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The Impact of Climate Change on Precipitation Effectiveness Indices in Northern Nigeria

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Abstract: The impact of climate change on six precipitation effectiveness indices in northern Nigeria was examined using rainfall data of three decades (1976-2005). The six derived indices are: onset, cessation and length of rainy season, hydrologic ratio, seasonality index and occurrence of pentad dry spells. The derived indices were subjected to time series analysis. Results of the analysis showed that the rains now start late but end early as a result length of rainy season is decreasing. Northern Nigeria is becoming drier as the rainy season is now spread within fewer months. Frequency of dry spells of 5 days is decreasing, however, dry spells of 10, 15 or more days are on the increase. This is diminutive to agriculture and water resources as well as the biodiversity of the region. It is a threat to food security and sustainable development. There is therefore, the urgent need for the Nigerian government to come up with a concrete action plan to face this reality of climate change.

Key words: Climate change, dry spells, hydrologic ratio, seasonality index

INTRODUCTION

Climate change refers to the state of the climate that can be identified using statistical tests by changes in the mean and or variability of its properties that persist for an extended period of a decade or longer (Liu and Penner, 2002; Free and Angel, 2002; Amman *et al*., 2003; Hegerl *et al*., 2007). Climate change may be attributed to both natural and anthropogenic causes.

Climate change currently constitutes an important environmental problem facing mankind in the 21st Century. This phenomenon has serious repercussions on man and his environment. The various consequences of climate change range from drought in some areas while flooding and inundation of coastal lands in others; affecting agriculture and food security, altering both surface and underground water supply and devastating ecosystems among others. It is now a topical issue that has been recognized at both national and international fora as a threat to sustainable development.

Over 60% of Nigerians are directly dependent on rain-fed agriculture and natural resources FAO (2003), Nigeria is therefore, very vulnerable to the impact of climate change Ayoade (2003). The perceived impacts of climate change that bear direct repercussions on agricultural practices in Nigeria is on precipitation effectiveness parameters. Precipitation effectiveness parameters are crucial indices derived from rainfall. These parameters include Onset and Cessation dates of the rains, Length of the Rainy Season (LRS), Rainfall amounts in the months in the growing season. Others include number of Rainy Days (RD), Hydrologic Ratio (HR), Seasonality Index (SI), Index of Replicability (IR), Specific Water Consumption or Water equivalent to avert drought (SWC), Mean Intensity of rainfall (RI) and Dry spells of various lengths during the rainy season.

The pattern of occurrence of these indices will certainly be affected (positively or negatively) by climate change. This study therefore, concerns itself with the impact of climate change on the following critical derived precipitation effectiveness indices in northern Nigeria: Onset, Cessation and Length of the rainy season; Hydrologic ratio, Seasonality index and Pentad (five day) dry spells of 5, 10 and 15 consecutive days.

The study area: The study area lies north of Latitude 10ºN within the Sudano-Sahelian region of northern Nigeria, delimited by latitude 14ºN and between longitudes 2º44′E and 14º42′E (Fig. 1). The area covers Bauchi, Borno, Gombe, Jigawa, Kaduna, Kano, Katsina, Kebbi, Niger, Sokoto, Yobe, Zamfara states and northern part of Adamawa state with a total area of over 500,000 sk^2.

The region of northern Nigeria north of latitude 10^0N possesses a tropical continental (AW) climate that is characterized by distinct wet and dry seasons as dictated by the oscillation of the Inter-tropical Discontinuity (ITD). These two seasons occur in April - October and November - March respectively. The region lies on the High Plains of northern Nigeria lying at an altitude of

