EFFECTIVENESS OF EARLY WARNING METHODOLOGY AND STANDARDIZED PRECIPITATION INDEX FOR DROUGHT MONITORING OVER GUINEA SAVANNA ZONE, NIGERIA

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Abstract

Rain-fed agriculture remains the most important economic activity in Nigeria, and a key barrier to its success has remained largely the irregular rainfall regime. The response to this variability motivated the development of drought monitoring early warning methodology scheme for determining these phases of the rainfall regime. This study confirmed the efficacy of the scheme by comparing its result with Standardized Precipitation Index. Daily rainfall data from 6 synoptic stations in the Guinea Savanna zone, Nigeria were collected for a period 47 years (1970-2016). The Intra-seasonal Rainfall Monitoring Index (IRMI) and Standardized Precipitation Index (SPI) methods were adopted for data analysis. The results indicate variability in onset of rain as well as the wet and drought periods. The onset phase detected twelve (12) seasons and 12 years that warranted issuance of early warning statements. The SPI captured nine (9) seasons and 9 years as a drought episodes which represents 75% efficacy. It also confirmed the effectiveness of early warning methodology scheme as a tool for drought monitoring in the study area. Recommendations include similar studies in other ecological zones in the country for total coverage and adapting the tools for drought monitoring.

Keywords: Onset rainfall, Droughts, Early Warning, IRMI, SPI

Introduction

Confirmatory study exists pointing to the fact that semi-arid and dry sub-humid areas in the tropics are characterized by high inter-annual and intra-seasonal rainfall variability (Usman, et al 2005). It is projected that this will increase rainfall extremes, such as intense rain as well as severe dry and wet phases with impact in many economic sectors (Hänsel, et al, 2015). It is based on this that regional-scale analyses and consequently societal adaptation to the expected consequences of changing local and regional climatological conditions are recommended.

Usman, *et al.* (2005) recognized that there were several climatic schemes currently employed by various agencies around the globe but a gap between product provision and user expectations have remain unaddressed. In relying on the study of (Archer, 2003) it was asserted that end users (farmers) were desirous to accept the seasonal total rainfall forecast, should it be made available. The existing scheme and there drawback were reviewed and the lesson learned led to conclusion and recommendation that researchers should develop efficient rainfall-only indicators of quality needs to satisfy the requirement of end users.

This open recommendation had remained unattended to, not until 2014, when a drought monitoring and early warning (EW) methodology (Usman and Abdulkadir, 2014) hinged on an Intra-seasonal Rainfall Monitoring Index (IRMI) developed as a tool for determining the real onset date of the summer monsoon rains. The EW have been tested in Kano for a record periods of 21 years (1970-1990). The results were encouraging as experimental application of the scheme identified and detected late initiation conditions of real monsoon onset (RMO) in those seasons that eventually witnessed disastrous rainfall situations. Although the results were encouraging, the authors (Usman & AbdulKadir, 2014) admitted that "efforts were also being made to have these results confirmed over Southern Africa and, possibly, Central Asia and the Middle East working in conjunction with colleagues at the University of Cape Town, South Africa". Similarly, it is noted that the station where the scheme were tested was Kano, located at 12.05^0N latitude. The question to answer is therefore, if the spatial coverage of the study area is extend in terms of longitude and latitude, will the scheme produce the same efficacy?

To answer this question, the spatial coverage of the experimental scheme is expanded to the Guinea savanna zone of Nigeria and the results acquired are compared with SPI values on 6 and 12 timescales. It is expected that the results demonstrate and ascertain if late initiation conditions of real monsoon onset (RMO) in a season had eventually resulted in disastrous rainfall situations as captured by SPI.

The Study Area

The study area is represented in Figure 1. The study lie between Longitudes 3° and 15° East and Latitudes 9° and 10.5°N. The weather observation stations located in these zones are Kaduna, Bauchi, Yola, Jos, Minna, and Bida.

