Spatiotemporal Variability of Rainfall as an Evidence of Changing Climate over the Nigerian Niger Delta

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Abstract

This study assesses the spatial and temporal variability of rainfall over the Niger Delta area (Benin, Calabar, Port Harcourt and Uyo) in Nigeria between 1990 and 2020. The daily rainfall data used for this study were obtained through secondary source from NASA's POWER (Prediction of Worldwide Energy Resources). Coefficient of variation, standardized anomaly index (SAI), precipitation concentration index (PCI) and seasonality index (SI) were used to evaluate rainfall variability and seasonality. The results of temporal analysis of annual rainfall indicated that Benin had the highest annual rainfall amount in 2000 and lowest in 1999 while Calabar and Port Harcourt had their highest rainfall amount in 2007 with the lowest occurring in 1991 and 2014 respectively. Uyo had the highest in 2000 and lowest in 2014. SAI also witnessed the presence of inter-annual variability of rainfall with negative and positive anomalies in 59.46% and 40.54% of the analyzed years, respectively. PCI and SI results implied that the Niger Delta area had strong irregular rainfall distribution. The results confirm the meteorological sensitivity to locations and provide support for the implementation of station and regional meteorological hazards prevention and to support the mitigation of hazards and improve the management practices of environment system in Niger delta area.

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Introduction

Climate changes significantly affect environmental and hydrological processes. Rainfall is one of the most significant climatic parameters and its variability and trends have great impacts on environmental and socioeconomic development (Binbin et al., 2020). Rainfall has been of primary importance in most studies on climate science, with its variability exerting significant impact on the society. The variations in the mean state of rainfall and temperature on all temporal and spatial scales beyond that of individual events is referred to as climate variability. The time scale could be in months to years (McDonnell et al., 2000; Shaibu and Weli et al., 2017). The United Nations Framework Convention on Climate Change (UNFCC) describes climate Change (CC) as "a change in climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere which is in addition to natural climate variability observed over comparable time periods" (UNFCCC, 2011, p. 2). Intergovernmental Panel on Climate Change (IPCC) refers to climate change as a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or because of human activity. The IPCC definition differs from that of the United Nations Framework Convention on Climate Change (UNFCCC), where climate change is attributed to human activity. There is new and strong evidence that most of the global warming observed over the last 50 years is attributable to human activities (IPCC, 2001, p. 788; UNFCCC, 2011, p. 1). Global warming, changing weather patterns, and rising sea levels have all been linked to climate change, which raises the chance of catastrophic flooding and affects agricultural production. The effects of climate change are unprecedented in scope and scale and are felt globally. The Niger Delta region of Nigeria is highly susceptible to adverse environmental changes caused by climate change, particularly a change in temperature and precipitation. The World Meteorological Organization (WMO) defines climate variability as variation in the mean state and other statistics of the climate (temperature, rain and wind)

on all temporal and spatial scales, beyond individual weather events (WMO, 2019). Character of climate variability is determined by exposure to climate related hazards e.g., increased precipitation and flooding. The concern for climate change has increased in recent times because it affects human survival in terms of food security and health. Extreme weather and climate events have constituted serious threat to global economic growth over the past years, especially to the socio-economic state of developing nations. In Nigeria, severe floods, windstorm, heat waves and several other extreme weather and climate events have affected its socio-economy negatively, and many people have been affected physically and psychologically. The world's coastal region, the Niger Delta, is currently experiencing floods because of a rise in sea level caused by the melting of polar ice, which is a result of an increase in temperature. Unquestionably, it is significant that oil exploration and exploitation have had a negative impact on the Niger Delta's temperature change. (Efenji et al., 2014).

Precipitation can be characterized by various indices, such as annual total amount, frequency, duration, and intensity (Zolina et al., 2010; Guilbert et al., 2015; Hu et al., 2017; Trenberth and Zhang 2018, Yu et al., 2021). Any change in these precipitation characteristics may lead to an increase or decrease in water use efficiency and thus affect water resource planning and management practices. Also, changes in extreme precipitation events may result in devastating effects on human society and their living environment. For example, a decrease in precipitation amount may cause drought, while an increase in precipitation intensity, frequency, and wet persistence may exacerbate soil erosion and trigger flooding and other disasters. According to (Weldegerima et al., 2018), one of the most significant climatic variables that influence agricultural output and ecosystem health both directly and indirectly is rainfall. Unpredictable rainfall patterns and frequent extreme events like droughts, floods, and irregularities in seasonal rainfall amount and distribution are among the major climate-related disasters that have a significant impact on food security and economic growth (Cattani et al., 2018). The importance of analyzing the spatial distribution and the temporal trends of rainfall cannot be overemphasized because it is crucial for water resource management, agricultural productivity, and

climate change mitigation (Ayalew et al., 2012). Furthermore, rainfall analysis gives vital information for decision-makers on tasks including water resource management, development, policy planning, and disaster readiness (Suzit et al., 2013).

Akinsanola et al., (2014) analyzed the occurrences of abrupt changes in temperature and rainfall values over Nigeria using data from 25 synoptic stations from 1971- 2000 (30years). The result shows that there have been statistically significant increases in precipitation and air temperature in vast majority of the country, with sequence of alternately decreasing and increasing trends in mean annual precipitation and air temperature in the study area. The Niger Delta region of Nigeria is highly vulnerable to adverse environment changes caused by climate change and chiefly a change in the temperature and rainfall. Abdullahi et al., (2019) noted that proximity of Niger Delta to the Atlantic Ocean and topography contributed greatly to variation in rainfall characteristics in Nigeria. Despite the spatial differences in rainfall trends, rainfall received across the study period in Nigeria is consistent. Some stations in the Niger Delta that has very close proximity to the Atlantic Ocean, seems to have noticeable variation in the characteristic of rainfall characteristics especially at the annual scale. Thornton et al., (2014) and Abdullahi et al., (2020) also noted that rainfall tends to decrease with distance from the equator. The variability of rainfall from annual average is greater in a region that gets little precipitation. The rising trend in rainfall amount may oppose a serious threat to areas that susceptible to flooding because reservoirs could easily overflow, resulting in the loss of lives and properties (Abaje et al., 2015). This variation despite having similar geographical characteristics calls for check in order to identify where changes are more pronounced. Therefore, this study seeks to assess the spatial-temporal distribution of rainfall over four coastal stations in the Niger Delta region of Nigeria for a period of 31 years (1990–2020). It will also examine climatic trends and patterns of rainfall over the study area in order to see if there is a major dispersion over the years.

Study Area

The Niger Delta region is situated in the southern part of Nigeria and bordered to the south by the Atlantic Ocean and to the east by Cameroon. It occupies a surface area of about 112,110 square kilometers (Niger Delta Regional Development Master Plan, 2006) and it occupies 7.5% of Nigeria's land mass. Furthermore, Niger Delta region is located on the Atlantic coast of Southern Nigeria, the Niger Delta lies within the lower reaches of the Niger river, extending between latitudes, longitudes of 05°19′34″N 06°28′15″E and 5.32611°N 6.47083°E (WGS, 1984). Historically and geographically, the Niger Delta consists of the present-day Bayelsa, Delta, and Rivers states. Abia, Akwa-Ibom, Cross River State, Edo, Imo, and Ondo States (of the Federal Republic of Nigeria) were included in the Niger Delta geopolitical zone by President Obasanjo in 2000. The South-South Zone of Nigeria is different from the Niger Delta region. Only six states make up the geographical region known as the South-South Zone of Nigeria: the states of Akwa-Ibom, Bayelsa, Cross-River, Delta, Edo, and Rivers. Nine (9) states make up the current Niger Delta region: Abia, Akwa-Ibom, Bayelsa, Cross River, Delta, Edo, Imo, Ondo, and Rivers (Niger Delta Regional Development Master Plan, 2006*)*. There are two distinct seasons with the wet season occurring from April to September and the dry season from October to February (World Bank, 1995). The natural vegetation of the study area is that of the rain forest but this has been destroyed by the activities of man such as bush burning, farming, construction and illegal crude oil refining activities. The vegetation consists of various kinds of evergreen trees, including palm trees and a variety of shrubs. More than 70 % of the inhabitants of the study area are engaged in subsistence farming and fishing. This work focused on four stations in Niger Delta area of Nigeria. The four (4) stations are Benin (Edo state), Calabar (Cross river state), Port Harcourt (River state) and Uyo (Akwa-Ibom state).
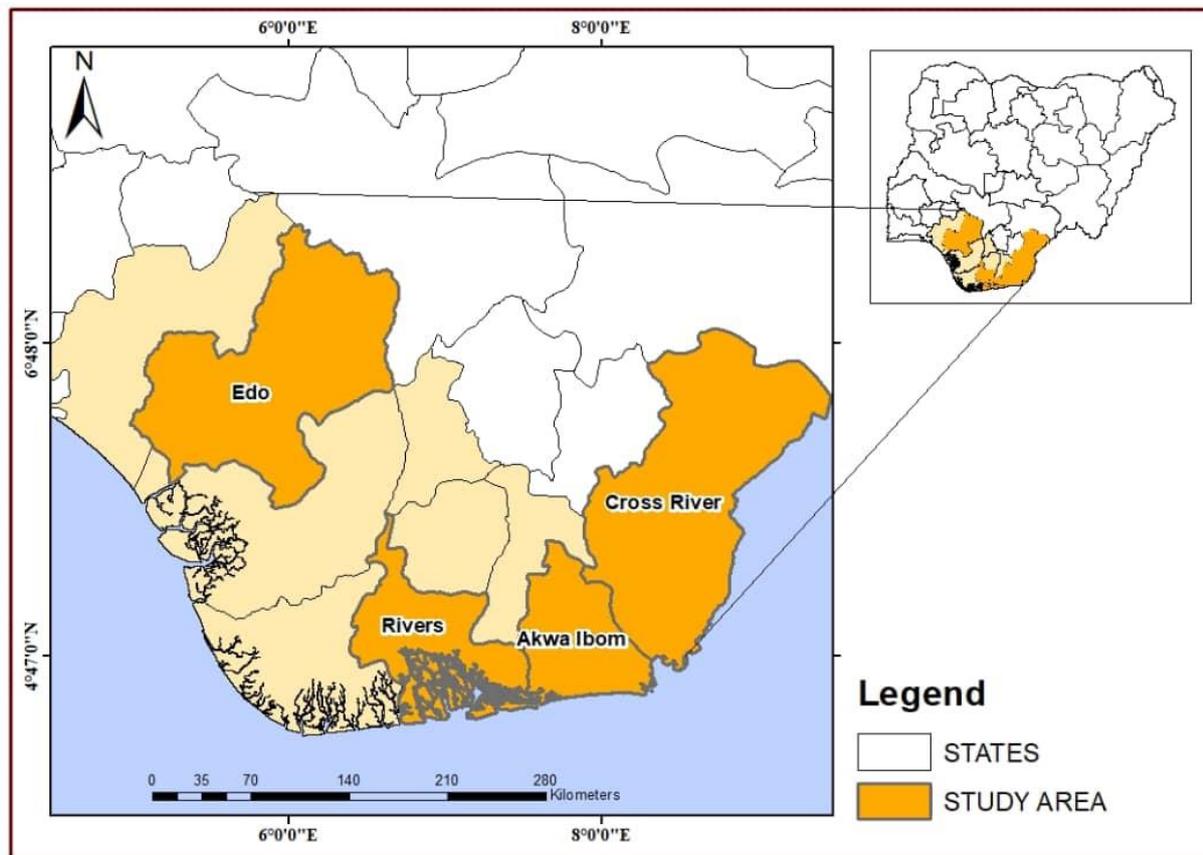
 Fig 1: Map of Nigeria, indicating study area.

