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# Rainfall Characteristics during the Years of Significant Departures from Normal in the Sudano-Sahelian Ecological Zone of Nigeria

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**Abstract**

The rationale examining the rainfall characteristics during the years of significant departures from normal in the Sudano-Sahelian Ecological Zone (SSEZ) of Nigeria is based on the devastating effects of extreme weather events and their subsequent implications for agriculture and food security in sub-Saharan Africa. This study designated Significant Years of Positive Departure (SYPD) and Negative Departure (SYND) of rainfall from normal using a Z-score analysis on 39 years of rainfall data (1980-2018) for Sokoto, Kano, Maiduguri, and Nguru.

The results show that nine years possessed significant positive departures in rainfall versus six years of negative departures significant at $\alpha = 0.05$. The frequency of occurrence of intra-seasonal dry spells outweighed that of wet spells in all the years except in 2000 (Maiduguri), 2012 (Kano and Nguru), and 2016 in Sokoto. Light rainfall contributed almost 60% of the total annual rainfall in the zone with heavy rains comprising 17.6% of the total in SYPD versus only 3% in SYND. The average length of the growing season (106 days) was higher during the SYND than the SYPD with an average of 99 days. Onset and retreat days were mostly recorded during June and September respectively in SSEZ. This study found that SYPD in Sudano-Sahelian Ecological Zone possessed more wet occurrences than dry periods resulting from below-normal rainfall. These wetter occurrences also possess food security concerns because of their timing, while the SYND years portend to drought and possible famine.

**Keywords:** Rainfall characteristics, significant departures, Positive departure, Negative departure, Wet-spells, Dry-spells, etc.

## 1. Introduction

Climate, a basic and an active factor in the physical environment is constituted by interactions among many elements of which precipitation plays a significant role (Umar & Bako, 2019 and Chinago, 2020). Rainfall in the tropics is important because it supports life, economic growth, and water supply in general. Annual rainfall is considered normal when it is calculated relative to a 30-year average. Significant departures or anomalies from this established mean or normal often comprise extreme weather events, which impact environmental processes (Olaniran, 2004). Such extremes are usually characterised by intense heavy downpours, dry spells within growing seasons, delays in onset and retreat of rainfall, and drastic changes to below or above the values accepted as normal for specific periods of the year. As noted by Odekunle (2004), extreme events related to the onset of the rainy season in Nigeria can result in a false start to the rainy season and may lure farmers to plant crops early and can spell disaster for farmers if the first rains are followed by a long period of drought. Capable of causing upsets in many important environmental parameters such as the water balance, these rainfall departures also possess implications for food security. Therefore, knowledge of rainfall characteristics during periods of excessively wet and dry years is required for accurate mitigation planning in agricultural endeavours, the major occupation of the residents of the region.

The seasonal rainfall pattern in Nigeria consists of two dimensions (Iloeje, 1981). In the South, annual rainfall distribution has double maxima, while in the North, it has a single peak. Studies (e.g., Odekunle, 2004) have shown that, although rainfall is generally experienced in Sudano-Sahelian Ecological Zone (SSEZ) between early June and the first ten days of September. Moreover, its distributional characteristics are adequate for crop germination, establishment, and development for only two months between the first ten days of July and the first five days of September. Despite its short growing seasonal period, the SSEZ has not only a persistent and severe drought tendency (Nicholson 2001 and Paeth & Hense, 2006) but also contains records of disastrous flooding (Aliyu & Abdullahi, 2016). The major drought periods with resultant famine reported in SSEZ during the twentieth century include: 1913–1914, 1931–1932, 1942–1943, 1972–1973, and 1983–1984 (Mijindad & Adegbehin, 1991 and Folland et al., 1991). By contrast, flood occurrences have been under-reported in the literature. Taken together, these droughts and flood events have led to severe environmental consequences and human tragedy. Available records on the various episodes of floods and droughts (e.g., Thambyahpillay, 1979; Oguntoyinbo, 1982; Olaniran, 1983; Akintola, 1992, Nkwunonwo, et al. 2015 and Aliyu & Abdullahi, 2016) have linked these extreme climatological events with the precipitation anomalies and shown the vulnerability of man to the menace.

Some studies on the climate of the SSEZ (e.g, Ifabiyi, 2013; Emeribe et al., 2017; and Umar & Bako, 2019) focused on the annual departures of rainfall from the mean only in terms of the annual total amount, leaving other rainfall characteristics unattended. In addition, contemporary emphases on the dry periods, leading to drought tendency, gives the impression that excessively wet periods (leading to flood occurrences), do not constitute a problem in the SSEZ. As noted by Odekunle (2001), of all the associated weather phenomena, the problem of rainfall-induced flooding appears to be the most calamitous. Adeaga (2008) also noted that flooding is among the most devastating natural disasters in the world, claiming more lives and causing more property damage than any other natural phenomenon. The consequences of floods are vast on the physical environment, economic and social well-being of the inhabitants of an area (Adeaga, 2008; and Akanni & Bilesanmi, 2011). Also, it appears that most studies (Adeaga, 2008; Aderogba, 2012a; Aderogba, 2012b; Akanni & Bilesanm, 2011; Aderogba et al., 2012; and Akintola, 1982) on climate-induced flooding in Nigeria focused on the southern part of the country creating the impression that incidents of heavy rainfalls resulting from wetter years do not have any impact in the north.

Meanwhile, Sudano-Sahelian Ecological Zone has experienced the devastating effect of floods and flooding associated with short-lived rainstorms. Recent data available from NKC African Economics, notes that flooding has damaged over 500,000 hectares of farm produce amounting to around 5 billion naira (13 million US dollar) in the region https://www.cnbc.com/2020/09/10/record-flooding-hammers-the-african-sahel-the-latest-in-a-series-of-shocks.html. Also, NEMA (2020) in Nigeria Hydrological Services Agency (NIHSA)'s 2021 Annual Flood Outlook (AFO) reported that the worst flooding occurred in early October, causing severe destruction in Kebbi, Kwara, and the Zamfara States affecting about 129,000 people. Based on the foregoing, a better understanding of the region's climate would occur by assessing rainfall characteristics during the years of significant departures from normal in the SSEZ of Nigeria.

Consequently, this study aims to determine: (1) the significant years of positive departure (SYPD) and significant years of negative departures (SYND) of rainfall in the SSEZ of Nigeria; (2) rainfall onset, retreat, and the length of the growing season during the departures; (3) the magnitude frequencies of wet and dry spells in the zone; and (4) the percentage contributions of frequency of the various rainfall magnitudes (light, moderate, and heavy rainfall) to the total annual rainfall amount during the periods of significant departures in the Sudano-Sahelian ecological zone (SSEZ).

## 2. Study Area

The Sudano-Sahelian Ecological Zone of Nigeria is located between latitudes 10$^o$ and 14$^o$N, and longitudes 4$^o$ and 15$^o$E in the northern part of the country (Figure 1). It occupies almost one-third of the total landmass of the country covering about 26,180 km$^2$, houses over one-quarter of Nigeria's population, supports about 90% of the cattle population, about two-thirds of the goats and sheep, and most of the donkeys, camels, and horses found in the country. Cereals, cowpeas, groundnut, and cotton are the main crops grown in the region (FMEN 2006). It stretches from the Sokoto plains through the northern section of the high plains of Hausa land to the Chad Basin (Odekunle 2007 and Odekunle et al. 2008). Principal towns and cities in the zone include Sokoto, Gusau, Katsina, Kano, Bauchi, Nguru, Potiskum, and Maiduguri (Figure 1).

