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Effect of Climatic Variability on Drought Occurrence Probability over Nigeria

O. O. Ajileye[1*], I. M. Aigbiremolen[1], S. O. Mohammed[2], A. S. Halilu[2] and A. T. Alaga[1]

[1]Advanced Space Technology Applications Laboratory, Obafemi Awolowo University, Ile-Ife, Nigeria.
[2]National Space Research and Development Agency (NASRDA), Federal Capital Territory, Abuja, Nigeria.

Authors' contributions

Authors OOA and IMA designed the research proposal, authors ATA and ASH supervised the research work, author SOM approved the work for execution. Author OOA carried out the analysis and interpretation of the results. Authors OOA and ATA prepared and edited the paper.

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ABSTRACT

Drought is grouped into meteorological, hydrological and agricultural classes. These classifications are done according to a number of criteria involving several variables, used either alone or in combination: rainfall, temperature, humidity, and evaporation from free water, transpiration from plants, soil moisture, wind, river and stream flow, and plant condition. The study extracted meteorological data including near surface temperature, relative humidity and precipitation averaged for the month of July covering a period of 1975 – 2014 grouped into 2 regimes of 20 years each. The data were analyzed using drought empirical models suitable for deducing meteorological, agricultural and hydrological drought phenomena with a view to deduce drought probability trend across Nigeria. Highly significant increase in atmospheric dryness was observed at Sokoto, Katsina, Maiduguri, Kaduna and Yola. Slight increase was observed at Kano, Abuja, Makurdi, Lagos, Osogbo, Benin, Enugu, Port Harcourt and Calabar. A slight decrease in

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**Corresponding author: E-mail: ajileyeseun@rocketmail.com;*

atmospheric dryness was observed in one station only – Jos from all the stations under consideration. All stations across Nigeria had a significant increase in dryness ratio for monitoring agricultural drought. Stations in the southern part of Nigeria had no significant change in drought occurrence probability except at Osogbo where a slight increase in drought occurrence probability was observed. Generally, the results offered a significant insight into occurrence probability of drought over Nigeria by comparing trends in two regimes of 20 years, respectively. A shift from wet to dry climatic in features was observed across Nigeria confirming gradual occurrence of drought in the past 20 years over Nigeria.

Keywords: Meteorological drought; dryness ratio; atmospheric dryness; evaporation indicator; climate variability.

1. INTRODUCTION

Drought is undoubtedly one of the human being's worst natural enemies [1,2]. Among the extreme meteorological events, drought is possibly the most slowly developing and long existing event, and probably is the least predictable among the atmospheric hazards. Due to these characteristics, particularly their temporal character, drought cannot be compared with other natural hazards such as flood, hurricane, tornado, lightening, hailstorm, frost, or plague of locust, which can also significantly contribute to a nation's annual loss due to disadvantageous natural circumstances. We can record flood and drought in the same vegetation period in some part of the world [3]. Because of its peculiar character, drought deserves the greatest scientific and operative/practical investigation.

More exact determination of drought could be made by means of plant-specific indicators of moisture deficiency, characterizing the water demand during the consecutive phenological phases of plants if the information was available and could be mathematically formulated. Drought is a compound concept. As a first guess, it seems that everybody determines it similarly [4]. However, if we go into details, we can compare the phenomenon from different parts of the world; from different types of climate zones we cannot find an absolute acceptable definition and absolute categorization. It means, on one side, a prolonged absence or marked deficiency of precipitation, on the other side, a yield decrease caused by the precipitation deficit.

The goal of this study is to extract meteorological data including near surface temperature, relative humidity and precipitation averaged for the month of July covering a period of 1975 – 2014. The data was analyzed using drought empirical models suitable for deducing meteorological, agricultural and hydrological drought phenomena with a view to describe drought probability trend across Nigeria.

2. LITERATURE REVIEW

Drought is grouped into meteorological, hydrological and agricultural classes. These classifications are done according to a number of criteria involving several variables, used either alone or in combination: rainfall, temperature, humidity, and evaporation from free water, transpiration from plants, soil moisture, wind, river and stream flow, and plant condition [5].

Meteorological Drought refers to short-period droughts or dry spells, when precipitation received is far below the expected normal. Meteorological drought is expressed solely on the basis of the degree of dryness (often in comparison to some "normal" or average amount) and the duration of the dry period.

Agricultural drought is related to physiological drought, which is determined from conditions of natural vegetation, crops, livestock, pastures and other agricultural systems. It is defined by measure of the availability of soil water to plants or animals [6]. In this case, radiation (heat), drying wind and evaporation become important factors. It is usually measured by the effects of water deficit in terms of economic losses to agriculturists. The economic loss terms can include factors like drop in crop production, livestock deaths, industrial losses; plants not planted or replanted changes in land use, emergency relief expenses, as well as losses incurred after the agricultural drought (e.g. losses through wind and water erosion).

Hydrological drought is the deficit of runoff into rivers and other surface water resources and in groundwater resources. It involves the description of availability of water, in the form of precipitation runoff, evaporation, infiltration, river systems, and other surface/ groundwater inflow/outflow systems Thus hydrological droughts are related more with the effects of periods of precipitation shortfall on surface or subsurface water supply (i.e. stream flow, reservoir and lake levels) rather than precipitation shortfalls [7].

Hydrological droughts are usually out of phase or lag the occurrence of meteorological and agricultural droughts. Meteorological droughts result from precipitation deficiencies; agricultural droughts are largely the result of soil moisture deficiencies [8]. More time elapses before precipitation deficiencies show up in components of the hydrological system (e.g. reservoirs, groundwater).

