International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 12 (2019), pp. 2200-2206

Gap Analysis in the Current Knowledge Limitations in Drought Assessment Research in the Eastern Nile River Basin

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Abstract

The drought recurrence builds up potential stresses affecting the countries with transboundary river basins. The Nile River is the lifeblood for 11 countries in Africa. In addition, it was and still a point of interest and under extensive researches since early civilization. According to the International Disasters Database (EM-DAT), the Eastern Nile Basin (ENB) suffered from several periods of droughts in the last 30 years that affected millions of lives and led to serious economic, environmental and health impacts. Moreover, the increase in water demand due to population growth and associated development will be most critical in severe drought periods. Therefore, drought monitoring and assessment techniques are crucial to allow mitigation measures to reduce the drought's destructive impacts and losses. This paper assesses the recent researches related to drought occurrence, its extent and distinguishing between types of drought and the commonly used drought indices on the ENB. It is revealed that the drought assessment studies never dealt with the dependency between the sub-catchments of the ENB that have a dynamic regime affected by drought events. In conclusion, the paper identified the gaps in drought assessment research if addressed by researchers, could create substantial leverage on water management under drought conditions.

Keywords: Eastern Nile Basin; Drought assessment; Drought indices; Transboundary Rivers

I. INTRODUCTION

Floods and Droughts are hydrological extreme events. Although flood has a beginning, an end and brutal impacts on infrastructures, drought is a slow-onset phenomenon that evolves over a season or years. Moreover, drought affects people more than any other event of natural disasters [1]. The definition of drought is complex. So far, there is no universal definition agreed by scientists, related disciplines and policy makers [2]–[4] or even defined strictly in terms of climate variability [5] which made Wilhite [3] deducing that drought definition should be region and impact specific. Consequently, many definitions of drought were derived based on drought type. Droughts are classified into four main types' namely meteorological drought, agricultural drought, hydrological drought, and socioeconomic drought [6]. The shortage of precipitation in contrast with average value for a period of time over a specific area is a meteorological drought; while the agricultural drought is described as shortage in crop growth and yield due to insufficient soil moisture content. The hydrological drought is related to deficiencies in water resources due to long dry period, and socioeconomic drought occurs when water supply unable to fulfil water demand, leading to negative impacts on society, environment, and economy [6]–[9]. It can be concluded that all drought types are related to the dry period and its negative impacts on different human activities. Many researchers, however, derived and developed drought indices based on different parameters to evaluate the influence of the drought and defining its different characteristics on a particular area[6].

Drought indices represent a single value that is a result of a huge amount of data. This uncomplicated source of information is easy to convey the important message to diverse audiences, and stakeholders such as decision-makers, stakeholders, policy-makers, end-users...etc. The majority of the used drought indices relies on precipitation and temperature values. They are the first variables in the timing chain in order to anticipate drought impacts and they have mostly free and available long-term records for many worldwide regions. However, the assessment of drought requires information and investigation on the dependency of regional and local communities on water use, agriculture productions, economic growth, population rate, as well as hydro-meteorological values. This could be accomplished by investigating the readily developed drought indices or develop new ones which can capture the drought characteristics on time and space scales. **Table *1*** shows a sample list of the available drought indices found in the literature. However, socioeconomic drought is the least investigated[10], and only few indices were derived, SEDI which was introduced by Shi et al. [10], and MSRRI created by Mehran et al. [11].

These indices have their own advantages and limitations and their performance is region-dependent. Some researchers provided literature reviews and classifications of the available drought indices[1], [12]–[17] which described their strengths and weaknesses. Furthermore, it was recommended combining drought indices to incorporate and utilize information effectively to define the droughts over a region[4], [17], [18].

