Investigation of Trends in Agricultural and Meteorological Drought in Nigeria

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ABSTRACT
Investigating the trend in meteorological and agricultural drought is important in water resources management. Drought affects agriculture, water resources and the ecosystems of Nigeria. This study investigated the trend in meteorological and agricultural drought in the guinea savannah, sudan savannah and sahel savannah agro ecological zones in Nigeria by using SPI (standardized precipitation index), SPEI (standardized precipitation and evapotranspiration index) and SSI (standardized soil moisture index) indices. SPI considers only precipitation, SPEI considers both precipitation and potential evapotranspiration to determine drought and SSI considers soil moisture to evaluate soil moisture deficit for both short and long period. Precipitation data (1981-2015) was obtained from Nigerian Meteorological Agency (NIMET) and soil moisture data (1981-2015) for 3 weather stations (1 from each zones) was obtained from the Climate Prediction Center (CPC). The result showed that; (1) Trend analysis revealed that the hypothesis of no trend was rejected in the three agro-ecological zones studied; (2) There was an observed significant drying trend at 95% significant level; (3) Over the three zones, the drought indicators showed significant trend; and (4) Comparison analysis of the 3 drought indices used in this study shows that SPI and SPEI are more consistent in the three zones showing relative correlation compared to SSI.

Keywords: Drought, Trend analysis, SPI, SPEI, SSI, Nigeria.

I. INTRODUCTION
Drought is a prolonged period of abnormally low rainfall or dryness leading to low amount or scarcity of water in the environment and the soil entirely which may cause famine. Droughts have been occurring in Nigeria for years and it has been a reoccurring phenomenon [7]. Nigeria is divided into six distinct vegetation zones of Coastal Mangrove Swamp Forest, Rain forest, Southern Guinea, Northern Guinea, Sudan and Sahel savannah vegetation zones. The vegetation varies regionally in consonance with the climatic pattern. Large areas of Northern Nigeria falling within the Sahel and Sudan ecological zones between latitude 9-14°N are susceptible to re-occurring droughts in one form or the other [2] [20]. Studies have also indicated that the Sudano-Sahelian region of Nigeria has suffered decrease in rainfall within the range of about 3 - 4% per decade since the beginning of the 19th century (FRN, 2003). This aggravating situation has led to several studies on drought in the region [1] [6] [13] [21] [23].
Drought is classified into four types namely meteorological, hydrological, agricultural, and socioeconomic [29]. A meteorological drought occurs when there is a prolonged time where there is less than average precipitation. Hydrological drought is brought about when the water level reserves available in sources such as lakes, aquifers and reservoir fall below the statistical average. Agricultural drought is the shortage of available water for plant growth [19], which according to Slegers and Stroosnijder [27] includes both meteorological drought and soil-water drought, since a decline of soil-water depends on both the weather conditions and the physical and biological properties of a soil. Socioeconomic drought, on the other hand, is described as an Imbalance between demand and supply ratio [11][12].
The influences of drought in general encompass mass starvation, famine and cessation of economic activity mainly in areas where rain fed agriculture is the mainstay of the rural economic system. The effects of drought include: low or no crop yields ensuing in low food safety index; mass famine; demise of livestock; low groundwater level resulting in dry wells (which had to be dug deeper and deeper to achieve water for drinking); drying of lakes and dams; loss of biodiversity and impoverishment of environment; acute scarcity of water for domestic use and for livestock; decline in GDP; migration into city areas; separation of families; and increased indebtedness [14].
Anonymous [4] reported that “Drought monitoring using Standard Precipitation Index (SPI), over five stations located in the extreme Northern States of Nigeria, namely Sokoto, Zamfara, Katsina, Yobe and Borno showed that drought occurrence was first noticed in 1968 with a Standardized Precipitation Index value of (–0.34), indicative of a mild drought, was recorded for that year. The negative SPI values of drought episodes continued up to 1973, with the exception of 1970, were immediately followed by a wetter period of (1974 –
1980) which were of positive values.” Other droughts included those of 1919, 1924, 1935, 1951-1954, 1972-1973, 1984-1985, 2007 and 2011 [5][16].

There will always be differences between the SPI and SPEI in drought monitoring due to variation in climate and the difference of climatic conditions in different regions [25]. Although the SPI can describe the variations of drought, it ignores the effect of evaporation on drought. On the other hand, the SPEI considers both precipitation and evapotranspiration, which is more suitable in monitoring and of drought in the context agriculture and global warming [25].

