METEOROLOGICAL DROUGHT MONITORING ACROSS DIFFERENT RAINFALL REGIMES OF ETHIOPIA USING CHIRPS V2- RAINFALL DATA

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ABSTRACT: Drought is a recurrent phenomenon in the arid and semi-arid regions of Ethiopia. In the past two decades, millions of people are affected by drought throughout the country. To assess and monitor droughts, accurate rainfall record is crucial at different spatial and temporal scales. However, rain gauges are sparsely distributed across Ethiopia. To overcome this limitation, considering the high spatial resolution and longer period record of the Climate Hazard group Infrared Precipitation with Stations (CHIRPS) v2 satellite rainfall data, the same has been used as an input to Effective drought index (EDI) for drought monitoring in Ethiopia . The study has been carried out across the three different rainfall regimes of Ethiopia for the period from 1981 to 2016. The obtained results show that the historical drought years across rainfall regime of Ethiopia are well captured by EDI with CHIRPS rainfall product as input variable. Thus, highlighting the efficacy of EDI index and CHIRPS rainfall product for operational drought monitoring in Ethiopia.

1. INTRODUCTION

Drought is a recurrent climatic phenomenon across the world having spatial and temporal characteristics that vary significantly from one region to another (Singh, 2003). Its definitions are region specific, reflecting the differences in climatic characteristics as well as incorporating different physical, biological and socioeconomic variables. The effects of droughts are severe particularly in East African countries due to high rainfall variability in space and time (Yared *et al.*, 2017). Among these countries, Ethiopia encounters frequent droughts (occurring once in every 2-3 years). Recently, severe drought events have occurred in Ethiopia in 2011, 2012, 2014 and 2015, with most of them covering the whole country (Edossa *et al*., 2009; Viste *et al.*, 2013). In order to mitigate the impacts of droughts in the country, proper drought monitoring and early warning systems are essential (Edossa *et al.*, 2009; Yared *et al*., 2015). For the purpose of appropriate drought detection, the slow developmental nature of drought is widely classified into four types; meteorological, agricultural, hydrological, and socio-economic drought (Mishra and Singh, 2010). In every drought monitoring practice more emphasis is given to meteorological drought (simple absence/deficit of rainfall from the normal) as it is the first to occur and other droughts are consequent to it. If the precipitation deficit continuous for a longer period, all the other drought happens one after the other (Hao *et al*., 2017).

Many countries consider that drought monitoring system is one of most effective ways for reducing drought damages by early drought detection and issuing warnings (e.g., Boken *et al*., 2005). This has been carried out mainly by developing an indicator that allows for detection and evaluation of drought events. As a result, several indices have been developed to quantify a drought (Vinit *et al.*, 2014). However, choosing the most appropriate drought index is difficult as not all drought indices are used and applied for all geographical and climatic regions. Among the available indices, Effective Drought Index (EDI) is one such index which is widely used across many regions, less complex and requires only rainfall as an input variable (Muumbe *et al*., 2017). However, to monitor meteorological drought in a particular area precipitation data is the primary requirement which can be obtained either from gauge collected precipitation data or from other alternate sources such as reanalysis and satellite rainfall products. However, the gauge based precipitation observations networks are sparsely distributed or not available for common users in many regions of the world particularly in the developing countries like Ethiopia. Due to the limited and uneven distributions of rain gauge stations, drought monitoring based on ground observations is subjected to limitations. However, with the development of remote sensing techniques a variety of high-resolution precipitation products are currently available at global scale. Among these products the Climate Hazard infrared precipitation station data (CHIRPS) rainfall products have received much attention starting from 1981 to present (Mou *et al*., 2017). CHIRPS rainfall product is beneficial with a relatively longer time period (greater than 35 years), near-global coverage, high spatial (0.05^0) and temporal (daily) resolution (Mou *et al*., 2017). Evaluation of CHIRPS rainfall product in West Africa (Burkina Faso), in parts of Ethiopia (the Upper Blue Nile river basin) and across the rainfall regime of Ethiopia showed good agreement with gauge observed rainfall for monthly time scale (Funk *et al.*, 2015; Moctar *et al.*, 2015; Yared *et al*., 2017; Estifanos, 2017).

