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[1] Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria
[2] Department of Physics, Obafemi Awolowo University, Ile-Ife, Nigeria

On the prediction of rainfall onset and retreat dates in Nigeria

T. O. Odekunle[1], **E. E. Balogun**[2], and **O. O. Ogunkoya**[1]

With 1 Figure

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Summary

This study examined the rainfall onset and retreat dates between 1962 and 1996 in Nigeria, and generated models for their prediction. The study used the composite of rainfall-promoting factors namely, sea surface temperature of the tropical Atlantic Ocean, land/sea thermal contrast between some selected locations in Nigeria and the tropical Atlantic Ocean, surface location of the Inter-tropical Discontinuity and the land surface temperature in the selected locations in Nigeria. Rainfall and temperature data were collected from Ikeja, Benin, Ibadan, Ilorin, Kaduna and Kano, in Nigeria. Cumulative percentage mean rainfall was employed to generate the rainfall onset and retreat dates series, while the method of stepwise multiple regression analysis was used to construct the required prediction models.

The results obtained showed that the hypothesized rainfall-promoting factors are efficient in predicting rainfall onset and retreat dates in Nigeria. The correlation coefficients (R^2) obtained are in most cases (>75%) higher than 0.50 (with several of them approaching 0.90). Sea surface temperature and land/sea thermal contrast are the most significant predictor variables. The results also indicated that all the areas of the tropical Atlantic Ocean, from the Gulf of Guinea, through St Helena and Ascension Island, up to the Benguela Current region, influence the inter-annual variability in the rainfall onset and retreat dates of Nigeria.

1. Introduction

Rainfall onset can be taken as the period, at the beginning of the rainy season, when rainfall distribution has become adequate for crop development, while rainfall retreat refers to the period, towards the end of the rainy season, when rainfall distribution may no longer sustain crop growth. In an inter-tropical country like Nigeria, rainfall commences, reaches its peak and retreats on different days of the year at different places. This results from the northward and southward sun-synchronous movements of the Inter-Tropical Discontinuity (ITD), and the associated rain-belt (Walter, 1967; Ayoade, 1988; Hayward and Oguntoyinbo, 1987; Adejuwon et al., 1990).

Rainfall onset and retreat periods appear to be of paramount importance in West Africa and particularly in Nigeria since they affect regional economies (Walter, 1967; Olaniran, 1983; Adejuwon et al., 1990). The most notorious seasonal component, in this regard in West Africa, appears to be the rainfall onset, as it is usually foreshadowed by a succession of isolated showers of uncertain intensity with intervening dry periods of varying duration (Walter, 1967). A failure in the early establishment of rainfall onset usually indicates a drought in the early part of the rainy season. This affects farmers negatively since it is essential that, after a given date, the rain will become fairly continuous and sufficient to ensure adequate soil moisture after planting commences and that such moisture levels will be maintained or surpassed as the season advances.

Numerous attempts have been made to estimate and forecast the rainfall onset and retreat dates in the tropics. The existing methods include: (a) rainfall-based models i.e. based on rainfall data alone (e.g. Ilesanmi, 1972a; Fasheun, 1983; Nnoli, 1996), (b) ITD-rainfall models (e.g. Ilesanmi, 1972a; Kowal and Knabe, 1972), (c) rainfall-evapotranspiration relation models (e.g. Cocheme and Fraquin, 1967; Benoit, 1977), (d) the wind-shear scheme i.e. model based on upper air data (Omotosho, 1990, 1992) and, (e) Theta-E technique i.e. based on the daily mean values of surface pressure, temperature, and relative humidity (Omotosho et al., 2002). But, as observed by Omotosho et al. (2002), most of these methods of determining or predicting rainfall onset and retreat dates give the same dates every year. In other words, most of the methods only give the mean onset and retreat dates of rainfall but failed to address their variability from year to year. According to these authors, the methods that are capable of addressing the problem of year to year (inter-annual) variability in the rainfall onset and retreat dates are; (a) the wind shear scheme, and (b) the Theta-E technique. The major problem confronting the method based on the wind shear scheme is that of the coarseness of the network of upper-air data gathering stations over the entire West African region. Therefore, and as noted by Omotosho et al. (2002), a new method (probably, most recent) of predicting rainfall characteristics in the tropics is the use of sea surface temperature (SST) (e.g. Folland et al., 1991; Fountain and Janicot, 1996; Colman et al., 2000; Chiang et al., 2002). However, this method has so far been applied only to rainfall between June and September, and annual rainfall totals (Omotosho et al., 2002). Although, as noted by Omotosho et al. (2002), the correlation coefficient of the prediction model generated by earlier studies, using SST for the above rainfall parameters, are rather weak (mostly 0.30–0.40), many recent studies have established correlation coefficients of 0.70 (see for example, Folland et al., 1991; Berte and Ward, 1998; Colman et al., 2000). A result is that SST has become a more promising parameter for the prediction of rainfall in West Africa. SST has, however, not been applied in the prediction of rainfall onset and retreat dates.