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Table 1. Sample of drought indices

Index	Type
Palmer Drought Severity Index: P.D.S.I.	Meteorological
Standardized Precipitation Index: S.P.I.	Meteorological
Statistical Z-Score : Z-Score	Meteorological
Standardized Precipitation Evaporation Index : S.P.E.I.	Meteorological
Reconnaissance Drought Index: R.D.I.	Meteorological
Crop-Specific Drought Index: C.S.D.I.	Agricultural
Soil Moisture Drought Index: S.M.D.I.	Agricultural
Evapotranspiration Deficit Index: E.T.D.I.	Agricultural
Crop Moisture Index: C.M.I.	Agricultural
Surface Water Supply Index: S.W.S.I.	Hydrological
Palmer Hydrological Drought 0Index: P.H.D.I.	Hydrological
Standardized Reservoir Supply Index: S.R.S.I.	Hydrological
Standardized Runoff-discharge Index: S.R.I.	Hydrological
Socioeconomic Drought Index: S.E.D..I	Socioeconomic
Multivariate Standardized Reliability and Resilience Index: M.S.R.R.I.	Socioeconomic
Aggregate Drought Index: A.D.I.	Combined

Many drought studies in the last years concluded that climate change and variability are the triggers of the occurrence and severity in some areas in Eastern Africa [19]–[23]. Drought assessment research activities in the Eastern Nile Basin (ENB) had been increased in recent years because of the historical recurrence of the dry periods. The International Disasters Database EM-DAT reported that in the last years there have been several periods of droughts in Ethiopia and Sudan, which contributed to food-insecure conditions and in consequence led to people displacement and a massive economic damage costs. Therefore, in order to mitigate the drought negative impacts, the need for monitoring mechanisms and assessment of drought became very crucial.

The aim of this paper is to provide an up to date information on drought assessment of the ENB and focused on the knowledge limitations in using the drought indices. This will lead to a better water management for the three-shared countries under drought conditions.

II. THE EASTERN NILE BASIN (ENB)

The Eastern Nile area covers a large part of the Nile Basin and maintains the millions of lives in Egypt, Ethiopia, and Sudan. The area covers three major sub-basins namely, the Baro-Akobo-Sobat, the Blue Nile and the Tekeze-Atbara, and has a contribution of 85% to the total Nile flow **Figure *1***. The region is characterized by heavy seasonal rainfall, which has a great impact on the essential aspects of life in the region.

Two major tributaries perform the Baro-Akobo-Sobat River: The Pibor River originates from the Southern Sudan and northern Uganda and the Baro River originates from Ethiopia. Half of the flow of the White Nile comes from the Baro-Akobo-Sobat River, as it has the same outflow of Sudd [24]. This might because of the large-scale waterlogged areas, which are creating marshlands.

The Blue Nile River originates from Ethiopian plateau, with a basin area of about 324,530 km^2 [25]. There are many streams, which discharge in Lake Tana, where Blue Nile starts, however the little Abbay is considered the main tributary. Some studies divided the Blue Nile drainage basin into two parts; The Upper Blue Nile which represents the part of river inside Ethiopia until it reaches the border with Sudan and the lower basin part that outside Ethiopia until it joins the White Nile River at Khartoum. There are several tributaries of the Upper Blue Nile that feed the river from left and right banks, while two tributaries, Rahad, and Dinder inside Sudan.

The Tekeze-Atbara is the last and the most seasonal tributary for the Nile. The basin has a drainage area of about 231,000 km^2 where the majority of the basin about 51% is located in Sudan then 39% of the area in Ethiopia and only 10% in Eritrea [26].

