as indicated in Table2, 100% parts of the ALOFLZ was affected from mild to extremely severe drought in the years of 1984, 1990, 1991, 1994, 1999, 2000, 2004, 2007, 2008, 2009 and 2013. However, from 1985-1987, 1995-1999 ALOLZ has recorded a better precipitations relative to the three livelihood zones. However, since 1992 up to 2016 the TCLZ, and RVLZ were recorded fluctuated dry and wet Belg seasons. In the years of 1988, 1990, 1991, 2001, 2004, 2007, 2009, 2013 and 2014, all parts of (100%) TCLZ were affected from mild to extremely Belg season drought. All parts of RVLZ were affected by drought in Belg seasons from 1990-1991, 1998-2000, 2004, 2007-2009 and 2013-2014. The rest study years for the study LZs were partial affected mild to extremely severe drought or free from drought in Belg season.
The summary of the spatially drought coverage of the study years in Belg season for the study livelihood zone presented blow in Table 2 and Figure 4 and the trends of area coverage presented below in Figure 3. Mohammed (2018) study indicated that, increasing tendency of drought Belg season timescale in North East Highland of Ethiopia and this study coincided with his study. The trends of drought in Belg season has steadily increasing both temporally and spatially in all LZs in the study years. From 1989-2016 the frequencies of drought have increased in Belg within the study years but with a slight difference between the livelihood zones. As seen below in Figure 3, relatively the two LZs the area coverage of Belg drought has rapidly increasing in RVLZ.

Table 2. The spatial drought trends in % of area coverage n Belg season from 1983-2016.
| Years | Spatial drought area coverage in % for Belg season |
|--------|-------------------------------------------------|
|        | ALOFLZ (1106.19 KM²) in % | TCLZ (933.56 KM²) in % | RVLZ (1850.10 KM²) in % |
|        | DF       | MD       | MOD      | SD       | ESD      | DF       | MD       | MOD      | SD       | ESD       | DF       | MD       | MOD      | SD       | ESD      |
| 1983   | 72.05    | 27.95    | -        | -        | -        | 54.26    | 45.74    | -        | -        | -        | 98.04    | 1.96     | -        | -        | -        |
| 1984   | -        | 81.45    | 9.16     | -        | -        | 10.72    | 74.61    | 14.66    | -        | -        | 11.97    | 75.31    | 9.95     | 2.77     | -        |
| 1985   | 93.98    | 6.02     | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1986   | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1987   | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1988   | -        | 100      | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1989   | 100      | -        | -        | -        | -        | 97.38    | 2.62     | -        | -        | -        | 99.06    | 0.94     | -        | -        | -        |
| 1990   | -        | 10.73    | 89.27    | -        | -        | -        | 61.98    | 38.02    | -        | -        | -        | 55.57    | 44.43    | -        | -        |
| 1991   | -        | 6.27     | 54.58    | 1.57     | 17.32    | -        | 49.92    | 42.66    | 7.42     | -        | -        | 11.44    | 84.82    | 3.75     | -        |
| 1992   | 93.73    | 6.27     | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1993   | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1994   | -        | 75.18    | 24.82    | -        | -        | 30.17    | 69.83    | -        | -        | -        | 36.00    | 64.00    | -        | -        | -        |
| 1995   | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1996   | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1997   | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1998   | 1.57     | 98.43    | -        | -        | -        | 9.34     | 90.66    | -        | -        | -        | 100      | -        | -        | -        | -        |
| 1999   | -        | 1.57     | 28.19    | -        | -        | 100      | -        | -        | -        | -        | -        | 42.4     | 57.62    | -        | -        |
| 2000   | -        | 100      | -        | -        | -        | 4.47     | 95.53    | -        | -        | -        | 100      | -        | -        | -        | -        |
| 2001   | 46.99    | 53.01    | -        | -        | -        | -        | 45.23    | 14.96    | 39.80    | -        | 3.17     | 86.80    | 10.02    | -        | -        |
| 2002   | 36.03    | 54.80    | 6.03     | -        | -        | 24.89    | 30.38    | 28.22    | 16.50    | -        | 10.47    | 87.93    | 1.60     | -        | -        |
| 2003   | 68.92    | 31.08    | -        | -        | -        | 26.82    | 70.56    | 2.62     | -        | -        | 48.94    | 51.06    | -        | -        | -        |
| 2004   | -        | 43.61    | 56.39    | -        | -        | 32.44    | 67.56    | -        | -        | -        | 94.02    | 5.98     | -        | -        | -        |
| 2005   | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        | 50.25    | 49.75    | -        | -        | -        |
| 2006   | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        | 99.06    | 0.94     | -        | -        | -        |
| 2007   | -        | 100      | -        | -        | -        | -        | -        | -        | -        | -        | 90.45    | 9.55     | -        | -        | -        |
| 2008   | -        | 36.01    | 48.33    | -        | -        | 7.95     | 49.24    | 42.81    | -        | -        | -        | 3.55     | 56.20    | 40.3     | -        |
| 2009   | -        | 37.59    | 46.76    | -        | -        | 18.09    | 80.07    | 1.84     | -        | -        | 9.17     | 84.18    | 6.65     | -        | -        |
| 2010   | 62.41    | 37.59    | -        | -        | -        | 91.96    | 8.04     | -        | -        | -        | 94.26    | 5.74     | -        | -        | -        |
| 2011   | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        | 100      | -        | -        | -        | -        |
| 2012   | 28.19    | 71.81    | -        | -        | -        | 55.03    | 44.97    | -        | -        | -        | 6.64     | 93.36    | -        | -        | -        |
| 2013   | -        | 20.35    | 21.93    | 3.13     | 34.65    | 7.91     | 16.27    | 58.65    | 17.2     | -        | 31.51    | 61.20    | 7.30     | -        | -        |
| 2014   | 14.10    | 76.50    | 9.40     | -        | -        | 100      | -        | -        | -        | -        | 96.83    | 3.17     | -        | -        | -        |
| 2015   | 56.14    | 43.86    | -        | -        | -        | 56.93    | 43.07    | -        | -        | -        | 38.12    | 54.50    | 7.38     | -        | -        |
| 2016   | 96.87    | 1.57     | 1.57     | 17.33    | 59.65    | 28.47    | 2.24     | 9.64     | -        | -        | 46.61    | 52.45    | 0.94     | -        | -        |

