



ANALYSIS OF RAINFALL TREND IN BENIN AND WARRI CITIES OF SOUTHERN NIGERIA

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ABSTRACT

In this study the trends and patterns in the rainfall of Benin and Warri cities in Southern Nigeria were examined. Rainfall data (1983-2014) for Benin and Warri cities were used. The mean, standard deviation, coefficient of skewness, coefficient of kurtosis, coefficient of variation and standardized anomaly index were used as statistical tools to analyze the data and establish the distribution of rainfall in these cities. SPSS 17 and Minitab 16 were used to analyse the data the data obtained. The result of the trend analysis revealed that the year 2005 recorded the lowest annual rainfall of 229.10mm and 1925.8mm for Benin and Warri respectively. The years 2008 and 2011 recorded the highest rainfall of 4489.8mm and 3068.70mm for Warri and Benin respectively. The mean annual rainfall for the study period was 2162.46mm. The annual rainfall trend indicated a progressive increase in the annual rainfall during the period of study. The implications are that 2011 and 2008 recorded the highest rainfall event, including heavy rainfall, that can lead to flooding for Benin and Warri respectively while 2005 recorded the lowest rainfall events that can lead to drier year, potentially affecting crop yield in both cities. It is recommended that water resources managers should make adequate arrangement on how to prevent flooding by designing and constructing water carrying structures, including adequate urban and regional planning

1.0 Introduction

Due to the detrimental impacts on natural and human systems caused by climate variability and change, it has become a topical issue. Agriculture, forestry, and fisheries activities are the most affected by climate variability and change (FAO 2012). Crop productions are influenced significantly by variability in rainfall characteristics (Nyong, 2008). The emission of excess greenhouse gases has generally been accepted to cause climate change (Falaiye et al., 2021). Intense flooding, severe and more frequent droughts, increase in wildfires, and heat waves in various parts of the world have been caused by climate change (Shiru et al., 2019). Studies and reports on climate change and variability are on the increase due to its considerable impact on hydrometeorological variables, namely rainfall, temperature and evaporation (Wen et al., 2017, Zhang et al., 2003; Scalzitti and Kochanski, 2016 and Xu et al., 2016). The most important component is rainfall and its variability are related to flood and drought. This affects the supply of water for agricultural purposes and socio-economic development (Wang et al., 2014). The overflowing of the normal confines of stream or other bodies of water that can result from storm surge, melting of glacier or heavy rainfall over areas that are habitually dry is defined as flooding (Zbigniew et al., 2013).

The impact of climate change is becoming more pronounced worldwide with consequences of climatic hazard such as severe storms, floods, heat waves and droughts (Umuteme and

Orusi, 2012). The Niger Delta, region of Nigeria is recorded as the largest single area subjected to annual flooding in the country (Olanrewaju et al., 2017). This is because it is a flat low-lying swampy area of alluvial deposition across which the tributaries of the Niger meander (Agbonkhese et al., 2014). As a result of the large inter-annual rainfall variability which often results in climatic and environmental hazard, there is dire need to study rainfall trends in the areas as a result of recent socio-economic developments such as urbanization, industrialization and over population (Joshua and Ekwe, 2013).

Furthermore, it is important to analyze rainfall trends and their applicability to various aspects of economic activity. For instance, rainfall regime has strong effect on agriculture, air traffic and other means of communication. Rainfall is effective for plant growth and thus influences the efficiency of water for agricultural purposes. Rainfall trends (variations) are of great interest to climatologists as well as agriculturists due to the important role of moisture in agriculture.

Therefore, it is very important that rainfall trends (variations) and patterns of the cities of study be investigated to recognize the exact impact of rainfall on economic growth and development. Also, almost every farmer is interested in what the expected rainfall would be, more than any other climatic element as it determines the success or failure of crops. The objective of this work was to analyze the rainfall trends and patterns in Benin and Warri cities in Southern Nigeria. The parameters addressed were the examination of annual variability of rainfall depths of the selected locations in Southern Nigeria.

