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Teleconnection of spatial variations of effective onset of rainfall and ENSO\IOD over savanna zones of Nigeria

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Abstract
This study characterised the spatio-temporal patterns of effective rainfall onset dates, their variability and their relationship with ENSO/IOD over Savanna zones of Nigeria. Daily rainfall and ENSO/IOD data for the period 1971–2015 were used. The Intra-Seasonal Rainfall Monitoring Index (IRMI) was applied to identify and classify effective rainfall onset dates. The classified effective rainfall onset dates were subjected to the Mann-Kendall trend test. The coefficient of variation (CV) was employed for the variability test, while Pearson's product-moment correlation was employed to establish an association between variables. The results indicate a variation in the effective start of rainfall of 15 days, and 30–60 days, in the Guinea Savanna and Sudano-Sahelian Savanna zones, respectively, between the western and eastern axes. The onset date trend test revealed that stations in the guinea savanna zone tended to have later effective onset dates while stations in the Sudano-Sahelian savanna zone tended to have earlier onset dates of rainfall. The correlation test showed a significant and insignificant positive relationship between effective rainfall onset dates and the ENSO/IOD phase, particularly in the stations across the guinea savanna zones of the study area. It is expected that this information on the variability of effective rainfall onset dates, when provided in aid of rain-fed agriculture, could support decision-making on crop types to be cultivated and on the planning of sowing dates across the study area. These findings are of high importance to the entire West African sub-region, including other parts of the world that share similar monsoon rainfall and physical characteristics of these savanna zones.

Keywords Onset Rainfall · Onset Variability · Synoptic · Rain-fed Farming · ENSO · IOD

1 Background to the study

Evidence abounds that there is a concerted effort by the Federal Government of Nigeria to make agriculture an all-year-round business as a basis for improving rural livelihoods and lifting millions out of poverty. To successful lift millions out of poverty, there is the need to pay attention to the seasonal rainfall regime since rain-fed farming remains the dominant socio-economic activity among the peasant farmers. Usman et al. (2005) posited that agriculture, which employs an ever-increasing population in the Sahel and sub-humid areas of Africa, is largely rainfall-dependent. Similarly, Calzadilla et al. (2013) posited that 97% of the total cropland in Sub-Saharan Africa (SSA) is dominated by rain-fed farming. Cooper et al. (2013) observed that this agricultural practice is likely to remain the major source of staple food production for most people in rural areas. Therefore, this study analysed the effective onset dates of rainfall which is the most fundamental component of rain-fed agriculture. The effective onset date is defined in this study as the date from which rain is consistent enough to allow for the sustenance of minimally required moisture to support plant growth.

As important as rain-fed agriculture is to rural inhabitants' livelihoods in the tropics, a fundamental challenge remains the impact of climate variability, such as variation in onset dates of rains from 1 year to another. Previous studies (Akinseye et al. 2015; Norrgård 2017; Ojo et al. 2004; Sultan and Janicot 2003; Usman 2000) established that rainfall within this region is highly variable. Owing to the variability of rainfall, particularly within West Africa, Dalu et al. (2008) established that the regions with the same average onset dates tend to have different cessation dates. In a similar study, Beyer et al. (2014)

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reasoned that the consequence of the onset of rainfall variability is that rain-fed agriculture in rural areas is mostly based on a "trial-and-error" principle. The authors further reported that in response to the uncertainty in the effective onset of rainfall, cereal crops are usually planted after the first drops of the rainy season, hoping that the subsequent weeks will deliver enough rainfall to allow for germination and growth. Usman and AbdulKadir (2013) agreed with the submission that the perceived high variability of onset and cessation dates has made agricultural planning virtually impossible. The foregoing discourse suggests that the onset phase of rainfall remains critical to rain-fed agriculture.

Several research works (e.g. Usman 2000; Omotosho et al. 2000; Camberlin and Okoola 2003; Odekunle et al. 2005; Hachigonta et al. 2008; Recha et al. 2012, among others) on the onset, cessation and duration of the rainy season have been conducted in Nigeria and other parts of the SSA. The researchers have often tended to adopt different methodologies (with varying complexities) to determine the onset dates of rainfall. Invariably, therefore, not only have their results tended to be different, the varying methodologies adopted have had their weaknesses. For example, Odekunle et al. (2005) subjectively employed cumulative percentage mean rainfall to generate the rainfall onset date as that date when the value exceeds a given threshold. Other studies (for example, Amekudzi et al. 2015; Ati et al. 2002; Marteau et al. 2011; Mupangwa et al. 2011; Ngetich et al. 2014; Oguntunde et al. 2014) employed different methodologies in the onset of rainfall analysis across sub-Saharan Africa. To overcome the challenges of onset of rainfall variability and the observed drawbacks in the different methodologies, several studies (for example, Usman and Reason 2004; Tadross et al. 2005; Hachigonta et al. 2008) have pointed to the need for a more detailed investigation of rainfall regimes especially in support of peasant farming. It is based on the drawbacks in other methodologies that this study adopted the newly developed Intra-seasonal Rainfall Monitoring Index (IRMI) by Usman and AbdulKadir (2013) to provide important information in aid of rain-fed agriculture.

