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Assessment of Prediction Schemes for Estimating Rainfall Onset over Different Climatic Zones in West Africa

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Authors' contributions

This work was carried out in collaboration between all authors. All authors designed the study and wrote the protocol. Authors OJM and OEA performed the data analyses and wrote the first draft of the manuscript. All authors managed the literature searches while authors MAA, LAS and OGI internally reviewed the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This study compares the predictive skills of some commonly used prediction schemes to estimate dates of onset of rainfall in various climatic regions of West Africa. Specifically, the abilities of seven different schemes, which are relatively easy to apply on a large scale, were compared from 1980 to 2014 over the three major climatic regions (Forest, Guinea and Sudan-Sahel savannah) of Nigeria. Three of them are dependent on rainfall data (ogive, daily rainfall probability and Walter-Olaniran methods); three on rain-evapotranspiration relation (Benoit, Anyadike, Kowal and Knabe) and one dependent on equivalent potential temperature (Theta-E). The prediction schemes demonstrated that the onset dates were much earlier (from Julian day 061 to 084) in the south than (146 to 162)

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the north. The results also showed that the onset dates varied slightly (by ±6 days) from east to west within the same climatic zone. Their performances varied across the stations and zones. However, they generally performed adequately well in the Savannah than the Forest. Particularly, Walter-Olaniran and ogive methods performed best in the Sudan-Sahel with predictive skills of less than ±7 days of actual date of onset. The study concludes that foremost criterion for a choice of any prediction scheme is the ability of the scheme for estimating rainfall onset over a region of interest.

Keywords: Rainfall; onset; prediction schemes; climatic zones; West Africa.

1. INTRODUCTION

The onset and cessation of rain have both been defined in various ways for different purposes by researchers [1]. The onset of rain, particularly over West Africa, is assumed to be the beginning of the growing season [2]. It is defined by most authors as the time a place receives an accumulated amount of rainfall sufficient for the growing of crops. On the other hand, the cessation (or retreat) of rainfall is described as the termination of the effective rainy season *i.e.* a period when rainfall can no more be certain or effective for the growing of crops [1,3,4]. Consequently, the period between the onset and cessation is generally known as the length of the rainy or growing season or wet season. It is the period of the year during which rainfall distribution characteristics are suitable for crop germination, establishment, and full development [5]. Accurate determination of (rainfall) onset and cessation dates with appropriately improved methods is therefore imperative as their variabilities affect planting/sowing dates, crop growth, yield and food production [6,7,8].

Available literature revealed that several methods have been developed and adopted for the determination of onset and cessation of rainfall over different parts of Nigeria and West Africa at large. Some of these techniques are based on rainfall data [9,10,11,12], rainfall–evapotranspiration relation [13,14] and equivalent potential temperature [4,15,16]. These methods have been widely used in recent studies to estimate onset and growing seasons over West Africa and beyond [5,8,16,17,18,19].

However, these methods were developed and validated for specific region(s) using both surface data measurements and model simulations. Hence, their performances could vary across climatic zones.

For example, it has been demonstrated that the empirical relations that are dependent on rainfall–evapotranspiration performed well over Savannah [13,14,20]. Similarly, the findings of [4] and [15] revealed that Theta-E, an equivalent potential temperature. dependent approach, gives a good estimate of onset dates, particularly over the Savannah. The approach, however, performs poorly for estimation of cessation dates [17]. These studies failed to demonstrate the strength and weakness of Theta-E over different regions of the country. Nevertheless, a few attempts have been made to compare a number of methods for onset determination over semi-arid climatic (northern) zone [20,21]; while leaving us in doubt about what happens in other regions. Then, [5] in his comprehensive work compared the predictive skills of only two methods (rainfall probability and the ogive methods) over different parts of Nigeria. He reported large disparities between the estimated onset dates using the two methods. For instance, he documented that the differences in the two methods for onset period are larger (by about 2 months) over the forest stations and (by about 1 month) over the savannah. However, his preference for the daily rainfall probability for assessment of the growing season over the whole country remains an insinuation as it was not backed-up by any reliable statistical comparison test. Hence, this present study compares the predictive skills of seven commonly used methods (including: ogive, daily rainfall probability, Walter-Olaniran, Benoit, Anyadike, Kowal and Knabe and Theta-E) to estimate the onset of rainfall in different climatic zones of Nigeria between 1980 and 2014. This is with a view to determining the strengths and weaknesses of these methods and suggesting the most effective method(s) for determination of dates of onset of rain over the region.

2. MATERIALS AND METHODS

2.1 The Data

Daily weather observations of surface ground temperatures, relative humidity and rainfall from 1980 to 2014 were collected from the Nigerian

Meteorological Agency, Abuja. However, daily pressure and solar radiation data were obtained from the regional climate model simulations of the Coordinated Regional Climate Downscaling Experiment (CORDEX) project as fully described in [22]. In the project, the International Centre for Theoretical Physics (ICTP) Regional Climate Model version 3 (RegCM3) was used for the simulations over Africa. Comprehensive descriptions of RegCM3 and the main model components are as discussed in [23]. The initial and time-dependent meteorological lateral boundary conditions for the mother domain (Africa) simulation are interpolated at 6-hourly intervals from an ECHAM5/MPI-OM A1B scenario simulation with the use of 50 km horizontal grid spacing and 18 vertical sigma levels. The integration spanned from 1980 to 2100 covering present-day reference period (1980–2010) forced by lateral boundary conditions from the ECHAM5 and the remaining years (2011–2100) forced by the ECHAM5 A1B enhanced CO_2 climate scenario. Model simulations from RegCM3 or RegCM4 had been widely used and validated in the literature for climate change impact and relevant application studies in West Africa [8,24].

2.2 Methods

Three meteorological stations each were selected from the three main climatic zones in Nigeria consisting of the Forest (4°-8°N), Guinea Savanna (8°-11°N) and Sudan- Sahel Savanna (11°-14°N; Fig. 1).

This classification follows that in [25,26,27]. The specific locations, totalling 9, are Enugu, Osogbo, Warri (representing the Forest zone); Ilorin, Ibi, Jos (Guinea Savanna zone); Kano, Maiduguri and Sokoto (Sudan-Sahel Savanna zone). These stations were so selected such that the latitudinal and longitudinal (*i.e*. north-south and east-west) variations weather patterns and onset estimations can be well captured in this study.