So far, West African rainfall characteristics have been explained in terms of three main factors, namely: the Inter-Tropical Discontinuity (e.g. Ilesanmi, 1972a; Kowal and Knabe, 1972), sea surface temperature (Adedokun, 1978; Folland et al., 1991; Colman et al., 2000) and land/sea thermal contrast (Carlson, 1969; Adedokun, 1978). The ITD is the boundary zone separating the tropical maritime (mT) air mass from the tropical continental (cT) air mass, and as noted by Ilesanmi (1972b) and Adedokun (1981), although this boundary zone is not a rain-producing phenomenon in itself, its importance derives from the weather zones that occur in a latitudinal–spatial relationship to it. Well to the north of it, a rainless clear-sky climate and the northeasterly Harmattan winds prevail. The vicinity of its surface location is a region of fair weather with scarce cloudiness (Hastenrath, 1985). At a distance of between 400 km and 1000 km south of ITD, where the layer of moist, cool monsoon airstreams is deep (at least 1,500 m deep, Ojo, 1977) frequent storms and showers are observed. Thus, as observed by Ayoade (1974), whatever kind of weather types occurring at a particular place – the Harmattan, the steady rain and drizzle, the disturbance line thunderstorms and the 'little dry season', their time of occurrence, their onset, duration, intensity and retreat, are primarily determined by the location of that place relative to the moving ITD. Thus, the movement of the ITD into the sub-continent marks the onset of rain, while its withdrawal means the retreat of rainfall from the sub-continent.

The role of ocean-atmosphere interaction (mainly in terms of the SST) in climatic variability in general, and rainfall variability in particular, is increasingly being understood (see for example, Adedokun, 1978; Adejuwon et al., 1990; Folland et al., 1991; Colman et al., 2000). The basic tenet central to all sorts of explanations of this ocean-atmosphere phenomenon is that a lot of atmospheric disturbances are due to anomalously high or low temperature of the ocean surface. An anomalously low SST in the Atlantic Ocean has long been recognized as a significant cause of inter-annual climatic variability in West Africa (Bjerknes, 1969; Krueger and Winston, 1975; Adedokun, 1978). The unusually low SST is observed particularly around the Gulf of Guinea.

The low SST in this region of the Atlantic Ocean is believed to be affected by the combined action of a cold under current – the Benguela current, and a two-sided divergence of the Ekman transport found within Guinea coast (Flohn, 1971). It is, however, probable that the upwelling in the region is initiated by persistent equatorial easterlies in the cold tongue region to the south. The ocean-atmosphere interactions promote a number of consequences on the moist southwesterly winds. These include: (a) chilling effect at the coast when the sea surface is cold, resulting in the winds acquiring negative buoyancy. Warming on the land may reverse the situation; (b) the chilling effect may promote an increase in pressure and thus a strengthening of the winds. This chilling and strengthening may inhibit precipitation around the coastal area but enhance rainfall further inland after appropriate warming has taken place. Also, the winds penetrate further inland (Adedokun, 1978); and (c) it has been argued by Carlson (1969) that low SST can effect a change in the temperature contrast between the potentially hot Sahara area and the relatively colder southern region. Increase in the temperature contrast enhances easterly shear through the process described by Adedokun (1978) as "thermal – wind adjustment". The increase in easterly shear should in turn result in increased precipitation (but in the Sahel region only; Adedokun, 1978). It is also believed that enhanced thermal contrast would result in the ITD moving further north, which could promote more rainfall in the north. The SST-rainfall relationships described above depicts the Gulf of Guinea as the main area of the Atlantic Ocean having a significant influence on the nature of precipitation in West Africa. More recently however, Folland et al. (1991) have found that this area of influence is not limited to the Gulf of Guinea but extends southward to include the region of origin of the Benguela Current in the South Atlantic Ocean. In fact, these authors have found a strong coherent relationship between the SST anomalies in the tropical Atlantic (most especially, the Bengula current region) and Sahel rainfall.

This study attempts to generate multivariate models that can predict rainfall onset and retreat dates in Nigeria. Earlier prediction models on rainfall characteristics utilized one predictor variable. This perhaps accounts for the weak correlation coefficients obtained in some studies on the SST-rainfall relationship and some poor forecasting skills for the West African region (Adejuwon and Odekunle, 2004). A recent study by Adejuwon and Odekunle (2004), on the "skill assessment of the existing capacity for extended-range weather forecasting in Nigeria" has established that better rainfall forecasts could be achieved with inclusion of more predictor variables, especially those of a synoptic nature. The rainfall onset and retreat dates' prediction models, are based on the combined effect of the SST (from the Gulf of Guinea up to the Benguela current region), land/sea thermal contract between some selected rainfall stations and the selected SST stations, ITD and land surface temperature, for individual rainfall stations. Furthermore, the prediction models generated from this study are for individual rainfall stations as opposed to the earlier studies that are regional in approach and general in perspective. This is especially necessary in view of the fact that rainfall onset and retreat dates vary considerably over space. Perhaps this may be part of the reasons why Folland et al. (1991) concluded their study by advocating for a separate study of the predictability of rainfall in a few longitudinal subdivisions.