Methodology

Data

The data for this work consist of daily rainfall values. The daily rainfall data were obtained through secondary source from NASA's POWER (Prediction of Worldwide Energy Resources). The data span from 1990 to 2020 (31 years) for the four (4) locations which are located in Niger Delta area of Nigeria. These locations include; Benin (Lat. 6.33°N, long. 5.60°E), Calabar (Lat. 4.97°N, long. 8.34°E), Port Harcourt (Lat. 4.81°N, long. 7.05°E) and Uyo (Lat. 5.04°N, long. 7.91°E)

Method of analysis

The monthly mean and total annual rainfall values were computed for the period under study from daily data. Statistical analysis such as summation and averaging were carried out on the data.

The annual rainfall amount was computed for each location using equations 1

$$A_R = \sum_{i=1}^{12} Ri \quad \text{--------} \quad 1$$

Where R is the monthly rainfall amount at each location, A_R is the annual rainfall amount at that location

The mean monthly rainfall amount for the period of thirty-one years were computed for each location using equation 2

$$\bar{R} = \frac{\sum_{j=1}^{31} Rj}{31} \quad \text{----------} \quad 2$$

Where $\bar{R}$ represents the mean monthly rainfall amount for each location over the 31 years period, while j is the period of thirty-one years.

The data were graphically analyzed for the four (4) locations to determine the trend and pattern of rainfall and temperature, and temporal variation of rainfall and temperature for the months and years over the locations. The spatial variation analysis of rainfall and temperature from 1990-2020 were carried out using surfer 13.0 and ARCGIS 10.3 (Aeronautical Reconnaissance Coverage Geographic Information System) was used to map the areas of study.

COEFFICIENT OF VARIATION (CV)

Coefficient of variation is computed using equation 3.

$$CV = \frac{\sigma}{\mu} \times 100 \quad \text{----------} \quad 3$$

Where σ is the standard deviation and μ is the mean rainfall for the chosen temporal scales. Generally, CV is used to classify the degree of variability of rainfall events into three: low (CV < 20), moderate (20< CV< 30), and high (CV> 30). (Asfaw et al., 2018).

STANDARDIZED ANOMALY INDEX (SAI)

Standardized anomaly index is computed using equation 4.

$$\text{SAI}_i = \frac{X_i - \bar{X}}{\sigma} \quad \text{----------} \quad 4$$

Where X_i is the annual rainfall of the particular year; $\bar{X}$ is the long-term mean annual rainfall over a period of observation and σ is the standard deviation of annual rainfall over the period of observation. Negative values indicate a drought period as compared to the chosen reference period while the positive ones indicate a wet situation.

PRECIPITATION CONCENTRATION INDEX (PCI)

Precipitation concentration index is computed using equation 5.

$$\text{PCI} = \frac{\sum_{i=1}^{12} P^2 i}{(\sum_{i=1}^{12} Pi)^2} \times 100 \quad \text{---------} \quad 5$$

Where Pi is the monthly precipitation in month i. Oliver (1980) suggested that PCI value <10 represents a uniform precipitation distribution; PCI values from 11 to 15 show moderate rainfall concentration; values from 16 to 20 indicate an irregular distribution; and values above 20 represent a strong irregular precipitation distribution.

SEASONALITY INDEX (SI)

Seasonality index is computed using equation 6.

$$\text{SI} = \frac{1}{\bar{P}} \sum_{i=1}^{12} (\bar{P}_i - \frac{\bar{\bar{P}}}{12}) \quad \text{-----------} \quad 6$$

Where, $\bar{P}_i$ is the mean rainfall (mm) of the ith month, and $\bar{\bar{P}}$ is the mean annual rainfall (mm). The index varies from zero, if all the months have equal rainfall, to 1.83 if all the rainfall occurs in a single month.

Results and discussion

Annual variations of Rainfall (1990-2020)

Figure 2 depicts annual rainfall amount over Benin, Calabar, Port Harcourt and Uyo from 1990-2020
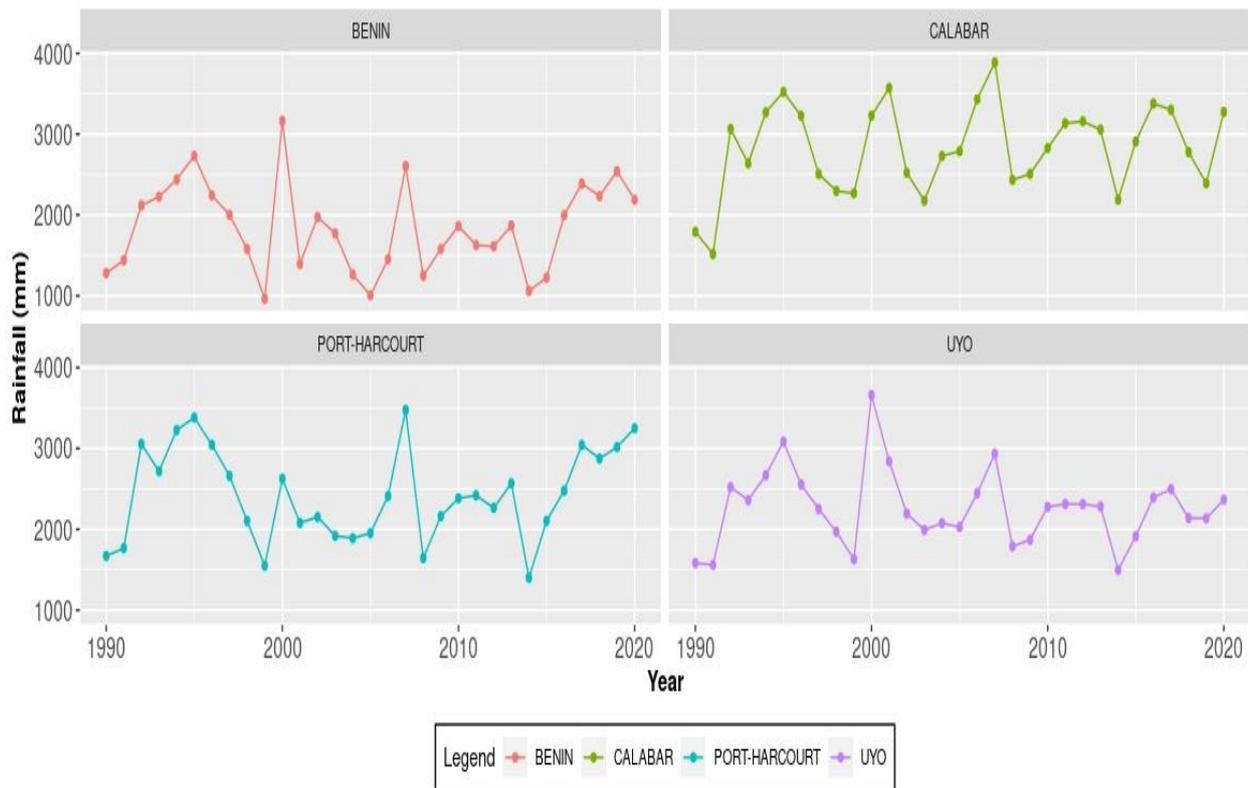
Figure 2: Annual rainfall amount over Benin, Calabar, Port Harcourt and Uyo from
1990-2020.

