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Comparative Analysis of Characteristics of Drought over Some West Africa Regions Based On Selected Drought Assessment Indices

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ABSTRACT: Prolonged absence of moisture exacerbates drought and assessment indices such as Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI) are critical tools. Therefore, the objective of this paper was to evaluate the comparative characteristics of drought over West Africa using SPI and SPEI. The data used in this work was established on four monthly time scales of 3, 6, 12, and 24 and covered a period between 1979 and 2021 (42 years) at five regions in Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid region, Moist-Sub-humid region. The data was further analyzed and the characteristics of the drought were assessed. Data obtained revealed that there were some differences between SPI and SPEI in regional drought characteristics. Most of the regions considered experienced extreme drought in 1982. The result also revealed that more droughts were experienced in the eighties than in the nineties. Likewise some regions experienced severe drought in 2021 due to increase in drought intensity in the year 2021 as recorded by SPI and SPEI. Therefore it is vital for frequent assessment of meteorological drought characteristics in West Africa using recent data in order to explore its impact because climate change prediction can cause places that are currently experiencing mild or moderate drought to become more severe in the future, and the total impact of drought in West Africa will increase. This study could also assist water resource planners to better understand the drought events.

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Drought is a natural phenomenon characterized by low rainfall or precipitation over a long period of time. A natural decrease in precipitation over an extended time, such as a season, year, or decade, leads to drought, which is frequently associated with high temperatures, strong winds, and low humidity. (Yacoub and Tayfur, 2017). It is one of the major natural calamities that has a negative impact on people, river basins, water resource systems, and ecosystems (Wambua *et al.*, 2014). Sequel to climate variability, droughts have increased in frequency and severity on a worldwide scale, with different regions experiencing them at varying periods and intensities (Shiru *et al.*, 2020). Intensity and duration of rain, timing and characteristics of rainfall, including distribution of wet days during agricultural growth seasons, high winds, low relative humidity, and temperatures all significantly contribute to the occurrence of droughts (Mishra and Singh, 2010; Li *et al.,* 2020). Drought is categorized into four parts, namely meteorological drought, hydrological drought, agricultural drought, and socioeconomic drought.

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Meteorological drought is determined by the amount of dryness, the lack of rain, and the length of the dry period. Occurrence of meteorological drought results occurrence of the other three types of drought. River basins can be affected by this drought either directly or indirectly, hence, there is decline in crop output, a rise in livestock and wildlife mortality rates, an increase in soil erosion and land degradation, as well as an increase in plant diseases and insect infestations (Wambua *et al.*, 2014). The Sahel, a semiarid region of West Africa between the Sahara desert and the rainforest along the Guinea coast, had been suffering from a drought of exceptional severity since the late 1960s making it one of the poorest regions in the world (Mishra and Singh, 2010). According to the UN World Food Programme, which defined the situation as serious, Niger, Chad, eastern Mali, and northern Cameroon have all been severely impacted by the failing rains. Global warming is a major concern now because of how it influences the rate and timing of evapo-transpiration. Some areas of the world are likely to get wetter due to global warming, while those that are already dry are probably going to become drier. (Li *et al.*, 2020; Wambua *et al.*, 2014). For the planning and management of freshwater resources, drought assessment is of the utmost importance. Understanding the region's past droughts and their effects on the local environment is necessary for this (Mishra and Singh, 2010). Sequel to increasing drought occurrence in West Africa, researchers have been working on highlighting the impact of drought using different drought indices. It is possible to use meteorological variables or parameters to monitor meteorological drought using drought indexes. Drought Indexes are numerical measurements that combine data from one or more variables (indicators), such as precipitation and evapotranspiration, into a single number to quantify the severity of drought. (Yacoub and Tayfur, 2017). These linked indexes are commonly based on temperature and precipitation data series. (Mehr *et al.*, 2020). Several drought indexes exist, these include normal Standardized Precipitation Index (normal-SPI), log normal Standardized Precipitation Index (log-SPI), Standardized Precipitation Index using Gamma distribution (Gamma-SPI), Percent of Normal (PN), the China-Z index (CZI), and Deciles (Yacoub and Tayfur, 2017), and the most recent standardized precipitation evapotranspiration index (SPEI). These DIs were used to launch drought relief initiatives and to calculate water resource shortages to gauge the severity of the drought (Yacoub and Tayfur, 2017). Hence, the objective of this paper was to evaluate the comparative characteristics of drought over West Africa using Standardized Precipitation Index (SPI) and the Standardized Precipitation Evapotranspiration Index (SPEI) from 1979-2021 at five regions in Hyper-Arid region, Sahelian region, Sudano region, Dry Sub-humid region, Moist Sub-humid region