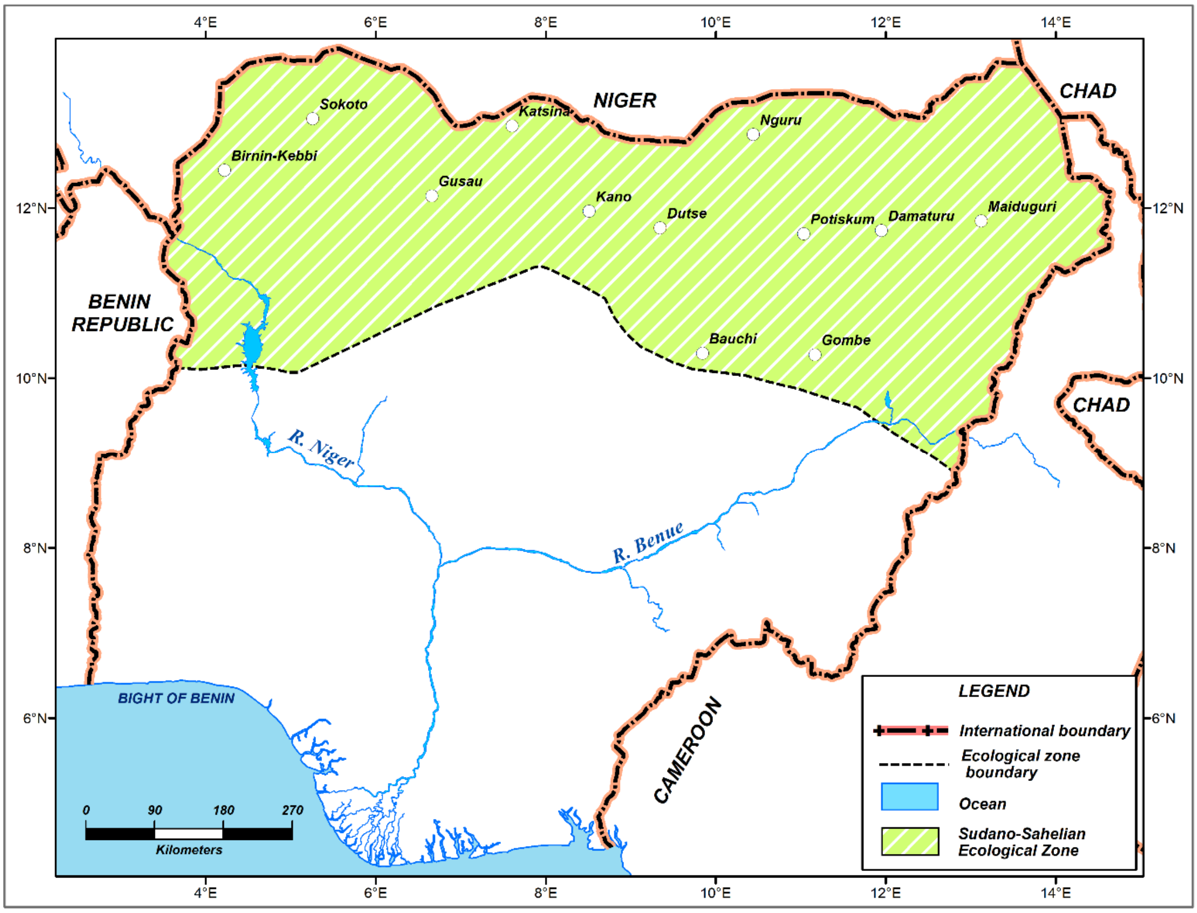



Figure 1. Map of Nigeria showing Sudano-Sahelian Ecological zone

The annual rainfall of the region ranges from less than 600mm to 1000mm (Ministry of Environment of the Federal Republic of Nigeria [MEFRN], 2003). The climate of the SSEZ is dominated by three major meteorological features: the tropical maritime (mT) air mass, the tropical continental (cT) air mass, and the equatorial easterlies (Ojo, 1977 and Iloeje, 1981). The mT air mass originates from the St. Helena anticyclone located off Namibia and in its trajectory, picks up moisture from over the South Atlantic Ocean, crosses the equator where warmer sea surface temperatures prevail, and enters southwestern Nigeria. The dry cT air mass originates from the Azores and Libyan anticyclones over the Sahara Desert north of the tropic of Cancer. The two air masses (mT and cT) meet along a slanting surface, the Intertropical Discontinuity or Inter-Tropical Front (ITD/ITF). The Equatorial Easterlies represent a rather erratic cool air mass, which comes from the east and flows in the upper atmosphere along the climatic equator. Occasionally this air mass dives and undercuts the mT or cT air mass, thus giving rise to line squalls or dust devils (Iloeje, 1981).

Apart from these three air masses, studies by Druyan & Koster (1989) and Nicholson & Grist (2001) found a fourth air mass, the Equatorial Westerlies. The deep, well-developed Equatorial Westerlies originate from the Atlantic Ocean off the west coast of Western Africa within 5-12° N latitude and advect moisture eastward over the Sahel starting from late spring and extending into summer (Druyan & Koster, 1989). This air mass, which supplements moisture advection into the Sudan-Sahel region, is a major factor in the rainfall dynamics of the Sudan-Sahel region (Nicholson & Grist, 2001). An interesting observation is a pronounced decrease since the late 1950s through the 1990s in the depth of the air mass, more so in the months of July - September (Nicholson & Grist, 2001). Nicholson and Grist (2001) further state that a key factor controlling the occurrence of the 'wet Sahel' mode versus the 'dry Sahel' mode is the relative strength or weakness of the Equatorial Westerlies.

## 3. Methods

The data used for this study consists of the daily rainfall totals for a period of 39 years from 1980 to 2018 at Sokoto and Kano in the Sudan area, and Nguru and Maiduguri, in the Sahel. The data were sourced from the archive of the International Institute for Tropical Agriculture (IITA), Ibadan. The IITA data are collected using Automatic Weather Station (AWS), which are retrieved through data loggers and downloaded hourly, daily, monthly, and yearly.

Positive and negative years of rainfall departures were determined using standardized anomaly (Z-score analysis) (equation 1). This involves the descriptive statistical methods of mean deviation as directly proportional to the standard deviation. The standardized anomaly is usually expressed using equation 1:

$$\frac{(x - \bar{x})}{S} \tag{1}$$

Where $x$ is the total annual rainfall, $\bar{x}$ is the mean annual rainfall and S is the Standard deviation which is usually expressed using equation 2:

$$S = \sqrt{\frac{\Sigma(x - \bar{x})^2}{N}} \tag{2}$$

A dry spell has been defined by Olaniran (1987) as a period of five or more consecutive days, each with less than 2 mm of rainfall. By implication, a wet spell is a period of five or more days with rainfall equal to or greater than 2 mm. Therefore, the determination of the Wet and Dry spells in this study was done based on these thresholds. In Nigeria, daily rainfall amounts can be partitioned into three different categories: light, moderate and heavy rainfall (Olaniran, 1991). The partitioning is such that a light rainy day has rainfall less than 10.4 mm, a moderate rainy day has rainfall of between 10.4 mm and 25.4 mm while a heavy rainy day has rainfall greater than 25.4 mm. This was adopted in this study. Magnitude frequencies which measure the extent of the number of occurrences of these parameters were presented.

Various methods have been used to determine the onset and retreat dates of rainfall in West Africa, and particularly in Nigeria. These methods can be classified into five main categories: (i) Intertropical Discontinuity (ITD) – rainfall model, (e.g. Ilesanmi, 1972a; Kowal & Knabe, 1972), (ii) rainfall-evapotranspiration relation model (Cocheme & Franquin, 1967 and Benoit, 1977), (iii) percentage cumulative mean rainfall model – based on rainfall data alone Odekunle et al. (2006) (iv) wind shear model (Omotosho 1990), and (v) the theta – E technique (Omotosho, 2002). The percentage cumulative mean rainfall model appears to be the one most frequently adopted (e.g., Ilesanmi, 1972b; Olaniran, 1983; Adejuwon et al., 1990 and Bello 1995) since it provides for a mean onset of the rains, which does not differ significantly from the mean start of the growing season relative to all locations in the country (Olaniran, 1983). It is also mathematically efficient and free of assumptions of rainfall threshold values (Olaniran, 1983; Odekunle et al., 2005).

Consequently, the rainfall onset and retreat dates, and length of the growing season were determined using the percentage mean cumulative rainfall method. The basic procedures of the method as outlined by Odekunle et al. (2006) are: (a) derivation of the percentage of mean annual rainfall that occurs at each 5-day interval; (b) cumulating the computed percentage at 5-day intervals; (c) plotting the cumulative percentage at five-day intervals through the year; and (d) identification of the time of rainfall onset and retreat. In this method, the first point of the maximum positive curvature corresponds to rainfall onset date, while the last point of maximum negative curvature indicates the rainfall retreat (Ilesanmi, 1972a; Adejuwon et. al., 1990; Odekunle, 2004 and Odekunle et al., 2005). The point of onset on the graph corresponds to the time when an accumulated 7 – 8% of the annual rainfall totals has been obtained, whereas that of rainfall cessation is 90% (Ilesanmi, 1972).