Therefore, with an aim to develop a simple and effective drought monitoring system for Ethiopia using remotely sensed rainfall products, this study attempts to assess the potential of CHIRPS rainfall product and EDI by investigating historical droughts across Ethiopia from 1981 to 2016.

2. STUDY AREA AND RAINFALL REGIMES OF ETHIOPIA

2.1 Description of the Study Area

Ethiopia, with a total area of 1,131,472 km^2, is found in the north-eastern part of the Horn of Africa. Geographic location of Ethiopia lies between 3^{0}N to 15^{0}N and 33^{0}E to 48^{0}E. The country is landlocked, sharing frontiers with Eritrea to the north and northeast, Djibouti to the east, Somalia to the east and southeast, Kenya to the south, and Sudan to the west. Ethiopia has 11 regional states and 81 zones. Ethiopia's topographical diversity encompasses high and rugged mountains, flat-topped plateaus, and deep gorges with rivers and rolling plains with altitudes ranging from 152 m below sea level at the Danakil depression in the northeast to over 4300 m above sea level in the Simien Mountains in the north (Mount Ras Dashin). In recent years, Ethiopia has suffered from a number of severe droughts and associated famines. For last three decades, Ethiopia was highly affected by recurrent droughts (DRM, 2009).

2.2 Rainfall Regimes of Ethiopia

Because of its geographical location and complex topography, Ethiopian rainfall exhibits high variability both spatially and temporally (Degefu, 1987; Bekele, 1997; Diro *et al*., 2009). In Ethiopia, three main rainfall regimes are commonly identified by the National Meteorological Agency (NMA) of Ethiopia (NMA, 1996). As shown in Fig.1 Regime 1 comprises central and eastern parts of the country, which have two rainy periods: February to May (smaller rainy season) and June to September (main rainy season). Regime 2; comprises the western part of the country, which experience a long rainy season (February to November). Regime 3; comprises the south and southeast, have two distinct rainy periods: March to May and October to November (Diro *et al*., 2009).

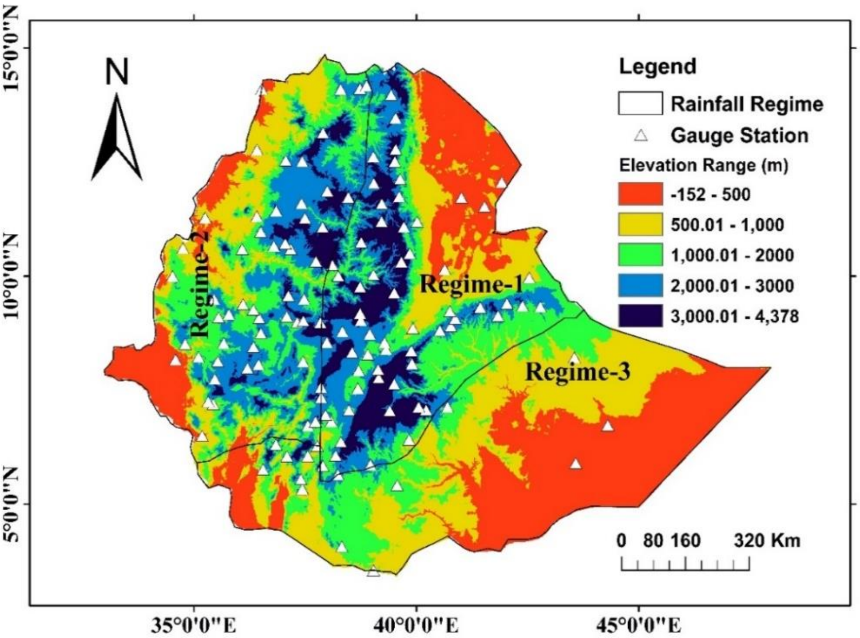

Figure 1. Location map and Rainfall regime of Ethiopia

Generally, climatic seasons in Ethiopia are categorically divided in to three main seasons. These are; i) main rainy season from June to September, ii) dry season from October to December/January, and iii) smaller rainy season from February/March to May, known locally as Kiremt, Bega and Belg respectively (Yilma *et al.*, 2004).