MATERIALS AND METHODS

Study Area: West Africa as defined by the United Nation is the 16 countries of Benin, Burkina Faso, Cameroon, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, and Togo. It is located on coordinate 13.5317°N, 2.4604°W and covers an area of 6.14 million km². It is bordered by the Atlantic Ocean on the west, the Gulf of Guinea on the south, and the Sahara and the Sahel, a semiarid belt-shaped transition region between the Sahara desert and the Sudanian Savanna, on the north. Owing to latitudinal oscillation of the Inter-tropical Discontinuity (ITD), West Africa exhibits a bi-modal rainfall pattern. The dry season begins in October and lasts until March of the following year, whereas the wet season begins in April and lasts until September (Eresanya *et al.*, 2017). The dry Sahara to the north and east, which produces dry winds during the harmattan and the humid climate of the Atlantic to the south and west, which produces seasonal monsoons, have a significant impact on the climate and ecosystem. West Africa can be split into five broad east-west bands that define the climate and vegetation from north to south or from the Sahara to the humid southern coast. The bioclimatic regions are referred to as the Saharan, Sahelian, Sudanese, Guinean, and Guinea-Congolian Regions. The Sahel and Sudan zones are the "harsh lands" of West Africa.' These arid and semi-arid lands include parts of present day Senegal, Mali, Northern Ghana, Mauritania, Niger, Northern Benin, Upper Volta, Chad, and Northern Nigeria. The term "harsh lands" describes an area of extreme environmental uncertainty, but it also describes as a place where man has learned to survive by taking advantage of its natural resources and its productive microenvironments, by cooperating with people who lead different but complementary lifestyles, and by creating biologically rich habitats where specific plants can grow (Scott, 1979). In West Africa, farmers and nomads frequently use these survival strategies; while they may not be particularly effective by western standards, they are very trustworthy (Scott, 1979). The study area covers the Sahara, Sahel and the Sudan zones. The Sahara Desert to the north and the Sudanese Savana to the south are divided by the West African Sahel region, which extends from the Atlantic Ocean eastward to Chad. The area is one of the poorest and most environmentally damaged in the world, and because temperature rises are expected to be 1.5 times higher than elsewhere in the world, it is also one of the locations that are most sensitive to climate change. Sahel is well known for the severe droughts that ravaged the region in the 1970s and 1980s (Nicholson, 2013). The Sahel region features a hot, semi-arid environment with high temperatures (average of 21.9°–36.4°C) all year long, a long, harsh dry season from October to May, and a short, erratic rainy season related to the West African monsoon. The Sahara, also known as the Saharan Region, is the whole northern portion of West Africa and is made up of the Sahara Desert. It has several different desert environments, from sand sheets and dune fields to gravel plains, low plateaus, and rough mountains. Sahara records between 0 and 150 mm of rain fall on average each year. The Saharan region is the hottest big region on earth due to the high position of the Sun, the extremely low relative humidity, the lack of vegetation, and rainfall. Sudan sits in the transitional zone between the humid, lush equatorial rainforest and the Sahelian arid desert environment. The range of the yearly average temperature is between 23 to 29 degrees. The coldest months have highs of 20 degrees Celsius, while the hottest months have highs of 30 degrees Celsius. Hay, forest cliffs, and gallery forests along the rivers are characteristics of Sudan. Desertification is a problem in the area due to the drought and livestock grazing.

