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Characterizing Spatiotemporal Patterns of Drought among the Pastoralists of Southern Ethiopia, Eastern Africa

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Abstract

This paper is an inquiry of investigating trends and spatiotemporal patterns of meteorological drought in semi-arid pastoral areas in southern Ethiopia. Monthly gridded rainfall and temperature data for thirty years between 1986 to 2016 were obtained d from Ethiopian Meteorological Agency. Nonparametric Mann Kendall's test (MK) along with Sen's slope estimator was employed to see trends of drought. In addition, Reconnaissance Drought Index (RDI) was used to characterize the drought patterns. The result indicates that under all time scale, drought events tend to show an increasing trend with varying magnitude and intensity. The highest drought severity category for major and small rainy months was identified during May 2000 with RDI= -2.28 and September 2000 with RDI= -2.55 . The drought magnitudes of the small rainy months range from -11.15 in November to -11.76 in September, while it ranges from -10.08 in April to -11.38 in March for the major rainy months. There are some variations of drought magnitude among the seasons while rainfall tend to show gradual decline as a manifestation of spatially varying drought severity, frequency and intensity in the watershed.

Keywords: RDI, Mann Kendall, Drought, Drought trends, Watershed, Guji, Pastoralist

Introduction

Drought is an incessantly happening climatic phenomenon mostly related to the reduction of precipitation (Alok and Anil, 2018) and is time of prolonged below-normal supply of water (Rajib et al., 2013; Ndlovu and Brain, 2011). Although drought happens ubiquitously in the world; the intensity, frequency, severity and impacts vary spatiotemporally. The available estimates on drought impacts suggest that, during the period 1900-2013, there were 642 drought events reported across the world resulting in a huge toll to humanity, killing about 12 million people and affecting over 2 billion (Kiumars et al., 2016). There was a tremendous change in terms of its frequency, severity and geospatial coverage (IPCC, 2007; Shiao and Hsiao 2012 and Mishra and Singh, 2011). To this end, there are number of indications about projection of threats from the drought where the fatalities are also escalating. According to IPCC (2007) report drought is expected to expose between 75-250 million people to water stress by 2020 globally. By 2020, there will be a significant reduction in arable land in Africa, yields from rain-fed agriculture will decline by as much as 50%, which worsens the need of food stuff (Oxfam, 2008).

Due to regional variability of rainfall, countries in Africa face varying drought incidences. The highest spatial and temporal variability of rainfall is found across most of the countries having a semi-arid climate within western, eastern and southern Africa (Misangi, 2014). Kenya has a tropical climate with two rainy seasons, one occurring in March, April and May and the second one in October, November and December (Peter et al., 2001 and Francis et al., 2015). Over 80% of the country falls under arid and semi-arid lands (ASAL) which are prone to droughts International Federation of Red Cross and Red Crescent Societies (IFRCRCS, 2014 and Francis et al., 2015). This can also be largely linked with the differences in intra-annual variability of the rain each region receives. Southern Africa receives most of the rainfall during October–March, whereas Sahel rainfall is concentrated during July-August summer monsoon period

(Mavhura et al., 2013). The countries in the Horn of Africa usually receives rainfall in two seasons; October-December as short rainfall season and March-May a long rainfall season (Gebrehiwot et al., 2011; Georgis, 1997 and Seleshi and Camberlin, 2006). North Western Africa receives most of the rainfall during October to April (Temesgen, 2010).

In African countries there is variability and below average rainfall at regional basis, which gives birth to variation of drought severity and frequencies across the continent (Araya and Stroosnijder, 2011 and Agnew and Chappell, 1999). In the continent alone, the droughts that was occurred in 1972-1973, 1983-1984 and 1991-1992 were most intense and widespread (Masih et al., 2014). Regionally, Northern Africa receives very low rainfall and has a desert climate (Davies et al., 1991) in which the persistent dry years reduced societies coping capacity to droughts. Prolonged droughts were recorded in the recent past in 1999-2002 in northwest Africa and between 1970s-1980s in western Africa (Dembele and Zwart, 2016, Agnew and Chappell, 1999). From 2010-2011, there was drought with varying intensity recorded in eastern Africa (Degefu and Bewket, 2014; Degefu et al., 2017, and Gebrehiwot et al., 2011) and by 2001-2003 in southern and south eastern Africa (Masih et al., 2014 and Oxfam, 2008).

