International Journal of Scientific Research in Multidisciplinary Studies
Vol.**10**, Issue.**3**, pp.**34-44**, March **2024**
E-ISSN: 2454-9312 P-ISSN: 2454-6143
Available online at: www.isroset.org

Research Article

Analysis of Rainfall Trend and its Relationship with Sorghum Yield in Sudan Savanna Region of Nigeria

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Received: 18/Jan/2024; **Accepted**: 21/Feb/2024; **Published**: 31/Mar/2024

Abstract — This research analysed rainfall trend and its relationship with the yield of sorghum in Sudan Savanna region of Nigeria by examining the trends of rainfall, crop yield and relate annual rainfall trend with length of the growing season. Rainfall data (1956-2018) were sourced from the Nigerian Meteorological Agency (NiMet). The data were used to characterise the climate of the study area. Pearson's correlation was employed to show the relationship between rainfall and sorghum yield. The result shows increase in annual rainfall in Bauchi, Gusau, Kano, and Yola polygons while there was a decrease in annual rainfall in Katsina, Potiskum and Sokoto polygons. In terms of trend, there was a relatively early rainfall onset dates in all the Thiessen polygons with exception of Bauchi and Yola area where rainfall onset date changes insignificantly toward early pattern. There was also a decline in rainfall cessation in Bauchi, Gusau, Kano, Katsina and Sokoto Thiessen polygons within the study period. The Pearson's correlation indicates a significant relationship between annual rainfall and sorghum yield in the study areas with an average P-value of 0.71 which indicates a strong and positive relationship. The study therefore recommends sensitization of sorghum farmers on the relationship between sorghum and rainfall and the need to adopt variety of sorghum that can endure drought as a way of reducing the possible crop loss due to rainfall variability since rainfall show high variability.

Keywords — Agriculture, Sudan Savanna, Rainfall, Trend, Sorghum, Yield

1. Introduction

Rainfall is the most variable climatic elements. It determines the growing season in developing countries like Nigeria where agriculture is predominantly rain-fed [1]. The variability of rainfall and the pattern of extreme high or low precipitation are very important for agriculture as well as the economy of the country. Rainfall is changing on both the global and the regional scales due to global warming. As the move to encourage agriculture in order to ensure food security continues to gain ground and acceptability, information on rainfall pattern and trend is inevitable for the design of water supply, irrigation schemes and the evaluation of soil water management plans for adaptation [2].

Most farmers in the Sudan Savannah region of Nigeria practice rain-fed agriculture on marginal lands in rural areas. Any negative change in rainfall amount threatens agricultural production on these marginal lands, thereby exacerbating poverty and undermining economic development. The impact of rainfall variability in both economic and mortality terms is generally larger for relatively simple and predominantly agricultural economies. The low crop yields or total crop failure due to drought results in mass poverty and starvation as agriculture remains the mainstay of Nigeria's rural economy [3]. The poor households that are affected by drought and desertification do not have adequate resources to deal with food shortages leading to food insecurity and hunger that affects millions of people [4].

1.1 State of the research problem

Agriculture is the main economic activities in Nigeria (which account for around 40% of the country's GDP and employs about 60% of the active labour force), thus, rainfall anomaly would lead to a catastrophe with severe repercussions [5]. The most severe consequence of rainfall variability is drought which culminates to famine. This problem of rainfall variability in Sudano-agro-ecological zone has attracted many research interests to investigate either the level of change in climate or its concomitant effects on agriculture and other sources of livelihood especially in northern Nigeria. Sorghum is one of the major staple crops grown in northern Nigeria. It forms the food base of the people. Sorghum is sensitive to rainfall excess or deficit [6,7]. A study of this nature needs continuous and serious attention due to the importance of crop production in this area, the proportion of the population that engage in farming and the climate change reality on agriculture [8].

1.2 Aim and Objectives of the Study

The study, therefore, sought to examine the relationship between rainfall and the yield of sorghum. Objectives for the study are to; analyze annual rainfall trend, onset of rainfall, cessation, length of the growing season and their relationship with the yield of sorghum.

2. Related Work

[1] asserted that rainfall decreases from 1350 mm (1941–1970) to 1276 mm (1970–2002) in Nigeria, thereby impacting on the agricultural activities. Within the same period, the coastal area experienced slight increase as against interior parts of the country. The study concluded that this oscillating rainfall pattern culminated into ecological destabilization and has altered the pattern of the vegetation belt especially in the northern fringes of the country. The study added that rainfall pattern has also enhanced wind erosion/desertification and coastal flooding in the north, east and coastal areas of Nigeria respectively.

[9] examined the effect of climate change on maize production in Zambia. The research focused on determining how the change in rainfall and temperature affect maize production. Yield data for 20 years were collected and used. The results of the study showed that maize yield declined between 1986 and 2005 by about 56% which can be attributed to climate change. The study further revealed that, yield was dependent on both climatic and non-climatic factors such as rainfall, temperature, solar radiation, planting dates, fertilizer application and seeding rates.

The result of [10] showed a general decline pattern with a drop of 163mm of rainfall over the past 106 years (1910-2016). The result revealed a drastic fall in rainfall from 1977-1989 and from 2003-2011. The study attributed this drastic decrease in rainfall to global warming.

In a study on climate change in Nigeria [11], the findings revealed a statistically significant downward trend in annual rainfall at Bauchi, Enugu, Jos, Maiduguri, Minna, Portharcourt and Sokoto states.

Similarly, [12] revealed that 1971-1980 recorded an increase in rainfall in almost all parts of Nigeria with exception of Bida and Minna which had decreasing trends in annual rainfall. Cities like Yola, Bauchi, Jos, Kaduna, Enugu and Benin had normal rainfall. The study also revealed that between 1981-1990 Nguru, Minna and Jos experienced decreasing rainfall, while Sokoto, Bauchi, Kaduna, Zaria, Benin, Yelwa and Gusau had normal rainfall, while other parts of the country showed positive trends. Decreasing amount of rainfall was observed in larger parts of Nigeria between 1991-2000 in locations such as Bauchi, Gusau, Bida, Minna, Osogbo, Ondo, Benin, Enugu and Warri [13]. There was decrease in rainfall amounts in Jos and Katsina while areas around longitude 3°E-9°E experienced increase and the remaining part of the country having their normal rainfall [14]

[13] reported increase in the rainfall amount in cities like Jos, Enugu, Kaduna, Minna, Nguru and Katsina in the first decade of 1971-2000, while a decline in rainfall amount was recorded in larger part of south-west and north-eastern Nigeria. They also asserted that, Jos and Katsina were the only stations with dry tendencies while most parts of the country were having abundant rainfall amount. This gradual reduction/decrease in rainfall amount was attributed to variation in local factors such as orography, boundary layer forcing, and moisture build up.