As a result, impacts are out of phase with those in other economic sectors. Also, water in hydrological storage systems is often used for multiple and competing purposes (e.g. power generation, flood control, irrigation, recreation) further complicating the sequence and quantification of impacts [9]. Competition for water in these storage systems escalates during drought, and conflicts between water users increased significantly.

3. MATERIALS AND METHODS

3.1 Study Area

The seasonal northward and southward oscillatory movement of the Inter-Tropical Discontinuity (ITD) largely dictates the weather pattern of Nigeria. The moist southwesterly winds from the South Atlantic Ocean, which is the source of moisture needed for rainfall and thunderstorms to occur, prevail over the country during the rainy season (April – October) [10].

In reverse, northeasterly winds which raise and transport dust particles from the Sahara Desert prevail all over the country during the harmattan period (November – March). The overall changes in temperature, rainfall and other meteorological parameters determine the changes in climate in the country each year.Nigeria covers a total area of 923,768 sq. km. making it the thirty second largest country of the world. It has a small coastline of 853 km in comparison to its total land boundary of 4047 km. The latitudinal and longitudinal extent of the country is between latitude 4°N and 14°N and longitude 2°E and 15°E, respectively.

The climate of the country varies from equatorial in the south to arid in the north and tropical in the centre. 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.

The study area contains 17 gridded (1° by 1°) locations randomly selected and spreading across different climatic zones over Nigeria as shown in Fig. 1. The coastal area – in the Mangrove Rain Forest has 5 locations namely, Port Harcourt, Calabar, Enugu, Lagos, and Benin. There are 7 inland stations – in the Tropical Rain Forest namely, Makurdi, Osogbo, Abuja, Bida, Yola, Minna, and Jos. There are 5 stations in the up north – in the Sudan Sahel - namely, Kaduna, Maiduguri, Kano, Katsina, and Sokoto.

3.2 Data Structure

In general, Prediction of Worldwide Energy Resource (POWER); Surface meteorology and Solar Energy (SSE) experiment for POWER/SSE Release 6.0 were obtained from the NASA science mission directorate's satellite and re-analysis research programs. Release 6.0 extends the temporal coverage of the solar and meteorological data from approximately 11 years to 22 years (e.g. July 1983 through June 2005) with improved NASA data, and includes new parameters and validation studies [11]. It is generally considered that quality ground-measured data are more accurate than satellite-derived values. However, measurement uncertainties from calibration drift, operational uncertainties, or data gaps are unknown or unreported for most ground site data sets. In 1989, the World Climate Research Program estimated that most routine-operation solar-radiation ground sites had "end-to-end" uncertainties from 6 to 12%. Specialized high quality research sites are hopefully more accurate by a factor of two [12].

Satellite meteorological point data from Goddard Earth Observing Satellite Model, version 5, (GEOS-5) comprising relative humidity averaged monthly within 10 m height for a period of 22 years 1983 – 2005 and 2008 – 2013 were obtained from NASA databank as shown in Table A.1 (see Appendix 1 for sample data). The data

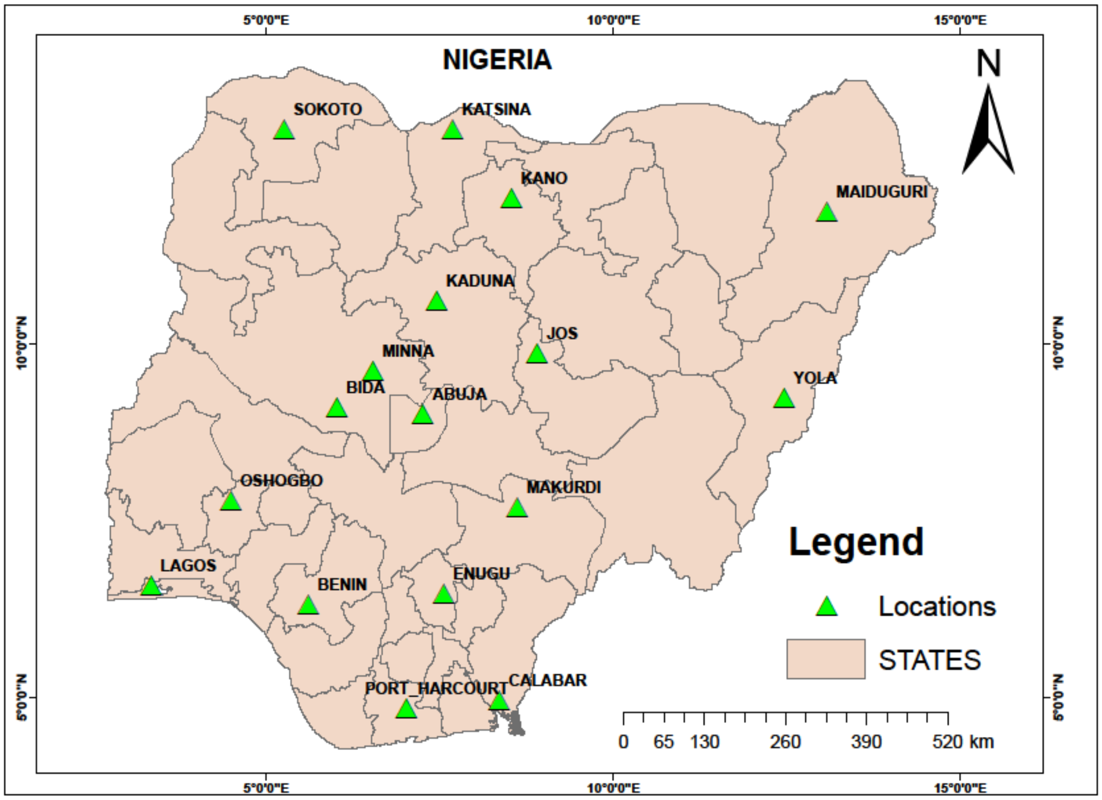

Fig. 1. Map of the study area

were gridded data covering 17 geo-referenced locations across Nigeria. The data was arranged in Microsoft EXCEL spreadsheet for further manipulation. Work flow chart for the analysis was presented in Fig. 1A.

