

## Time Series Analysis of Black Carbon and Rainfall Pattern in some Selected States in the Guinea Savannah Region of Nigeria

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### ABSTRACT

Time series analysis of black carbon and rainfall patterns in some selected states in the Guinea Savannah region of Nigeria was assessed in this study over 40 years (1983 – 2023) using Satellite-derived datasets and images depicting the frequency, intensity, and concentration of black carbon in the region were produced and examined through remote sensing techniques utilizing Earth data resources from the NASA GESDISC data repository accessed via the NASA Giovanni platform. Trend analysis on black carbon and rainfall data from six (6) states (Oyo, Kaduna, Enugu, Benue, and Taraba states) was done using Microsoft Excel software. The lowest level of Black carbon concentration (0.65  $\mu\text{g}/\text{m}^3$ ) in Benue State was observed in 1996. High concentrations of Black carbon (1.09  $\mu\text{g}/\text{m}^3$ ) were observed in 1995, followed by 1.13  $\mu\text{g}/\text{m}^3$  in 1990. The lowest amounts of rainfall (1070.63 mm) in Benue state were observed in 2023. A lower amount of rainfall (1619.84 mm) was observed in 2023. The lowest level of Black carbon concentration (0.52  $\mu\text{g}/\text{m}^3$ ) in Bauchi was observed in 1983. High levels of Black carbon concentration (1.07  $\mu\text{g}/\text{m}^3$ ) in Kaduna were observed in 2000 which the lowest amount of rainfall 940.71 mm was observed in 2021. The lowest amount of rainfall (860.34 mm) in Oyo State was observed in 2001. The data presented in this study will be crucial in influencing climate change mitigation strategies, enhancing climate resilience, and shaping policy frameworks in Nigeria.

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### Introduction

Time series analysis of rainfall and black carbon in the Guinea savannah of Nigeria is very crucial to every nation because it aids in understanding climate patterns [1]. Rainfall patterns in the Guinea savannah are critical for agriculture, water resource management, and overall ecosystem health [2]. Time series analysis helps in identifying trends, cycles, and anomalies in rainfall data over years or decades [3]. This understanding is essential for predicting future climate scenarios and adapting agricultural practices accordingly. In addition, agriculture in the Guinea savannah heavily relies on rainfall. Time series analysis can reveal long-term trends in rainfall patterns (such as increasing or decreasing trends, seasonal variations, and extreme events like droughts or floods). This information is vital for farmers and policymakers to develop strategies for drought preparedness, water management, and crop selection [4].

Furthermore, black carbon (BC) is a significant air pollutant emitted from incomplete combustion processes. It has implications for both climate change (as a potent contributor to global warming) and human health (due to respiratory problems). Time series analysis can track BC concentrations over time, helping to understand seasonal variations, sources of emissions, and the effectiveness of pollution control measures [5]. More so, governments and environmental agencies can use time series analysis results to

formulate evidence-based policies and regulations. For instance, understanding the relationship between rainfall patterns and agricultural productivity can guide policies on water management, irrigation systems, and crop insurance schemes [6]. There is limited information on the time series analysis of rainfall patterns and black carbon concentration in the Guinea belt of the country. The time series analysis of black carbon and rainfall patterns in some selected states in the Guinea Savannah region of Nigeria was therefore assessed in this study.

### Materials and Methods

#### Study Location

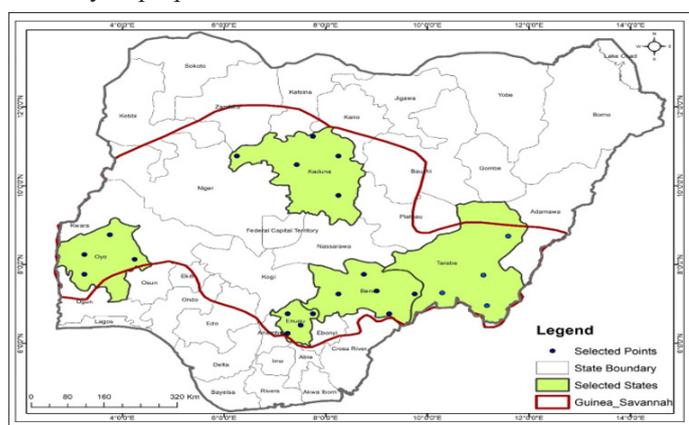
The research area under consideration is the Guinea Savanna Zone, Nigeria (GSZN), situated within longitudes 4o – 10oE and latitudes 6o – 11o30'N (Figure 1). To the north, it is adjacent to the Sudano–Sahelian Zone, Nigeria (SSZN), while to the south, it borders the Rain Forest, Nigeria (RFN). Positioned centrally within the country, the Guinea Savannah stands out as the most extensive ecological region in Nigeria, encompassing almost fifty percent of the nation. The Guinea savanna region represents the largest expanse within the West African savanna. This particular zone constitutes the predominant portion of the savanna area and is occasionally categorized into the Southern Guinea Savannah which includes states such as Kwara, Benue, Enugu, Ebonyi, Oyo, Ekiti, Osun, and the Northern Guinea Savannah which encompasses states like Niger, Taraba, Kaduna, Bauchi, Kano, Adamawa, Benue, Kwara, Kogi, among others.