## 4. Results

### *4.1 Positive and Negative Years of Significant Departures of Rainfall*

Figure 2 shows the graphs of the years of positive and negative rainfall departure in Sokoto, Kano, Maiduguri, and Nguru in the SSEZ of Nigeria, computed for the period 1980 to 2018. Nine years had a significant positive departure, while six years possessed negative departures in all the stations based on $\alpha = 0.05$. Figure 2 also shows that positive departure occurred in Sokoto, (1994, and 2016) in Kano (2012), Maiduguri, (1988, 1995), in Nguru (1994, 2012, 2017, and 2018). Significant negative departure occurred in Sokoto, (1984), in Kano (1999 and 2004) in Maiduguri (2000 and 2004,) and in Nguru (1983).

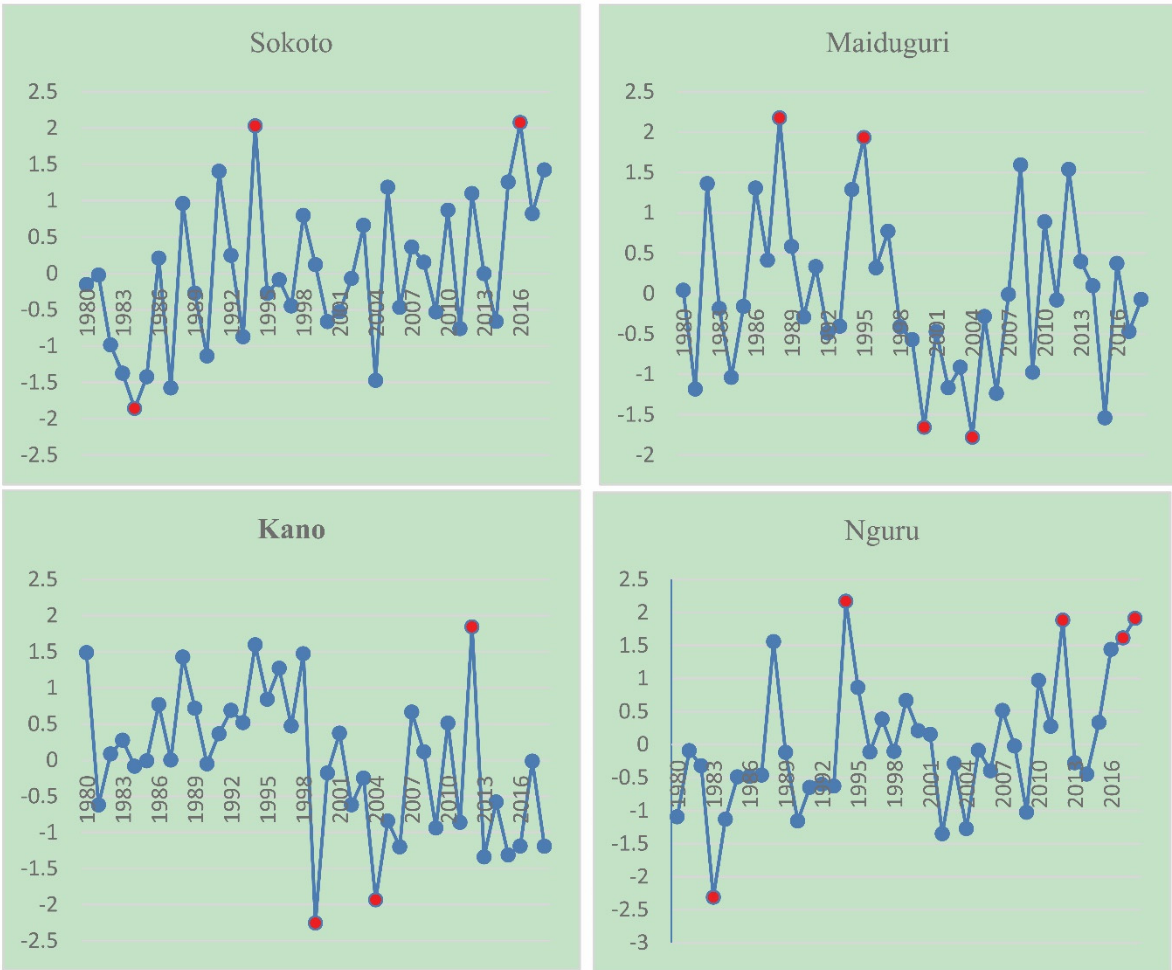



Figure 2. Years of Positive and Negative Rainfall departures (1980-2018) with significant years in red dot.

*4.2 Onset and Retreat Dates and the Length of the Growing Season*

Figures 3 through 6 show the graphs of the mean cumulative percentages of 5-days rainfall total from January to December during the years of significant positive and negative departures in Sokoto, Kano, Maiduguri, and Nguru respectively, between 1980 and 2018. Table 1 summarizes the onset and retreat dates and the length of the growing season for all significant years of departure. Figures 3 through 6 specifically show the onset and retreat periods and the length of the growing season with their corresponding cumulative percentages of rainfall and pentad values during the departures.

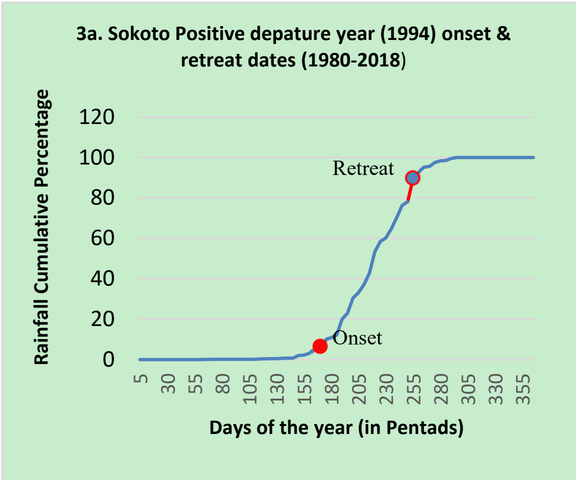
Examining Figure 3, the first points of maximum positive curvature (corresponding to time of rainfall onset) for 1984 (year of negative departure), 1994 and 2016 (years of positive departure) on the graphs of Sokoto yielded cumulative percentage of 8.39%, 8.92% and 7.34%, respectively. These percentages corresponded to 137th, 173rd, and 160th days of the year, respectively. Their corresponding rainfall onset dates were 17th May, 22nd June and 9th June, respectively. The second points of maximum negative curvature (corresponding to time of rainfall retreat) for 1984, 1994 and 2016 had cumulative percentages of 88.64%, 89.68% and 94.93%, respectively. These correspond to 272nd, 255th and 252nd days of the year, respectively. Their corresponding retreat dates are 29th, 12th and 9th September. The length of the growing season is thus: 133 days (1984), 83 days (1994), and 93 days for 2016.