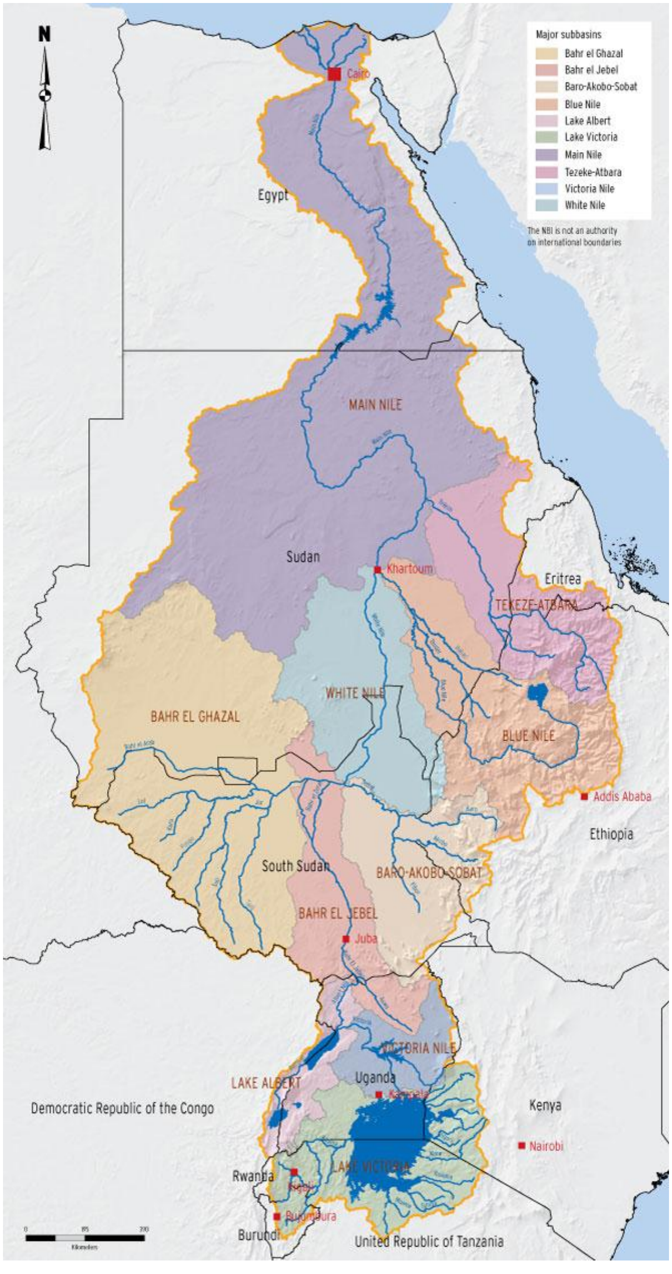

Figure 1. Major Sub-Basins of the Nile (Source: Nile Basin Water Resources Atlas)

III. THE DROUGHT ANALYSIS

III.I The Drought in the Eastern Nile Basin (ENB)

Two researches used the SPI to evaluate the historical meteorological droughts in the ENB. During the period 1965 – 2000, twenty- eight meteorological gauges scattered all over the basin were used to identify the changes in drought frequency, magnitude, duration, and intensity[27]. The SPI analyses were able to indicate several drought events with the most severe event in 1984. In the other research, two reference rainfall datasets were used in exploring the effect of climate change on drought risk (A- The rainfall data set provided by the Climatic Research Unit (CRU), and B- rainfall reanalysis data set (ERA40) provided by the European Center for Medium-Range Weather Forecasting) [28]. The authors applied their study on the Blue Nile Basin and Atbara River for historical period of 1961 – 1990 and for future period of 2021 – 2050. Although both datasets gave analogous results for the probability of drought, the rainfall from ERA40 was overestimated compared to the rainfall from CRU. Both studies detected the historical droughts by SPI. However, it is difficult to compare between them since they used different data set and did different statistical analyses.

III.II The Drought in the Upper Blue Nile (UBN)

The SPI was used to analyze the frequency of the drought classifications and their distribution over the UBN [29]. In addition, the authors investigated the effect of the different record length on drought classifications. They used 14 rainfall stations as an indication for long records (1953 – 2009) and 23 rainfall stations for short records (1975 – 2009). The analyses showed that the data length has a limited effect on the SPI values and in consequences, the drought classification. The SPI captured the drought events occurred in 1970s, 1980s, 1990s, and 2000s. Although it was difficult to define which areas are drought-prone, more than 50% of drought frequencies were noticed in the central, western and southern parts of the Basin. Additionally, the analyses did not reveal any notable trend for droughts either for descending or ascending. That was the same result gotten by Khadr [30] who applied the SPI to assess the magnitude and the trend of the historical metrological drought on temporal and spatial attributes for the 49 years (1960 – 2008) using 22 rainfall gauges. The SPI was calculated for quartile time scale from 3 to 24 months. The SPI series show frequent moderate to severe droughts during 1961, 1965 and 1980–1987. Furthermore, the constructed Severity Areal Extent Frequency (SAF) curves marked that the severe drought with short return periods affects only small parts of region while a long return period with near-normal 24 months may cover the whole region. The drought prone areas were different based on the year analyzed. The center was the most affected part during the drought of 1964, while the western and northern parts are the most affected during the drought of 1984.

Likewise, the Hidden Markov Model (HMM) was used to forecast droughts using the SPI at short-medium term with same date of the previous study [31]. With adequate accuracy, the model could forecast the monthly SPI about 7 months backward and can be used as a tool for drought early warning.

