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Analysis of Meteorological Drought for Water Resources and Irrigation Planning in Ado – Ekiti, Nigeria

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Abstract

Drought is a natural hazard with far-reaching impacts on agriculture, hydrology and water resources. This study employed the Standardized Precipitation Index (SPI) to analyze meteorological drought patterns in Ado-Ekiti over three temporal scales: 3-month, 6-month, and 12-month, using monthly rainfall data covering the period 1980 to 2022. Plot of annual rainfall series showed high rainfall variability over Ado-Ekiti during the period of study, especially between 1985 and 2010, but with an increasing trend from the period till 2022. Moreover, the results of drought analysis also revealed that it has be more of wet years in Ado-Ekiti irrespective of the different time scales used, with most months mildly wet, followed by moderately wet, severely wet and extremely wet conditions, respectively. However, extreme and severe drought conditions were observed especially at shorter timescales, especially during decade 1980s. Consequently, it was concluded that occurrence of drought has been very rare in Ado-Ekiti which may translate to increasing agricultural productivity if effectively harnessed. However, in view of the extreme drought conditions observed during few months, it is recommended that farmers should always prepare for supplementary irrigation, especially during off-season farming activities, while construction of water storage and flood control facilities should be prioritized by governments at all levels in the town.

Keywords: Droughts, Normal condition, Extremely wet, Severe drought, Extreme drought

1.0 Introduction

Understanding the dynamics of drought occurrence, duration and severity can be of immense benefits for agriculture and water resources planning in any geographical setting. This is particularly so under the prevailing global climate change which exacerbates fluctuations in rainfall and temperature with increasing extreme events in forms of flood and drought. While the majority of climate models predict that droughts will become more frequent and severe in the years to come (Nam et al., 2015; Touma et al., 2015), the effects of climate change on drought are probably going to be more noticeable in East Asia, South Asia, and Africa (Shiru et al., 2018). Meanwhile, increased severity of droughts across the globe has severely affected agriculture, livelihoods, and national economies in many countries around the world. Ayanlade et al. (2018) noted that drought is becoming a significant obstacle to agricultural production in many parts of Africa, negatively affecting both crops and cattle. In this regard, analysis of drought in a specific agricultural environment, such as Ado Ekiti where many households rely on agriculture for survival, offers a right step towards early warning system.

Simply defined, drought is a state of water scarcity that lasts for months or years and is accompanied by less rainfall than usual (Bae et al., 2018). WMO (2012) described it as a deceptive natural hazard that is made worse by precipitation amounts below the commonly recognised threshold. Due to the fact that the impacts of drought typically occur after the failure of the climate variables that generate it, it is misleading. According to Paulo et al. (2012), drought's impacts can linger long after its causes have subsided, yet its beginning and termination are both gradual and hard to see. Meteorological, agricultural, hydrological, and socio-economic droughts are the four categories of drought that have been distinguished based on their duration, traits, and economic effects (FAO, 2013). Depending on the region, meteorological drought happens when precipitation deviates from the long-term average (Dai, 2011). When soil moisture is insufficient to meet a crop's needs during a given period, agricultural drought (often lasting three to six months) occurs. This is typically evident following a meteorological drought but prior to a hydrological drought (FAO, 2013). In contrast, hydrological drought is frequently associated with meteorological droughts and describes abnormally low water levels in streams, rivers, and reservoirs for a longer period of time (12 months to 2 years or more) (Rouault and Richard, 2003). Furthermore, the consequences of this kind of drought on the surface and subsurface water supplies are typically evident (FAO, 2013).

Several studies have been conducted on drought across the world over the past few decades using different indices with different results (e.g. Barke and Brown, 2010; Wang et al., 2017; Rahman et al., 2021). Within Africa and specifically in Nigeria, many authors have also reported different results over diverse spatial and temporal scales (Oguntunde et al., 2017; Shiru et al., 2018; Oladipo, 1995). However, most of the studies described droughts in general without providing specific information as per extent and severity. Moreover, many of the studies covered a wide range of agro-climatic zones within the country, thus making it difficult to apply their results for planning at any specific locations. Understanding how climate variability affects droughts at different specific locations is crucial for sustainable agriculture management and food security, even though the effects of climate change on droughts would differ across the nation due to variations in climate and seasons (Shiru et al., 2019).