The stations had the highest rainfall amount of 3164mm, 3887mm, 3476mm and 3660mm respectively for Benin, Calabar, Port Harcourt and Uyo, which were recorded in year 2000, 2007, 2007 and 2000. The lowest were observed in 1999, 1991, 2014 and 2014 with a value of 962mm, 1516mm, 1400mm and 1498mm respectively for Benin, Calabar, Port Harcourt and Uyo

Monthly mean of Rainfall (1990-2020)

Figure 3 shows the monthly mean of rainfall over Benin, Calabar, Port Harcourt and Uyo from 1990-2020
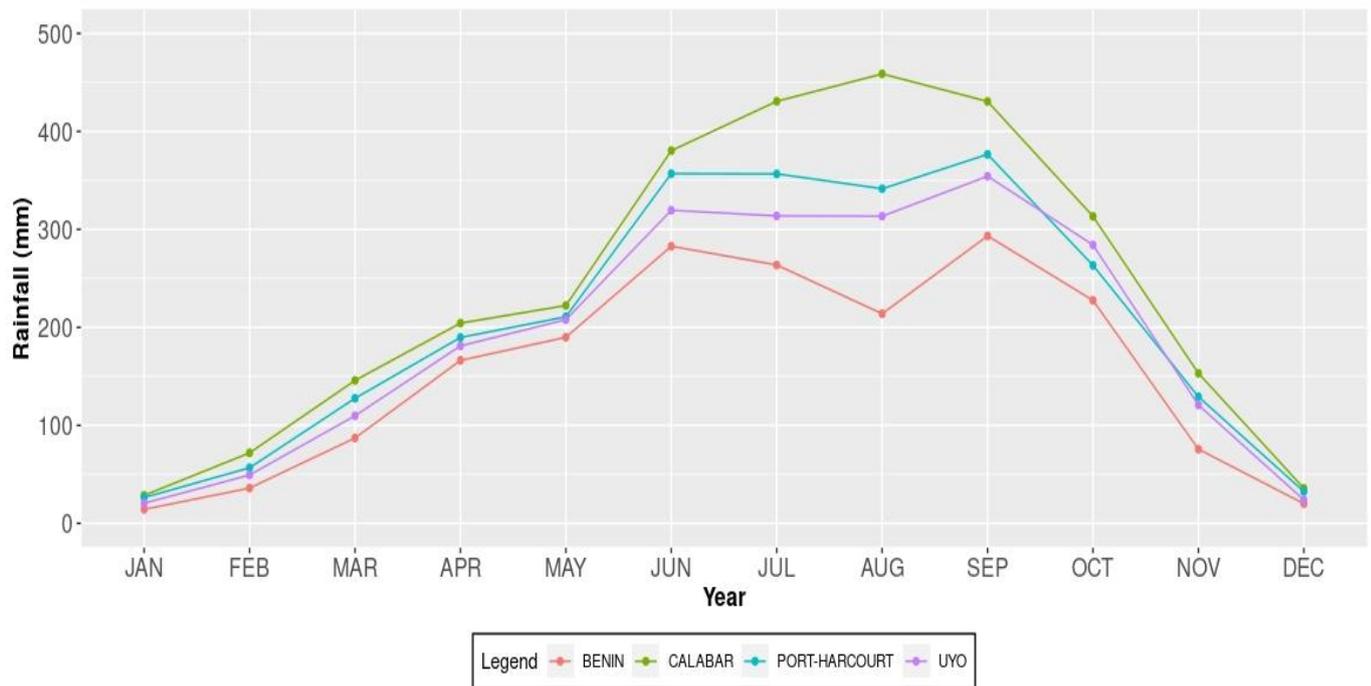
Figure 3: Monthly mean of rainfall over Benin, Calabar, Port Harcourt and Uyo from 1990-2020.

The pattern of monthly rainfall agrees with Adejuwon, (2012) based on the onset and cessation of rainfall, which rainfall starts in February/March and terminates November/December. It is observed that there is more rainfall between March and October, and less rainfall between November and February. The four locations are expected to have a bi-modal rainfall peaks, with a little dry season within the rainy season but from figure 4 Benin has a more pronounced little dry season followed by Port Harcourt while Uyo is not clearly noticeable. Little dry season does not occur in Calabar. In August, a brief dry season accounts for a small decrease in the monthly mean rainfall.

Spatial variation of Rainfall

Figure 4a-4f depicts the spatial variation of rainfall on a five-year interval scale over Benin, Calabar, Port Harcourt and Uyo.
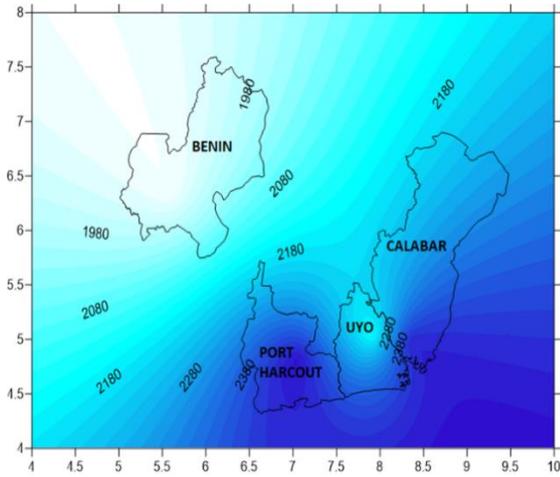
Fig 4a: Spatial analysis of rainfall from 1990-1994   Fig 4b: Spatial analysis of rainfall from 1995-1999
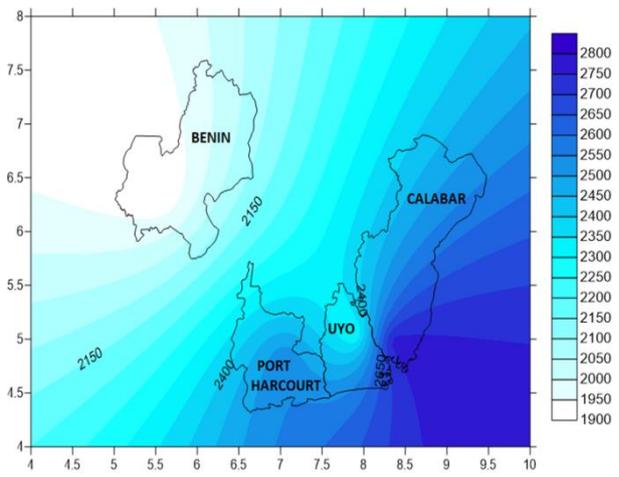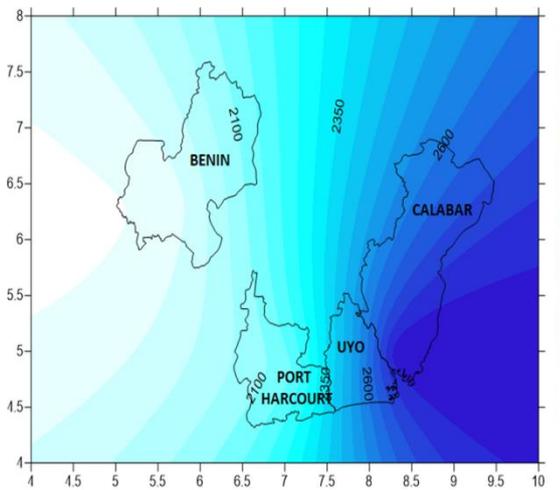
Fig 4c: Spatial analysis of rainfall from 2000-2004   Fig 4d: Spatial analysis of rainfall from 2004-2009
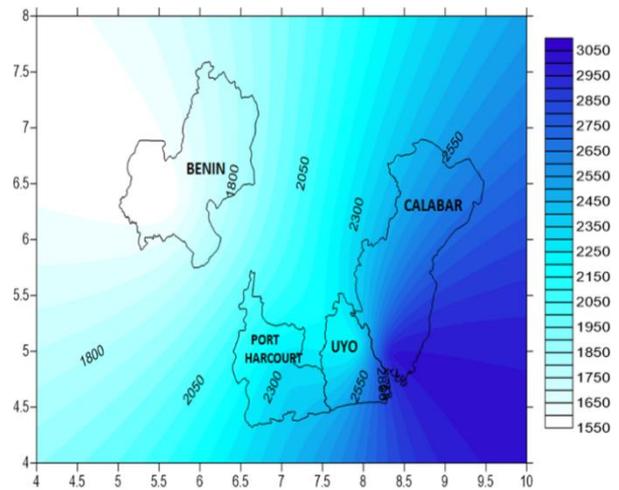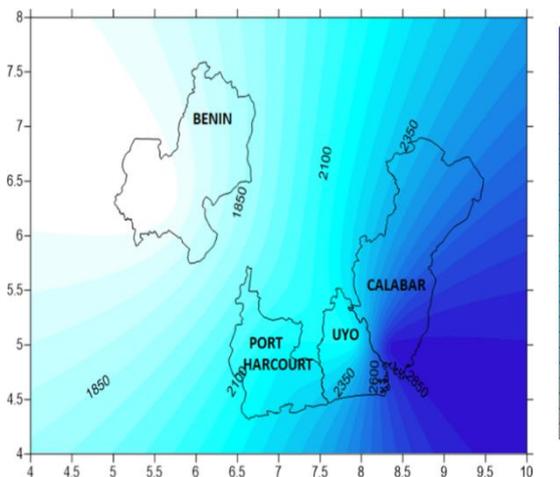
Fig 4e: Spatial analysis of rainfall from 2010-2014   Fig 4f: Spatial analysis of rainfall from 2015-2020
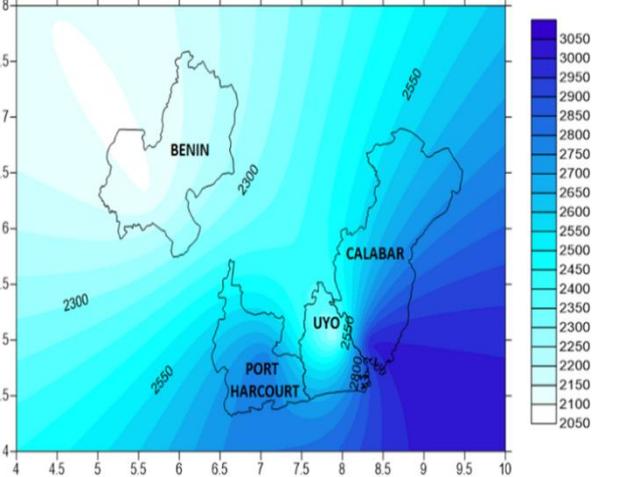
From the figure, it shows that the locations with blue colorations have the highest annual rainfall amount and the locations with white colorations have the lowest annual rainfall amount. Rainfall amount in the Niger Delta is observed to be high due to its closeness to the Atlantic Ocean and presence of highlands that aids orographic processes. The Atlantic Ocean provides maritime tropical trade winds (Southwesterly wind) which brings moisture to the land. The Niger Delta is also influenced by highlands, which improve orographic processes in this region, which in turns result in rain. The average of annual rainfall amount of the four locations during the period of study vary from 1,800 to over 3,000 millimeters. These results show that Calabar is the location with highest amount of rainfall of all the four locations throughout the study period (1990-2020), followed by Port Harcourt, Uyo and Benin. According to the distribution, each location's rainfall is determined by its proximity to the Atlantic Ocean. The locations closest to the Atlantic Ocean receive the most rainfall, while the locations furthest from the equator receive the least, according to Abdullahi et al., (2019). In addition, Benin, which is the closest of all the study areas to the North, had the least rainfall amount. This indicates a northward reduction for rainfall as supported by the studies of Oguntunde et al., (2012), Adejuwon, (2012).