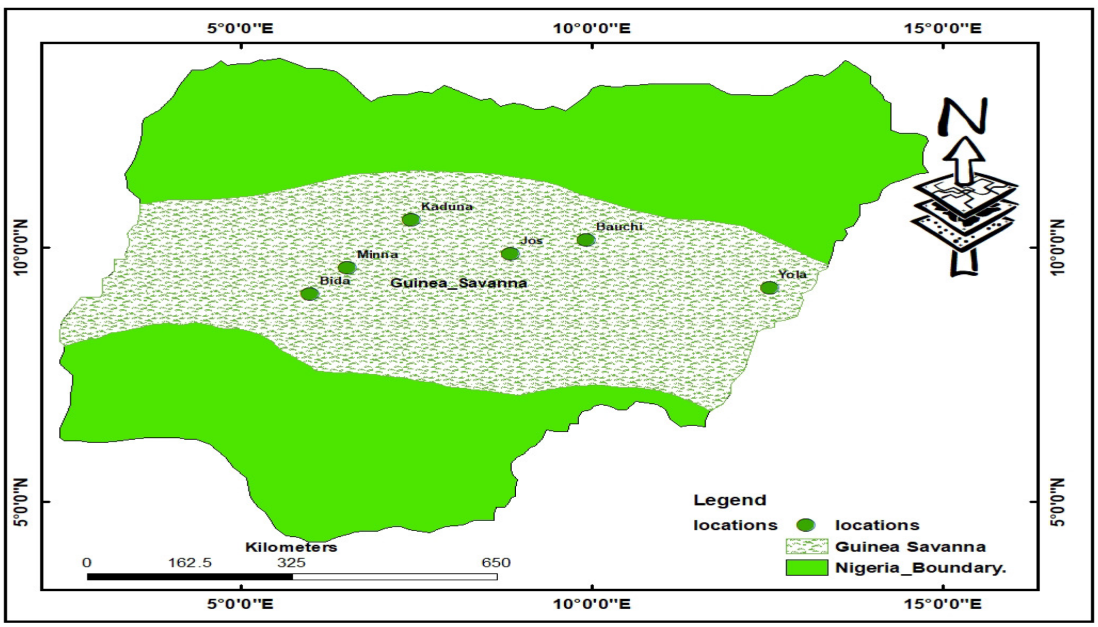

Figure 1: the study area and data collection points

Materials and Methods

Data Used: The daily rainfall data for the period of 1970-2015 from globally reference meteorological stations of Kaduna, Bauchi, Yola, Jos, Minna, and Bida were acquired from the archive of Environmental Management Programme, Department of Geography, Federal University of Technology Minna.

Data Analysis

Drought Monitoring and Early Warning (EW) Methodology: The observed data of daily rainfall totals were aggregated into pentad totals, beginning from first of May (25th pentad of the year from first of January of a given year). A pentad with less than 5 mm of rainfall is taken as a break. The cumulative amount of rainfall and the highest pentad total since the 25th pentad are noted and combined with the number of breaks to compute an Intra-seasonal Rainfall Monitoring Index (IRMI) using the equation developed by Usman & Abdulkadir (2014)**;**

$$IRMI = \frac{(Cpt)^2}{(hpt \times Nb \times 100)} \qquad (1)$$

Cpt = cumulative pentad rainfall since May 1

hpt = the highest pentad total rainfall since May 1

Nb = number of breaks in rainfall (pentads with less than 5mm of rainfall)

The 'actual' or 'real' onset of rains is taken as the pentad within which the index is ≥1 for the first time. The drought monitoring and Early Warning (EW) methodology are stated following the effective onsets of rainfall.

Consequently effective onsets of rainfall on or before pentad number 36 is stated as an indicative of a good rainfall season in the semi-arid and dry sub-humid zones of Nigeria as long as damaging breaks do not occur in succession within the growing season.

If rainfall is not effective before pentad 36 (30 June), it should justified the issuance of an advisory statement to farmers. Any effective onset of rain at about pentad 41 (25 July) is an indication of deficient moisture conditions (severe drought), and this should justify the issuance of an alert to farmers (Table 1).

Finally, a very severe deficient moisture situation is said to occur if the seasonal rains are not effective by the 43rd pentad (5 August), and this should warrant the declaration of an emergency as the growing season is not likely to be long enough for crops to mature and yield any tangible harvest for the season (see Table 1).