The aim of this research was to investigate the trends analysis of SPI, SPEI and SSI indices on Agricultural and Meteorological Drought. It enabled us to (1) Perform descriptive statistics of the climatic parameters ; (2) Perform the trend analysis of the climatic parameters (Temperature, rainfall, soil moisture) and indices (SPI, SPEI, SSI) ; (3) Investigate the characteristics of drought indices (SPI, SPEI, SSI) on meteorological and agricultural droughts and their trend in Nigeria ; (4) Investigating the drought episodes in the selected region of the agro-ecological zones in Nigeria and (5) Check the degree of correlation between the indices used. Result from this research can be used as reference for selection and comparison of SPI, SPEI and SSI drought indices for future research.

II. MATERIALS AND METHODS

2.1 Study Area

Nigeria is in West Africa between latitude 4° N and 14° N and between longitudes 2° E and 15° E [22]. It has a total land area of 925,796 km². Nigerian climate is humid in the south (with annual rainfall over 2,000 mm) and semi-arid in the north (with annual rainfall less than 600 mm). The climate of the country varies from equatorial in the south to arid in the north and tropical in the center. The topography of the country has valley, plateaus, and hilly areas. Nigeria’s location in the tropics has given her a tropical hot climate. Temperatures in Nigeria vary according to the seasons of the year as with other lands found in the tropics. Nigeria’s seasons are determined by rainfall with rainy season and dry season being the major seasons in Nigeria.

For this study, locations were randomly selected within 3 agro-ecological Zones spreading across different climatic zones over Nigeria.

![Figure 1: Map of Nigeria showing the Agro-ecological Zones (www.intechopen.com)](image)

Guinea Savannah: The Guinea Savannah, located in the center region of the country, it is the most extensive ecological zone in Nigeria. Guinea savannah zone has a unimodal rainfall distribution with the average annual temperature and rainfall of 27.3°C and 1051.7 mm respectively where the wet season lasts for 6–8 months.

Sudan Savannah (short grass savannah): The Sudan Savannah zone is found in the Northwestern part of the country. The low average annual rainfall of 657.3mm and the prolonged dry season (6-9 months) sustain fewer trees and shorter grasses than the Guinea Savannah.

Sahel Savannah (marginal savannah): This is the last ecological zoological zone with proximity to the fringes of the fast-encroaching Sahara Desert. It
occupies about 18,130 km of the extreme Northeast corner of Nigeria and is the last vegetation zone in the extreme northern part of the country, where the dry season lasts for up to 9 months and the total average annual rainfall is hardly up to 700mm.

2.2 Data Acquisition and Data Processing

Rainfall data spanning over 35 years period (1981–2015) was obtained from the Nigerian Meteorological Agency (NIMET), it comprised of daily temperature (maximum and minimum) and rainfall. Soil moisture data was obtained from CPC soil moisture from 1981 to 2015 for 3 weather stations scattered across Nigeria covering the 3 agro-ecological zones considered by this study. Data quality was controlled, and suspicious values were corrected by using the mean of the earlier and later years of the same. Descriptive statistics was performed to obtain a quantitative and simple description by reducing the dataset into simpler summary by time series, year, minimum value, maximum value, mean, standard deviation and variance.

2.3 Drought Indices

In the study, the drought indices used are Standardized precipitation index (SPI), Standardized precipitation evaporation index (SPEI) and Standardized soil moisture index (SSI)

2.3.1 Standardized precipitation index (SPI)

SPI was developed by McKee et al. (1993) in order to know the effect of precipitation deficits in both the short period that mainly impacts agriculture, and long period which impacts water resources [26]. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The Standardized Precipitation Index (SPI) is a probability index that considers only precipitation. The SPI is an index based on the probability of recording a given amount of precipitation, and the probabilities are standardized so that an index of zero indicates the median precipitation amount (half of the historical precipitation amounts are below the median, and half are above the median). The index is negative for drought, and positive for wet conditions. As the dry or wet conditions become more severe, the index becomes more negative or positive. The SPI is computed by NCEI for several time scales, ranging from one month to 24 months, to capture the various scales of both short-term and long-term droughts. The concept of SPI can be applied to other climatic/land surface variables such as Standardized Soil Moisture Index [9]. Hence, SSI is typically used as an indicator of agricultural drought. Previous studies show that SPI is a suitable indicator for detecting drought onset, while soil moisture-based indices (e.g., SSI) describe drought persistence more reliably [10].