2. Study area

The area chosen for the study is Nigeria, located within Latitudes 4°–14° N and Longitude 3°–15° E. The Republic of Niger, Cameroon, Republic of Benin and the Gulf of Guinea border it in the north, east, west and south respectively (Fig. 1).

The Nigerian climate is principally governed by the influence of three wind currents. These are: the maritime tropical (mT) air mass, the continental tropical (cT) air mass and the equatorial easterlies (Ojo, 1977). The first two air masses converge around a boundary zone popularly called the Inter-Tropical Discontinuity (ITD). The movement of the ITD is sun-synchronous (Ayoade, 1974), but there is six-week lag between the ITD's movement and the solar cycle (Adedokun, 1978). It reaches its northern limits between latitudes 19.6° N and 22.2° N in August, and its southern extremity between latitudes 5.2° N and 8° N in February (Obasi, 1965). Across Nigeria, rain falls mostly when an area is overlain by the mT air mass, and there is

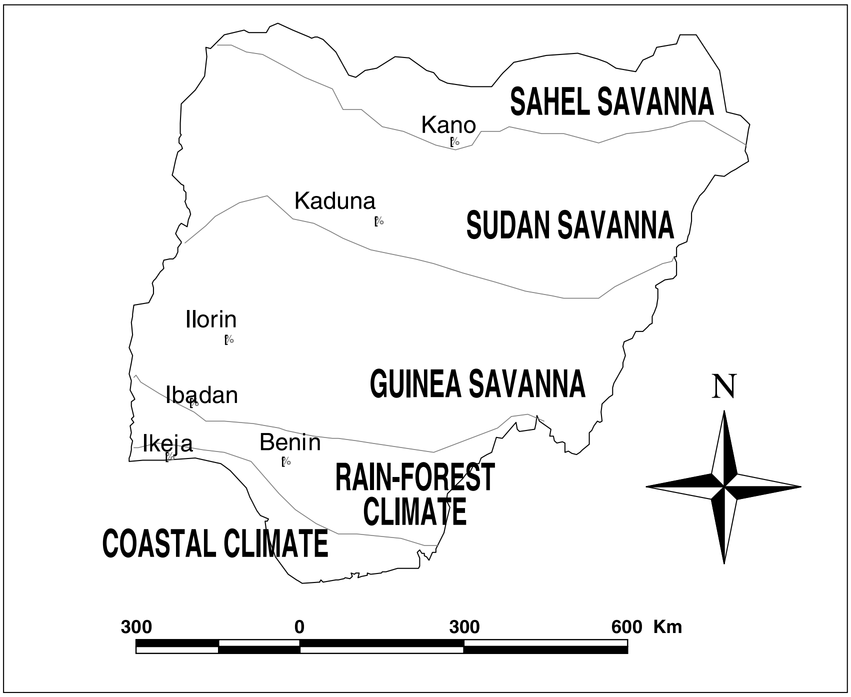

Fig. 1. Map of Nigeria, Showing the Selected Rainfall stations

drought when the area is overlain by the cT air mass. The equatorial easterlies are rather erratic cool air masses, which come from the east and flow in the upper atmosphere along the ITD. Occasionally however, the air mass dives down, undercuts the mT or cT air mass and gives rise to line squalls or dust devils (Iloeje, 1981).

The specific locations selected to represent Nigeria and for which rainfall and temperature data were collected are: Ikeja, Benin, Ibadan, Ilorin, Kaduna and Kano. Each of the six locations were chosen as representative of areas with similar climatic tendencies in the country. For instance, while Ikeja is selected to represent the coastal climatic zone, Benin, Ibadan, Ilorin, Kaduna and Kano represent forest, southern Guinea, Northern Guinea, Sudan and Sahelian zones, respectively.