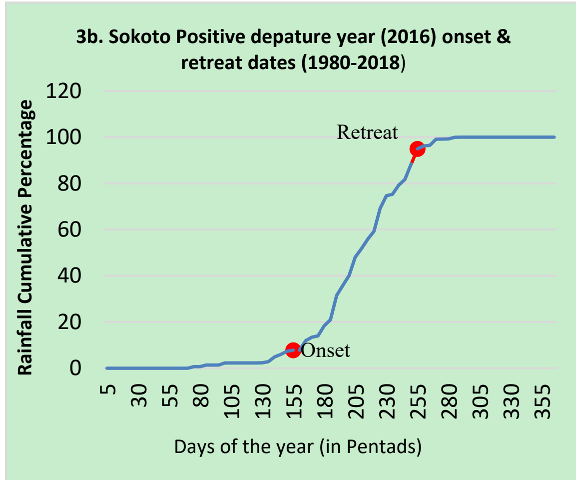
Table 1. Onset, Retreat and Length of the growing season (LGS) during the Years of significant departure in the Sudano Sahelian Ecological Zone.

| Year | Onset date | Retreat date | LGS (days) |
|---|---|---|---|
| | **Sokoto** | | |
| 1984 (Negative) | 17/05 | 29/09 | 130 |
| 1994 (Positive) | 22/06 | 12/09 | 93 |
| 2016 (Positive) | 09/06 | 09/09 | 93 |
| | **Kano** | | |
| 1999 (Negative) | 23/06 | 06/10 | 106 |
| 2004 (Negative) | 13/05 | 30/08 | 110 |
| 2012 (Positive) | 27/05 | 17/09 | 114 |
| | **Maiduguri** | | |
| 1988 (Positive) | 30/05 | 21/09 | 115 |
| 1995 (Positive) | 13/06 | 05/10 | 115 |
| 2000 (Negative) | 17/06 | 23/09 | 99 |
| 2004 (Negative) | 27/05 | 08/09 | 105 |
| | **Nguru** | | |
| 1983 (Negative) | 15/06 | 06/09 | 84 |
| 1994 (Positive) | 08/06 | 16/09 | 101 |
| 2012 (Positive) | 03/06 | 12/06 | 102 |
| 2017 (Positive) | 12/06 | 04/09 | 85 |
| 2018 (Positive) | 16/06 | 04/09 | 81 |

The corresponding rainfall onset time for the first points of maximum positive curvature for 1999 and 2004 (years of negative departure), and 2012 (year of positive departure) for Kano in Figure 4 had cumulative percentage of 8.36%, 10.99% and 6.38%, respectively. These correspond to the 174th, 133rd, and 147th day of the year, respectively. The respective rainfall onset dates are 23rd June, 13th May and 27th May. The corresponding rainfall retreat time as depicted by the second point of maximum negative curvature for 1999, 2004 and 2012, had cumulative percentages of 90.83%, 88. 62% and 90.55%, respectively. These correspond to the 279th, 242nd and 260th day of the year. The respective rainfall retreat dates are 6th October, 30th August, and 17th September. The lengths of the growing season were: 106 days (1999), 110 days (2004) and 114 days for 2012.

The first points of maximum positive curvature (time of rainfall onset) for 1988 and 1995 (year of positive departure), and 2000 and 2004 (years of negative departure) in Maiduguri in Figure 5 possessed cumulative percentage 8.12%, 8.49%, 9.93% and 9.91%, respectively. These correspond to the 150th, 164th, 168th and 147th days of the year. The corresponding rainfall onset dates are 30th May, 13th June, 17th June and 27th May, respectively. The second point of maximum negative curvature on the graphs (time of rainfall retreat) in Maiduguri had cumulative