3.3 Data Analysis

Complex indicators give more comprehensive characteristics. In Russia, the relative indicator known as G. T. Selyaninov's hydrothermal coefficient (HTC) has been widely used [13]:

$$\mathrm{HTC} = 6.11*\exp\frac{17.67*(T-276.16)}{T-29.65}\left(1-\frac{RH}{100}\right)*10 \quad (1)$$

T is surface temperature in Kelvin and RH is relative humidity in %. This empirical equation was used to estimate atmospheric dryness indicator over Nigeria for 2 periods of 20 years each (1975 – 1994 and 1995 – 2014).

The result is classified in terms of meteorological drought as atmospheric dryness indicator: 20 – 29 hPa (weak atmospheric dryness); 30 – 39 hPa (moderate atmospheric dryness); 40 – 49 hPa (intensive atmospheric dryness); and > 50 hPa (very intensive atmospheric dryness)

A more detailed assessment of drought for vegetation classification was proposed by [14], it was expressed in terms of dryness ratio as:

$$D = \frac{0.1651*d*L*4.95e^{0.062*T}}{P} \quad (2)$$

L is the mean monthly hours of daylight in hours; d is the number of days in the month; T is temperature in degree Celsius and P is monthly precipitation. Results from this analysis was used to detect change in vegetation cover over Nigeria within the 2 periods of 20 years each. The dryness ratio (D) is classified as follows: D <0.33 – Mangrove; 0.33 ≤ D < 1 – Tropical Rain forest; 1 ≤ D < 2 – Guinea Savannah; 2 ≤ D < 3 – Sudan Sahel and D ≥ 3 – Desert)

An equation for atmospheric and soil drought, which is the most dangerous type of drought for agricultural production, was proposed by [15] as an empirical formula for calculating evaporation:

$$E = 0.0018 * (25 + T)^2 * (100 - a) \quad (3)$$

E is monthly evaporation in mm; T is the monthly mean air temperature in degree Celsius and a is the mean relative humidity for the month. Results from the empirical equation were used to determine and compare variation in evaporation during the first period (1975 – 1994) and the second period (1995 – 2014). All calculations were carried out in Microsoft EXCEL spreadsheet and exported into Geographic Information System (GIS) software for spatial and statistical representation.

4. RESULTS AND DISCUSSION

4.1 Meteorological Drought Analysis over Nigeria

Figs. 2, 3 and 4 showed the spatial analysis of meteorological drought over Nigeria within a period of 1975 – 2014. The period was partitioned into 2 regimes of 20 years each – 1975 – 1994 and 1995 – 2014. In Fig. 2, weak atmospheric dryness was prevalent in Benin, Osogbo, Calabar, Yola and Kaduna while moderate atmospheric dryness was dominant mostly in southern part Nigeria except in Katsina. Sokoto, Kano, Maiduguri, Bida and Minna experienced very intensive atmospheric dryness. The characteristic of very intensive atmospheric dryness was observed only in 6 stations out of 17 stations under consideration.

Fig. 3 showed the spatial distribution of atmospheric dryness in the second regime (1995 – 2014). The characteristic of moderate atmospheric dryness had almost disappeared completely except in Calabar. Southern part of Nigeria had prevalence of moderate atmospheric dryness; the inland stations had prevalence of very intensive atmospheric dryness except in Abuja and Enugu where intensive atmospheric dryness was observed. Jos was the only station that had weak atmospheric dryness unlike the situation in the first regime. Another characteristic of extreme atmospheric dryness came up in the second regime. This was not the situation in the first regime. Sokoto, Katsina and Maiduguri had prevalence of extremely intensive atmospheric dryness.

Comparative analysis of meteorological drought between the 2 regimes was shown in Fig. 4; the values were represented by a bar chart to show the extent of increase/decrease in meteorological dryness within the period of the study. Meteorological drought is expressed solely on the basis of the degree of dryness (often in comparison to some “normal” or average amount) and the duration of the dry period. Highly significant increase in atmospheric dryness was observed at Sokoto, Katsina, Maiduguri, Kaduna and Yola. Slight increase was observed at Kano, Abuja, Makurdi, Lagos, Osogbo, Benin, Enugu, Port Harcourt and Calabar. A slight decrease in atmospheric dryness was observed in one station only – Jos in all the stations under consideration. The results from meteorological drought were strong monitors for rainfall amount and duration over Nigeria.

4.2 Agricultural Drought Analysis over Nigeria

Figs. 5, 6 and 7 showed the spatial analysis of agricultural drought in terms of dryness ratio for vegetation classification. In Fig. 5 during the first regime (1975 – 1994), southern Nigeria had prevalence of Mangrove rain forest except at Calabar and Enugu that had classification of Tropical rain forest. Other zones in Nigeria from latitude 8^0N had prevalence of Guinea Savannah except Minna. On the average, in the first regime, dryness ratio for vegetation classification indicated that Nigeria had features of three vegetation type namely Mangrove Rain forest in 4 stations in the South; Tropical Rain Forest in 2 inland stations and Giunea Savannah at 7 core North stations and 3 inland stations.