[15] in their findings on the influence of climate change in the Niger Basin established the reality of variability in both spatial and temporal rainfall distribution in the area. This confirmed the assertion of [16] in their study on rainfall climatology Nigeria, there is variability in rainfall both in space and time.

[17] worked on climate change and variation in rainfall receipt per rain-day in Nigeria. The findings showed that there has been a progressive early retreat of rainfall over the whole country. Significant decline in rainfall frequency in September and October were also reported which coincided with the end of the rainy season in the northern and central parts of Nigeria.

A study by [18] reported a general decline in rainfall trends in recent times. The findings showed that the rainfall values for the years under review (1990-2005) was between 265.37mm and 320.21mm. This result supports the findings of [19] which reported that there was a progressive early decline of rainfall over Nigeria. Following the pattern, they reported a noticeable and significant decline of rainfall frequency in September and October which coincide with the end of rainy season in almost every parts of the country especially in the Northern and Central parts of Nigeria.

Rainfall versus crop yield relationship has received a lot of attention in previous and in recent time. [20] in their study on forecast model for the yield of millet and sorghum in the Semi-arid region of northern Nigeria using dry spells parameter found out that there is a relationship between rainfall and crop yield. Their result further explained that about 54.5% and 65.2% of variation in the yield of sorghum and millet are accounted for by variation in occurrence of dry spells.

[21] investigated water and crop yield relationship in Nigeria; the result presented a variability of rainfall distribution in Nigeria with more emphasis on northern part of the country. The study revealed that there exists a significant relationship between rainfall distribution and crop yield in Nigeria.

[22] studied the impact of climate change on precipitation effectiveness indices in northern Nigeria. Rainfall data for three decades (1976 – 2005) were used to derive onset, cessation, and length of rainy season, hydrologic ratio, seasonality index and occurrence of pentad dry spells. Results of the study showed that the rains now start late but end early as a result length of rainy season is decreasing. The study

stated that these results is a threat to food security and sustainable development. They concluded by recommending urgent need for the Nigerian government to come up with a concrete action plan to face this reality of climate change.

[23] examined the impact of climate change on crop yields in Sub-Saharan Africa. The study estimated the impacts of climate change on yields of the four most grown crops (millet, maize, sorghum and cassava) in Sub-Saharan Africa. A panel data was used to relate yields to standard weather variables, such as temperature and precipitation. The results showed that climate change has altered the climatic characteristics of most countries in the Sub-Saharan Africa including Nigeria. The result further revealed that the impact of precipitation on crop yields depends on national agricultural conditions among the countries of the Sub-Saharan Africa. Changes in precipitation were found to have a larger impact on millet and sorghum yields.

[24] examined the dynamics of hydrological growing season at Kano as evidence of climate change. They reported that the semi-arid region of Nigeria is experiencing the effects of climate change. Daily rainfall records from 1976 – 2011 were used to determine the onset, cessation, length of rainy season and the impact of climate change on hydrological growing season at Kano. The estimated parameters were subjected to time series analysis. The result show that the rainy season has progressively been starting late. The result further show that rains ceases earlier in recent decades. The result also indicated that the hydrological growing season is progressively shortening. The researchers highlighted that these results will affect both surface and underground water resource management, agriculture and sustainable food security not only for the Kano region but Nigeria at large.

To ascertain the pattern of rainfall trends [25] carried out a thirty-year (1989-2018) rainfall data study for Iwo in Osun State, southwest Nigeria. The data analysis employed the Mann-Kendall statistic with a single parameter. The findings indicated that seven months (January, March, May, June, September, October, and November) revealed a positive trend (positive y-values), suggesting increasing rainfall while five months (February, April, July, August, and December) showed a negative trend (negative y-values) indicating declining rainfall over the period. However, a general analysis of the 30-year data revealed a negative trend in the research area's rainfall, indicating a general decline in the incidence of rainfall in Iwo over the study period. The monthly trend data showed that rainfall is no longer a reliable source for sustainable agricultural practices. As a result, water conservation strategies must be used to save crops from the precipitation deficit brought on by climate change. [26] investigated the nexus between Nigeria's agricultural output and rainfall trend in relation to food security. Time series data on rainfall and the Nigerian agricultural production index from 1970 to 2008 were used in the study. The Nigerian Meteorological Agency and the Central Bank of Nigeria's different publications provided the data. The augmented dickey fuller (ADF) test, vector autoregression (VAR), lag order selection test, and pairwise Granger causality were among the econometric tools used to analyze the data. The study's main finding showed a unidirectional causal relationship between rainfall patterns and agricultural productivity at a 5% probability level, suggesting that patterns of rainfall had a considerable impact on agricultural production throughout the studied period. As a result, one of the main factors influencing agricultural productivity and, ultimately, the achievement of food security is variations in rainfall brought about by climate change. Based on these findings, it was suggested that farmers, particularly small-scale farmers who produce the majority of Nigeria's agricultural output, be encouraged to adopt adaptation strategies to changing rainfall, such as investing in irrigation and cultivating drought-tolerant crop varieties.

[27] investigated the correlation between rainfall and temperature and Delta State (Nigeria) yield of maize, yam, and cassava. The research employed multistage sampling technique to randomly choose rural households, local government, and communities. The Nigerian Meteorological Agency (NiMet) provided annual mean time series data on temperature and rainfall, while Agricultural Development Programmes (ADP) provided annual mean time series data on maize, yam, and cassava yield. Descriptive statistics, trend analysis, correlation matrix, and growth model were used to analyze the data. The result revealed that the State's predicted future values for the annual mean temperature and annual mean rainfall show a growing tendency in the former and a declining trend, respectively. Rainfall has a negative relationship with corn, yam, and cassava yields, respectively, which is not ideal for the highest possible yields of those crops. The state's corn yield trended downward, signifying a possible cause of hunger. Accordingly, the study suggests that in order to prevent hunger and food insecurity in the state, mitigation and adaptation strategies for climate change should be implemented.