Fig 1: Map of West Africa bioclimatic regions (United Nation, 2014)

Data collection: Many researchers in climatology and related areas rely on long-term observations from precipitation stations. This data is necessary for analyzing climate variability and change (Trenberth, 2011). Monthly precipitation data are primarily used in drought analysis to specify the absence of precipitation at various time scales. These time ranges represent the consequences of drought on the ability to utilize various water supplies (Nosrati and Zareiee, 2011). The meteorological data (precipitation and temperature) used in this research were collected from Copernicus Service managed by The European Commission. Based on long-term recording data and a combined record period duration of 42 years (1979–2021), the monthly precipitation data of 12 stations across three climate zones in West Africa have been chosen. Four different time scales (3, 6, 12, and 24) were considered.

Standard Precipitation Index (SPI): Standardized Precipitation Index (SPI) is a popular metric for describing meteorological drought on various timescales. The SPI is a multi-scalar probability indicator that determines the amount of precipitation lacking during periods of both wet and dry weather and permits drought monitoring at various timescales (McKee *et al.*, 1993). It is the most widely used indicator for identifying and describing meteorological droughts worldwide. Due to its simplicity, monthly data requirement, and general acceptance on a larger scale, this index was recommended by the World Meteorological Organization as a starting point for meteorological drought monitoring and has been utilized in numerous prior research (Mehr and Vaheddoost 2019; Mehr *et al.*, 2020).

SPI was developed by McKee *et al.*, (1993) and described in detail by Edwards (1997). The goal of SPI is to categorize precipitation into a single numerical number that may be compared across places with distinctly differing climates. Any location's SPI computation typically needs a long-term precipitation record for the relevant time period. After fitting the long-term data to a probability distribution, which is then transformed into a normal distribution, the mean SPI for the place and desired period is set to zero (Edward, 1997; McKee, 1993). Using monthly input data, the SPI can be constructed for various time periods ranging from 1 to 36 months. The Index was designed to show that it is possible to simultaneously experience wet conditions on one or more time scales, and dry conditions at other time scales. Consequently, a separate SPI value is calculated for a selection of time scales. Strictly speaking, the SPI does not have a specific threshold, but a drought is regarded as drought when the SPI is −1.0 or lower (Kwak *et al.*, 2016). Table 1 reveals the drought category as classified by McKee *et al.*, (1993) and Kwak *et al.*, (2016). SPI has been acknowledged as the standard index that should be used for quantifying and reporting meteorological drought on a global scale. However, given that it ignores changes in evapotranspiration, questions have been raised about the SPI's usefulness as a gauge of drought changes brought on by climate change. SPEI and other indexes that address evapotranspiration have been suggested.

Table 1: Drought intensity with SPI

SPI values	Drought category
0 to −0.99	Mild drought
−1.00 to −1.49	Moderate drought
−1.50 to −2.00	Severe drought
< −2.00	Extreme drought

Standard Precipitation Evapotranspiration Index (SPEI): An expansion of the often used Standardized Precipitation Index (SPI) is the Standardized Precipitation Evapotranspiration Index (SPEI). When determining drought, the SPEI is intended to consider both precipitation and potential evapotranspiration (PET).

Table 2: Classification of moisture level with SPEI

SPEI values	Drought category
+2.0 and greater	Extremely wet
+1.5 to 1.99	Very wet
+1 to 1.49	Moderately wet
−0.99 to 0.99	Near normal
−1.49 to −1.0	Moderately dry
−1.99 to −1.5	Severely dry
Less to −2.0	Extremely dry

Thus, in contrast to the SPI, the SPEI effectively measures the primary effect of rising temperatures on water demand. Since its creation in 2010, a rising number of meteorological and hydrological researches have used the standardized precipitation evapotranspiration index (SPEI) (Beguería *et al.*, 2014). Like the SPI, the SPEI can be calculated on a range of timescales from 1-48 months, it can determine the beginning and end of drought events as well as the severity of the drought based on its intensity and duration. Moreover, Keyantash and Dracup (2002) suggested that drought indices must be simply produced, statistically reliable, and have a transparent and understandable calculating process. Table 2 presents its classification according to the moisture state as stated by Quenum et al. (2019).