With respect to water resources planning and management, Hernandez and Uddameri (2014) emphasised that prediction of the nature and occurrence of droughts is important for regional water planning process. Yet, such planning can only be achieved using appropriate indices that can relate climate variables to occurrence of extreme events such as drought both at spatial and temporal scales. Although many drought indices, including the Self-calibrated Palmer Drought Severity Index (Sc-PDSI), Standardized Precipitation Evapotranspiration Index (SPEI), Standardized Runoff Index (SRI), the Standardized Precipitation Index (SPI) recommended by the WMO (2012) is adopted in the present study. Therefore, the aim of this study was to carry out an analysis of meteorological drought water resources and irrigation planning in Ado-Ekiti, Nigeria.

2.0 Materials and Method

2.1 The Study Area

Ado Ekiti is the state capital of Ekiti State, Nigeria (Fig. 1). The city lies between Latitude 7°37’ N and 7° 16’ N and Longitude 3°13’ E and 3°17’ E, covering approximately about 293 km^2. It lies in the Yoruba hills at the intersection of roads from Akure, Ilawe Ekiti, Ilesha, Ikere. According to the 2006 population census, the population of the city was put at about 308,621. The rainy season in Ado Ekiti is humid, cloudy and oppressive, while the period of the dry season is warm, muggy, and partially cloudy. The average annual temperature ranges from 29 ºC to 30 ºC. Ado Ekiti is mainly known in the south west of Nigeria for being a hilly state. It is also known for being the site of a large textile mill in 1967. The people of the city have a long history of cotton weaving. The major crops grown are Yams, Cassava, Grain, Tobacco, Maize, Cocoa, Cotton and other fruits are the chief articles of trade. It is a key export location for Cocoa, Palm products, fruit, and Kola nuts, Timbers, Cocoa yams and fruit vegetables.

