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Full-Length Research Article

Analyzing Drought Conditions, Interventions and Mapping of Vulnerable Areas using NDVI and SPI Indices in Eastern Ethiopia, Somali Region

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ABSTRACT

Analysis of a long-term temporal and spatial drought conditions in Somali region was done using Standardized Precipitation Index (SPI) and Coefficient of Variation (CV) for 6 meteorological stations and Normalized Difference Vegetation Index (NDVI) analysis were performed by enhancing images from Landsat 5 TM of two different years. CV was computed for Belg season, Deyr season and yearly basis. Rainfall variability for Belg and Deyr was higher than annual variability. Characterization of the temporal variation of drought using 3-months and 6-months SPI for each meteorological station were analyzed and plotted against long time series in yearly basis. The NDVI values and SPI indices were able to show extent and variability of drought. The 3-months SPI results revealed that maximum frequency of severe drought events were experienced in Gode (7 times), followed by Hurso (6 times) within the study period. The 6-months SPI results show that less frequency of dry and wet events were observed in the entire study period as compared to 3-months SPI results. The frequency of any drought events (moderate to extreme) occurrence in the study area is once in every two years at all stations. Whereas, severe and extreme drought event in majority of study area is commenced nearly once in three years with the exception of Degahabur having once in five years. Overall, a preliminary comparison between results obtained using the SPI and NDVI shows a general good agreements.

Keywords: Drought Analysis, CV, SPI, NDVI

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1. INTRODUCTION

Drought damages national economy, especially agriculture and water resources. Ethiopia is one of the worst drought affected countries in Africa (NMSA, 1996b). There have been reports of rainfall variability and occurrence of drought in northern, eastern and south eastern part of Ethiopia (Tilahun, 2006; Araya and Stroosnijder, 2011; Yemenu and Chemeda, 2010;). In the rural community of Somali region, drought was cited as the number one risk to people's livelihoods affecting every aspect of their activities (Devereux, 2006). Therefore, as described by Tadesse *et al*. (2008), reducing the impact of drought and famine remains a challenge despite ongoing drought relief assistance in recent decades. This is because drought and famine are primarily addressed through a crisis management approach when a disaster occurs, rather than stressing preparedness and risk management. Even though, these drought-related studies have been conducted so far in some portions of Ethiopia, no due emphasis has been given to relate drought indices and NDVI in Eastern part of the country. Though the region is prone to recurrent drought, drought characteristics are poorly understood in the region. Thus, for a developing country like Ethiopia particularly Somali region, delineating drought vulnerable areas using GIS spatial analysis for regular monitoring of the vegetation status, climatic, and socioeconomic condition of people is necessary. This information can be effectively and accurately handled with GIS Spatial analysis. Similarly, analyzing interventions in these drought prone areas is essential. The goal is to make the system available to all stakeholders in the region including government agencies, research institutions, NGOs and the global research community. It may be used as a drought-monitoring tool and as a tool for decision support in regional drought assessment and management.

Objectives

The study was conducted with the main objective of integrating enhanced satellite imagery with meteorological drought indices for delineating drought vulnerable areas in Somali region in terms of its characteristics (intensity, duration, magnitude, frequency, severity and spatial extent) and analyzing interferences of different stakeholders. The specific objectives were (1) to determine spatial characteristics of drought (drought return period and area cover) using SPI and NDV and

(2) to assess and evaluate pre and post drought interventions and implementation of early warning systems.

2. MATERIALS AND METHODS

2.1 Description of Study Area

The study area, Somalia region, is geographically located in eastern and southeastern parts of Ethiopia between 4º and 11º N latitudes and between 40º and 48º E longitudes with a population of 4,445,219 (CSA, 2007).

Most part of the area is arid and semi-arid together with low rainfall amount in each season which makes them vulnerable to drought. Under normal conditions, the region obtains rainfall twice a year–during *Belg* season (March–June), and during *Deyr* season (October–December) (Funk *et al*., 2012).