[28] examined the effects of varying rainfall on a few important food crops in the semi-arid Northern Nigeria region. The Institute for Agricultural Research (IAR), Ahmadu Bello University, Zaria, provided fifty years daily rainfall data (1963–2012), which were then processed using the VISUAL-BASIC-Net programme. The research used Ashok Raj's (1979) idea of "onset of effective monsoon and dry spells". Agricultural Development Projects (ADP) in the State provided grain yield data. To evaluate the association between agricultural yield and dry spells, correlation analysis was used. The outcome showed a shift of roughly ten days from the typical planting time. Additionally, a negative relationship between cowpea, rice, sorghum and maize was shown to be significant at the 5% level of confidence and the 1% level of confidence, respectively. Science-based mitigation and adaptation options were proposed, and smallholder farmers and policy makers were briefed on the implications of the reduced and unpredictable rainfall pattern to agricultural production.

The impact of rainfall variability and its effects on crop productivity in Niger State were investigated by [29]. The objective was to incorporate solutions for adapting climate change into agricultural practices. In order to do this, the standard deviation was used as a justification tool in a climatic index (CI) analysis of rainfall to determine the degree of rainfall extremes occurrences arising from rainfall variability. Crop yield was also employed in the study to examine the correlation between yield and rainfall parameters over a thirty-year period (1990-2019). Data on rainfall and crop yields (sorghum, maize, and soybeans) were gathered. The findings demonstrated that different intensity rainfall extremes, from moderate to severe dry spells to mild to severe wet spells occurred. Regression analysis also reveals that F-values are greater than p-values. As a result, agricultural productivity was adversely affected by the frequency of severe wet spells and mild to severe dry spells, undermining food security.

[30] examined how farmers in Lagos, Nigeria, are interpreting and impacted by rainfall as it relates to their maize and cassava farming operations. Meteorological data, which spans from 1998 to 2018, shows no influence on cassava yield but a considerable impact on maize yield. Additionally, according to survey data, farmers in this region are presently using strategies to adjust to climatic variations depending on the kind of crop they plant. Most of the agriculture in Lagos, Nigeria, is rain-fed, and climate change has a detrimental effect on crop productivity by lowering crop yield and soil fertility, restricting soil water availability, accelerating soil erosion, and facilitating pest transmission. According to this study, programmes that provide finance access, irrigation capabilities, and creative approaches for coping with climate change are necessary to inspire both younger and older farmers.

To address the issue of food insecurity in Kwara State, Nigeria, [31] looked at the effects of variations in rainfall onsets, cessations, and Length of Growing Season (LGS) on yam yield. Monthly rainfall data were gathered for six stations in Kwara State between 1961 and 2017 (a span of 57 years). To display fluctuations, a decadal partitioning of the crop and rainfall features was created. The investigation of trends was done using time series analysis. Correlation analysis was also used to determine how strongly the growing season's duration and yam yield are related. The results indicated a negative trend in the late cessation of rain, an increase in the beginning of the rainy season, and a decrease in the length of the growing season. There was an increase in the frequency of late-onset and late-cessation of rains on a decadal basis. The LGS and yam production have a favourable association (r = 0.455).

[32] looked at how variations in rainfall affected the yam output in Benue State, Nigeria. The yam yield response to rainfall pattern (increase or reduction) was characterized by analyzing rainfall and yield data spanning 33 years (1988–2021). The rainfall pattern was represented by a trend line equation, and the degree of the association between rainfall and yam yield was indicated by Pearson's Correlation Coefficient (r). The trend line equation's conclusion ($y = 7.1873x + 1106.4$) indicated an increase in the total annual rainfall. The outcome of the yam yield pattern also indicated an increase in yam yield ($y = 3.3328x + 284.52$). The correlation's result indicated a strong relationship between yam yield and yearly rainfall (r=0.65), suggesting that yam yields rise in tandem with rainfall levels. Based on these results, the study advises the implementation of workable adaptation techniques for the area's ongoing yam production in order to increase food security.

3. Theory

3.1 The Study Area

The Sudan Savannah region is in northern Nigeria, located approximately between Latitudes 10°N to14°N and Longitudes 4°E to 15°E (see Figure 1). Sudan Savannah accounts for more than 25% (230,942 km^2) of the entire land area of Nigeria (Federal Government of Nigeria [FGN], 2000). The climate of this ecological region is the tropical wet and dry type classified by Koppen as Aw.

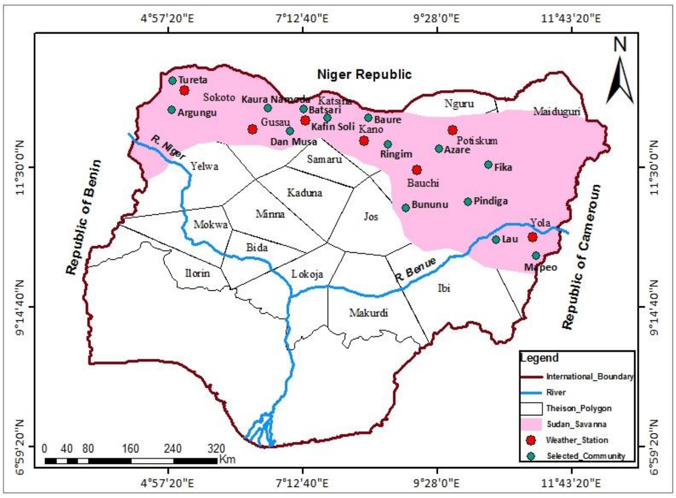

Figure 1: Map of Nigeria showing the Sudan savanna

The average annual rainfall of the area ranges from 500 mm in the northern part to 1000 mm in the southern part of the ecological zone [26]. The seasonality of the rainfall is highly influenced by the interaction of two air masses: the relatively warm and moist tropical maritime (mT) air mass, which originates from the Atlantic Ocean; and the relatively cool, dry and stable tropical continental (cT) air mass that originates from the Sahara Desert. The air mass is associated with the dry, cool and dusty North-East winds known as the Harmattan [27]. The meeting point of these two influential air masses has been named differently by tropical climatologist: Inter-tropical Front (ITF), Inter-tropical Confluence (ITC), Equatorial Front (ET) and Inter-tropical Discontinuity (ITD) and Intertropical Convergernce Zone (ITCZ) [27]. The vegetation of this area is that of Sudan savannah as the name implies, with short grasses and shrubs dominating. The seasonal character of rainfall in this area has influenced the vegetation which turns evergreen during the wet season and pale brown in the dry season respectively. This vegetation belt is found in the north-west stretching from the Sokoto plains in the west, through the northern sections of the central highland [28].