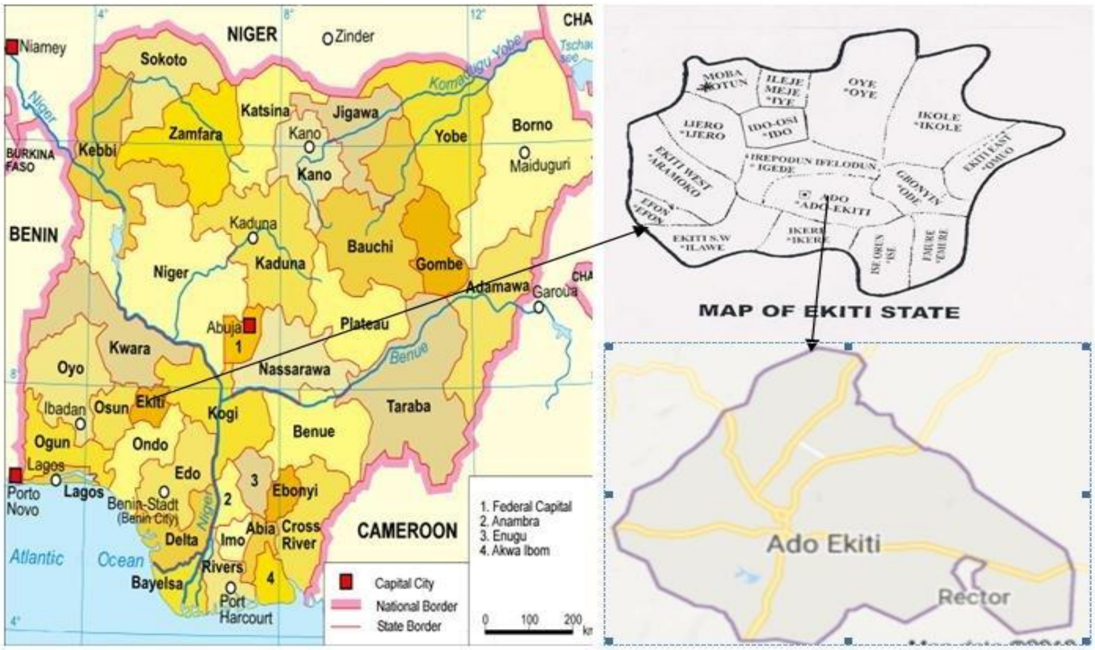

Fig. 1: Location of Ado-Ekiti in Nigeria

2.2 Data

This study relied mainly on secondary data. The monthly rainfall data for Ado-Ekiti covering 1980 to 2022 used for this study were retrieved from the archive of Climate Hazards Group Infra-Red Precipitation with Station data (CHIRPS). The algorithm combines three main data sources: (i) the Climate Hazards group Precipitation climatology (CHPclim), a global precipitation climatology at 0.05° latitude/longitude resolution estimated for each month based on station data, averaged satellite observations, elevation, latitude and longitude (Funk et al., 2012; 2015), (ii) TIR-based satellite precipitation estimates (IRP), and (iii) in situ rain-gauge measurements. The CHPclim is distinct from other precipitation climatologies in that it uses long-term average satellite rainfall fields as a guide to deriving climatological surfaces. This improves its performance in mountainous countries like Ethiopia (Funk et al., 2015).

2.3 Data Analysis

Assessment of Annual Times Series

Annual time series plot of the rainfall data was carried out to visually assess the data and have an initial understanding of the dynamics of temporal change in annual rainfall over the study area.

Standardized Precipitation Index (SPI)

In view of the need to have an index that is simple, easy to calculate and statistically relevant and meaningful, scientists in the United States led by McKee, Doesken and Kleist developed the Standardized Precipitation Index (SPI) in 1993 (WMO, 2012).The first step in calculating the SPI index is to determine the probability density function for selected precipitation series. The distribution most commonly used in calculating the SPI is the gamma distribution (McKee et al., 1993; Lloyd-Hughes and Saunders, 2002; Oloruntade et al., 2017). The calculation of SPI for any location usually requires a record of long-term precipitation for a desired period. The long-term record is then fitted to a probability distribution, which is then converted into a normal distribution such that the mean SPI for the location and desired period is zero (Edwards and Mckee, 1997). McKee et al. (1993) established the criteria for determining the beginning and the end of a drought event. A drought event begins when the SPI is continuously negative and reaches the value of –1 or less while the drought event ends when the SPI value becomes positive. Mathematically SPI can be calculated using the equation below:

$$SPI = \left(\frac{x_{i-}\bar{x}}{\delta}\right)$$

Where x_i is the rainfall for a particular timescale, $\bar{x}$ is the long term mean for the station and δ is the standard deviation.

Table 1: Drought classification by SPI (Lloyd-Hughes, 2002)

SPI values	**Category**
2.0 or more	Extremely wet
1.50 to 1.99	Severely wet
1.00 to 1.49	Moderately wet
0.00 to 0.99	Mildly wet
0.00 to -0.99	Mildly drought
-1.00 to -1.49	Moderately drought
-1.50 to -1.99	Severe drought
-2 or less	Extreme drought

3.0 Results and Discussion

3.1 Assessment of Annual rainfall Data over Ado Ekiti

Plot of annual time series for the period 1980 to 2020 shows high rainfall variability with an increasing trend especially since the beginning of the last decade (Fig. 2). The trend was such that the annual rainfall which fell to about 1250 mm during the decade 1980s, particularly in 1983, recovered thereafter and remained higher than 1500 mm for most parts of the last two decades of the previous century. Oloruntade et al. (2017) earlier reported the recovery of wet conditions in most parts of the country since early 1980s after the drought of the early 1970s. However, the fall in annual rainfall in 1983, over the entire period, somehow also repeated itself in 1993, 2003 and 2013, creating an interesting cycle which may require further study. Moreover, since 2013 increasing rainfall trend has been witnessed over the study area, more noticeable from 2018.