The current study used the gamma distribution to fit the long-term rainfall record (1981–2015) that was collected from three (3) meteorological stations scattered across Nigeria. Gamma distribution was defined by its probability density function of equation (1).

\[
f(x; \alpha; \beta) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \text{ for } x, \alpha, \beta > 0 \quad 1
\]

Where, \(\alpha\) and \(\beta\) are the shape and scale parameters respectively; \(x\) is the rainfall amount; and \(\Gamma(\alpha)\) is the gamma function.

The resulting parameters were then used to derive the cumulative probability for non-zero rainfalls using equation (2).

\[
F(x; \alpha, \beta) = \int_{0}^{x} f(x; \alpha, \beta)dx = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_{0}^{x} x^{\alpha-1} e^{-x/\beta}dx \quad 2
\]

The cumulative probability was transformed into a standardized normal distribution so that the SPI mean and variance were zero and one respectively. The current study employed the approximate transformations provided by Mishra and Desai (2006) to transform the cumulative probability distribution into a standardized normal distribution, which were given in equations (3) and (4):

\[
SPI = \left( k - \frac{c_0 + c_1 k + c_2 k^2}{1 + d_1 k + d_2 k^2 + d_3 k^3} \right), \quad \text{when } k = \sqrt{\ln \left( \frac{1}{H(x)} \right)^2} \text{ for } 0 < H(x) \leq 0.5 \quad 3
\]

\[
SPI = + \left( k - \frac{c_0 + c_1 k + c_2 k^2}{1 + d_1 k + d_2 k^2 + d_3 k^3} \right), \quad \text{when } k = \sqrt{\ln \left( \frac{1}{H(x)} \right)^2} \text{ for } 0 < H(x) \leq 0.5 \quad 4
\]

Where, \(c_0 = 2.515517, c_1 = 0.802853, c_2 = 0.010328, d_1 = 1.432788, d_2 = 0.189269, d_3 = 0.001308\). The SPI values were calculated for multiple monthly time scales (1, 2, 3, 6, 12 and 24-month time scales). The SPI threshold ranges that were used to define drought conditions are presented in table 1 [17].

2.3.2 Standardized precipitation evaporation index (SPEI)

The Standardized Precipitation Evapotranspiration Index (SPEI) is an extension of the Standardized Precipitation Index (SPI). The SPEI is designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought. Thus, unlike the SPI, the SPEI captures the main impact of increased temperatures on water demand. Like the SPI, the SPEI can be calculated on a range of...
timescales from 1-48 months. At longer timescales (>~18 months), the SPEI has been shown to correlate with the self-calibrating PDSI (sc-PDSI). If only limited data are available, say temperature and precipitation, PET can be estimated with the simple Thornthwaite method. In this simplified approach, variables that can affect PET such as wind speed, surface humidity and solar radiation are not accounted for. In cases where more data are available, a more sophisticated method to calculate PET is often preferred in order to make a more complete accounting of drought variability. However, these additional variables can have large uncertainties. Its calculation follows the derivation of SPI index [28]. The software package that was used to analyse SPEI was developed using R-programming language and obtained from (http://cran.r-project.org/web/packages/SPEI). SPEI was calculated on a six (6) month time scales.

A gridded SPEI data set is available for 1981-2015 based on CRU TS3.2 input data and the Penman-Monteith method. A real-time SPEI is published for global drought monitoring based on the Thornthwaite method. Finally, an R package is available for calculating the SPEI from user-selected input data using the Thornthwaite, Penman-Monteith, or Hargreaves methods.

**Key Strengths:** Combines multi-timescales aspects of the Standardized Precipitation Index (SPI) with information about evapotranspiration, making it more useful for climate change studies. Statistically based index that requires only climatological information without assumptions about the characteristics of the underlying system.

**Key limitations:** More data requirements than the precipitation SPI. Sensitive to the method to calculate potential evapotranspiration (PET), as with other drought indices, a long base period (30-50+ years) that samples the natural variability should be used.