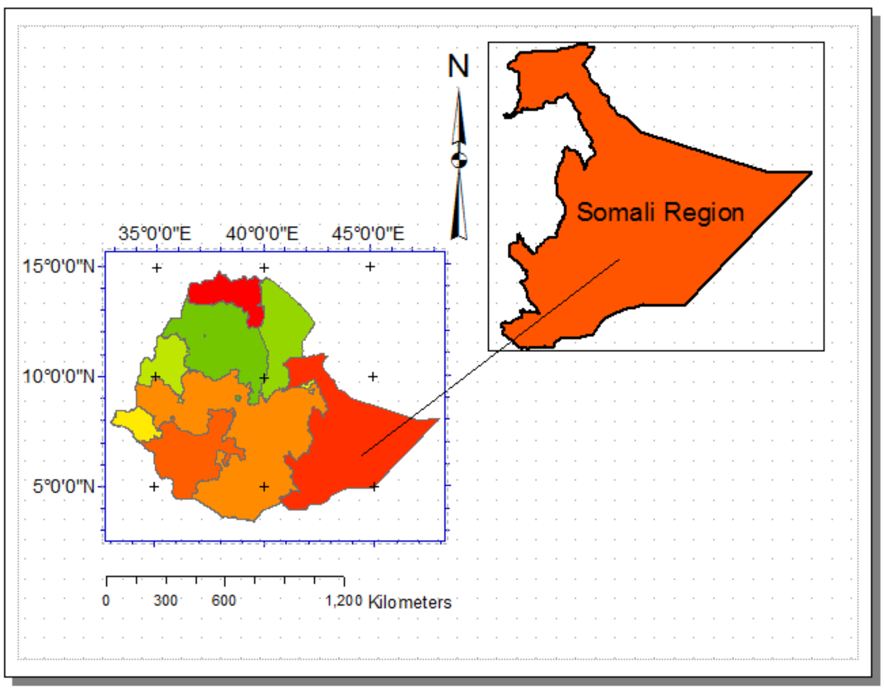


Figure 5. Location of the Study Area

2.2 Data Collection

Long year monthly rainfall data of different stations have been used as shown in Table 1.

Table 2. Rainfall data used for analysis

SN	Station Name	Lat (deg)	Lon (deg)	Period of data		Total
				Beginning	End year	
1	Degahabur	8.22	43.55	1980	2013	34
2	Dire Dawa	9.6	41.85	1980	2013	34
3	Gode	5.9	43.58	1980	2013	34
4	Hursso	9.62	41.63	1980	2007	28
5	Meiso	9.23	40.75	1991	2007	17
6	Gurusum	9.35	42.38	1980	2007	28

The missing data for all meteorological stations (Table 2) were filled using long year monthly average values.

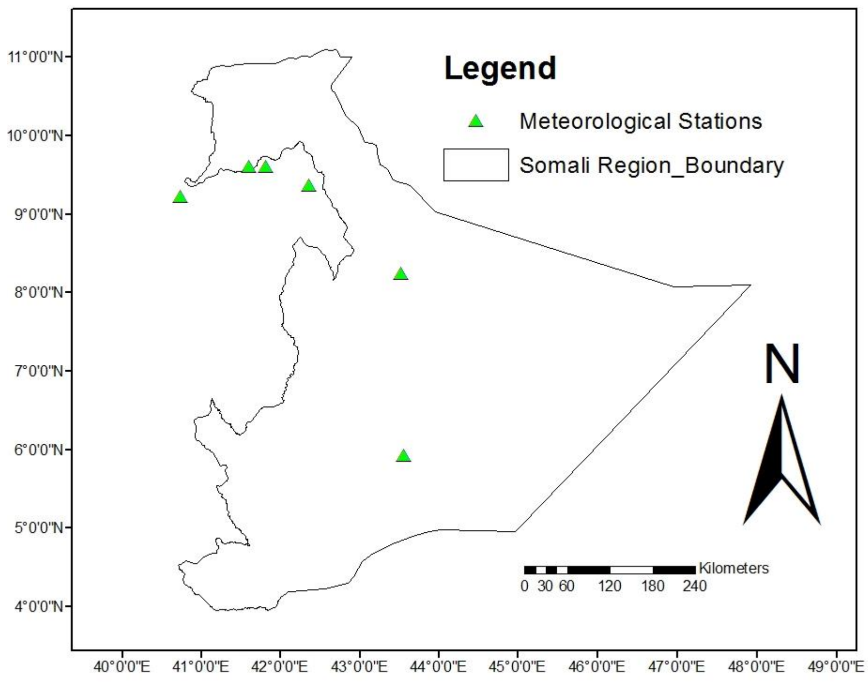


Figure 6. Location of selected meteorological stations

Landsat 4-5 TM satellite images of 30m spatial resolution were downloaded from http://earthexplorer.usgs.gov/. The selection of images temporal domain was done based on the analysis of metrological rainfall data which showed a poor rainfall amount from December 1999 to January 2000 and a good rainfall amount from December 1998 to January 1999.

However, some images were also used outside these intervals (see table 2) due to data unavailability of good and cloud free image.

Table 3. The nearest cloud free Images used for the year 1999-2000 and 1998-1999.

Path	Row	Image used
166	57	16 Jan, 1995*
167	56	23 Jan, 1995*
167	57	23 Jan, 1995*
167	58	23 Jan, 1995*
166	54	5 Feb, 1985**
166	55	20 Jan, 1985**
166	57	5 Feb, 1985**
167	56	22 Dec, 1994**
167	57	12 Feb, 1985**
167	58	22 Dec, 1994**

** For the year 1999-2000 and ** for the year 1998-1999*

Data of drought early warning and dissemination of this information was obtained from Somali Regional State Disaster Prevention & Preparedness Bureau (DPPB). Interviews and group discussions regarding drought early warning and post drought interventions were conducted in some pastoral and agro-pastoral areas of Jijjiga woreda and pastoral areas of Shinile Woreda. In addition, reaction and intention of drought victims to drought interventions and inventory of indigenous knowledge in forecasting and mitigating drought were collected by having interviews with randomly selected key informants from the entire study area.

2.3 Data Analysis

2.3.1 Drought characterization using SPI

The monthly values of SPI were computed using the software spi_sl_6 for each station at two time-scales (3 and 6-months). Then, the long years time series versus SPI values were plotted for different stations. The drought events at each time scale were characterized with magnitude, duration (onset and end times), intensity, frequency and areal extent of droughts.