Being a country in the eastern Africa, Ethiopians has been facing different drought incidences with dozens of animal and human deceases. According to Zenebe et al., (2016), despite the fact that Ethiopia has a long history of drought, the frequency and spatial coverage of droughts have increased over the past decades since 1960s. Both the rise in temperature and prolonged deficiency of precipitation are major factors (Yuei and Getachew, 2019). The drought apparently escalated food shortages through declining agricultural productivity in the 1970s and 1980s (Terefe and Mengistu, 2012). The most severe drought Ethiopia faced was the

notorious famines known as *Kifuken*¹, which devastated major areas of the country during 1980s Ethiopian Environmental Authority (EEA, 1998). In the year 2002-2003 a drought resulted from El Niño occurred in Ethiopia which laid an overwhelming impact on the already vulnerable households, particularly in rural communities (Sujakhu et al., 2018). As a very recent history, during the year 2011, about 13.4 million people of the Intergovernmental Authority on Development (IGAD) region including Ethiopia, predominantly pastoralists and agro-pastoralists were affected by drought (Viste et al., 2013; MoA, 2012 and USAID, 2016).

Nowadays, drought incidences put pastoralism and agro-pastoralists livelihoods at high risk (MoA, 2012). During the years 1960-1990s, Ethiopia used to face drought frequencies every eight-ten years (Tsega, 1997), but now the time interval reduced to every five years and even below (Zenebe et al., 2016 and USAID, 2016). As vulnerability continued to increase, the impacts are similarly increasing for both pastoralist and farming community. There is continued failure of harvest far less than the expectations due to an extended extreme dry season and strong rain in the wet season, followed by a prolonged absence of precipitation, which is likely due to a manifestation of global warming (Gebrehiwot et al., 2011 and MoA 2012). The El Niño Southern Oscillation (ENSO) phenomenon hugely impacts Ethiopian rainfall (Peter et al., 2010; Camberlin, 1997 and Woldeamlak and Conway, 2007). It hugely resulted in uncertain drought. For instance, a drought crisis in Ethiopia, triggered by erratic and severely declined rainfall in early 2015, has affected 9.7 million Ethiopians (Roop et al., 2016). This in turn made pastoralism and pastoral livelihoods unsustainable. Moreover, this kind of situation created the cycle of vulnerability and depletes the capability to overcome hunger and poverty (Abate, 2013).

¹ is years of Ethiopian great famine from 1988-1892 which locally known as ‘evil days’

In the very recent time, the drought of 2015/16 also troubled rural population mainly pastoral communities in southern and eastern parts of the country to the large extent. Thus, it is believed that the 2015 drought triggered price increases from August 2015 through to May 2016, with average nominal price increases of 5.7%, 16%, and 15% for maize, sorghum and teff respectively, along with a 22.5% price increase for aggregate pulses (USAID 2016; Roop et al., 2016 and Yonas 2019). Meanwhile, *Guji* pastoralist in Southern Ethiopia, being economically and politically marginalized and already inhabited to drought sensitive environment, continued to live under drought continuum. Diminishing of pasture land and overpopulation reduced adaptive capacity to habitually occurring drought. Most of the drought responses are rarely proactive, building economically coping and adapting pastoralism has been challenging. The provision of pasture and water in very limited amount from their environment were managed through institutionally systematized pool of indigenous knowledge. This knowledge also gradually abandoned due to different pressures both from within and externally. The state plan which aimed to form sedentary life in pastoral area abandoned mobility. This in turn substantially restrained communal resource exploitation tradition that pastoralist used to practice for the time immemorial. The activities of building-up solid resilient pastoral community which easily survive drought and other climate related hazards were not met. Traditionally, pastoralists were defending champions when they used to follow institutionally managed ploy of utilizing scarce resources. Under all this complexities, identifying trends and spatial patterns of drought helps intervene drought incidences and limit impacts. Thus, the aim of this paper is to analyze trends and spatiotemporal variation of drought in Burkitu watershed of Guji zone in southern Ethiopia.