3. Study methodology

3.1 Data collection

The data used for this study are the daily rainfall amount, the monthly surface location of the ITD, the monthly land surface temperature and the monthly sea surface temperature. Data for the first three climatic parameters were sourced from the archives of the Nigerian Meteorological Services, Oshodi, Lagos. The SST data were sourced from the archives of the Hadley Centre for Climatic Prediction and Research, U.K. Data on the surface location of ITD were collected along three longitudinal positions across West Africa. The three longitudinal positions namely, 5° W, 0° and 5° E, give the average position of the ITD's NNW–ESE orientation. The data were collected at 0600Z and are available only for the period between 1962 and 2000. Data on the SST were collected for twelve locations over the Atlantic Ocean namely, 22.5°; 7.5° E, 22.5° S; 2.5° E and 22.5° S; 2.5° W; in the Benguela current region of the South Atlantic Ocean, 17.5° S; 2.5° W and 17.5° S; 7.5° W, near St. Helena, 7.5° S; 2.5° E and 7.5° S; 12.5° W, near Ascension Island and 2.5° S; 2.5° E, 2.5° S; 2.5° W; 2.5° S; 7.5° W, 2.5° N, 2.5° E and 2.5° N; 2.5° W to represent the Gulf of Guinea. The resolution of the data set is 5×5 degree. Data availability on the SST and ITD determined the length of the data used in this study. While the data availability of the former is between 1945 and 1996 that of the latter is between 1962 and 2000. Thus, the study made use of 35 years data (1962–1996). Ten years of the thirty-five year data set (1962–1969; 1995–1996) were utilized in testing the models. The data from the other twenty-five years were used to calibrate the models. The 1962–1969 period was used to hindcast, while data for 1995 and 1996 were used to forecast.

3.2 Analysis

3.2.1 Determination of rainfall onset and retreat dates

Data were first analyzed to determine the mean rainfall onset and retreat dates. The method employed is that proposed by Ilesanmi (1972a, b), i.e. the cumulative percentage mean rainfall method. The method is one of the most commonly used and is preferred to other methods of determining rainfall onset and retreat dates because it is mathematically elegant, efficient, and is free of assumptions of rainfall threshold values (Olaniran, 1983). Odekunle (2004) has also argued in favour of this method by pointing out that it is a more direct approach relying on rainfall data alone rather than the mere inferential methods based on some rainfall related factors. The basic procedures of the method are outlined as follows:

(a) Derivation of the percentage of mean annual rainfall that occurs at each 5-day interval;
(b) Cumulation of the computed percentage at 5-day intervals;
(c) Plotting the cumulative percentage at 5-day intervals through the year; and
(d) Identification of the time of rainfall onset and retreat.

The point of first maximum positive curvature and last maximum negative curvature on the graph of the cumulative percentage are respectively, the mean periods of rainfall onset and retreat. Alternatively, onset of the rains would be the timing of an accumulated 7 to 8 percent of the annual rainfall, and the retreat commences after the accumulation of 90 percent of the annual rainfall (Ilesanmi, 1972a). In this study, the second method is adopted – onset and retreat periods were identified as when 7 to 8 percent and 90 percent of the accumulated annual rainfall are attained, respectively. The respective mean proportions were employed to estimate the rainfall onset and retreat dates for each year.

3.2.2 Prediction model

The stepwise multiple regression algorithm was adopted for the construction of the prediction models. Rainfall onset and retreat dates of the six locations (Ikeja, Benin, Ibadan, Ilorin, Kaduna and Kano) constitute the dependent variables, while SST, ITD, land/sea thermal contrast and land surface temperature constitute the explanatory variables.

Data involving time series tend to move in the same direction because of the trend that is common to them all. Thus, it has been argued that trend be included among the explanatory variables so as to avoid misleading forecasts (Grager and Newbolt, 1974). Time (year) has therefore been included among the explanatory variables. The predictor variables of all months preceding the rainfall onset and retreat months were used.

3.2.3 Model "goodness of fit" assessment

The values of sampling distribution 'F' at which the explanatory variables were added or deleted from the prediction equation, and the values of the associated coefficient of multiple determination (R^2) of the equation were adopted as representative of the "goodness of fit" of the models. This however may not be an efficient means of determining 'goodness of fit'. Therefore, in addition, a set of data, different from those employed in calibrating the model, were used to assess the level of skill that the models were likely to achieve in real time forecasting. Data from the period 1962–1969, 1995 and 1996 were used to assess the 'goodness of fit' of the models. Omotosho et al. (2000) in their study over West Africa (argument was based on the decadal crop-water requirement), described a method for testing for goodness of fit. In this method, the predicted rainfall date is taken as correct if it is within 10 days of the actual date of rainfall onset. This study rated the model prediction skill performance on the rainfall onset and retreat dates in three categories. The skill is rated high, moderate and low if is within 10 days, between 10 and 20 days and above or below 20 days of the actual date, respectively.

4. Results

4.1 Rainfall onset and retreat dates

The results obtained show that the mean rainfall onset date for Ikeja is March 28th with cumulative percentage rainfall of 7%. Those of Benin, Ibadan, Ilorin, Kaduna and Kano are respectively, on the 31st March, 14th April, 19th May and 28th May and with cumulative percentage rainfall values of 7%, 8%, 8%, 9% and 7%, respectively. The mean rainfall retreat dates are respectively 10th November, 1st November, 24th October, 14th October, 26th September and 8th September for Ikeja, Benin, Ibadan, Ilorin, Kaduna and Kano. Their respective cumulative percentage rainfall values are 96%, 96%, 96%, 94%, 92% and 89%.