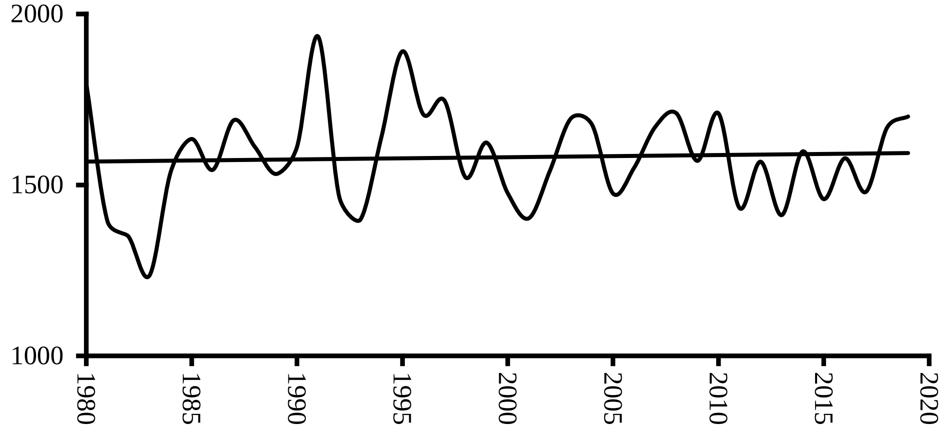

Fig. 2: Plot of annual rainfall time series of Ado-Ekiti

3.2 SPI at Different Timescales

SPI 3-Month

Fig. 3 shows the SPI values of Ado-Ekiti on a 3-month time scale. Extreme drought conditions (SPI values of -2 and less) were obtained in 1982, 1983, 1987, 1991, 1994, 1997 and 1999, indicating that annual rainfalls during those periods were well below the long-term average, resulting in dry spells. Similarly, severe droughts (SPI values from -1.5 to -1.99) were obtained in 1980, 1982, 1984, 1985, 1989, 2002, 2011 and 2017, while mild droughts (SPI values between -0.99 and 0.99) were obtained in 1981, 1983, 1984, 1992, 2001, 2003, 2006, 2008, 2009, 2010, 2012, 2016, 2017, 2018, 2019 and 2022, indicating relatively near normal conditions with no severe dryness and no excessive wetness. SPI values between 1 and 1.49 were obtained in 1988, 1997 and 1999 these years experienced moderately wet conditions. SPI values between 1.5 and 1.99 were obtained in 1994, 1995, 1996 and 1998 experienced very wet conditions which shows that there was abundant rainfall within those years. SPI values of 2.0+ were obtained in 1980, 1982, 1985, 1987, 1990, 1997, 2003, 2008, 2015 and 2018, implying that the city of Ado-Ekiti were extremely wet during those years. Given that droughts at 3-month timescale are of significant importance to most food crops, the results of extremely dry conditions in many years in this study suggests that production of such crops may have been negatively affected.