**Figure 1:** The Agro-Ecological zones of Nigeria - Guinea Savannah (Source: Field Work).

### Sample and Sampling Technique

Data sets and images derived from satellites showing rainfall characteristics, frequency, intensity, and Black carbon levels in the specified region were acquired through remote sensing techniques utilizing data sources from the NASA GESDISC data archive accessed via the Nasa Giovanni platform. The geographical layout of the Guinea Savannah region in Nigeria was procured with the assistance of Google Earth, and specific maps of the five states of interest were extracted as shape files. Through the utilization of Earth Data satellite sources, satellite signals indicating rainfall patterns and Carbon remnants were obtained by initiating the NASA Giovanni platform and examining satellite images originating from satellites such as Modern-Era Retrospective Analysis for Research and Applications - 2 (MERRA - 2), Atmospheric Infrared Sounder (AIRS), Moderate Resolution Imaging Spectroradiometer (MODIS - Aqua and MODIS - Terra), and Ozone Monitoring Instrument (OMI) onboard NASA's Aura satellite. Data sets representing the selected five states within the Guinea-savannah region of Nigeria were retrieved. Additionally, Time Average Maps and Time series Average Area were graphed for analysis purposes.



**Figure 3.2:** The Guinea Savannah and the 5 selected States in each Geopolitical Zone (Source: Field Work).

**Table 1: Coordinates of 5 Selected States in each Geopolitical Zone of the Guinea Savannah**

States	Oyo	Kaduna	Enugu	Benue	Taraba
Longitude	4.237276	7.428579	7.507991	9.000531	7.668983
Latitude	8.131337	10.52936	6.458064	7.327793	11.040769

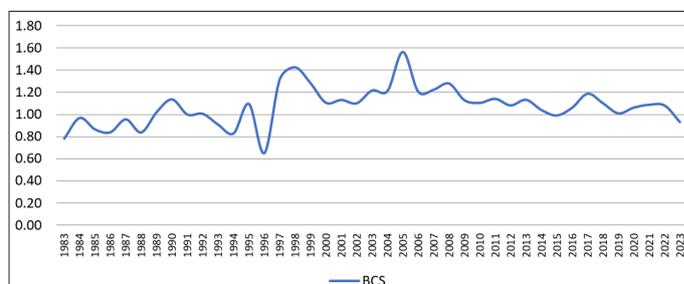
### Statistical Analysis

Rainfall and Black carbon generated were used for the Time Series Analysis using Microsoft Excel.