4.2 Modelling

The results of the analyses show that there are coherent relationships between rainfall onset and retreat dates and the hypothesized causative factors since all of the twelve regression equations that were generated are significant at $\alpha = 0.05$.

With regards to the rainfall onset dates, the predictor variables, namely the SST of the Atlantic ocean, land/sea thermal contrast between Nigeria and the selected SST locations in the Atlantic Ocean, ITD, land surface temperature and time (year) of the months of January and February were used for Ikeja, Benin and Ibadan. For Ilorin, they are the months of January, February and March, while January, February, March and April were used for Kaduna and Kano. The various relationships obtained are expressed by the following equations:

$$\text{Ikeja rainfall onset date} = -475.74 + 25.31KtM_2 + 40.36T_5M_1 - 26.78T_4M_1 - 17.26T_{12}M_2 \quad (1)$$

$\alpha = 0.05$, $R = 0.82$, $R^2 = 0.68$

where:

KtM_2 is the February land surface temperature at Ikeja;
T_5M_1 is the January SST at location 17.5° S; 7.5° W;
T_4M_1 is the January SST at 17.5° S; 2.5° W; and
$T_{12}M_2$ is the February SST at 2.5° N; 2.5° W

$$\text{Benin rainfall onset date} = 91.68 + 17.26T_6M_2 - 12.97Yt_8M_1 - 31.74T_9M_1 + 15.82T_6M_1 \quad (2)$$

$\alpha = 0.05$, $R = 0.75$, $R^2 = 0.60$

where:

T_6M_2 is the February SST at 7.5° S; 2.5° E;
Yt_8M_1 is the January land/sea thermal contrast between Benin and 2.5° S; 2.5° E;
T_9M_1 is the January SST at 2.5° S 2.5° W; and
T_6M_1 is the January SST at 7.5° S 2.5° E

$$\text{Ibadan rainfall onset date} = 85.11 + 11.69Bt_{11}M_2 \quad (3)$$

$\alpha = 0.05$, $R = 0.44$, $R^2 = 0.20$

where:

$Bt_{11}M_2$ is the February land/sea thermal contrast between Ibadan and 2.5° N; 2.5° E.

$$\text{Ilorin rainfall onset date} = 461.89 - 13.54T_8M1 \quad (4)$$

$\alpha = 0.05$, $R = 0.45$, $R^2 = 0.20$

where:

T_8M_1 is the January SST at 2.5° S, 2.5° E

$$\text{Kaduna rainfall onset date} = -235.11 + 11.29T_{12}M_4 + 6.31\times M_2 + 5.35Dt_{11}M4 \quad (5)$$

$\alpha = 0.05$, $R = 0.76$, $R^2 = 0.58$

where:

$T_{12}M_2$ is the April SST at 2.5° N, 2.5° W;
XM_2 is the February surface location of ITD; and
$Dt_{11}M_4$ is the April land/sea thermal contrast between Kaduna and 2.5° N; 2.5° E.

$$\text{Kano rainfall onset date} = -317.69 + 17.44T_8M_3 - 29.51Nt_9M_3 + 24.34Nt_{10}M_3. \quad (6)$$

$\alpha = 0.05$, $R = 0.84$, $R^2 = 0.65$

where:

T_8M_3 is the March SST at 2.5° S; 2.5° E; and
Nt_9M_3 and $Nt_{10}M_3$ are the March land/sea thermal contrasts between Kano and at 2.5° S, 2.5° W and 2.5° S; 7.5° W, respectively.

With regards to the rainfall retreat dates the predictor variable of the months of January to August were used for all the study stations. The various relationships obtained are expressed by the following equations:

Ikeja rainfall retreat date

$$= -1242.21 + 0.94\text{ year} - 38.40T_{12}M_8 + 26.48T_{11}M_8 \quad (7)$$

$\alpha = 0.05$, $R = 0.81$, $R^2 = 0.63$
where:

$T_{12}M_8$ is the August SST at 2.5° N; 2.5° W; and
$T_{11}M_8$ is the August SST at 2.5° N; 2.5° E.

Benin rainfall retreat date

$$= 1039.68 - 33.82T_5M_7 - 9.78\ Yt_7M_6 + 22.78T_4M_7 - 14.02T_{12}M_8 - 8.45XM_6 \quad (8)$$

$\alpha = 0.05$, $R = 0.90$, $R^2 = 0.81$
where:

T_5M_7 is the July SST at 17.5° S, 7.5° W;
Yt_7M_6 is the June land/sea thermal contrast between Benin and 7.5° S; 12.5° W;
T_4M_7 is the July SST at 17.5° S; 2.5° W;
$T_{12}M_8$ is the August SST at 2.5° N; 2.5° W; and
XM_6 is the June surface location of ITD.