RESULTS AND DISCUSSION

Comparison of Drought Duration for SPI and SPEI over West African Regions: The assessment of drought duration in the 3, 6, 12 and 24 monthly SPI for Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and moist Sub-region are shown in Figure 2. It revealed that in the 3 monthly SPI, the drought duration for Hyper - Arid region, Sahelian region, Sudano region, Dry - Sub - humid region and Moist Sub- humid region were 265 months, 125 months, 235 months, 240 months, 245 months, 225 months respectively. Hyper -Arid region had the highest value of drought durations and Sahelian zone region had the lowest value of drought duration. Figure 2 also revealed that in the 6 monthly SPEI, the drought duration for Hyper -Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and Moist-Sub-humid region were 250 months, 240 months, 230 months and 235 months respectively. Hyper-Arid region had the highest value of drought duration while Dry-Sub-humid region had the lowest value of drought duration. Figure 2 further revealed that at 12 monthly SPEI, the drought duration for Hyper - Arid region, Sahelian region, Sudano region, Dry-Sub - humid region and Moist - Sub-humid and Moist Sub-region humid region were 250 months, 165 months, 235 months, 250 months, 255 months respectively.

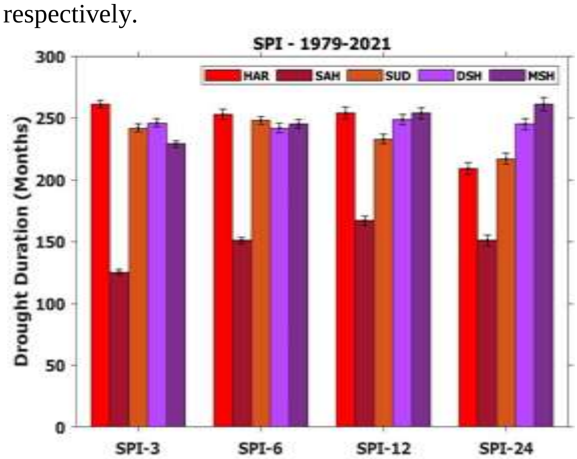

Fig 2: Assessment of Drought Duration for SPI over West Africa Region.

Hyper - Arid region had the highest value of drought and Sahelian region had the lowest value of drought duration. It also revealed that at 24 monthly SPI, the drought duration for Hyper Arid region, Sudano region, Dry -Sub humid region and Moist-Sub-humid region were 206 months, 260 months, 215 months, 245 months and 265 months respectively.

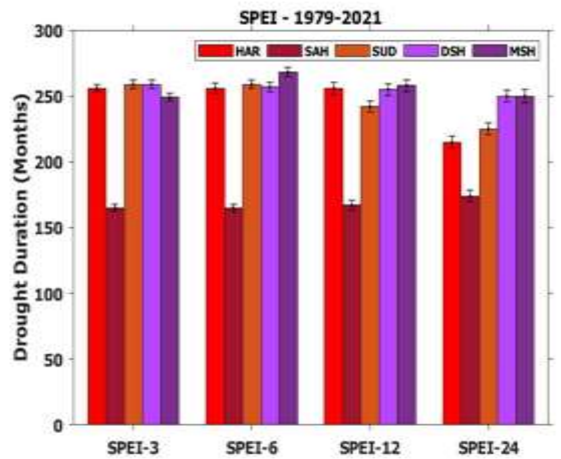

Fig 3: Assessment of Drought Duration for SPEI over West Africa Region.

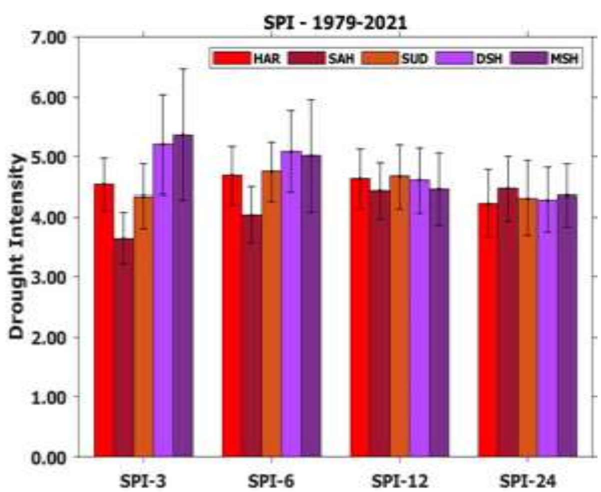

Fig 4: Assessment of Drought Intensity for SPI over West Africa Region.