Empirical studies (for example, Ronchail and Gallaire 2006; Manatsa et al. 2011; Kayano et al. 2013; Salimun et al. 2014) suggest that El Ni˜no-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) are synoptic features that influence rainfall across the globe. Similarly, some studies have shown a significant relationship between rainfall and physical environmental features (Sanchez-moreno et al. 2014; Tawde and Singh 2015). It has been suggested that in addition to the influence of ENSO and IOD, the rainfall regime in West Africa is also being influenced by the African Easterly Jet (AEJ) (Nicholson 2008; Omotosho 2008; Semunegus et al. 2017). In Nigeria, it is understood that the rainfall regime is being influenced by maritime (mT) and continental (cT) air masses (Ifabiyi and Ojoye 2013). The intertropical discontinuity (ITD) position, which is the meeting point between mT and cT, determines the rainy season in Nigeria (Oguntunde et al. 2014). The global climate change and the varying influences of climatic features on rainfall suggest the need to continue analysing rainfall to aid planning in resource-dependent regions of the world.

Although many studies are available regarding the onset of rainfall and the impact of synoptic features on the quantity of rainfall worldwide, there have been less studies on the spatial difference of effective onset of rain in the same climatic zone and latitudinal band. Similarly, the relationship between the onset phase of the rainfall and the synoptic features of ENSO/IOD have rarely been studied in this study area. Therefore, this study determined effective rainfall onset dates and analysed its spatial coherence, determined the relationship between the onset date of rain and the latitude, and the relationship between the onset date of rain and the synoptic feature of ENSO/IOD. This study's findings apply to the entire savanna zones of West Africa as they share similar climatic characteristics.

2 Material and methods

2.1 The study area

The savanna zones of Nigeria occupy nearly half of the total landmass of the country. The zones lie between longitudes 3° and 15° East and latitudes 8° and 14° North. The synoptic weather observation stations located in these zones are as follows: Sokoto, Yelwa, Gusau, Katsina, Kano, Kaduna, Bauchi, Yola, Jos, Minna, Bida, Nguru and Maiduguri. Major crops such as yam, millet, cowpeas, groundnut and cotton are grown in the region (Odekunle et al. 2008).

The types of major crops produced predispose the peasant farmer to negative impacts of variability in the effective onset date of rainfall. The mean basic character of rainfall in the study area is depicted in Fig. 1, showing a decrease in mean annual rainfall from the Guinea Savanna to the Sudano-Sahelian Savanna.

2.2 Data used

The daily rainfall data from the stations named in Table 1 was acquired from the archives of the Environmental Management Programme, Federal University of Technology, Minna, for 45 years (1971–2015). Monthly Indian-Pacific Ocean SST anomalies/DMI for the period 1971–2015 was obtained from http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/DMI while Monthly NOAA ENSO/SOI index for the period (1971–2015) was obtained from http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Nino34/. Previous studies (Philippon et al. 2012; Bridhikitti 2013; Manatsa et al. 2011;