Seven different methods, each dependent on either observed rainfall data, rainfall–evapotranspiration relation or equivalent potential temperature were used to estimate (annual) onset and cessation dates from 1980 to 2014 over the selected stations in Nigeria. These methods include ogive or cumulative percentage mean rainfall method, Og, as proposed by [10]; daily rainfall probability method, Pf [28]; Benoit,

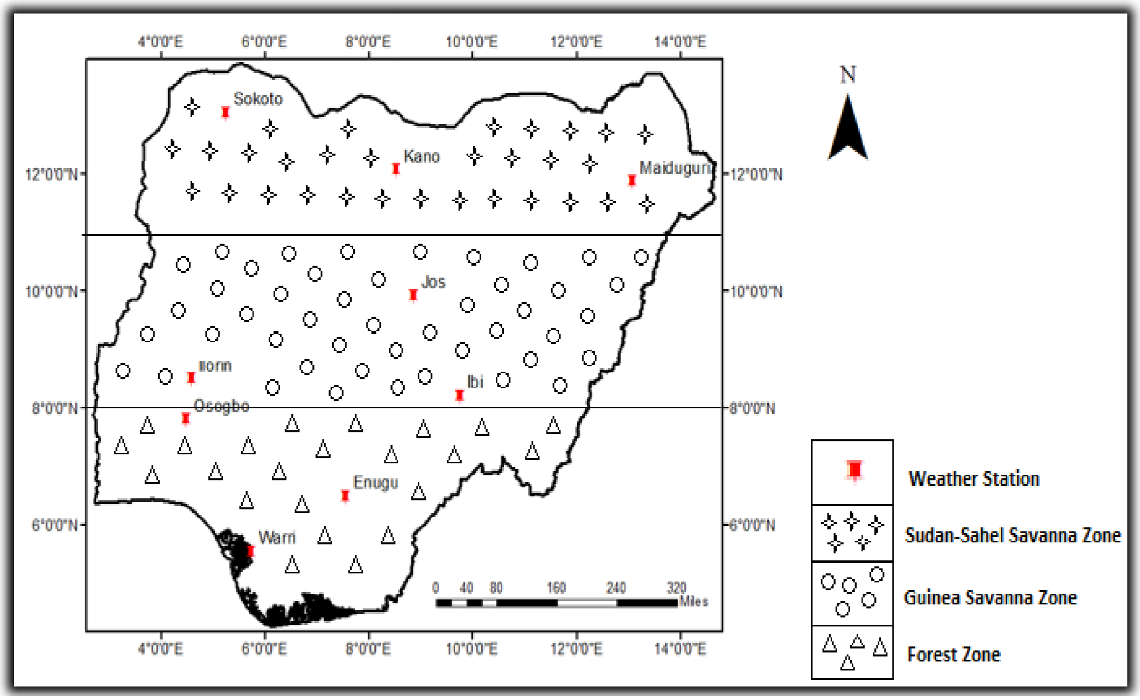

Fig. 1. Locations of the selected meteorological stations from the three climatic zones of Nigeria

Bn [14]; Kowal and Knabe, Kk [13]; Walter-Olaniran, Wt, [9] as modified by [11]; Anyadike, Ay [12]; and Theta-E method, Te, [4, 15]. Three of them are dependent on rainfall data (*e.g.* Og, Pf and Wt); three on rain-evapotranspiration relation (Bn, Ay, Kk) and one dependent on equivalent potential temperature (Te).

2.2.1 Ogive method

Firstly, the percentage mean annual total rainfall that occurs for each 5-day interval were estimated. This is followed by accumulating the percentages of the 5-day periods. Then the onset and cessation periods were taken as the times when an accumulated 7–8% and 90% of the annual rainfall totals respectively are obtained as proposed by [10].

2.2.2 Rainfall probability method

In this method, the probability of rain on any given date was estimated as the proportion of rainy days on that date. In other words, the probability of rainfall for each day of the year was expressed as the number of rainy days as a proportion of the total number of days considered for each day of the year. On the basis of this rainfall probability estimate of each day of the year, a comprehensive tabulation for all the days of the year was performed. Furthermore, since probability values range between 0 and 1, with success and failure breaking even at 0.50, a day with reliable rainfall was taken as a day with a probability value that is greater than or equal to 0.50. A threshold value of 0.85 mm, previously found appropriate for West African countries [28], was employed in this study to define a day as rainy [5]. This implies that any day with a rainfall amount below this threshold value is assumed to be rainless.

2.2.3 Walter-Olaniran method

Based on Nigerian data, Walter method [9] as modified by Olaniran [11] described the onset date OD as

$$OD = \frac{D(50.8-F)}{R} \tag{1}$$

where D is the number of days in the first month with effective rain (MER). The MER is the first month in which the accumulated rainfall totals equal or exceed 50.8 mm (2 inches). F (mm) is the accumulated rainfall total of previous months; R is the total rainfall in the MER month. To calculate the rainfall cessation, the same formula was applied but monthly rainfall value was accumulated from December backward. The month that has accumulated rainfall totals equal or exceed 50.8 mm then becomes the end of the raining season.

2.2.4 Anyadike method

The dates of the onset, and end of the rain, D, was estimated using the equation [12];

$$D_m = \left(\frac{0.083 \times T_r - A}{R_m}\right) \tag{2}$$

Where:

D_m = number of days in the month of onset
T_r = total annual rainfall
A = accumulated total rainfall on the previous month
Rm = total rainfall for the month of onset and end.

The Walter method [9] was adopted to determine the month of onset. The monthly rainfall was then reversed and accumulated to determine the month of cessation

2.2.5 Theta-E method

Theta-E prediction scheme is a potential temperature-dependent scheme developed by [4] for estimation of onset and cessation dates, particularly over Savannah zone of West Africa [15,17]. Using the method, the thermodynamic parameters such as the equivalent potential temperature (θ_e) and saturated equivalent potential temperature (θ_{es}) were used to compute their respective anomalies, θ'_e and θ'_{es}, on daily basis and averaged over 5 day periods to give time series of pentad values. From the temperature, pressure and relative humidity data, the specific (q) and saturated specific humidity (qs), were evaluated. Thus, the θ_e and θ_{es} parameters were computed as follows:

The saturation vapour pressures, $e_s(T)$ only, were computed from the integral of the Clausius–Clapeyron equation as

$$e_s = e_{so} \exp\left(\frac{M_v L_v (T-T_0)}{R^* \, T_0 T}\right) \tag{3}$$

where e_{so} = 6.11 hPa, T_0 = 273.16 K, R* is the universal gas constant, L_v is the latent heat of vaporisation and M_v is the molecular weight of water vapour.

