Analysis of meteorological drought in Sokoto State for the past four decades (1970-2009)

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ABSTRACT

Meteorological drought disaster is a serious problem in the Sahelian region of the world. This strongly affects the hydrology of the region and creates severe constraint to agriculture and water management. This paper therefore, examines the rainfall characteristics and the extent of meteorological drought in Sokoto state, Nigeria. Daily rainfall data were obtained for a period of four decades (1970-2009) from Nigerian Meteorological Agency (NIMET) through Sultan Abubakar III International Airport, Sokoto Synoptic Station. Data collected were analysed using statistical techniques. The result of the descriptive statistics varies from year to year and slight increase of mean monthly rainfall was observed. Standardized Precipitation Index (SPI) and Rainfall Anomaly Index (RAI) were used in classifying drought severity into severe, moderate and mild conditions. The result is already anticipated since Sokoto State lies within the Sudano-Sahelian region that generally known to be draught prone. Recommendations were offered based on the outcome of the result.

Keyword: Meteorological Drought; SP1; RA1; ITD Model; Sokoto State

1. INTRODUCTION

A major evidence of global climatic anomaly drought, it is a climatic phenomenon peculiar to the African continent, especially in the Sudano-Sahelian region and northern part of Nigeria where Sokoto State is located (Fidelis, 2003). Drought is universally acknowledged as a phenomenon associated with scarcity of water that has significant impact on the human environment, consequently, worsening the nation's economic structure (Bruins & Berliner, 2004). It varies with regards to time of occurrence, duration and extent of the area affected. It is broadly classified into four categories, namely: meteorological, hydrological, agricultural and socio-economic drought.

Concept of Drought

There is no universally acceptable definition of drought. Therefore, definitions have been classified as conceptual and operational. Operational definition on the one hand is crucial because it attempts to determine the onset, severity, spatial distribution and cessation of drought condition. On the other hand, conceptual definition of drought is also very important because it helps people to understand the concept (Gonzalez, et-al 2001). According to Fidelis (2003), drought is a protracted period of deficiency in precipitation which causes extensive damage to crops and loss of agricultural produce. On the other hand,

it is an insidious hazard of nature that originated from a deficiency of precipitation over an extended period of time, usually a season or more.

This deficiency results in a water shortage for human activities and the functioning of physical environment. In general, drought gives an impression of water scarcity due to insufficient precipitation, high evapo-transpiration and over-exploitation of water resources or combination of these parameters.

Drought has three distinguishing features which include: intensity, duration and spatial coverage. Intensity refers to the degree of the precipitation shortfall and severity impacts associated with the shortfall. Duration considers the temporal pattern, while spatial features involve the affected areas (WMO, 2006).

The dynamic character of drought challenges the ability of planning and effort at providing relief to affected areas. It has been estimated that drought result in annual economic losses of about 86-88 billion dollars in the United States (Jesslyn et-al, 2002).

Types of Drought

As has been said earlier, drought can be categorized into four, namely: meteorological, hydrological, agricultural and socio-economic.

Meteorological Drought

Meteorological drought is defined as the extent of precipitation departure from normal in comparison with long average and duration of the dry period (Smakhtin and Hughes, 2004). Definition of drought should be considered from one region to another, this is because, the atmospheric conditions that result in deficiencies of precipitation are highly variable from one region to another (Fidelis, 2003). Basically, there are numerous indices which are used for meteorological drought quantification.

These integrate various hydro-meteorological parameters obtained from data series of rainfall, stream flow, evaporation and other water deficiency indicators (Otun and Adewumi, 2009). The most commonly used meteorological drought indices are: Palmer Drought severity Index (PDSI), Bhalme and Mooley Drought Severity Index (BMDI), Rainfall Anomaly Index (RAI), Reclamation Drought Index (RDI), Surface Water Supply Index (SWSI) and Standardized Precipitation Index (SPI).

However, there are other indices for quantifying metrological drought in a place over a period of time. These are: Onset of Rainy Season (ORS) defined as the first day it rains in a season; Cessation of Rainy Season (CRS) defined as the last day it rains in season.