Materials and Methods

Description of the Study Area

Dugda Dawwa Woreda is found in Eastern Guji zone Oromia regional state. It is one of the woredas of the Eastern Guji zone with area coverage of mentioned to be 2180 km². Fincawa is the capital town of the woreda which is located at about 500 km from Addis Ababa and 25 kms from Bule Hora, the capital town of the zone. It is mainly inhabited by pastoralists with very small number of agro-pastoral households. Agro-ecologically, the area is known for its arid and semi-arid climate. The mean maximum and minimum temperature of the area is 27^oc and 17^oc, respectively. The study area receives bimodal rainy season with 60% occurring in the spring (*Ganna*²), which occurs from March to May and in the autumn (*Hagayya*³) reaches the area starting from September-November. The long dry season (*Bona Hagayya*) occurs from December to February in the Winter followed by the short dry season (*Adoolessa*) occurs from June to August in the Summer season. In the district, the average annual rainfall ranges between 350 and 850 mm, with considerable spatial and temporal variability. Inconsistent rainfall results in great variability of forage and range production.

Fig 1 Location Map of the Study Area

² *Ganna* is local name given to the time of relatively long rainy season

³ *Hagayya* is local name to short rainy season

In few areas of the district, agricultural crops like maize, teff, sorghum and haricot beans are produced. It is estimated that 55.4% of the income in the zone is derived from the sale of livestock. The main livestock being reared are cattle, sheep, goats, sheep and camels. Cattle contribute much to the milk for home consumption and butter production used both for consumption and sold at market. Subsistence agriculture also contributes to a lesser extent to food needs in the district. Beside this, bee keeping practice and crop production activities in the high land areas of the district practiced in limited custom. In the very recent time, rearing livestock becoming challenge due to degradation of range land, population pressures, water shortage, recurrent drought and livestock diseases. In addition, petty trades are highly practiced at Finchawa town and few kebeles nearby to the town. Similarly, sale of livestock, production and sale of vegetables, charcoal, firewood, water, minerals (such as gold, marble and granite), incense and natural gum were common in the study area.

Data sources and acquisition

Drought analysis in this paper was holistically focused on investigating trends, magnitude, severity, intensity and spatial pattern in the watershed. Basically, calculations of drought pattern were based on the long-term meteorological data that were acquired from Ethiopian National Meteorological Agency (ENMA) for the year 1986-2016. Therefore, gridded data of rainfall and temperature were taken for thirty years and calculations were made for different time (1-month, seasonal and annual) scales.

Drought Indices

In drought characterization based on its magnitude and spatial analysis, different indices can be used. In the arid climate, Standardize Precipitation Index (SPI) and Reconnaissance Drought Indexes (RDI) are most commonly used. They are recommended to quantify the deficiency of

precipitation at different time scales and across space (Kumar and Anil, 2018; Melaku, 2013; Oloro, 2006 and Alok and Anil, 2018). Often times, SPI criticized for it fails to precisely quantify drought condition of prolonged time over the areas with scarce rainfall. This is due to it solely uses precipitation as an input and not considering temperature and its influences. Others suggest, SPI is computed for shorter-term and intermediate periods to quantify drought in different time steps to represent agricultural/meteorological droughts (Abebe et al., 2020). Thus, SPI is less preferred to be used for drought analysis in the case of extreme droughts (over longer period) occur with same frequency on all locations (Tsakiris and Vangelis, 2005). It can't identify drought prone regions and areas with small seasonal precipitation for the values might be large positive or negative which would be terribly misleading (Jemai et al., 2016). Therefore, in the areas where temperature is high throughout the year and rainfall is inconsistently received annually, RDI is appropriate for it considers potential evapotranspiration (PET). Therefore, RDI is a meteorological index used for drought assessment (Mohammad et al., 2011; Mohammed et al., 2018 and Zarch et al., 2011) and it was developed to analyse water deficit in a more accurate way, as a sort of balance between input and output in a water system (Tsakiris et al., 2007c). Moreover, RDI can be effectively used to compare the drought conditions between areas with different climatic characteristics (Haied et al., 2017). It also has an advantage as it enables universal applicability over the other indices (Haied et al., 2017). By employing monthly or seasonal measures of PET from the general index of meteorological drought, extent of drought spatial pattern and severity for different time scale over the space can be mapped. Therefore, as the area under study is categorized under an arid climate, RDI were used to characterize the drought.