2. Materials and Method

2.1 Description of the Study Area

2.1.1 Location, Climate and Vegetation

Benin City is the capital of former Bendel State and now Edo State. It comprises of three major Local Government Areas of the State, namely Oredo, Egbor and Ikpoba Okha. It has an area of about 1125km² It is located between latitude 06° 19' 00" N and longitude 5°34' 00" E and has an average elevation of 77.8m above sea level (Figure 1). The soil consists of sedimentary formation of the Miocene-Pleistocene-age known as the Benin formation (Odemerho, 1988). The current population of Benin City is 13, 875,786 (as of 12/27/2023) and is projected to surpass 30 million people in 2030 according to United Nation's data (Source: World Population Prospects, 2022 Revision).

Warri City is in the South-Western part of the Niger Delta in Delta State, Nigeria. Warri City is located at latitude 5° 31' 7" North and longitude 5° 44' 53" East and has an elevation of 6m above the sea level (Figure 2). Warri has a population of 3,600,000 according to 1991 population census. It is directly underlain by a quaternary formation, the somebreiro-Warri Deltaic plain sand consisting of fine and coarse-grained unconsolidated sediments of sand, peats, and gravel (Obafemi et al., 2012; Abotutu and Ojeh, 2013). Benin and Warri Cities are located in the humid forest belt of Nigeria with rainfalls that begin in March or April and ends in October or November, while the dry season is from December to February. These Cities experience double maxima rainfalls with a dry little spell in August referred to as 'August Break'.