DF = Drought Free, MD = Mild Drought, MOD = Moderate Drought, SD = Severe Drought, ESD = Extremely Severe Drought, (-) = Zero value

3.1.3. Drought condition during the Kiremt rain season
The study area is highly dependent on Kiremt for rain and the majority of agricultural activities and productivities are dependent on the precipitation condition of this season. As stated in Figure 5 of SPEI3 temporal trends, from 1983 to 2016 in Kiremt mild, moderate, and severity seasonal droughts were recorded. From these seasonal drought years, 7 of them were moderate up to severe seasonal droughts. However, the severity, persistence, and frequencies of Kiremt drought were seen from 1983-1993 in all livelihood zones. The highest extreme severity drought was recorded in SPEI3 in 1984. In this year, SPEI3 recorded from -1.74 in TCLZ to -1.68 in RVLZ. The severity, persistence, and frequencies of Kiremt drought were seen in the years 1983, 1984, 1985, 1987, 1989, 1990, 1991, and 1993 in all livelihood zones. The better wet Kiremt season has occurred in the years 1988, 1994, 1998, 2001, 2007, and 2010 in all livelihood zones. Besides, the years of 2012 for RVLZ and 2016 for ALOFLZ and TCLZ were wet Kiremt. The 1998 Kiremt season was the wettest in thirty-four study years for all livelihood zones.

For spatial drought coverage, as seen in Table 3 and Figure 6, from mild to extreme Kiremt drought were occurred on partial or in total study zones. In ALOFLZ, about 87.47, 100, 100, 100, 100, 100, 100, 100, 92.17, 100, and 62.66% in the years of 1983, 1984, 1985, 1987, 1989, 1990, 1991, 1993 and 20015 were affected from moderate to extreme Kiremt drought respectively. Besides moderate to extreme Kiremt drought in TCLZ were 98.14, 100, 100, 97.38, 100, 100, 43.96, 100, 1.58, 9.99 and 62.66% of the area affected in the years of 1983, 1984, 1985, 1987, 1989, 1990, 1991, 1993, 2002, 2004, and 20015 respectively. Moderate to extreme Kiremt drought in RVLZ were covered the area of 96.36, 99, 79.47, 97.19, 98.13, 100, 100, 97.56, 2.79, 85.16 and 62.66% in the years of 1983, 1984, 1985, 1987, 1998, 1990, 1991, 1993, 2002, 2008, and 20015 respectively. As seen in Figure 6, the spatial drought trends in area coverage slightly decreased in all LZs.