4. Experimental Method/Procedure

Rainfall data and geographical location of the meteorological stations were acquired from the archive of the Nigerian Meteorological Agency (NiMet), Oshodi-Lagos. Information on the Thiessen polygons of meteorological stations in the area was obtained from Agro-climatological Atlas of the northern states of Nigeria by [29]. The selected Meteorological stations are presented in Table 1.

Table 1: Selected Meteorological Stations in the Sudan Savannah and their Locations

Station	Station WOM Index No.	Latitude	Longitude	Altitude
Bauchi	650550	10°17'N	09°49'E	609.7m
Gusau	650150	12°10'N	06°42'E	468.00m
Kano	650460	12°03'N	08°32'E	475.80m
Katsina	650460	13°01'N	07°41'E	516.63m
Potiskum	650730	11°43'N	11°07'E	487.68m
Sokoto	650100	12°55'N	05°12'E	309.00m
Yola	651670	09°14'N	12°28'E	214.00m

Source, NIMET, 2007

In computing the Total Annual Rainfall (TAR) for each station, rainfall amount received from January to December of each station were sum up for every year. Rainfall onset date was calculated using the formula below:

Rainfall onset = Number of days in the month
X (51 - Accumulated rainfall of the previous months)
Total rainfall for the month (1)

The computation of the cessation date was done in the same way as the onset except that the computation was done backward from December following [30] method, it is:

= 51- rainfall total of the previous month
Total rainfall of the first month with greater that 51 mm. (2)

The length of the Growing Season (LGS) is the difference between the cessation date of rains and the onset date. The LGS can be computed by subtracting the onset date from the cessation date [31]. The Julian calendar dates were used to determine the onset and cessation.

Trend charts were employed to examine the annual rainfall trend, onset and cessation trends and the trend of LGS. Sorghum yield of the area were sourced from states' agriculture and rural development authority, agricultural development projects and national bureau of statistics. The sorghum yield was subjected to simple Correlation using the statistical package for social science (SPSS) at 0.05 significance level to ascertain its relationship with TAR, onset and cessation dates and LGS.

5. Results and Discussions

5.1 Rainfall Trends in the Sudan Savanna Region of Nigeria

Rainfall trends from 1956-2018 computed for the selected meteorological stations in the Sudan savanna region of Nigeria are presented in Figure 2. The trends revealed a general decreasing pattern of rainfall from 1956-1974 in Bauchi, Gusau, Katsina, Potiskum, and Sokoto polygons. Kano and Yola polygons exhibited an irregular pattern characterized by fluctuations within this same period. From the trends, it was observed that Bauchi, Gusau, Kano, Katsina, Potiskum, Sokoto and Yola areas experienced the least TAR in 1972, 1988, 1974, 1998, 1994, 1984 and 1970 respectively. Within these periods, there was no location that experienced a TAR that exceeded 400 mm. This result agrees with [32] which reported low rainfall amount in the Sudan savanna ecological zone during these years. The result disagrees with the findings of [33] which reported an increasing TAR in Sokoto State between 1970 – 2018.

As indicated in Figure 2, there was an increase in rainfall in Bauchi, Gusau, Kano, Katsina and Sokoto stations from 1975-1980. These same areas experienced a general decline in rainfall from 1981-1986. However, the Bauchi station has not experienced an annual rainfall that dropped below 800 mm from 1976 -2015. The wettest years at Gusau were 1983, 2004 and 2010. These are years that the TAR was 1000 mm and above. Similarly, 1963, 1981, 2000, 2006 were the wettest years at Kano. These were years that rainfall was 1000 mm and above. The wettest years at Katsina area were 1967 and 1981, when TAR was 1000 mm. The wettest years in Potiskum area were 1962, 1964 1990 and 2014; with annual rainfall reaching 1000 mm or more. Sokoto area is the driest area in the ecological zone. The station has only one year with annual rainfall that exceeded 900 mm.

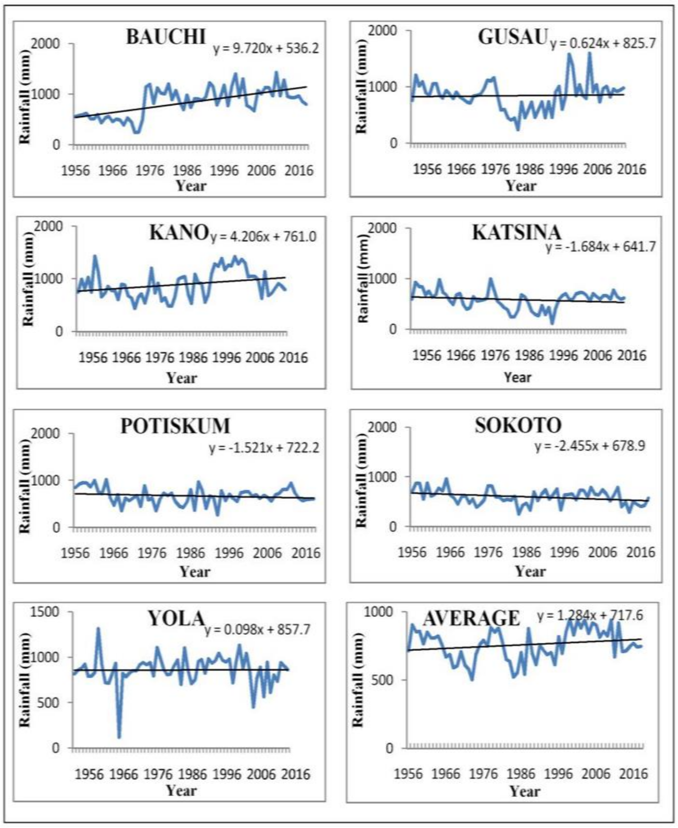

Figure 2: Rainfall Trends of the study areas

This result agrees with the study of [11] on climate change evidence from meteorological parameters; which suggested a high degree of rainfall dynamism in northern Nigeria.