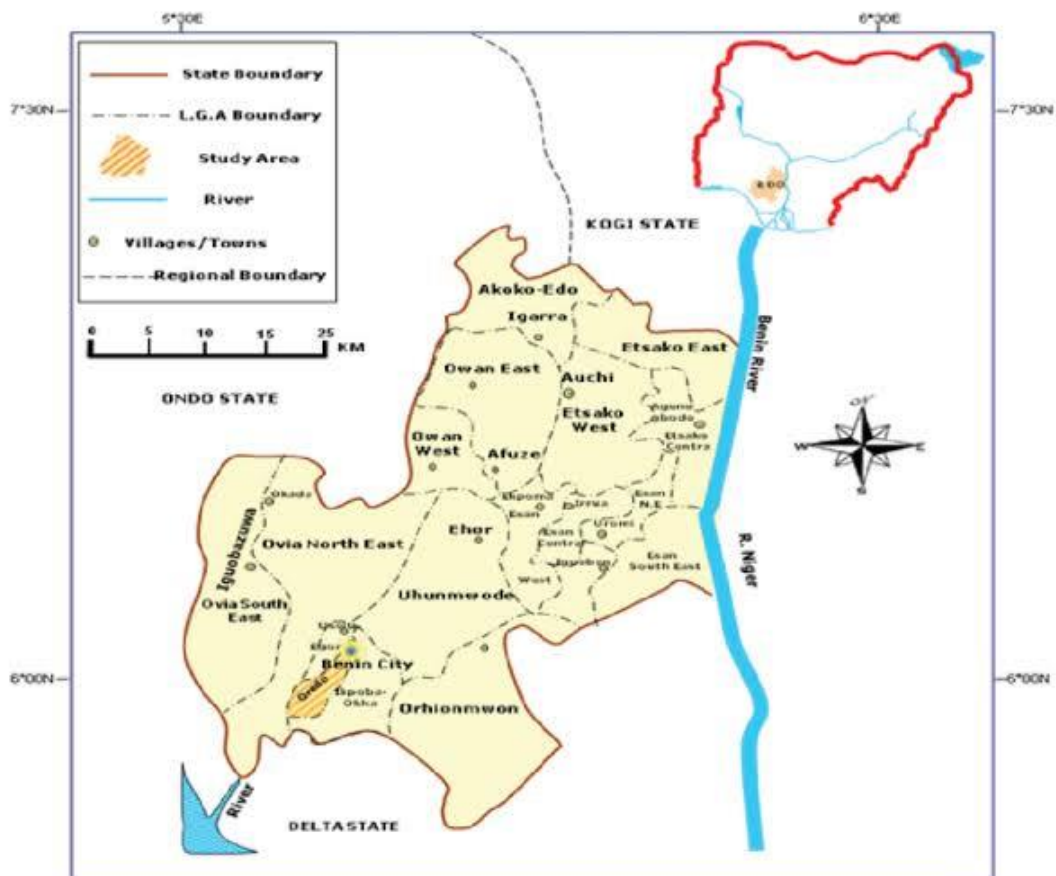


Figure 1: Map of Edo showing Benin City

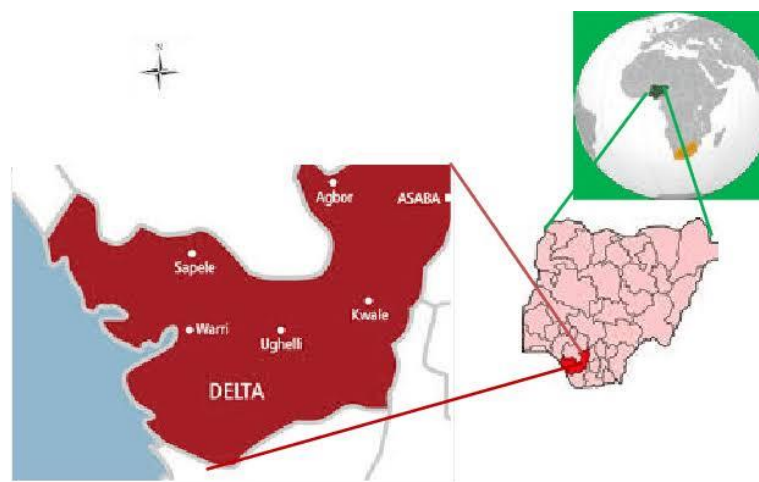


Figure 2: Map of Delta State showing Warri City

2.2 Data Collection

The relevant data used for the study are monthly rainfall data of the study areas (Benin and Warri). These data are amount of monthly and annual rainfall depths recorded in these study areas from 1983-2014 using automatic rain gauges by Nigerian Meteorological Agency (NIMET) in Oshodi, Lagos State. At NIMET Station, observation is made at fixed hours, namely 0000(midnight), 0600 (6am), 1200 (noon) and 1800 (6pm) Greenwich mean time. Additional observations are made at other time between the four main times often hourly or at three hours interval. This procedure is in line with World Meteorological Organization (WMO, 2008). Daily rainfall measurements were taken by NIMET Meteorologist using rain gauges. The data covered a period of thirty-two years from 1983-2014. These data are monthly rainfall records from 1983 to 2014. The parameter used here is the annual rainfall depths or amounts recorded in millimeter by rain gauges.

The data were collected in an electronic format to enable effective analysis in Microsoft Excel version 2010.

2.3 Data Analysis

In analyzing the required data, descriptive statistical tools were used. These include determination of the mean annual rainfall depths, standard deviation of the yearly rainfall depths, coefficient of skewness of annual rainfall depths, coefficient of variation, standard anomaly index of the annual rainfall depths and graphical plots for each city.

These are mainly plots of Standard Anomaly Index over time and trend line plots of annual rainfall over time (i.e. years the rainfall amount were recorded).

2.3.1 Mean Yearly (Annual) Rainfall

This is a measure of central tendency. Mathematically, it is denoted as \bar{X} and computed as:

$$\bar{X} = \frac{\sum_{i=1}^n x_i}{n} \quad (1)$$

Where \bar{X} = mean yearly rainfall, depth measured in mm
 x_i = yearly rainfall values (mm)
 n = total number of observations.

2.3.2 Yearly Rainfall depth Standard deviation

This is a measure of dispersion. The standard deviation measured the absolute dispersion for variability. The greater the standard deviation, the greater will be the magnitude of the deviation of the yearly rainfall values from the mean yearly rainfall for the periods.

A small standard deviation means a high degree of uniformity of the yearly rainfall values.

Computationally, it is denoted as σ and given by

$$\sigma = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{X})^2}{n-1}} \quad (2)$$

Where: x_i = annual rainfall for the year
 \bar{X} = mean annual rainfall
 n = total number of observations
 σ = standard deviation

2.3.3 Standard Coefficient of Skewness

To measure the co-efficient of skewness, the Karl Pearson's co-efficient of skewness method was used, which is based upon the difference between mean and mode. The difference value is divided by the standard deviation to give the relative measure. This is obtained using the formula:

$$\text{Coefficient of Skewness} = \frac{\text{Mean} - \text{Mode}}{\text{Standard deviation}} \quad (3)$$

When, Skew > 0: Right skewed distribution that is most values are concentrated on left of the mean with extreme values to the right.