In Fig. 6 is the map showing vegetation classification over Nigeria in the second regime (1995 – 2014). Stations in the south had Tropical Rain Forest vegetation charateristic except at Port Harcourt. Minna and Makurdi had Guinea Savannah; Bida, Abuja, Jos, Yola, Katsina and Kano had Sudan Sahelian charaterictic while Sokoto Maiduguri and Kaduna had symptoms of desertification. On comparing the 2 regimes in Figs. 5 and 6, there is a shift in the vegetation class showing desertification in the north and dissapearance of Mangrove Rain Forest in the south. There is a significant deviation which point to impact of climate change on Nigerian climatic zones.

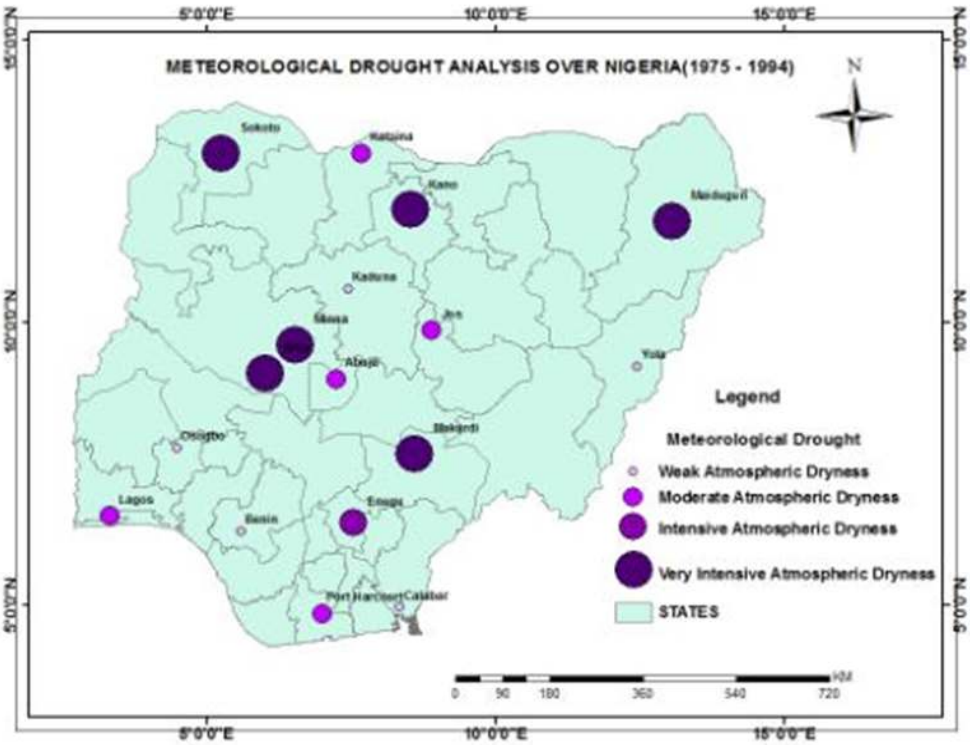

Fig. 2. Meteorological drought analysis over Nigeria (1975 – 1994)

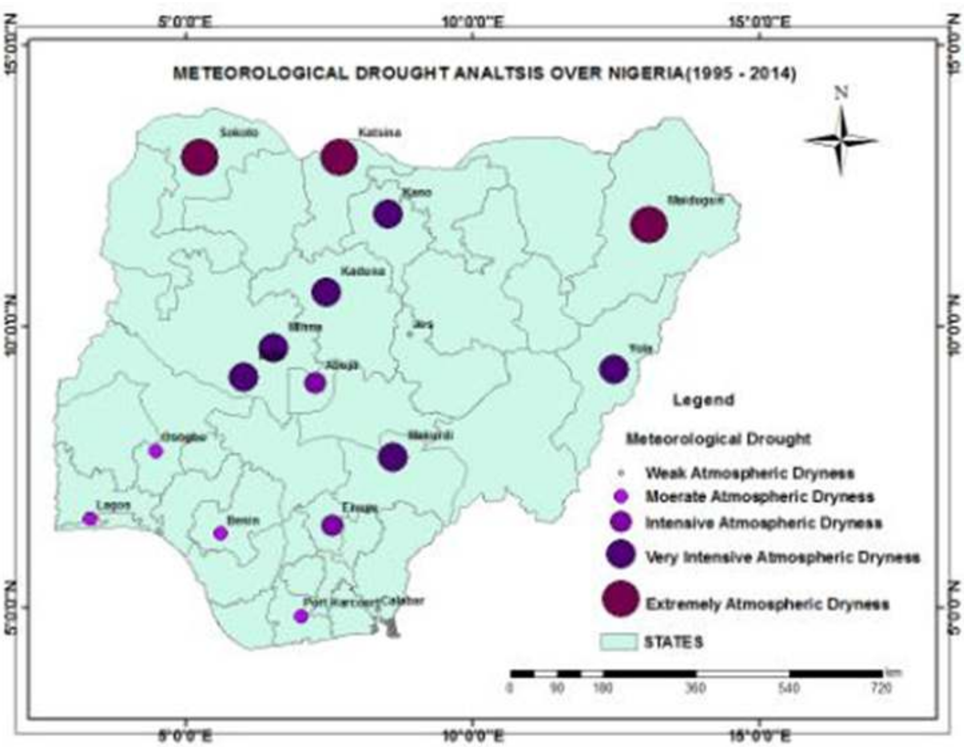

Fig. 3. Meteorological drought analysis over Nigeria (1995 – 2014)