It is imperative to note that 1970s and 1990s were periods of the great Sudano-Sahelian droughts as documented in the literature [34]. The observed variability in rainfall in these areas could be associated with the anomalies in South-North movement of the inter-tropical discontinuity (ITD) and associated surface conditions [35].

The lines of best-fit in Figure 2 indicate an increase in annual rainfall in Bauchi, Gusau, Kano, and Yola polygons from 1956 - 2018. Similarly, the result revealed a decreasing annual rainfall in Katsina, Potiskum and Sokoto polygons from 1956 - 2018. This result shows that despite the similarity in the ecological location of these polygons, the rainfall trend varies from one location to the other. It is also observed that the Sudan Savanna is getting wetter than what was attainable in the past. This result contradicts the assertion of [30] which shows that the Savanna region is getting drier. Similarly, [36], [10] and [37] in separate studies recorded rainfall decline in most stations in the Sudan Savanna. The result agrees with the assertions of [12], [7] and [32] which observed an increase in rainfall in most parts of the savanna.

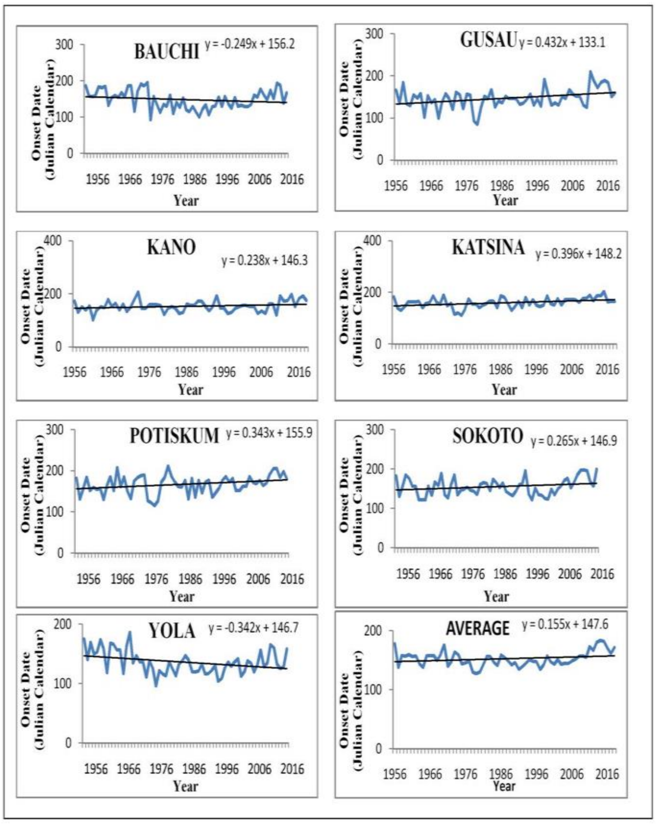

Figure 3: Rainfall Onset trend in Sudan Savanna Region of Nigeria

Figure 3 presents rainfall onset trend of the area. From the result, it was observed that there is a relative decline in rainfall onset dates in all the polygons with exception of Bauchi and Yola area where rainfall onset date changes insignificantly toward early pattern. However, the trend in Bauchi area exhibits a delay in rainfall onset between 1966 to 1974 and 2006 to 2016. However, earlier rainfall onset in Bauchi area was experienced between 1976 and year 2000. Within these periods' rainfall onset was experienced as early as between 9th April and 28 may (100 and 150 day of the Julian calendar).

The average onset date of rainfall in Gusau is 25th of May (146 day of the Julian calendar). However, a later onset dates were experienced between 1996 and 2016, when rainfall onsets were delayed up to between 28th June and 18th July. Earlier rainfall onset was experienced between 1978 and 1980 when the onset date of between 5th and 11th April (96 and 102 days of the Julian calendar) was recorded in Gusau area. The results in Kano polygon revealed an average rainfall onset date of 1st June, which is equivalent to 153 days of the Julian calendar. A delay in rainfall onset was recorded in Kano in 1968, 1989, 1997 and 2018. Within these periods, rainfall onset delayed as late as July 18th (200 day of the Julian calendar). The years: 1957, 1959, 1961, 1970, 1980 and 1985 saw earlier rainfall onset in Kano area. Within these periods' rainfall onset of between 11th April and 28th May (102 and 149 days of the Julian calendar) was recorded in this area.

Katsina area has an average rainfall onset date of 9th June which is equivalent to 161 day of Julian calendar. This area experienced relatively later rainfall onset between the years 1986 and 2018 when rainfall onset dates of between 5th and 22nd July (187 and 204 days of the Julian calendar) were recorded. Earlier onset dates of between 11th April and 30th May (102 and 151 days of the Julian calendar) were recorded in 1961, 1974 - 1975, 1980-85 and 1998 - 2010. The average onset date in Potiskum Polygon between the years reviewed (1956-2018) was 15th June which is equivalent to 167 days of the Julian calendar. This area experienced a delayed rainfall onset in the years; 1956, 1971, 1975, 1997 and 2009 - 2018. During these periods, there was delay in onset date as late as between 18th June and 24th July. Relatively early rainfall onset was recorded in 1965, 1975 - 1986 and 1990. These years saw a relatively early rainfall onset of 24th April - 13th May (115-135 days of the Julian calendar).

The onset of rainfall in Sokoto polygon from the year 1956 to 2018 was averagely around 16th July which is equivalent to 167th day of the Julian calendar. There was delay in rainfall onset in the years: 1956, 1960, 1971, 1975, 1987, 1997 and 2000-2018. During these period rainfall onsets delayed as late as 23rd June and 13th August (150 and 226 days of the Julian calendar). However, a relatively early rainfall onset was experienced in this area in the years: 1965, 1975 - 1981 and 1990. During these years, rainfall onset between 1st and 28th May (122 and 149 day of the Julian calendar) was recorded in the area. Yola polygon has mean rainfall onset date 136 day of the Julian calendar which is equivalent to 15th May. In other words, this area has relatively earlier rainfall onset compared with other polygons, though late rainfall onset was recorded in the years: 1956 and 1970 when onset dates of 25th June and 4th July (175 and 186 days of the Julian calendar) were recorded respectively. The result confirmed the findings of [38] and [39] who in their separate studies on the effects of rainfall variability on millet and sorghum yield in Sudan savanna ecological zone recorded a delayed rainfall onset trend. The average onset date as indicated in Figure 3 showed delaying trend of rainfall onset in the study area. However, the average trend does not depict the reality of most polygons. Although the outcome shows gradual delaying trend of rainfall onset, the ecological zone translates into either delay in planting of crops or crop loss due to insufficient soil moisture in most of the polygons.