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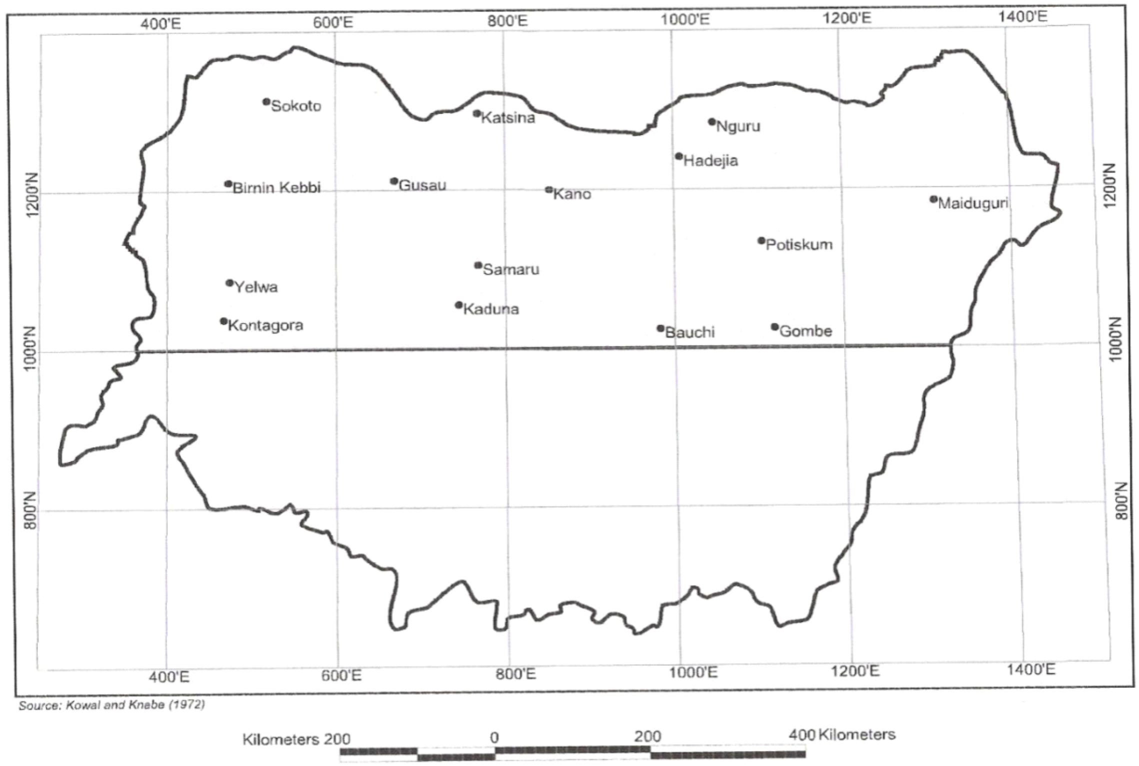

Fig. 1: Study area with selected meteorological stations

between 450 and 750 m above sea level. Granitic inselbergs such as the Kufena hills of Zaria and volcanic plateaux like the Jos Plateau occasionally interrupt the monotonous High Plain.

MATERIALS AND METHODS

Data used in this study was daily rainfall records from 1976-2005 for 15 selected synoptic stations in northern Nigeria which was obtained from the achieves of the Nigerian Meteorological Agency, Oshodi, Lagos.

Derivation of Indices:

Onset, cessation and length of the rainy season: The definition of Onset, Cessation and Length of the Rainy Season in tropical climates has been a problematic one due to the intermittent and patchy nature of rainfall in the region. These three terms have been defined in various ways for different purposes by researchers. Onset refers to the time a place receives an accumulated amount of rainfall sufficient for growing of crops. It is not the first day the rain falls. Cessation means termination of the effective rainy season. It does not imply the last day rain fell, but when rainfall can no more be assured or be effective. Length of the rainy season is the period between the onset and cessation dates. Various methods abound for determination of onset, cessation and length of the rainy season example: (Walter, 1967; Ilesanmi, 1972; Kowal and Knabe, 1972; Stern *et al*., 1982b; Stern and Coe, 1982; Olaniran, 1984, 1988; Sivakumar; 1988 and Adefolalu, 1993).