Ibadan rainfall retreat date

$$= 231.08 + 12.80Bt_{11}M_2 + 10.90T_6M_1 - 13.99T_8M_1 + 17.22T_3M6 - 6.29T_8M_6 \quad (9)$$

$\alpha = 0.05$, $R = 0.87$, $R^2 = 0.76$
where:

$Bt_{11}M_2$ is the February land/sea thermal contrast between Ibadan and 2.5° N; 2.5° E,
T_6M_1 is the January SST at 7.5° S; 2.5° E,
T_8M_1 is the January SST at 2.5° S; 2.5° E,
T_3M_6 is the June SST at 22.5° S; 2.5° W; and
T_8M_6 is the June SST at 2.5° S, 2.5° E.

Ilorin rainfall retreat date

$$= 9.17 - 16.50T_8M_7 + 12.75T_{10}M_2 + 6.18Lt_{11}M_2 + 11.20T_9M_3 \quad (10)$$

$\alpha = 0.05$, $R = 0.94$, $R^2 = 0.87$
where:

T_8M_7 is the July SST at 2.5° S; 2.5° E,
$T_{10}M_2$ is the February SST at 2.5° S; 7.5° W,
$Lt_{11}M_2$ is the February land sea thermal contrast between Ilorin and 2.5° N; 2.5° E; and
T_9M_3 is the March SST at 2.5° S; 2.5° W.

Kaduna rainfall retreat date

$$= 143.16 - 13.06Dt_2M_6 - 8.73Dt_{12}M_8 + 7.19T_9M_2 - 4.88Dt_{10}M_7 \quad (11)$$

$\alpha = 0.05$, $R = 0.88$, $R^2 = 0.78$
where:

Dt_2M_6 and $Dt_{12}M_8$ are the June and August land/sea thermal contrasts between Kaduna and 22.5° S, 2.5° E and 2.5° N; 2.5° W, respectively;
T_9M_2 is the February SST at 2.5° S; 2.5° W; and
$Dt_{10}M_7$ is the July land/sea thermal contrast between Kaduna and 2.5° S, 7.5° W.

Kano rainfall retreat date

$$= 292.10 - 17.21T_5M_5 + 14.29T_7M_8 \quad (12)$$

$\alpha = 0.05$, $R = 0.66$, $R^2 = 0.43$

where:

T_5M_5 is the May SST at 17.5° S; 7.5° W; and
T_7M_8 is the August SST at 7.5° S; 12.5° W.

A number of deductions can be made from these equations. One is that the coefficient of multiple determination (R^2), which represents the variance in the dependent variable explained by the independent variable (s), is above 50% (i.e. $R^2 = 0.50$) in 75% of the regression equations. For instance, SST alone constitutes 67% of the total explanatory variables found to be significant in the various equations. Land/sea thermal contrast, ITD and land surface temperature constitute 26%, 5% and 2%, respectively. Thus, SST and the land/sea thermal contrast alone constitutes 93%. This means that rainfall onset and retreat dates of Nigeria can be predicted using SST and the land/sea thermal contrast alone.

4.3 Model's actual "goodness of fit" assessment

Tables 1 and 2 summarize the actual "goodness of fit" assessment of the prediction equations developed for the rainfall onset and retreat dates, respectively. With regards to the rainfall onset dates, the skill is rated high in 42%, moderate in 25% but low in 33% of the cases tested. As

Table 1. Model's "Goodness of Fit" assessment of rainfall onset dates in Nigeria (1962–1969; 1995 and 1996)

Year	Ikeja				Benin				Ibadan				Ilorin				Kaduna				Kano			
	OBS. ROD	PRE_1 ROD	DB. OBS PRE	RRE_2 SKL.	OBS. ROD	PRE_1 ROD	DB. OBS PRE	RRE_2 SKL.	OBS. ROD	PRE_1 ROD	DB. OBS PRE	RRE_2 SKL.	OBS. ROD	PRE_1 ROD	DB. OBS PRE	RRE_2 SKL.	OBS. ROD	PRE_1 ROD	DB. OBS PRE	RRE_2 SKL.	OBS. ROD	PRE_1 ROD	DB. OBS PRE	RRE_2 SKL.
1962	81	61	20	Mod	104	85	19	Mod	81	81	0	High	113	106	7	High	136	130	6	High	122	143	21	Low
1963	86	60	26	Low	93	90	3	High	95	74	21	Low	112	101	11	Mod	150	128	22	Low	144	168	24	Low
1964	60	77	17	Mod	82	105	23	Low	81	81	0	High	112	91	21	Low	135	129	6	High	147	158	11	Mod
1965	105	57	48	Low	78	105	27	Low	85	80	5	High	68	105	37	Low	144	127	17	Mod	161	168	7	High
1966	82	92	10	High	89	80	9	High	83	79	4	High	115	99	16	Mod	124	128	4	High	143	164	21	Low
1967	112	90	22	Low	94	105	11	Mod	108	84	24	Low	80	94	14	Mod	118	129	11	Mod	141	140	1	High
1968	114	54	60	Low	98	103	5	High	108	82	26	Low	103	106	3	High	113	125	12	Mod	110	146	36	Low
1969	85	63	22	Low	68	76	8	High	84	82	2	High	103	96	7	High	124	135	11	Mod	164	150	14	Mod
1995	68	64	4	High	79	102	23	Low	90	95	5	High	118	82	36	Low	142	144	2	High	160	171	11	Mod
1996	46	102	56	Low	82	98	16	Mod	62	66	4	High	111	107	4	High	144	144	0	High	155	163	8	High