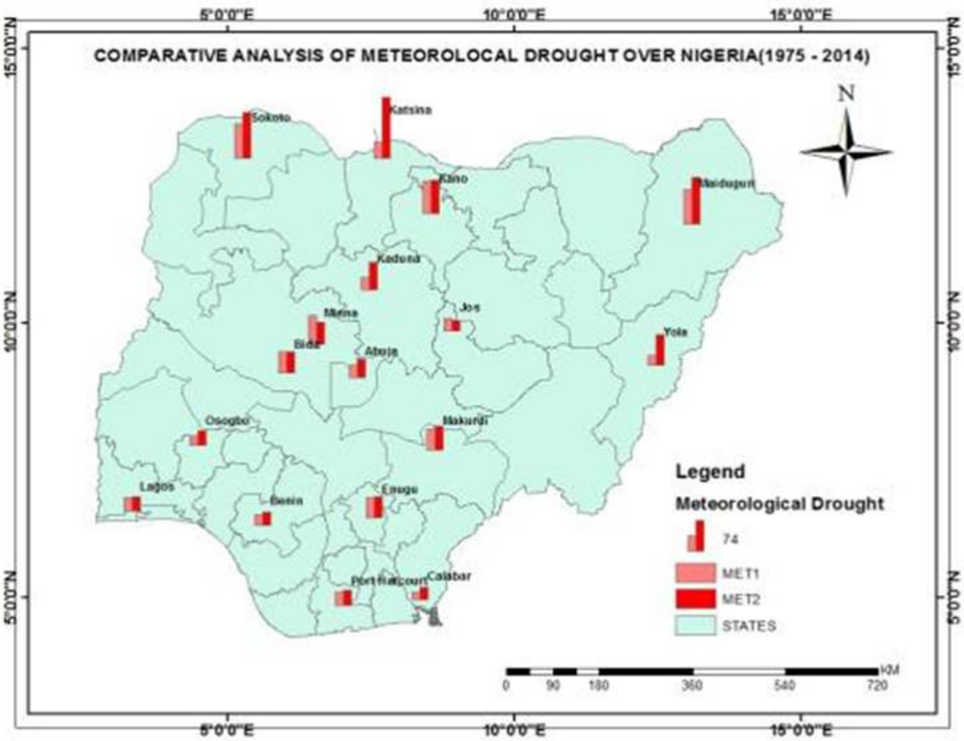

Fig. 4. Comparative analysis of meteorological drought over Nigeria (1975 – 2014)

Fig. 7 shows comparative analysis of dryness ratio for vegetation classification over Nigeria. All stations across Nigeria had a significant increase in dryness ratio. In northern Nigeria, the increase in drought index is a result of an increase in herbivour densities more than the capacity of the vegetation to sustain their grazing pressure, resulting in devegetation, compaction and erosion of the soil. This brings about displacement of pastoralists from maginal lands previously used for dry season grazing reserves, by farmers who occupy the high potential rangeland for subsistence agriculture thereby leading to overgrazing of the available pasture. Concentration of livestocks around watering points, breakdown of traditional grazing systems and fragmentation of communal land holding are some of the factors that contributed to an increase in livestock herds beyond core North stations into north central stations.

Inland stations in Fig. 7 also recorded an increase in dryness ratio which was due to loss of vegetation cover as a result of urbanization activities in the region. It is known that plants play a vital role of stabilizing the soil, maintaning the hydrological cycle, providing shade among others. However, intense construction activities at Abuja, extending to adjoining communities, had incrased the rate of devegetation exposing the the rangeland to the vagaries of the weather.

Stations in the south also had its challenges, an increase in dryness ratio observed due to encroachment into marginal lands and increase in population density within a constrained land mass.

Long – term climatic fluctuations and continuous mining of the land had resulted with time in degradation by water erosion, decrease in chemical fertility, physical deterioration of the soil structure, destruction of useful vegetation and loss of productive land most especially in Niger – Delta areas. Far lands had been utilized more intensely than permitted by its natural fetility. Farmers often fail to compensate for the exports of nutrients by use of artificial fertilizers or fallowing to allow for natural regeneration of fertility. Over – cultivation therefore tends to reduce soil fertility, damages soil structure and exposes it to erosion. This is why there have been occurrences of gully erosion in different part of South East and South South stations in Nigeria.

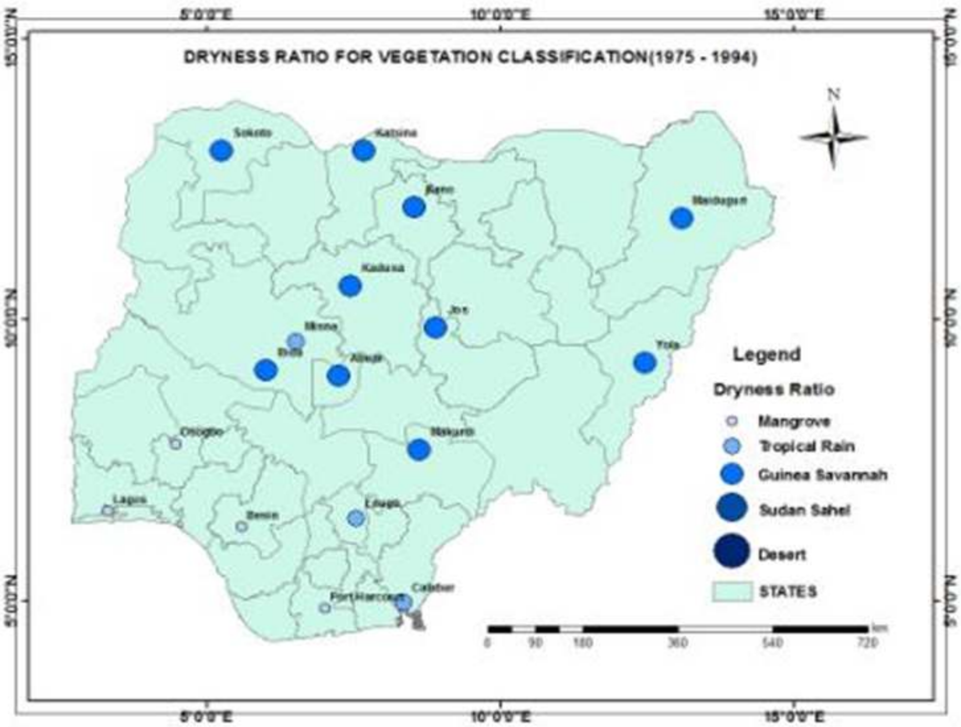

Fig. 5. Dryness ratio for vegetation classification (1975 – 1994)