The saturation specific humidity qs was then evaluated from the relation:

$$q_s = \frac{\epsilon_1 e_s}{P - \epsilon_2 e_s} \quad (4)$$

where ε_1 = 0.622 and ε_2 = 0.378.

Next, the potential temperature, θ, is evaluated from the Poisson equation as

$$\theta = T(\frac{100}{P})^K \quad (5)$$

Where k is equal to R/Cp, and R and Cp are the gas constant and specific heat for dry air at constant pressure, respectively.

Thus, the equivalent potential temperature, θ_e, is defined as [4]:

$$\theta_e = \theta[exp\left(\frac{L_c \times q}{C_p \times T_v}\right)] \quad (6)$$

Where Lc is the latent heat of vaporization (condensation);

T_v is the virtual temperature given as

$$T_v = T(1 + 0.61q) \quad (7)$$

and

$$\theta_{es} = \theta[exp\left(\frac{L_c\, q_s}{C_p\, T}\right)] \quad (8)$$

The daily anomalies are then evaluated using the relations below:

$$\theta'_e(P,t) = \theta_e(P,t) - \overline{\theta_e}(P) \quad (9)$$

$$\theta'_{es}(P,t) = \theta_{es}(P,t) - \overline{\theta_{es}}(P) \quad (10)$$

Then, according to [4]:

(i) the date 'a' when θ'_e >0 for at least three pentads, which indicates the beginning of abundant moisture supply, was used to predict the date of rainy season onset; and

(ii) the date "b" is the point of maximum separation between θ'_e and θ'_{es} i.e. the date of the highest pre-season moisture build-up, was employed to predict the cessation date of the rainy season.

2.2.6 Benoit method

Benoit [14] defined the onset date as the date when accumulated daily rainfall exceeded 0.5 of the accumulated potential evapotranspiration for the remainder of the season, provided that no dry spell longer than 5 days occurs immediately after that date. The Blaney-Morin-Nigeria model developed for the estimation of reference evapotranspiration, ET (mm/day), in Nigeria by Duru [29] was used. The model is given by:

$$ET = \frac{r_f(0.45Ta+8)(\,520-R^{1.31})}{100} \quad (11)$$

Where, r_f is the ratio of daily radiation to the annual maximum radiation, T_a the temperature (℃), R the daily relative humidity. However, Walter method [9] as modified by Olaniran [11] was used for the cessation date.

2.2.7 Kowal and Knabe method

Kowal and Knabe [13] defined the onset date as the 10-day in which rainfall is equal to or greater than 25 mm, but where the subsequent 10-day rainfall total is greater than 0.5 of the potential evapotranspiration.

2.3 Data Analysis

For all the methods fully described above, the onset and cessation dates were estimated from 1980 to 2014 over each station. Then the length of the rainy or growing season (LRS or LGS) was obtained using the following formula:

$$LRS\ or\ LGS = (Cessation\ Date - Onset\ Date) + 1 \quad (12)$$

Conditions of false start of rainfall was tested for the seven selected methods. It was assumed that an estimated onset date is a false start if there is an occurrence of dry period of seven or more consecutive days occurring 30 days after the date [18]. For a given day, the estimated onset dates from the seven selected methods were compared and the earliest or primary date without false start alarm was adjudged the actual onset date.

The bias, *BIAS,* is the deviation of the estimated onset date from the actual value. It was calculated for each method using the relation:

$$BIAS = \frac{\sum_{i=1}^{n}(SIM - OBS)}{n} \quad (13)$$

where *SIM* is the estimated onset value, *OBS* the actual value and *n* is the sample size (*n* =35) for the validation period (1980-2014).

It measures the average tendency of the estimated values to be larger or smaller than their actual counterparts. Its optimal value equals 0.0; indicating no difference between the estimated and the actual onset values. Similarly, negative bias value indicates underestimation while positive bias means overestimation.

3. RESULTS

Fig. 2 depicts the observed annual total rainfall from 1980 to 2014 in the selected meteorological stations in Nigeria.

The annual total rainfalls were 2858 mm (Warri, WAR), 1729 mm (Enugu, ENU) and 1402 mm (Osogbo, OSO) over the Forest zone. The values were 1334 mm (Jos, JOS), 1168 mm (Ilorin, ILO) and 1041 mm (Ibi, IBI) in Guinea Savannah zone and 877 mm (Kano, KAN), 665 mm (Sokoto, SOK) and 559 mm (Maiduguri, MDG) in Sudan-Sahel Savannah. The seasonal cycle of the rainfall across the meteorological stations and climatic zones are illustrated in Fig. 3.

The seasonal patterns were bimodal with the peaks in June/July and September over the Forest zone. Specifically, the monthly rainfall peaks of 428 mm (WAR), 248 mm (ENU) and 183 mm (OSO) were recorded in June/July and 409 mm (WAR), 275 mm (ENU) and 213 mm (OSO) in September. However, the patterns of seasonal rainfall distributions were generally unimodal in the Sudan-Sahel Savannah with the peaks of 280 mm (KAN), 212 mm (SOK) and 173 mm (MDG) in the month of August. Over the Guinea zone, the distributions were unimodal in JOS (300 mm in August) and IBI (205 mm in September) but bimodal in ILO (peaks of 177 and 218 mm in June and September respectively).

Fig. 4 shows the results of the estimated onset dates using the seven selected methods [*i.e.* Ogive (Og), Benoit (Bn) Kowal and Knabe (Kk), Anyadike (Ay), Walter-Olaniran (Wt), rainfall probability (Pf), and Theta-E (Te)].