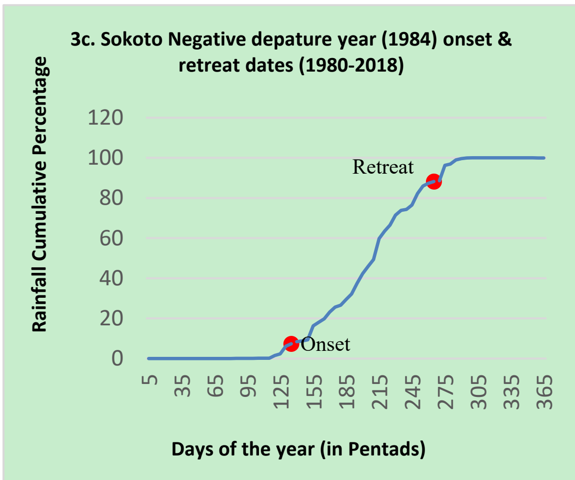




Figure 3. Onset and Retreat dates and the Length of the growing season in Sokoto

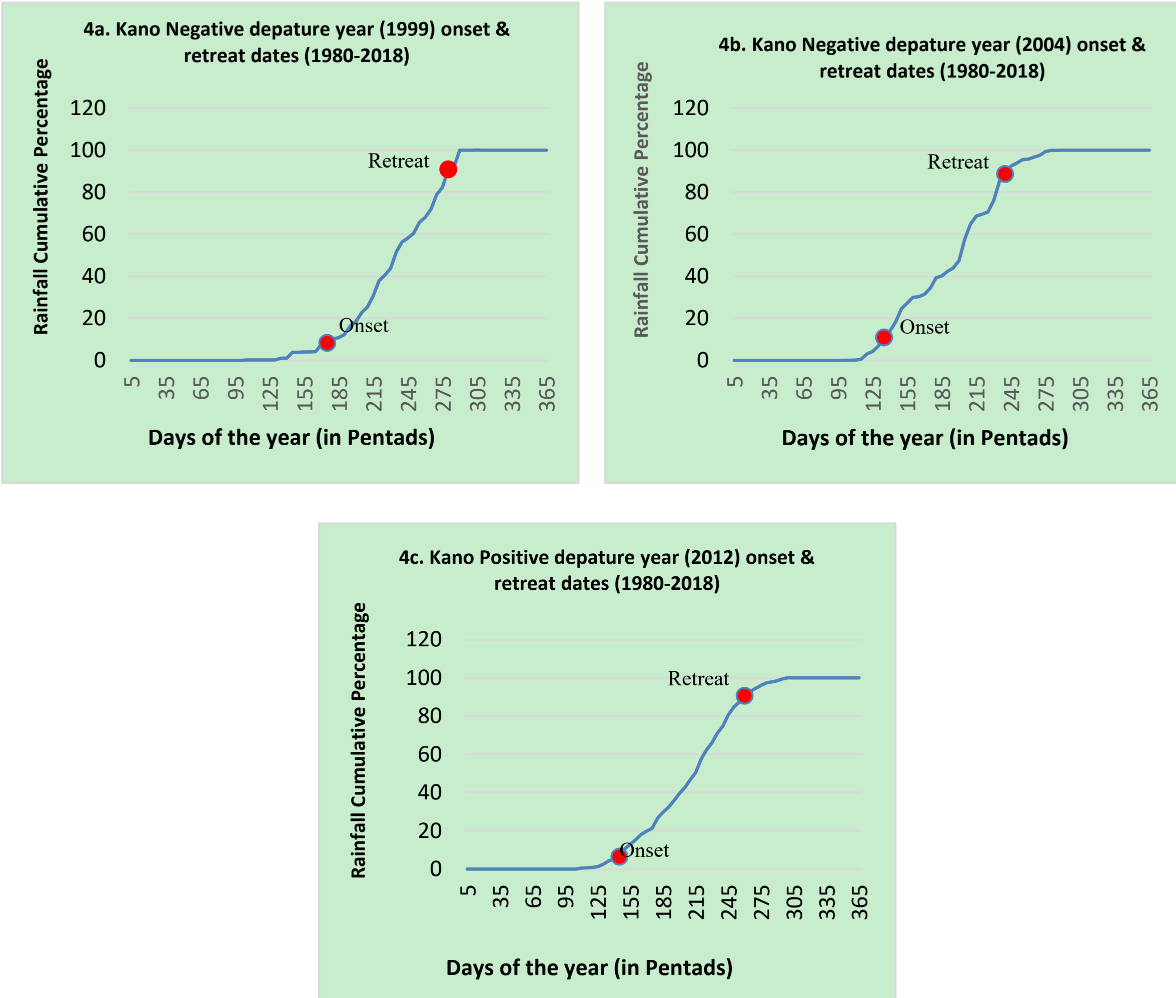



Figure 4. Onset and Retreat dates and the Length of the growing season in Kano

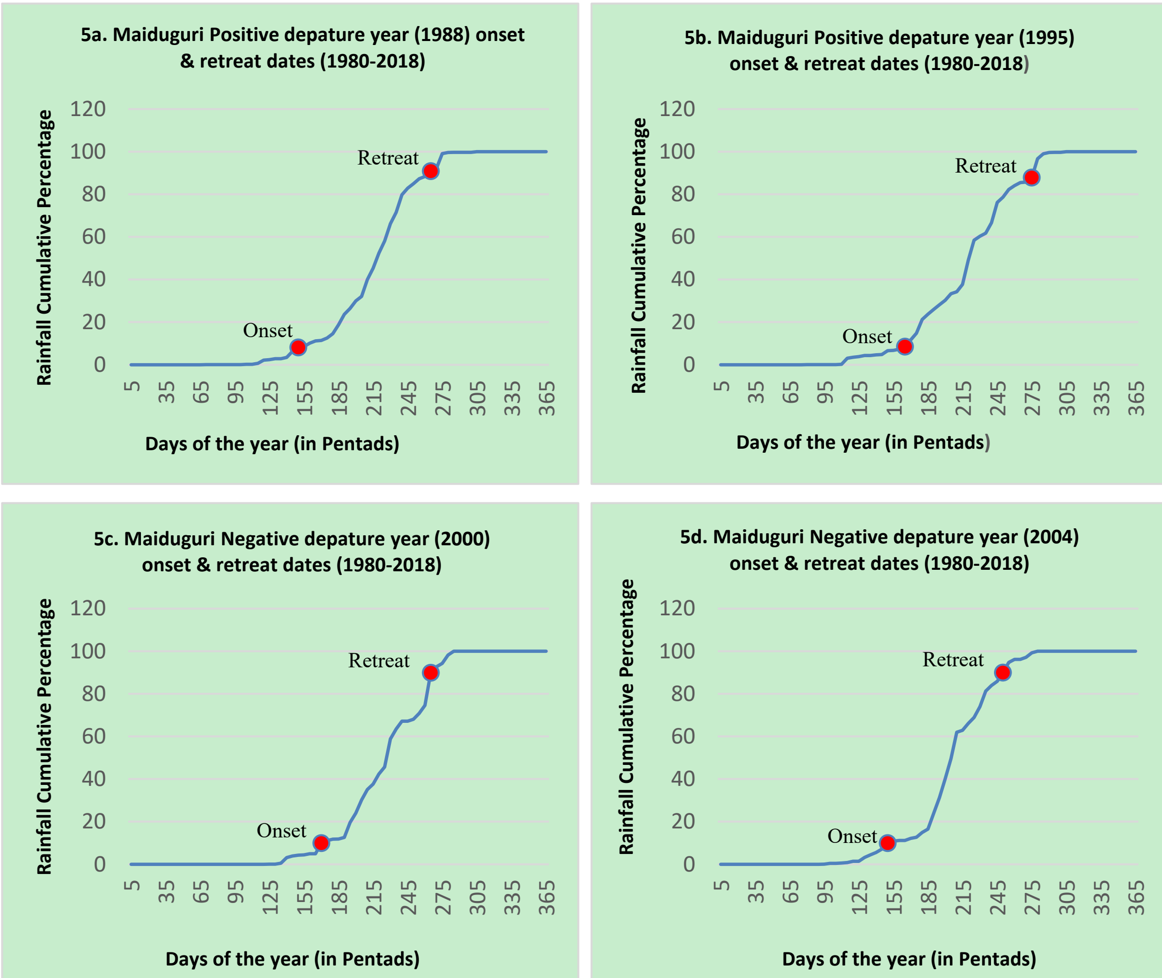
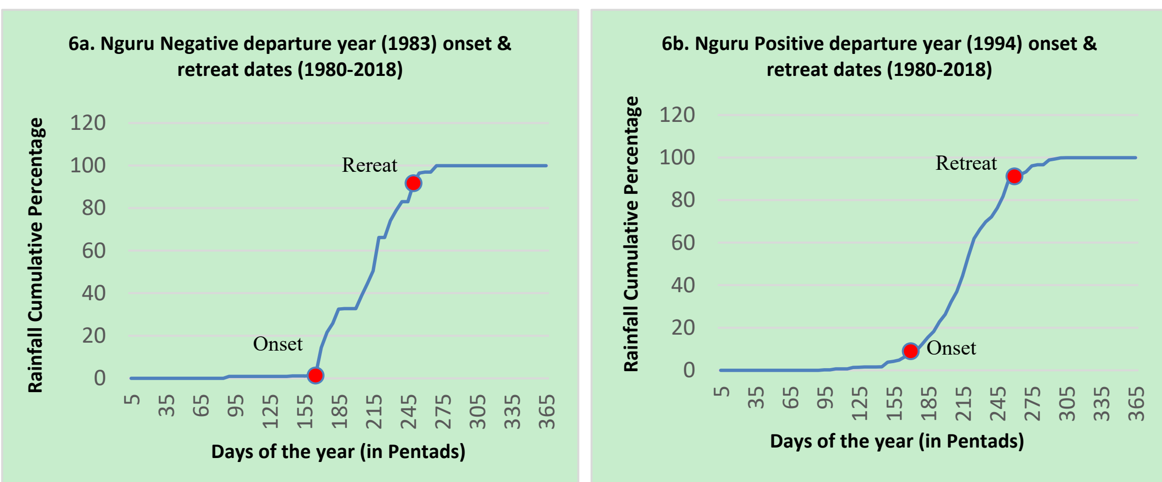
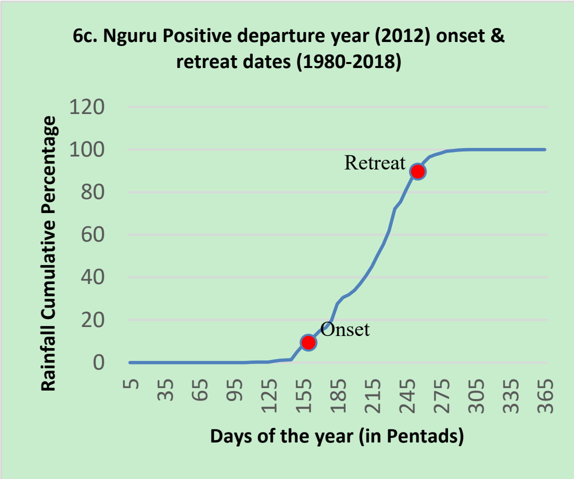
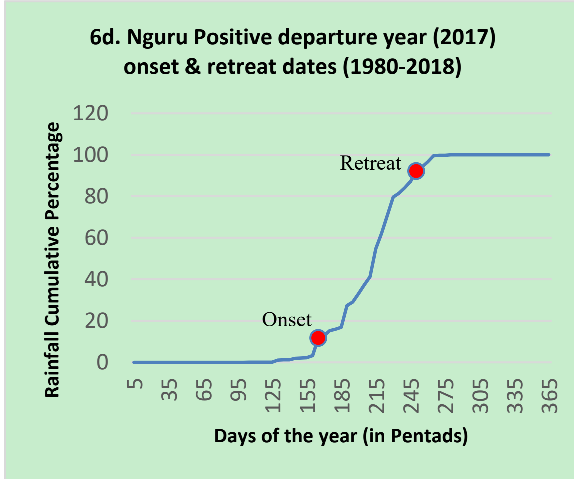



Figure 5. Onset and Retreat dates and the Length of the growing season in Maiduguri





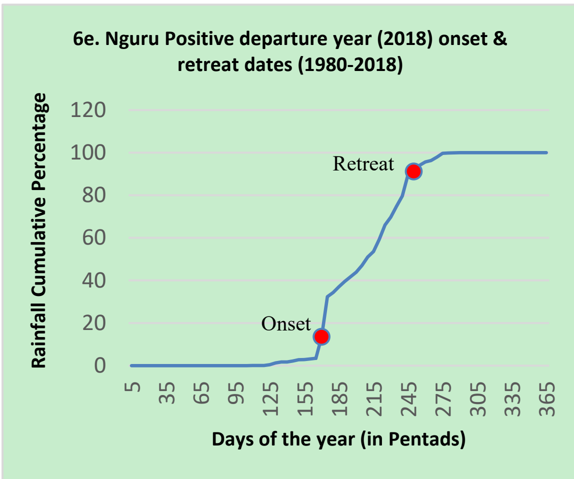




Figure 6. Onset and Retreat dates and the Length of the growing season in Nguru

percentages of 90.89% (1988), 87.82% (1995), 89.88% (2000), and 89.94%, for 2004. These percentages corresponded to: the 264th, 278th, 266th, and 251st day of the year, respectively. The respective rainfall retreat dates were: 21st September, 5th October, 23rd and 8th September, respectively. The lengths of the growing season are 115 days (1988 and 1995), and 99 days (2000), and 105 days for 2004.