Even if the drought frequencies were reduced from 2001 to 2016, the 7 wet Kiremt seasons were recorded below 0.5 SPEI values which was mild wet. This precipitation value was too low for agricultural practices. A plant's demand for water is dependent on prevailing meteorological conditions and vulnerable to dry weather conditions. This small precipitation sources and frequently happened mild spatiotemporal metrological drought in the study LZs, the agricultural scoter have been badly affected. Besides, the kiremt drought season becoming locally discriminated even at village levels. Little is heard, about the study area except when large-scale drought occurs at regional or nationwide scales. This study coincides with (Gidey, 2012) study that stated, an isolated drought is particularly dangerous drought for the affected people. Furthermore, drought is often elapsed once it ends, and consequently, the government will again be ill informed when the next large scale drought occurs. For all study years and study livelihood zones all spatial drought magnitudes from mild to extreme Kiremt drought were presented below in Table 3. For Kiremt drought and wet seasonal trends, for the study area and the study years, the following SPEI3 (Figure 5) temporal charts and spatial SPEI maps in (Figure 7) were presented.

Table 3. The spatial drought trends in % of area coverage in Kiremt season from 1983-2016.
| Years | Spatial drought area coverage in % for Kiremt season |
|-------|-----------------------------------------------------|
|       | ALOFLZ (total area 1106.19 KM²) | TCLZ (total area 933.56 KM²) | RVLZ (total area 1850.10 KM²) |
|       | DF   | MD  | MOD | SD  | ESD | DF   | MD  | MOD | SD  | ESD | DF   | MD  | MOD | SD  | ESD |
| 1983  | -    | 12.53 | 79.64 | 7.83 | -   | 1.86 | 72.39 | 25.75 | -   | 3.63 | 88.53 | 7.84 | -   |
| 1984  | -    | -    | 100  | -    | -   | 8.34 | 91.66 | -    | 0.94 | 2.93 | 96.14 | -    |
| 1985  | -    | -    | 100  | -    | -   | 100  | 100  | -    | -   | 20.53 | 79.47 | -    |
| 1986  | 82.77 | 17.23 | -    | -    | 100  | -    | -    | -    | 100  | -    | -    | 100  |
| 1987  | -    | 100  | -    | -    | -   | 2.62 | 88.36 | 9.02 | -   | 2.81 | 95.18 | 2.01 | -    |
| 1988  | 100  | -    | -    | -    | 100  | -    | -    | -    | 100  | -    | -    | -    |
| 1989  | -    | 65.79 | 32.66 | 1.55 | -   | 93.52 | 6.48 | -    | 1.87 | 79.36 | 18.77 | -    |
| 1990  | -    | 100  | -    | -    | -   | 97.38 | 2.62 | -    | -   | 98.13 | 1.87 | -    |
| 1991  | 7.83 | 92.17 | -    | -    | 56.04 | 43.96 | -    | -    | 97.19 | 2.81 | -    |
| 1992  | 100  | -    | -    | -    | 87.99 | 12.01 | -    | -    | 95.18 | 4.82 | -    |
| 1993  | -    | 100  | -    | -    | -   | 100  | -    | -    | 2.44 | 97.56 | -    |
| 1994  | 100  | -    | -    | -    | 100  | -    | -    | -    | 100  | -    |
| 1995  | 100  | -    | -    | -    | 100  | -    | -    | -    | 92.51 | 7.49 | -    |
| 1996  | 92.17 | 7.83 | -    | -    | 88.39 | 11.61 | -    | -    | 84.56 | 15.44 | -    |
| 1997  | -    | 100  | -    | -    | -   | 100.00 | -    | -    | -    | 100  |
| 1998  | 100  | -    | -    | -    | 100  | -    | -    | -    | 100  | -    |
| 1999  | 100  | -    | -    | -    | 100  | -    | -    | -    | 100  |
| 2000  | 100  | -    | -    | -    | 100  | -    | -    | -    | 100  |
| 2001  | -    | 100  | -    | -    | -   | 100  | -    | -    | -    | 100  |
| 2002  | 100  | -    | -    | -    | 100  | -    | -    | -    | 98.42 | -    | 97.21 | 2.79 | -    |
| 2003  | 86.14 | 13.86 | -    | -    | 63.61 | 36.39 | -    | -    | 97.25 | 2.75 | -    |
| 2004  | 23.48 | 76.52 | -    | -    | 90.01 | -    | -    | -    | 85.55 | 14.45 | -    |
| 2005  | 100  | -    | -    | -    | 100  | -    | -    | -    | 95.26 | 4.74 | -    |
| 2006  | 100  | -    | -    | -    | 100  | -    | -    | -    | 94.14 | 5.86 | -    |
| 2007  | 100  | -    | -    | -    | 100  | -    | -    | -    | 100  |
| 2008  | -    | 100  | -    | -    | -   | 100.00 | -    | -    | -    | 100  |
| 2009  | 49.88 | 50.12 | -    | -    | 57.58 | 42.42 | -    | -    | 82.04 | 17.96 | -    |
| 2010  | 100  | -    | -    | -    | 100  | -    | -    | -    | 82.04 | 17.96 | -    |
| 2011  | 21.93 | 78.07 | -    | -    | 62.27 | 37.73 | -    | -    | 5.18 | 94.82 | -    |
| 2012  | 70.48 | 29.52 | -    | -    | 62.43 | 37.57 | -    | -    | 82.36 | 17.64 | -    |
| 2013  | 100  | -    | -    | -    | 97.38 | 2.62 | -    | -    | 98.13 | 1.87 | -    |
| 2014  | 60.84 | 39.16 | -    | -    | 44.59 | 55.41 | -    | -    | 44.17 | 55.83 | -    |
| 2015  | -    | 34.21 | 62.66 | 3.13 | -   | 1.86 | 33.62 | 64.53 | -   | 0.94 | 40.38 | 58.69 | -    |
| 2016  | 100  | -    | -    | -    | 98.14 | 1.86 | -    | -    | 18.05 | 81.95 | -    |