Bhalme and Mooley (1980), defined onset as the beginning of rainy season which accumulates at least 20 minutes of rainfall in 3 days after 1st May; while cessation of the rainy season is considered as 20 successive days without rain after the 1st September of a year.

Other indices are: length of rainy season which is defined as the difference between CRS and ORS (LRS), total wet days, defined as the total number of days it rains within a season (TWD), total number of dry days which is the number of days without rain within the whole season (TDY), length of dry season (LDS), maximum dry spell length within a wet season (MDL) and mean seasonal rainfall depth (MAR) (Otun and Adewumi, 2009).

Hydrological Drought

This is defined in terms of the departure of surface and subsurface water supplies for some average conditions at various points in time (Sinha-Ray, 2002). Surface and subsurface

water supplies include: Stream levels, ground water, aquifers, stream flow, reservoirs and lakes. They are often used for multiple purposes such as flood control, irrigation, recreation, navigation, hydroelectric power generation and wildlife habitat. Competition for water in these storage systems increases significantly during hydrological drought.

Agricultural Drought

This refers to situations in which the moisture in the soil is no longer sufficient to meet the crop growing in an area. Soils also vary in their water characteristics. For example, soil having a high water holding capacity soils are prone to drought (Smakhtin and Hughes, 2004). Agricultural drought is interrelated with meteorological and hydrological drought, through storage of precipitation, difference between actual and potential evapo-transpiration, soil water deficits and reduction of ground water reservoir level.

Socio-Economic Drought

Socio-Economic drought refers to the situation where water shortages affect people's lives. This type of drought differs from other types of drought because it associated human activities with element of meteorological, hydrological and agricultural drought (ISOR, 2003).

Conceptual Framework

The Inter-tropical Discontinuity (ITD) services as the conceptual framework for this paper. It is the boundary zone separating the air masses from the northern and southern hemisphere respectively which is neither frontal nor always convergent.

These air masses include the tropical continental air mass which is dry, dust and blows from Sahara desert, while the tropical maritime air mass which is dry, humid and moisture – laden is blowing from Atlantic-ocean.

The ITD assumes its northern most position around latitude 20° N in August, and this marks the height of the rainy season in west Africa; in January, the ITD attains its southern most position around latitude 6° N and this marks the peak of the dry season in west Africa with the exception of the coastal areas. According to Adekunle (2004), seasonal distribution, type of rainfall and length of the rainy season as well as the general weather conditions experienced in the course of the year at a given location in West African region depends primarily on the location relative to the position of ITD and associated weather zones.

Study Area

Sokoto state was created and separated from Niger State in 1976. Geographically it is located within Sudan Savannah Zone on latitudes 13° 35′ N to 14° 0′ N and on longitudes 4° E to 6° 40^1 E. It has a total population of 3,702,676 million (NPC 2006). Sokoto State shares borders with Niger Republic to the North, Kebbi State to the West and South and Zamfara State to the East.

2. MATERIALS AND METHODS

This paper heavily relies on the rainfall data for the period of forty-years (1970-2009) collected from the Nigerian Meteorological Agency (NIMET) via Sultan Abubakar III

International Airport Synoptic Station. The collection of fourty-years rainfall data was based on the World Meteorological Organization (WMO) standard so as to allow for the calculation of climatic normal whether of temperature or of precipitation (Ayoade, 2004).

2. 1. Methods of Data Analysis

Time Series Analysis (TSA)

The mean monthly was estimated by dividing the accumulated rainfall for a month by the total number of days in rains it that month using mean equation. The data were input into Microsoft Excel and transposed to make a sum of 480 months (40 years). The analysis was carried out using Minitab software.

