Spatio-temporal Variations in Mean Heavy Rainfall Days over the Guinea Savanna Ecological Zone of Nigeria

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ABSTRACT

Variations in weather parameters are phenomena confirmed by many studies. Various derived rainfall parameters are variable in nature. One of such derived rainfall parameters is heavy rainfall. Rainfall that is $\geq$ 50 mm/day (24 hours) has been considered in this study as heavy. The objectives of the study were to assess the spatio-temporal variations in mean heavy rainfall days and also to determine the pattern of mean heavy rainfall days over the Guinea Savanna Ecological Zone of Nigeria (GSEZN). Purposive sampling was used to select nine (9) major meteorological stations within the zone. These data points which were later divided into flanks (northern, southern, eastern and western) include Makurdi, Lokoja, Jos, Ibi, Abuja, Minna, Ilorin, Lafia and Kaduna. Daily rainfall (mm) data from these points were collected and used for this research. The data spanned from 1981-2015 (35 years) and were split into seven (7) episodes of five (5) years each. Statistical mean and geostatistical analyst built in arctoolbox of ArcGIS were adopted for analysis. Results showed both inter and intra spatio-temporal variations and pattern in mean heavy rainfall days. Northern part had zero (0) high mean heavy rainfall days which are the least, while southern part had eleven (11) which is the highest. Northern and eastern parts had seven (7) moderate mean heavy rainfall days each, west had six (6) which is the least and south had eleven (11) which is the highest. Northern part had fourteen (14) low mean heavy rainfall days which is the highest, east had two (2), south had one (1) and west had zero (0) which is the least. Over the study area, mean high and low heavy rainfall days are four (4) each, while moderate is eight (8). Episode 1 (1981-1985) had the least mean heavy rainfall days of 14, while the 4th episode (1996-2000) had the highest of 19. The overall long-term mean heavy rainfall days is 7 and there is positive trend in mean heavy rainfall days in recent time. The major implication of this study is annual flooding in the study area. The recommendation of this study focused mainly on frequent heavy rainfall forecast.

Keywords: *Rainfall, rainfall variations, heavy rainfall, flooding, rain forecast*

INTRODUCTION

The concept of rainfall is not strange in Nigeria since it is the commonest type of precipitation experienced. It is the major source of fresh water supply on earth which has three (3) major uses such as industrial, agricultural and domestic (Buggu *et al*., 2020). Rainfall modifies the temperature of an area aside providing water for crop farming, water transportation, domestic water supply, water erosion, landslides and flooding which are affected by the variations in rainfall attributes. Over the years, rainfall pattern is said to vary over space (Yusuf and Mohammed, 2012) even within the same climatic region. Rainfall which is more varied than other climate parameters varies across Africa as it decreases from the coast of West Africa inland. Heavy rainstorms are experienced in some places in Africa, while extreme droughts in others like Uganda, Tanzania, Rwanda and Somalia (Ladan, 2012). Atiku *et al*. (2012) opined that the Sahel region of Africa has seen crop failures because of intense and more frequent drought. In Nigeria, the late 70s and early 80s were marked with rainfall deficiency. Ofedi and Grain (2009) remarked that, rainfall in the 1970s and 1980s was half the rainfall of the 1950s and 1960s.

On rainfall variability, Olanrewaju, (2006) opined that, rainfall particularly at the beginning of the rainy season in Nigeria does not effectively satisfy the evaporative demand of the atmosphere. Okpiliya *et al*. (2007) observed that, the production capacity of crops is influenced by the variabilities associated with changes in elements of weather and climate such as temperature, rainfall, evaporation and sunshine. The study of Adakayi, (2008) revealed that annual rainfall varies greatly in Kano State. Likewise, Akut, (2012) opined that variability of rainfall over Nigeria is said to have an annual decrease of about 50-100 mm and that annual rainfall has declined over both space and time. Lamidi, (2012) stated that the effect of rainfall and drought on agricultural outputs in the arid zone depends on the intensities of the rainfall and duration which is devoid of flooding. These attributes of rainfall vary over space and time. The disparity in rainfall over both space and time could be associated with latitudinal location within the same climatic zone as well as other local peculiarities such as vegetation, urbanization, orographic lifting, Convective Available Potential Energy (CAPE), availability of precipitable water (APW) in the atmosphere and meso scale convective systems (MSCs).According to Eniola and Afiesimama, (2013), the CAPE value of 2000-3600 J/kg from the hour of 06-09 on 27th June, 2012 over Nigeria could be the possible threshold value that led to heavy rainfall.