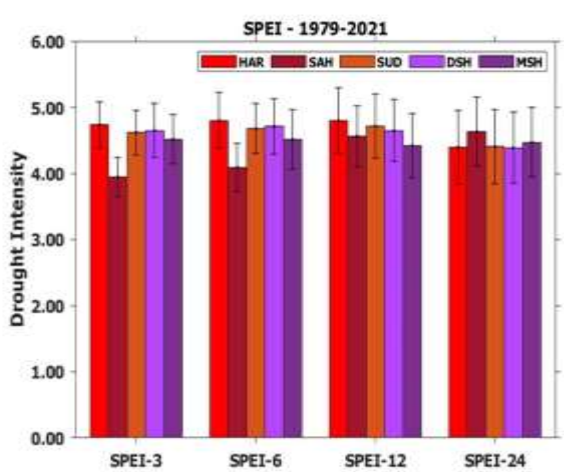

Fig 5: Assessment of Drought Intensity for SPEI over West Africa Region.

Moist Sub-humid region had the highest value of drought duration and Sahelian region had the lowest value of drought duration. The drought duration in the 3,6, 12 and 24 monthly for SPEI for Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and Moist-Sub-humid region are shown in figure 3 which revealed that in the 3 monthly SPEI, the drought duration for Hyper -Arid region, Sahelian region, Sudano region, Dry Sub - humid region and Moist - Sub humid region were 260 months, 165 months, 265 months, 265 months and 245 months, respectively. Hyper -Arid region had the highest value of drought duration while Sahelian region had the lowest value of drought duration.

Comparison of Drought Intensity for SPI and SPEI over West African Region: The drought intensity in the 3,6,12 and 24 monthly SPI for Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and Moist-Sub-humid region are shown in Figure 4 which revealed that in the 3 monthly SPI, the drought intensity for Hyper-Arid region, Sahelian region, Sudano region, Dry sub - humid regions and Moist Sub-humid region were 4.5, 3.6, 4.3 5.2, and 5.3 respectively. Moist - Sub - humid had the highest value of drought intensity and Sahelian region had the lowest value of drought intensity. It also revealed that in the 3 monthly SPI, the drought intensity revealed that for Hyper - Arid region, Sahelian region, Sudano region, Dry - Sub - humid region and Moist - Sub humid region were 4.7, 3.9, 4.6, 4.6 and 4.5 respectively. Hyper Arid region had the highest value of drought intensity and while Sahelian had the lowest value of drought intensity. It also revealed that in the 6 monthly SPI, the drought intensity for Hyper - Arid region Sahelian region, Sudano region, Dry - Sub - humid region and Moist - Sub - humid regions were 4.7, 3.8, 4.8, 5.2 and 5.1 respectively. Dry-Sub humid region had the highest value of drought intensity and Sudano region had the lowest value of drought intensity. Figure 4 further revealed that in the 12 monthly SPI, the drought intensity for Hyper - Arid region, Sahelian region, Sudano region Dry-Sub - humid region and Moist- Sub humid region were 4.6, 4.4, 4.6, 4.5, and 4.3 respectively. Hyper-Arid and Sudano regions had the highest value drought intensity and while Moist-Sub- humid had the lowest value of drought intensity. It also revealed that in the 24 monthly SPL, the drought intensity for Hyper-Arid region, Sahelian region, Sudano region, were 4.2, 4.5, 4.3, 4.3 and 4.4. The Sahelian region had the highest value of drought intensity while Sudano and Dry-Sub humid regions had the lowest value of drought intensity. The drought intensity in the 3, 6, 12 and 24 monthly SPEI for Hyper-Arid region Sahelian region, Sudano region, Dry -Sub- Arid region humid region and Moist-Sub -humid region are displayed in figure 5. It revealed that in the 3 monthly SPEI, the drought intensity for it Hyper-Arid region, Dry-Sub-humid region and Moist-Sub-humid region were 4.7, 3, 8, 4.6 , and 4.5 respectively. Hyper-Arid region had the highest value of drought intensity and Sahelian had the lowest value of drought intensity. It also revealed that in the 6 monthly SPEI, the drought intensity for Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid and Moist-Sub-humid region were 4.7, 4.2, 4.6, 4.6,and 4.5 respectively. Hyper-Arid region had the highest value of drought intensity and Sahellan region had the lowest value of drought intensely. Figure 5 further revealed that in the 12 monthly SPEI, the drought intensity for Hyper - Arid region, Sahelian region, Sudano region, Dry - Sub humid region and Moist-Sub-humid region were 4.7, 4.3, 4.5, 4.4, and 4.1 respectively. Hyper-Arid region had the highest value of drought intensity and Moist-Sub-humid region had the lowest value of drought intensity. Moreover, figure 5 revealed that 24 monthly SPEI, the drought intensity for Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and Moist-Sub-humid region were 4.2, 4,5, 4.3,4.3, and 4.4 respectively. Sahelian had the highest value of drought intensity and Hyper-Arid region had the lowest value of drought intensity. This implied that region with the highest value of drought intensity would experience cracked soil, low output of agriculture, low availability of water in soil, reservoirs, starvation, malnutrition and sometimes death.