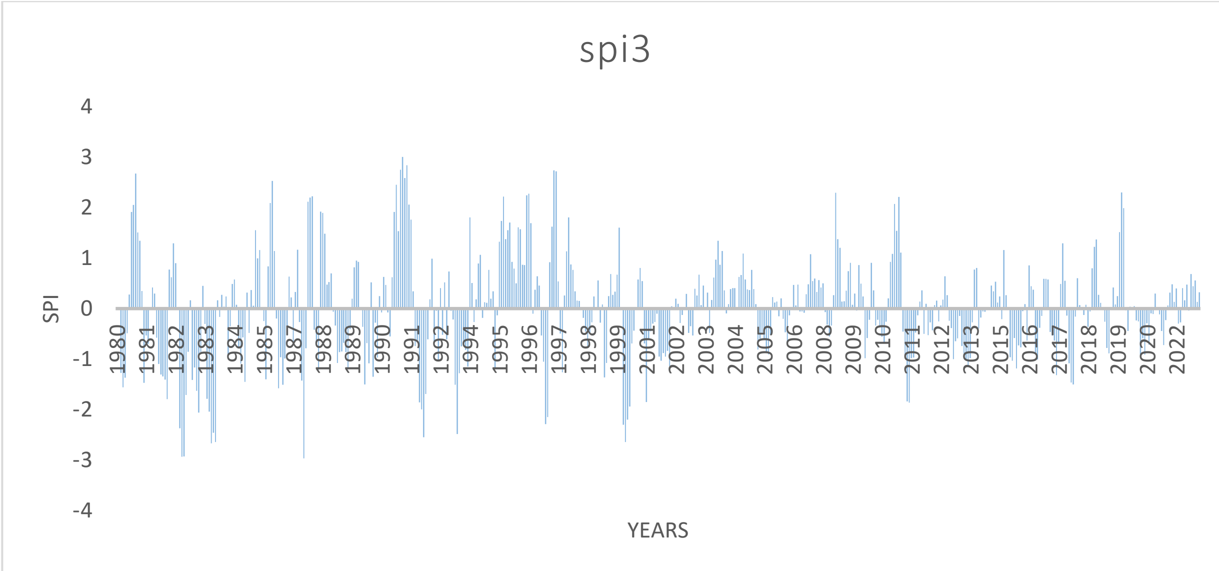

Fig. 3: Time Series plot of SPI 3-month

SPI 6-Month

Fig. 4 shows the SPI values of Ado-Ekiti on a 6-month time scale. In 1992, 1984, 1992 and 2000, SPI values of -2 and less were obtained which means there was extreme drought in that period in Ado-Ekiti, it shows that the region experienced severe deficiency in rainfall over a 6-month period. In 1993 and 2012, SPI values that were between -1.5 to -1.99 were obtained, this suggests that there was a significant shortage of precipitation, leading to series of severe dry conditions. Ado-Ekiti had SPI values from, -1.0 to -1.49 in 1981, 1982, 1986, 1989, 1990, 1998, 2001, 2013, 2016, 2017 and 2018, which also indicates moderately dry conditions during those periods. In 1998, 2002, 2006, 2010, 2014, 2020 and 2021, SPI values of between -0.99 and 0.99 were obtained. This means near normal conditions during those periods and suggests that rainfall was sufficient. Moreover, during the years 2004, 2009 and 2018, moderately wet conditions were observed as SPI values ranged between 1.0 to 1.49. The SPI values in 1986, 1988, & 2020 were between 1.5 – 1.99 and this means that very wet conditions in those periods. In addition, there were cases of extremely wet conditions in 1980, 1991, 1996, 1997 and 2010 as a result of excessive rainfall which might have resulted in flooding or other water related problems.