DF = Drought Free, MD = Mild Drought, MOD = Moderate Drought, SD = Severe Drought, ESD = Extremely Severe Drought, () = Zero value
3.1.4. Drought condition both during the Belg and Kiremt rainy seasons

This part focuses on the average combined rainy seasons of the study area. Using SPEI6, the drier and wettest years for the six months from March-August were analyzed. From 1983 to 1991, there were 2 wet and 7 consecutive drought years in all livelihood zones in SPEI6 for the study months. However, from 1992 to 2007, there were 2 droughts and 10 wet recorded years for six months. Besides in 2010 and 2012 for all livelihood zone, and 2016 for ALOFLZ and TCLZ were recorded as wet years. Generally, from 1983 to 2016, 15 drought were recorded for the combined rainy season in all livelihood zones; with 2 additional drought seasons for RVLZ. From 1983-1991 long durations and the high severities of drought were occurred in all livelihood zones in SPEI6 records. From SPEI6 recorded value, severe drought was seen in years of 1984 in all livelihood zone. The lowest recorded SPEI6 value in the year of 1984 were ranged from -1.90 in ALOFLZ to -1.77 in RVLZ. For further information to see temporal and spatial drought trends using SPEI6 records for each year for the combined rainy season and all livelihood zones are presented below in Figure 8 and Figure 9 respectively. As seen below in Figure 9, the area coverage of the combined rainy season slightly decreasing in both ALOFLZ and TCLZ, but increasing in RVLZ.

3.2. Discussion

The Belg and Kiremt drought had an inverse relationship with drought histories in the study area within-study years. As previously mentioned in Belg and Kiremt drought seasonal graphs, if Kiremt gets good rain in some years, the Belg did not get and there were versus. Hence, most of the study years, there have been Belg or Kiremt or both drought seasons in the study areas. Gidey et al., (2018) study show that agricultural drought increased even in the main rain seasons of the Raya valley and its environs using the Vegetation Health Index (VHI). Their findings stated that drought frequencies, durations, and severity are higher in the lowland area than the mid and highlands during the last 15 years. The current study coincides with the Gidey et al., (2018) frequencies and persistence of drought, however, the Kiremt drought severity were reducing since 2000 in the study livelihood zones except for the 2015 drought. Further, their findings show that, 2001, 2003, 2003, 2006, 2007, and 2010 years were free from incidences of agricultural drought in the three livelihood zones. However, yearly there were Kiremt or Belg or drought in both seasons at local or in livelihood zone levels. Mohammed (2018) study indicated that, increasing tendency of drought Belg season and tendency of reducing drought in Kiremt and annual timescale in North East Highland of Ethiopia. This study partially coincided with study of Mohammed (2018). The trends of drought in Belg and Kiremt seasons had an inverse relation with the incidences of drought records within study years of this study. From 1989-2016 the frequencies of drought have increased in Belg and decreased in Kiremt within the study years but with a slight difference between the livelihood zones.