**Penman-Monteith Model (PM)**

The data set that was used to generate PM ET on monthly basis between January, 1981 – December, 2015 includes; precipitation, minimum temperature (Tmin), maximum temperature (Tmax), relative humidity (RH), wind speed, solar radiation (Rs) and Sunshine hours.

\[
\lambda ET = \frac{\Delta (R_n - G) + \rho_a c_p \left( e_s - e_a \right)}{\Delta + \gamma \left( 1 + \frac{r_s}{r_a} \right)}
\]

where \( R_n \) is the net radiation, \( G \) is the soil heat flux, \( (e_s - e_a) \) represents the vapour pressure deficit of the air, \( \rho_a \) is the mean air density at constant pressure, \( c_p \) is the specific heat of the air, \( \Delta \) represents the slope of the saturation vapour pressure temperature relationship, \( \gamma \) is the psychrometric constant, and \( r_s \) and \( r_a \) are the (bulk) surface and aerodynamic resistances [3]. The full description of each parameter can be found in FAO-56 manual.

### Table 1: Limit values for SPI and SPEI

| Classification      | SPI [17]        | SPEI [28]       |
|---------------------|-----------------|-----------------|
| Extremely wet       | ≥ 2.00          | ≥ 2.00          |
| Very wet            | 1.50 to 1.99    | 1.50 to 1.99    |
| Moderately wet      | 1.00 to 1.49    | 1.00 to 1.49    |
| Normal              | 0.99 to -0.99   | 0.99 to -0.99   |
| Moderately dry      | -1.0 to -1.49   | -1.0 to -1.49   |
| Very dry            | -1.5 to -1.99   | -1.5 to -1.99   |
| Extremely dry       | ≤ -2.00         | ≤ -2.00         |

### 2.3.3 Standardized soil moisture index (SSI)

SSI is typically used as an indicator of agricultural drought. SSI was developed in order to know the effect of soil moisture deficits in both the short period that mainly impacts agricultural productivity. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The Standardized soil moisture Index (SSI) is a probability index that considers soil moisture. The SSI is an index based on the probability of recording a given amount of soil moisture, and the probabilities are standardized so that an index of zero indicates the median precipitation amount. The index is negative for drought, and positive for wet conditions. As the dry or wet conditions for soil become more severe, the index becomes more negative or positive.

\[
SSI = \frac{x_{SMAP} - \bar{\mu}_{NLDAS}}{\delta_{NLDAS}}
\]

Where \( x_{SMAP} \) is the soil moisture content, \( \bar{\mu}_{NLDAS} \) is the mean value of soil moisture content for the corresponding day from NLDAS, and \( \delta_{NLDAS} \) is the standard deviation.

**Trend Analysis Using Nonparametric Mann-Kendall’s Test**

The Mann-Kendall (MK) test is a statistical test widely used for the analysis of trends in climatologic and hydrologic time series [22]. Trend analysis was performed to understand the pattern of gradual change in
the drought process and identify the vulnerable zones in Nigeria with increasing trend. The Mann-Kendall statistic can be obtained as

\[ S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sign} (T_j - T_i) \]

Sign \((T_j - T_i) = 1\) if \(T_j - T_i > 0\)

0 if \(T_j - T_i = 0\); \(-1\) if \(T_j - T_i < 0\)

In this study, a long-term trend analysis was performed on the four drought indices time series for the time period 1975 – 2015. The statistical significance of upward or downward trends was evaluated using the MK test statistics at varying significance level of \(\alpha\).

Pearson Correlation Statistics

Correlation Coefficient was computed pair wise between all the Drought Index time series for the entire period of record creating a cross correlation matrix. It will be calculated using equation 8.

\[ r = 1 - \frac{1}{n} \sum_{i=1}^{n} \left( \frac{x_i - \bar{x}}{S_x} \right) \left( \frac{y_i - \bar{y}}{S_y} \right) \]

where, \(x_i\) and \(y_i\) represent the values of arrays with ‘n’ number of elements being compared and \(\bar{x}\) and \(\bar{y}\) are the mean values of two arrays and \(S_x\) and \(S_y\) are the standard deviation of \(x_i\) and \(y_i\), respectively.