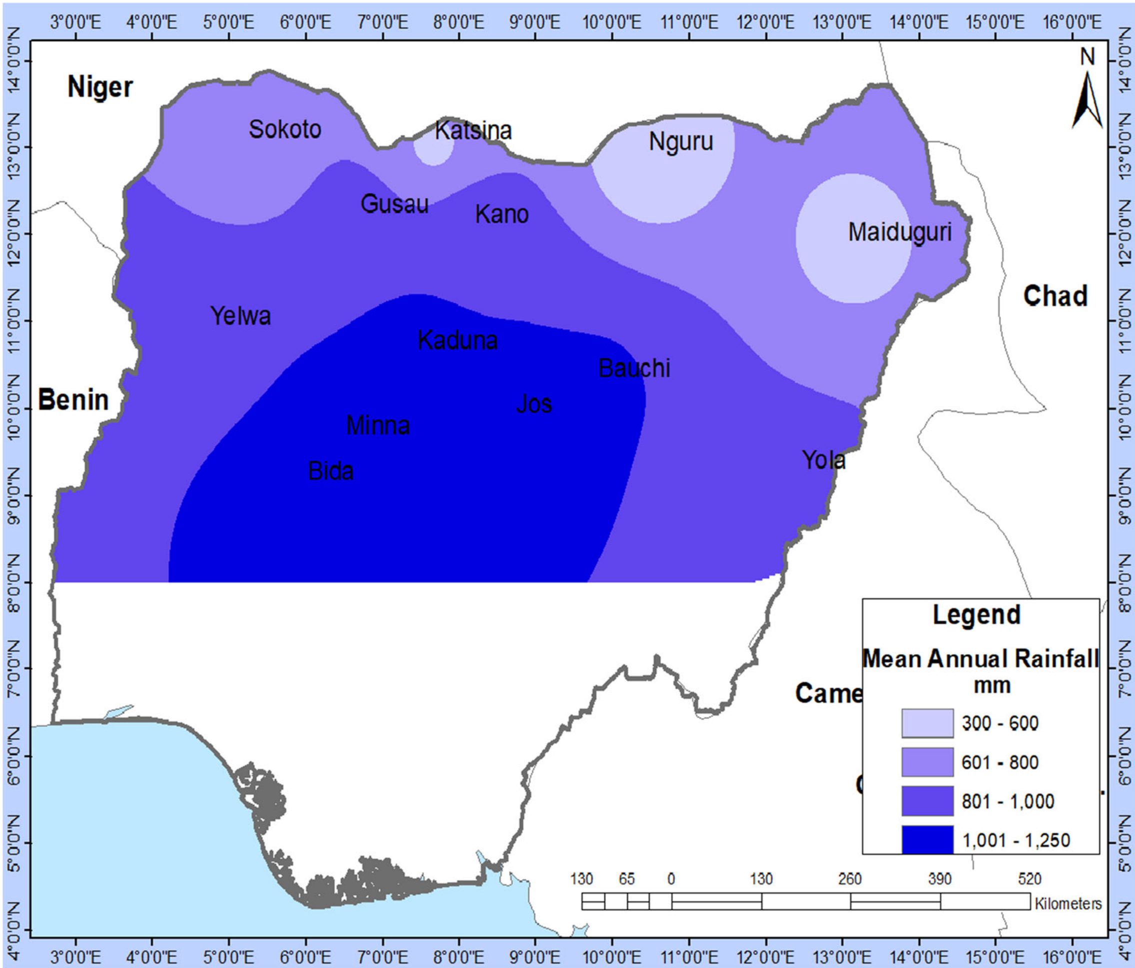

Fig. 1 The mean annual rainfall of the study area

Table 1 Pentad and corresponding onset date of rainfall

Pentad number	Corresponding date	Pentad number	corresponding date
25	5th May	43	3rd August
26	10th May	44	8th August
27	15th May	45	13th August
28	20th May	46	18th August
29	25th May	47	23rd August
30	30th May	48	28th August
31	4th June	49	2nd September
32	9th June	50	7th September
33	14th June	51	12th September
34	19th June	52	17th September
35	24th June	53	22nd September
36	29th June	54	27th September
37	4th July	55	2nd October
38	9th July	56	7th October
39	14th July	57	12th October
40	19th July	58	17th October
41	24th July	57	22nd October
42	29th July	60	27th October

Tedeschi et al. 2013) have used the ENSO and IOD data to determine their impacts on rainfall regime.

2.3 Data analysis

Intra-Seasonal Rainfall Monitoring Index (IRMI) developed by Usman and Abdulkadir (2013) was adopted to achieve the objective of this study. The acquired daily rainfall total was grouped into 5-day (pentad) totals. A pentad value with <5 mm of rainfall is taken as a break. The 25th pentad of the year from the first of January (in May) is taken as the pentad of reference across the Savanna zones of Nigeria. The cumulative amount of rainfall, the highest pentad total since the 25th pentad and the number of breaks are noted. IRMI calculation is shown in Eq. (1):

$$IRMI = \frac{(Cpt)^2}{\left(hpt \times Nb \times 100\right.} \tag{1}$$

Cp cumulative pentad rainfall since May 1
hpt the highest pentad total rainfall since May 1
Nb number of breaks in rainfall (pentads with less than 5 mm of rainfall) and
100 a factor

The effective onset of rains is taken as the pentad within which the IRMI is ≥1 for the first time. The onset pentad is translated into the corresponding date in Table 1.

The effective onset pentad values were subjected to analysis to determine the average effective rainfall onset for each station. The pentad values were further subjected to spatial analysis. Similarly, we sought to test the tendency towards early or late case scenarios of effective onset date across the study locations. Mann-Kendall trend test (Mann 1945; Kendall 1975) was adopted to analyse rainfall onset dates trends. The Mann-Kendall (MK) test is a non-parametric test commonly used to detect significant trends in hydrological and meteorological time series (Tabari and Talaee 2011). The test is suitable for the data that do not follow a normal distribution (Tabari and Nikbakht 2012) and supports multiple observations per time series (Kampata et al. 2008). The MK test is given as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sign}(x_J - x_k) \tag{2}$$

$$\text{where } \operatorname{sign}(x_j - x_k) = \left\{ \begin{array}{l} 1 \text{ if } (x_j - x_k) > 0 \\ 0 \text{ if } (x_j - x_k) = 0 \\ -1 \text{ if } (x_j - x_k) < 0 \end{array} \right\} \tag{3}$$

$$\mathrm{VAR(S)} = \frac{\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)\right.}{18} \tag{4}$$

where:

n the number of data points
t_i the number of ties for the *i* value and
m the number of tied values (a tied group is a set of sample data having the same value)

Then, Eqs. (4) and (5) will be used to compute the test statistic Z from the following equation:

$$Z = \left\{ \begin{array}{ll} \frac{S-1}{\sqrt{VAR(S)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & \text{if } S < 0 \end{array} \right\} \tag{5}$$

A positive value of Z is classified as an upward (towards later effective onset date) trend, and a negative value is classified as a downward (towards earlier effective onset date) trend while zero value indicates no trend. The coefficient of variability (CV) was adopted to determine the rate of variability in the effective onset date of rainfall. The CV was calculated as hereunder:

$$CV = \left(\frac{\text{Standard Deviation}}{\text{Mean}} \right) 100\% \tag{6}$$

The monthly values of ENSO and IOD were subjected to mean to generate annual value. Pearson's correlation method was adopted at 95% confidence level to determine the influence of the latitudinal location of rainfall stations, ENSO and IOD phases on the effective onset date of rainfall. Pearson's correlation determines how the latitude and the mesoscale convective systems (ENSO and IOD) phases influence the onset rainfall pattern over the selected synoptic stations in the savanna zones of Nigeria.

2.4 Spatial interpolation of derived climatic parameters

The derived onset date of rain and CV were subjected to spatial interpolation using inverse distance weighting (IDW). The IDW interpolation hinges on the assumptions that things that are close to one another are more alike than those farther apart. The implication of this is that each station has a local influence that decreases with distance through a power parameter (Yavuz and Erdogan 2012). The interpolation was performed with the aid of the IDW function inbuilt within ArcGIS software. The IDW method is adjudged to be a simple as well as effective interpolation method, and previous researchers have used it (for example, Huang et al. 2015; Liang et al. 2011; Some'e et al. 2012; Wu et al. 2016; Yavuz and Erdogan 2012) as a standard.