However, the accuracy of forecasting decreases as the lead time increases.

Away from using the SPI, the Z-Score index was used [32]. The index captured the recorded drought events in 1980s, 1990s, and 2010s, resolution of Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) v2.0 was used in calculation of the 3-month Z-Score values through the rainy Kiremit season for the period 1983 – 2015 but it didn't capture the drought of 2003/2004 like previous studies[29], [30]. Nonetheless, the central part of the basin was a drought-prone area to severe drought which agreed with the previous studies.

On the other hand, El Niño index was used to analyze the correlation between it and the outflow of the UBN for 48 years starting from 1965[33]. The results found that there is a high connection between the time of El Niño and La Niña events and the incidence of floods and droughts. In particular, there is 80 percent likelihood of drought if the El Niño begins in June-August and July – September and a higher percentage of 83% if the El Niño begins in April –June. However, the authors declared that the obtained results are based on only six events of El Niño which require more investigation.

Following a new path toward using more than one index to assess the drought, a comparison of six drought indices (SPI, SPEI, ETDI, ADI, and SRI) was done to characterize the historic drought in the UBN [34]. In addition, they utilized various data from year 1970 to year 2010 in their calculation for these six indices. It was found that the meteorological indices characterize the drought in shorter months than the agricultural indices. In contrast, was for maximum drought duration was higher in meteorological indices compared to the agricultural indices. This is mainly because that the agricultural indices embrace other inputs which affected by the wet events between two droughts events. In general, the agricultural drought was affected by the meteorological drought differently temporally and spatially, and the hydrological drought was more persistence even at lower time scale.

III.III The Drought in the Blue Nile (BN)

Based on Precipitation forecasting taken from the seasonal climate forecast systems, the SPI was used on five African basins, incl. the Blue Nile, to determine the ability of an integrated drought monitoring and seasonal forecasting system to predict up to 5 months lead time [35]. The authors found that the scarce climate data in the studied basins lessened the capabilities of the verification and monitoring of droughts in the different basins. Yet, The Blue Nile showed higher reliability for the seasonal forecasts. Furthermore, the quality of the precipitation products affects the quality of the seasonal forecasts.

From 130 of long streamflow time series at Aswan, the probability of occurrence of droughts was investigated [36]. The authors used a combination between the linear moments (L-moments) for parameter estimation with a segmentation procedure to avoid the effects of the outliers. After separation of the White Nile inflow contribution to track the seasonality of the Blue Nile and Atbara, they found that the variation in the flow affirmed the Hurst phenomenon and the results captured the drought periods of the 1980s with affirmation of non-stationarity of the flow series.

IV. DISCUSSION

This article is inspired by the fact that, although there are many drought indices developed around the world, the majority of them were developed for regions that have completely different characteristics than the Nile Basin and its varieties. Additionally, their suitability was not tested appropriately for the basin. We investigated the most of the up-to-date drought indices studies on the ENB for drought assessment purpose, which is summarized in **Table *2***. Obviously, more than 50 percent of the studies addressed the UBN and little attention was given to the ENB while there was thoughtlessness towards Baro-Akobo-Sobat Basin and the Tekeze-Atbara basin. Moreover, most of the studies focused on the meteorological drought by using the SPI to investigate its capabilities to capture the historical droughts of the entire basin or the sub-catchment. The SPI is widely used for its only one-based precipitation parameter and its straightforward calculation where there is limited access to the data or non-availability of long-records data. Most of the studies did their investigations based on observed data covering the period of the 1960s to 2000s to comprise the most critical drought periods that occurred historically. The calculation procedure was point-based representing the location of the metrological stations. Then the researchers used different statistical techniques to interpolate the results spatially in order to explore the drought-prone areas.