### III. RESULTS

**Descriptive Statistics for Climatic Variables**

The climatic variables used for the trends in meteorological and agricultural drought for the three (3) agro ecological zones namely (Yelwa, Makurdi and Sokoto) are listed below in table 4.1. The table shows precipitation, minimum and maximum temperature, soil moisture data, the starting year and also the ending year, the table gives a thorough description of all the variables used whereby the minimum value and maximum value of each variables are known, also the mean value, standard deviation and variance of the variables are also calculated and listed below.

| Location | Variables  | Years | Min Value | Max Value | Mean | S. Dev | Variance |
|----------|------------|-------|-----------|-----------|------|--------|----------|
| Yelwa    | Precipitation | 35    | 824.8     | 2394.8    | 1424.9 | 315.8  | 99705.3  |
|          | Tmax       | 35    | 406.4     | 427.2     | 417.99 | 4.98   | 24.79    |
|          | Tmin       | 35    | 230.8     | 274.9     | 259.25 | 9.19   | 84.5     |
|          | Soil moisture | 35    | 382.05    | 623.92    | 535.30 | 51.59  | 2661.6   |
| Sokoto   | Precipitation | 35    | 372.9     | 1146.7    | 657.3  | 152.6  | 23284.1  |
|          | Tmax       | 35    | 411.22    | 439.21    | 425.69 | 6.30   | 39.73    |
|          | Tmin       | 35    | 259.75    | 283.53    | 271.80 | 5.39   | 28.99    |
|          | Soil moisture | 35    | 219.23    | 623.92    | 535.30 | 51.59  | 2661.6   |
| Makurdi  | Precipitation | 35    | 978.5     | 2408.5    | 1669.9 | 331.2  | 109720   |
|          | Tmax       | 35    | 389.74    | 405.34    | 396.33 | 3.73   | 13.93    |
|          | Tmin       | 35    | 248.43    | 279.98    | 268.38 | 6.21   | 38.58    |
|          | Soil moisture | 35    | 176.70    | 443.59    | 315.03 | 69.15  | 4781.7   |

The statistical analysis of the parameters of climate change in the agro-ecological zone namely (Yelwa, Sokoto and Makurdi) from 1981 until 2015 is shown in table 2. The analysis revealed that the mean of the monthly average precipitation of Yelwa, Sokoto and Makurdi are 1424.9mm, 657.3mm, 1669.9mm and 1669.9mm respectively. The mean of monthly average minimum temperature of these locations is 259.25, 271.80 and 268.38 also the mean of monthly average maximum temperature of these locations is 417.99, 425.69 and 396.33. Also, the mean value for the monthly average soil moisture of this locations is 535.30, 535.30 and 315.03 respectively. Makurdi shows the highest annual mean precipitation (1669.9) and the lowest mean maximum temperature of 396.33°C throughout the years, this is due to the fact that it falls in the guinea savannah agro-ecological zone of Nigeria, the guinea savanna is characterized with a low rainfall and long dry period, it’s vegetation is characterized by a mixture of tress and tall grasses in the north. Other locations have lesser mean annual precipitation but high mean maximum temperature values, Sokoto mean maximum temperature value is relatively high with lesser value of mean annual precipitation throughout the year.

**Trend Analysis of Climatic Variables**

The climatic variables were input into a Mann Kendall trend analysis interface. The z test was used to know if there is an increasing trend when there is as positive value or a decreasing trend if the value is negative with varying degree of confidence level of significance.
Table 3: Mann-Kendall trend analysis and slope test for annual precipitation

| Location | Years | Test Z | Significance | Slope  |
|----------|-------|--------|--------------|--------|
| Yelwa    | 35    | 2.05   | *            | 7.974  |
| Sokoto   | 35    | 2.39   | *            | 6.436  |
| Makurdi  | 35    | 0.95   |              | 5.950  |

Confidence levels (*=0.05, **=0.01, ***=0.001, +=0.1)

Table 4: Mann-Kendall trend analysis and slope test for annual minimum temperature

| Time Series | Years | Test Z | Significance | Slope  |
|-------------|-------|--------|--------------|--------|
| Yelwa       | 35    | 3.22   | **           | 0.357  |
| Sokoto      | 35    | -0.54  |              | -0.073 |
| Makurdi     | 35    | 0.20   |              | 0.022  |

Confidence levels (*=0.05, **=0.01, ***=0.001, +=0.1)

Table 5: Mann-Kendall trend analysis and slope test for annual maximum temperature

| Time Series | Years | Test Z | Significance | Slope  |
|-------------|-------|--------|--------------|--------|
| Yelwa       | 35    | 2.30   | *            | 0.200  |
| Sokoto      | 35    | 3.81   | ***          | 0.356  |
| Makurdi     | 35    | 1.48   |              | 0.110  |

Confidence levels (*=0.05, **=0.01, ***=0.001, +=0.1)

Table 3 shows the annual temperature of precipitation from 1981 to 2015, from the table it can be seen that there is positive trend in the 3 selected zones most notably Sokoto with a value of 2.39. Also table 4 and 5 shows the minimum and maximum temperature value where Sokoto was having the highest increasing trend in the maximum temperature with a value of 3.81 and this show a vast increase in the level of temperature in the zone followed by Yelwa with a maximum temperature value is of 2.30 within the 35-year period.