3 Results and discussion

3.1 Effective onset date of rainfall

The rainfall regime in the Guinea and Sudano-Sahelian zones of Nigeria has only one season. The climatological onset date of rainfall over the Savanna zones of Nigeria is normally during May with substantial interannual variability. The May to October of each year are considered as the rainy season, corresponding to the growing season over the study area. Figure 2(a–d) depicts the computed effective onset dates of rainfall across the considered stations and reveals a general fluctuation in the onset date of rainfall. The fluctuation of the onset date is consistent with findings in the other parts of Africa; for example, Recha et al. (2012) found high variability of onset in Kenya. The more southerly stations, Bida, Yola, Minna, Jos, Bauchi and Kaduna, except for Yelwa, show low fluctuation. It is observed that the Jos station exhibited the lowest variability, pointing to strong localised influences, most likely, orographic. The more northerly stations, Kano, Gusau, Sokoto, Maiduguri, Nguru and Katsina, witnessed higher fluctuation. Figure 2(d) shows that Maiduguri, Nguru and Katsina recorded some years without the effective rainfall onset. In Maiduguri, the years 1975, 1983, 1995 and 1997 recorded no effective onset of rainfall. In Nguru, the years without the effective onset of rainfall were 1973, 1984, 1987, 1988, 1994, 1996 and 2001. Expectedly, these stations (Maiduguri and Nguru) are both on the eastern flank of the study area, where the rainfall amount is the lowest and the season, relatively shortest. Katsina is the only station relatively on the western flank of the study area with no effective rainfall onset in 1992 and 1993. The results also revealed that effective rainfall onset on the eastern flank is highly variable relative to Western flank stations.