RDI computation

The RDI is expressed in three forms namely, the initial value (αk), normalized RDI (RDI_n) and standardized RDI (RDI_{st}) (Tsakiris and Vangelis, 2005). The initial value (αk) is presented

in an aggregated form using a monthly time scale and be calculated on a monthly, seasonal or annual basis. Concerning the values, positive values of the RDIst indicates wet periods, whereas the negative values indicate dry periods compared with the normal conditions of the area. The computation of RDI was done by using Drinc Software which is based on the ratio of total precipitation (P) to potential evapotranspiration (PET) accumulated over the selected time scale (k). On the annual basis (k=12), we have:

$$\alpha^{(i)} = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}} \quad (1)$$

Where P_{ij} and PET_{ij} the precipitation and potential evapotranspiration of the j-th month of the i-th year.

The standardized RDI is computed by:

$$RDI_{(k)}^{(i)} = \frac{y_{(k)}^{(i)} - \bar{y}_k}{\sigma_{yk}} \quad (2)$$

with $y^{(i)} = \ln(a^{(i)})$, y_k arithmetic mean and σ_{yk} standard deviation.

The Hargreaves equation can be written as:

$$PET = 0.0023Ra (T + 17.8) \sqrt{(T_{\max} - T_{\min})} \quad (3)$$

where PET is the computed reference evapotranspiration (mmd^{-1}); while Ra is the water equivalent of the extraterrestrial radiation (mm d^{-1}). Similarly, $T_{\max}$, $T_{\min}$ and T are the monthly maximum and minimum temperature in ($^{\circ}\text{C}$), with T calculated as the average of

Tmax and Tmin, where 0.0023 is the original empirical coefficient proposed by Hargreaves and Samani in 1985 (Seleshi and Camberlin, 2006).

According to Tsakiris et al., (2015), drought can be grouped in to different category based on the RDI values. An example for development of the α_k relationship and fixing of ranges for drought classes is illustrated for Burkitu watershed in Dugda Dawa district. Using this relationship, the levels of drought have been fixed based on α_k for Burkitu Watershed and given below in the (Table 1).

Table 1: Drought level characterization based on RDI value

Number	Drought category	RDI value
1	No drought	>-0.50
2	Mild drought	-0.50 to -1.0
3	Moderate drought	-1.00 to -1.50
4	Severe drought	-1.50 to -2.0
5	Extreme drought	<-2.0

Source: Alok and Anil, 2018.

Characterizing drought events: Magnitude, Intensity and Severity

The analysis of the drought trend was done using a non-parametric Mann Kendall (MK) test. The rank-based MK test is commonly used to assess the significance of monotonic trends in hydro meteorological time series (Mohammed et al., 2018; Mekonnen and Woldeamlak, 2014 and Tabari, 2011). In the process of computation, determination of trend was run by taking values of Reconnaissance Drought Index (RDI). MK test was used by many researchers for trend detection (Kendall, 1975 and Mohammed et al., 2018). It is widely used to detect trends

of meteorological variables (Mekonnen and Woldeamlak, 2014). It has two advantages and thus preferably used by different researchers. First, MK test does not require the data to be normally distributed and secondly, it has low sensitivity to abrupt breaks due to inhomogeneous time series (Tabari, 2011). It entails an assumption of either increasing or decreasing trend in the element (data). According to this test, the null hypothesis, H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1 , which assumes that there is a trend (Neha, 2012). In the analysis of trends of drought in observed rainfall time-series (1-month, seasonal and annual) was calculated on annual and seasonal basis. The M-K test statistic S is calculated using the following formula:

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

Where, x_i is the data time series ranked from $i = 1, 2, \dots, n-1$; and $j = 2, 3, \dots, n$. Each of the data point x_i was taken as reference point, which is compared with the rest of the data points, x_j :

$$\text{sgn} (x_j - x_i) = \begin{cases} -1 & \text{for } x_j < x_i \\ 0 & \text{for } x_j = x_i \\ 1 & \text{for } x_j > x_i \end{cases} \quad (2)$$

A positive value of S indicates increasing trend, and a negative value indicates decreasing trend. It has been documented that when $n \geq 8$, the statistic S is approximately normally distributed with the mean zero and variance computed as:

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

Where, m is the number of tied groups and t_i is the number of ties in sample i .