Variations in rainfall account for some environmental, agricultural and socio-economic problems such as erosion, flooding, outbreak of pests and diseases, water (surface and underground) depletion, crop failure (due to late onset, early cessation, shortened length of growing season, wet spells, dry spells and droughts), food shortage, poverty among farmers, hunger, malnutrition and food insecurity. According to the Intergovernmental Panel on Climate Change (IPCC, 2007a; 2012), changes in climate, either negative or positive have direct influence on the environment and human activities globally or locally as poor agricultural yields, food insecurity, flooding and even death are some of the catastrophes of drastic climate change. Sambo *et al*. (2016) opined that changes in rainfall pattern have direct effect on changes in stage level of rivers in Cross River Basin Area. As weather and climate of Nigeria are changing, there is need to modify the climate models hitherto used, to suit the recent weather and climate realities.

Studies conducted on variations in rainfall across Nigeria, Oluleye and Ogunjobi, (2010); Umar, (2010); Yahaya and Abubakar, (2012); Ifabiyi and Ashaolu (2013); Okoloye *et al*. (2013) all revealed sharp variations in rainfall over various climatic zones. As good as these studies were, they failed to discuss the spatio-temporal variations in mean heavy rainfall days over the Guinea Savanna Ecological Zone of Nigeria. This is the major lull which this research intends to address by answering the following research questions:

1. How are the spatio-temporal variations of mean heavy rainfall days in the GSEZN?
2. What is the pattern of mean heavy rainfall days over GSEZN?

The aim of this study is to examine the spatio-temporal variations in mean heavy rainfall days over the Guinea Savanna Ecological Zone of Nigeria (GSEZN). The objectives were to assess the spatio-temporal variations in mean heavy rainfall days over the GSEZN and to determine the pattern of mean heavy rainfall days in the GSEZN.

MATERIALS AND METHODS

The Study Area

The Guinea Savanna Ecological Zone of Nigeria (GSEZN) is the study area and it lies between longitudes 4°–10°E and latitudes 6°–11°30[1]N. It is bordered to the north by Sudano-Sahelian Ecological Zone of Nigeria (SSEZN), to the south by Rain Forest Ecological Zone of Nigeria (RFEZN), east by Cameroun and to the west by Benin Republic (Figure 1).

The highest mean monthly temperature is about 37°C and the minimum is about 27°C (Magaji, 2009). The two (2) predominant air masses influencing the weather and climate of the zone are Tropical Maritime air mass (mT) and Tropical Continental (cT) air mass. These two air masses gave rise to two (2) seasons in the zone, namely rainy which lasts between April-October and dry which lasts between October-April with harmattan in November-February (Mallo &Ochai, 2009). The average daily wind speed is about 89.9km/hr.