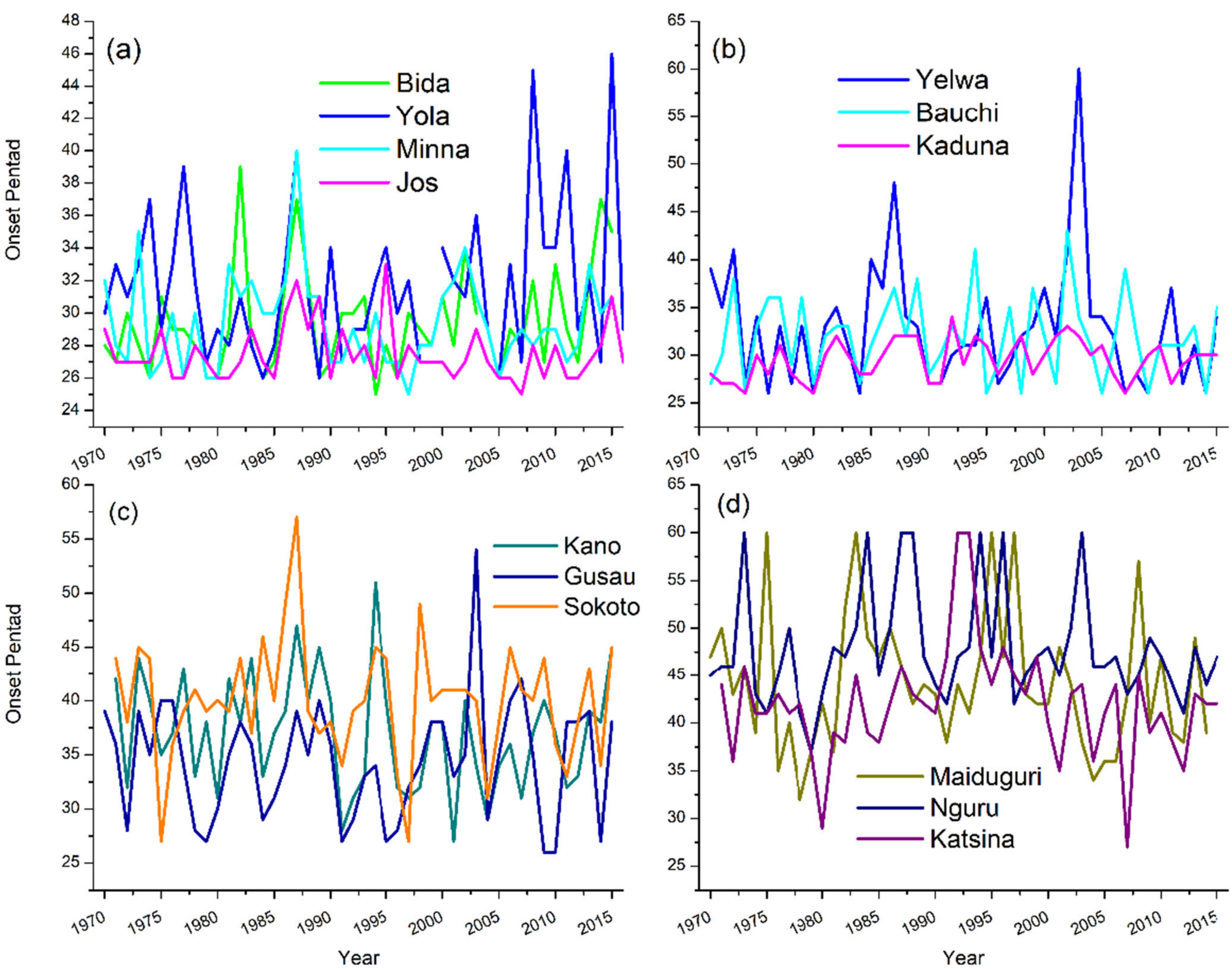

Fig. 2 **a**–**d** Seasonal onset pentad of the study area

Table 2 Mean, early and late effective onset rainfall characterisation

Stations mean	Mean onset pentad	Earliest onset pentad	Year	Latest onset pentad	Year
Bida	29 (25th May)	25 (5th May)	1994	39(14th July)	1982
Yola	32 (9th June)	26 (10th May)	1984	46 (18th August)	2015
Minna	29 (25th May)	25 (5th May)	1997	40 (19th July)	1987
Jos	28 (20th May)	25 (5th May)	2007	33 (14th June)	1995
Bauchi	32 (9th June)	26 (10th May)	1995/09	43 (3rd August)	2002
Kaduna	29 (25th May)	26 (10th May)	2007	34 (19th June)	1992
Yelwa	32 (9th June)	26 (10th May)	1976	48 (28th August)	1987
Maiduguri	43 (3rd August)	32 (9th June)	1978	57 (12th October)	2008
Kano	37 (4th July)	27 (15th May)	2001	51 (12th September)	1994
Gusau	34 (19th June)	26 (10th May)	2009/2010	54 (27th September)	2003
Nguru	46 (18th August)	37 (4th July)	1979	50 (7th September)	1983
Sokoto	40 (19th July)	27 (15th May)	1975	57 (12th October)	1987
Katsina	41 (24th July)	27 (15th May)	2007	48 (28th August)	1994/1996

3.2 Mean effective onset date of rainfall

Table 2 shows the mean, early and late effective rainfall onset date across the stations. Except for Maiduguri and Nguru, the mean effective rainfall onset date has been normal (25th May–19th July). On average, the rainy season effectively begins earliest over the western part of the savanna zone, which also experiences a significantly higher rainfall total relative to the eastern part. A variation in the start of rainfall of 15 days, and 30–60 days, in the Guinea Savanna and the Sudano-Sahelian Savanna zones, respectively, is also seen between the western and eastern axes. The variation in the start of rainfall is similar to Chenoli et al. (2018)'s findings in Malaysia, where a gradual change in the onset of rain was detected between Peninsular Malaysia and East Malaysia. Similarly, Akinseye et al. (2015) established differences in the onset date of rain between the Sudano-Sahelian and Guinea Savanna zones in Mali. These similarities in onset dates may point to a global synoptic climate effect on the general rainfall system.

Table 3 also reveals the oft-reported spatio-temporal variability in rainfall characteristics over the study area with inconsistencies in the earliest and latest effective onset dates. Of particular interest is the observed north-south pattern in suppressed rainfall events across the study area, with Minna, Yelwa and Sokoto, all located on the western axis but spread south to north, recording the latest effective onset date of rainfall in 1987, a year denoted with below-normal annual total rainfall in large parts of northern Nigeria. This implies a meridional influence exercised on the known features that normally define the West African Monsoon (WAM) season. It is the considered opinion of this paper that this could be a resultant impact of the Walker circulation and its documented cause of isolated high-pressure cells that often suppress convection and consequently rainfall during the WAM season, known along the coastal regions as the "Little Dry Season" (e.g. Adejuwon and Odekunle 2006). Generally, Fig. 2(a–d) and Table 2 demonstrate that the onset of rainfall and its associated characteristics are earlier on the western flank than on the eastern flank.

3.3 Spatial distribution of mean onset of rainfall

The mean effective onset date of rainfall is categorised into 5th May to 30th May (pentad 25–30), 4th June to 29th June (pentad 31–36) and 4th July (pentad ≥37). Figure 2 depicts these

Table 3 Mann-Kendall test statistic (test *Z*) for the onset

Stations	Year	n	Test Z
Bida	1971–2015	45	1.60
Yola	1971–2015	45	0.54
Minna	1971–2015	45	0.19
Jos	1971–2015	45	−0.67
Bauchi	1971–2015	45	−0.39
Kaduna	1971–2015	45	1.48
Yelwa	1971–2015	45	−1.21
Maiduguri	1971–2014	44	−0.24
Kano	1971–2015	45	−1.07
Gusau	1971–2015	45	0.00
Nguru	1971–2015	45	0.95
Sokoto	1971–2015	45	−0.28
Katsina	1971–2015	45	−0.03

The trend was taken at $\alpha = 0.05$

dates over the study area. The central stations have early effective onset dates in the range of 5th May to 30th May; the stations surrounding the central area have near-normal dates in the 4th June to 29th June range, while the extreme northern region shows late effective onset dates, from 4th July and beyond. A related study conducted by Masupha et al. (2016) in South Africa showed a high risk of yield reduction with planting following the late onset of rain. Thus, the general patterns indicate a northward gradation of effective onset dates, consistent with the general northwards decline in rainfall receipt across the West African sub-region. It is also observed that Bida, Minna and Kaduna, with effective onset dates in the range of 5th May to 30th May, are located westward of Jos, pointing to the possible influence of orography (due to the Jos Plateau). This influence is supported by findings (Sanchez-moreno et al. 2014; Tawde and Singh 2015) that show a significant relationship between topography and rainfall in Cape Verde and Western Ghats of India, respectively. It is believed that the orography in the Jos area introduces thermodynamic lifting, which leads to the formation of local thunderstorms that influence rainfall events in areas west and southwest of Jos.