Co-efficient of Variation

The inter-annual and inter-decadal variability of rainfall in Sokoto state over the period (1970-2009) were examined using the co-efficient of variations. It is expressed mathematically as follows:

$$CV = \frac{\bar{\sigma}}{\bar{x}}$$

where: CV = Co-efficient of Variation
$\bar{\sigma}$ = Standard deviation
$\bar{x}$ = Mean of the Time series

Walter's (1967) technique

This formula or technique is used in the determination of onset and cessation dates of the rains as well as the length of the growing season. The computations were based on the following formula:

Days in Month X $\underline{(51 - \text{accumulated rainfall in previous month)}}$
                           Total rainfall for the month

where the month under reference is that particular month in which the accumulated total of rainfall is in excess of 51mm. For computing the cessation date, the formula above is applied in the reverse order by accumulating the totals backward from December.

Dry Spells Analysis

The analysis was carried out using daily rainfall data from 1970-2009. Five consecutive days with rainfall below 2.5 mm proposed by Chowdhury (1978) within the growing season were used in determining the frequency of dry spells that is between 7th May to 30th September.

Standardized Precipitation (SPI)

SPI is an Index based on precipitation record for a location and the chosen periods are usually months or years. 12 months time scale was considered. This is because of the discrete

nature of rainfall in semi arid environment. SPI for a particular station as determined using the following equation:

$$SPI = (X_{ik} - X_i\ 1\ \sigma_i)$$

where:

SPI	= Standardized Precipitation Index
X_{ik}	= Rainfall observed for the station
X_i	= Mean rainfall recorded for the station
σ	= Standard deviation for the station

All negative SPI values indicate the occurrence of drought while positive values show no drought (Akeh et al, 2000).

Rainfall Anomaly Index (RAI)

In this technique, the precipitation values for the period of study were ranked in the descending order of magnitude with the highest precipitation being ranked first and the lowest precipitation being ranked last. The average of the ten highest precipitation values as well as that of the ten lowest precipitation values for the period of the study was calculated. The first average is called the maximal average of 10 extrema and the second average is called the minimal average of 10 extrema. They are known as average precipitation of 10 extrema for positive and negative anomalies respectively. This technique which was developed by Rooy-van (1965) is given by the following equations:

$$RAI = \pm\ 3\ \frac{P - \bar{P}}{\bar{E} - P}$$

Where:

RAI	= Rainfall Anomaly Index
$\bar{P}$	= Long-term average of the annual rainfall (mm)
$\bar{E}$	= Average precipitation of 10 – Extrema (mm) for both positive and negative anomalies
P	= Actual rainfall for each year
±3	= Constant.

Spatial Analysis of Drought

The analysis of spatial occurrences of drought were carried out using recent series data from (2000 – 2009). The analysis was carried out using Arc Gis map software.

3. RESULT AND DISCUSSION

Trend in Mean Monthly Rainfall in Sokoto (1970 – 2009)

The result of the mean monthly rainfall for 40 years (1970 – 2000) in Sokoto State was subjected to time series analysis. The result shows slight level of variation especially in the mean monthly rainfall. It also indicates that Mean Absolute Percentage Error (MAPE) is 181. 173, Mean Absolute Deviation (MAD) is 6.706 and the Mean Square Deviation (MSD) is 63.015. The MAPE, MAD, and MSD values measure the accuracy level for the time series. The trend line equation is presented as follows:

Linear trend equation = Yt = 5.14675 + 4.40E – 30*t

The above equation implies that slight increase has been recorded in monthly values of rainfall in the period under study. Thus, the mean monthly rainfall in Sokoto suggests that the rainfall has been increasing on monthly basis through out the rainy season. Indeed, the equation shows that for every 5.1 mm monthly mean in Sokoto, rainfall will increase by 0.0044 mm. The trend suggests an increase in rainfall in the near future, which is an evidence of climate change as predicted by NIMET (2011).

Inter-Annual Variability of Rainfall in Sokoto State

Table 1. below which contains the data on the pattern of Annual Rainfall departure from normal shows the result of the annual rainfall for four decades (1970 – 2009) and the long term mean calculated as 600.06 mm. The analysis shows high level of inter-annual variability from year to year with the highest amount in 1998 (844.1 mm) and 1977 (342.8 mm) which were characterized as meteorological drought periods of 40 % below the long term mean and 43 % below the mean value. This is related to Sinha-Ray (2000) definition of meteorological drought as stated earlier. The co-efficient of variation indicates high level of variability with the highest inter-annual variability in 1970 (218 %) and the lowest in 1985 with 0.71 %. the result also reveals that the standard deviation was highly variable from 1970 – 2009.