It can't be said that there is agreement between the studies for specific drought-prone areas. This could be affected by several reasons, the scattered distribution of the meteorological station which leads to inappropriate representation for the area, the different interpolation methods, and the different analysis season for the same year. Furthermore, although most of the studies used the SPI but not all of them captured the same drought years. This situation should prompt questioning about the reliability of each interpolation method since it depends on the data length and its quality. On the other hand, only one study that investigated the agricultural and hydrological drought indices and their relation with the meteorological drought. Another sole study that provided a long-term analysis of droughts considering past and future perspective at the ENB scale. None of the studies considered the socio-economic drought or the effect of the planned development projects on the ENB on sub-catchment or on basin scale. Nor did any of the studies deliver an appropriate drought assessment tool that can be used to define the changes in the seasonality of precipitation combined with agricultural and industrial growths and takes into account the delay of the socioeconomic response to drought. Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted

Table 2. Summary of the reviewed studies

Ref. No	Year	Study Name	Basin	Drought Index	Investigated years	Type of data
27	2018	Drought analysis in the Eastern Nile basin using the standardized precipitation index	ENB	SPI	1965 – 2000	Observed
28	2017	Drought Risk Assessment in Eastern Nile under Current and Future Climate Conditions	ENB	SPI	1961 – 1990/ 2021 – 2050	Referenced data/ Remote sensing data
29	2015	patio-temporal assessment of meteorological drought under the influence of varying record length: the case of Upper Blue Nile Basin, Ethiopia	UBN	SPI	1953 – 2009 1975 – 2009	Observed
30	2017	Temporal and spatial analysis of meteorological drought characteristics in the upper Blue Nile river region	UBN	SPI	1960 – 2008	Observed
31	2016	Forecasting of meteorological drought using Hidden Markov Model (case study: The upper Blue Nile river basin, Ethiopia)	UBN	SPI	1960 – 2008	Observed
32	2017	Evaluation of Satellite-Based Rainfall Estimates and Application to Monitor Meteorological Drought for the Upper Blue Nile Basin, Ethiopia	UBN	Z-Score	1983 – 2015	Remote sensing data
33	2014	Droughts and floods over the upper catchment of the Blue Nile and their connections to the timing of El Niño and La Niña events	UBN	El Niño index	1965 – 2012	Remote sensing data
34	2018	Comparison of the Performance of Six Drought Indices in Characterizing Historical Drought for the Upper Blue Nile Basin, Ethiopia	UBN	SPI, SPEI, ETDI, SMDI, ADI, SRI	1970 – 2010	Observed
35	2013	Seasonal forecasts of droughts in African basins using the Standardized Precipitation Index	BN	SPI	1979 – 2010	Remote sensing data
36	2014	Evolution of the Nile River drought risk based on the streamflow record at Aswan station, Egypt	BN	-	1871 - 2000	Observed

V. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, the investigation held on drought analysis in the ENB gave insight about gaps that, if resolved, could have substantial leverage on water management and planning. Since water management in the basin has historically been a controversial issue and might be a cause of tension between the countries, which often have a sole dependency on the Nile as a water resource (e.g., Sudan and Egypt). In this context, the availability of an adequate drought assessment tool will significantly contribute to essential aspects in the region such as water security, food security, hazard management, and risk reduction.

The gap analysis inspired the authors to propose the following recommendations which could lead to a better understanding of the complexity of the drought assessment in the ENB;

- The most important suggestion, in our point of view, is to investigate the ENB as one unit of sub-catchments. Knowing how a multi-objective system with a dynamic regime is affected by drought events will help in taking the right action towards coping with potential associated risks.
- More attention should be given to the drought assessment of the Baro-Akobo-Sobat Basin, and the Tekeze-Atbara basin.
- Additional research into the applicability of more drought indices is necessary.
- Set assessment criteria to choose the most appropriate index/indices for detecting the drought characteristics on the ENB scale.
- The different response time of the hydrological and the agricultural drought to the meteorological drought crucially needs further analysis.
- Drought under the effect of climate change and the ongoing and future developments projects should be investigated.
- The knowledge over the necessity of drought assessment and forecasting tools should be highlighted to the decision-makers and stakeholders.

REFERENCES

[1] J. Keyantash and J. A. Dracup, "The quantification of drought: An evaluation of drought indices," *Bull. Am. Meteorol. Soc.*, vol. 83, no. 8, pp. 1167–1180, 2002.

[2] J. A. Dracup, K. S. Lee, and E. G. Paulson, "On the definition of droughts," *Water Resour. Res.*, vol. 16, no. 2, pp. 297–302, Apr. 1980.