3. DATASETS AND METHOD

3.1 Data Used

3.1.2 Climate Hazards Group Infrared precipitation with station data version 2 (CHIRPSv2): In this study Climate Hazard Group Infrared Precipitation with station data version 2 (CHIRPSv2) rainfall product has been used. CHIRPS datasets were developed by the US Geological Survey (USGS) and the Climate Hazards Group at the University of California, Santa Barbara (UCSB). The inputs used for CHIRPS creation are: the Climate Hazards Precipitation Climatology (CHPClim), TIR, CFSv2 (climate forecasting system version 2), TRMM 3B42; and in-situ precipitation observation from national and regional meteorological services (Funk *et al*., 2015; Moctar *et al*., 2016). The CHIRPS dataset builds based on infrared Cold Cloud Duration (CCD) concept with more number of inputs and better spatial and temporal resolution. CHIRPS product has a daily, pentadal and monthly precipitation product explicitly designed for monitoring drought and environmental change over land (Funk *et al*., 2015). CHIRPS products are available at a spatial resolution of 0.05° for the quasi-global coverage of 50°N-50°S from 1981 onwards. For the current study, CHIRPSv2 daily product from 1981 to 2016 covering entire Ethiopia has been used.

3.1.3 Historical drought records: In Ethiopia, there is no well-organized and documented historical drought information for detailed drought analysis. However, the Emergency Events Database (EM-DAT), www.emdat.be., have all-natural disasters record information throughout the world. Among those natural disasters, drought is the main one. Hence, as per the available information, in Ethiopia, major droughts have occurred in 1965, 1969, 1978, 1983/84, 1987/89, 1992, 1997, 1998, 1999/00, 2003/04, 2005/06, 2008/09, 2010, 2011/12 and 2015/16 (EM-DAT, 2017; Surya, 2016). These historical drought record have been used for evaluation and comparison purpose.

3.2 Methodology

In the current study, meteorological drought assessment has been done using CHIRPS monthly rainfall data and Effective Drought Index (EDI) from 1981 to 2016. Figure 2 shows the overall process of historical drought assessment across rainfall regimes of Ethiopia.