Table 1. Pattern of Annual Rainfall Departure from Normal in Sokoto State (1970 – 2009).

Years	Annual Rainfall. (mm)	Deviation
1970	625.7	+25.64
1971	342.8	-257.3
1972	534.1	-65.96
1973	330.2	-269.9
1974	479.7	-120.4
1975	542.2	-57.86
1976	674.7	+74.64
1977	836.0	+235.9
1978	711.7	+111.6
1979	594.9	-5.160
1980	549.9	-50.16
1981	560.3	-39.76
1982	565.9	-34.16
1983	623.2	+23.14
1984	439.0	-161.1

1985	434.8	-165.3
1986	475.8	-124.3
1987	369.4	-230.7
1988	667.3	+67.24
1989	478.4	-121.7
1990	653.9	+53.84
1991	708.8	+108.7
1992	549.0	-51.06
1993	642.2	+42.14
1994	762.1	+162.0
1995	508.3	-91.76
1996	641.0	+40.94
1997	645.5	+45.44
1998	844.1	+244.0
1999	755.4	+155.3
2000	710.2	+110.1
2001	514.2	-85.86
2002	730.0	+129.9
2003	706.7	+106.6
2004	648.1	+48.04
2005	624.3	+24.24
2006	715.7	+115.6
2007	631.9	+31.64
2008	506.4	-93.66
2009	668.5	+68.44
Mean	600.06	

Source: Author's Computation, 2014

Trend in Onset, Cessation and Length of the Growing Season in Sokoto State

Onset and cessation dates play a significant role in measuring precipitation effectiveness. The overall concentration of the onset dates as indicated in Table 2 shows that June recorded highest with 50 %, while July had 20 % and May 30 %. However, the Table 2 shows 80 % of cessations are between 1st to 15th September, while 5 % of the cessations were experienced in October and 15 % around August. It can also be conspicuously seen from table 1.2 that the year 1976 had the longest duration of the rainy season with 132 days,

followed by 125 days in 1981 and 2005. These indicated that there is variability in the annual rain days for the period 1970-2009. The lowest duration of the wet season were recorded in 1974 with only 39 days, 1971 had 64 days and 1970 had 68 days. Variability in rain days and duration could be said to have adversely affect food production and poses danger to food security.

Trend in Dry Spells in Sokoto State

The rainy season in the Sahel is characterized by a sequence of days without precipitation or very low precipitation known as dry spell. The length of dry spell is the number of days until the next day with rainfall greater than a given threshold value (Sivakumar, 1992). The threshold value of dry spell is considered to be less than 2.5 mm (Chowdhury, 1978). The analysis of dry spells were examined using five consecutive days without rains or very low rainfall of less than 2.5 mm between 7th May, (onset date) to 30th September (cessation date). The highest frequency of dry spells was recorded in 1971 with value 16. The frequency decreases to 10 (1972), 9 (1973) and 8 in 1974; while the lowest frequency was recorded in 1998 with value 6.

Table 2. Rainfall Characteristics in Sokoto State.

Years	Onset	Cessation	Duration of Rainy Season	No. of Rain Days
1970	2nd July	15th September	74	40
1971	9th June	10th August	63	30
1972	18th May	8th September	113	38
1973	27th June	22nd September	83	40
1974	11th July	8th September	59	52
1975	18th May	16th September	121	50
1976	23rd May	2nd October	132	54
1977	4th June	19th September	107	50
1978	15th June	8th September	85	44
1979	11th June	19th September	101	43
1980	23rd May	2nd August	72	40
1981	19th May	20th September	125	43
1982	2nd June	24th September	85	33
1983	1sth June	23rd September	115	32
1984	24th June	12th September	81	30