Selection of the time scale were done based on the information obtained from the pastoralists and usually the rain has to come at least every 6 month to avoid loss of life and asset. Therefore, the 3-month time scale were used for better characterization of a short duration rainfall and 6-months SPI result indicate relatively a long duration of drought characteristics. Table 3 indicates the drought category classification based on SPI values. In addition, coefficient of variation was also used to characterize the annual rainfall variability and during the Belg and Deyr season.

Table 4 Drought category based on SPI values (Vermes, 1999)

SPIclasses	Period classification
SPI ≤ -2	Extremely dry
-2 < SPI ≤ -1.5	Severely dry
-1.5 < SPI ≤ -1	Moderately dry
-1 < SPI ≤ 1	Near normal
1 < SPI ≤ 1.5	Moderately wet
1.5 < SPI≤ 2	Very wet
SPI > 2	Extremely wet

2.3.2 NDVI Analysis using Landsat

A total of 24 scenes were used which covers the entire study area. Image reclassification, stacking and mosaic tools were used to preprocess all the images. The NDVI values were then computed in the ARCGIS software extension based on the formula given in equation 1 (Aranha et al., 2008).

$$\mathbf{NDVI = \frac{NIR - RED}{NIR + RED}} \qquad \mathbf{1}$$

In Landsat 4-5 Thematic Mapper (TM), Band 3 belongs to Red waveband and Band 4 belongs to Near Infrared (NIR) waveband. Water has an NDVI value less than 0, bare soil between 0 and 0.1, and vegetation over 0.1. The more closer the value to +1 means the greener the vegetation (Tan et al., 2010).

Finally, the result of NDVI and SPI were used for analyzing and mapping of drought vulnerable areas in the region and for comparing the results between the two drought indices.

3. RESULTS AND DISCUSSIONS

3.1 Rainfall Variability

The coefficient of variation of rainfall, defined as the standard deviation divided by the average areal rainfall (Wong et al., 2009), was used to characterize the annual rainfall variability for all stations. As mentioned in Kisaka et al. (2015), CV value greater than 30% shows high rainfall variability. The maximum annual CV value of 42.26% was recorded at Gode, whereas, the minimum value, of 24.7% was observed in Meiso station. In Gode and Degahabur stations, large annual variability of rainfall amounts and distributional patterns are observed as compared to the other stations. The maximum CV (122%) of deyr was recorded at Gursum, whereas, the maximum CV (53%) of Belg season was recorded at Degahabur station. Minimum CV for Deyr and Belg seasons were recorded at Gode and Gursum respectively. In General, extremely higher seasonal variability of rainfall (75.28 to 122.22%) is observed in months of October to December at all stations where as it is relatively lower in Belg season (38-52%) as compared to Deyr season ranges between 75.28 to 122.22%. This result is agreed with the finding of Seleshi and Zanke (2004) that the annual and seasonal rainfalls in Ethiopia were highly variable with CV values ranging between 0.1 and 0.50. The annual rainfall variability in terms of CV in all stations is given in Table 4.

Table 5. Coefficient of Variation (CV) and mean annual rainfall for different stations (%)

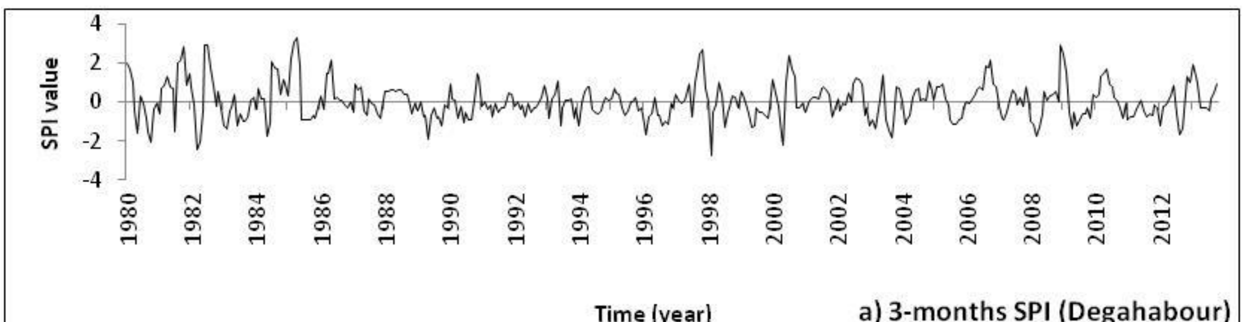
Lat (deg)	Lon (deg)	Station	Average Annual RF (mm)	Annual CV (%)	CV-Deyr	CV-Belg	Year
8.22	43.55	Degahabur	359.45	39.66	112.22	52.98	1980-2013
9.6	41.85	Dire Dawa	647.14	22.74	103.01	41.93	1980-2013
5.9	43.58	Gode	233.65	42.26	75.28	42.17	1980-2013
9.62	41.63	Hurso	565.78	29.68	80.37	43.33	1980-2007
9.23	40.75	Meisso	749.83	28.93	90.21	46.06	1991-2007
9.35	42.38	Gursum	823.74	24.77	122.29	38.91	1980-2007