Figure 4 presents trends in rainfall cessation in the Sudan Savanna region of Nigeria. The trend shows a general decline in rainfall cessation in Bauchi, Gusau, Kano, Katsina and Sokoto polygons within the study period. Potiskum and Yola areas had a relative delayed rainfall cessation date. The ecological zone has an average cessation date of 24th September, which is equivalent to 268th day of the Julian calendar. The average cessation date in Bauchi polygon was 15th September which is equivalent to 259th day of the Julian calendar. Early rainfall cessation date was recorded in1996. This was a period when rainfall cessation was experienced on the 21st of June. The year1990 recorded latest rainfall cessation in Bauchi area; during this period a cessation date of 23rd October was recorded.

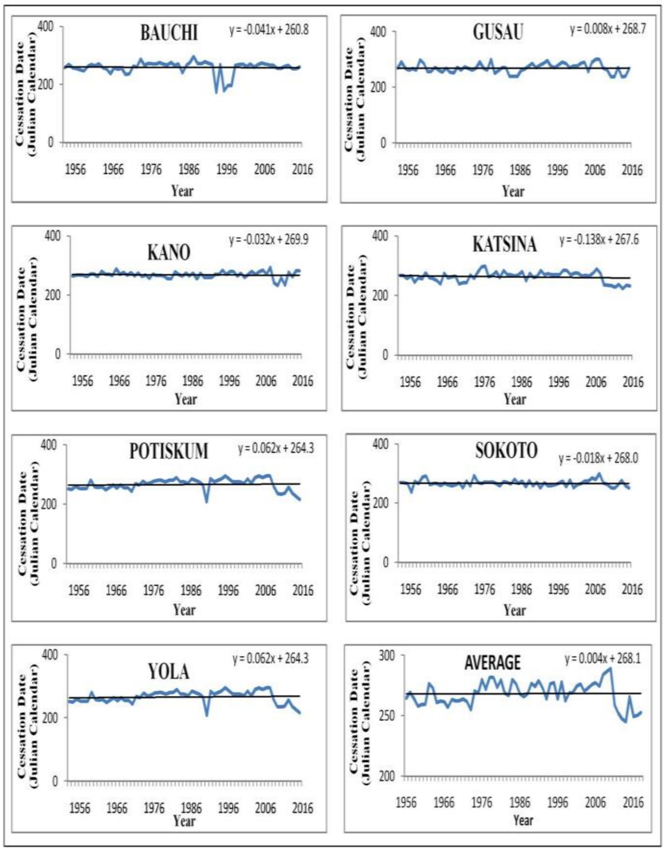

Figure 4: Rainfall Cessation Trend in Sudan Savanna Region of Nigeria

As presented in Figure 4, Gusau polygon has an average rainfall cessation date of 25th September, which is equivalent to 269th day of the Julian calendar. However, a later rainfall cessation date of 26th October (300 day of the Julian calendar) was recorded in 1981, 2008 and 2011; while the years: 2014 and 2016 recorded early rainfall cessation (19th August). The mean rainfall cessation date in Kano area within the study period was 21st September (265 day of the Julian calendar). However, Kano polygon recorded a relatively later rainfall cessation in the years 1997, 2008 and 2010. Within these years, cessation dates of 11th -25th October (285-295 days of Julian calendar) were recorded. The area saw a relatively earlier rainfall cessation 19th-22nd August (232-235 day of Julian calendar) in the years: 2012 and 2014.

Katsina polygon has an average rainfall cessation date of 25th September. This is equivalent to 265 days of the Julian calendar. The area recorded a relatively late rainfall cessation of 25th October 1979, and a relatively earlier rainfall cessation of 10th - 25th August (232-238 days of the Julian calendar) between 2011 - 2018. Potiskum has an average rainfall cessation date of 22nd September (266 day of Julian calendar) within the study period. However, a relatively late rainfall cessation was recorded between 2006 - 2010. Within these years, a cessation date of 17th -22nd October (290-295 days of the Julian calendar) was recorded.

The rainfall cessation date in Sokoto area within the study period was 23rd September, which is equivalent to 267 days of the Julian calendar. However, a relatively later rainfall cessation of 19th -26th October was recorded in this area in 1976 and 2010. Earlier, rainfall cessation of 8th - 9th September was recorded in 2013 and 2018.

The result in Yola Polygon was relatively different from other polygons; the average rainfall cessation date in this area during the study period was 9th October which is equal to 283 days of the Julian calendar. In other words, Yola experiences a relatively late rainfall cessation compared to other areas in the Sudan Savanna region of Nigeria. A relatively late rainfall cessation of after 26th October (300 day of the Julian calendar) was recorded in 1976, 1978, 1979, 1985, 1988, 1990-1992, 1994-1995, 1997 and 2009. However, a relatively earlier cessation of 12th September (255 day of Julian calendar) was recorded in 1961 and 2017-2018. This implies that different area polygons in Sudan Savanna region have different rainfall cessation dates. This call for different agricultural planning regarding to farm preparation, planting and harvesting of the products. The average rainfall cessation indicates a relative increase in the trend of cessation dates in the ecological zone. It is therefore important to educate farmers about the difference, as ignorance could lead to wrong planning that may culminate into crop failure due to early or late rainfall cessation.

Figure 5 presents trends in LGS. The result indicates a decreasing trend in LGS in Gusau, Kano, Katsina, Potiskum and Sokoto polygons within the study period. Bauchi and Yola Polygon had relatively increased trend in LGS. Bauchi area had a mean LGS of 111 days. The area recorded the shortest LGS of 39 days in 1999 and the longest LGS of 197 days in 1976. An average LGS in Gusau within the study period was 122 days; and the shortest LGS of 53 days was recorded in 2014. The longest growing season of 198 days was recorded in 1978. The average for the ecological zone shows a general decrease in LGS. This implies that the wetter Savanna is not due to the LGS, but as a result of the increase in rainfall amount received within a short growing season.

