Drought monitoring on the Awash river basin of Ethiopia

Getachew Mehabie Mulualem, and Yuei-An Liou *

Abstract: This study mainly evaluated satellite products for the drought monitoring of the Awash River Basin, the most important river basin in Ethiopia covering a total land area of 110,000 km^2 and home of around 10.5 million inhabitants. The Standardized Precipitation Index (SPI) results indicate that severe hydrological drought events occurred during the years 2009, 2011, and 2015. Pixel-based trend analysis revealed significant decreasing trends of rainfall and NDVI occurred in the middle and lower parts of the basin signaling the presence of regional drought.

Keywords: Awash River Basin; Drought analysis; Standardized Precipitation Index; NDVI

1. Introduction

Droughts are one of the natural events which develop slowly and are usually recognized when the drought is already established. It is mainly caused by weather events like El Niño and high-pressure systems, deforestation, global warming, and also though altering the surface water quantity. The phenomena is a result of variability in the water cycle that is inter-linked with the climatic and oceanic circulation patterns (Golian et al., 2015). As in many environmental variabilities, a global perspective of drought is often necessary conversely a regional drought of far-reaching impacts that lead to global impacts. For instance, the 2010 Russian drought increase global food prices (Wegren, 2011). In the year 2011, the Greater Horn of Africa was affected by a severe drought due to the failure of rainy seasons. Thus, drought poses significant water and food security challenges in developing countries.

Droughts are broadly classified into four major groups starting with meteorological drought (a deficit in precipitation amount), agricultural drought (a deficit in soil moisture), hydrological drought (a deficit in runoff and groundwater), and socioeconomic drought (imbalance between demand and supply due to water shortage).

Traditionally, droughts have been monitored using ground-based point observations or interpolated grids. However, in many parts of the world, the available observations are not sufficient to capture the spatiotemporal variability of drought-related variables such as precipitation, temperature, and soil moisture; and often observations stations suffer from data quality and consistency which make drought monitoring challenging. Through the success of the missions of satellite remote sensing in the 1960s, a series of geostationary and low earth orbit satellites have been used to monitor the weather and climate-related parameters. Multispectral, infrared, and microwave data have been successfully utilized to retrieve drought-related parameters, such as precipitation, soil moisture, evapotranspiration, vegetation health, etc.

The incidence of meteorological drought has increased in Ethiopia since around 1970 and increased in central and northern Ethiopia (Gebrehiwot et al., 2011). Nowadays, researchers have plenty of indices to choose for the drought-related study, while most of the methods are usually complex to produce and that could gain the sensitivity within the index, which means they may not be able to adapt themselves to some regional scopes of discussions. This paper tries to evaluate satellite products to monitor drought changes in Awash River Basin of Ethiopia. The monthly gridded data of Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) precipitation, and Moderate Resolution Imaging Spectroscopy (MODIS) Terra NDVI products were used to assess the spatial and temporal meteorological drought. Furthermore, a non-parametric Mann-Kendall method was used to test for a monotonic trend at each grid level, and magnitude was estimated by the Sen's method.

2. Study area

The Awash River Basin, the most important river basin in Ethiopia covering a total land area of 110,000 km^2 and home of around 10.5 million inhabitants (Hailu et al., 2019). Droughts have

Corresponding author's name: Professor Yuei-An Liou

Affiliation: Center for Space and Remote Sensing Research, National Central University, Taiwan Group on Earth Observations, Hsinchu, Taiwan,

E-mail address: yueian@csrsr.ncu.edu.tw

frequently occurred throughout Awash River Basin in recent years due to land degradation, high population density, and wetland degradation.

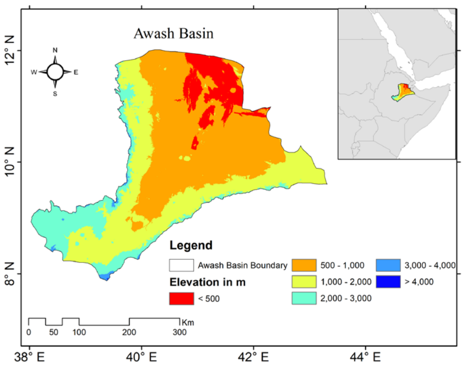

Figure 1. The location of the study area, Awash river basin of Ethiopia.

Awash Basin is a home for the country's development sector: irrigated agriculture (25% national agricultural production) and industrial development (36% national manufacturing value and 65% of all industries in the country). In addition, expansion of urbanization has been taking place in the basin. In connection with this, the basin has experienced tremendous challenges of recurring drought and flood hazards at extensive scale (Edossa et al., 2010).