The normal test statistic Z_{MK} is computed as:

$$Z_{MK} = \begin{cases} \frac{S-1}{\sqrt{\text{VAR}(S)}}, & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S-1}{\sqrt{\text{VAR}(S)}}, & \text{if } S < 0 \end{cases} \quad (4)$$

The trend is said to be increasing, if ZMK is positive and computed ZMK statistic is greater than the ZMK value corresponding to a desired level of significance (0.01, 0.05 or 0.10); and the trend is said to be decreasing, if ZMK is negative and computed ZMK statistic is greater than the ZMK value corresponding to desired level of significance (Mekonnen and Woldeamlak, 2014). The Sen's slope estimator has been found to be a better and more power tool as compared to simple linear regression to detect the linear trend as it is unaffected by gross data errors and outliers (Kumar and Anil, 2018). The Sen's slope is estimated as the median of all pair-wise slopes between each pair of points in the data set. The pair-wise slope T_{ij} of all data points is computed as:

$$T_{ij} = \frac{x_j - x_i}{j - i} \quad (5)$$

Where, x_j and x_i are data values at the times i and j ($j > i$), respectively. For n values in data set, there will be $N = n(n-1)/2$ number of slope estimates, and the median of these N values of T_{ij} is represented as Sen's estimator of slope (Q_i), which is calculated as:

$$Q_i = T_{(N+1)/2}, \text{ if } N \text{ is odd} \quad (6)$$

And

$$Q_i = 1/2 (T_{N/2} + T_{(N+2)/2}), \text{ if } N \text{ is even} \quad (7)$$

Positive value of Q_i indicates an increasing trend, while a negative value indicates a decreasing trend. In characterising temporal drought events, frequency, severity, magnitude and intensity were computed. In this analysis, drought frequency is a return period between drought events that have negative values of RDI. In Abebe et al (2020) drought magnitude is a drought event corresponds to the cumulative water deficit during the drought period below some threshold (RDI-values ≥ -1) and drought intensity is the ratio between drought magnitude (DM) and duration (DD) of the event given as:

$$DM = -\sum_{i=j}^n RDI_{ij} \quad (8)$$

$$DI = \frac{DM}{Dd} \quad (9)$$

Where: DM is drought magnitude, n =number of months with drought event at j time step, Dd is drought duration.

Mapping spatial distribution of drought incidences

The RDI values produced by DrinC software were used as an input to ArcGIS to generate drought severity maps for the study area at 1, 3 and 12-month time scales. To assess the spatial extent of droughts in the study area, RDI time series values were interpolated by Ordinary Kriging method using the Spatial Analyst tool of ArcGIS. Kriging refers to a surface interpolation technique based on spatially dependent variance (Webster and Oliver, 2007).

Zarch et al., (2011) classified drought severity as no drought >-0.5 , mildly drought -0.5 to -1.0 , moderate drought -1.0 to -1.50 , severely drought -1.50 to -2.00 and extreme drought less than -2.0 .

Result and Discussion

Characterizing Drought Events: Magnitude, Intensity and Severity

In characterizing drought events using RDI, drought conditions for rainy months for different time scale (1-month, 3-month/seasonal and 12-Months/annual) was examined for the period 1986-2016. Varying drought events with different magnitude, intensity and severity were observed (Table 1). Both main and small rainy months had moderate drought intensity category in April with value of $RDI \leq -1.26$ and September with $RDI -1.30$ respectively.