Extreme to severe drought becoming decreasing, but moderate to mild drought frequencies and persistence were increasing in all livelihood zones. This study agreed with Kenawy et al., (2016) study on changes in the frequencies and severity of hydrological droughts over Ethiopia, which reveal statically signicant decreasing in the severity of droughts( extreme and severe drought) compared to the moderate droughts over the 54 year period(1960-2013). More over this study coincides with Zeleke et al., (2017) findings on trends and periodicity of drought over Ethiopia during the period of 1979-2014. The severity and frequencies of drought in this study higher from 1983 to 1991, better from 1993 to 1998 and returned mild to moderate drought from 2000-2016.

From the year 1984-1998 the Kiremt, and from March-August drought have been relatively severe in ALOFLZ and TCLZ, than in RVLZs. However, from the years 1992-2016, the ALOFLZ and TCLZ relatively recorded moderately wettest Kiremt than RVLZs. Mild to severity short Kiremt drought frequencies frequently happened from the year 1997 to 2016 in TCLZ and RVLZ than ALOFLZ. All livelihood zones had severity drought from SPEI6 records in the years 1983, 1984, 1989, 1990, 1991, and besides 2015 for RVLZ.

The Belg and Kiremt seasons are the main moisture sources for agriculture activities, animal forage productions as well as sources of moisture budget for the local ecosystems’ stabilities of the area. However, since 2000, the wet seasons were recorded below 0.5 SPEI values which was too low for agricultural practices and ecosystem stability’s. The moisture amount of these months can have an implication on the evapotranspiration budget and its process as well as on drought induces or resistances for the study area. There are long and short growing season crops that are sensitive for the two wet seasons of rain conditions. When one of the rainy seasons failed, the long and short seasonal growing crop failure has occurred in the area. This needs the special confederations on current moisture harvesting system and afforestation practices to reduce human induced droughts and its impacts. As this study uncovered, long before 25(2000) years, drought causalities were tremendous in the lives of humans and livestock in the study area. Since the frequencies and persistence of mild drought has increasing and the intensity of the precipitation amount is too small to cultivate crops and forage growth, the recent drought incidents have many fatalities to the livestock than to human suffering. Human may searches other alternative income sources like power sale, remittance income sources, relief supports, and firewood sales.

4. Conclusions

In this study, the trends of spatiotemporal seasonal drought frequencies, durations, and severity were analyzed. Studying drought with long recorded meteorological data from a large number and uniformly distributed meteorological grids in small scale livelihood zones had great
implications to identify the real trends of spatiotemporal meteorological drought. This enabled the researchers to investigate the real drought frequencies, severity, and durations in small scale areas. The short and medium time scales (3, and 6 months) have strong implications to see the spatiotemporal drought frequencies, magnitudes, and severities. Studying drought in small scale livelihood zones is important to find out natural and human-induced drought susceptible areas.

The authors find that, there were seasonally recurring droughts that vary in severity, frequencies, and durations within as well as between the livelihood zones. Drought frequency and persistence has been increasing in RVLZs followed by TCLZs. In most of the study years, there have been seasonally or yearly human or climate-induced droughts occurrences in station levels or livelihood zone scale in RVLZ and TCLZ. In the last thirteen years (2003-2016), the RVLZ has suffered immensely due to persistent drought incidents. However, in the same years, the central parts of ALOFLZ have been less vulnerable to drought than others.

The finding of this study would help to manage drought incidents and would have a significant contribution to early warning systems, particularly in district levels. Depending on local drought maps and histories they can intervene and develop strong livelihood systems that can withstand the drought impacts, and strengthen the resilience for communities and their environments. Ended, it needs to consider solutions for short and long drought impacts. The agricultural sector should consider the long-cycle crops (sorghum, maize) or long season crop growth patterns to reduce crop failures and forage problems. On the ground, further study is needed to see the community perceptions, their adopting and adaptation mechanism to put appropriate measurements and interventions.

**Declarations**

**Ethics approval and consent to participate**

This research paper is part of our own project entitled “Synergetic Impact of Drought and Land Use Land Cover Dynamics on Livelihood of the Local Communities in Northern Western Escarpments of Ethiopian Rift Valley”. Therefore, all authors approve to publish the findings and there is no ethical conflict.