The results showed that the arrival dates of onset were first noticed in Forest zone before the Savannah. For examples, the values (in Julian day) in WAR, ENU and OSO (Forest) respectively were 093:104:094 (Og), 034:072:070 (Bn), 039:074:066 (Kk), 038:062:059 (Ay), 039:071:070 (Wt), 080:105:101 (Pf) and 041:105:106 (Te). In ILO, JOS and IBI (Guinea), the estimated onsets were 108:123:121 (Og), 087:099:112 (Bn),

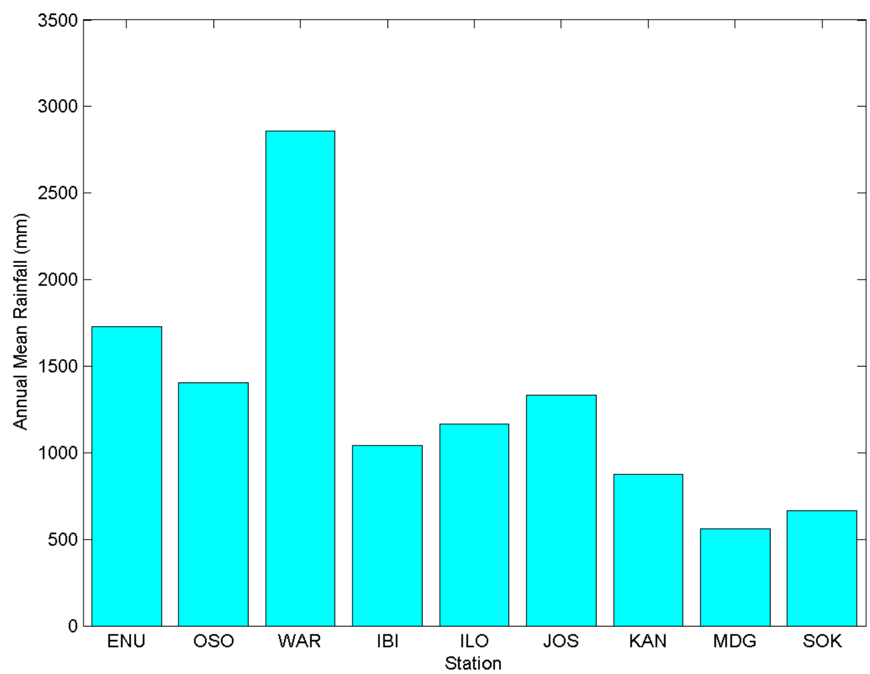

Fig. 2. Annual mean rainfall (1980-2014) over the selected meteorological stations in Nigeria (Enugu, ENU; Osogbo, OSO; Warri, WAR; Ibi, IBI; Ilorin, ILO; Jos, JOS; Kano, KAN; Maiduguri, MDG; Sokoto, SOK)

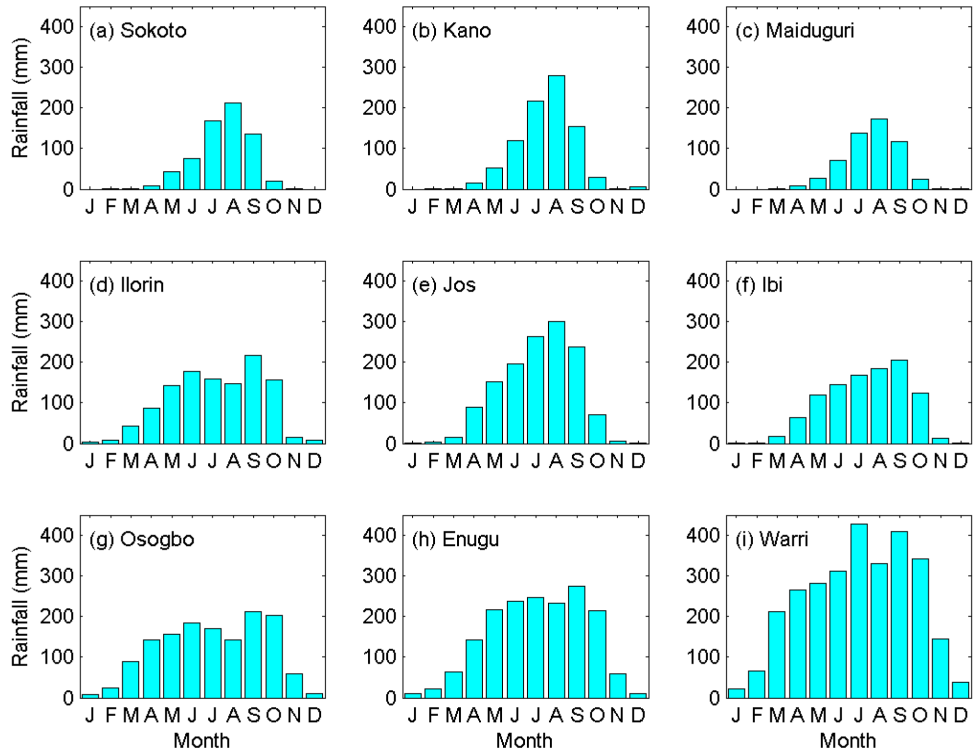

Fig. 3. Seasonal cycle of the mean rainfall (1980-2014) over the selected meteorological stations in Nigeria (1980-2014)

084:104:113 (Kk), 076:093:097 (Ay), 086:103:108 (Wt), 119:118:132 (Pf) and 115:119:130 (Te) respectively. Similarly, the onsets were 155:153:160 (Og), 164:151:178 (Bn), 161:153:177 (Kk), 137:133:146 (Ay), 150:145:160 (Wt), 159:154:161 (Pf) and 163:153:171 (Te) in SOK, KAN and MDG (Sudan-Sahel) respectively.

The cessation date estimates (in Julian day) in SOK, KAN and MDG stations (Sudan-Sahel), were 255:260:260 (Og), 284:287:276 (Bn), 284:287:276 (Kk), 272:278:268 (Ay), 284:287:276 (Wt), 250:252:251 (Pf) and 227:229:229 (Te) respectively (Fig. 5).

These values were followed closely by those in ILO, JOS and IBI (Guinea) and lastly by WAR, ENU and OSO (Forest). Fig. 6 describes the estimated length of growing season across the selected stations and zones.

The results indicated longer growing lengths over the Forest than the Savannah zones. For examples, the values (in days) in WAR, ENU and OSO (Forest) respectively were 195:182:198 (Og), 256:251:297 (Bn), 261:250:292 (Kk), 258:253:293 (Ay), 256:252:292 (Wt), 183:176:212 (Pf) and 118:130:168 (Te). In ILO, JOS and IBI (Guinea), the growing season spanned 173:139:156 (Og), 222:198:197 (Bn), 225:192:196 (Kk), 225:193:202 (Ay), 222:193:200 (Wt), 152:144:136 (Pf) and 113:100:97 (Te) respectively. Similarly, the lengths of raining season were 101:107:100 (Og), 120:137:98 (Bn), 123:135:100 (Kk), 136:145:121 (Ay), 134:143:116 (Wt), 92:99:90 (Pf) and 64:76:58 (Te) in SOK, KAN and MDG (Sudan-Sahel) respectively.