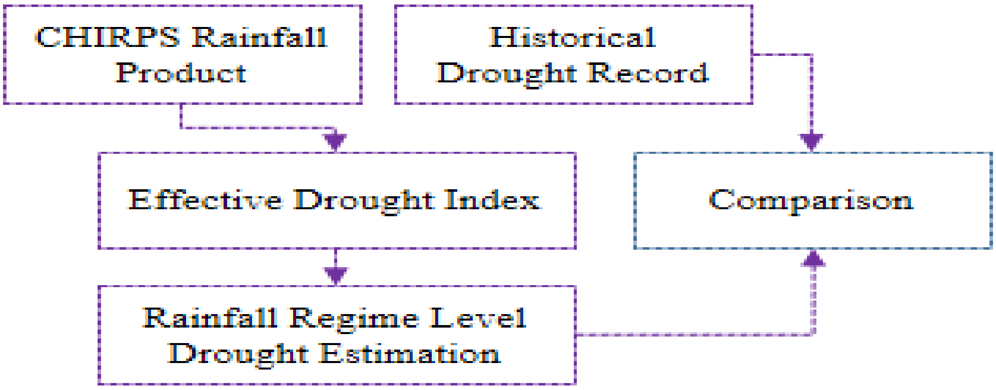

Figure 2. Framework for rainfall regime level drought monitoring across Ethiopia

3.2.1 Effective Drought Index (EDI): To compute severity and duration of drought events for each rainfall regime in Ethiopia, monthly time scale EDI has been used. EDI was developed by Byun and Wilhite (1999) with a concept of effective precipitation to monitor the duration and severity of drought. The effective precipitation (EP) is the accumulation of the parts of precipitation of the certain days before estimation time, which affects the available water resources at the estimation time (e.g., rainfall of 3 days prior to present day can affect soil moisture of present day). Effective precipitation is calculated by summing precipitation over time, considering the loss of rainfall due to runoff or evaporation with the passage of time.

The steps involved in the calculation of EDI are as follows: (i) calculate the monthly EP. (ii) Calculate the 30-year mean EP (MEP) for each month. (iii) Calculate the DEP, which is the difference between the EP and MEP. (iv) Divide the DEP for each month by the standard deviation of DEP over the past 30 years: Thus, first step in calculation of EDI is to calculate EP. If P_i is rainfall 'm - 1' months before the current month and N is the duration of preceding period, then effective precipitation for the current month (EP_j) is given as;

$$\mathbf{EP_j = \sum_{m=1}^{N}[(\sum_{i=1}^{m} P_i)/m]} \quad \mathbf{(1)}$$

For example, if N=3 then EP=P_1+ (P_1+P_2)/2 + (P_1+P_2+P_3)/3, where P_1, P_2 and P_3 are rainfall during current month, previous month and 2 months before respectively. EPj is Effective Precipitation of 'j' month. Then average and standard deviation of EP values for each month are calculated and the time of EP values is converted to deviations from the mean (DEP):

$$\mathbf{DEPj = EP_j - \overline{EP_j}} \qquad \mathbf{(2)}$$

When DEP is represented by a negative number, this signifies that it is drier than the average, and while DEP is represented by a positive number, this signifies that it is wetter than the average. Then finally, the EDI can be calculated as,

$$\mathbf{EDI = DEP/SD(DEP)} \qquad \mathbf{(3)}$$

Finally, the obtained the monthly EDI values were categorized based on McKee's (1963) classification in to different drought severity categories as shown in Table 1.

Table 1. EDI values to categorize drought severity
(Source: McKee et al, 1993)

EDI values	Drought Category
1.5 and above	Wet
1.0 to 1.49	Normal
-.99 to 0.99	Mild drought
-1.0 to -1.49	Moderately drought
-1.5 to -1.99	Severely drought
-2 and less	Extremely drought

4. RESULT AND DISCUSSIONS

The results obtained for temporal drought analysis carried out during main and smaller rainy seasons across the rainfall regimes of Ethiopia are discussed herein. Figures. 3 and 4 show the temporal drought evolution based on the average value of all grids across the rainfall regimes of Ethiopia. The temporal drought evolution is explained in terms of severity and duration. To make the discussion easier and understandable among the mentioned historical drought events, only the following historical drought periods (years) are considered: 1983/84, 1987/89, 1999/00, 1992, 2003/04, 2008/09, 2011/12 and 2015/16 reported herein.

4.1 Drought Analysis During Smaller Rainy Season

Figure 3 illustrates the time series plot of monthly EDI across the three rainfall regimes of Ethiopia for the period 1982 to 2016 during smaller rainy season (April to June). The result shows the occurrence of mild to severe drought events in all three rainfall regimes. As mentioned earlier, 1983/84, 1987/89, 1999/00, 1992, 2003/04, 2008/09, 2011/12 and 2015/16 were some of the historical drought years in the country. The temporal assessment of meteorological drought index computed by EDI indicates the occurrence of these drought years, however with different severity levels. For example, moderate to severe drought conditions were occurred during 1983/84 and 2008/09 in rainfall regime 1; during 1986/88 in rainfall regime 2 and during 1983/84, 1999/00 and 2011/12 in regime 3. However, in the remaining historical drought years, mild droughts were observed. In general, in smaller rainy season, regime 1 and regime 3 (located in the eastern and southwestern part of the country) experienced relatively more number of drought years than regime 2 (western part of the country).