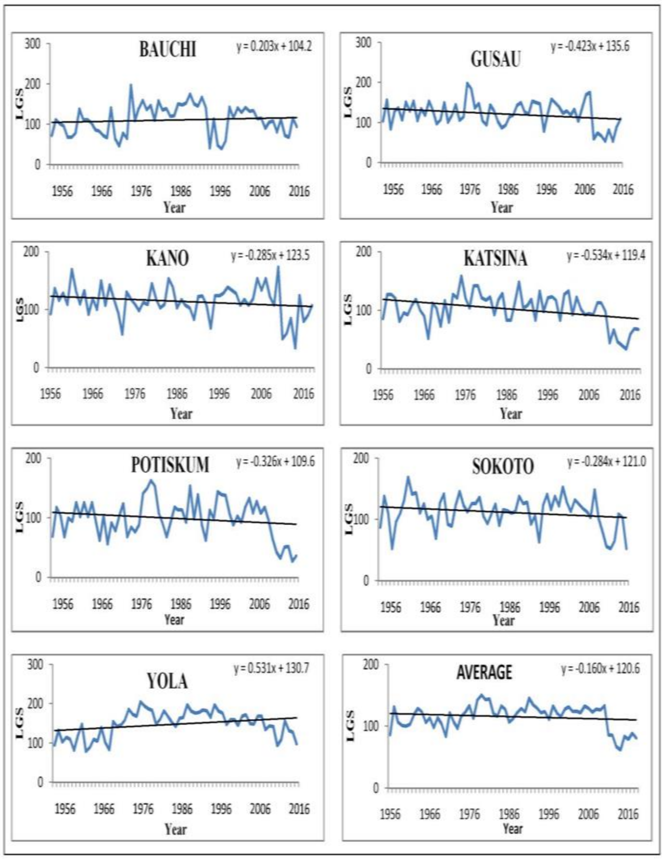

Figure 5: LGS Trend in Sudan Savanna Region of Nigeria

Kano polygon recorded a mean LGS of 114 days within the study period. However, the shortest LGS was recorded in 2014 when the growing season lasted for only 34 days; the year 2010 recorded 174 days of the growing season which seems to be the longest in the Polygon (1956-2018). Katsina station recorded a mean LGS of 102 days and a short growing season of 34 days in 2014. The longest growing season was experienced in 1975 as the growing season lasted for 159 days.

The average LGS in Potiskum from 1956-2018 was 99 days and the shortest growing season was experienced in 2017 when the season lasted for only 27 days. The 1981 had the longest growing season in Potiskum area; this was the year the growing season lasted for 163 days. The average LGS in Sokoto station within the study period was 112 days. The shortest growing season in Sokoto was recorded in the year 1959; this was when the season lasted for only 52 days. The year 1963 experienced the longest growing season in Sokoto area; during this year the growing season lasted for169 days. Yola area has an average LGS of 148 days, the shortest growing season in Yola was recorded in 1964, this was when the season lasted for 78 days; while the longest growing season in Yola was 1978 this was the year the season lasted for 205 days.

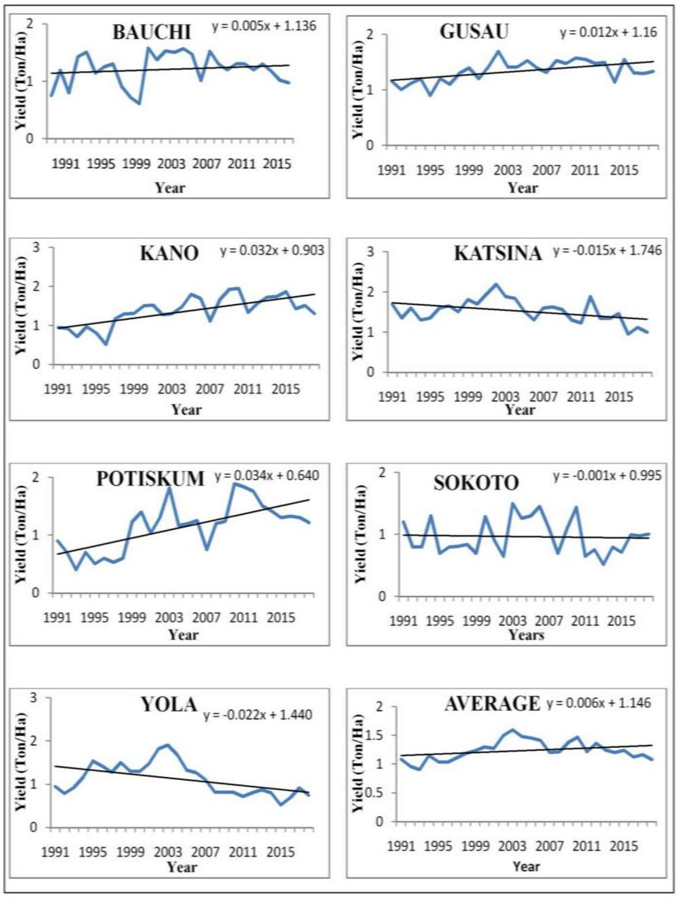

Figure 6: Sorghum Yield Trend in the Sudan Savanna Region of Nigeria

Sorghum yield trend for the study area is shown in Figure 6. The result shows that the trend in sorghum yield is not stable but characterised by variability. The line of best-fit revealed a general increasing trend in Bauchi, Gusau, Kano and Potiskum. The result further shows a decreasing trend in Katsina and Sokoto Polygons. The result revealed that Bauchi experienced an increase in sorghum yield in 1990-1993, 1996-1998 and 2002 - 2006; whereas 1994 - 1995, 1999 - 2001 and 2007 - 2015 were years of low sorghum yield. This result agrees with the findings of [39] which revealed an increase in maize, rice and sorghum yield in Sokoto State. The years of increased crop yield are related to years of relatively more rainfall. This result means that rainfall is one of the major factors of sorghum production in this area.