The actual mean onset dates (in Julian days), as deduced from the results of the false start test are presented in Fig. 7. The results showed that the actual onset dates were 061 (WAR), 084 (ENU) and 075 (OSO) over the Forest zone. In Guinea, the truthful onset dates were 103 (ILO), 108 (JOS) and 114 (IBI). Similarly, the values in SOK, KAN and MDG (Sudan-Sahel) were 150, 146 and 162 respectively.

The biases in the mean onset dates estimations using the seven methods are illustrated in Fig. 8. The biases (in days) in Og estimations were 32 (WAR), 20 (ENU) and 19 (OSO) in the Forest;

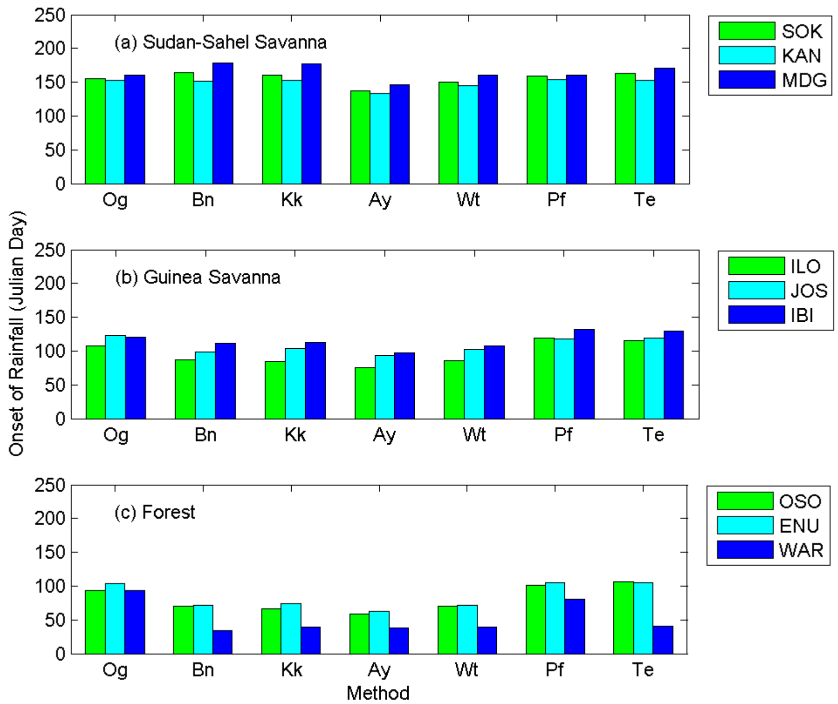

Fig. 4. Estimated mean onset of rainfall over the selected meteorological stations across the different climatic zones of Nigeria (1980-2014): Ogive (Og), Benoit (Bn), Kowal and Knabe (Kk), Anyadike (Ay), Walter-Olaniran (Wt), rainfall probability (Pf) and Theta-E (Te) method

4 (ILO), 15 (JOS) and 7 (IBI) in Guinea; and 5 (SOK), 7 (KAN) and -1 (MDG) in Sudan-Sahel. With Bn method, the biases were -27 (WAR), -11 (ENU) and -5 (OSO) in the Forest; -16 (ILO), -9 (JOS) and -2 (IBI) in Guinea; and 14 (SOK), 5 (KAN) and 17 (MDG) in Sudan-Sahel. Biases in Kk method were -22 (WAR), -10 (ENU) and -9 (OSO) in the Forest; -19 (ILO), -4 (JOS) and -1 (IBI) in Guinea; and 11 (SOK), 6 (KAN) and 15 (MDG) in Sudan-Sahel. Similarly, Ay method gave biases of -24 (WAR), -21 (ENU) and -16 (OSO) in the Forest; -27 (ILO), -15 (JOS) and -17 (IBI) in Guinea; and -13 (SOK), -13 (KAN) and -15 (MDG) in Sudan-Sahel. The biases in Wt were -22 (WAR), -12 (ENU) and -5 (OSO) in the Forest; -17 (ILO), -5 (JOS) and -6 (IBI) in Guinea; and 0 (SOK), -1 (KAN) and -2 (MDG) in Sudan-Sahel. With *Pf* method, the biases were 19 (WAR), 22 (ENU) and 26 (OSO) in the Forest; 18 (ILO), 9 (JOS) and 16 (IBI) in Guinea; and 10 (SOK), 8 (KAN) and 0 (MDG) in Sudan-Sahel. The biases in *Te* estimations were -21 (WAR), 22 (ENU) and 31 (OSO) in the Forest; 11 (ILO), 11 (JOS) and 16 (IBI) in Guinea; and 14 (SOK), 7 (KAN) and 10 (MDG) in Sudan-Sahel.

The annual variabilities in actual onset dates of rainfall are described in Fig. 9. The results demonstrated high variabilities in the annual truthful onset date (ranged between -60 and 60 days) over the Forest and Sudan-Sahel zones. However, the variations were shorter (between -30 and 40 days) over the Guinea zone.

4. DISCUSSION

The results indicated that the annual total rainfall decreased progressively from a range of 1402-2858 mm in the Forest zone to 559-877 mm in the Sudan-Sahel (Fig. 2). There were also indications that the annual rainfall varied from east to west within the same climatic zone. For example, while the annual mean total was 1334 mm in JOS (Guinea), it was 1168 mm in ILO and 1041 mm in IBI; stations west and east of JOS. Similarly, KAN recorded 877 mm while SOK in the west recorded 665 mm and MDG in the east had 559 mm annual mean. This pattern of rainfall follows the movement of the rain belt and the position and strength of the Inter Tropical Discontinuity (ITD), which regulates the pressure system of the West African Monsoon. These results are in tune with what has been previously obtained by [5,11,30,31,32,33]. For example, [31] and [34] reported that annual distribution of rainfall varies considerably with season and across the latitude with total annual amount generally decreasing inland (northward) from the coast; ranging from 2,500 mm in the southeast to 870 mm in the north.

Results of this study also demonstrated that seasonal patterns of rainfall were bimodal in the Forest zone with peaks in June/July (183-428 mm) and September (213-409 mm (Fig. 3)). However, the patterns of seasonal rainfall distributions were generally unimodal in the Sudan-Sahel Savannah with the peak (173-280 mm) in August. The stations in Guinea were unique as the distributions were unimodal in JOS and IBI but bimodal in ILO. These findings support the forth and back migration of the ITD as reported in [8].