3.2 Drought Characterization using SPI

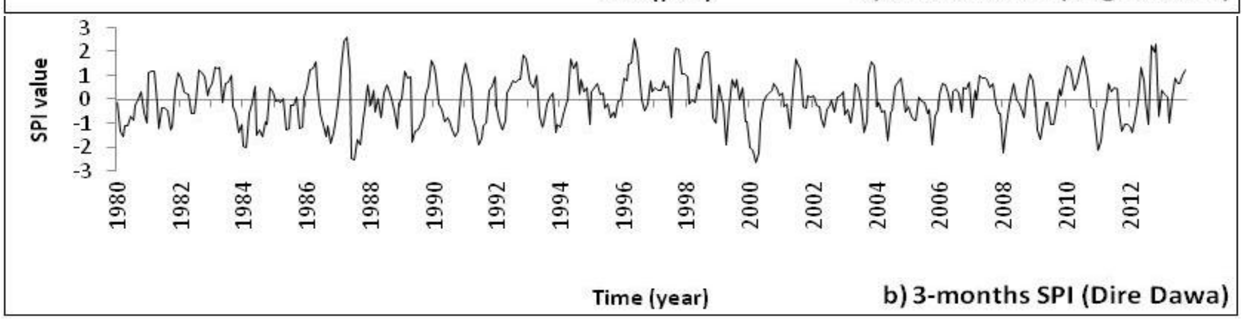
A) 3-Months SPI

The 3-months SPI at all stations indicated that a high frequency of dry and wet spells were observed throughout the study period (Figure 3).

Severe drought and above event were frequently recorded in Degahabour (November and December 1980, May and June 1982, June and July 2000), Dire Dawa (March and April 1984, August to November 1987, March to June 2000, March and April 2011), Gode (May, June, October and November 1980, April to July 1984, April to June 1993, April to June 2001, November and December 2010, November and December 2012), Gursum (March to August 1984, May to July 1986, April and May 1988) and Hurso (March and April 1984, August to November 1984, March to May 1985, March to May 2000, September and October 2004, April to June 2005). Hurso station was hit by more than 11times short duration of dry spells between the periods of 1980-2005. In general, Gode area was experienced a maximum frequency (7 times) of severe and above drought event and followed by Hurso (6 times) and the rest (Degahabour, Dire Dawa and Gursum) encounters 3 times within the study period.



a) 3-months SPI (Degahabour)



b) 3-months SPI (Dire Dawa)