Skew < 0: Left skewed distribution that is most values are concentrated on the right of the mean, with extreme values to the left.

Skew = 0: Mean = Mode = Median; and distribution is symmetrical.

2.3.4 Standard Coefficient of Kurtosis

It refers to the degree of flatness or peakness of the distribution of rainfall data (depth)

When a distribution is normal or symmetrical, the co-efficient of kurtosis is equal to 3. When it is more than 3, it is more peaked than the normal and when it is less than 3, it is less peaked than the normal.

Mathematically,

$$\begin{aligned} \text{Kurt (x)} &= \frac{\mu^4}{\sigma^4} \\ \text{Where } \mu^4 &= \text{fourth moment about the mean} \\ \sigma &= \text{standard deviation} \end{aligned} \quad (4)$$

2.3.5 Coefficient of Variation

In determining the coefficient of variation, the following were done:

- The annual rainfall data (depths) for the area of studies were collected from NIMET office in Oshodi, Lagos State
- The mean(average) of the annual rainfall depth were calculated using formula in equation 1 above
- Then the standard deviation of the annual rainfall data for the areas of studies calculated using the formula in equation 2
- The result of the standard deviation (σ) is divided by the mean (\bar{X})
- The result in 'd' is multiplied by 100 to express the coefficient of variation as a percent

Mathematically (Gupta, 2011),

$$\text{Coefficient of variation, C. V} = \frac{\sigma}{\bar{X}} \times 100 \quad (5)$$

Where σ = yearly rainfall standard deviation
 \bar{X} = mean annual rainfall

2.3.6 Standardized Anomaly index (S.A.I)

It is used in the analysis of rainfall variability. It is given as

$$\text{SAI (Z-scores)} = \frac{x_i - \bar{X}}{\sigma}, \quad i = 1, 2, \dots, 0. \quad (6)$$

Where,

x_i = yearly observations

\bar{X} = mean annual rainfall depth

σ = yearly rainfall standard deviation.

2.3.7 Graphical Plots

Graphical plots were used to plot annual rainfall data (depths) against time(years) and standard rainfall anomaly index values against time (years).

Statistical tools, mainly SPSS 17 and minitab 16 were used in rainfall depth trend analysis and in the graphical representation.

3. Results and Discussion

3.1 Descriptive Statistics of the Annual Rainfall

The results of the descriptive statistics of the annual rainfall are shown in Tables 1 to 2. The annual variations in the rainfall during the thirty-two years (1983-2014) studied are presented in Table 1.

It is evident that some years recorded higher values of the rainfall values than others. It was observed for Benin that 2011 recorded the highest rainfall value of 3068.7mm, while 2005 recorded the lowest rainfall value of 229.1mm. Also, for Warri, it was observed that 2008 recorded the highest rainfall value 4489.8mm, while 2005 recorded the lowest rainfall value of 1925.8mm. These results for both Benin and Warri revealed that there were variations in the annual rainfall depths. The variations in rainfall depths (both seasonal and spatial) to a greater extent have effects on agricultural activities as most farmers depend on favourable weather condition to commence their agricultural activities and this plays a crucial role in determining agricultural yields (Audu *et al.*, 2012). It also has effect on other human activities. The year

2005 recorded lowest rainfall depth for both Benin and Warri. The implication is that 2005 was driest year and suggests low agricultural production/ crop yield.

The mean, maximum and minimum annual rainfall amount (depth in millimeters) from 1983 to 2014 as shown in Table 2 for Benin were 2,162.46mm, 3,068.70mm and 229.10mm, respectively. Maximum and minimum annual rainfalls were recorded in the years 2011 and 2005, respectively. The rainfall distribution was found to be highly skewed with a skewness coefficient of -1.16. This negative skewness coefficient suggests that there may be a higher frequency of above –average values. It may indicate that extreme or heavy rainfall events are more prevalent in the dataset, potentially influencing long-term trends and variability. Understanding this implication of negative skewness, it is crucial in making informed decisions related to various applications such as agricultural, urban planning and environmental management.