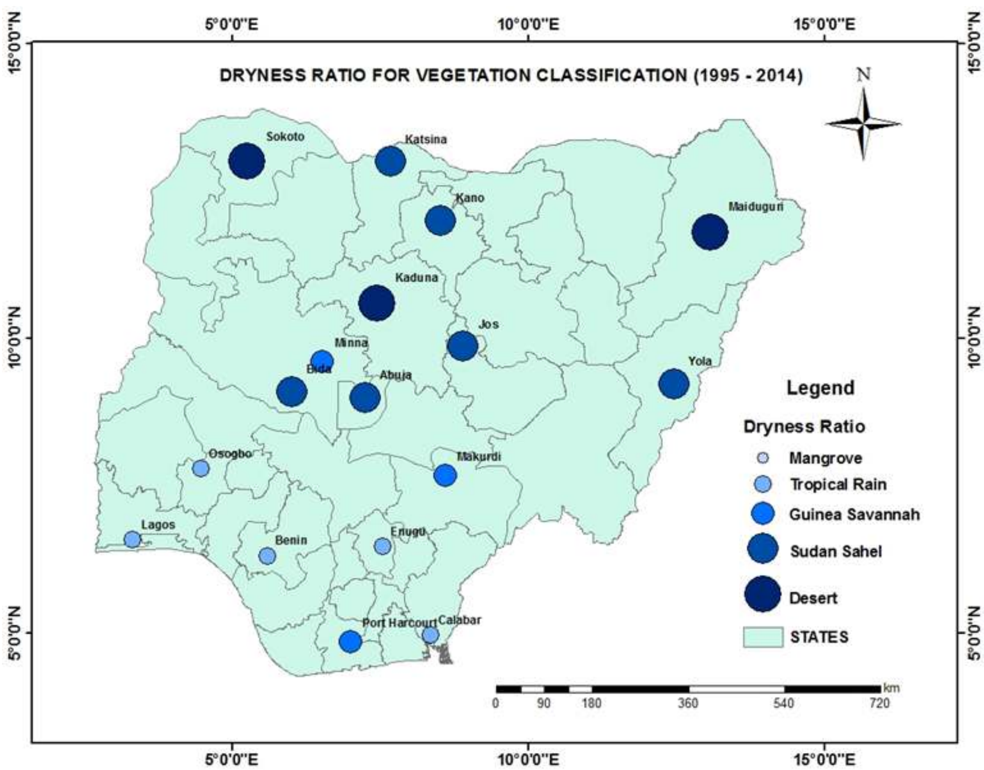

Fig. 6. Dryness ratio for vegetation classification (1995 – 2014)

4.3 Evaporation Indicator for Hydrological Drought Analysis

Fig. 8 showed spatial distribution of drought occurrence probability indicator over Nigeria. The probability indicator in the 2 regimes were represented comparatively in a pie chart. Stations in the southern part of Nigeria had no significant change in drought occurrence probability except at Osogbo where a slight increase in drought occurrence probability was observed. Port Harcourt, Calabar, Lagos, and Enugu had an increase of 4.30%, 2.93%, 1.43% and 2.54% respectively. Benin and Osogbo also increased by 9.11% and 19.07%.

Inland stations had a slight reduction in stations such as Minna (-11.59%), Jos (-11.50%) and Bida (-1.87%) while Abuja had a significant increase up to 15.40% in drought occurrence probability. Highly significant increase in drought occurrence indicator was observed at Katsina (53.50%), Yola (49.94%), and Kaduna (36.84%). Sokoto and Maiduguri had slight increase of 12.26% and 12.93%, respectively.

Inefficient water management is observed at all levels leading to drought-like situations. The availability of renewable freshwater resources is gradually declining, most especially at 5 stations where drought occurrence probability indicator increased more than 15%. Excessive pumping of groundwater for irrigation purposes in intensively cultivated areas in the northern Nigeria has caused the lowering of ground water table in certain pockets