OBS.ROD.OBS. – Observed Rainfall Onset Date (in Days of the Year)
PRE_1.ROD. – Predicted Rainfall Onset Date (in Days of the Year)
DB.OBS.PRE – Difference between the Observed and Predicted (in days)
PRE_2.SKL – Prediction Skill Level
Mod. – Moderate
High Skill – When the difference between the observed and predicted rainfall onset and retreat dates is within 10 days
Moderate Skill – When the difference between the observed and predicted rainfall onset and retreat dates is within 10–20 days
Low Skill – When the difference between the observed and predicted rainfall onset and retreat dates is more than 20 days

Table 2. Model's "Goodness of Fit" assessment of rainfall retreat dates in Nigeria (1962–1969; 1995 and 1996)

Year	Ikeja				Benin				Ibadan				Ilorin				Kaduna				Kano			
	OBS. RRD	PRE_1 RRD	DB. OBS PRE	RRE_2 SKL.	OBS. RRD	PRE_1 ROD	DB. OBS PRE	RRE_2 SKL.	OBS. RRD	PRE_1 RRD	DB. OBS PRE	RRE_2 SKL.	OBS. RRD	PRE_1 RRD	DB. OBS PRE	RRE_2 SKL.	OBS. RRD	PRE_1 RRD	DB. OBS PRE	RRE_2 SKL.	OBS. RRD	PRE_1 RRD	DB. OBS PRE	RRE_2 SKL.
1962	314	285	29	Low	315	300	15	Mod	312	298	14	Mod	310	281	29	Low	279	284	5	High	254	245	9	High
1963	304	281	23	Low	298	249	49	Low	295	266	29	Low	279	260	19	Mod	283	280	3	High	246	258	12	Mod
1964	299	292	7	High	318	320	2	High	295	302	7	High	294	291	3	High	264	279	15	Mod	243	242	1	High
1965	288	298	10	High	284	317	33	Low	300	285	15	Mod	293	299	6	High	264	276	12	Mod	244	242	2	High
1966	323	298	25	Low	305	274	31	Low	295	285	10	High	285	242	43	Low	264	282	18	Mod	259	254	5	High
1967	307	302	5	High	337	319	18	Mod	307	276	31	Low	306	300	6	High	266	274	8	High	245	250	5	High
1968	292	287	5	High	288	277	11	Mod	304	287	17	Mod	271	265	6	Low	265	273	8	High	236	261	25	Low
1969	306	306	0	High	306	318	12	Mod	301	285	16	Mod	301	305	4	High	285	264	21	Low	255	247	8	High
1995	310	314	4	High	307	297	10	High	298	290	8	High	299	270	29	Low	264	263	1	High	252	264	12	Mod
1996	287	317	30	Low	276	262	14	Mod	290	303	13	Mod	276	286	10	High	271	288	17	Mod	258	248	10	High

OBS.RRD. – Observed Rainfall Retreat Date (in Days of the Year)
PRE_1.RRD. – Predicted Rainfall Retreat Date (in Days of the Year)
DB.OBS.PRE. – Difference between the Observed and Predicted (in days)
PRE_2.SKL. – Prediction Skill Level
Mod. – Moderate
High Skill – When the difference between the observed and predicted rainfall onset and retreat dates is within 10
Moderate Skill – When the difference between the observed and predicted rainfall onset and retreat dates is within 10–20 days
Low Skill – When the difference between the observed and predicted rainfall onset and retreat dates is more than 20 days

for the rainfall retreat dates, the skill is rated high in 48%, moderate in 29% but low in 23% of the cases tested. Generally, in both the cases of rainfall onset and retreat dates, the skill is rated high in 45%, moderate in 27% but low in 28% of the cases tested. Both the "high skill" and "moderate skill" categories constitute 72% of the cases tested. These results tend to indicate that the models generated for the prediction of rainfall onset and retreat dates of the sub-region are reliable.