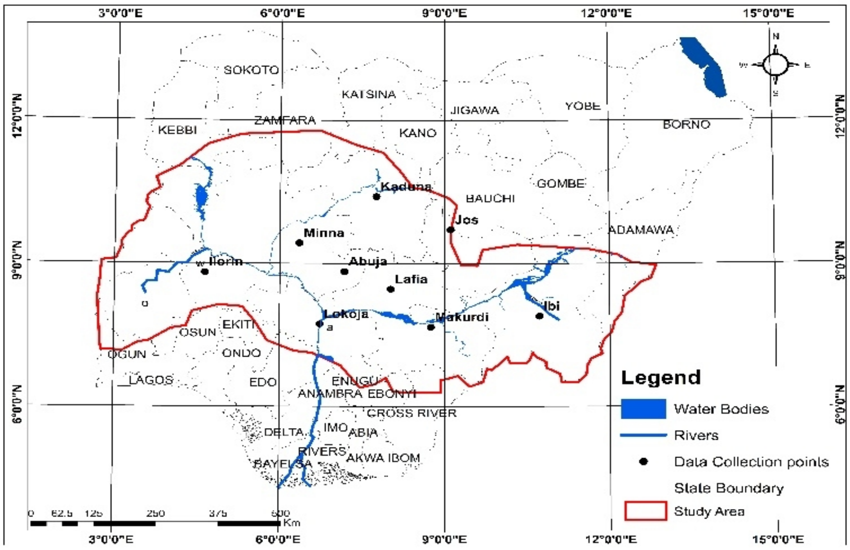

Figure 1: Geographical location of Study Area

Source: Adapted from Audu (2019)

The study area has undulating plains with some dispersed hills, ridges and plateaux with different sizes and heights ranging between 300m-900m (Balogun, 2001). There are also other features of tourist attractions (Gonap, 2018) Zuma Rock at Suleja, Niger State and Wase Rock in Plateau State (Chup, 2005). Rivers Niger and Benue are the two (2) major rivers in the area which facilitated the occurrences of gallery forests and alluvium soil.

Purposive sampling was used to select nine (9) data collection points within the study area Makurdi, Lokoja, Jos, Ibi, Abuja, Minna, Ilorin, Lafia and Kaduna. In this study, Makurdi and Ibi are the eastern flank, Minna, Jos and Kaduna are the northern fringe; Ilorin lies to the west; while Lokoja, Abuja and Lafia lie on the southern flank.

Methods of Data Collection and Analysis

Daily rainfall (mm) data for the data collection points were used for this research. The data spanned from 1981-2015 (35 years) except for Abuja which spanned from 1983-2015 (33 years) and Ibi, 1981-2013 (33 years). The duration of the data was long enough to determine the average of any weather parameter over an area. The secondary data on daily rainfall (mm) used for this research were obtained from the Nigerian Meteorology Agency, Oshodi, Lagos. Heavy rainfall is based on the accumulated rainfall amount within a day (24 hours). Expert

Team on Climate Change Detection Monitoring and Indices (ETCCDMI, n.d.) opined that, heavy and very heavy precipitation values are $\geq$10 mm and $\geq$ 20 mm which is categorized as frequency-related precipitation extreme (FP). This classification is based on a global scale and failed to consider the local peculiarities of Nigeria, hence; not adopted in this study. Ilesanmi (1992) method was adapted by Babatolu *et al*. (2014) to classify heavy rainfall as a value which is $> 25.4\ mm.$ This method has been over taken by recent weather and climate realities especially global warming and climate change.

According to Hounkpé *et al*. (2016), heavy rainfall is a threshold of 50 mm/day; while the study of Salack *et al*. (2018) centred mostly on extreme rain events (EREs) using the 99th percentile thresholds of daily accumulated rainfall in the West African Sahel, hence; was not applied in this study. Odekunle *et al*. (2008); Dami (2008); Chu *et al*. (2009); Ifabiyi and Ojoye (2013); defined heavy rainfall as accumulation of rain which is $>$50.8 mm (2 in)/day^{-1}. However, the description of heavy rainfall adopted in this study was that by Audu *et al*. (2019) which described heavy rainfall as a value which is ɏ 50 mm/day over a specific area. This method takes into cognizance local peculiarities of Nigeria and also recent weather and climate realities.