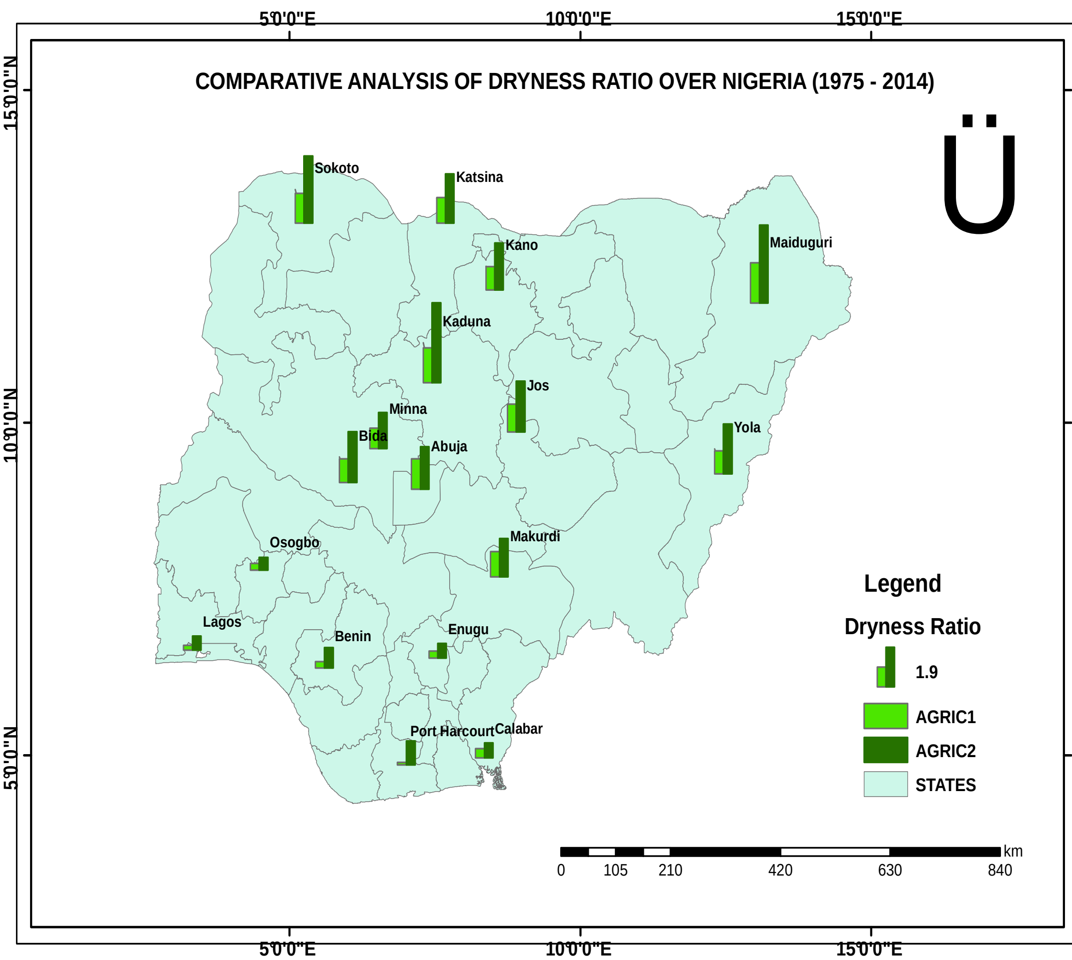

Fig. 7. Comparative analysis dryness ratio for vegetation classification (1975 – 2014)

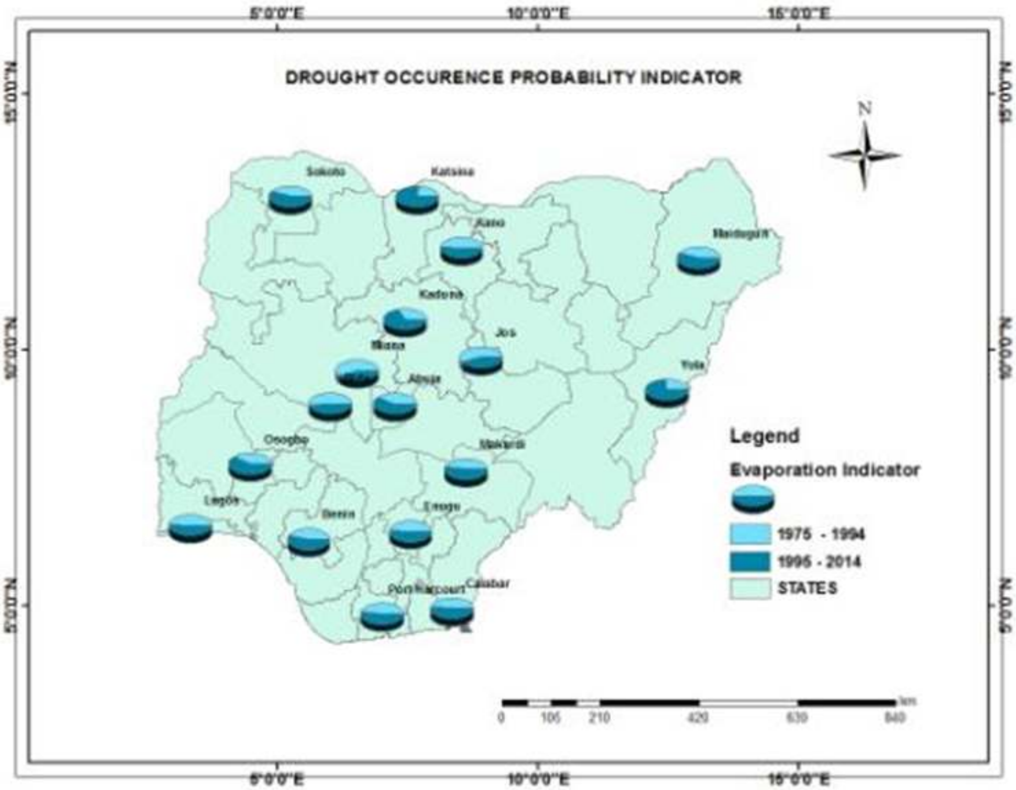

Fig. 8. Evaporation indicator for hydrological drought analysis

5. CONCLUSION

Drought is a phenomenon associated with scarcity of water. It is broadly classified into three categories. Meteorological drought is said to occur when there is a prolonged absence or marked deficiency or poor distribution of precipitation compared to normal rainfall in a given region. Hydrological drought indicates the scarcity of water in surface and underground resources. Agricultural drought occurs when the rainfall and soil moisture are inadequate to meet the water requirement of crops. It is a temporary feature caused by climate variations, and occurs in virtually all climate regimes but with a higher frequency and probability in semi-arid and sub-humid regions. Meteorological drought should be seen as a major cause of desertification, especially if drought conditions occur during several consecutive years, leading to a drastic impact on human activity.