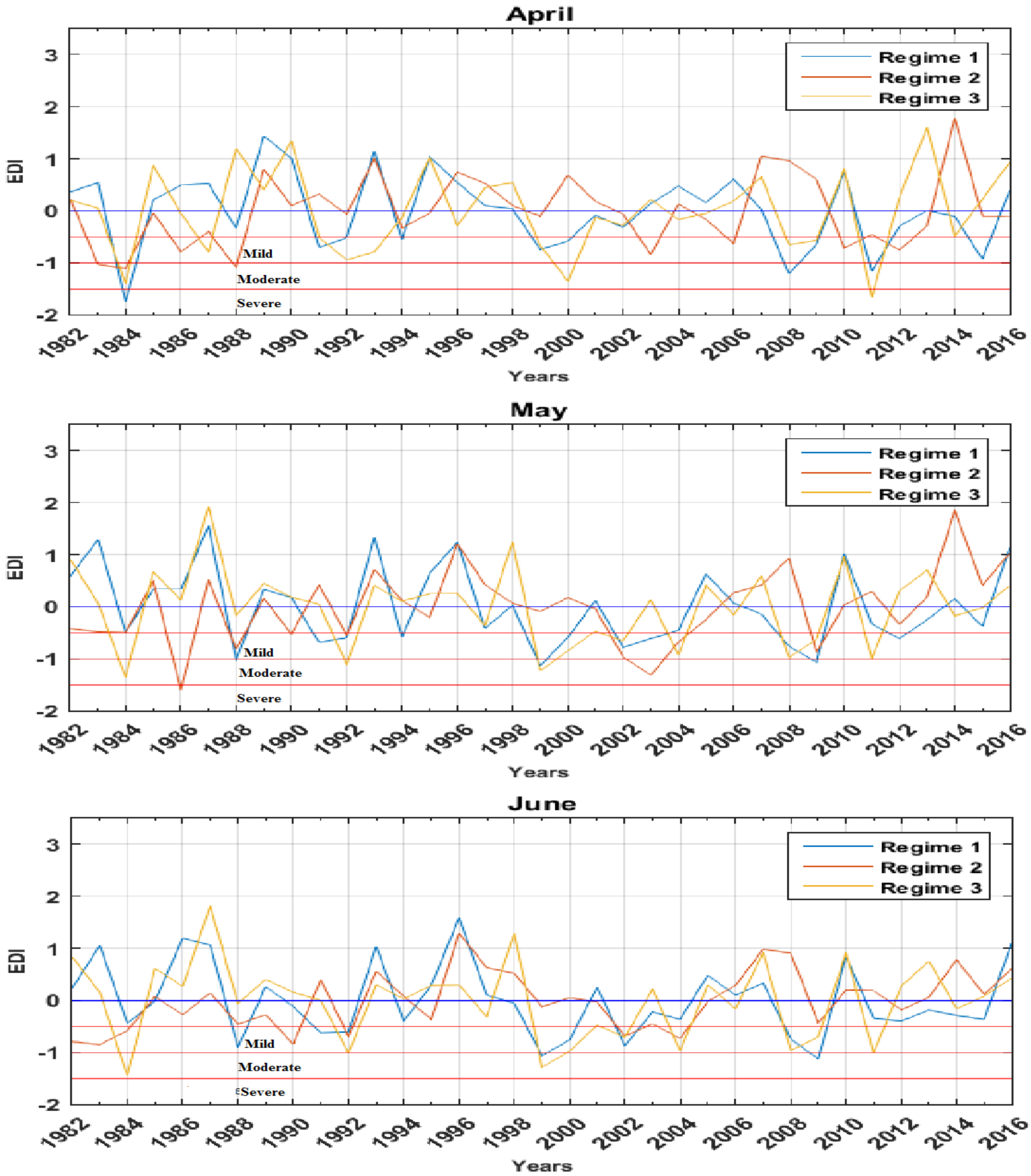

Figure 3. Temporal evolution of meteorological drought based on EDI at monthly time scales during smaller rainy season (April to June) from 1982 to 2016 across three rainfall regimes of Ethiopia.