Adefolalu (1993) applied the ogive method and determined the start of the growing season for some places in northern Nigeria. Here the months of the year are divided into pentads using the pentad calendar. Pentad rainfall was calculated for each pentad and cumulated. An ogive was then constructed from this. The points on the pentad axis corresponding to the first and the last points of maximum in flexion on the ogive gave the onset and cessation pentads respectively. While the last date in the onset pentad gives the exact date of onset of the rains, the first date in the cessation pentad gives the exact date of the cessation of the rainy season. Length of the rainy season is obtained by subtracting the onset pentad from the cessation pentad and multiplying the difference by 5 (i.e., number of days in a pentad. Adefolalu (1993) noted that the ogive method is more accurate than the others. Thus, this was the approach used for the determination of onset, cessation and length of the growing season in this study.

Hydrologic Ratio (HR): Hydrologic Ratio (HR) is the degree of wetness or dryness of a place. It is defined as the ratio of the mean annual rainfall (P) to the

Potential Evapotranspiration (PE) (Adefolalu 1988 and Adebayo 1997). The value indicates soil moisture deficiency or surplus. It is one of the best methods of estimating water availability as soil moisture. In this context, it is the most appropriate drought indicator, which not only gives an indication of the adequacy of rainfall but also serves as an empirical measure of the contribution of drought 'tendency' in the decertification process. It is the best indicator of the hydro-neutral zones (best zones for crop performance due to neither water logging nor deficient soil moisture content). This index helps in decision making in agriculture because it provides a guide to the best choice of the area where a particular type of crop will not only thrive well but reach optimum growth level and give high yield.

Hydrological ratio was mathematically derived by the equation:

$$HR = P/PE$$

where;

HR = Hydrologic ratio
P = Precipitation
PE = Potential evapotranspiration. The higher the value derived, the drier the wet season and vice versa.

Rainfall Seasonality Index (SI): Seasonality Index measures the spread and steadiness of the rainfall during the wet season. Walsh and Lawler (1981) mathematically expressed seasonality index as the sum of the absolute deviations of the mean monthly rainfall from the overall monthly mean multiplied by the exponent of the mean annual rainfall given as:

$$SI = \frac{1}{R}\sum\left|\overline{xn} - R/12\right|$$

where;

SI = seasonality index
R = mean annual rainfall
n = mean rainfall of the month n

This was used to derive the spread of the rainy season in the study area. The higher the SI values, the shorter the spread of the rainy season, implying the drier the place, and vice versa.

Pentad dry spells: Wet and Dry days were defined according to the Nigerian Meteorological Agency standard. The daily rainfall observations were then used to determine pentad (five day) dry spells of 5, 10 and equal to or longer than 15 consecutive days after Stern and Dale (1982). Here, the last rainy day in October was coded ¯1 and the following dry days were coded 1, 2, 3 …n into November until the next wet day, which may be in April or May the preceding year. Consecutive wet days were coded ¯1, ¯2 …¯n so that the daily observations are recorded as sequences of wet and dry days. The runs of pentad dry spells of the specified lengths were, therefore, computed directly for each of the meteorological stations.

Each of these six indices discussed was derived on regional basis for each year. The derived values therefore, formed the data base on which statistical analysis was carried out.

Statistical analysis: The derived station year onset, cessation dates and length of the rainy season, the regional values of hydrologic ratio, seasonality index and the frequencies of pentad dry spells of the specified lengths were all subjected to time series analysis. The year to year variability in each of these rainfall effectiveness indices were smoothed by the 5-year moving average. Linear trend lines and best fit trend line equations were plotted for each rainfall parameter and presented graphically by means of EXCEL software of the computer.

RESULTS AND DISCUSSION

Onsets dates: The linear trend and trend line equation for the onset dates of the rainy season in the study area are shown in Fig. 2. It is obvious from the figure that the onset of the rainy season is characterized by marked 'noises' (variability) from year to year unlike in its cessation and duration. This figure clearly indicates an increasing trend line in the onset dates. The best fit line equation is positive (y = 0.1711x + 40315). This means increasing Julian days and implies that rainfall progressively starts later in recent times in the area. Figure 2 shows that on the average, the rainy season starts from the 20th of May in this region as against the earlier dates in April as it used to be in earlier periods.