[3] D. A. Wilhite, "Drought as a natural hazard: Concepts and definitions," in *Drought: A Global Assessment, Vol. I*, D. A. Wilhite, Ed. London: Routledge, 2000, pp. 3–18.

[4] W. M. O. (WMO) and G. W. P. (GWP), *Handbook of Drought Indicators and Indices*, no. 1173. Geneva: Integrated Drought Management Programme (IDMP), 2016.

[5] N. A. Coles and Saied Eslamian, "Definition of Drought," in *Handbook of Drought and Water Scarcity. Vol 1. Principles of Drought and Water Scarcity*, S. Eslamian and F. Eslamian, Eds. Taylor Francis, 2017.

[6] A. K. Mishra and V. P. Singh, "A review of drought concepts," *J. Hydrol.*, vol. 391, no. 1–2, pp. 202–216, Sep. 2010.

[7] D. A. Wilhite and M. H. Glantz, "Understanding: the Drought Phenomenon: The Role of Definitions," *Water Int.*, vol. 10, no. 3, pp. 111–120, Jan. 1985.

[8] A. Dai, K. E. Trenberth, and T. Qian, "A Global Dataset of Palmer Drought Severity Index for 1870–2002: Relationship with Soil Moisture and Effects of Surface Warming," *J. Hydrometeorol.*, vol. 5, no. 6, pp. 1117–1130, Dec. 2004.

[9] J. ten Broek, A. J. Teuling, and A. F. Van Loon, "Comparison of drought indices for the province of Gelderland, The Netherlands MSc Thesis, Wageningen," 2014.

[10] H. Shi, J. Chen, K. Wang, and J. Niu, "A new method and a new index for identifying socioeconomic drought events under climate change: A case study of the East River basin in China," *Sci. Total Environ.*, vol. 616–617, pp. 363–375, Mar. 2018.

[11] A. Mehran, O. Mazdiyasni, and A. Aghakouchak, "A hybrid framework for assessing socioeconomic drought: Linking climate variability, local resilience, and demand," *J. Geophys. Res. Atmos.*, vol. 120, no. 15, pp. 7520–7533, 2015.

[12] A. Dai, "Drought under global warming: a review," *Wiley Interdiscip. Rev. Clim. Chang.*, vol. 2, no. 1, pp. 45–65, Jan. 2011.

[13] R. R. Heim, "A Review of Twentieth-Century Drought Indices Used in the United States," *Bull. Am. Meteorol. Soc.*, vol. 83, no. 8, pp. 1149–1165, Aug. 2002.

[14] Q. Mu, M. Zhao, J. S. Kimball, N. G. McDowell, and S. W. Running, "A Remotely Sensed Global Terrestrial Drought Severity Index," *Bull. Am. Meteorol. Soc.*, vol. 94, no. 1, pp. 83–98, Jan. 2013.

[15] E. L. tate and A. Gustard, "A. Drought Definition: A Hydrological Perspective," in *Drought and Drought Mitigation in Europe*, J. Y. Vogt and F. Somma, Eds. Kluwer Academic Publishers., 2000, pp. 23–48.

[16] S. M. Quiring, "Monitoring Drought: An Evaluation of Meteorological Drought Indices," *Geogr. Compass*, vol. 3, no. 1, pp. 64–88, Jan. 2009.

[17] A. Zargar, R. Sadiq, B. Naser, and F. I. Khan, "A review of drought indices," *Environ. Rev.*, vol. 19, no. NA, pp. 333–349, Dec. 2011.

[18] M. V. K. Sivakumar, R. P. Motha, D. A. Wilhite, and D. A. Wood, Eds., "Agricultural Drought Indices Proceedings of a WMO Expert Meeting," in *d P. Motha, Donald A. Wilhite and Deborah A. Wood (Eds.). 2011. Agricultural Drought Indices. Proceedings of the WMO/UNISDR Expert Group Meeting on Agricultural Drought Indices, 2-4 June 2010, Murcia, Spain*, 2010, p. 197.

[19] O. Rojas, A. Vrieling, and F. Rembold, "Assessing drought probability for agricultural areas in Africa with coarse resolution remote sensing imagery," *Remote Sens. Environ.*, vol. 115, no. 2, pp. 343–352, Feb. 2011.

[20] W. B. Anderson *et al.*, "Towards an integrated soil

moisture drought monitor for East Africa," pp. 2893–2913, 2012.