Heavy rainfall data were extracted from the daily rainfall using micro soft excel application in which all cells containing the considered thresholds were selected. Conditional formatting was chosen with cells rules highlighted and ɏ was clicked, then the available text box with the rainfall value of$\geq$50 mm was clicked. This allows for frequency count of annual heavy rainfall which was used for the calculation of mean, sub-division of the mean into seven (7) episodes of five (5) years each and the classification into high, moderate and low mean. The episodes are 1st, 1981-1985; 2nd is 1986-1990, 3rd is 1991-1995, 4th is 1996-2000, 5th is 2001-2005, 6th is 2006-2010 and 7th is 2011-2015. In this study, high mean heavy rainfall days is taken to be 20+, moderate is from 10-19 and low is 0-9.

Mean annual heavy-rainfall-days data were converted into areal data using geostatistical analyst built in arctool box of arcGIS. Point data were interpolated into rasterized layer which allows point data to be spatially interpolated to areal data using an inverse distance weighting method.

To determine the spatio-temporal mean heavy rainfall days, mean annual heavy rainfall days for each episode was computed using equation 1.

$$\overline{R_d}(h_r) = \frac{1}{n}\sum_{i=1}^{n} f_i \qquad Eqn.\ 1$$

To determine the summary of high, moderate and low mean heavy rainfall days over the flanks, regional mean heavy rainfall days was computed using equation 2.

$$\overline{ZR}_d(h_r) = \frac{\sum_{hi}^{n} R_i}{n} \qquad Eqn.\ 2$$

Where: n= number of stations in the zone, Z = zonal stations

To determine the mean annual heavy rainfall days in each episode, mean heavy rainfall days for each data collection point and episode was computed using equation 3.

Where:

$$\overline{R_D}(h_r) = \frac{1}{N}\sum_{i=1}^{N} F_i \qquad Eqn.\ 3$$

In equations 1-3,

h_r= heavy rainfall

$\overline{R}_d$= mean number of rainfall days

n= number of years in an episode (5 years)

ƒ= the count number of mean heavy rainfall in an episode

i=1,2,....................................n (5 years)

Equation 4 was used to determine the mean regional high heavy rainfall days.

$$\overline{HR}_d(h_r) = \frac{\sum_{i=1}^{n} HR_i}{n} \qquad Eqn. 4$$

Where:

$\overline{HR}_d$= mean high regional rainfall days, h_r = heavy rainfall, HR_i= heavy rainfall days, n = number of data sampling points.

To obtain the mean regional moderate heavy rainfall days, equation 5 was used.

$$\overline{MR}_d(h_r) = \frac{\sum_{i=1}^{n} MR_i}{n} \qquad Eqn. 5$$

Where:

$\overline{MR}_d$ = mean moderate regional rainfall days, h_r = heavy rainfall, MR_i= heavy rainfall days, n = number of data sampling points.

To determine the mean regional low heavy rainfall days, equation 6 was used.

$$\overline{LR}_d(h_r) = \frac{\sum_{i=1}^{n} LR_i}{n} \qquad Eqn. 6$$

$\overline{LR}_d$ = Mean low regional rainfall days, h_r = heavy rainfall, LR_i= heavy rainfall days, n = number of data sampling points.

To determine the overall long term mean heavy rainfall days over the study area, equation 7 was used.

$$\overline{Z_{c(Hml)}} = \sum_{i=1}^{N} Hml_z \qquad Eqn. 7$$

Where:

Z_c= zonal count of mean heavy rainfall days

Hml= high, moderate and low mean heavy rainfall days

z = four regions (northern, southern, eastern and western)

N= total number of Hml within the regions (12)

i = 1..............................N (12)

RESULTS AND DISCUSSIONS

Figures 2-8 show the spatio-temporal variations in mean heavy rainfall days over the study area, 1981-2015. In Figure 2 (1981-1985), the spatial analysis shows that; high mean heavy rainfall days were recorded at the eastern flank of the study area, moderate at the southern and part of the western flanks; while low was observed in part of the western and northern flanks. In Figure 3 (1986-1990), high mean heavy rainfall days was recorded in part of the southern fringe, moderate at the western, part of the southern, eastern and part of northern fringes; while low was recorded in part of the northern fringe.