3. Methodology

3.1 Normalized Difference Vegetation Index (NDVI)

A common way of measuring vegetation greenness is using NDVI. It quantifies vegetation by measuring the difference between near-infrared, and red light. Healthy vegetation (chlorophyll) strongly reflects near-infrared and green bands compared to other wavelengths and it absorbs red light. NDVI is computed using the formula:

$$NDVI = \frac{NIR - R}{NIR + R}$$

NDVI varies between -1 and 1 where the negative values are mostly from water bodies. A value close to 1 signifies dense green leaves, whereas NDVI values close to zero are related to an urbanized area. It has been tested under all environments and it successfully quantifies vegetation by measuring the difference between near-infrared and red lights. Thus, in a case when water limits the vegetation growth the NDVI values become lower and it indicates that drought has occurred. It is a well-established fact in remote sensing community that that NDVI is an effective indicator of vegetation response to drought.

3.2 Standardized Precipitation Index (SPI)

One of the most commonly employed methods in monitoring drought is the use of indices that accurately estimate the drought conditions. A commonly used precipitation-based drought index is the Standardized Precipitation Index (SPI) (Mckee et al., 1993). It has been used as a global measure of metrological drought by the World Meteorological Organization (WMO). The SPI was intended to measure the precipitation deficit for multiple timescales. The SPI calculation based on the long-term precipitation record for the desired period called the base period. This long-term record is fitted to a probability distribution in most cases to Gamma distribution and then transformed into a normal distribution. Consequently, the mean SPI for the location and desired period is zero. Positive SPI values indicate greater than mean precipitation and negative values indicate less than mean precipitation.

Table 1. SPI based drought classifications

SPI values	Drought Category
-2 and less	Extreme
-1.5 to -1.99	Severe
-1 to -1.49	Moderate
0 to -0.99	Normal
above 0	No

SPI represents the number of standard deviations from the mean and these SPI values show the different categories of drought severity (Table 1). Moreover, the timescales reflect the impact of drought on the availability of the different water resources.

Daily gridded precipitation data for the period of (1981 – 2018) from the Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) precipitation for the Awash River Basin region (shown in Fig. 1) were extracted. The monthly precipitation data were used as input for the calculation of SPI.

3.3 Mann-Kendall (M-K) trend analysis

Mann - Kendall non-parametric test (Larbi et al., 2018) is applicable in non-normal distribution, incomplete, or a small number of outlier data. Vegetation changes from one stable state to another and these situations often can be met in time series analysis. Therefore, we detected the change tread by this method. The M-K test is based on the test statistic S defined as:

$$S = \sum_{j<1}^{n} sgn(X_i - X_j)$$

where the xi are the sequential data values, n is the length of the data set. The standardized M-K Statistic Z follows the standard normal distribution with mean of zero and variance of one. Full descriptions of the method can be found on (Sobrino and Julien, 2011).

4. Results and discussions

4.1 Results of SPI analysis

The study produced the maps of drought severity at 3, 6 and 12 months' time steps, in the Awash river basin (here we present for the 12-month scale only). Month of September was chosen for calculating SPI for 12-month time step as July to September is normally wet season for the study area. Month of September was chosen for the calculation as negative SPI values in the wet season will indicate drought throughout the year.

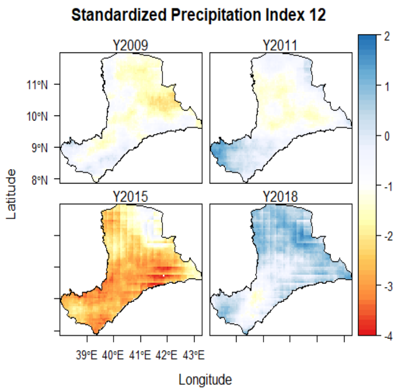

Figure 2. The SPI values for 12-month time scale for the years 2009, 2011, 2015 and 2018.

Results show that the most frequent droughts occurred in the middle and lower Awash Basin during the period of analysis (2001-2018). The SPI 12 results indicate that severe hydrological drought events occurred in the middle Awash Basin during the years 2009, 2011, and 2015.

The hydrological drought being a changing phenomenon is mostly unpredictable over the study period. The spatiotemporal character of the hydrological drought of Awash river basin indicated that the region was vulnerable to drought incidents on the basis of the past rainfall records.