Although, the onset estimations by the seven methods varied, the results demonstrated that the stations did not experience the start of rainy season at the same time. They all consistently suggested that onset dates were much earlier in the Forest (south) than Sudan-Sahel (north). Similarly, all the methods steadily predicted progressive movement in cessation dates from Sudan-Sahel to the Forest zone with some disparities in the estimated values. In agreement with [7] our results indicated that earlier onset most often leads to longer rainy season. Thus, all methods suggested that length of growing season were longer over the Forest (south) than the Savannah zones (north) with some disparities in the estimated values. The rains are starting late in the north but are ending earlier than normal, therefore, shortening the duration of the rainy season. These results agree well with the findings of [5] where the growing length in Forest zone stations was 150 days (5 months); 120 days (4 months) in Guinea and 60 days (2 months) in Sudan-Sahel for 1961 and 2000 period. The results also indicate that the length of the rainy season is more dependent on the rainfall onset than its cessation [15,35]. These results agree with previous studies where it is reported that the length of the rainy season decline steadily as you move from south to north with early cessation dates in the north and late in the south [5,7,11,33].

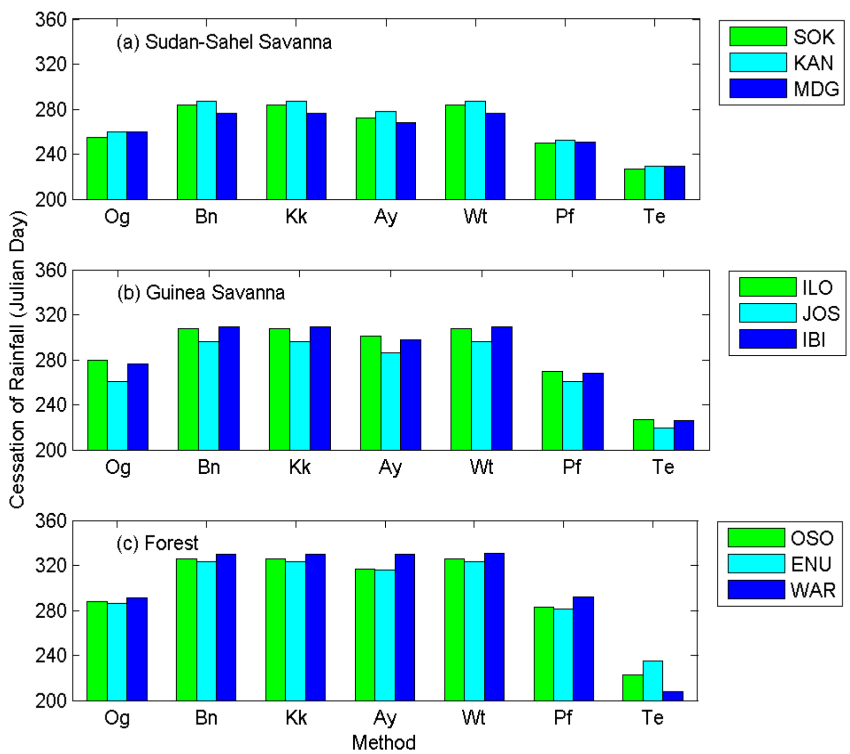

Fig. 5. Estimated mean cessation of rainfall over the selected meteorological stations across the different climatic zones of Nigeria (1980-2014): Ogive (Og), Benoit (Bn), Kowal and Knabe (Kk), Anyadike (Ay), Walter-Olaniran (Wt), rainfall probability (Pf) and Theta-E (Te) method

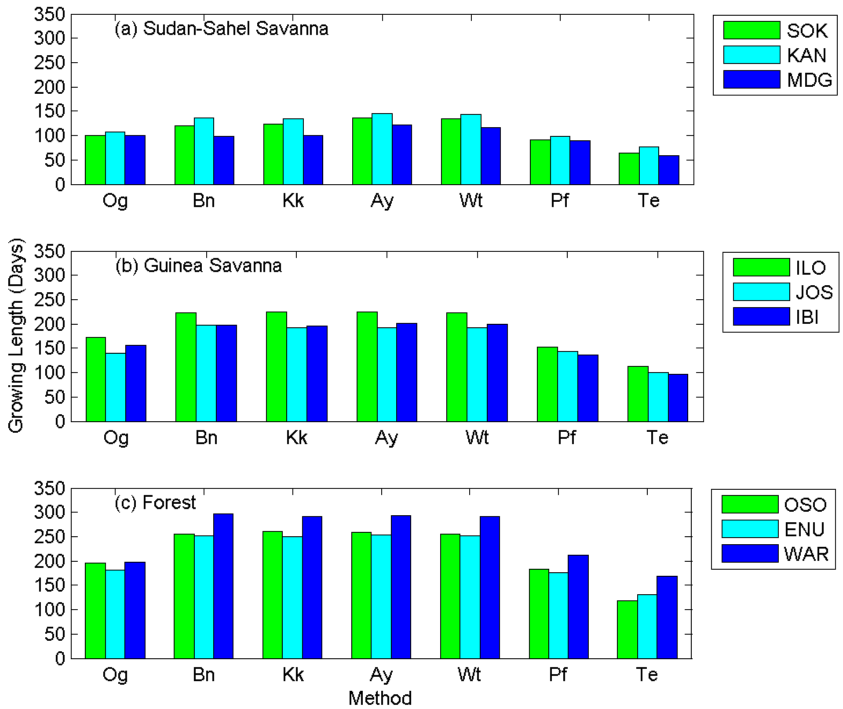

Fig. 6. Estimated mean length of growing season over the selected meteorological stations across the different climatic zones of Nigeria (1980-2014): Ogive (Og), Benoit (Bn), Kowal and Knabe (Kk), Anyadike (Ay), Walter-Olaniran (Wt), rainfall probability (Pf) and Theta-E (Te) method