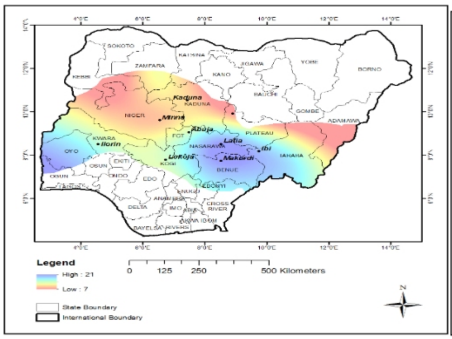

Figure 2: 1981-1985

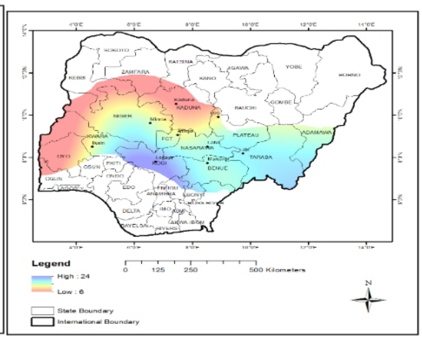

Figure3: 1986-1990

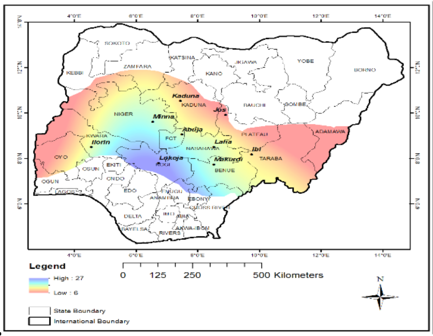

Figure 4: 1991-1995

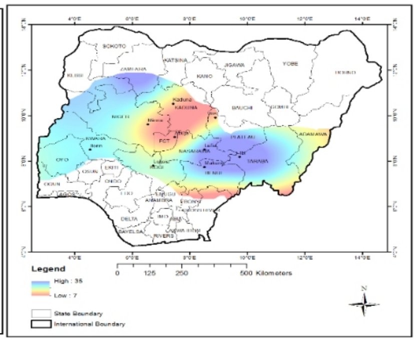

Figure 5: 1996-2000

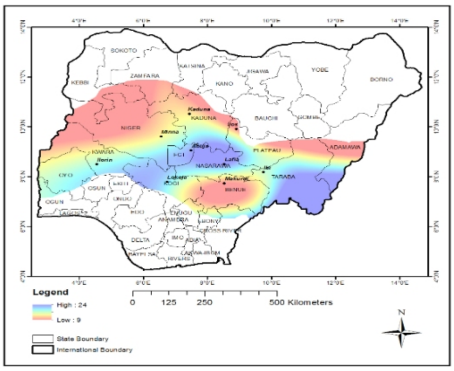

Figure 6: 2001-2005

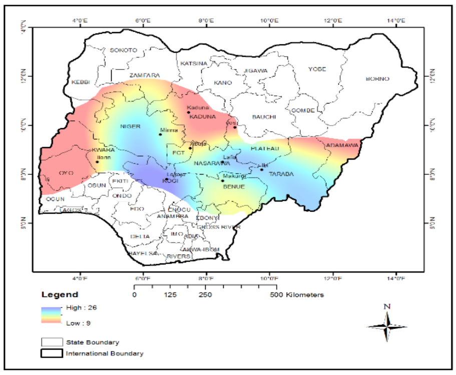

Figure 7: 2006-2010

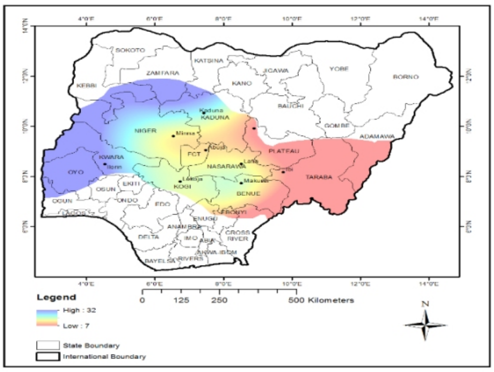

Figure 8: 2011-2015

Analysis in Figure 4 (1991-1995) shows high mean in parts of the southern edge, moderate at the eastern, part of the sourthern and western edges; while low was recorded at the northern edge. In Figure 5 (1996-2000), high mean was observed at the eastern side; moderate in parts of the southern and western sides; while low mean occurred in parts of the southern, western and the northern sides. Figure 6 (2001-2005) shows high mean at the southern and part of the eastern pleuron; moderate at western and part of the eastern pleuron; while low was observed at the northern and part of the eastern pleuron. In Figure7(2006-2010), high mean was observed over part of the southern flank; greater part of the eastern flank; moderate at western, parts of the southern and eastern flanks; while low was observed at the northern flank. In Figure 8 (2011-2015), part of the western flank observed high mean heavy rainfall days; moderate was observed in part of the western flank, part of the northern flank, southern part and greater part of the eastern flank; while low mean was observed at parts of the northern and eastern flanks.