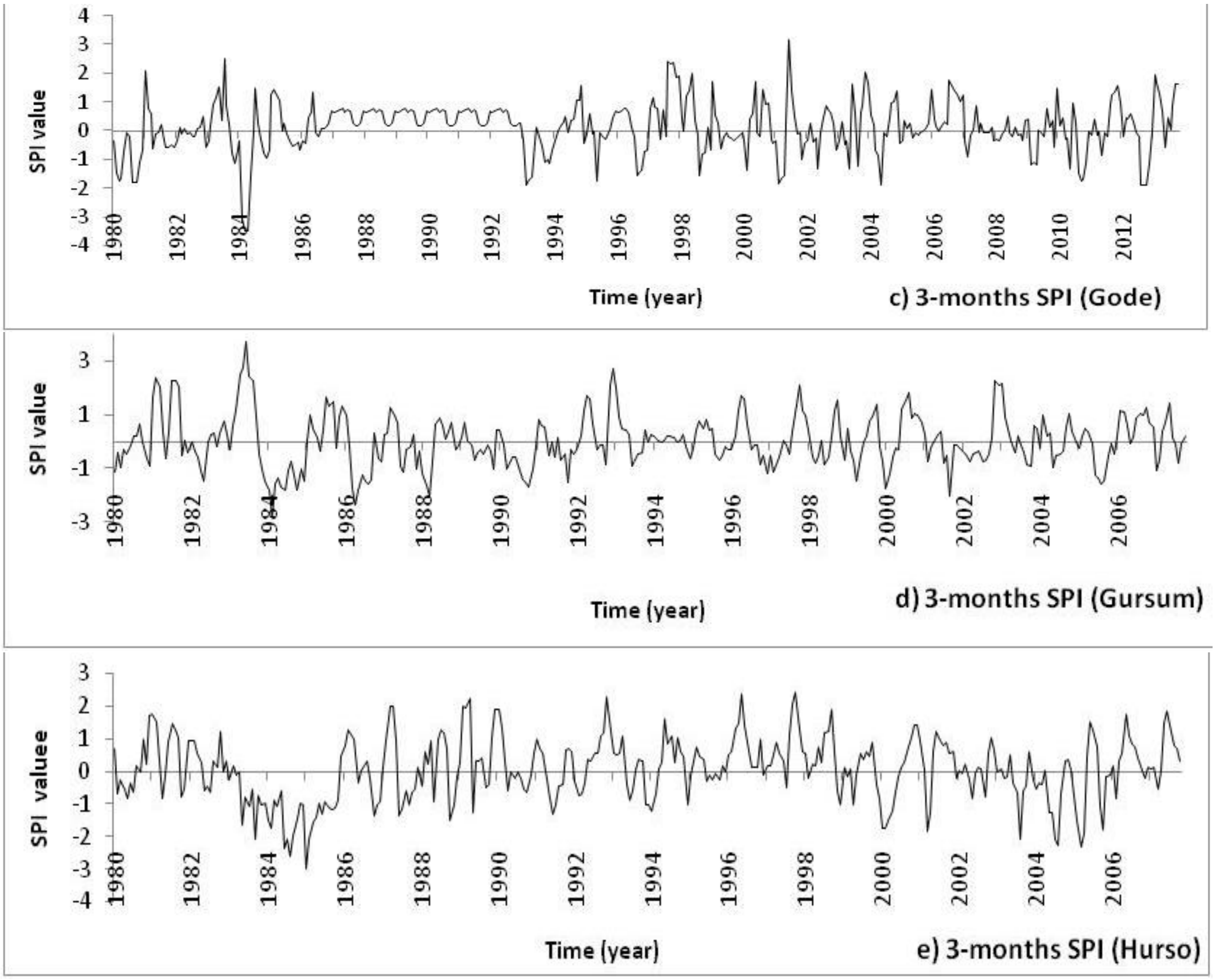


Figure 7: Plot of 3-months SPI for a) Degahabour b) Dire Dawa c) Gode d) Gursum e) Hurso

B) 6-Months SPI

As the time scale is increasing, less frequency of dry and wet periods were observed in the entire study period as compared to a 3-month SPI results. For this study, a detail analysis of 6-months' time scale was considered for characterizing the long drought events.

Degahabur

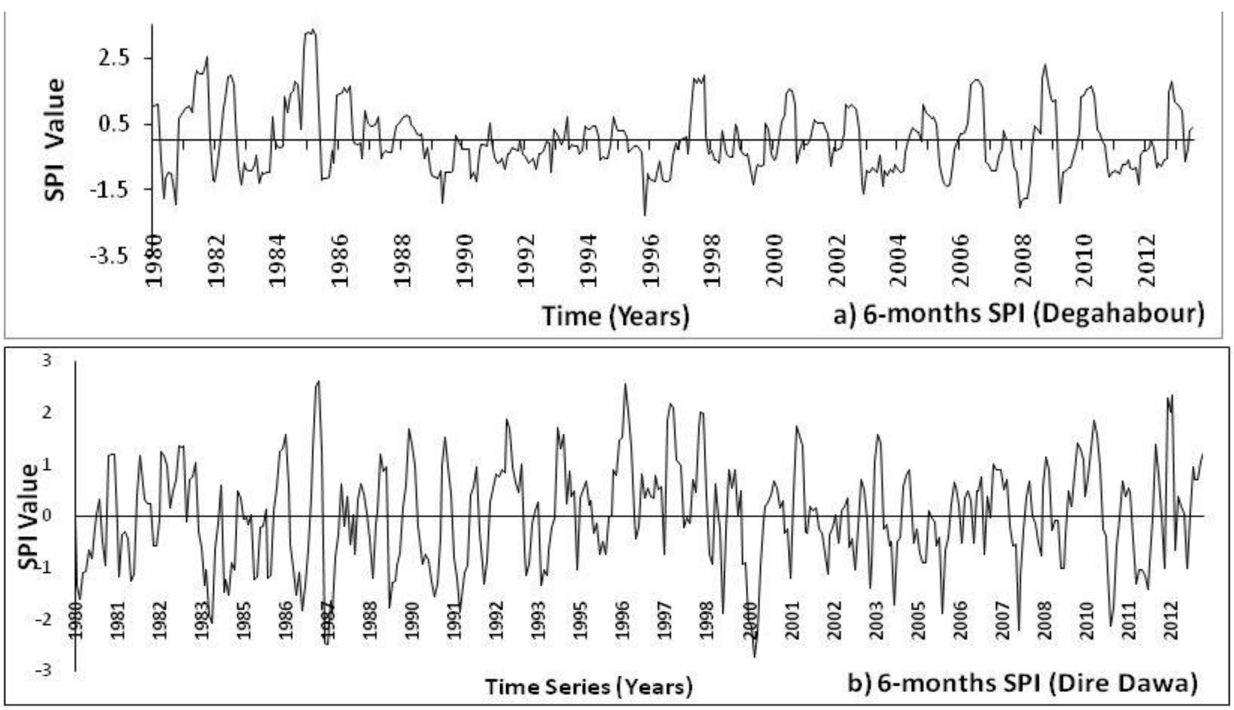
An extreme dry events was sustained only for a months by the year of 1996 (April) and 2008 (May). Moderate drought events were recorded in 1980 (September and October) and its effect was extended with severe drought events until the months of February and March 1981. Furthermore, moderately drought event for consecutive years of 1985 (November and December) and 1986 (January and February), and extended drought events by the year of 1996 for 7 successive months (May-December) were recorded.

Extremely wet events were observed from November 1981 to March 1982; and from April 1985 to end of September 1985 with SPI value ranges between 2.77 to 3.3. This might results in excess floods in Degahabour area. Furthermore, a very wet season for six consecutive months were recorded from October 2006 to end of March 2007.