Table 2: Drought event characteristics for rainy months of $RDI \leq -0.5$ values

	Drought	Drought	Drought	Years of observation
Time scale	Magnitude	Intensity	Severity	
March	-11.38	-1.13	-1.67	1986,1992/3/9/00/01/02/04/10/16
April	-10.08	-1.26	-1.99	1986,1992/97/99//00/01/02/04
May	-11.32	-1.25	-2.28	1986,1992/93/95/99/00/01/02/16
September	-11.76	-1.30	-2.55	1986,1992/95/99/00/01/03/10/16
October	-11.64	-1.16	-1.86	1992/3/96/99/00/01/03/09/10/16
November	-11.15	-1.11	-1.82	1992/96/98/99/00/01/03/09/10/16
Spring (Mar-May)	-24.9	-3.55	-2.56	1993/98/01/09/10/12/16
Autumn (Sep-Nov)	-29.87	-4.26	-2.54	1992/99/00/01/03/10/16,
Annual	-11.76	-1.68	-2.55	1991/98/00/2/9/15/16

At 3-months (seasonal) time scale, Spring and Autumn had a total drought severity of -2.56 and -2.54 respectively. For Spring season, March was identified as a month with highest drought frequency and high drought magnitude. Showing little differences among seasons, the drought magnitudes of the small rainy months range from -11.15 in November to -11.76 in September, while it ranges from -10.08 in April to -11.38 in March for the major rainy months.

The total drought events for the main rainy season are relatively lower as compared to the small rainy months. However, for the rain of small rainy months in the region is apparently inconsistent, strong drought with high RDI value is often commonly identified. Thus, duration of drought event is higher for small rainy months than the main rainy months. Annually, the year 2000 showed the highest drought magnitude and severity with RDI value of above -2.0. The highest drought severity category for major and small rainy months was identified for May 2000 with RDI= -2.28 and September 2000 with RDI= -2.55 respectively. Thus, the complexity and persistent drought events for small and main rainy months and seasons played a significant role in determining harvested water and the rate of pasture growth in the area respectively. In April, the severe drought category was identified in the year 2001 and 2016 while extreme drought was observed in the year 2012. At seasonal time scale (3-month), for *belg* (spring), there was a lower drought intensity but higher drought severity as compared to Autumn. Due to the lesser moisture in the months from December to February which proceeds the *belg* season, rain was highly affected as aridity increases in these months which tend to increase drought magnitude and severity. Moreover, the long dry season (*Bona Hagayya*) occurs from December to February play a significant role over the rain pattern in the area. Ostensibly, holding a drought magnitude of -24.9, drought intensity of -3.55 and severity of -2.56, *belg* season of the entire years had experienced spatiotemporally varying drought distribution in the watershed. Cognizant to this, in pastoral zones observed rainfall declines during the *belg* season is reducing the quantity and quality of viable pasturelands (USAID 2012, Oxfam 2008 and Boku 2010).

Temporal drought variation

The drought condition for rainy months (main and small) of thirty years in different time scale, covering the period of 1986-2016 calculated. From the computation, a mix of dry and wet years

has been observed. From the computation, several drought risk incidences with $RDI \leq -1.00$ were detected. For both rainy seasons Spring and Autumn, the year from 1999-2000 was the driest in the history of drought in the study area. For the main rainy months, March, April, and May as well as spring (*belg*) season has shown temporal variation with varying severity and intensity (Fig 2). For instance, May 1986 and 1992 were characterized by severe drought events with $RDI \leq -1.5$ while spring season of 2000 were characterized by extreme drought event. Similarly, in 1-month RDI, March of the year 1986, 2001 and 2004 and April of the year of 1992, 1999 and 2000 shows a drought of severe category respectively. Month of May in 1986 and 1992 showed severe drought while May of the year 2000 identified for extreme drought severity. At seasonal (3-months RDI), the years of 1986 and 2000 showed extreme drought category with little variation in magnitude.

Fig: 2-Month and Seasonal RDI for Spring

Fig: 3-Month and Seasonal RDI for Autumn

RDI for small rainy months also shows some temporal variations. In 1-months RDI for small rainy seasons September of the year 1992 and 2016 identified for severe drought while it showed extreme drought category in the year 2000. Similarly, in the October, for the year 1999, 2003 and 2016 identified as months with severe drought category. In the month of November, only the year 2016 identified for severe drought while season of the small rainy season (Autumn) showed severe drought category in the years 1999, 2000 and 2016. Rain condition for small rainy months and the autumn season is also impacted by the short dry season (*Adoolessa*) occurs from June to August in the area. In sum, temporal variation of drought is slightly higher for small rainy season.