The result of Gusau is not far from that of Bauchi polygon; 1991-2000 and 2014-2015 witnessed increase in sorghum yield whereby years 2002-2008 and 2015 were years of increase in sorghum yield in Gusau area. In Kano polygon, the result revealed that there was increase in sorghum yield in 1996 - 2003 and 2014; the years 1991 - 1995, 2004 - 2012 and 2015 witness a decrease in sorghum yield. Katsina area has relatively general increase in sorghum yield. However, the area experienced a slight decrease in sorghum yield during the years 1997 - 1998 and 2012. There was a general increase in sorghum yield in Potiskum polygon with relative decrease in the years 1991 - 1993, 2007 and 2015.

The result at Sokoto presents a cyclical trend with increased sorghum yield in 1995, 2000, 2002 - 2006 but the years 1992, 1994 - 1999, 2007 and 2011 - 2015 experienced decrease sorghum yields. Yola polygon experienced a general decrease in sorghum yield with slight increase in the years 1995 - 2003. Rainfall may not be the only determinant of sorghum yield; however, the sorghum yield trends show a slight resemblance with the rainfall trend in these areas.

Table 2: Correlation Test Results between Rainfall and Sorghum Yield in the Selected Thiessen Polygon in Sudan Savanna Region of Nigeria

Theison Polygon	DF	Sig. Level	Critical-r	Observed-r			
				Total AR	**Onset**	**Cessation**	**LGS**
Bauchi	26	0.05	0.396	0.319	0.081	0.784*	0.230
Gusau	26	0.05	0.396	0.768*	0.279	0.470*	0.401*
Kano	26	0.05	0.396	0.666*	0.385	0.509*	0.416*
Katsina	26	0.05	0.396	0.741*	0.421*	0.260	0.398*
Potiskum	26	0.05	0.396	0.600*	0.355	0.398*	0.560*
Sokoto	26	0.05	0.396	0.409*	0.601*	0.208	0.319
Yola	26	0.05	0.396	0.397*	0.24	0.184	0.010
Average	**26**	**0.05**	**0.396**	**0.711***	**0.19**	**0.177**	**0.099**

*. Correlation is significant at 0.05 level

The relationship between trend in rainfall and sorghum yield is presented in Table 2. The result show that there is a significant relationship between sorghum yield and TAR in all the polygons except Bauchi. There is also an insignificant relationship between rainfall onset and sorghum yield in Bauchi, Gusau and Postikum areas; while Kano, Katsina, Sokoto and Yola seem to have significant relationship between Sorghum yield and rainfall onset. There is a significant relationship between rainfall cessation dates and sorghum yield in Bauchi, Gusau and Kano, while the relationship between rainfall cessation dates and sorghum yield in Katsina, Sokoto and Yola areas are statistically insignificant. Moreover, there exists a significant relationship between LGS and sorghum yield in Gusau, Kano, Katsina and Potiskum areas; while an insignificant relationship exists between sorghum yield and LGS in Bauchi, Sokoto and Yola Polygons. The correlation between averages indicates a strong relationship between annual rainfall and sorghum yield and insignificant relationship between sorghum yield and rainfall onset, cessation and LGS. This is an indication that rainfall has a significant effect on sorghum yield and is one of the major determining factors of sorghum production in the ecological zone. In other words, increase in rainfall may lead to increase in sorghum yield and decreased in rainfall may also lead to decrease in sorghum yield.

This result confirmed the result of [22] which show a significant relationship between rainfall and sorghum yield in Wailo. Similarly, the result also confirmed the assertion of [39] and [40] which reported that rainfall has significant influence on agricultural productivity in West Africa. The result disagrees with [41] which reported a significant relationship between TAR and crop yield but insignificant relationship between crop yield and other precipitation parameters in the study area; this may be due to the nature of data collected. [42] reported that rainfall and water moisture contents have significant impact on rice yield. The study recommended that the yield gap can be overcome using improved seed varieties.

6. Conclusion and Future Scope

This study concluded that there were increase in annual rainfall in Bauchi, Gusau, Kano, and Yola polygons from 1956 – 2018, while Katsina, Potiskum and Sokoto experienced a decrease. Also, there was a relative decline in rainfall onset dates in all the polygons with exception of Bauchi and Yola area where rainfall onset date changes insignificantly toward early pattern. There was a general decline in rainfall cessation in Bauchi, Gusau, Kano, Katsina and Sokoto polygons within the study period. Potiskum and Yola areas had a relative delayed rainfall cessation date. There was a decreasing trend in LGS in Gusau, Kano, Katsina, Potiskum and Sokoto polygons. Bauchi and Yola Polygon have relatively increasing trend in LGS. There is a significant relationship between sorghum yield and TAR, rainfall cessation date and LGS in all polygons selected from the ecological zone. Similarly, the result revealed a significant relationship between crop yield and rainfall onset date in all the polygons except Katsina.

Based on the findings of the study, the study therefore recommends: sensitization of sorghum farmers on the relationship between sorghum and rainfall and the need to adopt variety of sorghum that can endure drought as a way of reducing the possible crop loss due to rainfall variability since rainfall show high variability. Qualitative climatic data should be made available and accessible to sectors that are sensitive to climate such as agriculture and water resources. Efforts should be made to provide early warning weather information to farmers; policies should be formulated to ensure unlimited access to seed varieties and credit facilities by farmers. Establishment of agro-climatological research institutes in the study area for academic research and development planning purposes.

There is need to embark on further research in the following areas: analysis of rainfall trend and its relationship with sorghum yield and farmers' adaptation strategies. Adaptation is very important in a study that shows the vulnerability of agriculture to the impact of climate variability.

Data Availability
The rainfall data used for this research was sourced from the Nigerian Meteorological Agency (NiMet), Lagos, Nigeria.

Conflict of Interest
The authors have not declared any conflict of interests.

Funding Source
The research was funded by personal contribution

Authors' Contributions
Ariko Joseph: Researched literature and conceived the study
Ikpe Elisha: Data analysis and drafting of the article
Sawa Bulus: Revision and improvement of the article before final submission

Acknowledgements
We acknowledged Mr. Hassan Muazu of the Ahmadu Bello University, Zaria for the map of the study area. We also thank the staff and management of Nigerian Meteorological Station, Oshodi, Lagos for the release of rainfall data.

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