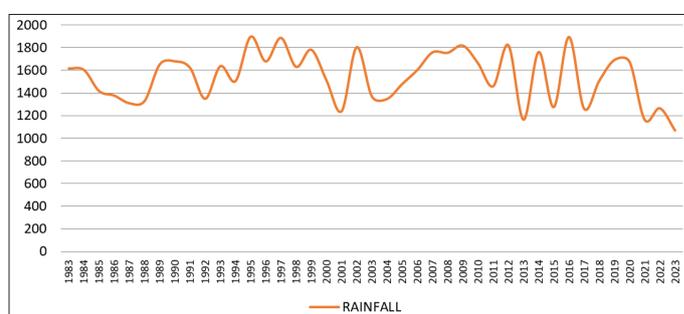
### Results

Figure 1 shows the variation of Black carbon concentration for Benue state (1983 - 2023). The lowest level of Black carbon concentration ( $0.65 \mu\text{g}/\text{m}^3$ ) was observed in 1996, followed by  $0.78 \mu\text{g}/\text{m}^3$  in 1983,  $0.83 \mu\text{g}/\text{m}^3$  in 1994, and  $0.84 \mu\text{g}/\text{m}^3$  respectively in 1986 and 1988. High concentrations of Black carbon ( $1.09 \mu\text{g}/\text{m}^3$ ) were observed in 1995, followed by  $1.13 \mu\text{g}/\text{m}^3$  in 1990, slightly high concentrations ( $1.42 \mu\text{g}/\text{m}^3$ ) observed in 1998, with the highest concentration of Black carbon ( $1.56 \mu\text{g}/\text{m}^3$ ) in 2005, where it slightly decreased to ( $1.28 \mu\text{g}/\text{m}^3$ ) in 2008, followed by a slight depression ( $0.99 \mu\text{g}/\text{m}^3$ ) in 2015, thereafter it peaked ( $1.19 \mu\text{g}/\text{m}^3$ ) in 2017, followed by a slight decrease ( $0.93 \mu\text{g}/\text{m}^3$ ) in 2023.

Figure 2 shows the Time Series of Rainfall for Benue State (1983 - 2023). The lowest amount of rainfall (1070.63 mm) was observed in 2023, closely followed by 1163.25 mm in 2021, 1165.54 mm in 2013, 1262.26 mm in 2017, 1276.58 mm in 2015, 1329.47 mm in 1988, 1349.20 mm in 1992 and 1459.89 mm in 2011. The highest amount of rainfall (1894.93 mm) was observed in 2016, with higher levels of rainfall observed 1887.45 mm in 1997, 1804.70 mm in 2002, 1680.34 mm in 1990, 1676.09 mm in 2020, with elevated amounts of rainfall (1818.94 mm) in 2009 and 1822.75 mm in 2012.



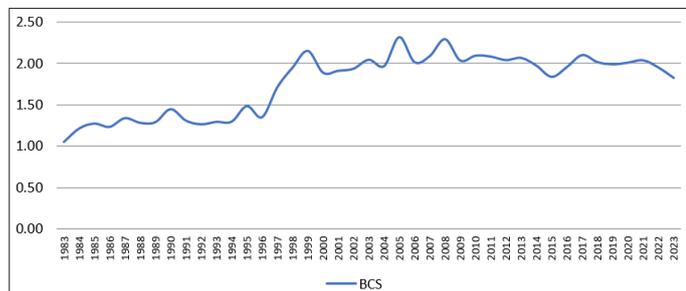
**Figure 1:** Time Series of black carbon for Benue State (1983 - 2023)



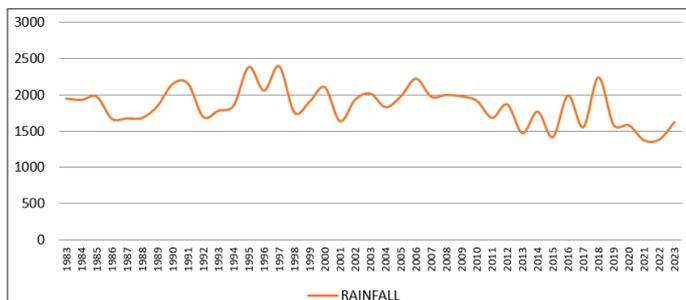
**Figure 2:** Time Series of Rainfall for Benue State (1983 - 2023)

Figure 3 shows the variation of Black carbon concentration for Enugu state (1983 - 2023). Lower levels of Black carbon concentration ( $1.94 \mu\text{g}/\text{m}^3$ ) were observed in 2002, followed by ( $1.83 \mu\text{g}/\text{m}^3$ ) in 2023, ( $1.84 \mu\text{g}/\text{m}^3$ ) in 2015, ( $1.35 \mu\text{g}/\text{m}^3$ ) in 1996, ( $1.29 \mu\text{g}/\text{m}^3$ ) respectively in 1993 and 1989, followed by ( $1.23 \mu\text{g}/\text{m}^3$ ) in 1986 and the lowest level of Black carbon concentration ( $1.05 \mu\text{g}/\text{m}^3$ ) was observed in 1983. High levels of Black carbon concentration ( $2.04 \mu\text{g}/\text{m}^3$ ) were observed in 2021, ( $2.10 \mu\text{g}/\text{m}^3$ ) in 2017, ( $2.15 \mu\text{g}/\text{m}^3$ ) was observed in 1999, followed by ( $2.30 \mu\text{g}/\text{m}^3$ ) in 2008, and the highest level of Black carbon concentration ( $2.32 \mu\text{g}/\text{m}^3$ ) was observed in 2005.