4.2 Vegetation trends

The mean NDVI and trends were spatially varied in different parts of the basin regions. The annual mean NDVI in northern parts was very low and the NDVI value was high (above 0.4) in the western, and south western zone of Awash river basin (Figure 3). The NDVI generally ranged from 0.1 to 0.5 in the low lands middle and northern regions. The maximum mean NDVI ranges from 0.5 to 0.7, mainly in mid-hill areas occupied by cropland and agricultural areas.

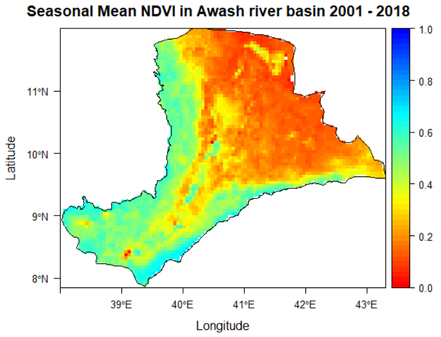

Figure 3. The seasonal (JJAS) mean NDVI for the awash river basin derived from monthly MDIS NDVI product, 2001 -2018.

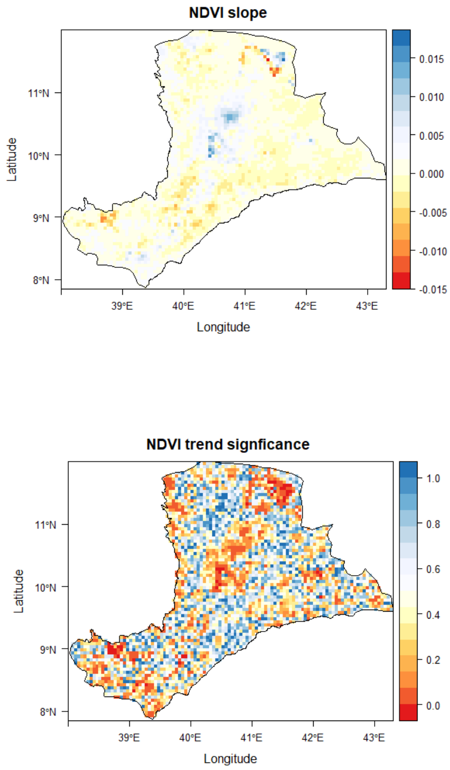

Figure 4. The seasonal (JJAS) mean NDVI trends for the awash river basin.

A large area of significant NDVI declining was found during the study period, which coincides with the crop growing seasons. Pixel-based trend analysis revealed significant decreasing trends ($\alpha = 0.05$) of rainfall and NDVI occurred in the middle and lower parts of the basin.

Acknowledgments: This research was financially supported by Ministry of Science and Technology (MOST) of Taiwan under the codes 108-2923-M-008 -002 -MY3 and 108-2111-M-008 -036 -MY2.

References

Edossa, D.C., Babel, M.S., Das Gupta, A., 2010. Drought Analysis in the Awash River Basin, Ethiopia. Water Resour. Manag. 24, 1441–1460. https://doi.org/10.1007/s11269-009-9508-0

Gebrehiwot, T., van der Veen, A., Maathuis, B., 2011. Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. Int. J. Appl. Earth Obs. Geoinf. 13, 309–321. https://doi.org/10.1016/j.jag.2010.12.002

Golian, S., Mazdiyasni, O., AghaKouchak, A., 2015. Trends in meteorological and agricultural droughts in Iran. Theor. Appl. Climatol. 119, 679–688.

Hailu, R., Tolossa, D., Alemu, G., 2019. Water security: stakeholders' arena in the Awash River Basin of Ethiopia. Sustain. Water Resour. Manag. 5, 513–531. https://doi.org/10.1007/s40899-017-0208-2

Larbi, I., Hountondji, F., Annor, T., Agyare, W., Mwangi Gathenya, J., Amuzu, J., Larbi, I., Hountondji, F.C.C., Annor, T., Agyare, W.A., Mwangi Gathenya, J., Amuzu, J., 2018. Spatio-Temporal Trend Analysis of Rainfall and Temperature Extremes in the Vea Catchment, Ghana. Climate 6, 87. https://doi.org/10.3390/cli6040087

Mckee, T.B., Doesken, N.J., Kleist, J., 1993. The relationship of drought frequency and duration to time scales. Eighth Conf. Appl. Climatol. 17-22 January 1993, Anaheim, Calif. 179, 17–22.

Sobrino, J.A., Julien, Y., 2011. Global trends in NDVI-derived parameters obtained from GIMMS data. Int. J. Remote Sens. 32, 4267–4279. https://doi.org/10.1080/01431161.2010.486414

Wegren, S.K., 2011. Food security and Russia's 2010 drought. Eurasian Geogr. Econ. 52, 140–156.