Cessation dates: Trend in the cessation dates of the rains in northern Nigeria is presented in Fig. 3. Figure 3 indicates that the mean cessation date of the rains in this region of northern Nigeria is 27th of September. From Fig. 3, it is observed that the trend in cessation dates of the rains is on the decline. The linear trend line equation is negative (y = -0.2218x + 40.452). This further indicates that in the study area, the rains progressively stop earlier in recent times. The average expected cessation date is from 20-25th of September.

Length of the rainy season: The pattern of progressive length of the rainy season in northern Nigeria is shown in Fig. 4. Figure 4 indicates a downward trend in length of the rainy season in the area. A negative trend line equation of y = -0.3758x + 138.06 implies that the length of the rainy season is progressively declining in the area.

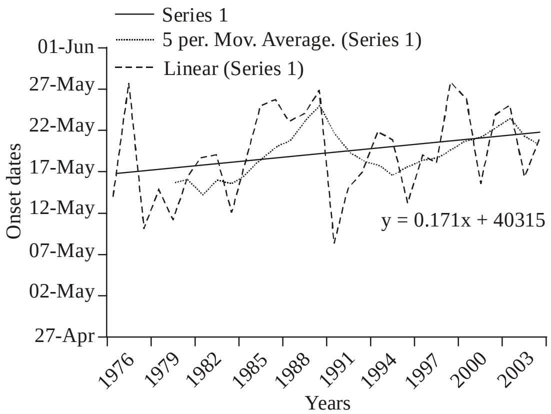

Fig. 2: Trends in rainfall onset dates in Northern Nigeria

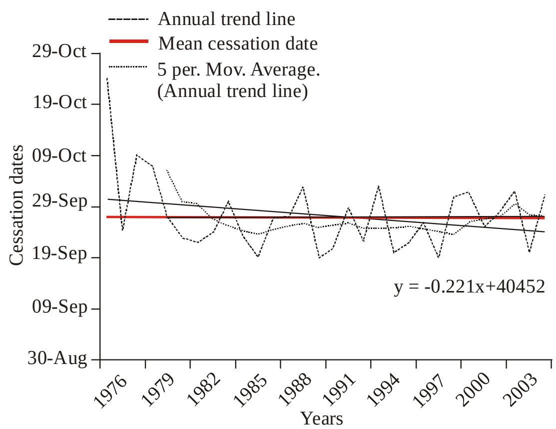

Fig. 3: Trends in rainfall cessation dates in Northern Nigeria

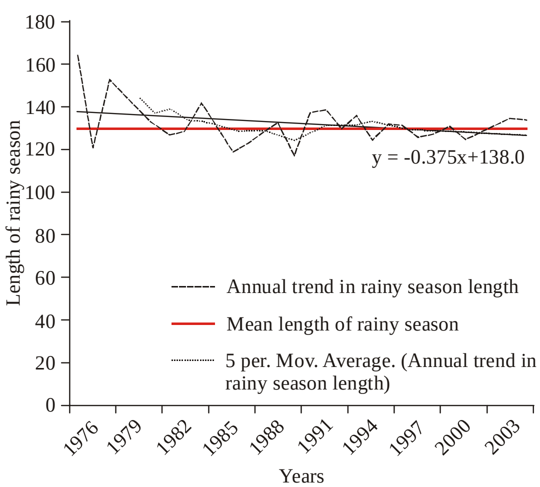

Fig. 4: Trends in length of rainy season in Northern Nigeria

The mean duration of rainy season in northern Nigeria as shown in Fig. 4 is about 130 days. This figure shows that the variability (noise) in duration of the rainy season is not as marked as the variability in onset and cessation of the rains. Figure 4 shows that the general trend in the length of the rainy season is declining. This is further supported by a negative trend line equation of y = -0.375x + 138.0. This signifies that the duration of the rainy season in the study area is gradually shortening over the years.