Comparison of Drought Severity for SPI and SPEI over West African Regions: The assessment of drought severity in the 3, 6, 12 and 24 monthly SPI for Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and Moist Sub-region are shown in Figure 6. Figures 6 further revealed that in the 3 monthly SPI, the drought severity for Hyper-Arid region, Sahelian region, Sudano region, Dry sub - humid regions and Moist Sub-humid region were 0.65, 1.55, 0.65, 0.85, and 0.95 respectively. Sahelian region had the highest value of drought severity which was 1.55 and Hyper-Arid and Sudano region had the lowest value of drought severity which was 0.65. It also revealed that in the 6 monthly SPI, the drought severity for Hyper - Arid region, Sahelian region, Sudano region, Dry - Sub - humid region and Moist - Sub humid region were 0.65, 1.60, 0.70, 0.75 and 0.65 respectively. Sahelian region had the highest value of drought severity which was 1.60 and Hyper-Arid and Moist-Sub-humid region had the lowest value of drought intensity which was 0.65. It further revealed that in the 12 monthly SPI, the drought severity for Hyper - Arid region, Sahelian region, Sudano region, Dry - Sub - humid region and Moist - Sub - humid regions were 0.65, 1.60, 0.75, 0.70 and 0.65 respectively. Sahelian region had the highest value of drought severity which was 1.60 and Hyper-Arid and Moist-Sub-humid region had the lowest value of drought severity which was 0.65. It also revealed that in the 24 monthly SPI, the drought severity for Hyper-Arid region, Sahelian region, Sudano region Dry-Sub - humid region and Moist- Sub humid region were 0.75, 1.40, 0.75, 0.75 and 0.65 respectively. Sahelian region had the highest value drought severity which was 1.40 and Moist-Sub- humid had the lowest value of drought severity which was 0.65. The assessment of drought severity in the 3, 6, 12, and 24 monthly SPEI for Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and Moist-Sub-humid region are shown in figure 6 which revealed that in the 3 monthly SPEI, the drought severity for Hyper-Arid region, Sahelian region, Sudano region, Dry sub-humid regions and Moist Sub-humid region were 0.80, 1.45, 0.70, 0.65, and 0.70 respectively. Sahelian region had the highest value of drought severity which was 1.45 and while Dry-Sub-humid region had the lowest value of drought severity which was 0.65.