In temporal variation analysis (Figures 2-8), the eastern flank had high mean heavy rainfall days in the 1st, 4th, 5th and 6th episodes; while southern part had it in the 2nd, 3rd, 5th and 6th episodes. Southern and western flanks had moderate mean heavy rainfall days in the 1st and 4th episodes; western, southern, eastern and northern fringes had it in 2nd and 7th episodes; eastern, southern and western had it in the 3rd and 6th episodes; southern and western parts had it in the 4th episode; while western and eastern flanks had it in the 5th episode. Western and northern flanks had low mean heavy rainfall days in the 1st episode, northern part had it in the 1st, 2nd and 6th episodes; southern, western and northern fringes had it in the 4th episodes; while the northern and eastern parts had it in the 5th and 7th episodes. The zone of high, moderate and low mean heavy rainfall changes with episodes.

The summary of high, moderate and low mean heavy rainfall days as shown in Figure 9 revealed zero (0) high mean over northern part; eastern part had five (5), southern part had nine (9) and western part had one (1). In the area of moderate mean high rainfall days, northern and eastern parts had seven (7) each, eleven (11) in southern part, while western flank had six (6). In terms of low mean heavy rainfall days, northern part had fourteen (14), eastern part had two (2), southern part had one (1), while western flank had zero (0). Over the study area, the mean high and low heavy rainfall days are four (4) each; while moderate is eight (8). There are more moderate mean heavy rainfall days over the study area than both high and low. This can be substantiated by the fact that, the study area is sandwiched between Rain Forest Ecological Zone of Nigeria with high annual rainfall and the Sudano-Sahelian Savanna Ecological Zone of Nigeria with low annual rainfall.