Generally, the results offered a significant insight into occurrence probability of drought over Nigeria by comparing trends in two regimes of 20 years respectively. A shift from wet to dry climatic in features was observed across Nigeria confirming gradual occurrence of drought in the past 20 years over Nigeria.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

Table 1A. Sample meteorological data

Station	Year	T(^{0}C)	RH(%)	P(mb)
Port Harcourt	1979	26.2	84.0	0.00
	1981	23.8	90.5	0.00
	2005	26.1	86.1	2.04
	2006	26.7	86.0	0.00
	2008	26.2	83.8	84.07
	2011	25.8	87.7	14.23
	2013	25.3	88.4	72.14
	2014	26.0	87.0	26.16
Lagos	1999	25.5	88.7	0.00
	2001	25.5	87.0	148.07
	2002	25.7	89.7	378.47
	2003	25.7	85.4	27.17
	2005	26.0	87.2	21.08
	2006	26.5	86.6	35.06
	2007	25.7	87.9	119.40
	2008	25.5	87.5	247.67
	2009	25.4	87.0	103.89
	2010	25.8	84.7	123.69
	2011	25.5	88.5	152.40
	2012	25.4	86.2	262.90
	2013	25.0	90.8	156.96
Maiduguri	1973	28.8	61.0	0.00
	1974	26.0	73.0	0.00
	1978	24.8	82.3	49.02
	1979	28.7	72.0	0.00
	1980	28.5	70.0	0.00
	1981	27.3	74.0	0.00
	2010	29.6	66.3	12.95
Kano	1974	24.8	77.6	0.00
	1977	26.2	77.0	0.00
	1978	25.1	77.0	0.00
	1979	27.0	72.3	0.00
	1980	26.8	71.8	0.00
	1981	25.5	77.0	0.00
	1982	27.2	66.9	43.94
	1983	28.8	62.8	58.93
	2001	22.5	96.0	0.00
	2004	26.1	76.1	1.02
	2005	26.3	74.6	0.00
	2006	29.0	64.6	43.94
	2007	28.0	71.6	0.00
	2008	26.6	73.8	0.00
	2009	27.0	72.5	328.16
	2010	26.6	78.6	23.11
	2011	26.6	73.6	40.14
	2012	26.8	76.8	0.00
	2013	28.0	66.4	8.89
	2014	27.6	69.3	0.00
		24.8	77.6	0.00

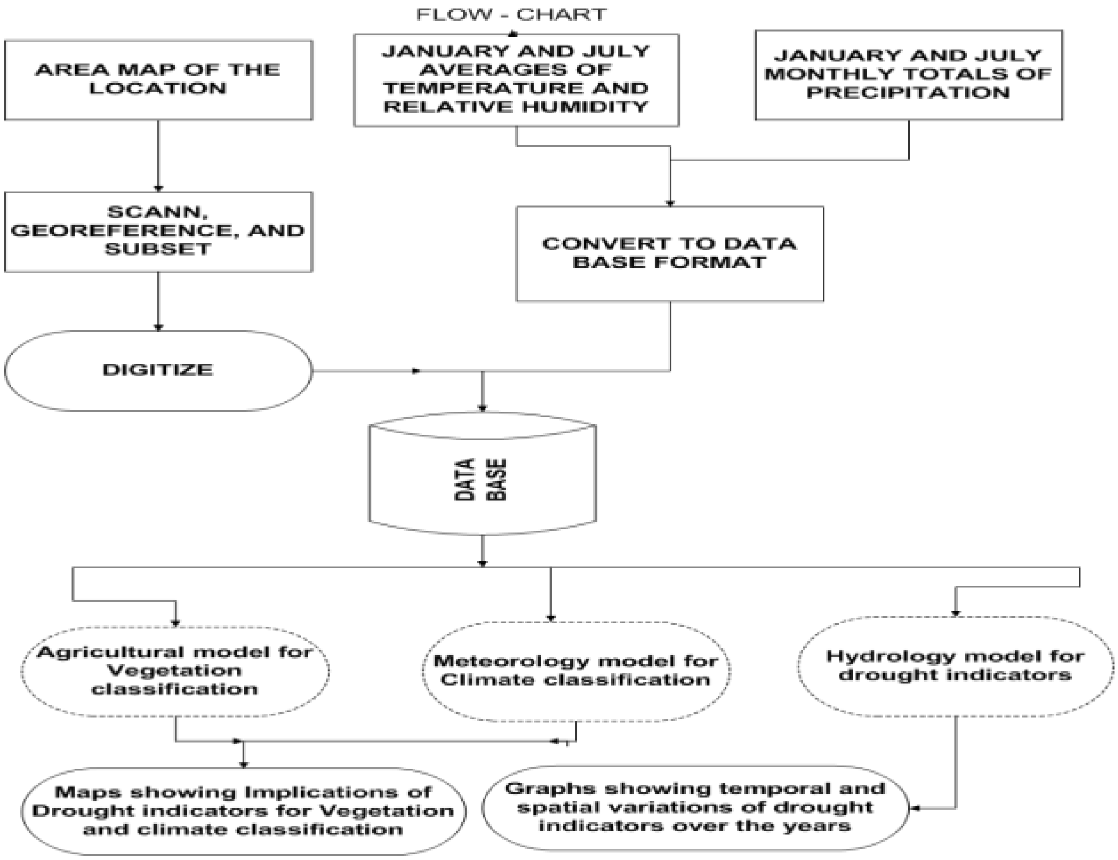

Fig. 1A. Data analysis flow chart

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