Fig 4: 12-Month (Annual) RDI

RDI for annual time scale shows some temporal variations with relatively exceeding magnitude and intensity than that of 1-month and seasonal time steps. Severe drought once happened in 1991 and didn't happen since 1998. In the 1998, rainfall started to readily decline and resulted to the occurrence of extreme drought in 1999 which stayed for two years until it ends in eventually in 2002. In the very recent time, the drought of 2015/16 was a disasterous in its kind which killed majority of livestock in the pastoral areas of southern Ethiopia mainly Guji, Borana, Gari and some Somali districts. Due to the absence of the rain in the main rainy season of the area, in the year 2016 severe drought was seriously hit the area and almost much of the harvested water was dried up and pasture scarcity prevailed. Evidently, the small rainy seasons that expected to reach the area in September of the year 1991/2 was lately arrived and resulted in severe drought which affected crop production that produced in some parts of the watershed mainly upper part.

Drought Trends

Table 3. Mann-Kendall's trend test for the rainy months of 1, 3 and 12-months timescale

Timescale	Months	MK test	Slope
1-Month	March	1.16	0.022
	April	1.46	0.031
	May	1.50	0.039
	September	1.33	0.027
	October	0.41	0.009
	November	0.07	0.003
3-Months	Spring (March-May)	1.27	0.025
	Autumn (September-November)	0.56	0.015
12-Months	January-December	0.95	0.01

Trends of the drought was examined using Mann Kendall and Sen Slope estimator for the years between 1986-2016. Incidences of drought trends for the small and big rainy months (RDI-1) and seasons (RDI-3 and RDI-12) timescales were shown in (Table 3). The Mann-Kendall trend test of RDI-values for all 1-months, 3-months and 12-months tends to shows a tendency of increasing trend. From the computation, it can be identified as very severe drought is occurring every 3-5 years and stay for two years. As compared to severe drought, the frequency of extreme drought is relatively low for both seasonal and annual time scale. For 1-month and seasonal time scale, the magnitude and intensities of drought incidences are increasing while its repeating period is witnessing gradually shortening. Evidence from Borana pastoralists also suggests that drought cycles have shortened from 5-10 years to 3-5 years (Boku 2010 and Oxfam 2010). In most pastoralist inhabiting parts of southern Ethiopia, drought is repeatedly occurring and highly influencing growth of pasture and water availability. Within the watershed alone, the spatiotemporal variability continued to affect pastoralist livelihood, pasture growth and water availability as the matter of degree of the stress. Water and pasture scarcity is already becoming a daily witness in the area which gave birth to the death of livestock and livelihood insecurity and calls for better interventions. Abbarufa (2011) highlighted that, previously drought has occurred once in Gada period (every eight years) and recently however, its magnitude and frequency is increasing from time to time (Bekele 2013). In pastoral communities of Ethiopia, climate-induced shocks such as droughts, rising temperature and irregular rainfall, reduced the availability of pasture areas and negatively impacted water availability and led to animal deaths owing to hunger and diseases (Angasse & Oba 2007 and Boku 2008).

As it was mentioned earlier, it was examined that, the year 1999-2000/1 was the years with extreme drought over -2.0 which led to over 80% of livestock death Angasse & Oba (2007) in

Borana and Guji pastoral areas. Similarly, the years from 1991-1992 and 2015 identified as the time of severe drought in the area. In Burkitu Watershed in particular and pastoral nearby in general, the drought of 2015/16 alone resulted in number of livestock death. During such droughts, most of pastoralists lost their entire livestock because of the stresses associated with impacts of drought, forage/grasses and water scarcity (Hesse and MacGregor, 2006). A survey conducted in southern pastoral areas in 2009 found that drought occurred in the district every 1-2 years, compared to every 6-8 years in the past, evidence that the area is vulnerable to stresses related to Droughts (Riché et al., 2009).