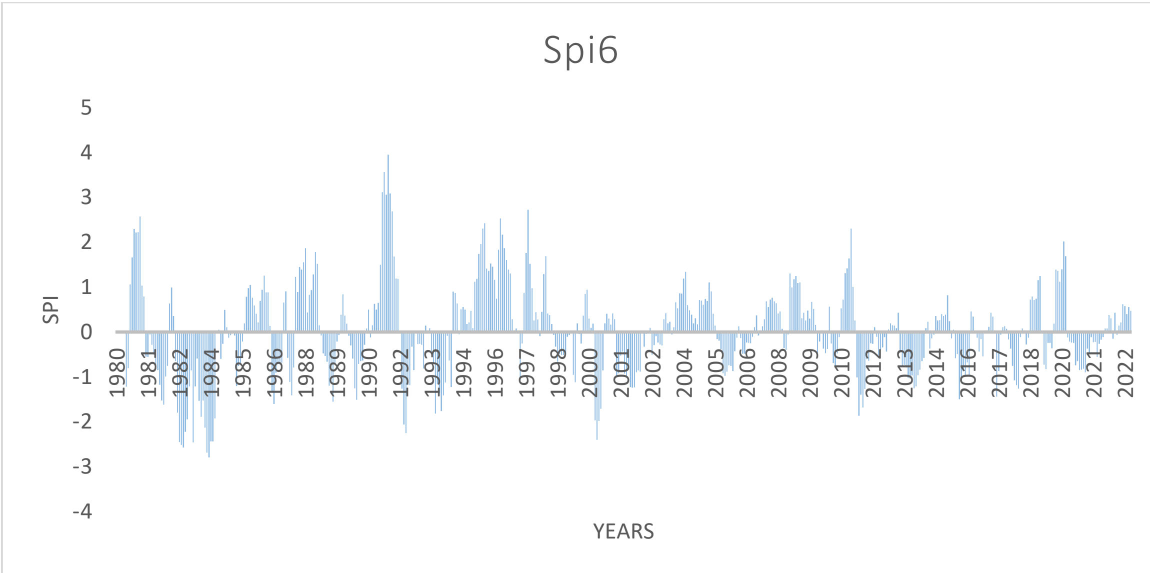

Fig. 4: Time Series plot of SPI 6-month

SPI 12-Month

Fig.5 shows the occurrence of drought for a 12-month SPI over Ado-Ekiti. First, there were extreme drought conditions from 1983 to 1984 as SPI values of -2 and less were obtained in those years signalling severe deficiency in precipitation, with significant negative impacts on agriculture and water resources. SPI values ranging between -1.0 and -1.49 were recorded in 1981, 1987, 1992, 1993, 2002, and 2014, which shows that Ado-Ekiti experienced a moderately dry condition during those periods. Moreover, SPI values ranging from -0.99 to 0.99 were recorded in 1989, 1990, 1999, 2001, 2007, 2010, 2016, 2017 and 2020 which shows that Ado-Ekiti experienced a near normal condition with balanced rainfall. However, in 1986, 1987, 1998, 2008, 2010, 2020, the SPI of between 1.0 – 1.49 were demonstrated that those periods experienced moderately wet conditions. SPI vales ranging from 1.5 – 1.99 were recorded in 1981 and 1998 which means that Ado-Ekiti experienced a very wet condition during those periods. Ado-Ekiti experienced extreme wetness in 1992 and 1996 because their SPI values were >2.0. This suggests that, rainfall was generally normal in many more years using 12-month timescale in the study area.

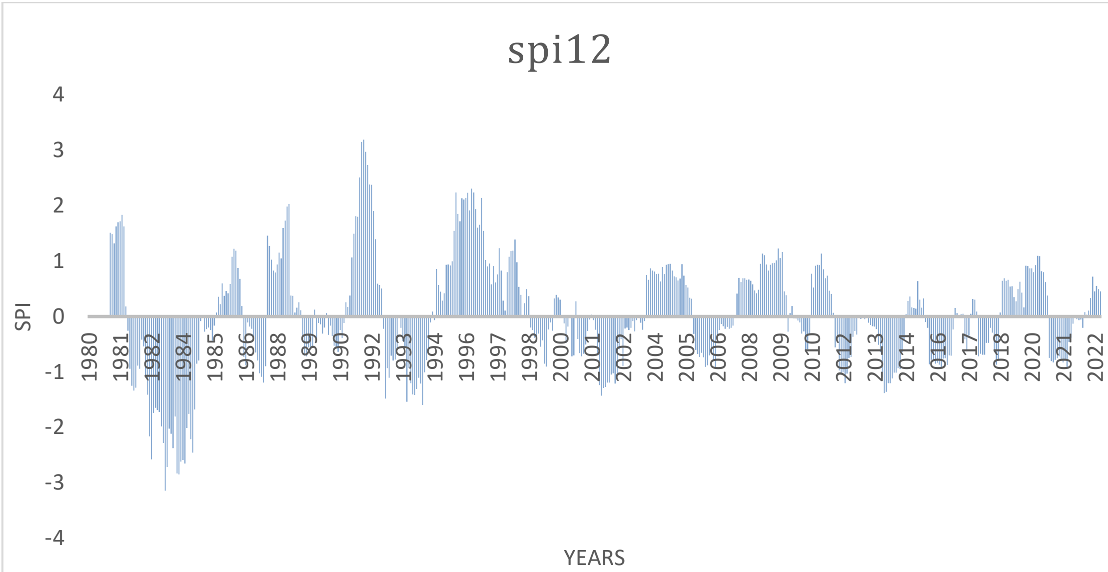

Fig. 5: Time Series plot of SPI 12-month

4. Conclusions and Recommendations

From the results of the study, the following conclusions are made:

(i) high annual rainfall variability which may make crop and irrigation planning difficult, especially during the growing season and off-season, respectively

(ii) despite that the study area has experienced more wet conditions which may lead to increased agricultural production if well harnessed, extreme and severe dry conditions were common at shorter timescales which could be detrimental to cultivation of many food crops.

Consequent upon the foregoing, the following recommendations are found useful:

(i) farmers should make provisions for supplementary irrigation during off-season farming

(ii) adequate provision should be made for water storage and flood control infrastructure in Ado-Ekiti following the mostly wet conditions observed in the study.

References

Ayanlade, A., Radeny, M., Morton, J. F. and Muchaba, T. (2018). Rainfall variability and drought characteristics in two agro-climatic zones: An assessment of climate change challenges in Africa. *Science of the Total Environment*, 630, 728-737.

Bae, S., Lee, S. H., Yoo, S. H. and Kim, T. (2018). Analysis of drought intensity and trends using the modified SPEI in South Korea from 1981 to 2010. *Water*, 10(3), 327.