Table 5: Mann-Kendall trend analysis and slope test for Yelwa precipitation

| Time Series | Years | Test Z | Significance | Slope  |
|-------------|-------|--------|--------------|--------|
| March       | 35    | -2.38  | *            | 0.000  |
| April       | 35    | 0.30   |              | 0.040  |
| May         | 35    | 0.71   |              | 0.582  |
| June        | 35    | 0.45   |              | 0.338  |
| July        | 35    | -0.85  |              | -1.100 |
| August      | 35    | 1.65   | +            | 2.727  |
| September   | 35    | 2.07   | *            | 2.114  |

Confidence levels (*=0.05, **=0.01, ***=0.001, +=0.1)

Table 6: Mann-Kendall trend analysis and slope test for Sokoto precipitation

| Time Series | Years | Test Z | Significance | Slope  |
|-------------|-------|--------|--------------|--------|
| April       | 35    | 2.44   | *            | 0.000  |
| May         | 35    | 2.06   | *            | 1.217  |
| June        | 35    | 0.54   |              | 0.340  |
| July        | 35    | 0.61   |              | 0.675  |
| August      | 35    | 2.13   | *            | 1.953  |
| September   | 35    | 1.09   |              | 0.850  |
| October     | 35    | 2.64   | **           | 0.411  |

Confidence levels (*=0.05, **=0.01, ***=0.001, +=0.1)
Table 7: Mann-Kendall trend analysis and slope test for Makurdi precipitation

| Time Series | Years | Test Z | Significance | Slope  |
|-------------|-------|--------|--------------|--------|
| March       | 35    | 0.71   |              | 0.648  |
| April       | 35    | -0.31  |              | -0.386 |
| May         | 35    | 0.03   |              | 0.129  |
| June        | 35    | -2.23  | *            | -3.191 |
| July        | 35    | -0.18  |              | -0.416 |
| August      | 35    | 0.61   |              | 1.068  |
| September   | 35    | 1.79   | +            | 1.642  |

Confidence levels (*=0.05, **=0.01, ***=0.001, +=0.1)

The tables 5, 6 and 7 above shows the monthly trend test for precipitation for the three agro-ecological zones, table 5 shows the trend for Yelwa in which the month of March showing high decreasing trend in the level of precipitation while August and September showing a positive increasing trend. Table 6 shows the trend for Sokoto which indicates a positive trend for precipitation in all the months (April-October) with October showing the highest increasing trend. Table 7 shows the trend in Makurdi with the month of June having the highest decreasing trend in the level of precipitation and the month of September having an increasing trend in precipitation level.

Trend Analysis of the Drought Indices for Meteorological and Agricultural Drought

The trend analysis was conducted using Mann-Kendall nonparametric trend test by computing all the variables for the 35-year period. The test shows if there is a monotonic decreasing or increasing trend in the indices with various confidence levels.

Table 8: Mann-Kendall trend analysis for standardized soil moisture index (6-month time series)

| Time Series | Years | Test Z | Significance | Slope  |
|-------------|-------|--------|--------------|--------|
| Yelwa       | 35    | -1.19  |              | -0.019 |
| Sokoto      | 35    | -1.19  |              | -0.019 |
| Makurdi     | 35    | -0.001 |              | -0.001 |

Confidence levels (*=0.05, **=0.01, ***=0.001, +=0.1)

Table 9: Mann-Kendall trend analysis for standardized precipitation index (6-month time series)

| Time Series | Years | Test Z | Significance | Slope  |
|-------------|-------|--------|--------------|--------|
| Yelwa       | 35    | -0.28  |              | -0.007 |
| Sokoto      | 35    | 0.44   |              | 0.005  |
| Makurdi     | 35    | -2.28  | *            | -0.034 |

Confidence levels (*=0.05, **=0.01, ***=0.001, +=0.1)

Table 10: Mann-Kendall trend analysis for standardized precipitation evapotranspiration index (6-month time series)

| S            | Years | Test Z | Significance | Slope  |
|--------------|-------|--------|--------------|--------|
| Yelwa        | 35    | -0.17  |              | -0.002 |
| Sokoto       | 35    | 1.54   |              | 0.014  |
| Makurdi      | 35    | -2.93  | **           | -0.028 |