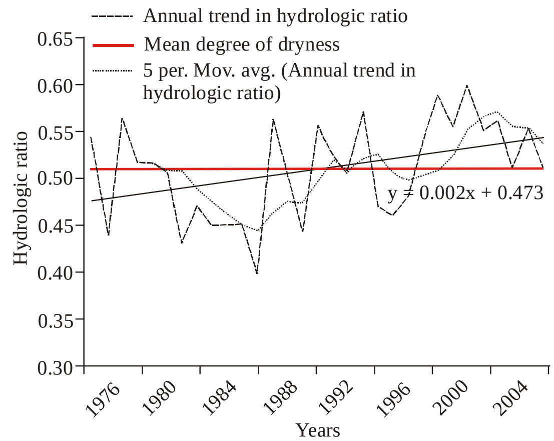

Fig. 5: Trends in degree of dryness in Northern Nigeria

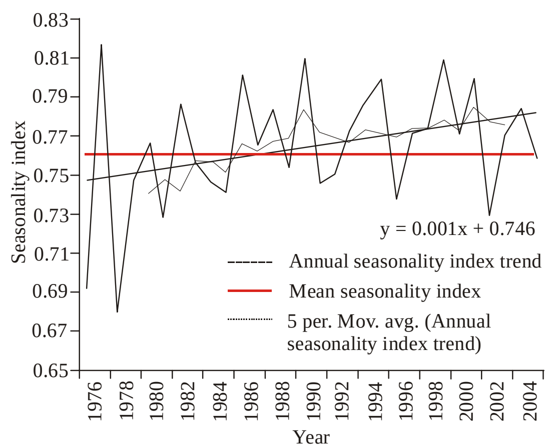

Fig. 6: Trends in seasonality of the rainy season in Northern Nigeria

Hydrologic ratio: Trends in the hydrologic ratio (degree of dryness) during the rainy season in northern Nigeria is presented in Fig. 5. The average degree of dryness in the region is about 0.51. The trend clearly shows an increasing pattern. The best fit line equation is y = 0.002x + 0.473. This positive equation implies that the degree of dryness in this region is on the increase.

Seasonality index: The spread of the rainy season in northern Nigeria is given in Fig. 6. The mean spread of the rainy season is 0.51 meaning that the area falls within the Guinea/Sudan Savanna climatic type. The pattern of spread of the rainy season in this region shows that the