The total amount of annual rainfall during these years was 161.4 and 218.3 mm respectively. As shown in the Figure 4, the near normal event (neither dry nor wet) were observed from the beginning of 1989 to the middle of 1997 with SPI value ranges between -1 to 1.

Dire Dawa

Extreme drought (SPI <-2) conditions were recorded during 1984 (March and April), 1987 (November and December) and 2000 (April to August) in Dire Dawa area and several extreme dry events also commenced between 1980's and 2013's. In addition, severe drought



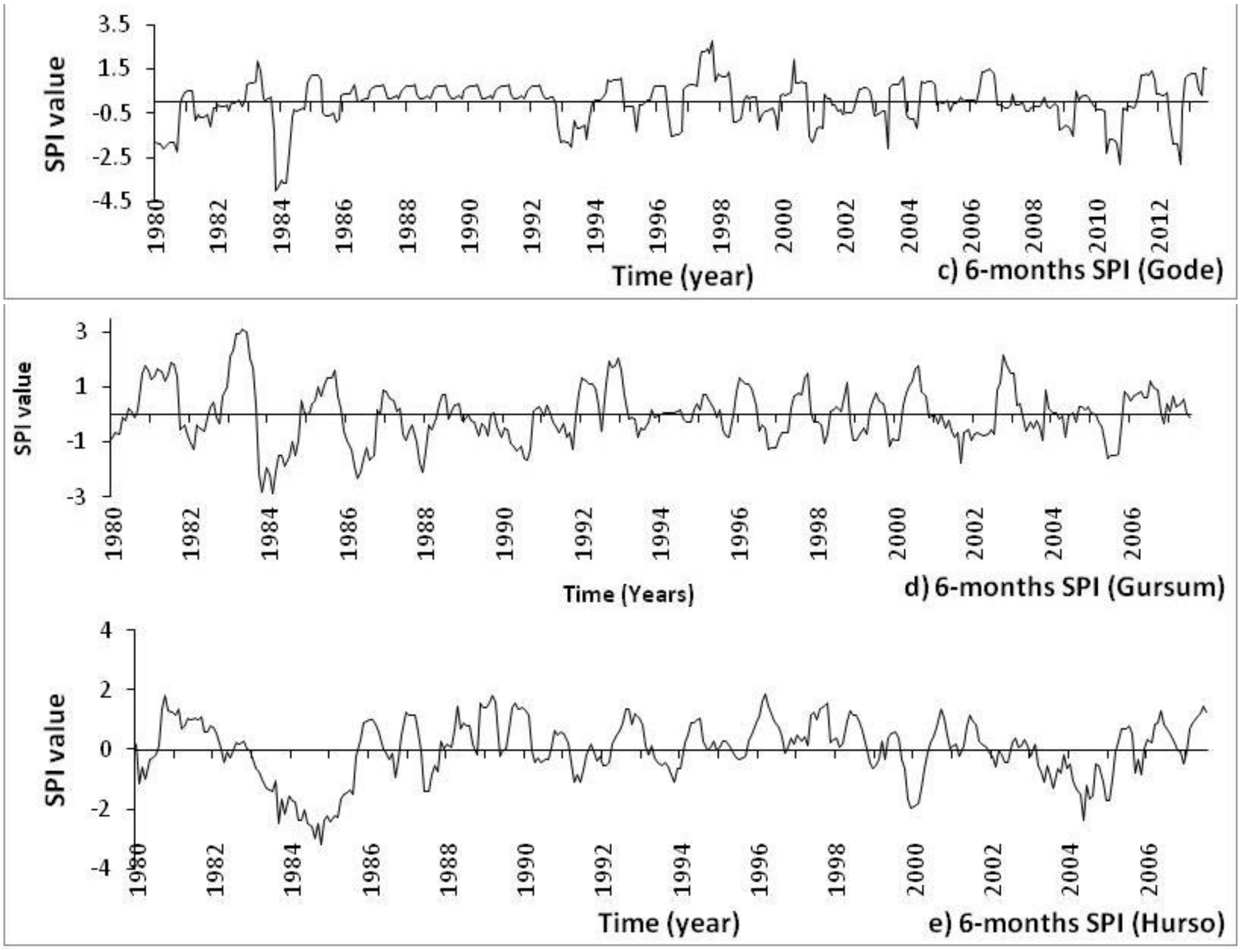


Figure 8: Plot of 6-months SPI for a) Degahabour b) Dire Dawa c) Gode d) Gursum e) Hurso

events (-2 < SPI < -1.5) in 1980 (July to Septemeber), 1991 (October and November), 2010 (September and October) and 2011 (September and October) were commenced for consecutive months.

Extreme wet events (SPI >2) for consecutive 3months were recorded in 1996 *Kiremt* season (July to September) and 1998 *Belg* season (January to March) which might result in flooding. Furthermore, a very wet events (1.5 < SPI < 2) in 1983 (August and September), 1987 (May to August), 1997 (October and November), 2010 (January to April), 2012 (May to December) and 2013 (November and December) was observed. Therefore, during those wet events, vegetation covers is expected to be enhanced.