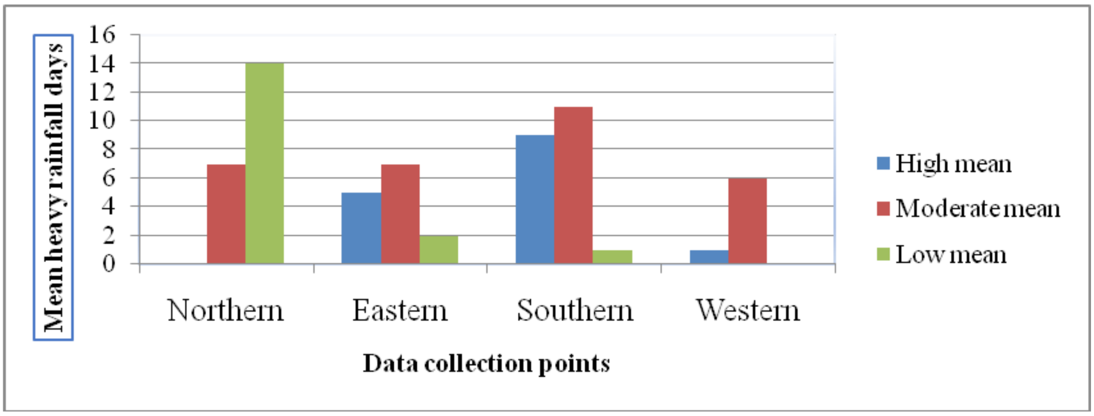

Figure 9: Mean heavy rainfall days over the flanks in the study area, 1981-2015

In Figure 10, episode 1 had the least mean heavy rainfall days of 14; 3rd, 5th and 6th episodes had 16 each, 4th episode had 19 and 7th episode had 17. The overall long-term mean heavy rainfall days over the study area is 7. There is a positive trend in mean heavy rainfall days over the study area in recent time.

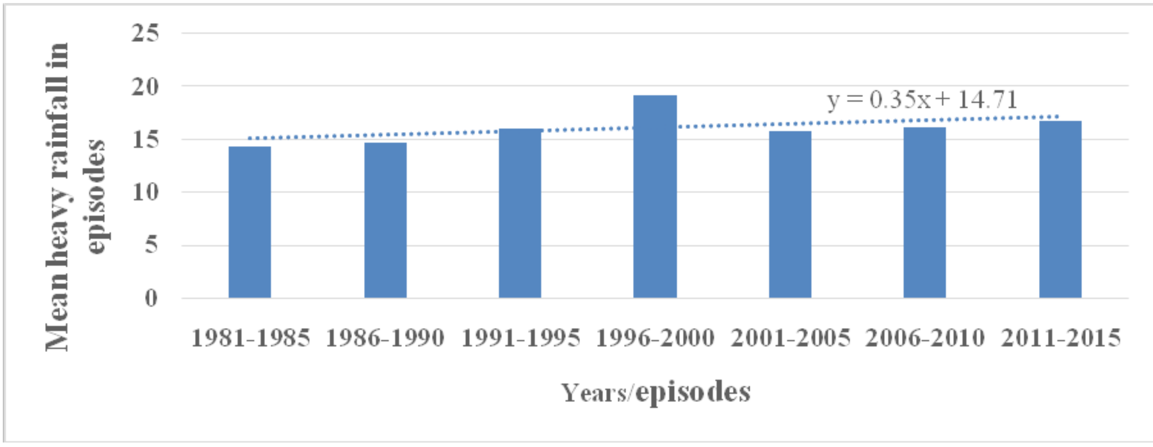

Figure 10: Mean heavy rainfall days in each episode, 1981-2015

In this research, both intra and inter annual variations and changes in the pattern of mean heavy rainfall days were detected across the study area. The spatio-temporal variations in mean heavy rainfall days are mostly attributed to the large spatio-temporal variations that are the general attributes of rainfall in Nigeria. Hence, corroborating the findings of Usman *et al.* (2005) which observed that, the semi-arid and sub-humid zones in the tropical regions are marked by high inter-yearly and intra-seasonal rainfall variations. Variations in the attribute of rainfall could be associated with variations in sunshine hours and intensity, degree of evapotranspiration, type and amount of cloud cover, period of the year, local winds in terms of origin, direction and speed; movement of the inter-tropical convergence zone (ITCZ), local relief as well as land use and land cover changes. IPCC (2007b) observed that, rising air temperature in several decades is tied to changes in some of the components of the water cycle such as rising atmospheric water vapour, rising evaporation, changes in precipitation patterns, intensities and extremes.

This was corroborated by Babatolu (2014) which remarked that, scientists have suggested that temperature changes will increase the average global rainfall, but decline in some locations as rainfall is positively correlated with temperature changes and the amount of solar energy reaching the earth. Adamu and Umar (2016) observed that, Zaria is getting warmer with increasing rainfall. Abubakar (2009) opined that, the amount of transpiration varies greatly over space and time with temperature, relative humidity, wind and air movement; soil moisture availability as well as type of plants as determinants. Mohammed (2008) stated that, urbanisation and urban expansion have led to drastic changes in land uses types in Sharada and Wailari, Kano State especially from rural based uses to urban-based uses. Mean heavy rainfall days decreases from southern towards the northern part of the study area.