5. Discussion

Both the statistical "goodness of fit" (using both the R^2 and α values) and the actual "goodness of fit" (by comparing the observed rainfall onset and retreat dates with the predicted values using 1962–1969 and 1995–1996 data) of the models obtained in this study tend to support the reliability of the models for predicting rainfall onset and retreat dates in Nigeria. The results have also demonstrated that the most important factors affecting inter-annual variability in rainfall onset and retreat dates in Nigeria are the SST of the Atlantic ocean (from the Gulf of Guinea, through St. Helena and Ascension Island, up to the Benguela current region) and the land/sea thermal contrast between selected stations in the country and the various SST locations. The land surface temperature and the surface location of ITD are somewhat less important.

The pattern of the results obtained is not unexpected because studies have demonstrated that SST anomalies are a significant cause of inter-annual variability in tropical rainfall characteristics (Adedokun, 1978; Folland et al., 1991; Colman et al., 2000). Also, the land/sea thermal contrast factor, through its effect on both the strength of southwesterlies and the frequency of easterly shear, has long been recognized as a prime factor of inter-annual rainfall variability in the sub-region (Carlson, 1969; Adedokun, 1978; Folland et al., 1991). The nature of the influence is such that increased land/sea thermal contrast (high temperature gradient) enhances the convergence strength around the ITD, which in turn increases the frequency of easterly shear and thus more precipitation (Carlson, 1969; Adedokun, 1978). It is the wind shear that promotes frequent squalls, disturbance lines and most convection and overturning that constitute the ITD band of rainfall (see for example, Riehl et al., 1974; Moncrieff and Miller, 1976; Nicholson and Chervin, 1983). The contributions made by the factors of ITD and land surface temperature that proved negligible are also easy to explain. As observed by Adejuwon and Jeje (1976) and Hayward and Oguntoyinbo (1987), land surface temperature does not constitute a climatological problem in the tropics because it is naturally abundant throughout the whole year. Also, it has been pointed out by Adefolalu (1981) that the ITD/rainfall relationship can only be used to explain the mean-state conditions of rainfall, and that inter-annual variability appears to be poorly defined in terms of the mean ITD positions.

The results obtained have also demonstrated that the relationship between the SST of the tropical Atlantic Ocean and rainfall onset and retreat dates is such that different parts of the ocean influence the rainfall onset/retreat dates of different locations at different times. For example, the SST of a location that proved insignificant in February may become important in March or April. This also applies to the factors of land/sea thermal contrast, ITD and land surface temperature. The results observed in this study further corroborates the observation of Trenbeth (1993) and Kane (2000) regarding SST characteristics. These authors have noticed the changes in the location, extent and time of year of SST anomalies in the tropical ocean, which promote differences in tropical rainfall.

Furthermore, the relationships between SST, land/sea thermal contrast, ITD and land surface temperature, and rainfall onset and retreat dates, as observed in this study are rather complex, i.e. sometimes direct and sometimes inverse. The results further corroborate the observation of Gbuyiro and Olaleye (1999), who noticed such dual-direction characteristics of SST-rainfall relationship in Nigeria. This complexity may be a result of the changes in the locations, extent and time of year of SST anomalies in tropical oceans (Trenbeth, 1993; Kane, 2000). This study underlines the fact that SSTs which are inversely related with the rainfall onset and retreat dates act to strengthen the southwesterlies, while those directly related act to enrich the moisture status of the southwesterlies. With regards to the land/sea thermal contrast, where it is found to be both directly and inversely related in the same equation, it may act to generate internal eddying within the southwesterlies, which may promote frequent precipitation.

6. Conclusion

This study has generated models that can predict rainfall onset and retreat dates in Nigeria, using the rainfall–producing factors of sea surface temperature, land/sea thermal contrast between the selected stations in the country and those of the tropical Atlantic Ocean, the ITD and land surface temperature. The specific locations selected to represent Nigeria and from which rainfall data were collected include: Ikeja, Benin, Ibadan, Ilorin, Kaduna, and Kano. The method proposed by Ilesanmi (1972a), cumulative percentage mean rainfall, was employed to obtain both the mean and individual year rainfall onset and retreat dates, while the method of stepwise multiple regression analysis was employed in the construction of the prediction model.

Results from the study show that the hypothesized rainfall-producing factors are efficient in predicting rainfall onset and retreat dates in Nigeria. At the 95% level of confidence, the values of coefficient of multiple determination (R^2) of most of the prediction models generated, are above 0.50 (with some of them approaching 0.90). SST and land/sea thermal contrast are the two most important factors in predicting rainfall onset and retreat dates. The results also clearly demonstrate that all areas of the tropical Atlantic Ocean, from the Gulf of Guinea, through St. Helena and Ascension Island, up to the Benguela Current region, have a significant bearing on the inter-annual variability of rainfall onset and retreat dates in Nigeria.

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Authors' addresses: T. O. Odekunle (e-mail: odeyemitheophilus@yahoo.com), O. O. Ogunkoya, Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria; E. E. Balogun, Department of Physics, Obafemi Awolowo University, Ile-Ife, Nigeria.