[21] I. Masih, S. Maskey, F. E. F. Mussá, and P. Trambauer, "A review of droughts on the African continent: a geospatial and long-term perspective," *Hydrol. Earth Syst. Sci.*, vol. 18, no. 9, pp. 3635–3649, Sep. 2014.

[22] E. Dutra *et al.*, "The 2010-2011 drought in the Horn of Africa in ECMWF reanalysis and seasonal forecast products," *Int. J. Climatol.*, vol. 33, no. 7, pp. 1720–1729, Jun. 2013.

[23] E. Coughlan de Perez *et al.*, "From rain to famine: assessing the utility of rainfall observations and seasonal forecasts to anticipate food insecurity in East Africa," *Food Secur.*, vol. 11, no. 1, pp. 57–68, Feb. 2019.

[24] J. V Sutcliffe and Y. P. Parks, *The Hydrology of the Nile*. Oxfordshire: The International Association of Hydrological Science, 1999.

[25] P. A. Johnson and P. D. Curtis, "Water Balance of Blue Nile River Basin in Ethiopia," *J. Irrig. Drain. Eng.*, vol. 120, no. 3, pp. 573–590, May 1994.

[26] M. Basheer, R. Sulieman, and L. Ribbe, "Exploring management approaches for water and energy in the data-scarce Tekeze-Atbara Basin under hydrologic uncertainty," *Int. J. Water Resour. Dev.*, vol. 00, no. 00, pp. 1–26, Apr. 2019.

[27] M. Elkollaly, M. Khadr, and B. Zeidan, "Drought analysis in the Eastern Nile basin using the standardized precipitation index," *Environ. Sci. Pollut. Res.*, vol. 25, no. 31, pp. 30772–30786, Nov. 2018.

[28] D. Amin, M. Elshamy, S. Fouda, and T. Kassem, "Drought Risk Assessment in Eastern Nile under Current and Future Climate Conditions," in *Eau–Société–Climat'2017 (ESC-2017) Hammamet*, 2017, vol. 1, pp. 2–7.

[29] Y. a. Bayissa *et al.*, "Spatio-temporal assessment of meteorological drought under the influence of varying record length: the case of Upper Blue Nile Basin, Ethiopia," *Hydrol. Sci. J.*, vol. 60, no. 11, pp. 1–16, Sep. 2015.

[30] M. Khadr, "Temporal and spatial analysis of meteorological drought characteristics in the upper Blue Nile river region," *Hydrol. Res.*, vol. 48, no. 1, pp. 265–276, Feb. 2017.

[31] M. Khadr, "Forecasting of meteorological drought using Hidden Markov Model (case study: The upper Blue Nile river basin, Ethiopia)," *Ain Shams Eng. J.*, vol. 7, pp. 47–56, 2016.

[32] Y. Bayissa, T. Tadesse, G. Demisse, and A. Shiferaw, "Evaluation of Satellite-Based Rainfall Estimates and Application to Monitor Meteorological Drought for the Upper Blue Nile Basin, Ethiopia," *Remote Sens.*, vol. 9, no. 7, p. 669, Jun. 2017.

[33] M. A. H. Zaroug, E. A. B. Eltahir, and F. Giorgi, "Droughts and floods over the upper catchment of the Blue Nile and their connections to the timing of El Niño and La Niña events," *Hydrol. Earth Syst. Sci*, vol. 18, pp. 1239–1249, 2014.

[34] Y. Bayissa *et al.*, "Comparison of the Performance of Six Drought Indices in Characterizing Historical Drought for the Upper Blue Nile Basin, Ethiopia," *Geosciences*, vol. 8, no. 3, p. 81, Feb. 2018.

[35] E. Dutra, F. Di Giuseppe, F. Wetterhall, and F. Pappenberger, "Seasonal forecasts of droughts in African basins using the Standardized Precipitation Index," *Hydrol. Earth Syst. Sci.*, vol. 17, no. 6, pp. 2359–2373, Jun. 2013.

[36] A. G. Awadallah, "Evolution of the Nile River drought risk based on the streamflow record at Aswan station, Egypt," *Civ. Eng. Environ. Syst.*, vol. 31, no. 3, pp. 260–269, Jul. 2014.