The kurtosis value was 4.13, so the distribution of Annual rainfall depth had heavier tails and it was noted to be a leptokurtic distribution. Benin’s annual rainfall distribution had coefficient of variation of 24.72%, which indicated the variability of the annual rainfall depths relative to the mean. A CV of 24.7% indicates a moderate level of variability in annual rainfall depths. It suggests that the annual rainfall depths have a notable amount of fluctuation relative to the mean, which can impact the reliability of rainfall patterns over time. Higher annual rainfall variability may increase the risk of extreme weather events, such as floods and this will influence decision making in agricultural planning, water resource management and infrastructure design.

Table 1: Annual Series of Rainfall from 1983 to 2014

YEAR	BENIN Annual Rainfall depth (mm)	WARRI Annual rainfall depth (mm)
1983	1657.9	2522.6
1984	1225.6	2741.4
1985	1557.7	2958.8
1986	1313.2	2887.1
1987	2419.2	2147.3
1988	2007.3	2442.6
1989	1939.8	2636.4
1990	2588.4	2567.7
1991	2439.2	2952.9
1992	2026.9	2944.5
1993	1899.1	2976.9
1994	2595.3	2870.7
1995	2677.9	3449.4
1996	2507	2592.1
1997	2082.8	2906.2
1998	2204.4	2537.3
1999	2164	3127.6
2000	2257.7	2879.9
2001	2424.3	2400.2
2002	2422.2	3307.4
2003	1860.1	2359.9
2004	2239.8	3138.5
2005	229.1	1925.8
2006	2183.9	2547.3
2007	1904.6	2642.4
2008	2727.7	4489.8
2009	2417.3	2656.1
2010	2663	2896.7

2011	3068.7	3179.5
2012	2568.9	3089.5
2013	2530.4	2307.6
2014	2395.3	2108.5

Table.2: Descriptive Statistics of Annual Rainfall for each Study Station.

	No of Years	Minimum Annual rainfall depth (mm)	Maximum Annual rainfall depth (mm)	Mean Annual rainfall depth (mm)	STD DEV of Annual rainfall depth (mm)	Skewness of Annual rainfall depth (mm)	Kurtosis of Annual rainfall depth (mm)	CV of Annual rainfall depth
Benin Rainfall (MM)	32	229.1	3068.7	2162.46	534.52	-1.61	4.13	24.72
Warri RAINFALL (MM)	32	1925.8	4489.8	2787.21	464.16	1.31	4.45	16.65

The mean, maximum and minimum annual rainfall depths from 1983 to 2014 for Warri were 2,787.2mm, 4, 489.80mm and 1, 925.80mm, respectively. Warri had positively skewed rainfall distribution, with skewness coefficient of 1.31. A positive skewness of 1.31 in annual rainfall trend means that there is a longer tail on the right side of the annual rainfall depth distribution, and the majority of the data points are concentrated on the left side. These suggests that there are more occurrences of lower rainfall amounts compared to higher rainfall amounts. This may impact water resource management, leading to potential challenges in ensuring an adequate water supply for agricultural, industrial and domestic use the agricultural implication is that it can lead to a higher frequency of drier years compared to wetter years, potentially affecting crop yields and overall agricultural productivity.

Its kurtosis value was 4.45. This showed that the annual rainfall depths of the city had leptokurtic distribution. A leptokurtic distribution suggests an increase in extreme rainfall events, including heavy rainfall conditions. This is important for infrastructure planning, etc. disaster preparedness and climate change adaptation

Warri experienced steady annual rainfall above 2100mm except for the year 2005 with annual rainfall value of 1, 925.8mm. However, this observation is different from the work of Olanrewaju *et al.* (2017), which revealed that in Warri, the year 2013 had the lowest total rainfall. The differences in observations can be due to differences in years of rainfall data analyzed and computational errors.