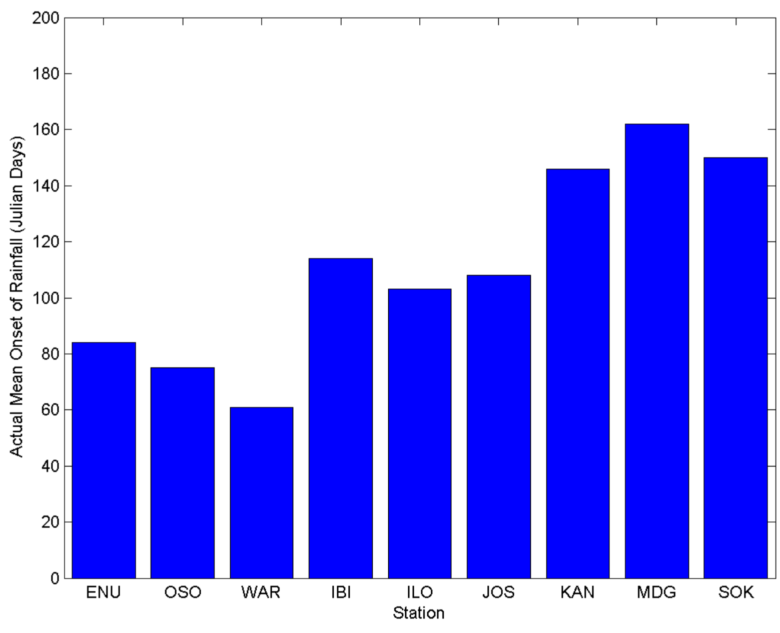

Fig. 7. Estimated actual mean onset of rainfall (1980-2014) over the selected meteorological stations in Nigeria (Enugu, ENU; Osogbo, OSO; Warri, WAR; Ibi, IBI; Ilorin, ILO; Jos, JOS; Kano, KAN; Maiduguri, MDG; Sokoto, SOK)

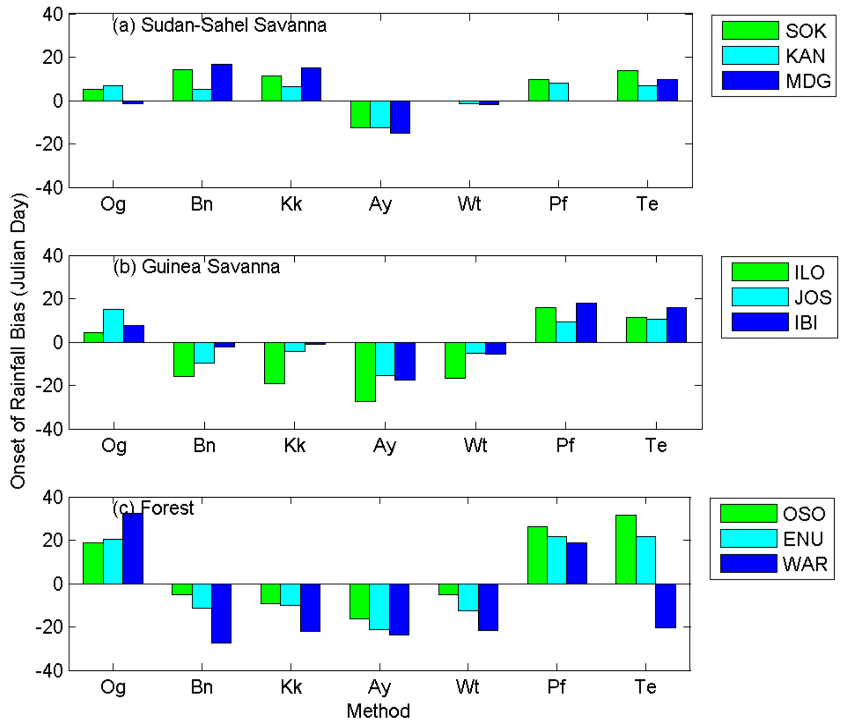

Fig. 8. Biases in the mean onset of rainfall over the selected meteorological stations across the different climatic zones of Nigeria (1980-2014): Ogive (Og), Benoit (Bn), Kowal and Knabe (Kk), Anyadike (Ay), Walter-Olaniran (Wt), rainfall probability (Pf) and Theta-E (Te) method

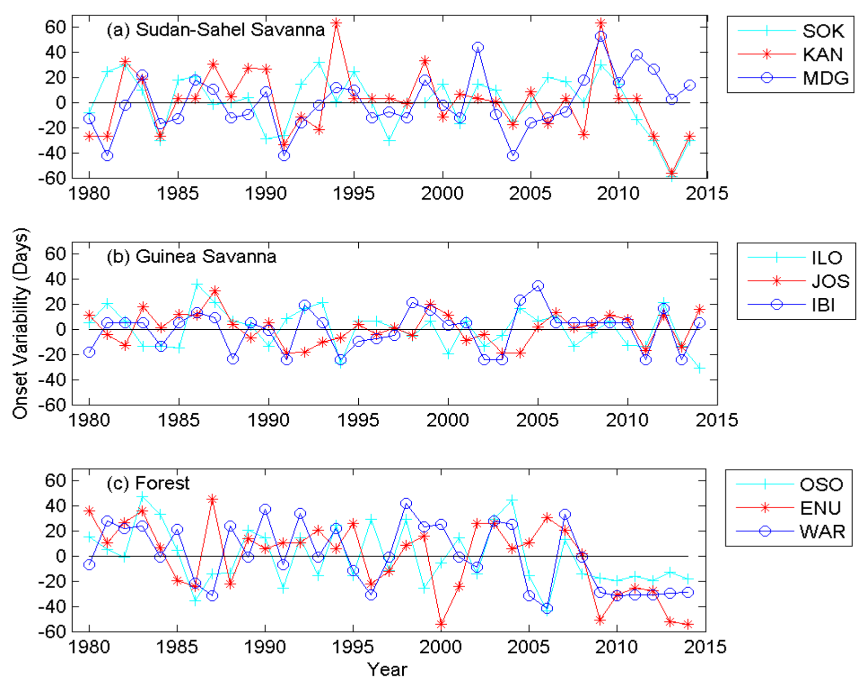

Fig. 9. Variabilities in the mean actual onset of rainfall over the selected meteorological stations across the different climatic zones of Nigeria (1980-2014)

The actual mean onset dates occurred between Julian day 061 and 084 in the Forest zone; 103 to 114 (IBI) in Guinea; and 146 to 162 in Sudan-Sahel (Fig. 7). There were also indications that the onset dates vary slightly from east to west within the same climatic zone. For example, while the onset was on Julian day 108 in JOS (Guinea), it was 103 in ILO and 114 in IBI; stations west and east of JOS respectively. Similarly, the actual mean onset in KAN was on Julian day 146 while it was 150 in SOK (a station west of KAN) and 162 in MDG (east). This pattern of rainfall follows that of annual total rainfall over the country. The results corroborate the findings of [34] who reported that rainfall commences at the beginning of the raining season around March/April from the coast (in the south), spreads through the middle belt, to eventually get to the northern part very much later. Similarly, these results were comparable with the findings of [5,36].