Depicted in Figure 6, the corresponding rainfall onset time for the first points of maximum positive curvature on the graphs of Nguru for 1983 (year of negative departure). Positive departures occurred 1994, 2012, 2017 and 2018 and had cumulative percentages of 14.4%, 8.99%, 9.27%, 11.72% and 13.53%. These percentages corresponded to the 167th, 169th, 155th, 162th and 168th day of the year, respectively. Their rainfall onset dates were: the 16th, 18th, 4th 11th and 17th June, respectively. The corresponding rainfall retreat time for the second points of maximum negative curvature on the same graphs had cumulative percentages of 91.71% (1983), 91.14% (1994), 86.69% (2012), 92.12% (2017) and 91.14% (2018). These correspond to the 250th. 260th, 256th, 248th, and 248th days of the year. The respective rainfall retreat dates are 7th, 17th, 13th, 5th, and 5th September. The lengths of the growing season were: 84 days (1983), 101 days (1994) 102 days, (2012) 85 days (2017) and 81 days in 2018.

*4.3 Wet and Dry spells*

Figure 7 shows the frequencies of occurrence of wet and dry spells during the significant years of positive and negative departures in the Nigerian SSEZ between 1980 and 2018. The figure generally shows that all the years of departure recorded both dry and wet spells. Magnitude frequencies of occurrence of wet spells during the years of significant positive departure in 1994 and 2016 (Sokoto) were 6 and 5; 2012 (Kano) was 8; 1988 and 1995 (Maiduguri) were 5 and 7; 1994, 2012, 2017, and 2018 (Nguru) were 6, 6, 2, and 2 respectively. The magnitude frequencies of occurrence of dry spell during this departure were 6 and 4 for 1994 and 2016 in Sokoto; was 4 for 2012 in Kano; were 6 and 7 for 1988 and 1995 in Maiduguri; and were 7, 4, 4 and 5 for 1994, 2012, 2017 and 2018 respectively in Nguru. The figure also revealed that during the years of significant negative departure, wet spells in 1984 in Sokoto was 1; in 1999 and 2004 in kano was 2 each; in 2000 and 2004 in Maiduguri were 4 and 3 and with no record of wet spell in 1983 in Nguru. The magnitude frequencies of occurrence of dry spell during this departure was 8 for 1984 in Sokoto; 7 and 9 for 1999 and 2004 in Kano; were 3 and 7 for 2000 and 2004 in Maiduguri.

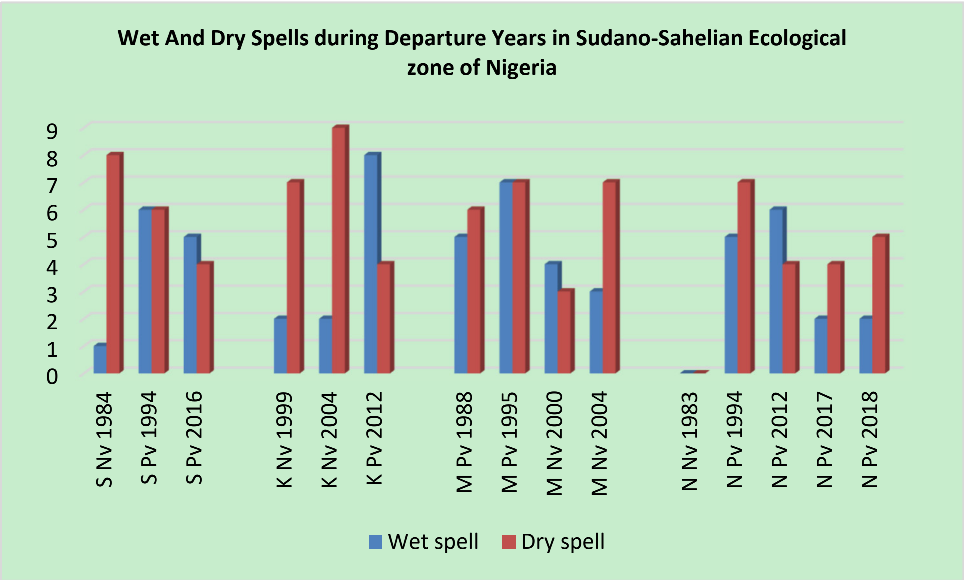



Figure 7. Frequencies of wet and dry spells in Sokoto, Kano, Maiduguri and Nguru during their Negative (Nv) and Positive (Pv) years.

There was no record of dry spell in 1983 in Nguru during this departure. The results also indicate that the frequencies of occurrence of the number of dry spells outweighed the number of wet spells in most years (i.e., 8 years) except in the year 2000 (Maiduguri), 2012 (Kano and Nguru) and 2016 in Sokoto during which, wet spell had edge over the dry spell. Also, the figure showed that the number of occurrences of dry and wet spells were similar in 1994 (Sokoto) and 1995 (Maiduguri) as both years recorded 6 and 7 wet and dry spells in each year, respectively.

The magnitude frequency of dry spells were more than that of the wet spells both during the significant years of positive departure: Maiduguri (1988), Nguru (1994, 2017 and 2018) and negative departure: Sokoto (1984), Kano (1999 and 2004) and 2004 in Maiduguri. However, Figure 7 also shows that there was no consistency in the relative abundance of dry spells compared to wet spells and vice versa, during years of positive and negative departures.

### *4.4 Percentage contributions of Rainfall Magnitude to the Total Annual Rainfall*

Figure 8 depicts the percentage contributions of rainfall magnitude to the total annual rainfall during the significant years of positive (SYPD) and negative departures (SYND) from normal in the SSEZ of Nigeria between 1980 and 2018. The results show that in 1984 (year of negative departure), 1994 and 2016 (years of positive departure) in Sokoto, light rainfall magnitude respectively contributed 85.1%, 55.4% and 41% to the total annual rainfall, respectively. In the same years, moderate rainfall magnitude contributed 14.88%, 27.8% and 25.7% to the respective annual rainfall totals, while heavy rainfall comprised 0%, 16.8% and 33.3% to the total annual rainfall, respectively. Figure 8 also reveals that in 1999 and 2004 (years of negative departure) and 2012 (year of positive departure) in Kano, light rainfall magnitude contributed 100%, 96.4% and 65.5% to the total annual rainfall. Moderate rainfall contributed 0%, 3.6% and 34.4% respectively, while heavy rainfall contributed 0% to the total annual rainfall in all the years.

For Maiduguri, Figure 8 illustrates that in 1988 and 1995 (during SYPD), 2000 and 2004 (during SYND) in light rainfall magnitude respectively contributed 48.5%, 54.4%, 65.2% and 71.4% to the total annual rainfall. The percentage contributions of moderate rainfall were 31%, 38.7%, 27.6% and 28.6%, respectively, while heavy rainfall magnitude contributed 20.5%, 9.9%, 7.2% and 0% respectively.