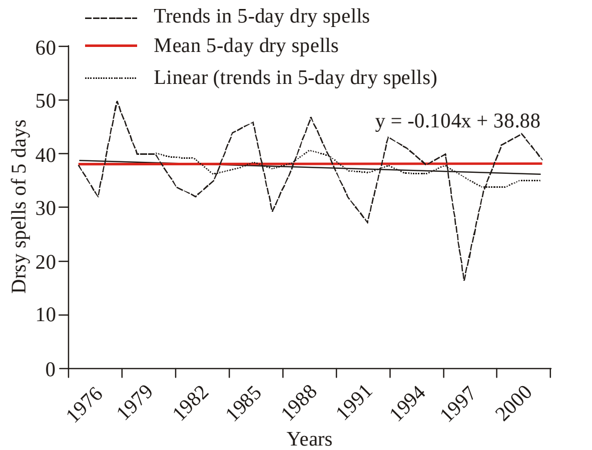

Fig. 7: Trends in occurrence of dry spells of 5 days in Northern Nigeria

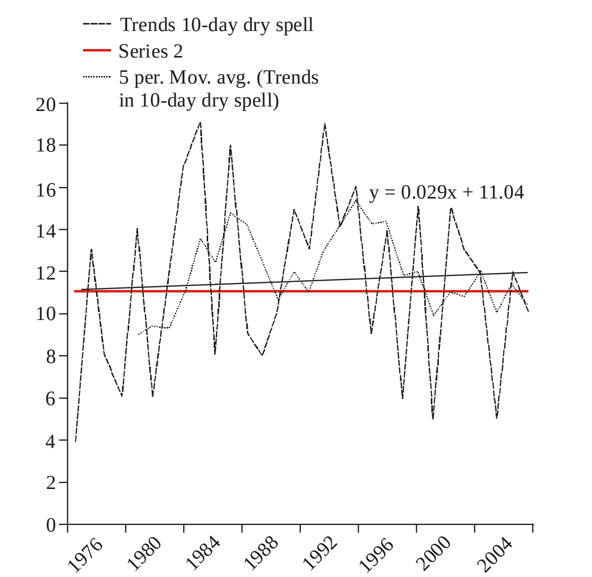

Fig. 8: Trends in occurrence of dry spells of 10 days in Northern Nigeria

wet season occurs only within some few (5-6) months. The negative best fit line equation agrees with the shorting spreading of the rainy season in the region.

Occurrence of pentad dry spells: Figure 7 shows trends in the occurrence of dry spells of 5 days in northern Nigeria. It is interesting to note from this figure that the frequency of occurrence of dry spells of 5 days in the region is declining. The best fit line equation is negative (y = -0.104x + 38.88) implying a decreasing trend in its occurrence. Decreasing frequency of dry spells of 5 days is of immense significance to agriculture as it means more moisture in the soil for plant utilization. The mean frequency of occurrence of dry spells of 5 days in northern Nigeria is about 38 times per rainy season.

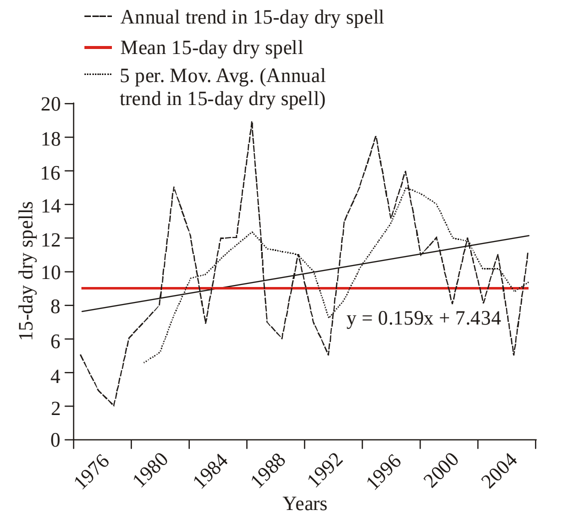

Fig. 9: Trends in the occurrence of dry spells of 15 or more days in Northern Nigeria

Occurrence of dry spells of 10 days: The frequency of occurrence of dry spells of 10 days in northern Nigeria is presented in Fig. 8. From this figure, it is seen that the average occurrence of dry spells of 10 days in the region is about 11 times a year. The pattern of occurrence of dry spells of 10 days in the region shows an increasing trend meaning its frequency is on the increase as indicated in Fig. 8. The trend line shows a positive best fit line equation (y = 0.029x + 11.04). This development is diminutive to agriculture in the region as two 10-day dry spells in a month in this area could lead to crop wilt and reduced yield.

Occurrence of dry spells of 15 or more days: Trends in occurrence of dry spells of 15 or more days are given in Fig. 9. On the average dry spells of 10 or more days occur about 9 times in a year. Figure 9 indicates that the frequency of occurrence of dry spells of 15 days or more days in the region is on the increase. A higher frequency of dry spells of this length has a negative impact on crop yield and food security in northern Nigeria. This is because dry spells longer than 15 days cause drought consequently if it is prolonged, crops may wilt and may completely dry leading to complete failure. Both surface and underground water become diminished and scarce.