Gode

Figure 4 shows that, extended extreme drought conditions which was led to a famine was observed having an SPI value ranges between -3.6 and -3.99 from April to September 1984. Besides, a severe dry event in 1980 (June to December), 1993 (May to July), 1996 (November and December), 2010 (November and December), 2011 (January and February) and 2012 (November and December) were observed. This result is further verified with findings of the analysis of total annual rainfall records during 1984 and 2011, which was 70.8 and 310 mm, respectively. However, the minimum total annual rainfall of 40.2 and 65 mm was recorded during 1980 and 1993 respectively.

In contrast, a very wet events in 2013 (November and December); and an extreme wet events in 1997 last two months of the year and the first three months of 1998 were observed.

Gursum

Like other parts of the study area, the Gursum area was also suffered by extreme drought events from March to August 1984 and severe drought event were commenced for two successive months of November and December. Furthermore, this severe drought event was also recorded during January and February 1987. Whereas, extreme wet season was experienced in 1983 for about 7month periods (June to December).

The Gursum station which is expected to cover Jigjiga woreda of Somali region, the maximum annual rainfall of 1564.3 mm was observed during 1983 with SPI value of 3.12. Whereas, the minimum rainfall of 360.1 mm was recorded during 1984, with SPI value of -2.88.

Hurso

As a result of the SPI analysis indicated that an extreme drought event observed in 1984 (November and December) and 1985 (June and July). Meanwhile, the severe drought events were recorded both in 1984 and 2000 from June to August. Besides, a moderate drought event for more than six times observed between 1984 and 1994.

Meisso

Though the number of available data considered for analyzing drought conditions using SPI software was less than 30 years, it is quite insufficient to indicate the exact trends of drought for *Meisso* area. The month with maximum rainfall was recorded during 1996 with SPI value of 2.89.

Furthermore, the driest month was observed during 1992 with SPI value of -2.21. Longest drought periods were observed for the whole year of 1992, from start of 2002 to the start of 2003 and from the mid of 1993 to the mid of 1994.

3.2.1 Drought Frequency and Intensity

The frequency of any drought events (moderate to extreme droughts) occurrence in the study area is once in every two years at all stations. Whereas, severe and extreme drought event in majority of study area is commenced nearly once in three years with the exception of Degahabur having once in five years (Table 5).

Table 6: Frequency of drought occurrence based on SPI-6 time scale.

Stations	Total years used	Moderate to Extreme dry (%)	Years occurred (moderate to extreme)	Ratio*	Years occurred (Severe to Extreme)	Severe and Extreme Drought (%)	Ratio**
Degahabur	34	58.82	20	1:1.7	7	20.59	1:5
Dire Dawa	34	52.94	18	1:1.9	11	32.35	1:3
Gode	34	52.94	18	1:1.9	13	38.24	1:2.6
Gursum	28	53.57	15	1:1.9	10	35.71	1:2.8
Hurso	28	57.14	16	1:1.8	9	32.14	1:3
Meisso	17	52.94	9	1:1.9	6	35.29	1:3

A maximum drought magnitude of 20.65 recorded in Gode while a minimum of 7.41 were recorded in Degahabur with the drought intensity of 3.44 and 1.85, respectively. Meanwhile, a drought magnitude of 17.48, 12.86, 11.28 and 6.19 were observed in Gursum, Dire Dawa, Hurso and Meisso with intensities of 2.19, 2.57, 2.26 and 2.06, respectively.

3.3 Drought Characterization using NDVI Results

As mentioned in Tan et al., (2010), the NDVI value is greater than 0.1 for normal healthy vegetation, while for rock and soil, the NDVI values are close to zero, and water bodies give a negative reading for the NDVI value. For computing the area of each cell covered with either water, bare soil or vegetation, the raster file of the NDVI was converted to shape file in ARCGIS extension tools.

As shown in Figure 5 and 6, the areal coverage of vegetation was larger during best rainfall season than poor rainfall season which coincides with the general truth that as moisture availability increases greenness of an area also increases. During the poor rainfall season (Figure 5, left), the total area covered by vegetation was only 1,973,843.64ha and the areal extent of bare land (sparse vegetation) was 20,070,272.16 ha. Whereas, the area covered by Sand was 6,033,421.26 ha. For the good rainfall season (Figure 5, right), the total area covered by vegetation was 12,147,800ha. The areal extent of bare land (sparse vegetation) was 6,524,850ha. Whereas, the area covered by sand was 9,134,670ha. As we can see from the spatial distribution of NDVI Maps, the vegetation cover (NDVI) was increased by 515.5%, whereas extent of bare land area was decreased by 67.5%.