Pearson's correlation test was carried out to determine the influence of latitude and average rainfall on the effective onset date of rainfall (see Fig. 3). The Pearson's correlation test between mean annual rainfall and mean onset date of rainfall revealed a significant negative relationship ($r = -0.96$), implying that earlier effective rainfall onset dates tended to be associated with higher rainfall totals. Similarly, Pearson's correlation test between latitudes and mean effective onset pentad revealed a significant positive relationship ($r = 0.85$), implying that the more southerly locations tended to have earlier effective rainfall onsets in line with the movement of the inter-tropical discontinuity (ITD) (Fig. 4).

3.4 Trends in effective onset date of rainfall

The result of a Mann-Kendall trend test is depicted in Table 3. It reveals generally insignificant upward and downward trends. The trend is related to Sonnadara (2015)'s findings in Sri Lanka, where no significant trend in the onset was detected. The stations in the lower latitudes (guinea savanna zone), except for Bauchi, had tendencies towards later effective onset dates of rainfall. In comparison, stations in the higher latitudes (Sudano-Sahelian savanna zone), except for Nguru, had tendencies towards earlier effective onset dates of rainfall. Previous studies by Oladipo and Kyari (1993) and Sivakumar (1989) had established a significant relationship between onset date and the length of the growing season in Nigeria and Niger. This result implies that as the onset dates become early, the length of the growing season will be getting longer. The finding in onset trends of the Sudano-Sahelian savanna zone of Nigeria is consistent with Subash et al. (2011) in similar ecoclimatic settings where the effective onset date of monsoon tends to be early in most study sites in Bihar,