3.2 Standardized Anomaly Index

The variation of the standardized anomaly index for Benin with year is shown in Figure 3

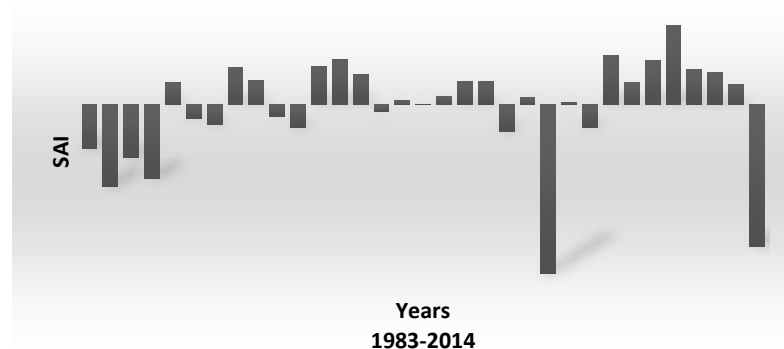


Figure 3: Standardized Anomaly Index for Annual Total Rainfall at Benin

Between 1983 and 2000, Benin experienced below- average long- term rainfall, with 6 periods of positive anomaly index indicating low annual rainfall. The 6 respites of positive anomaly index above average means between 1983-2000, there were only 6 years that the annual rainfalls depths were above average rainfall depth. There are 18 years between 1983- 2000 and since only 6 years recorded rainfall depth above average rainfall, then 1983-2000 recorded 12 years of low rainfall distribution.

This result is in line with the findings of Akinsanola and Ogunjobi (2014), who reported that there was decreasing amount of rainfall in Benin within the study period of 1983-2000. After 2000 there was above long-term averages of annual rainfall during the period spanning 2001 to 2014, with 4 respites of negative anomaly index below average. The implication is that between 2001 and 2014, there were more years of extreme rainfall events above average rainfall, including heavy rainfall than can lead to flooding. This can hamper growth of crops, lead to soil erosion etc.

The highest positive annual rainfall anomaly index above average was recorded in 2011, while the lowest negative annual rainfall anomaly index below average was recorded in 2005. The implications are that 2011 recorded the highest rainfall event, including heavy rainfall, that can lead to flooding while 2005 recorded the lowest rainfall events that can lead to drier year, potentially affecting crop yields. The standardized Rainfall anomalies Index (SAI) was used to establish the dry and wet years in the city for the period of study. The result revealed twelve dry years out of the thirty-two years period considered and twenty wet years on the negative and positive sides of the graph respectively. The positive SAI values indicate wetter- than – average years, while negative SAI values indicate drier- than- average years. SAI values above 0 are indicative of wet years, while SAI values below 0 are indicative of dry years. The established threshold here is 0(zero). The line corresponding to zero is the base line which signifies the average rainfall of thirty-two years

The plots of the standardized rainfall anomaly index against time (years) for Warri are shown in Figure 4.

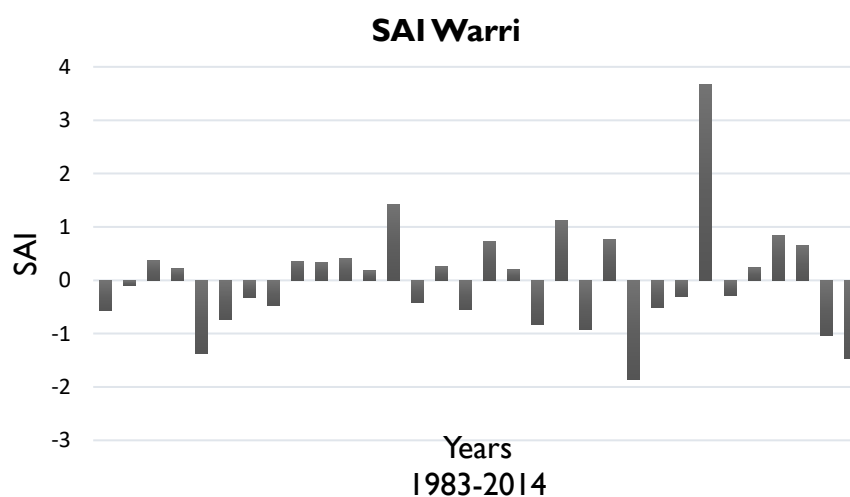


Figure 4: Standardized Anomaly Index for Annual Total Rainfall at Warri

From Figure 4, it can be seen that Warri experienced below long-term averages annual rainfall during the period spanning 1983 to 1995 with 7 respites of positive anomaly index above average years. The implication is that between 1983-1995, Warri recorded more years of low rainfall that can lead to drier years, which will impact on agricultural production and domestic water need