Rainfall summary statistics

Rainfall characteristics, such as mean, standard deviation (SD), Coefficient of Variation (CV), and percentage contribution of monthly and seasonal rainfall to annual rainfall were computed for the period 1990 to 2020 over the study area and the results are presented in table 1.

Table 1: Summary statistics of rainfall in Niger delta region (1990–2020)

MONTH	MEAN (MM)	SD (MM)	CV (%)	CONTRIBUTION TO ANNUAL RAINFALL (%)
JAN	22.4	6.4	28.5	0.94
FEB	53.5	15.0	28.0	2.25
MAR	117.6	25.1	21.3	4.94
APR	185.4	15.9	8.6	7.79
MAY	207.7	13.4	6.5	8.74
JUN	334.9	42.8	12.8	14.08
JUL	341.2	70.8	20.7	14.35
AUG	331.9	100.7	30.3	13.96
SEP	363.7	56.8	15.6	15.29
OCT	272.1	36.1	13.3	11.44
NOV	119.7	32.4	27.1	5.03
DEC	28.0	7.3	26.0	1.18
ANNUAL	2378.2	516.8	21.7	100.0
MAM	510.7	54.2	10.6	21.48
JJA	1008.1	212.8	21.6	42.39
SON	755.5	123.1	16.3	31.77
DJF	103.9	28.3	27.3	4.37
RAINY SEASON	2274.3	336.1	14.8	95.63
DRY SEASON	103.9	24.5	23.6	4.37

DJF (December, January and February), MAM (March, April and May), JJA (June, July and August)

and SON (September, October and November)

The mean annual rainfall was 2378.2 mm with standard deviation 516.8mm. September (363.7mm)

and July (341.2mm) contributed the maximum share to the annual rainfall budget (15.29% and

14.35%, respectively) followed by June (14.08%) and August (13.96%). December and January received the least rainfall, and contributed 1.18% and 0.94% of the annual rainfall, respectively. The major share of the annual rainfall 42.39% was received in JJA and 31.77% in SON 21.48% in MAM and 4.37% in DJF

Figure 5 depicts the spatial distribution of annual rainfall during the period of 1990–2020.
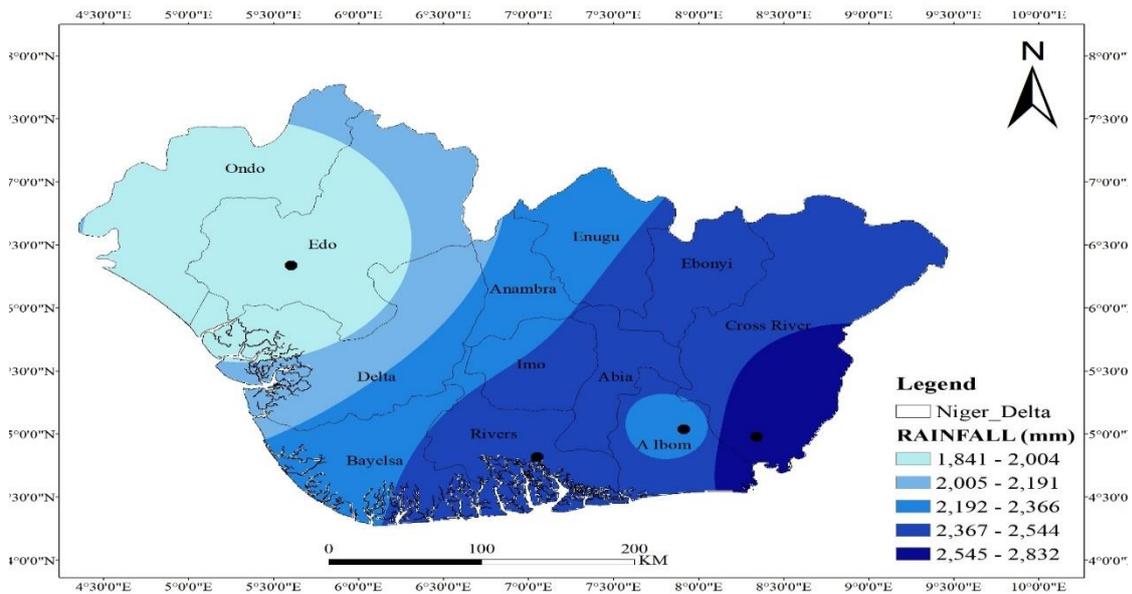
Figure 5: Spatial distribution of annual rainfall during the period of 1990–2020

From figure 5, it can be seen that the highest rainfall values were recorded in the eastern part and the lowest values were recorded in the western part of the study area.

Figure 6a & 6b depicts the spatial distribution of rainfall for all seasons from 1990-2020
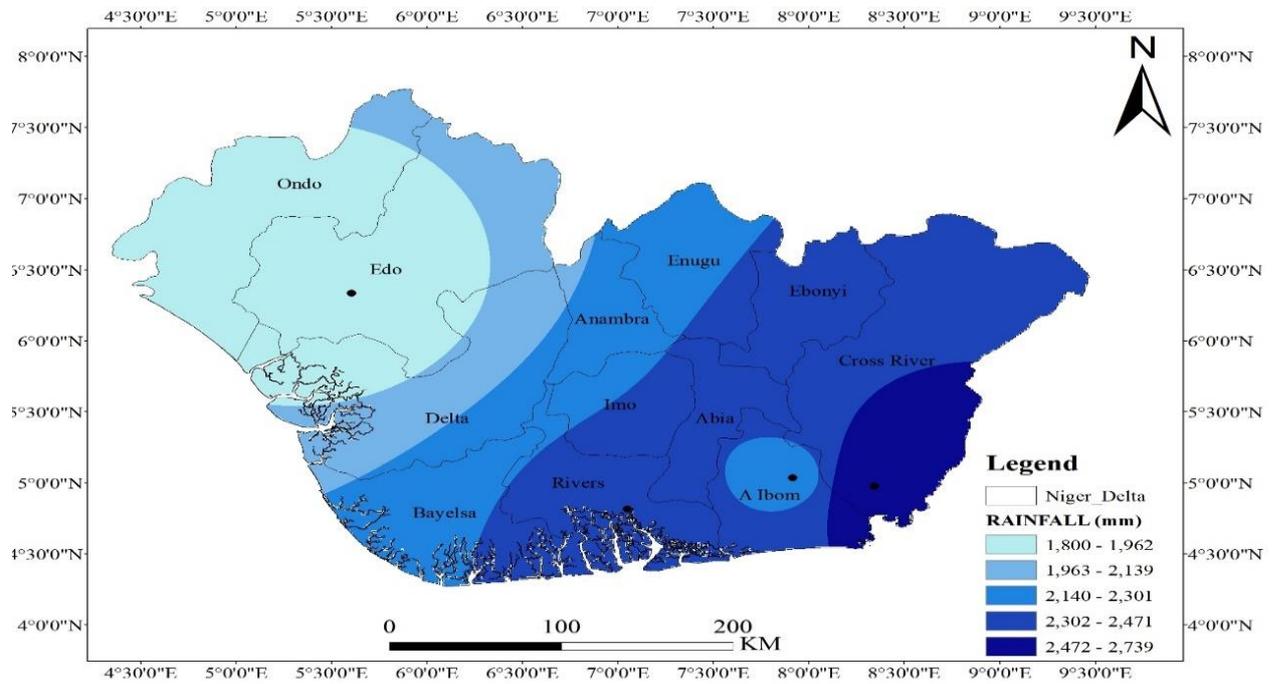
Figure 6a: Spatial distribution of Seasonal rainfall (Rainy season) of Niger Delta from
1990-2020
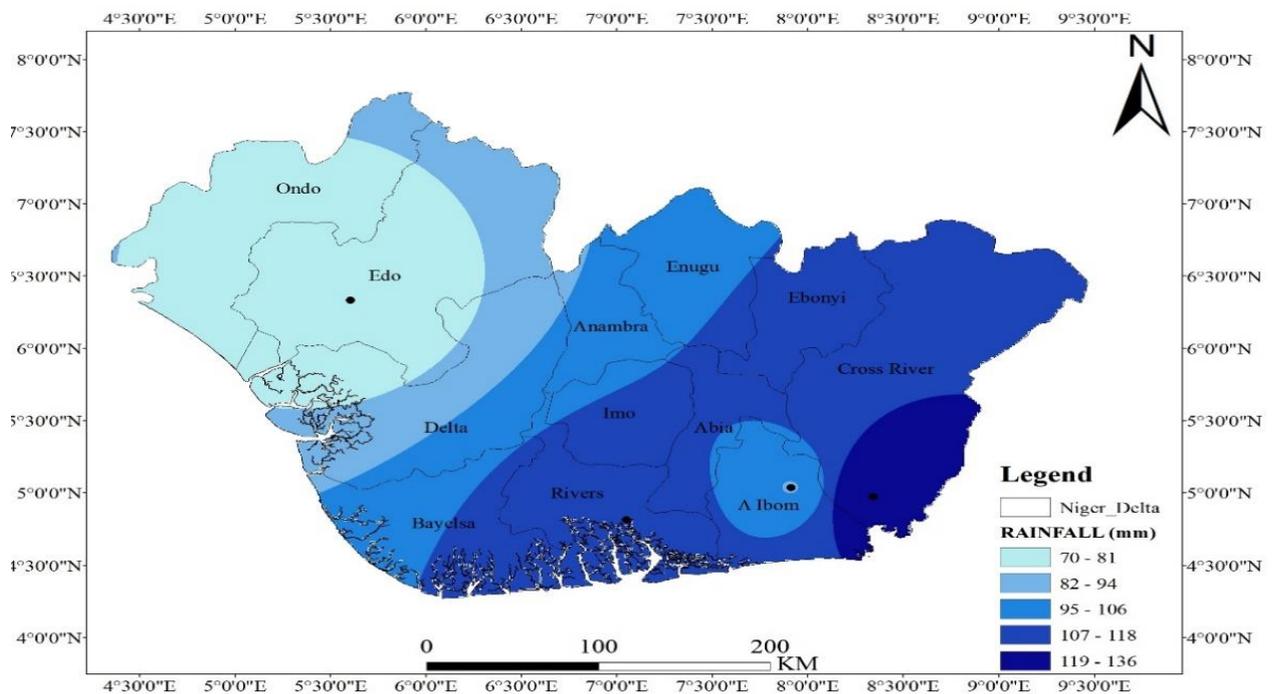
Figure 6b: Spatial distribution of Seasonal rainfall (Dry season) of Niger Delta from 1990-2020