CONCLUSION

The trends in onset, cessation, length of the rainy season, degree of dryness, spread of the rainy season and occurrence of pentad dry spells in Nigeria was examined. The analytical results show that the rains now start late but end early consequently the duration of rainy season is becoming shorter and shorter. The area is becoming drier than earlier periods as the rainy season is now spread within fewer months. Frequency of dry spells of 5 days is decreasing, however, dry spells of 10, 15 or more days are on the increase. There is the need for the Nigerian government to come up with a concrete action plan to face this reality as all these point to food insecurity.

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REFERENCES

Adebayo, A.A. and E.F. Adebayo, 1997. Precipitation effectiveness indices and upland rice yield in Adamawa state. Annals Borno, 13/14: 266-276.

Adefolalu, D.O., 1993. World Meteorological Organization. Lecture Series 1: 1-4.

Adefolalu, D.O., 1998. Precipitation, evapotranspiration and the ecological zones in Nigeria. Theor. Appl. Climatol., 39: 81-89.

Amman, C.M., G.A. Meehl, W.M. Washington and C.C. Zender, 2003. A monthly and latitudinal varying volcanic forcing data set in simulations of 20th century climate. Geophys. Res. Lett., 30(12): 1657.

Ayoade, J.O., 2003. Climate Change: A Synopsis of its Nature, Causes, Effects and Management. Vantage Publishers LTD. 98A Samonda, Oyo Road, Old Airport Area, Ibadan Nigeria, pp: 128.

Food and Agricultural Organization, 2003. African report - Nigeria. Microsoft Encarta Online Encyclopedia. Retrieved from: http://www.fao.org/docrep/004/w5994e/pays/af970833.htm, (Accessed on: July 16, 2007).

Free, M. and J. Angell, 2002. Effects of Volcanoes on the vertical temperature profile in radio sonde data. J. Geophys. Res., 107(10): 1029-1128.

Hegerl, G., F. Zwiers, W. Braconnot, N.P. Gillette, Y. Lou, O. Mareno, J.A. Orsini, N. Niholls, J.E. Penner and P.A. Sttott, 2007. Understanding and attributing climate change. Climate Change: The physical science basis contribution of working group 1 to the forth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, USA, pp: 663-745.

Ilesanmi, O.O., 1972. An empirical formulation of the onset, advance and retreat of rainfall in Nigeria. J. Trop. Geogr., 34: 17-24.

Kowal, J.M. and D.T. Knabe, 1972. An Agro-climatic Atlas of Northern States of Nigeria. Ahmadu Bello University Press, Zaria, pp: 111.

Liu, X.H. and J.E. Penner, 2002. Effects of Mount Pinatubo H_2SO_4/H_2O aerosols on ice nucleation in the upper troposphere using a global chemistry and transport model. J. Geophys. Res., 107(D12).

Olaniran, O.J., 1984. The onset of rains and the start of the growing season in Nigeria. Nigerian Geograph. J., 34: 17-24.

Olaniran, O.J., 1988. The distribution in space of rain-days of rainfall of different amounts in the tropics; Nigeria as a case study. Geoforum, 19(4): 507-520.

Sivakumar, M.V.K., 1988. Predicting rainy season potential from the onset of the rains in southern sahelian and sudanian climate zones of West Africa. Agric. Forest Meteorol., 42: 295-305.

Stern, R.D. and I.C. Dale, 1982. Statistical methods for tropical drought analysis based on rainfall data. Project AZ1: A Report on data requirements for estimating the likelihood of droughts. WMO Programme Res. Trop. Meteorol., (PRTM), 35.

Stern, R.D., M.D. Dennett and I.C. Dale, 1982b. Analysing daily rainfall measurements to give agronomically useful results II: A modeling Approach: Exp. Agric., 18: 237-253.

Walsh, P.R.D. and D.M. Lawler, 1981. Rainfall seasonality description, spatial pattern and change through time. Weather, 36(7): 201-208.

Walter, M.W., 1967. Length of the rainy season in Nigeria. Nigerian Geograph. J., 10: 123-128.