Figure 4 shows the Time Series of Rainfall for Enugu State (1983 - 2023). Lower amount of rainfall (1619.84 mm) was observed in 2023, followed by 1666.22 mm in 1986, 1634.33 mm in 2001, 1694.11 mm in 1992, followed by 1469.53 mm in 2013, 1415.18 mm in 2015 and the lowest amount of rainfall 1381.31 mm was observed in 2002. Elevated amount of rainfall 1998.08 mm was observed in 2016. This is closely followed by 2150.51 mm in 1991, 2218.06 mm in 2006, 2236.93 mm in 2018, and 2379.31 mm in 1995, and the highest amount of rainfall (2388.43 mm) was observed in 1997.



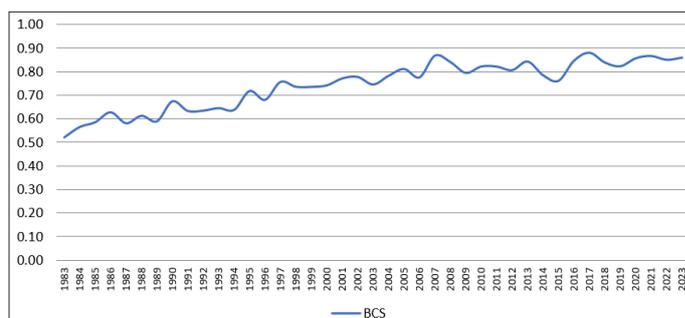
**Figure 3:** Time Series of black carbon for Enugu State (1983 - 2023)



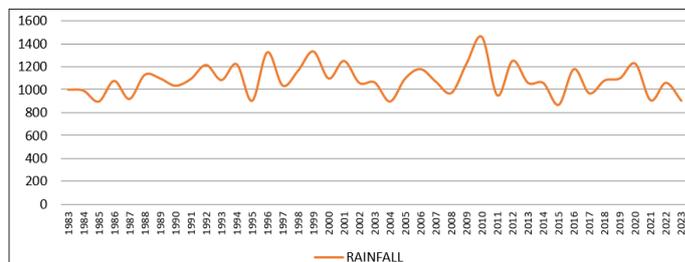
**Figure 4:** Time Series of Rainfall for Enugu State (1983 - 2023)

Figure 5 shows the variation of Rainfall and Black carbon concentration for Bauchi state (1983 - 2023). The lowest level of Black carbon concentration ( $0.52 \mu\text{g}/\text{m}^3$ ) was observed in 1983, followed by  $0.58 \mu\text{g}/\text{m}^3$  in 1987,  $0.59 \mu\text{g}/\text{m}^3$  in 1989 and  $0.65 \mu\text{g}/\text{m}^3$  in 1993. The highest level of Black carbon concentration ( $0.88 \mu\text{g}/\text{m}^3$ ) was observed in 2017, this is closely followed by  $0.87 \mu\text{g}/\text{m}^3$  in 2017 and 2007 respectively, elevated levels of Black carbon concentration ( $0.86 \mu\text{g}/\text{m}^3$ ) were observed in 2023, ( $0.81 \mu\text{g}/\text{m}^3$ ) and in 2005, ( $0.72 \mu\text{g}/\text{m}^3$ ) in 1995 and  $0.67 \mu\text{g}/\text{m}^3$  in 1990.

Figure 6 shows the time Series of Rainfall for Taraba State (1983 - 2023). The lowest amount of rainfall (865.31 mm) was observed in 2015, followed by 899.57 mm in 1995, 894.20 mm in 2004, 904.84 mm in 2021, 947.52 mm in 2011, 968.55 mm in 2008, 1033.14 mm in 1997 and 1094.63 mm in 2000. The highest amount of rainfall (1456.73 mm) was observed in 2010. This is followed by 1330.93 mm in 1999, 1324.49 mm in 1996, 1219.61 mm in 1994, 1213.18 mm in 1992, 1127.30 mm in 1988, and 1073.93 mm in 1986.