During rainy season, the southeastern part of the study area received maximum rainfall while the northern and northwestern parts of the study area received low rainfall. Similarly, during dry season, the highest rainfall was observed in the southeastern and southwestern parts of the region. Both rainy and dry season almost followed same pattern.

Variability and Anomalies of Rainfall between 1990 and 2020

The spatial distribution of the coefficient of variation of the annual rainfall in the study area is shown in Figure 7
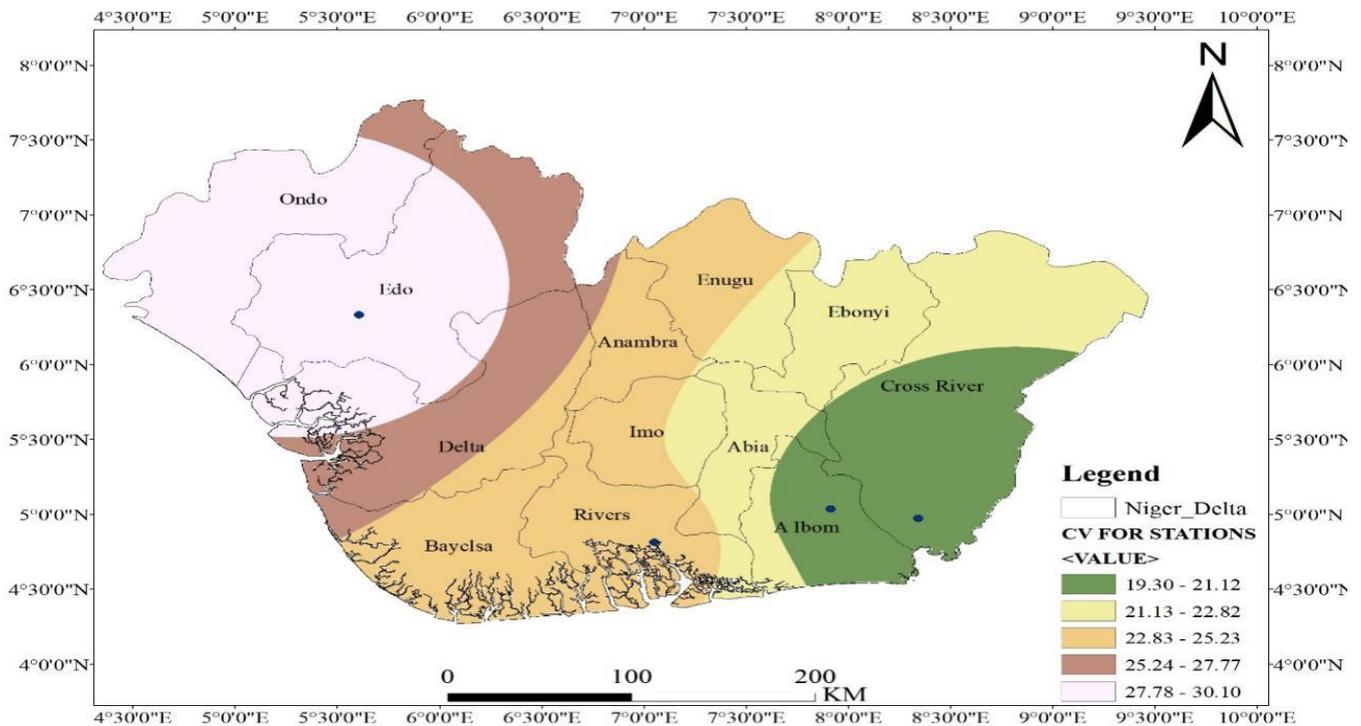
Figure 7: Spatial distribution of the coefficient of variation of the annual rainfall from

1990- 2020

The CV varied from 27.78% in the western part of the study area to 19.30% in the eastern part of the study area. Areas with high annual rainfall indicated less inter-annual variation whereas areas with low annual rainfall showed moderate inter-annual variation. The moderate inter-annual variability in low rainfall areas indicated that comparably there was a greater contrast in annual rainfall values from

year to year, and it suggested that in such areas, water availability became somehow more unpredictable as compared to areas with low CV.

Figure 8 shows the spatial distributions of the CV of seasonal rainfall (Dry) of Niger Delta from 1990-2020
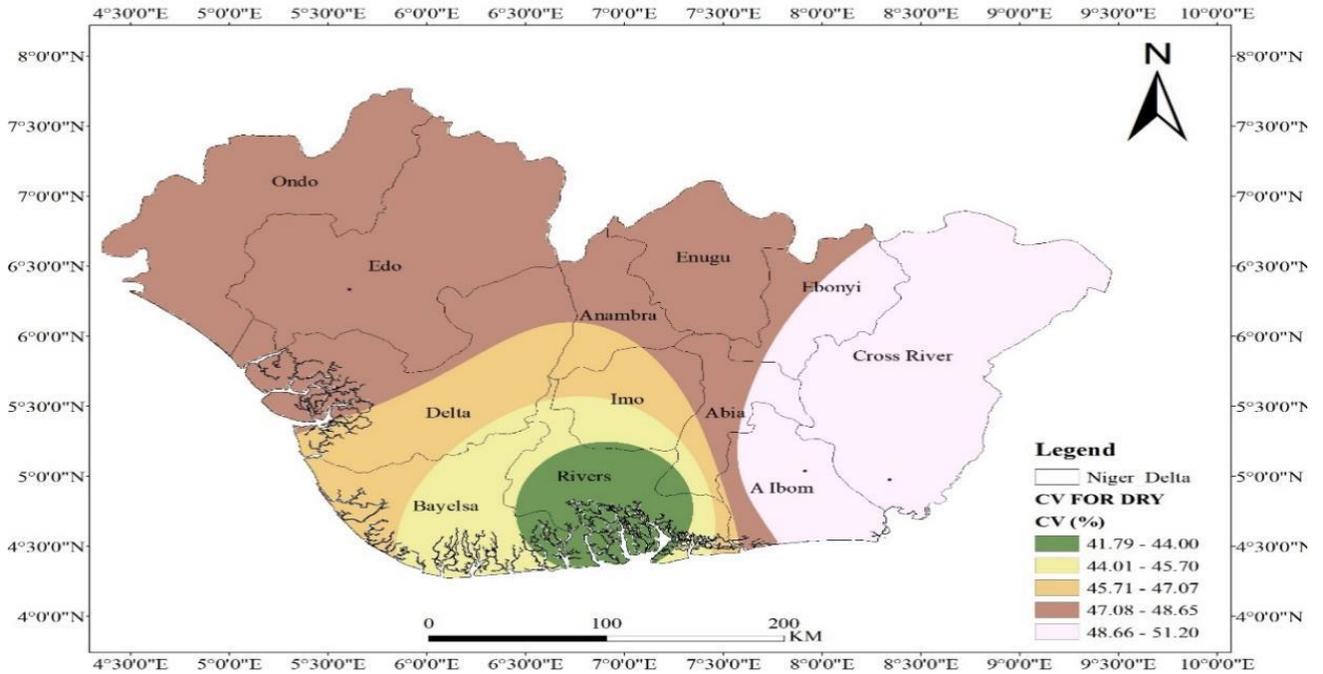
Figure 8: Spatial distribution of CV of the seasonal rainfall (Dry) of Niger Delta from 1990- 2020