Confidence levels (*=0.05, **=0.01, ***=0.001, +=0.1)

The tables 5, 6 and 7 above shows the monthly trend test for precipitation for the three agro-ecological zones, table 5 shows the trend for Yelwa in which the month of March showing high decreasing trend in the level of precipitation while August and September showing a positive increasing trend. Table 6 shows the trend for Sokoto which indicates a positive trend for precipitation in all the months (April-October) with October showing the highest increasing trend. Table 7 shows the trend in Makurdi with the month of June having the highest decreasing trend in the level of precipitation and the month of September having an increasing trend in precipitation level.

Table 8 shows the test for standardized soil moisture index (SSI), the SSI makes use of the soil moisture variable for the three selected location (Yelwa, Sokoto and Makurdi) in the agro-ecological zones. The tables show there is no significance decrease or increase in the level of drought occurrence for. The SSI helps to know the soil moisture deficit that impact agricultural productivity.

Table 9 shows the test for the standardized precipitation index (SPI) for the three locations and the
Table indicates that Makurdi is showing a decreasing trend in drought for standardized precipitation index (SPI) while Yelwa and Sokoto shows no significance in increase or decrease in the level of drought for SPI. The SPI considers only the precipitation variables and indicates the deficit in precipitation deficit.

Table 10 shows the test for the standardized precipitation evapotranspiration index (SPEI). The SPEI captures the main impact of increased temperatures on water demand. Makurdi shows a decreasing trend in the level of drought for SPEI while Yelwa and Sokoto shows no significance in increase or decrease in the level of drought.

### 3.4 Time series Graph and Characterization of Drought Event in Selected Regions

![Figure 2: Time series graph of 6-month SPI, SSI and SPEI (penman) over Yelwa](image)

![Figure 3: Time series graph of 6-month SPI, SSI and SPEI (penman) over Sokoto](image)
Figure 4: Time series graph of 6-month SPI, SSI and SPEI (penman) over Makurdi

Table 11: Characterization of most significant drought events for Yelwa

| Index | Start Month   | Duration (months) | End month     | Min value |
|-------|---------------|-------------------|---------------|-----------|
| SPI   | February 1984 | 21                | October 1985  | -5.047    |
|       | June 1986     | 20                | January 1988  | -1.227    |
|       | November 1988 | 14                | December 1989 | -2.213    |
|       | December 1999 | 14                | January 2001  | -0.623    |
|       | March 1983    | 26                | April 1985    | -1.840    |
|       | July 1985     | 15                | September 1986| -0.987    |
| SSI   | August 1987   | 17                | December 1988 | -1.323    |
|       | June 1989     | 75                | July 1995     | -5.363    |
|       | January 1997  | 23                | November 1998 | -2.129    |
|       | May 1986      | 23                | March 1988    | -1.612    |
|       | November 1988 | 14                | December 1989 | -1.828    |
|       | March 1991    | 20                | October 1992  | -1.293    |
| SPEI  | March 1995    | 12                | February 1996 | -1.192    |
|       | December 1997 | 19                | June 1999     | -1.313    |
|       | January 2000  | 14                | February 2001 | -1.109    |

Table 12: Characterization of most significant drought events for Sokoto

| Index | Start Month   | Duration (months) | End month     | Min value |
|-------|---------------|-------------------|---------------|-----------|
| SPI   | August 1981   | 22                | May 1983      | -1.468    |
|       | September 1983| 41                | January 1987  | -2.604    |
|       | March 1989    | 16                | June 1990     | -1.413    |
|       | December 1991 | 20                | June 1993     | -1.056    |
|       | March 1995    | 15                | May 1996      | -1.473    |
|       | September 1997| 12                | June 1998     | -1.281    |
|       | August 2005   | 13                | August 2006   | -1.350    |
|       | February 2008 | 23                | December 2009 | -1.350    |
|       | March 1983    | 43                | September 1986| -1.840    |
| SSI   | August 1987   | 17                | December 1988 | -1.323    |
|       | May 1989      | 75                | July 1995     | -5.363    |
|       | January 1997  | 23                | November 1998 | -2.129    |
Table 13: Characterization of most significant drought events for Makurdi