Table 1: Drought early warning scheme using effective onset dates

Effective onset dates (pentad number)	**Onset phase drought intensity (moisture deficit)**	**Early warning phase**
30th June (36th)	Mild	Advisory
25th July (41st)	Severe	Alert
5th August (43rd)	Very Severe	Emergency

Adopted from Usman and Abdulkadir (2014)

Standardized Precipitation Index (SPI)

The most widely accepted index is understood to be Standardized Precipitation Index (SPI) which is based on probability concept (Ahmad, et al., 2016). The SPI index was developed by (Mckee, et al, 1993) to quantify the precipitation deficit. The SPI index calculation of any place is based on the precipitation history over a long period corresponding to the period of time studied. The SPI is calculated as hereunder:

$$SPI = \frac{(R_{ij} - \bar{r}_i)}{\delta_i} \quad (2)$$

$$\delta_i = \sqrt{\frac{\sum_1^n (R_{ij} - \bar{r}_i)^2}{N}} \quad (3)$$

Where:
SPI = standard precipitation index for station i and year j
R_{ij} = rainfall depth at station i during j year
δ_i = standard deviation of the annual rainfall for station i
N = number of specific years for sample station

Table 2: Standardized Precipitation Index (SPI) Classification Values

SPI Values	Interpretation	Probability of Occurrence(%)
≥2.00	extremely wet	2.3
1.50 to 1.99	severely wet	4.4
1.00 to 1.49	moderately wet	9.2
−0.99 to 0.99	near normal	34.1
−1.00 to −1.49	Moderate drought	9.2
−1.50 to −1.99	Severe drought	4.4
≤−2.00	Extreme drought	2.3

The fundamental strength of SPI is that it can be calculated for a multiple time scales for example 1, 3, 6, 12, 24 and 48 months (Haied et al., 2017). The versatility allows SPI to monitor short-term water supplies, which is important for agricultural production and long-term water resources planning.

To calculate the SPI, a long-term precipitation record at the desired station is first fitted to a probability distribution which is then transformed into a normal distribution so that the mean SPI and variance are zero and one (McKee et al., 1993). A classification of the drought is carried out according to the values of the SPI represented in Table 2.

Results and Discussion

Onset Pentad

The rainfall system in the Guinea ecological zone of Nigeria has only one season. As such the month of May to October of each year were taken into consideration. The effective onset pentad series of the station across the study area are depicted in figure 1(a-b). Figure 1(a) depicts the temporal pattern of onset pentad of Bida, Yola, and Minna along the latitudinal line. The range of onset pentad in Bida is between 25 pentads (5th May) in 1994 and 39 pentad (14th July) in 1982, Yola between 26 pentad (10th May) in 1984 and 46 pentad (18th August) in 2015 and Minna. Although Yola is in between the latitude of Bida and Minna it demonstrated higher variability between the year 1973-1980 and year 2007- 2016. Although the onset rainfall reveal variability, the early warning could have been issued in Bida, Yola, and Minna.