1985	7th June	21st September	107	37
1986	3rd July	12th September	72	32
1987	1st July	6th September	68	32
1988	14th June	8th September	87	44
1989	6th June	17th September	104	53
1990	30th May	22nd September	116	42
1991	8th May	2nd August	87	57
1992	6th June	9th September	96	41
1993	26th May	15th September	113	42
1994	29th June	8th September	72	49
1995	4th July	16th September	75	47
1996	24th May	17th September	117	45
1997	11th May	2nd August	84	50
1998	16th June	4th September	81	52
1999	2nd July	5th September	66	58
2000	11th June	1st September	83	41
2001	2nd July	22nd September	83	41
2002	2nd June	4th September	95	48
2003	18th June	1st August	45	37
2004	7th May	1st August	87	45
2005	11th May	12th September	125	43
2006	2nd July	3rd September	64	51
2007	2nd June	15th September	106	47
2008	3rd June	16th September	106	47
2009	2nd June	15th October	104	43

Source: Author's Computation, 2014.

Table 3. Comparison between SPI and RAI.

Years	SP1	+ RAI	–RAI
1970	0.15	0.52	0.47
1971	-1.50	-5.21	-4.72
1972	-0.38	-1.33	-1.21
1973	1.57	-5.47	-4.95
1974	0.70	-2.45	-2.21
1975	-0.34	-1.17	-1.06
1976	0.43	1.51	1.37
1977	1.37	4.78	4.32
1978	0.65	2.26	2.04
1979	-0.03	-0.10	-0.09
1980	0.29	-0.87	-0.92
1981	0.23	-1.02	-0.72
1982	-0.20	-0.69	-0.63
1983	0.13	-0.47	0.42
1984	-0.94	-2.26	-3.03
1985	-0.96	-3.35	-2.28
1986	-0.72	-2.52	-4.22
1987	-0.34	-4.67	-4.22
1988	0.39	1.36	-1.23
1989	-0.71	-2.46	-2.23
1990	0.31	1.08	0.99
1991	0.63	2.20	1.99
1992	-0.30	-1.03	-0.93
1993	0.25	0.84	0.77
1994	0.94	3.29	-1.68
1995	-0.53	1.86	2.97

1996	0.24	0.83	0.74
1997	0.26	0.92	0.83
1998	1.42	4.95	4.48
1999	0.90	3.15	2.85
2000	0.64	2.23	2.02
2001	-0.50	-1.74	-1.57
2002	0.76	2.63	2.38
2003	0.62	2.16	1.96
2004	0.28	0.97	0.88
2005	0.14	0.49	0.44
2006	0.67	2.34	2.12
2007	0.19	0.65	0.58
2008	0.54	-1.21	-1.72
2009	0.40	1.35	1.26

4. CONCLUSION

This paper has critically analysed the meteorological drought in Sokoto State for the past four decades (1970-2009) and the result shows that there is strong seasonal concentration of rainfall in the months of June, July, August and September. Minimum amount were received in the months of May, April and October; while March, November, January and February were virtually very dry months receiving no rainfall except in few cases. Also, between 1971-1975, there was an evidence of meteorological drought as well as dry spell increase, where severe meteorological drought was experienced. In addition, temporal analysis of SP1 shows that different drought scenarios were emerged. These include mild, moderate and severe drought. Finally, the SP1 and RA1 as two meteorological indices show a strong relationship between them at 99.2 % significance level.

Recommendations

The paper recommends the followings:
1) There is need to develop strategies for drought preparedness and its mitigation for both short and long terms.
2) Meteorological based indicator of drought should be complemented with satellite based indicator. This can assist in advance early warning of drought.
3) Rainwater harvesting technology should be developed across the state such that during period of heavy rainfall the excess rain could be harvested and stored for use during period of dry spells and drought.

4) There should be effective communication with farmers concerning the appropriate dates of onset and cessation so as to enhance crop and food production in the state.

5) Further studies should be encouraged on the impact assessment of meteorological drought in the study area.

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