The least mean average heavy rainfall days observed in the 1st episode can be attributed to the drought of 1970s which extended to 1980s. Babatolu (2014) reported drought over Nigeria in 1972/73, while Nigerian Meteorological Agency (NiMet, 2016), observed that Northern Nigeria experienced droughts in 1987, 1990 and 2011. Also, between 1981-2015, 1983 had the least annual rainfall in Nigeria (NiMet, 2017). The highest average heavy rainfall days in the 4th episode is attributed to the high rainfall recorded in the late 1990s especially in 1999 over some areas within the study area which was due partly to global warming, climate variability and climate change. This corroborated the findings of Terdoo (2012) which stated that, between 1989-2008, Markudi observed the highest annual rainfall between 1997 to 1999. The positive trend in average heavy rainfall days is as a result of increasing rainfall over the area in recent time. NiMet (2017) observed positive anomalies in annual rainfall over Northern Nigeria in 2010, 2012, 2014, 2016 and 2017.

Annually, the study area records series of hydro-meteorological hazards with flooding (Akinsanola and Aroninuola, 2016) erosion, water pollution and landslides being the commonest. Of these hazards, flooding is most prominent, frequent, wide spread, sporadic and destructive. These hazards are attributed mostly to heavy, frequent, excessive and prolong rainfall. The study of Sambo *et al*. (2016), observed that the increase in rainfall intensities in Cross River Basin, Nigeria; has affected the flows of rivers thereby increasing the risk of flooding. Labiru *et al*. (2016) observed that flooding displaces people, claims lives and damages property. Flooding is increasing socio-economic hardship in Nigeria.

CONCLUSION AND RECOMMENDATIONS

This study has assessed the spatio-temporal variations of mean heavy rainfall days over the Guinea Savanna Ecological Zone of Nigeria using data on daily rainfall (mm). The study area was divided into four (4) flanks of north, south, west and east to allow for a better analysis. Heavy rainfall was determined by an accumulation of rain which is $\geq$ 50 mm/day which was extracted using micro soft excel application. Frequency count of annual heavy rainfall days was carried out and used to calculate the mean. The mean heavy rainfall days was later divided into seven (7) episodes of five (5) years each and classified into high (20+), moderate (10-19) and low (0-9). Results revealed both inter and intra annual spatio-temporal variations in mean heavy rainfall days over the study area. Also revealed is the pattern of mean heavy rainfall days (high, moderate and low) which cuts across all flanks within the study area.

Northern flank had zero (0) high mean (lowest), east had five (5), south had nine (9) which is the highest and west had one (1). In moderate mean heavy rainfall days, north and east had seven (7) each, south had eleven (11) which is the highest and west had six (6). In low mean heavy rainfall days, north had fourteen (14) which is the highest, east had two (2) south had one (1) and west had zero (0). High and low mean heavy rainfall days in the study area is four (4) each, while moderate is eight (8) days. Episode 1 (1981-1985) had the least mean heavy rainfall days of 14; 3rd, 5th and 6th had 16 each, 4th (1996-2000) had 19 (highest) and 7th had 17. The overall long-term mean heavy rainfall days is seven (7) and there is positive trend in mean heavy rainfall days in recent time. Based on the findings of this research, it is recommended that, there should be frequent forecast of heavy rainfall to serve as an early warning tool and also enable the government, individuals and Non-Governmental Organisations (NGOs) to educate the masses in areas that are highly flood-prone to prepare adequately for mitigation and adaptation measures. Annual variations in heavy rainfall days should be calculated using the long-term mean in order to ascertain the effect of changing rainfall pattern on the number of annual heavy rainfall days.

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