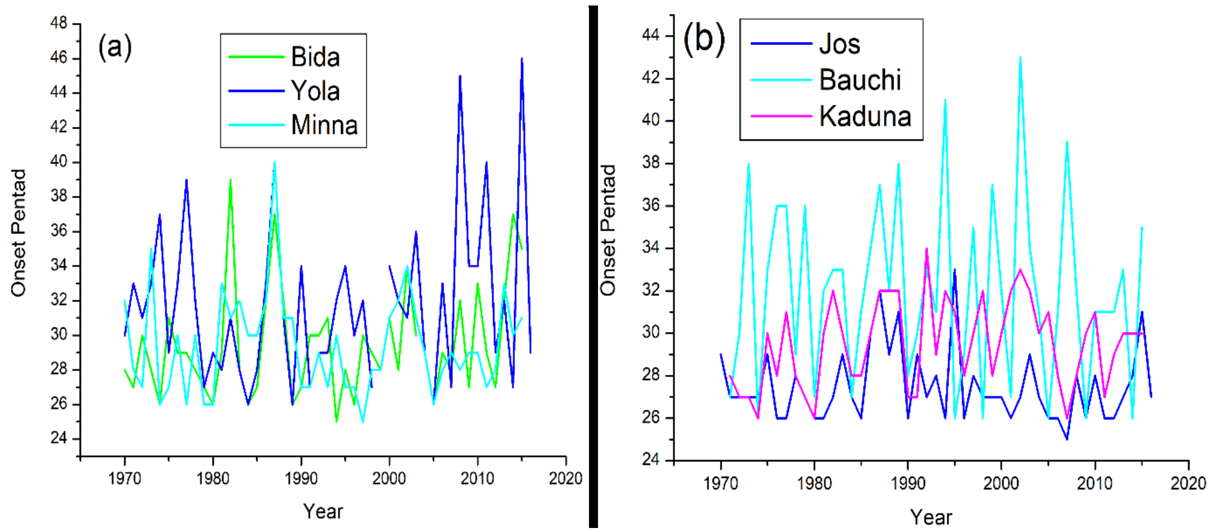

Figure 1 (a-b) Onset series of observation stations

Figure 1(b) depicted the effective onset pentad of Jos, Bauchi and Kaduna and Jos between 25 pentad (5th May) in 2007 and 33 pentad (14th Jun e) in 1995 (table 3), the onset pentad in Kaduna range from 26 pentad (10th May) in 2007 and 34 pentad (19th June) in 1992, Bauchi range from 26 pentad (10th May) in 1995/2009 and 43 pentad (3rd August) in 2002.

Spatio-Temporal Patterns of Seasonal Standardized Precipitation Index

The seasonal (6-months) SPI of the observation stations are presented in Figure 2 (a-b). These figures depict the seven (7) categories of SPI patterns for the stations in the study areas. The Figure 2 (a-b) revealed oscillation between wet and dry episodes across the stations in the study areas. The general pattern indicated near normal conditions. Figure 2(a) indicated that from 1975-1980, 1995-2000 and 2005-2009 had rainfall mostly above normal (wet years) while from 1971-1976, 1980-1985 and 2010-2014 had rainfall mostly below normal (drought years). Figure 2(b)

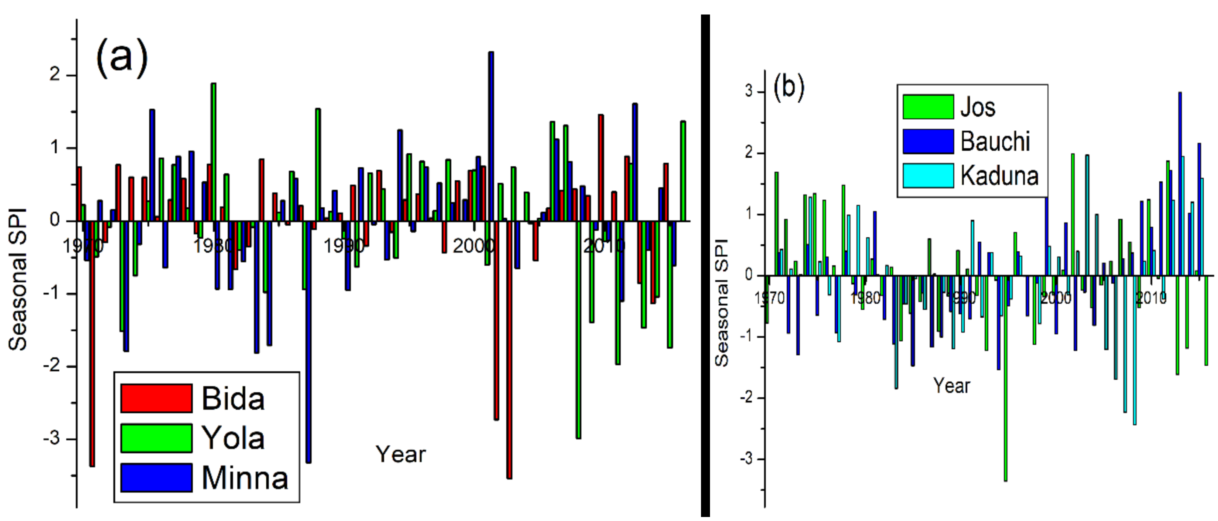

Figure 2 (a-b) Seasonal Standardized Precipitation Index of observation stations

Spatial Patterns of Annual Standardized Precipitation Index

The annual (12-months) SPI of the observation stations are presented in Figure 3 (a-b). These figures depict seven (7) categories of SPI patterns for various stations in the study areas. The Figure 3 (a-b) revealed oscillation between wet and dry episodes across the stations in the study areas. This generally indicate that the study area has been mostly under near normal conditions.