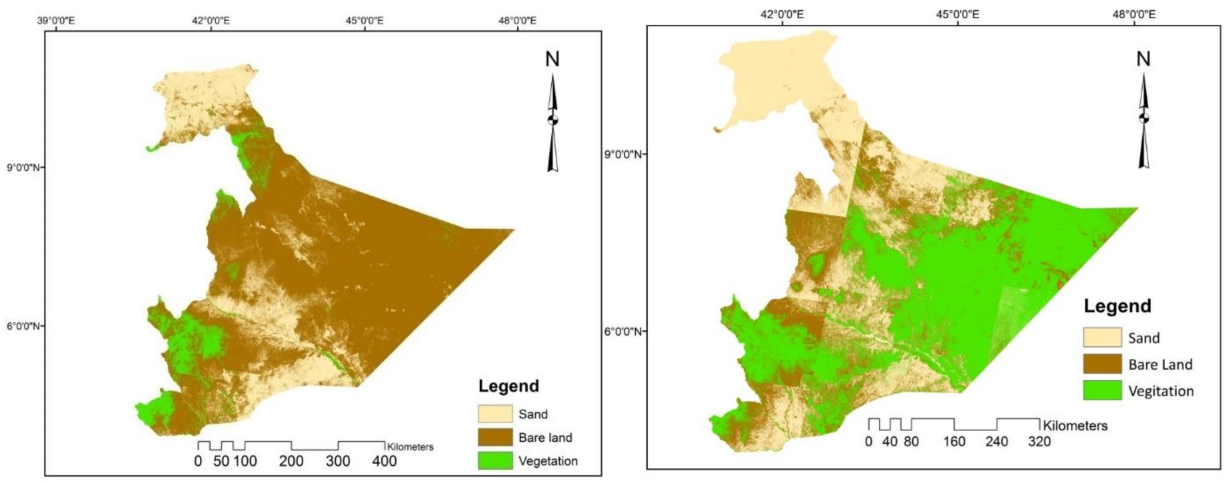


Figure 9. NDVI values for poor rainfall year (2000) (left) and good rainfall year (1998) (right)

3.4 Drought Early Warning and Post Drought Interventions

3.4.1 Drought early warning

The source of information for drought (climate prediction) as obtained from Somali Disaster Prevention and Preparedness Commission (SDPPC) comes from

1. Early Warning and Response Directorate (EWRD), Disaster Risk Management and Food Security Sector (DRMFSS) of MOA
2. Weekly Weather Hazards Summary from USAID funded Famine Early Warning Systems Network (FEWS NET)

3. Weekly bullets from National Oceanic and Atmospheric Administration (NOAA), Climate Prediction Center's Africa Hazards

Some years ago there was community based early warning, but because of lack of financial support, this practice is currently stopped. Though, the information is distributed at woreda level in meeting, as per the information obtained from SDPPC, at this time there is no formal way of disseminating information about drought to the pastoral community, direct victims of the disaster. The pastoralists are able to detect drought based on traditional practices like detecting of wind direction, wind dryness and using smelling.

3.4.2 Post Drought Interventions

When pastoralists face the occurrence of drought, they migrate to areas where food for cattle is available (4 to 15days' journeys). After the occurrence of drought, most the aid from governmental and non-governmental organization comes in the form of humanitarian aid. During the drought period the most critical supply needed is water. To solve this problem, the pastoralists dig out hole in a river courses to supply water for their cattle as well as for themselves for limited periods. In addition some NGOS like save the children supplied water from dug wells around city zone. However, due to lack of maintenance some of the water points are not functioning. Furthermore, there was not market setup for selling cattle during drought event. Though some pastorals were reluctant to sell their cattle during drought, most are willing to sell while keeping some good cattle.

4. CONCLUSIONS

The findings of this study indicate that the short timescale (3-months SPI) at all stations indicated that high frequencies of dry and wet spells were observed throughout the study period. Maximum frequencies of severe drought and above events were experienced in Gode (7 times) followed by Hurso (6 times) and the rest (Degahabour, Dire Dawa and Gursum) encounters three (3) times within the study period. The 6-months SPI results shows that less frequency of dry and wet events were observed in the entire study period as compared to 3-months SPI results but they are good indicators for describing the drought conditions. The frequency of any drought events (moderate to extreme droughts) occurrence in the study area is once in every two years at all stations.

Whereas, severe and extreme drought event in majority of study area is commenced nearly once in three years with the exception of Degahabur having once in five years. A maximum drought magnitude of 20.65 recorded in Gode while a minimum of 7.41 were recorded in Degahabour with the drought intensity of 3.44 and 1.85, respectively. Meanwhile, a drought magnitude of 17.48, 12.86, 11.28 and 6.19 were observed in Gursum, Dire Dawa, Hurso and Meisso with intensities of 2.19, 2.57, 2.26 and 2.06, respectively. From the NDVI figures, the areal coverage of vegetation was larger during best rainfall season than poor rainfall season which was increased by 194%, whereas extent of bare land area was decreased by 12%.Though, the SDPPC obtains drought early warning information, the information is not distributed to the pastoral community. After the occurrence of drought, most the aid comes in the form of humanitarian aid. As per the information obtained from local people and SDPPC, water is the most needed one during drought. Therefore, in the absence of measured meteorological data, NDVI values extracted from easily available satellite images are good options for working and assessing drought effects. It is also important to inform the pastoral community about the forthcoming drought so that they can either sell their cattle on time or migrate to other areas where water and food for cattle is available. In addition, it is also vital to train some people from the pastoral community on maintaining some of the existing points.

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