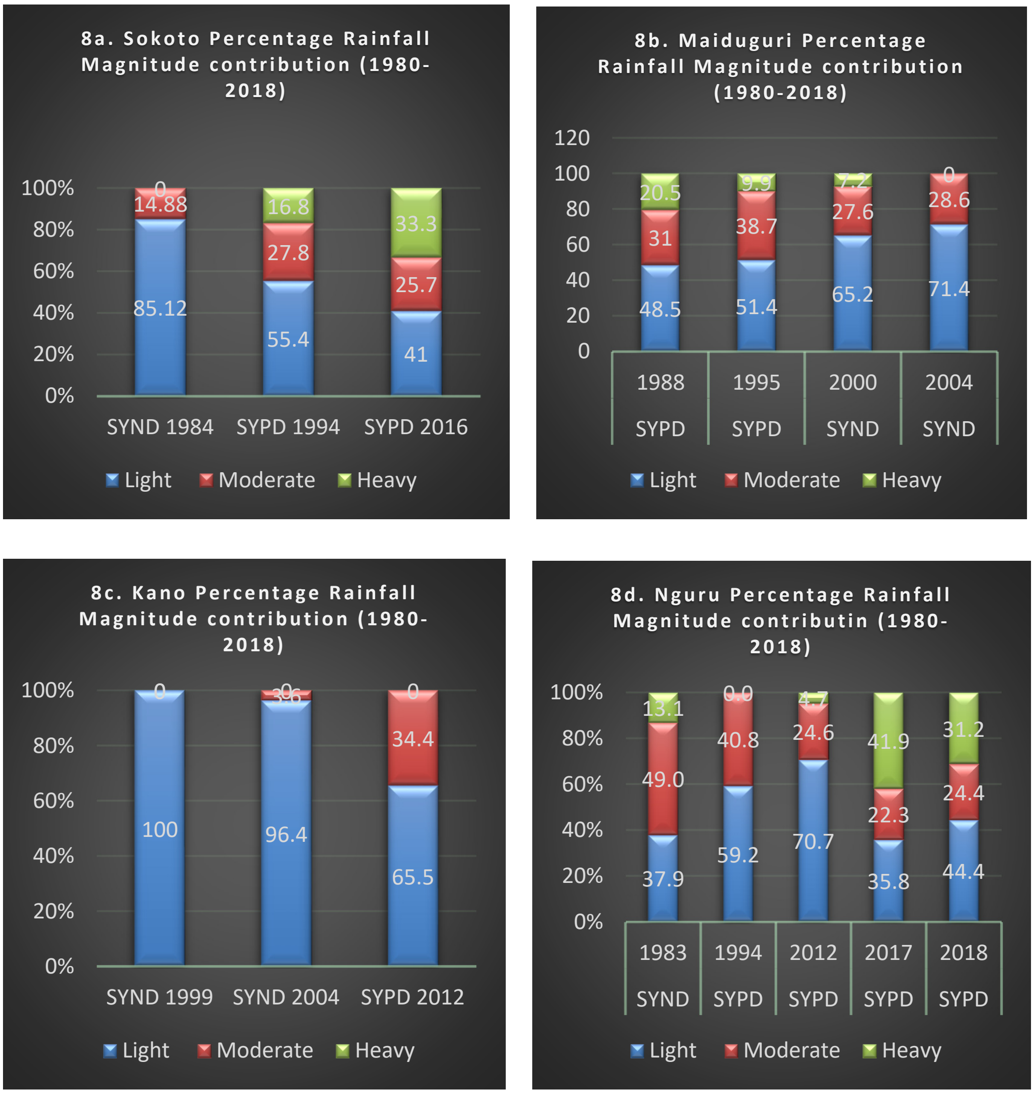



Figure 8. Percentages contributions of rainfall magnitude to the total annual rainfall

For Nguru, in 1983 (during SYND), and 1994, 2012, 2017, and 2018 (during SYPD), light rainfall respectively contributed 37.9%, 59.2%, 70.7%, 35.5% and 44.4% to the total annual rainfall. Moderate rainfall contributed 49.9%, 40.8%, 24.6%, 22.3% and 24.4% to the total annual rainfall, while heavy rainfall contributed 13.1%, 0%, 4.7%, 41.9% and 31.2%, respectively.

The results showed that during most of the significant years of positive departures (> 77%) for Sokoto (1994 and 2016), Maiduguri (1988, 1995 and 2000) and Nguru (1983, 2012, 2017 and 2018), all the rainfall magnitude classes (light, moderate and heavy rainfall) contributed to total annual rainfall. The results also indicated that light rainfall contributed an average of 52.8% to the total annual rainfall, during the SYPD whereas, an average of 77% contribution to the total annual rainfall occurred during the SYND.

Moderate rainfall magnitude contributed only an average of 28% to the total annual rainfall. The value for SYPD was 29.9%, while that for SYND was 36.6%. The total contributions of heavy rainfall to the total annual rainfall during all years of significant departure in the zone stood at an average of 13.5%. Heavy rainfall contributed only 3.4% to the total annual rainfall during the SYND. In contrast, heavy rainfall contributed 17.25% of the total annual rainfall during the SYPD. The actual rainfall amounts contributed by the various rainfall magnitude classes to the total annual rainfall during both positive and negative years of significant departure are shown in Tables 2-5.

Table 2. Sokoto percentage contributions of rainfall magnitudes (light, moderate, and heavy rainfall) to the total annual rainfall

| 1984 (year of negative departure) | | | |
|---|---|---|---|
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 333.8 | 85.12 | 392.16 |
| Moderate | 58.36 | 14.88 | 392.16 |
| Heavy | 0 | 0.0 | 392.16 |
| 1994 (year of positive departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 422.05 | 55.4 | 762.23 |
| Moderate | 212.18 | 27.8 | 762.23 |
| Heavy | 128 | 16.8 | 762.23 |
| 2016 (year of positive departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 314.15 | 41.0 | 766.7 |
| Moderate | 197.29 | 25.7 | 766.7 |
| Heavy | 255.26 | 33.3 | 766.7 |

Table 3. Kano percentage contributions of rainfall magnitudes (light, moderate, and heavy rainfall) to the total annual rainfall

| 1999 (year of negative departure) | | | |
|---|---|---|---|
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 294.06 | 100 | 294.06 |
| Moderate | 0 | 0.0 | 294.06 |
| Heavy | 0 | 0.0 | 294.06 |
| 2004 (year of negative departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 333.16 | 96.4 | 345.71 |
| Moderate | 12.55 | 3.6 | 345.71 |
| Heavy | 0 | 0.0 | 345.71 |
| 2012 (year of positive departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 625.14 | 65.5 | 953.62 |
| Moderate | 328.48 | 34.4 | 953.62 |
| Heavy | 0 | 0.0 | 953.62 |

Table 4. Maiduguri percentage contributions of rainfall magnitudes (light, moderate, and heavy rainfall) to the total annual rainfall

| 1988 (year of positive departure) | | | |
|---|---|---|---|
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 435.84 | 48.5 | 898.64 |
| Moderate | 278.58 | 31.0 | 898.64 |
| Heavy | 184.22 | 20.5 | 898.64 |
| 1995 (year of positive departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 445.25 | 51.4 | 866.89 |
| Moderate | 335.64 | 38.7 | 866.89 |
| Heavy | 86 | 9.9 | 866.89 |
| 2000 (year of negative departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 261.04 | 65.2 | 400.3 |
| Moderate | 110.42 | 27.6 | 400.3 |
| Heavy | 28.84 | 7.2 | 400.3 |
| 2004 (year of negative departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 274.39 | 71.4 | 384.3 |
| Moderate | 109.90 | 28.6 | 384.3 |
| Heavy | 0 | 0.0 | 384.3 |

Table 5. Nguru percentage contributions of rainfall magnitudes (light, moderate, and heavy rainfall) to the total annual rainfall

| 1983 (year of negative departure) | | | |
|---|---|---|---|
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 88.19 | 37.9 | 232.7 |
| Moderate | 114.02 | 49.0 | 232.7 |
| Heavy | 30.48 | 13.1 | 232.7 |
| 1994 (year of positive departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 380.07 | 59.2 | 643.03 |
| Moderate | 262.36 | 40.8 | 643.03 |
| Heavy | 0 | 0 | 643.03 |
| 2012 (year of positive departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 436.11 | 70.7 | 616.84 |
| Moderate | 151.74 | 24.6 | 616.84 |
| Heavy | 28.99 | 4.7 | 616.84 |
| 2017 (year of positive departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |

| | | | |
|---|---|---|---|
| Light | 212.03 | 35.8 | 592.25 |
| Moderate | 132.07 | 22.3 | 592.25 |
| Heavy | 248.15 | 41.9 | 592.25 |
| 2018 (year of positive departure) | | | |
| R. Magnitude | Contributed Amount (mm) | % | Annual Total |
| Light | 274.97 | 44.4 | 619.31 |
| Moderate | 151.12 | 24.4 | 619.31 |
| Heavy | 193.22 | 31.2 | 619.31 |

**5. Discussion**

The results obtained from this study have shown that there are positive and negative years of rainfall departure in the Sudano-Sahelian Ecological Zone (SSEZ). Nine years had significantly positive departures, while six years had significantly negative departures, which combined to fifteen years out of the thirty-nine years studied. This indicates that the Sudano-Sahelian Ecological Zone witnessed three more years of extreme wet climate between 1980 and 2018 leading to flood occurrences than dry periods resulting from below-normal rainfall occurrences leading to drought.