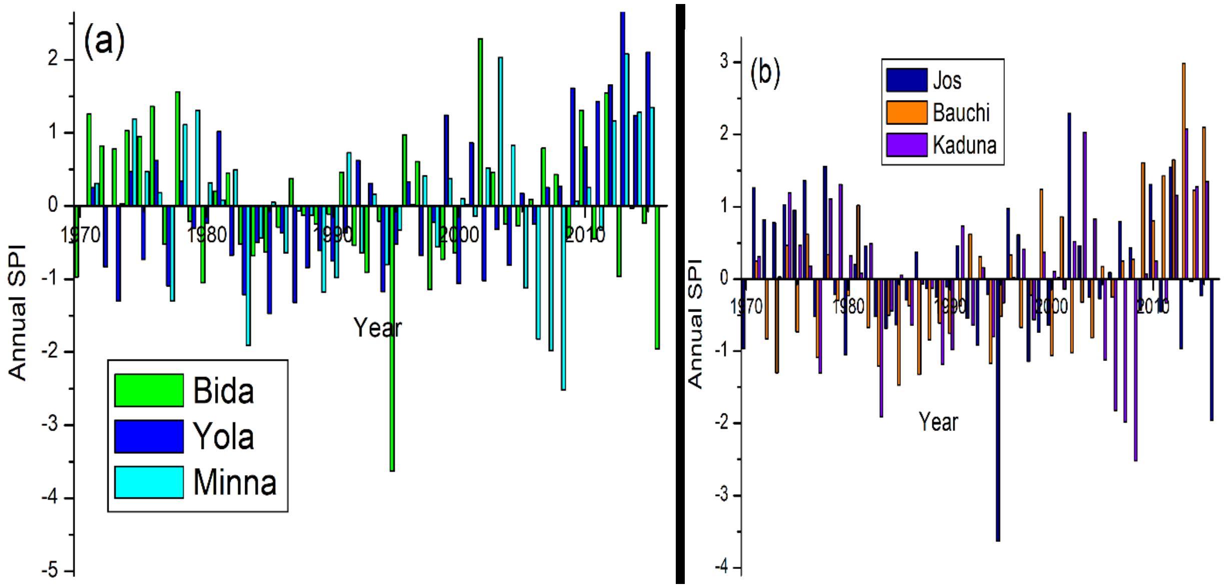

Figure 3 (a-b) Annual Standardized Precipitation Index of observation stations

Comparison of Early Warning Onset Phase and SPI

The comparison of early warning onset phase and SPI is depicted in Table 2. The table indicate that years adjudged to have warranted the issuance of early warning methodology were captured by a SPI as a drought year both seasonally and annually. Table further revealed that nine (9) out of twelve (12) early warning onset phases were capture by SPI as a drought year or season. This imply that the early warning methodology correctly detected 75% drought season and year. The season correctly detected by early warning methodology are represented with colour cyan while colour darkorchid represent season and year not correctly detected.

Table 2: Comparison of Early Warning Onset Phase and SPI

Bida	37(1987)	37(2014)	**Nil**	**Nil**	**Nil**
SPI-6	0.21	-1.13			
SPI-12	0.17	-1.22			
Yola	37(1974	40(1987)	45(2008)	40(2011)	46(2015)
SPI-6	-0.75	-0.94	-2.99	-1.97	-1.74
SPI-12	-0.73	-1.22	-2.96	-2.21	-2.21
Minna	40(1987)	**Nil**	**Nil**	**Nil**	**Nil**
SPI-6	-3.32				
SPI-12	-3.17				
Jos	**Nil**	**Nil**	**Nil**	**Nil**	**Nil**
SPI-6					
SPI-12					
Bauchi	38(1973)	38(1989)	41(1994)	43(2002)	**Nil**
SPI-6	-1.29	-0.58	-1.53	-1.22	

SPI-12	-1.3	-0.61	-1.17	-1.02	
Kaduna SPI-6 SPI-12	**Nil**	**Nil**	**Nil**	**Nil**	**Nil**

Note: Nil mean onset rainfall were sufficient not to justify issuance of early warning

Conclusion

This study is to confirm the efficacy of the scheme by comparing its result with Standardized Precipitation Index. Daily rainfall data from 6 synoptic stations were collected from the archives of Environmental Management Programme, Department of Geography Federal University of Technology, Minna for a periods of 1970-2016. The Intra-seasonal Rainfall Monitoring Index (IRMI) and Standardized Precipitation Index methods were adopted for data analysis. The findings revealed variability in onset rainfall as well as the wet and drought periods. The onset phase detected twelve (12) seasons and years that could have warranted issuance of early warning statement. The SPI capture nine (9) seasons and years as a drought episodes thus representing 75% efficacy. It also confirmed the effectiveness of early warning methodology scheme as a tool for drought monitoring in the study area. Recommendations include similar studies in other ecological zones in the country for total coverage and adapting the tools for continous drought monitoring.

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