Figure 9: shows the spatial distribution of CV of the seasonal rainfall (Rainy) of Niger Delta from 1990-2020
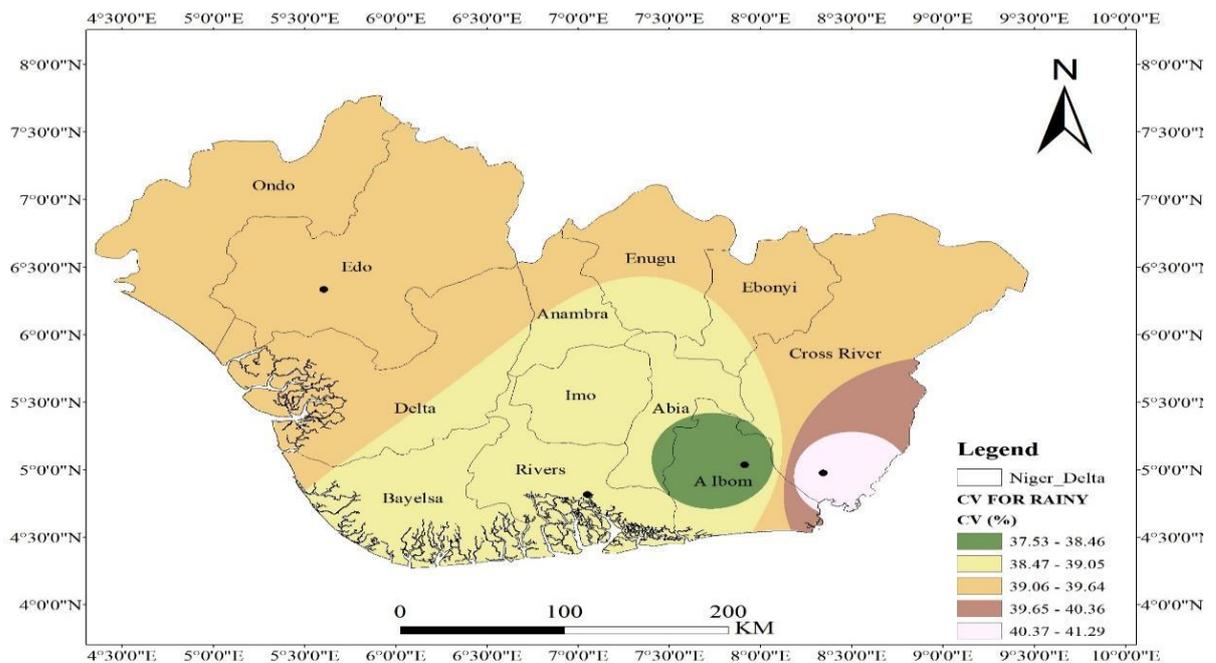
Figure 9: Spatial distribution of CV of the seasonal rainfall (Rainy) of Niger Delta from 1990-2020

Generally, results of CV of seasonal rainfall revealed variable spatial and temporal trends in the study area. Maximum CV in DJF rainfall was observed in the northwestern and northeastern parts of the area, whereas in SON rainfall, the maximum CV was observed in the eastern and southern parts. Similarly, in MAM and JJA, the highest values of the coefficient of variation were observed predominantly in the northern and eastern parts, respectively.

Figure 10 shows the annual rainfall anomalies over the Niger delta region from 1990 to 2020. The rainfall anomalies showed the presence of inter-annual variability of rainfall and the negative and positive anomalies. The highest positive anomaly was observed in 2007 with a value of 1.9 while the highest negative anomaly was seen in 2014 with a value of -1.7. The negative anomalies became more occurring for four consecutive years in 2002 to 2005.

Similarly, the results of the SAI analysis of seasonal rainfall of the study area during the study period are shown in Figure 11a-11d. During the study period, the number of negative anomalies exceeded that of the positive anomalies in MAM and DJF season while the positive anomalies exceeded that of negative anomaly in JJA and SON.

Like annual rainfall, inter-annual variability of rainfall was observed in MAM, JJA, SON, and DJF with negative anomalies in 51.6%, 45.2%, 48.4%, and 54.8% of the distribution.