Burke, E. J., Brown, S. J. and Christidis, N. (2006). Modeling the recent evolution of global drought and projections for the twenty-first century with the Hadley Centre climate model. *Journal of Hydrometeorology*, 7(5), 1113-1125.

Dai, A. (2011). Drought under global warming: a review. *Wiley Interdisciplinary Reviews: Climate Change*, 2(1), 45-65.

Edwards, D. C. and McKee, T. B. (1997). Characteristics of 20th century drought in the United States at multiple time scales. *Atmospheric Science Paper No. 634*, Climatology Report No. 97-2. Colorado.

FAO, 2013. Towards more resilient societies. In: The High-level Meeting on National Drought Policy, (Geneva, Switzerland).

Funk, C., Michaelsen, J. and Marshall, M. (2012). Mapping recent decadal climate variations in precipitation and temperature across Eastern Africa and the Sahel. In: Wardlow, B., Anderson, M. and Verdin, J. (Eds.) *Remote Sensing of Drought—Innovative Monitoring Approaches*. London: Taylor and Francis, pp. 331–357.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S. and Michaelsen, J. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific Data* 2(1): 1-21.

Hernandez, E. A. and Uddameri, V. (2014). Standardized precipitation evaporation index (SPEI)-based drought assessment in semi-arid south Texas. *Environmental Earth Sciences*, 71, 2491-2501.

Lloyd-Huges, B., Saunders, M.A. (2002). A drought climatology for Europe. *International Journal Climatology*, 22: 1571-1592.

McKee, T. B., Doesken, N. J., and Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In: *Proceedings of the 8th Conference on Applied Climatology*, 17(22): pp. 179-183).

Nam, W. H., Hayes, M. J., Svoboda, M. D., Tadesse, T. and Wilhite, D. A. (2015). Drought hazard assessment in the context of climate change for South Korea. *Agricultural Water Management*, 160, 106-117.

Oguntunde, P. G., Lischeid, G. and Abiodun, B. J. (2018). Impacts of climate variability and change on drought characteristics in the Niger River Basin, West Africa. *Stochastic Environmental Research and Risk Assessment*, 32, 1017-1034.

Oladipo, E. O. (1995). Some statistical characteristics of drought area variations in the savanna region of Nigeria. *Theoretical and Applied climatology*, 50, 147-155.

Oloruntade, A. J., Mohammad, T. A., Ghazali, A. H. and Wayayok, A. (2017). Analysis of meteorological and hydrological droughts in the Niger-South Basin, Nigeria. *Global and Planetary Change*, 155, 225-233.

Paulo, A. A., Rosa, R. D. and Pereira, L. S. (2012). Climate trends and behaviour of drought indices based on precipitation and evapotranspiration in Portugal. *Natural Hazards and Earth System Sciences*, 12(5), 1481-1491.

Rahman, M. N., Rony, M. R. H. and Jannat, F. A. (2021). Spatiotemporal evaluation of drought trend during 1979–2019 in seven climatic zones of Bangladesh. *Heliyon*, 7(11).

Rouault, M. and Richard, Y. (2003). Intensity and spatial extension of drought in South Africa at different time scales. *Water SA*, 29(4), 489-500.

Shiru, M. S., Shahid, S., Alias, N. and Chung, E. S. (2018). Trend analysis of droughts during crop growing seasons of Nigeria. *Sustainability*, 10(3), 871.

Shiru, M. S., Shahid, S., Chung, E. S. and Alias, N. (2019). Changing characteristics of meteorological droughts in Nigeria during 1901–2010. *Atmospheric Research*, 223, 60-73.

Touma, D., Ashfaq, M., Nayak, M. A., Kao, S. C. and Diffenbaugh, N. S. (2015). A multi-model and multi-index evaluation of drought characteristics in the 21st century. *Journal of Hydrology*, 526, 196-207.

Wang, H., Pan, Y. and Chen, Y. (2017). Comparison of three drought indices and their evolutionary characteristics in the arid region of northwestern China. *Atmospheric Science Letters*, 18(3), 132-139.

WMO, 2012. Standardized Precipitation Index User Guide. WMO-No. 1090, Geveva, Switzerland.http://www.wamis.org/agm/pubs/SPI/WMO_1090_EN.pdfhttp://dx.doi.org/10.1175/2007JCLI1348.1