This result is in line with the findings of Akinsanola and Ogunjobi (2014) who reported that there was decrease in the amount of rainfall in Warri within this period of study (1983-1995). From 1996, Warri experienced alternate negative anomaly index below average and positive anomaly index above average until 2014. The result revealed 16 dry years and 16 wet years on the negative and positive sides of the plot respectively for the thirty-two years period considered. The highest positive anomaly index above average was recorded in 2008. This trend may suggest a shift a wetter climate regime. Implications of highest positive anomaly index above average involve heightened risks of excessive rainfall, flooding, soil erosion and potential impacts on infrastructure, land use and water quality. Such conditions can also affect aquatic ecosystems, leading to changes in stream flow and water quality (IPCC, 2007). The lowest negative index below average was recorded in 2005. This trend indicates a prolonged period of drier- than – normal conditions.

Implications of negative anomaly index below average are increased risk of drought conditions, water scarcity and potential impacts on agricultural productivity, water resources and ecosystems health.

3.3 Trend Plots of Annual Rainfall

The trend of annual rainfall with index (time in years) for Benin City is shown in Figure 5

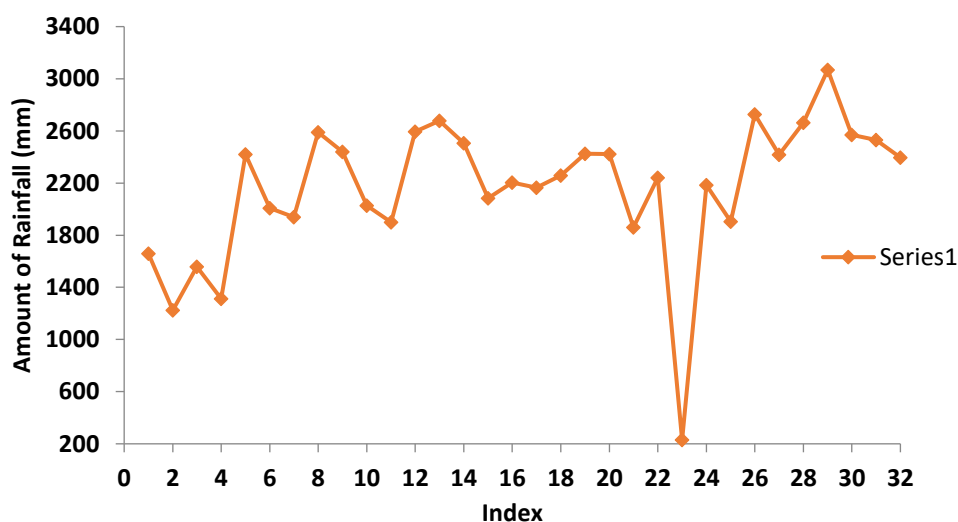


Figure 5: Trend Plot of annual Rainfall depths against index (time in years) in Benin

From Figure 5 it is evident that the year 2005 recorded the lowest annual rainfall of 229.10mm, while the year 2011 recorded the highest rainfall of 3068.70mm. The implications of lowest annual rainfall of 229.1mm are increased risk of drought conditions, water scarcity and potential impacts on agricultural productivity, water resources and ecosystems health. Implications of highest rainfall of 3068.70mm is that the condition will translate to soil erosion as well as flooding. The effects of these conditions are low agricultural production, destruction of infrastructure as well as health hazard.

The mean annual rainfall for the study period was 2162.46mm. Years 1983, 1984, 1985, 1986, 1988, 1989, 1992, 1993, 1997, 2003, 2005 and 2007 experienced annual rainfall below the mean value, while the years 1987, 1990, 1991, 1994, 1995, 1996, 1998, 1999, 2000, 2001, 2002, 2004, 2006, 2008, 2009, 2010, 2011, 2012 and 2013 experienced annual rainfall above the mean value. The trend line fluctuated from index 1 at annual rainfall of 1657.9mm until index 5 when it suddenly increased to 2419.2mm. Then the trend line decreased below mean annual rainfall of 2162.46mm between index 6 to 7. Thereafter, there was increase in trend line above mean annual rainfall from index 8 to 32, with few decreases in trend line above mean annual rainfall at indices 10, 11, 15, 21, 23 and 25 respectively. From the graph, there is a progressive increase in the annual rainfall depths during the period in the study area.