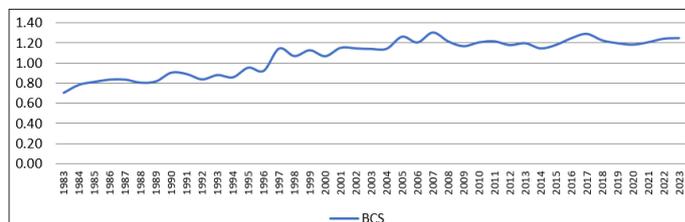
**Figure 5:** Time Series of Black Carbon for Taraba State (1983 - 2023)



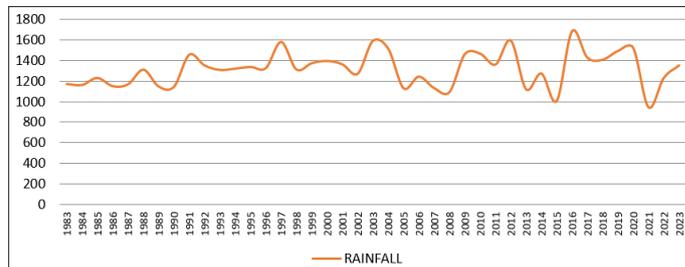
**Figure 6:** Time Series of Rainfall and Black Carbon for Taraba State (1983 - 2023)

Figure 7 shows the variation in Black carbon concentration for Kaduna state (1983 - 2023). The lowest Black carbon concentration ( $0.71 \mu\text{g}/\text{m}^3$ ) was observed in 1983, where it gradually increased to  $0.82 \mu\text{g}/\text{m}^3$  in 1989, closely followed by  $0.86 \mu\text{g}/\text{m}^3$  in 1994. High levels of Black carbon concentration ( $1.07 \mu\text{g}/\text{m}^3$ ) were observed in 2000,  $1.21 \mu\text{g}/\text{m}^3$  in 2006,  $1.17 \mu\text{g}/\text{m}^3$  in 2009,  $1.18 \mu\text{g}/\text{m}^3$  in 2015,  $1.25 \mu\text{g}/\text{m}^3$  in 2023,  $1.29 \mu\text{g}/\text{m}^3$  in 2017 and the highest level of Black carbon concentration ( $1.31 \mu\text{g}/\text{m}^3$ ) was observed in 2007.

Figure 8 shows the Time Series of Rainfall and black carbon for Kaduna State (1983 - 2023). The lowest amount of rainfall 940.71 mm was observed in 2021, followed by 1003.24 mm in 2015, 1090.68 mm in 2008, 1127.36 mm in 2005, 1165.28 mm in 1987, elevated amount of rainfall (1228.50 mm) was observed in 1985, 1318.98 mm in 1994, 1580.27 mm in 1997, with the highest amount of rainfall of 1592.23 mm observed in 2003.



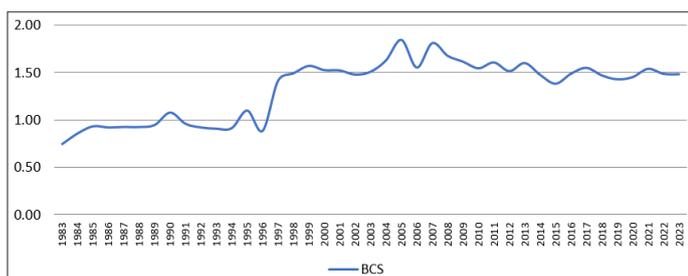
**Figure 7:** Time series of Black Carbon for Kaduna State (1983 - 2023)



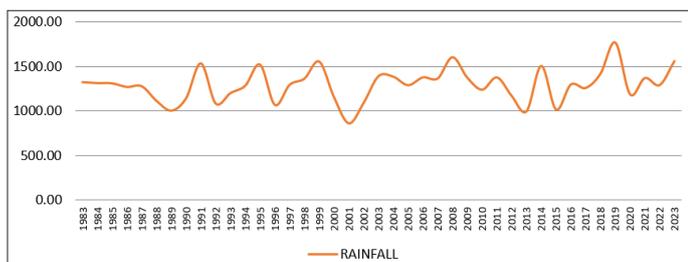
**Figure 8:** Time Series of Rainfall and Black Carbon for Kaduna State (1983 - 2023)