In addition, figure 12a & 12b depicts the SAI analysis of rainfall for dry and rainy season of the study area during the study period. From the figures, the number of negative anomalies exceeded that of the positive anomalies in dry season while the positive anomaly exceeded that of negative anomaly in rainy season.
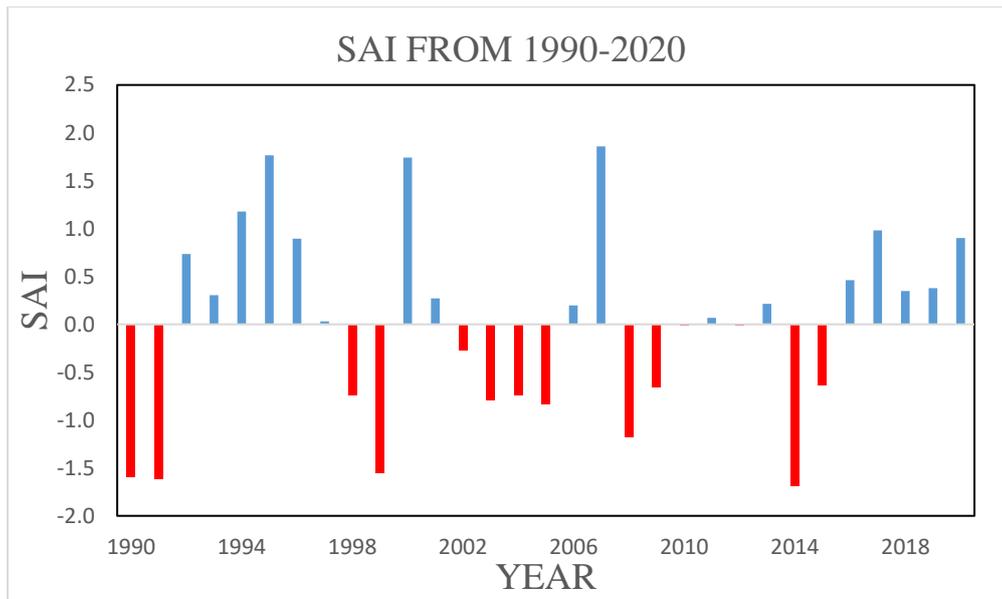
Figure 10: Annual anomalies of Rainfall from 1990-2020
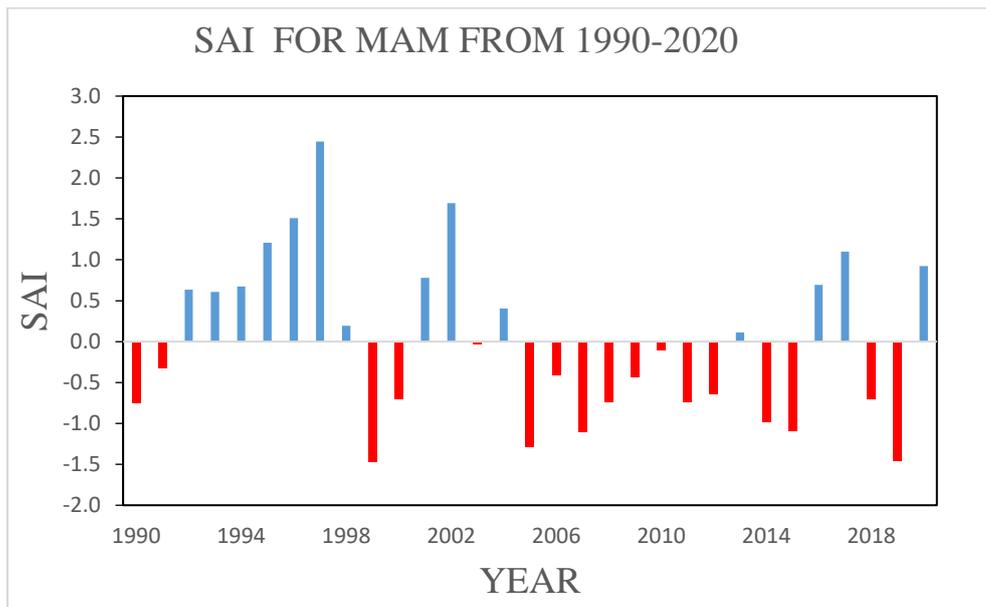
Figure 11a: Rainfall anomalies for March to May from 1990-2020
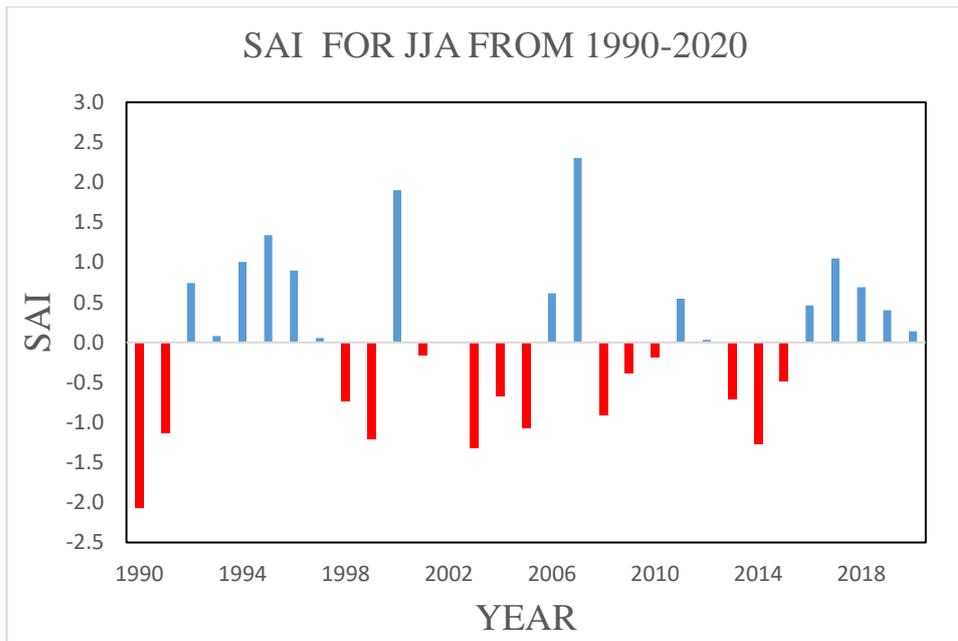
Figure 11b: Rainfall anomalies for June to August from 1990-2020
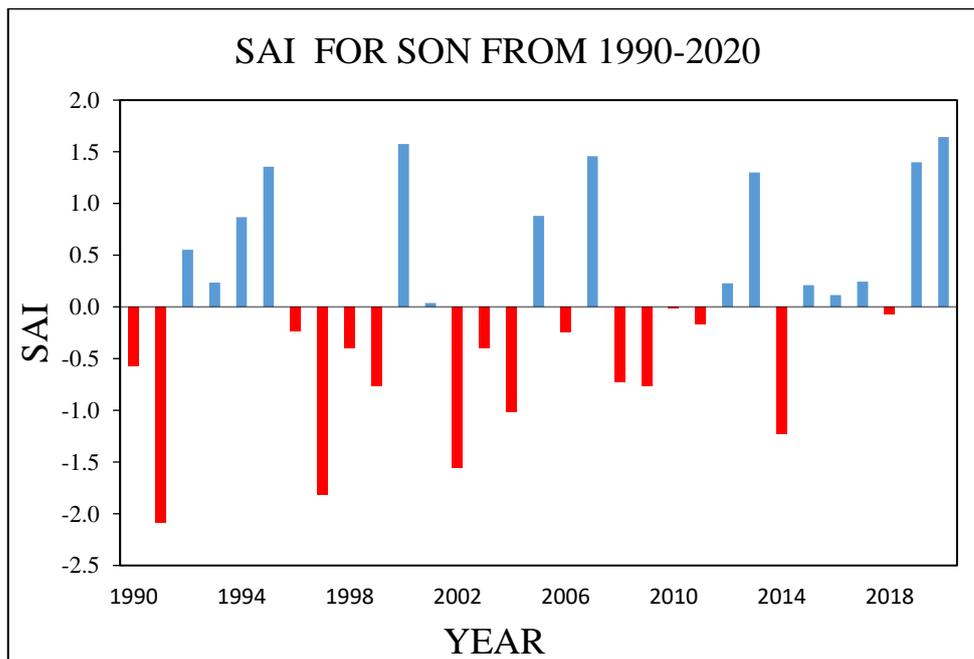
Figure 11c: Rainfall anomalies for September to November from 1990-2020
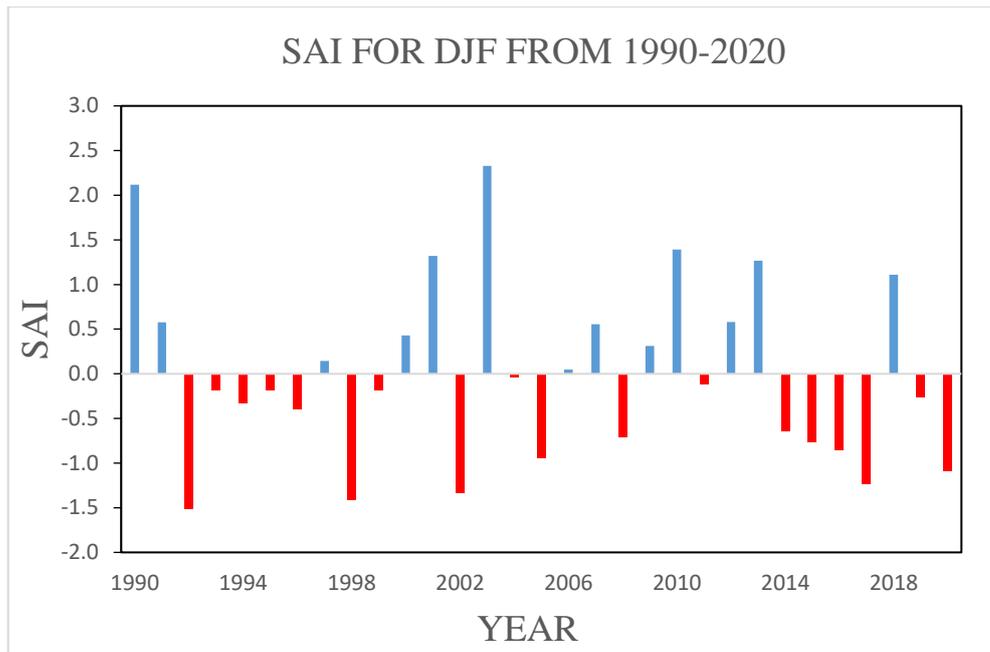
Figure 11d: Rainfall anomalies for December to February from 1990-2020
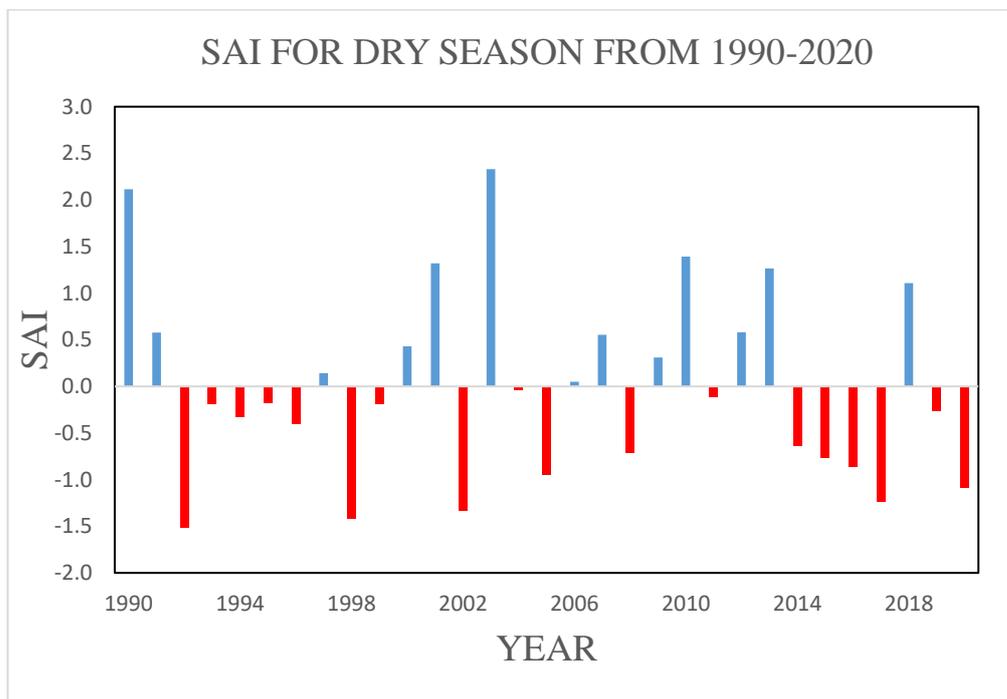
Figure 12a: Rainfall anomalies for Dry season from 1990-2020
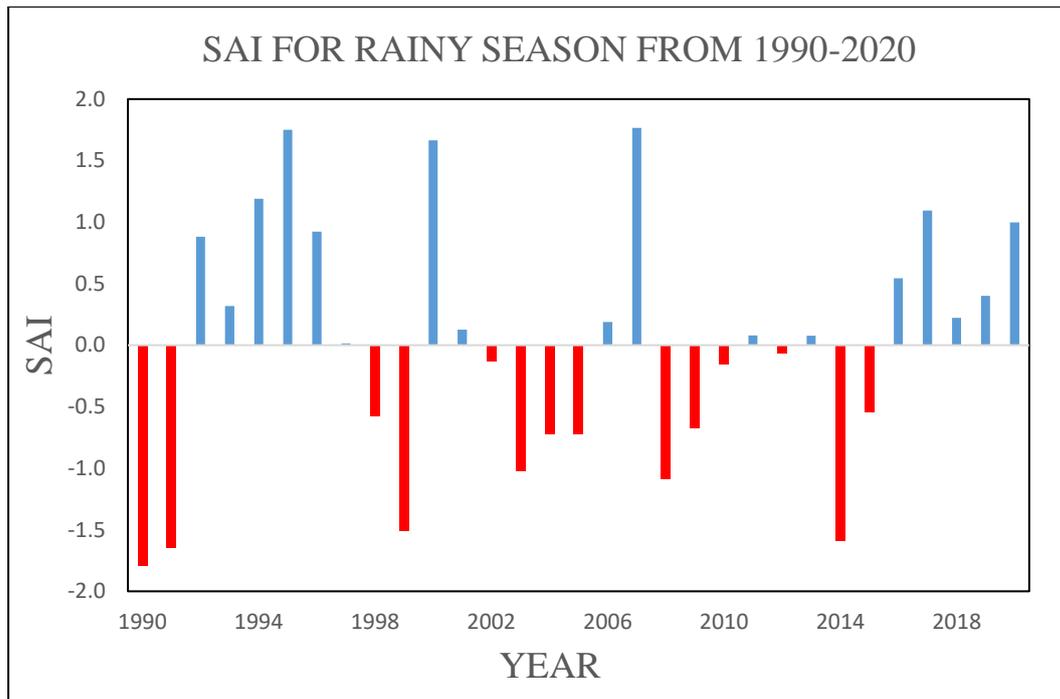
Figure 12b: Rainfall anomalies for Rainy season from 1990-2020

Rainfall Seasonality

Figure 13a presents the spatial distribution of the mean PCI rainfall of the Niger delta region from 1990 to 2020. As shown in the figure, PCI varied from 12.80 to 14.10. Maximum values of PCI were observed in the northwestern parts of the study area whereas the minimum values of PCI were observed predominantly in the southeastern part of the study area.