Figure 7 also revealed that in the 6 monthly SPEI, the drought severity for Hyper - Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and Moist - Sub humid region were 0.80, 1.45, 0.75, 0.70 and 0.75 respectively. Sahelian region had the highest value of drought severity which was 1.45 and Dry-Sub-humid region had the lowest value of drought intensity which was 0.70. Figure 7 further revealed that in the 12 monthly SPEI, the drought severity for Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and Moist-Sub-humid regions were 0.75, 1.55, 0.85, 0.75 and 0.65 respectively. Sahelian region had the highest value of drought severity which was 1.55 and while Moist-Sub-humid region had the lowest value of drought severity which was 0.65. Moreover, Figure 7 revealed that in the 24 monthly SPEI, the drought severity for Hyper-Arid region, Sahelian region, Sudano region, Dry-Sub-humid region and Moist- Sub humid region were 0.75, 1.10, 0.70, 0.70, and 0.75 respectively. Sahelian region had the highest value drought severity which was 1.10 and while Sudano and Dry-sub-humid region had the lowest value of drought severity. It was observed that there were differences in the value of SPI and SPEI because SPI did not address the effects of high temperature on drought conditions, such as changing cultivated and natural ecosystems, increasing evapotranspiration and water stress. High value of drought severity resulted in land subsidence, sea water intrusion and damage to ecosystems. A prolonged drought escalated the damage caused to plants, ecosystems and wildlife.

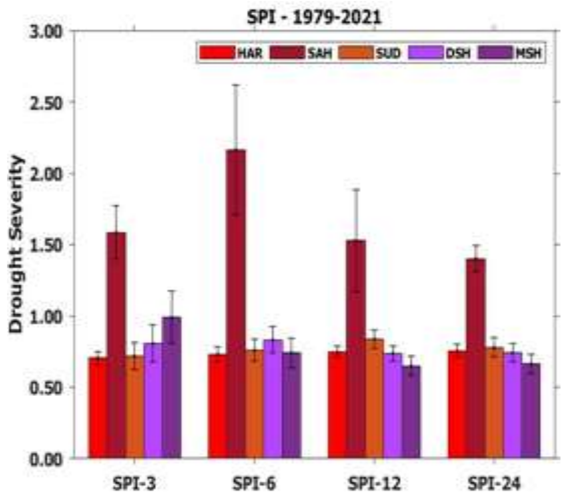

Fig 6: Assessment of Drought Severity for SPI over West Africa Region.

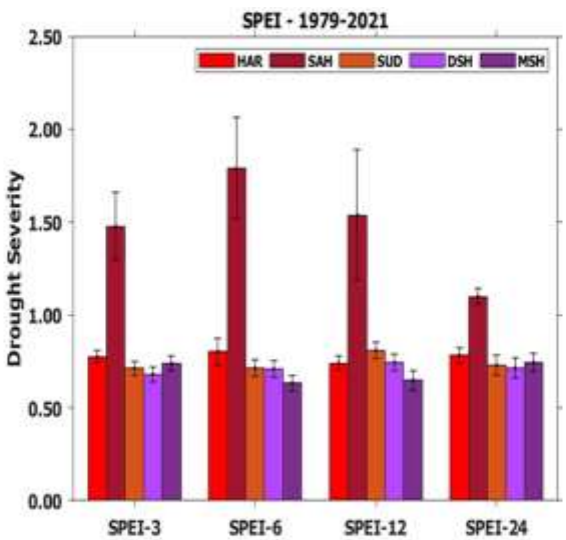

Fig 7: Assessment of Drought Severity for SPEI over West Africa Region.

Conclusion: This study explored and compared characteristics of drought based on SPI and SPEI indices for five regions in of Hyper Arid, Sahelian, Sudano, Dry Sub-Humid, Moist Sub-Humid from 1979-2021. The study revealed that there were some differences observed between the SPI and SPEI I regional drought characteristics which is as a result of the change in climatic conditions in different regions. The study also revealed that most of the regions experienced extreme drought in 1982 thus more droughts were experienced in the eighties than in the nineties. It also revealed that there were no definite patterns in the drought characterization and the values fluctuate over time, with a few regions displaying a slight increase in 2021. Greater number of the regions experienced severe drought in 2021 as a result of the increase in the drought intensity in the year 2021 as recorded by SPI and SPEI. The findings of the study could enhance the knowledge of water resource planners in understanding the occurrences of drought in different time periods and locations.

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