Figure 9 shows the variation of Rainfall and Black carbon concentration for Kaduna state (1983 - 2023). The lowest Black carbon concentration ( $0.75 \mu\text{g}/\text{m}^3$ ) was observed in 1983, low levels of Black carbon concentration ( $0.89 \mu\text{g}/\text{m}^3$ ) were observed in 1996, followed by  $0.94 \mu\text{g}/\text{m}^3$  in 1985,  $0.92 \mu\text{g}/\text{m}^3$  in 1994, elevated levels of Black carbon concentration ( $1.08 \mu\text{g}/\text{m}^3$ ) was observed in 1990,  $1.10 \mu\text{g}/\text{m}^3$  in 1995,  $1.39 \mu\text{g}/\text{m}^3$  in 2015,  $1.48 \mu\text{g}/\text{m}^3$  in 2002,  $1.50 \mu\text{g}/\text{m}^3$  in 1998, slightly higher levels of Black carbon concentration ( $1.60 \mu\text{g}/\text{m}^3$ ) was observed in 2013,  $1.81 \mu\text{g}/\text{m}^3$  in 2007, and the highest Black carbon concentration ( $1.85 \mu\text{g}/\text{m}^3$ ) was observed in 2005.

Figure 10 shows a Time Series Analysis of Rainfall and black carbon for Oyo State (1983 - 2023). The lowest amount of rainfall (860.34 mm) was observed in 2001, low levels of Black carbon concentration (994.01 mm) were observed in 2013, followed by 1002.46 mm in 1989, 1081.88 mm in 1992, 1362.27 mm in 2007, a high amount of rainfall 1516.98 mm was observed in 1995, followed by 1531.04 mm in 1991, 1557.46 mm in 2023, 1600.00 mm in 2008 and the highest amount of rainfall 1763.91 mm was observed in 2019.



**Figure 9:** Time series of Rainfall and Black Carbon for Oyo State (1983 - 2023)



**Figure 10:** Time Series of Rainfall and Black Carbon for Oyo State (1983 - 2023)

## Discussion

The fluctuation in annual rainfall patterns and the variability of black carbon levels may stem from various causes. Nevertheless, a correlation between the two has been established. According to Sand et al. (2020), black carbon can impact precipitation through diverse mechanisms, and the climate's response to black carbon presence heavily relies on its vertical dispersion. Essential climatic factors such as rainfall, temperature, relative humidity, and sunshine duration display fluctuations both in time and space, as observed by [7]. Hence, climate variability refers to the changes in statistical parameters like mean values, standard deviations, frequency of extreme events, etc., across various temporal and spatial dimensions, as emphasized by Olabode and Adeleke (2017). Comprehending the intricate interplay among these elements is vital for forecasting and addressing alterations in rainfall patterns and their consequences on ecosystems, agriculture, water reserves, and human communities (Abbass et al., 2022). Changes in rainfall

patterns and temperature variations can impact the growth of vegetation and subsequent biomass combustion. Arid conditions might result in more extensive wildfires and higher concentrations of black carbon [8].

Short-term fluctuations in precipitation patterns are predominantly influenced by localized weather phenomena like thunderstorms, cyclones, and frontal boundaries. These phenomena are notably erratic and can lead to unpredictable rainfall patterns within relatively confined geographical regions [9]. Additionally, seasonal variations are commonly observed in BC concentrations [10]. For example, areas where solid fuels (e.g., wood, coal) are commonly used for residential heating tend to experience higher BC concentrations during the winter months when heating demand peaks. Moreover, activities such as biomass burning for land clearing contribute to elevated BC levels during specific seasons. Variations in industrial operations, production processes, and technologies can also impact BC concentrations in neighboring areas [11].

The concentration of BC is significantly influenced by the intensity and nature of combustion sources within a particular region [10]. These variations may arise from natural internal mechanisms, external factors, or continual anthropogenic modifications in atmospheric composition and land utilization practices, as highlighted by Abaje [12]. These results are in line with the conclusions reached by Alawaye and Alao who conducted a statistical analysis of rainfall patterns to establish a suitable model based on time series data related to monthly rainfall distribution in Osogbo Metropolis [13]. Their study unveiled a considerable degree of volatility in the rainfall data marked by seasonal and irregular changes. Furthermore, Okorie documented that each rainy season in Nigeria is accompanied by tropical storms leading to substantial loss of life and property worth millions of naira nationwide [14]. These situations underscore the critical necessity of investigating rainfall variability for purposes such as agricultural and water resource management, flood risk evaluation, climate change impact analysis, and other environmental assessments, as stressed by Kumbuyo [15].

In conclusion, the data presented in this study will be crucial in influencing climate change mitigation strategies, enhancing climate resilience, and shaping policy frameworks in Nigeria.

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