This finding is in line with the work of Haarsma et al. (2005) who established in a study on the Sahel region that rainfall has been increasing since the mid-1980. It also follows the findings of Odekunle et al. (2008) that the climate of the region tends towards a wetter condition rather than the increasing aridity that was a feature of the period from 1960s to 1980s. The tendency towards wetter condition in the region has been noted to be overwhelmingly generated by the significant shift in the mean positions of the ITD/ITF (Odekunle, 2008). Kraus (1977), Adedokun (1978) and Lamb (1982; 1983) had earlier observed this shift in West African rainfall and argued that whenever the ITD/ITF surface location is pushed to its northern maxima, the mT air mass incursion possesses greater depth thereby generating heavy rainfall in the northern part of the country. The results of this study also partially confirm the future climate projections of USAID (2019), which indicate increased variability in rainfall and extreme rainfall events across most of Nigeria.

This study also confirms that the SSEZ is not only known for short growing period (Odekunle 2004) and a persistent and severe drought tendency (Nicholson 2001; Paeth & Hense 2006), but also for disastrous flooding occurrences (Aliyu & Abdullahi, 2016). This tendency towards a wetter condition in the region from 1980-2018 could be associated with the effect of climate change on rainfall. Trenberth (2011) argued that there is a direct influence of global warming on precipitation as increased heating leads to greater evaporation, and therefore surface drying, thereby increasing the intensity and duration of drought. Interestingly, Trenberth (2011) further observed that the water holding capacity of air (potential humidity) could increase by about 7% per 1°C warming, which would lead to increased water vapour in the atmosphere, assuming an adequate source of moisture. In this context, events such as storms, whether individual thunderstorms or tropical cyclones supplied with increased moisture, would produce more intense precipitation events, namely the heavy rainfall as witnessed in this study and the overall trend towards wetter Sahel.

The results obtained in this study has also established that rainfall commences between 3rd June and 22nd June during the significant years of positive departure; whereas, the rainfall onset dates during the significant years of negative departure are between 13th May and 23rd June. Rainfall cessation occurs between 30th August and 6th October during the significant years of negative departure, versus the 4th September and 5th October during the years of positive departure. The length of the growing season during the significant years of negative departure ranged from 84 and 130 days, whereas, during the significant years of positive departure, the growing season length ranged from 81 and 115 days. Consequently, the years with significant positive departure are not only more wet, but possess a much more tightly defined growing season for agricultural pursuits.

Rainfall onset time appears to be earlier during the significant years of negative departure compared to what obtains in the significant years of positive departure. Rainfall retreat time tends to be earlier during significant years of negative departure than during the significant years of positive departure, while the length of the growing season during the significant years of negative departure appears to be longer than that of positive years. The earlier onset dates recorded during the significant years of negative departure is usually a product of one or two large isolated showers at the beginning of the year which may meet the specified rainfall onset and retreat criteria, thus producing unrealistic rainfall onset and retreat dates (Odekunle, 2005) which by consequence may encourage a disastrous initiation of planting. In other words, during SYND early rains are often followed by intervening dry periods punctuated by intermittent light rainfall events that greatly increase agricultural risks.

The results have also shown that at varying frequencies, all the years of departure (negative and positive) with very few exceptions both recorded dry and wet spells. The magnitude frequency of occurrence of the number of dry spells outweighed the number of wet spells in most years. The pattern seems to agree with the observed climate trends of the Ministry of Foreign Affairs of the Netherlands (2018). The report on the '*Climate Change Profile of West African Sahel*' noted an increase in the number of warm days/nights and decrease in the number of cold days/nights. The edge in the number of warm days against cold days was attributed to the general increase in the temperature in the region. USAID (2019) also documented increase in temperature of an average of 0.8$^{o}$C between 1960 and 2006, with a steep increase since 1980 and larger increase in the northern region.

The results obtained in this study clearly show that most of the SYPD had the contributions of all the various rainfall magnitudes (light, moderate and heavy rainfall) to their total annual rainfall. Indeed, the larger percentage (more than 77%) of the years in which the contributions of all rainfall magnitudes were found occurred during the significant years of positive departure. The results also show that light rainfall magnitude recorded the highest contribution in all the significant years of departure with few exceptions when moderate and heavy rainfall magnitudes had the highest contributions. Among the various rainfall magnitude in all the years of departure, light rainfall with an average of almost 60% contributed most to the total annual rainfall. Light rainfall contributed an average of 52.8% to the total annual rainfall during the years of significant positive departure, while the contribution was 77% during the years of significant negative departure.

In the case of moderate rainfall magnitude, the results of the study show that its contributions were noticed in all the years except in 1999, when dominant contributions of light rainfall magnitude were recorded. Moderate rainfall contributed only 28% to the total annual rainfall, though the contribution to total annual rainfall was 29.9% during the years of significant positive departure as against 36.6% during significant years of negative departure. Contributions of heavy rainfall to total annual rainfall during years of significant departure in the zone stood at an average of 11.91%, while it contributed only 3.4% to the total annual rainfall during the years of significant negative departure, compared to 17.25% during the years of significant positive departure.

## 6. Conclusions

This study has examined rainfall characteristics during the years of significant departures from normal in the Sudano-Sahelian ecological zone of Nigeria. The study specifically: (i) determined the significant years of positive and negative rainfall departures (ii) examined the timing of rainfall onset and retreat, and the length of the growing season (iii) examined the frequencies of wet and dry spells and (iv) identified the percentage contributions of the various rainfall magnitudes (light, moderate, and heavy rainfall) to total annual rainfall amount during the periods of departures in the zone. Daily rainfall data spanning 39 years (1980-2018) for Sokoto, Kano Maiduguri and Nguru were collected from the International Institute for Tropical Agriculture (IITA), Ibadan. Z-score analysis was carried out for determining the years of rainfall departures. Onset, retreat and the length of the growing season were determined using the percentage mean cumulative rainfall approach. Thresholds were adopted for magnitude frequency analyses.

The results obtained showed that only annual rainfall of Sokoto (1994 and 2016), Kano (2012), Maiduguri (1988 and 1995) and Nguru (1994, 2012, 2017, and 2018) are positively significant, while Sokoto (1984), Kano (1999 and 2004), Maiduguri (2000 and 2004) and Nguru (1983) are negatively significant. Both were significant at $\alpha$ =0.05 (upper and lower tailed) with the critical value Z=1.645. The results also indicate that although in the same quantity in both departures, the frequencies of occurrence of the number of dry spells outweighed the number of wet spell in all the years except in 2000 (Maiduguri), 2012 (Kano and Nguru) and 2016 in Sokoto.

The percentage contributions of rainfall magnitude show that light rainfall largely contributed to the total annual rainfall with an average value of about 65.7% irrespective of the departure. However, during SYPD heavy rains accounted for 17.25% of the total precipitation versus only 3.4% in SYND.

The average length of the growing season (106 days) is higher during the years of significantly negative departure than the years of significantly positive departure, which had an average of 99 days. Onset and retreat days were mostly recorded during the months of June and September respectively. Observed patterns of rainfall characteristics during the years of significant departures from normal generally suggested mixed impacts for agricultural practices. This situation stems from the need for more water to produce better agricultural crop yields, but such rain events need to occur at specific times during the life cycle of crops or pasture. Indeed, excessive supply and/or the inaccurate timing of precipitation can enhance food insecurity and hence, 'famine' in Guinean Savanna of Nigeria (Odekunle, 2007).

Finally, this study found that from 1980-2018, there were 15 significant years of positive and negative rainfall departure in the Sudano-Sahelian Ecological Zone. The region witnessed three more years of extreme climate leading to flood occurrences (nine such instances) relative to the six dry periods resulting from below-normal rainfall occurrences that lead to drought tendency. As such, this finding in the Sudano-Sahelian Ecological Zone parallels other findings in the scientific literature that point towards wetter Sahel as the $21^{st}$ century unfolds.

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