Mapping spatial patterns of drought incidences

Fig 5: Spatial pattern of 1-month and 3-month (Spring Season) RDI

Thirty years (1986-2016) RDI was calculated and different classes of drought categories that varying spatially within the watershed unit (upper, middle and bottom) was identified. Within the watershed, 1-month (March, April and May) and 3-months Spring (*Belg*) RDI shows spatially varying in terms of magnitude, severity and spatial coverage. For 1-month and seasonal time scale, a drought varying from moderate to extreme category was observed. April

was identified for severe drought that unevenly distributed across watershed unit. Similarly, month of May has shown extreme drought in central (middle) and upper parts of the watershed while few parts of southern tip and pocket areas in the uper part tend to posess moderate drought. *Belg* season shows severe drought category that covers al most whole parts of the watershed where extreme and moderate drought category was identified in few pocket areas of the watershed. In sum, for both 1-month and seasonal time scale, extreme drought incidences was observed.

Fig 6: Spatial pattern of 1-month and 3-month (Autumn Season) RDI

For the small rainy season *Tseday* (Autumn), RDI of 1-month (September, October and November) and 3-month season also calculated. In 1-month RDI, Septemebr was observed as a month with moderate drought category that covered majority of the watershed unit while October is the month with severe drought category that nearly covered the whole watershed unit (Fig 6). During November, the whole areas of the watershed identified to exhibit only moderate and severe drought category. At seasonal time scale, a drought of varying severity category from moderate to extreme was identified across different watershed unit with varying magnitude. Large areas of the watershed was covered by severe drough while few areas of the

watershed experienced extreme drought. In comparative view, Autumn shown the lowest extreme drought as compared to Spring due to the fact *Belg* rainfall was highly influenced by long dry seasons *Bega* (winter) which takes place from December to February. However, it was observed that *Belg* season identified for its relatively low drought frequency of only 16.6% of the total drought years while *Tseday* (Autumn) appeared to relatively have higher drought frequency of about 23.3% of the total years.

Fig 7: Spatial pattern of 12-month (Annual) RDI

Conclusions

Within the watershed, both annual and seasonal distribution of drought found to be varying over the space and time. Being a long rainy season of the area, spring identified as season with extreme drought in 2001, 2002 and 2012-2013, which resulted from the influence of long dry winter season. Severe drought was observed in the years from 1986-1987, 1992, 1993, 2000 and 2004. In the year from 1986-2016, about 240 and 336 months were identified as months with extreme and severe drought respectively receiving rainfall below the mean of the observed years. Moderate and severe drought incidents occur more frequently as compared to the other

drought category. With gradually declining trend of rainfall in the season, a varying drought frequency, intensity and magnitude were revealed in the watershed. Currently, changes in the intensity and frequency of drought events have significantly impacted pastoral society and their livelihood through determining water and pasture availability. Agro-ecologically and temporally varying drought events tends to weaken pastoralists' adaptive strategies where the drought of 2015/16, alone caused toll of death of their livestock due to severe drought in the area.

Declarations

Availability of data and materials: the data used or analyzed during the study are available from the corresponding author upon reasonable requests.

Competing Interests: The authors declare that they have no competing interests in this section

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Authors contribution: The corresponding author contributed in data gathering, analysis and interpretation. The coauthors contributed in commenting and reframing the content of the research.

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List of Abbreviations

MoA; Ministry of Agriculture

EEA: Ethiopian Environmental Authority

USAID: Unite States Agency for International Development

ENSO: El Niño Southern Oscillation

RDI: Reconnaissance Drought Index

SPI: Standardized Precipitation Index

ASAL: Arid and Semi-Arid Lands

IFRCRCS: International Federation of Red Cross and Red Crescent Societies

ENMA: Ethiopian National Meteorological Agency

PET: Potential Evapotranspiration

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Figures

Figure 1

Location Map of the Study Area Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 2

Month and Seasonal RDI for Spring

Figure 3

Month and Seasonal RDI for Autumn

Figure 4

Month (Annual) RDI

Figure 5

Spatial pattern of 1-month and 3-month (Spring Season) RDI Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 6

Spatial pattern of 1-month and 3-month (Autumn Season) RDI Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

Figure 7

Spatial pattern of 12-month (Annual) RDI Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.