| Index | Start Month | Duration (months) | End Month | Min Value |
|-------|-------------|-------------------|-----------|-----------|
| SPEI  | January 1982 | 17                | May 1983  | -4.398    |
|       | April 1985   | 13                | April 1986| -1.861    |
|       | February 1988| 15                | April 1989| -1.887    |
|       | April 1992   | 15                | June 1993 | -1.935    |
|       | April 1994   | 14                | May 1995  | -1.598    |
|       | March 2003   | 38                | April 2006| -2.289    |
|       | April 2008   | 12                | March 2009| -1.386    |
|       | June 1990    | 25                | July 1992 | -1.386    |
|       | July 1997    | 13                | July 1998 | -1.701    |
| SSI   | August 2001  | 12                | July 2002 | -0.964    |
|       | July 2003    | 72                | June 2009 | -1.501    |
|       | July 2011    | 15                | September 2012| -0.777 |
|       | September 2013| 28              | December 2015| -2.775 |
|       | January 1982 | 26                | February 1984| -1.492 |
|       | February 1988| 16                | May 1989  | -1.85     |
| SPEI  | May 1992     | 14                | June 1993 | -1.998    |
|       | January 1994 | 13                | January 1995| -1.579  |
|       | February 2003| 24                | January 2005| -2.209   |

From the tables 11, 12 and 13, the extent of severity of drought in the selected location (Yelwa, Sokoto and Makurdi) of three (3) agro-ecological zone in Nigeria are known, this shows that meteorological and agricultural droughts occur at approximately the same time. Table 11, 12 and 13 also shows the soil moisture index (SSI) severity ranging from 72 to 75 months respectively for the three locations and this is due to a very high amount of dryness over these locations which is characterized with very high temperatures and low amount of rainfall.

Pearson Correlation and Coefficient of Determination

| R² | R |
|----|---|
| 0.0465 | 0.2156 |

The Pearson correlation assume that there is linear relationship between two variables. The Karl Pearson’s correlation is conveniently interpreted by using the square value of correlation coefficient (coefficient of determination "r²"). The coefficient of determination explains the variation of dependent variables in the independent variable throughout the total variation.
Figure 6: Pearson correlation of (SPI and SPEI (pen)) for Yelwa

Figure 7: Pearson correlation of (SPI and SPEI (pen)) for Sokoto

Figure 8: Pearson correlation of (SPI and SSI) for Sokoto
From the figures 5-10 above, it was noticed that the correlation between standardized precipitation index and standardized soil moisture index was relatively low for all the three (3) locations with Makurdi showing the lowest level of correlation of 0.05 between the indices, while there was a very strong correlation between standardized precipitation index and standardized potential evapotranspiration index across the three (3) location with Yelwa showing a moderate correlation value of 0.4199 between the SPI and SPEI indices and this is due to the fact that Standardized Precipitation Index (SPI) and Standardized Potential Evapotranspiration index (SPEI) makes use of the same precipitation values in order to know the effect of precipitation deficits in both the short period that mainly impacts agriculture, and long period which impacts water resources with the only difference been that SPEI is designed to take into account not only precipitation but also potential evapotranspiration (PET) by capturing the main impact of increased temperatures on water demand in determining drought. SSI is used to know the effect of soil moisture deficits in both the short period that mainly impacts agricultural productivity. Thus, the Pearson correlation shows the relationship between the indices with mostly notable relationship between the SPI and the SPEI and this may be since precipitation and potential evapotranspiration happens virtually the same time.

IV. CONCLUSION

Droughts affect agriculture, water resources, and ecosystems of Nigeria. Most parts of Nigeria suffer from water scarcity, and droughts can substantially exasperate the pressure on the water resource systems. Water resource systems are sensitive to climatic change and variability and hence, changes in droughts could affect
water availability. Using precipitation data from NIMET and soil moisture data from CPC this study investigated the trends and patterns of meteorological and agricultural droughts in three (3) agro-ecological zones in Nigeria, the meteorological and agricultural droughts were assessed using the SPI, SPEI and SSI, respectively. The overall meteorological–agricultural drought conditions are also evaluated.

The results indicate that the hypothesis of no trend was rejected in the three (3) agro-ecological zones in Nigeria with a significant drying trend at 95% confidence level has been observed. Over the entire country, the drought indicators show significant trend. The most severe drought across the county and the selected regions occurred between 1981 and 1985, 1982 and 1985, 1989 and 1995 and between 2003 and 2009. Nearly the entire locations were under drought for a couple of months during this period. In this study, SPI and SPEI were more consistent for the entire three locations showing relatively correlation compared to the SSI.

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