Figure 13b presents the spatial distribution of the mean SI rainfall of the Niger delta region from 1990 to 2020. As shown in the figure, SI varied from 0.04 to 0.09. Maximum values of PCI were observed in the south and southeastern parts of the study area whereas the minimum values of SI were observed predominantly in the northwestern part of the study area.

Generally, the rainfall seasonality derived from mean PCI and SI showed an almost opposite geographic pattern with little spatial variability. More pronounced rainfall seasonality was observed as we go from the southern to the northern parts of the study area.
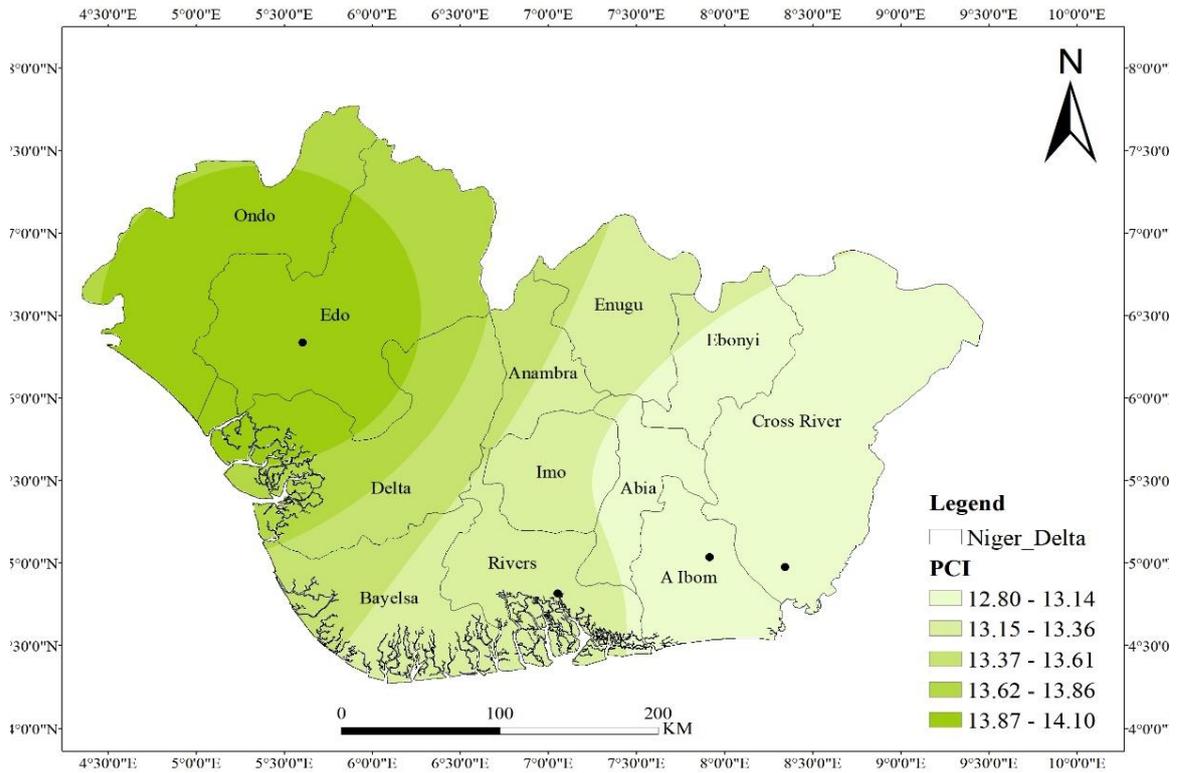
Figure 13a: Spatial distribution of mean PCI of annual rainfall of the Niger Delta from 1990-2020
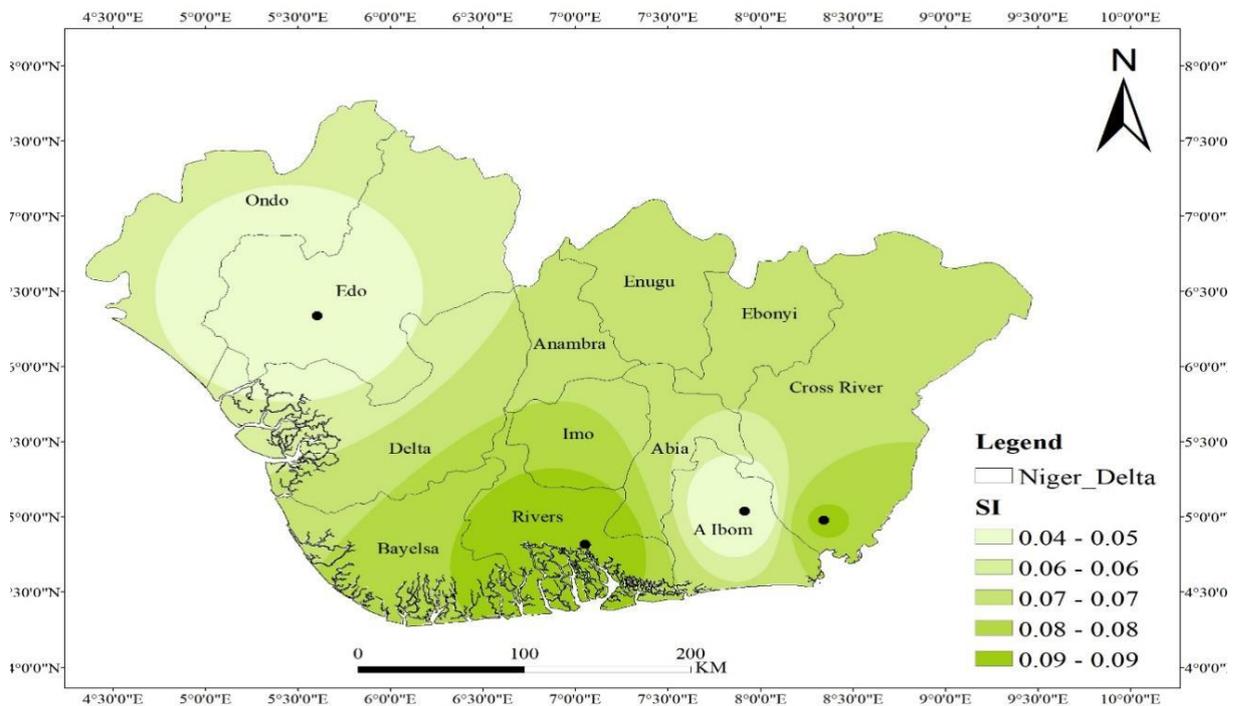
Figure 13b: Spatial distribution of mean SI of annual rainfall of the Niger Delta from 1990-2020

This discussion covers mainly the spatiotemporal variation of rainfall over the past 31 years in Niger delta. Rainfall analysis of four stations in the Nigerian Niger Delta for 31 years of data has revealed the existence of a latitudinal belt of more pronounced dryness between Calabar and Benin with Calabar having no marked little dry season. The lower rainfall observed in Benin can be due to the stronger subsidence associated with outflows from deep convective systems located to the north of the area (Omotosho, 1988). The spatial variability of rainfall amount across stations clearly shows that urban feedback produces an increase in the spatial variation of rainfall across different parts of the stations, intensifying the rainfall non-uniformly within the urban space (Paul et al., 2018). This can be of immense benefits to farmers to manage their cultivation practices better and plan their crops. Furthermore, the study is of great help in managing long-term hazards such as floods and drought. The Nigerian climate comprises of two seasons, the dry and the wet season with little dry season within the wet season. These seasons are determined by two winds, namely, the southwestern monsoon and the northeastern trade wind.

Conclusion and recommendation

The study shows rainfall variability over the study areas. Result from temporal analysis shows that, Benin recorded the lowest annual rainfall amount (962mm) while Calabar recorded highest annual rainfall amount (3887mm) across the study areas and over the years.

The monthly mean of rainfall over the four study areas shows more rainfall between March and October (Rainy reason), we have less rainfall between November and February (Dry season) and the four study areas have bi-modal rainfall peaks.

Furthermore, results from spatial analysis indicates that Calabar had the highest rainfall amount followed by Port Harcourt, Uyo and Benin, this is due to the closeness of these locations to the Atlantic Ocean that contribute a lot of moisture in these locations.

Conclusively, the findings of this study have the potential to be used as an indication of climate change in Nigeria and to provide guidance for decision-makers on disaster risk management and mitigation processes. With increasing rainfall at both the annual and seasonal level, it is likely that there will be an increased risk of floods in the southern region in the future. Finally, with the results of this study, the attention of the decision-makers should be brought to the northern region of the study area because the region may face severe droughts in the future due to the declining rainfall. Therefore, it is advisable to introduce effective drought and flood management and preparedness measures with special attention to the area.

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