**Consent for publication**

All authors read the manuscript and agreed for publication.

**Availability of data and material**

The data is presented with additional supporting file.

**Competing interests**

The Authors declare that they have no competing interests.

**Funding**

This research is partially funded by Addis Ababa University and Aksum University for data collection and processing only.

**Authors' contributions**

The correspondent author initiate the research idea, review relevant literatures, design the methods, field data collection, data cleaning, analysis and interpretation, prepare draft manuscripts for publication. Coauthors evaluate the research idea, supervise the whole research activities, and develop the manuscript.

**Acknowledgements**

The authors are grateful for Addis Ababa and Aksum Universities for their financial support and we wish too, to thank Ethiopian Meteorology Agency for providing meteorological data used in this study.

**References**

Abdolin, A., Khalili, K., Behmanesh, J., & Shirzad, A (2019) Drought Monitoring and Prediction Using SPEI Index and Gene Expression Programming Model in the West of Urmia Lake. Theoretical and Applied Climatology 138(1-2):553-567

Abraha, M. G., & Simhadri, S (2015) Local Climate Trends and Farmers ‘ Perceptions in Southern Tigray, Northern Ethiopia. Journal of Environmental Sciences 11(4): 262-277
Andargie, G (2014) Military Rule Responses to the Ethiopian Agony: Famine of 1984-1985. International Journal of Humanities Social Sciences and Education 7(8):183–192

Annys, S., Demissie, B., Zenebe, A., & Miro, A (2016) Land Cover Changes as Impacted by Spatio-Temporal Rainfall Variability Along the Ethiopian Rift Valley Escarpment. Regional Environmental Change 17(8): 451–463

Bae, S., Lee, S., & Yoo, S (2018) Analysis of Drought Intensity and Trends Using the Modified SPEI in South Korea from 1981 to 2010. Water 10(3): 327

Beharry, S. L., Gabriels, D., Lobo, D., & Clarke, R. M (2019) A 35-Year Meteorological Drought Analysis in the Caribbean Region: Case Study of the Small Island State of Trinidad and Tobago. SN Applied Sciences 1(10): 1–16

Biru, D., & Amanuel M. Dibaba (2018) Assessment on the Operationalization of DRR System at Local Level. Asist Mission Report September 2018, 35. International Cooperation and Development.

Chen, S., Zhang, L., Zhang, Y., Guo, M., & Liu, X. (2020) Evaluation of Tropical Rainfall Measuring Mission (TRMM) satellite precipitation products for drought monitoring over the middle and lower reaches of the Yangtze River Basin, China. Journal of Geographical Sciences 30(1): 53–67

Dai, A. 2011. Drought Under Global Warming. WIREs Climate Change 2(1): 45–66

Díaz, V., Corzo, G. A., Lanen, H. A. J. Van, Solomatine, D., & Varouchakis, E. A (2020) An Approach to Characterise Spatio-Temporal Drought Dynamics. Advances In Water Resources 137(7):103512

Drechsler, Mareile; Soer, Wolter (2016) Early Warning, Early Action : The Use of Predictive Tools in Drought Response through Ethiopia's Productive Safety Net Programme. Policy Research Working Paper No. 7716. World Bank, Washington, DC. © World Bank

Gebru, G. W., & Beyene, F (2012) Rural Household Livelihood Strategies in Drought-Prone Areas: The Case of Gulomekeda District, Eastern Zone of Tigray National Regional State, Ethiopia. Journal of Development and Agricultural Economics 4(6):158-168

Gidey, E., Dikinya, O., Sebego, R., Segosebe, E., & Zenebe, A (2018a) Analysis of the Long-Term Agricultural Drought Onset, Cessation, Duration, Frequency, Severity And Spatial Extent Using Vegetation Health Index (VHI) in Raya And Its Environ, Northern Ethiopia. Environmental Systems Research. Https://Doi.Org/10.1186/S40068-018-0115-Z

Gidey, E., Dikinya, O., Sebego, R., Segosebe, E., & Zenebe, A (2018b) Modeling the Spatio-Temporal Meteorological Drought Characteristics using the Standardized Precipitation Index (SPI) in Raya and its Environment. Earth Systems and Environment 2(2):2006