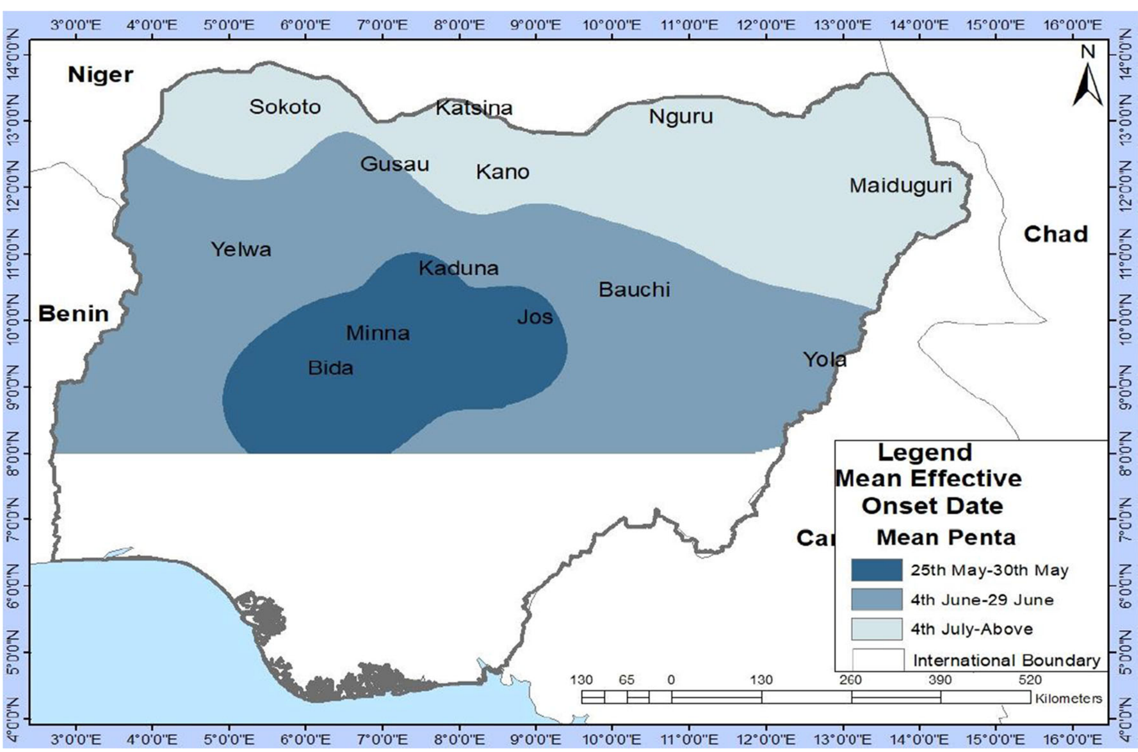

Fig. 3 Spatial distribution of mean effective onset date of rainfall

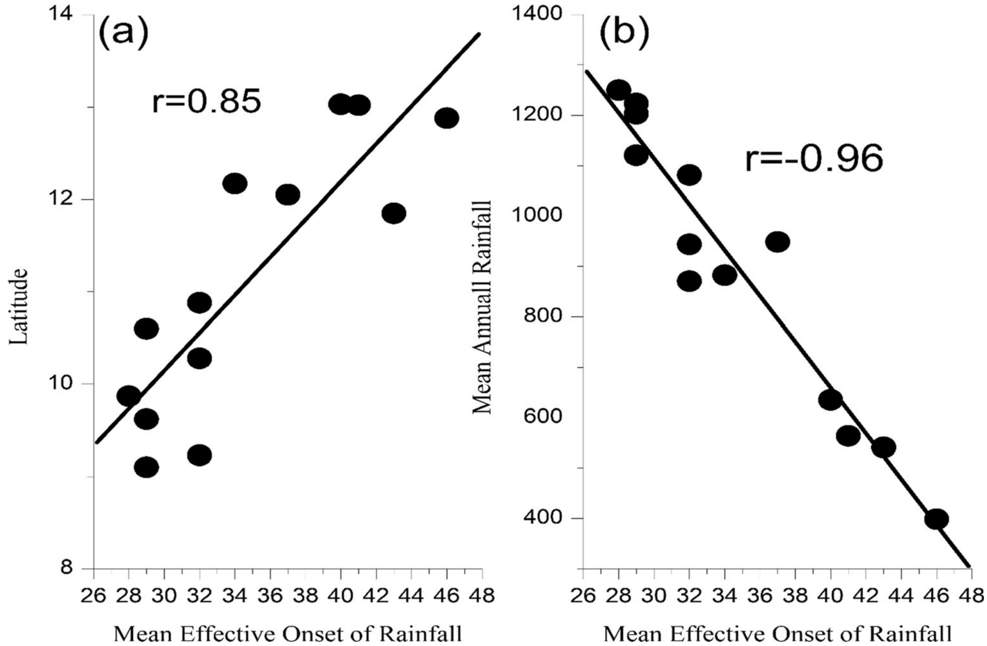

Fig. 4 Pearson's correlation (a) latitudes, (b) mean annual rainfall and mean effective onset of rainfall

India. This is potentially good news for the peasant farmers in the more sensitive Sudano-Sahelian zone, where the hydrologic growing season is usually relatively shorter. Kebede et al. (2016) supported this assertion by showing that change in the onset brings about little setback in smallholder agriculture in the climate-sensitive western part of Ethiopia.

3.5 Coefficient of variation in onset date of rainfall

The spatial rate of variability in effective rainfall onset is depicted in Fig. 5. The stations on the eastern flank of the study area have higher variability than stations on the western flank. Generally, Jos has the least variability, and Nguru has the highest variability. The surprising exception is Yelwa, which, though on the western flank, witnesses high effective onset date variability. The finding may not be unconnected because Yelwa is farther away from the zone of influence of the Jos Plateau and is therefore not swept by the thunderstorms that emanate from there, unlike Kaduna, Minna and Bida.

3.6 Relationships between the season onset and large-scale field of ENSO and IOD

The correlations between onset dates and synoptic climate features of ENSO/IOD are shown in Table 4. The results suggest that mixed relationships exist: significant, insignificant, positive and negative, between onset dates and ENSO and IOD. The onset and ENSO relationships are positive across the study area except for four stations (Yelwa, Maiduguri, Gusau and Katsina). Coincidentally, stations with the negative relationship are all in the upper latitudes, the Sudano-Sahelian savanna zone of the study area. Two stations (Bida and Kaduna) have significant positive relationships and are in the lower latitude (Guinea Savanna zone) of the study area. These mixed findings imply that while ENSO as a global synoptic feature influences the commencement of rainfall, individual station physical features also play a part. Usman and Reason (2004) demonstrated this in the context of a strong positive relationship between ENSO and dry spell frequency in southern Africa.

The onset and IOD relationship indicate that other stations have positive relationships except for three stations (Minna, Kaduna and Maiduguri). Unlike the ENSO case, the stations with the negative relationship between onset date and IOD are both to the south (Minna and Kaduna) and the north of the study area (Maiduguri). Three stations (Bida, Yola and Bauch), on the other hand, showed significant positive relationships. Similar to the relationship between effective onset date and ENSO, the stations with a significant positive onset and IOD relationship are also to the south (Guinea Savanna zone) of the study area. In a previous study by Bridhikitti (2013) where a significant relationship was found between rainfall and IOD, it has been suggested that IOD signals have greater responsibility for Thai monsoon rainfall. This is similar to the study of Chenolia et al. (2018) in Malaysia, where the monsoon onset date was found to be late in El Niño years. Therefore, it is safe to conclude that this study's findings suggest that ENSO and IOD years tend to be associated with late effective onset date over the study area.