4.2 Drought Analysis During Main Rainy Season

Figure 4 illustrates the time series plot of monthly EDI across the three rainfall regimes of Ethiopia for the period 1982 to 2016 during main rainy season (July to September). The temporal assessment of meteorological drought indicates the occurrence of these historical drought years with different severity levels. In this season, moderate to severe drought conditions were occurred during 1983/84 and 2015/16 in rainfall regime 1; during 2002/03 and 2008/09 in rainfall regime 2 and during 1983/84 and 1992 in regime 3. In the remaining historical drought years mild droughts were observed.

Overall, the historical drought years were detected by EDI either during smaller season or main rainy season or both, however with different severity levels. The drought severity for each rainfall regime in Figs.3 and 4 show the average EDI value of all grids. However, individual grids in each rainfall regimes might have different severity levels. The temporal assessment results obtained in this study are in line with the previous findings (Yared *et al.*, 2017; Yared *et al.*, 2015). Hence, it can be said that the CHIRPS rainfall combined with EDI can be used as an alternative source of information in developing drought monitoring and early warning in the rainfall regimes of Ethiopia.

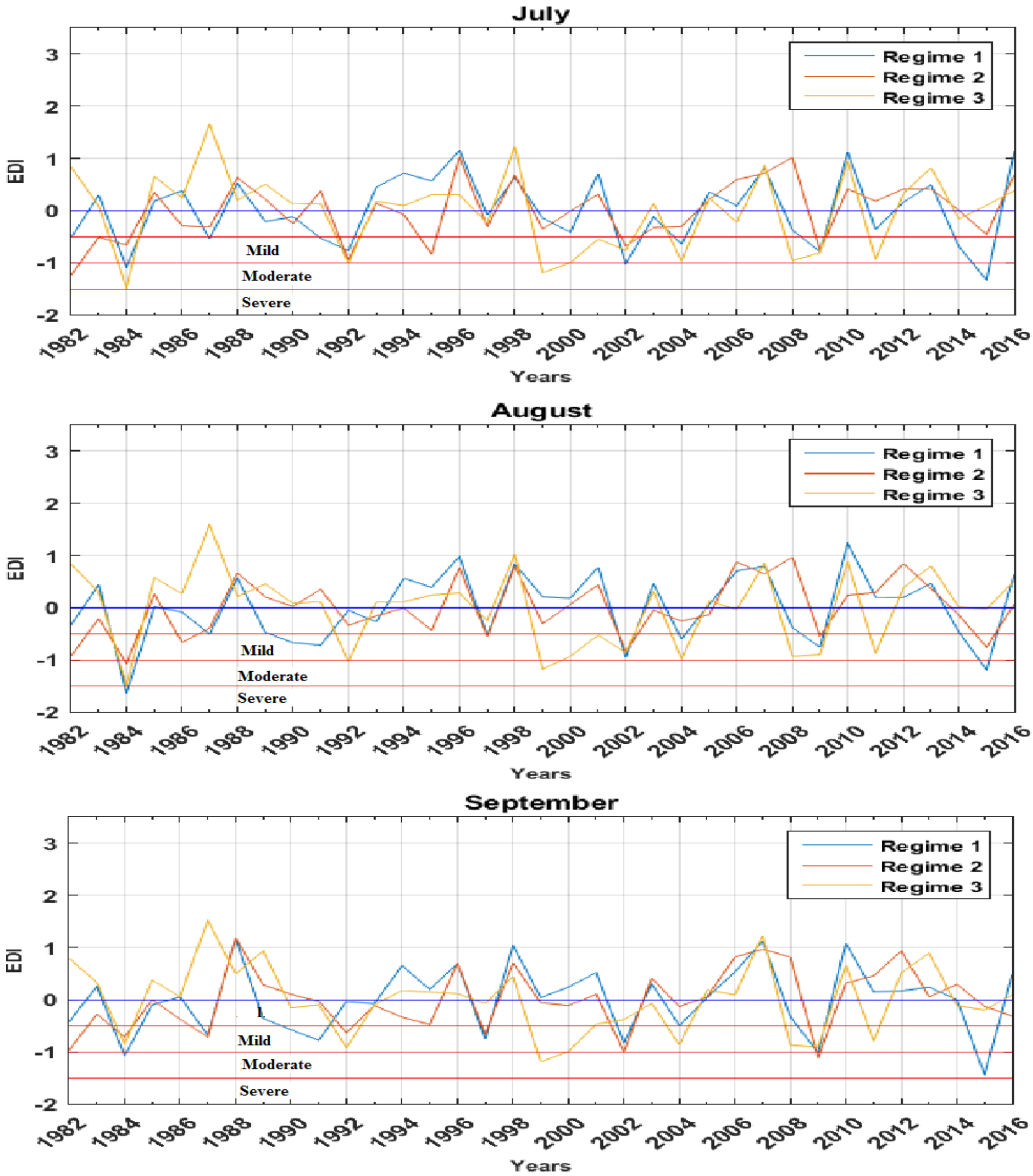

Figure 4. Temporal evolution of meteorological drought based on EDI at monthly time scales during main rainy season (July to September) from 1982 to 2016 across three rainfall regimes of Ethiopia.

5. SUMMARY AND CONCLUSION