This is in agreement with the work of Ihimekpen *et al.* (2018) and Floyd *et al.* (2016) which indicated that rainfall data from Benin City showed statistically significant evidence of an increasing trend. The effect is that there is possibility of flood occurrence with time and so water resources managers should make adequate arrangement on how to prevent the flood by designing/constructing water carrying structures, including adequate and regional planning. The trend of annual rainfall depth for Warri city is shown in Figure 6.

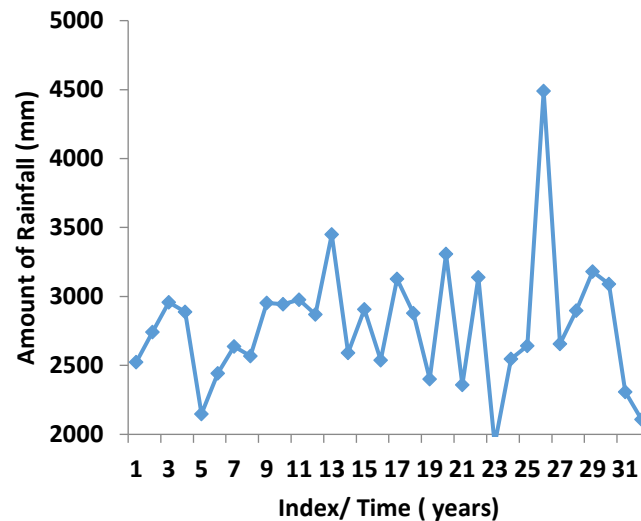


Figure 6: Trend Plot of annual Rainfall depth against Index/ time (years) in Warri

From Figure 6, it is evident that the year 2005 recorded the lowest annual rainfall of 1925.8, while the year 2008 recorded the highest rainfall of 4489.80mm. The mean annual rainfall for the study period is 2787.21mm. A mean annual rainfall of 2787.21mm indicates abundant water supply, sustainable ecosystem support and agricultural potential. However, it also necessitates careful water management and preparedness for extreme events to ensure the well-being of both natural and human systems. It has become an annual environmental problem during every rainy season. Umuteme and Orusi (2012) reported that in July 2012 over 300 people were rendered homeless in Warri due to an early morning rain that lasted for several hours. According to Efe and Mogborukor (2010), the 4th – 6th August 2002 flood in Warri which resulted from rainfall submerged several houses, workshops in the metropolis. It reoccurred in the following years leading to the destruction of properties worth over 3.6 million of Naira and rendering over 3,250 people homeless.

Years 1983, 1984, 1987, 1988, 1989, 1990, 1996, 1998, 2001, 2003, 2005, 2006, 2007, 2009, 2013 and 2014 experienced annual rainfall below the mean value, while the years 1985, 1986, 1991, 1992, 1993, 1994, 1995, 1997, 1999, 2000, 2002, 2004, 2008, 2010, 2011 and 2012 experienced annual rainfall above the mean value.

The trend line increased from 2522.6mm at index 1 until index 5 at 2147.3mm where it decreased below mean annual rainfall up to index 8 at 2567.7mm. Thereafter, it increased above mean annual rainfall up to index 30, with few decreases below annual rainfall at indices of 13, 14, 16, 19, 21, 23, 24, 25, 27, 31 and 32 respectively.

4. Conclusion

The study examined the rainfall trends and patterns in two Southern cities (Benin and Warri) of Nigeria for the period 1983-2014. It was observed that these two cities showed fluctuations in trend of annual rainfall depths. The results clearly show a variable rainfall pattern over the years in all the cities studied, making it challenging to predict rainfall for upcoming seasons. It was generally observed that the climate of the region indicates a rainfall characterized by alternating wet and dry periods, and that the beginning of rainfall is becoming earlier which implies possible longer rainy season in the area. Rainfall depths are climatic variables which

influence human well-being, plant growth and crops production. The variation in rainfall patterns results to unfavourable growing conditions.

From the outcome of this study, it is recommended that:

1. Efficient use of agricultural land should drive the focus of water resources development. This requires a strong government policy for harnessing and managing water resources.

2. Models that rely on anticipated reductions in rainfall, such as drainage systems and dams should be reassessed to prevent potential flooding in these cities.

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