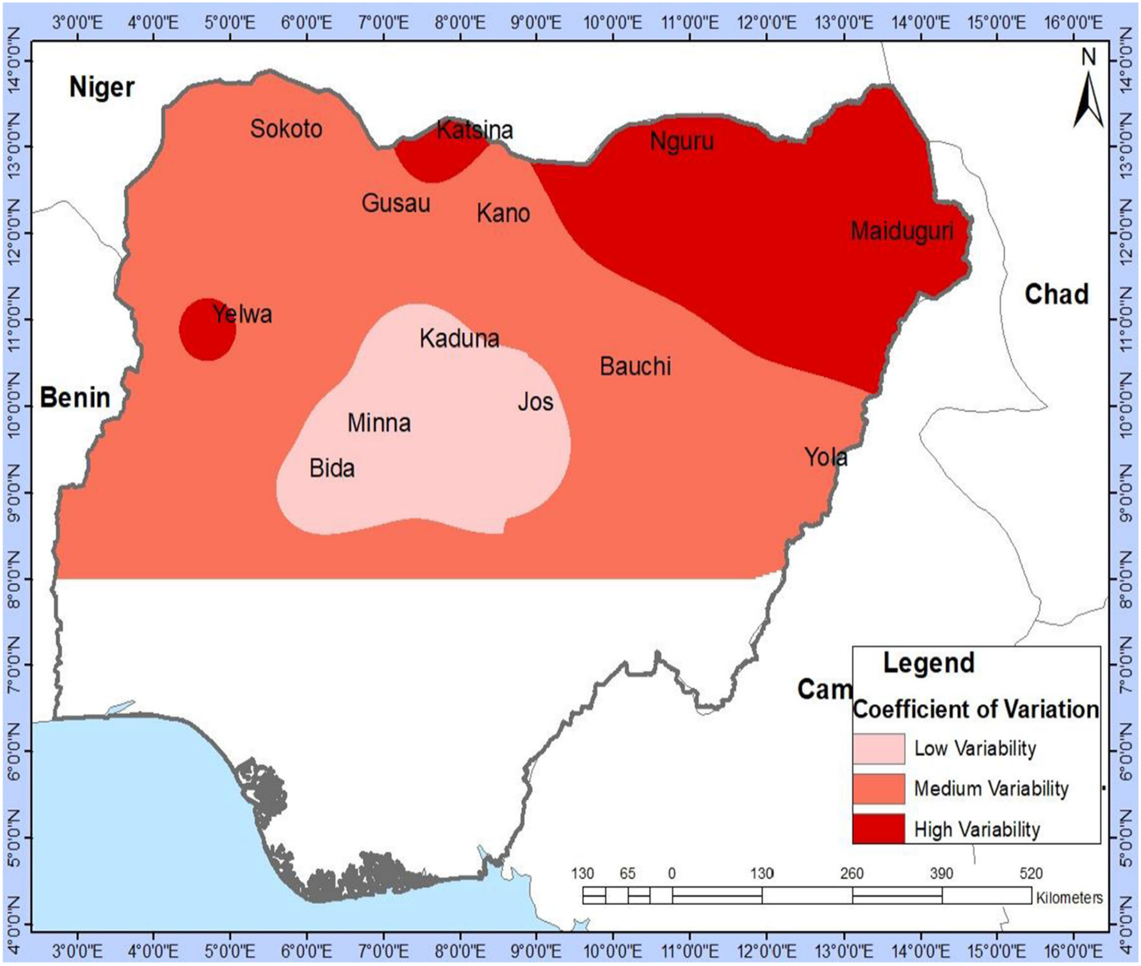

Fig. 5 Spatial rate of the variability of effective onset date of rain

Table 4 Relationship between effective onset date of rain and synoptic feature of ENSO/IOD

Stations onset and ENSO		Onset and IOD		
P value correlation		*P* value correlation		
Bida	0.01	0.41*	0.04	0.32
Yola	0.40	0.13	0.01	0.37
Minna	0.45	0.12	0.97	−0.01
Jos	0.16	0.21	0.92	0.02
Yelwa	0.95	−0.01	0.89	0.02
Bauch	0.30	0.16	0.05	0.30*
Kaduna	0.04	0.31*	0.94	−0.01
Maiduguri	0.32	−0.15	0.66	−0.07
Kano	0.76	0.05	0.52	0.10
Gusau	0.34	−0.15	0.24	0.18
Sokoto	0.43	0.12	0.90	0.02
Nguru	0.59	0.08	0.02	0.89
Katsina	0.36	−0.14	0.08	0.27

*The trend is significant at $\alpha = 0.05$

4 Conclusion

This study has characterised the effective onset date of rainfall and its variability over the savanna zones of Nigeria. The onset date of rainfall has considerable impacts on rain-fed agriculture, which is a major contributor to rural livelihoods. Farmers depend on the onset of rainfall to plant crops and on the onset being effective when they do to prevent losses in time and finances. This study has shown that the effective onset date of the seasonal rain is highly variable in parts of the savanna zones of Nigeria known for intensive rain-fed farming, with the frequency of variability increasing from the Guinea savanna to the Sudano-Sahelian savanna. Conversely, though, the Guinea savanna stations are tending to later effective onset dates while stations in the Sudano-Sahelian savanna zone are tending to earlier effective onset dates of rainfall. Zonally, the study established two distinctive rainfall patterns (western and eastern flank) with the effective onset date of rainfall on the eastern flank more variable relative to stations on the western flank, even within the same ecological zones, as a result of local forcing factors such as the orographic effect of the Jos Plateau. It has also been established that synoptic convective features such as ENSO and IOD have significant positive relationships with an effective onset date of rainfall, most particularly over the stations within the study area's guinea savanna zones (and possibly, by extension, entire west Africa). This finding suggests that the ENSO and IOD years tend to be associated with late effective onset date. With the reliance of many peasant farmers in the study area on the seasonal rains, findings on the variability and trend in effective rainfall onset date should be at the heart of attempts to help them cope with uncertainties and thus enhance the sustainability of their livelihoods. These findings should support decision-making on crop types to be cultivated and on the planning of sowing dates.

Author contribution This work was carried out in collaboration between authors. Author 1 (Ishiaku Ibrahim) designed the study, performed the statistical analysis and wrote the manuscript's first draft. Author 2 (Muhammad T. Usman) managed the study analyses and managed the literature searches and editing. We all read and approved the final manuscript.

Data availability Some of the data are free online (http://www.esrl.noaa.gov/psd/gcos_wgsp/ Timeseries/DMI and http://www.esrl.noaa.gov/psd/gcos_wgsp/Timeseries/Nino34/).

Code availability Available on request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no competing interests.

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