In this study, meteorological drought was assessed across three rainfall regimes of Ethiopia using CHRIPS satellite rainfall data and EDI for a period starting from 1981 to 2016. The temporal drought analysis shows that EDI detects the historical drought years with different severity level (mild, moderate and severe). The study also highlighted the importance of doing rainfall regime wise analysis as the severity of drought varies from regime to regime for a same historical drought year. Overall, the study shows that CHIRPS rainfall product in combination with EDI could be used to identify drought severity and to develop the drought monitoring systems for an early warning system across the rainfall regimes of Ethiopia. It should be noted that, in the present study these EDI values only represent the average situations at each rainfall regime scale, so higher or lower values may be found in individual grids. Therefore, representing the drought severity in grid wise would be of significant importance to study the spatial extents of drought.

REFERENCE

Bekele F., 1997. Ethiopian use of ENSO information in its seasonal forecasts. International Journal of African Studies 2, in press.

Boken, V. K., A. P. Cracknell, R. H. Heathcote, 2005. Monitoring and Predicting Agricultural Drought: A Global Study. Oxford University Press, New York, pp.472.

Byun, Hi Ryong, & Wilhite, D. A., 1999. Objective quantification of drought severity and duration. American Meteorological Society, 12, pp.2747-2756.

Degefu W., 1987. Some aspects of meteorological droughts in Ethiopia. In Drought and Hunger in Africa: Denying Famine a Future, Glantz M (ed.). Cambridge University Press, Cambridge, pp. 23–36.

Disaster Risk Management (DRM), 2009. The preparation of the Ethiopia Disaster Risk Management. Addis Ababa, Ethiopia.

Edossa, D.C., Babel, M.S., and Gupta, A.D., 2009. Drought analysis in the Awash River Basin, Ethiopia. Water Resources management, 24, pp.1441–1460.

Estifanos Lemma, 2017. Evaluation of satellite and reanalysis rainfall product across rainfall regime of Ethiopia. Second Annual Progress Report, IIT, Bombay, India.