Gidey, E., Dikinya, O., Sebego, R., Segosebe, E., & Zenebe, A (2018c) Using Drought Indices to Model the Statistical Relationships between Meteorological and Agricultural Drought in Raya and its Environments. Earth Systems and Environment, 0123456789. Https://Doi.Org/10.1007/S41748-018-0055-9

Gidey, T. G (2012) Food Security Policy: Does It Work? Does It Help? Research output: PhD Thesis. University of Twente, Faculty of Geo-Information Science and Earth Observation (ITC)

He, B., Lü, A., Wu, J., Zhao, L., & Liu, M (2011) Drought hazard assessment and spatial characteristics analysis in China. Journal of Geographical Sciences 21(2):235–249

Humi, H., & Zeleke, G (2018) Soil and Water Conservation in Ethiopia (Issue April)

Kenawy, A. M. E. L., McCabe, M. F., & Robaa, S. M (2016) Changes in the Frequency and Severity of Hydrological Droughts over Ethiopia from 1960 to 2013. Cuadernos De Investigación Geográfica 42(1):145–166

Kiros, F. G (1991) Economic Consequences of Drought, Crop Failure and Famine in Ethiopia, 1973-1986. Royal Swedish Academy of Sciences 20(5): 183–185

Lu, H., Mo, X., & Liu, S (2015) Intercomparison of Three Indices for Addressing Drought Variability in North China Plain During 1962 – 2012. Proceedings of the International Association of Hydrological Sciences 366(4): 141–142

Masih, I., Maskey, S., & Trambauer, P (2014) A Review of Droughts on the African Continent: A Geospatial and Long-Term Perspective. Hydrology Earth System Sciences 18(9): 3635–3649
Mavromatis, T (2012) Changes in Exceptional Hydrological and Meteorological Weekly Event Frequencies in Greece. Climatic Change 110(1): 249–267

Mohammed, Y (2018) Meteorological Drought Assessment in North East Highlands of Ethiopia. International Journal of Climate Change Strategies and Management 10(1): 142–160

Santiago Beguería, A Sergio M. Vicente-Serrano, B* F. R. And B. L (2014) Standardized Precipitation Evapotranspiration Index (SPI) Revisited: Parameter Fitting, Evapotranspiration Models, Tools, Datasets and Drought Monitoring. International Journal of Climatology 3023 (December 2013): 3001–3023

Shi, B., Zhu, X., Hu, Y., & Yang, Y (2017) Drought characteristics of Henan province in 1961-2013 based on Standardized Precipitation Evapotranspiration Index. Journal of Geographical Sciences, 27(3), 311–325

Tefera, A. S., & Bello, J. O. A. N. J (2019) Comparative Analyses of SPI and SPEI as Drought Assessment Tools in Tigray Region, Northern Ethiopia. Sn Applied Sciences 1(10): 1–14

The Livelihoods Integration Unit (2010) An Atlas of Ethiopian Livelihoods

Tian, L (2019) Spatial And Temporal Patterns Of Drought in Oklahoma. International Journal of Climatology 39(3): 3365–3378

Vicente-Serrano, S. M., Beguería, S., Lorenzo-Lacruz, J., Camarero, J. J., López-Moreno, J. I., Azorin-Molina, C., Revuelto, J., Morán-Tejeda, E., & Sanchez-Lorenzo, A (2012) Performance of Drought Indices for Ecological, Agricultural, and Hydrological Applications. Earth Interactions 16(10):1-27

Webb, P., & Braum, J (1990) Drought And Food Shortages in Ethiopia: A Preliminary Review of Effects and Policy Implications. International Food Policy Research Institute, March, 176

WMO (2012) Standardized Precipitation Index User Guide. WMO- No. 1090 ; Issue 1090

Yacoub, E., & Tayfur, G (2020) Spatial and Temporal of Variation of Meteorological Drought and Precipitation Trend Analysis over Whole Mauritania. Journal of African Earth Sciences 163(1): 103761

Zarei, A. R (2019) Analysis of Changes Trend in Spatial and Temporal Pattern of Drought over South of Iran using Standardized Precipitation Index (SPEI). Sn Applied Sciences 1(5): 1–14

Zeleke, T. T (2017) Trend and Periodicity of Drought over Ethiopia. International Journal of Climatology 37(13): 4733-4748

Zhang, J., & Shen, Y (2019) Spatio-temporal variations in extreme drought in China during 1961–2015. Journal of Geographical Sciences 29(1): 67–83