In agreement with the submission of [20] the estimated onset dates between stations are never comparable because of the highly variable rainfall distributions between stations.

However, the methods are inter-comparable for the same station, hence we compared the biases in onset estimations by the seven different methods adopted in this study.

According to [4,17,37], the prediction is regarded as having high skill if it is within ±10 days of actual date of onset. Thus, the Og onset estimations were very good in Savannah with biases of < 7 days except for Jos where the bias was +15 days (Fig. 8). Its performance in the Forest zone was however poor with biases of 19 to 32 days. Similarly, results suggested that Bn, Kk, Ay and Wt methods consistently performed fairly well with biases of ± (2 to 17) days across all the zones except for Warri station. The performance of Wt was better than Og in Sudan-Sahel with maximum negative bias (under-estimation) of 2 days. In addition, the biases in Bn and Kk estimations were more comparable than other methods and both were positive (over estimation) in Sudan-Sahel but negative in others. Lastly, the biases in Pf and Te estimations were mostly positive (later than the actual onset date) over all zones. One could therefore mistakenly take these results as the best, without statistical comparisons with the actual onset dates. Nevertheless, their best performances were in Sudan-Sahel with maximum biases of 14 days and the least in Forest zone. These results agree with the predicted onset dates using Te and

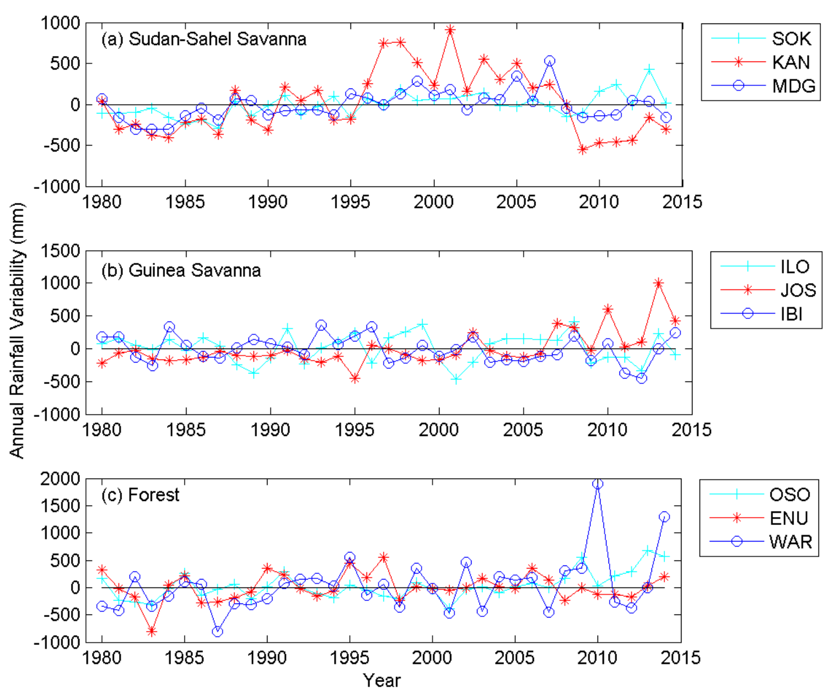

Fig. 10. Variabilities in the mean annual rainfall over the selected meteorological stations across the different climatic zones of Nigeria (1980-2014)

Pf [5,17]. These various prediction schemes generally showed strong performances over the Savannah but weak over the Forest zone. The reason could be attributed to the high variabilities in monthly rainfall and soil moisture contents over the Forest zone; since the schemes are dependent on either rainfall amount, rain-evapotranspiration relation or equivalent potential temperature.

Lastly, the results demonstrated high variabilities in the annual actual onset dates with variations across the zones. These results corroborate the findings of [16] who submitted that rainfall onset dates could vary remarkably on an annual basis. An attempt was made to investigate the performances of these schemes during unusual year(s) (*i.e.* extremely dry or wet) across the zones. However, results in Fig. 10 show vastly variable annual rainfall distributions between stations within the same zone. There were also indications that if a particular station experiences occurrence of an unusual dry or wet year, other stations within the zone or the country might not. In 2010, for example, unusual rainfall of about +1900 mm above the mean (an indication of an unusual wet year) was observed in Warri station (Forest) while the variabilities in other stations within the zone in the same year were 35 (OSO) and -125 mm (ENU; Fig. 10). Similar patterns of rainfall distributions were obtained over other zones. It is therefore impossible to compare the various scheme onset estimations during these unusual years.

5. CONCLUSION

This study compared the predictive skills of seven commonly used methods to estimate dates of onset and cessation of rainfall in various climatic regions of Nigeria. It assessed their strengths and weaknesses for determination of dates of onset from 1980 to 2014 over the Forest, Guinea and Sudan-Sahel savannah regions of the country as a representative climate of West Africa. These methods include ogive (proposed by [10]), daily rainfall probability [28] and Walter-Olaniran (by [9]) and modified by [11]) methods all dependent on rainfall data. Others include Benoit [14], Anyadike [12], Kowal and Knabe [13] which are rain-evapotranspiration relation dependent. The last method is Theta-E, proposed by [4] is dependent on equivalent potential temperature. The estimated onset dates obtained were tested for the condition of false starts and the earliest or primary no-false-start dates were taken as the actual onset dates. The onset estimations by the prediction schemes indicated that the stations did not experience the start of rainy season at the same time. They consistently suggested that onset dates were much earlier in the south than the north. The onset dates varied slightly from east to west within the same climatic zone. On annual basis, it was observed that rainfall onset dates varied remarkably across the zones. Similarly, all the methods steadily predicted progressive movement in cessation dates from north to the south zone with some little disparities in the estimated values. As expected, all methods suggested that length of growing season were longer in the south. In all, no single method performed very well over all the stations, however, all the seven methods performed better in the Savannah than the Forest. It can be concluded that Walter-Olaniran and ogive schemes performed best in the Sudan-Sahel with predictive skills of less than ±7 days of actual date of onset. The implication of these results is that, major criterion for a choice of any prediction scheme is the performance of the scheme for estimating the onset and cessation of rainfall over the zone. It is thus recommended that some of these methods require modifications in order to improve their predictive skills particularly in the Forest zone.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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