EM-DAT: The Emergency Events Database, 2017. Universite catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium.

Funk, C. et al., 2015.The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. Sci. Data. 2:150066.

G. T. Diro,a* D. I. F. Grimes,a E. Black,a A. O'Neilla and E. Pardo-Iguzquizab, 2009. Evaluation of reanalysis rainfall estimates over Ethiopia. Int. J. Climatol. 29,pp. 67–78.

Hao Guo , Anming Bao ,*, Tie Liu , Felix Ndayisaba ming He, Alishir Kurban and Philippe De Maeyer, 2017. Meteorological Drought Analysis in the Lower Mekong Basin Using Satellite-Based Long-Term CHIRPS Product. Sustainability **2017**, 9, pp.901.

K.V. Suryabhagavan, 2016. GIS-Based Climate Variability and Drought Characterization in Ethiopia over three decades. Weather and Climate Extremes, http://dx.doi.org/10.1016/j.wace.2016.11.005.

McKee, T.B.; Doesken, N.J.; Kleist, J., 1993. The relationship of drought frequency and duration to time scales. In Proceedings of the 8th Conference on Applied Climatology, Anaheim, CA, USA, 17–22 January 1993, American Meteorological Society, Boston, MA, USA, pp. 179–184.

Mishra, A.K., Vijay P. Singh b, 2010. A review of drought concepts. Journal of Hydrology 391 (2010), pp. 202–216.

Moctar Dembélé & Sander J. Zwart, 2016. Evaluation and comparison of satellite-based rainfall products in Burkina Faso, West Africa. International Journal of Remote Sensing, 37:17, pp. 3995-4014.

Mou Leong Tan 1,*, Kok Chooi Tan, Vivien P. Chua and Ngai Weng Chan, 2017. Evaluation of TRMM Product for Monitoring Drought in the Kelantan River Basin, Malaysia. Water 2017, 9, pp.57.

Muumbe K. Lweendo, Baohong Lu *, Meng Wang, Hanwen Zhang and Wei Xu, 2017. Characterization of Droughts in Humid Subtropical Region, Upper Kafue River Basin (Southern Africa). Water 2017, 9, pp.242.

National Meteorological Agency of Ethiopia, NMA, 1996. Climatic & agro-climatic resources of Ethiopia. NMSA Meteorological Research Report Series, vol. 1, No. 1, Addis Ababa.

Singh, S. 2003. Drought and its management in India, Short term course on Drought analysis and management, IIT, Roorkee, SS, pp.1-15.

Vinit K.Jain a,n, Rajendra P.Pandey b, Manoj K.Jain c, Hi-Ryong Byun, 2015.Comparison of drought indices for appraisal of drought characteristics in the Ken River Basin. Weather and Climate Extremes (2015), pp.1–11.

Viste, E., Korecha, D., Sorteberg, A., 2013. Research drought and precipitation tendencies in Ethiopia. Theoretical and Applied Climatology. 112, pp.535–551.

Yared Bayissa, Semu A. Moges, Yunqing Xuan, Schalk J. Van Andel, Shreedhar Maskey, Dimitri P. Solomatine, Ann Van Griensven & Tsegaye Tadesse, 2015. Spatiotemporal assessment of meteorological drought under the influence of varying record length: the case of Upper Blue Nile Basin, Ethiopia. Hydrological Sciences Journal, 60:11, pp.1927-1942.

Yared Bayissa, Tsegaye Tadesse, Getachew Demisse and Andualem Shiferaw, 2017. Evaluation of Satellite-Based Rainfall Estimates and Application to Monitor Meteorological Drought for the Upper Blue Nile Basin, Ethiopia. Remote Sens. 2017, 9, pp.669.

Yilma Seleshi,* and Ulrich Zankeb, 2004. Recent Changes in Rainfall and Rainy Days in Ethiopia. Int. J. Climatol. 24: pp.973–983.