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Climate change and rainfall variability in Bida, Nigeria: A three-decade analysis (1991–2020)

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Abstract:
Climate change has increasingly disrupted hydrometeorological patterns globally, with local manifestations posing severe challenges to agriculture, water supply, and public health. This study investigates the impact of climate change on rainfall variability in Bida, Niger State, Nigeria, over a 30-year period (1991–2020), a region where livelihoods depend heavily on climate-sensitive activities. The study aims to analyze long-term changes in rainfall patterns and examine their relationship with temperature and relative humidity to understand localized climatic shifts and inform adaptation planning. Historical climate data were sourced from the ERA5 Reanalysis Dataset and NASA POWER platform, covering rainfall, temperature, and relative humidity. These datasets were aggregated into annual and decadal series and subjected to descriptive statistical analysis, including mean, standard deviation, and coefficient of variation. Seasonal trends were also examined by distinguishing between wet and dry periods. Results show a steady decline in average annual rainfall by 1.083 mm over the three decades, coupled with a 1.03°C increase in average annual temperature. Relative humidity exhibited slight fluctuations, with more variability observed in recent years. The most significant rainfall was recorded in 1995 (5.00 mm), while the lowest was in 1999 (0.89 mm). Temperature peaked in 2005 at 28.55°C. Seasonal analyses further indicate reduced rainy season rainfall and rising dry season temperatures. The findings confirm a pattern of increasing climatic stress in Bida, characterized by reduced water availability and elevated heat levels. These trends highlight the urgent need for climate-resilient policies, especially in agriculture, water resource management, and public health planning. Promoting climate-smart agriculture, improving water infrastructure, and strengthening local climate data systems are recommended for building regional resilience to ongoing climate variability.

Keywords: *Climate change, Rainfall Variability, Relative Humidity, Temperature*

1. Introduction

Climate change has emerged as a global challenge with significant implications for natural systems and human well-being. Rainfall and temperature, as core climatic variables, directly affect agriculture, water supply, health, and economic productivity, especially in developing countries like Nigeria [1]. According to IPCC [2], climate change can be recognized as a dominant global threat, with widespread consequences for ecosystems, agriculture, and human health. Temperature and precipitation shifts are among the most observable effects, particularly in vulnerable tropical regions [3]. In Nigeria, climate variability has led to erratic rainfall, increased heat waves, flooding, and drought posing serious threats to agricultural productivity and water security[4–6]. Studies have shown that these climate anomalies have intensified in the last two decades, particularly in the Guinea Savannah and Sahel regions [7].

These disruptions are particularly evident in Bida town and environs, a semi-arid region in Niger State, where livelihoods are heavily reliant on climate-sensitive sectors like farming and livestock rearing. Declines in rainfall and increases in temperature have adversely affected crop yields, water availability, and livestock health.These variabilities are reported in a recent studies by Mohammed [8] indicating altered seasonal rainfall patterns and rising temperatures.

Previous studies have shown that regional-scale analyses of climatic variables are essential for understanding localized climate trends [9]–[11]. This calls for data-driven policy action to support climate adaptation and resilience building at the local level [12–15].

The present study focuses on analyzing the variability in rainfall patterns in Bida, Niger State and their linkage with changes in temperature and relative humidity between over a 30 – year period (1991 and 2020), and to assess their relationship with changes in temperature and relative humidity. By evaluating decadal and seasonal trends, the study aims to identify clear indicators of climate change in the region and to provide evidence-based recommendations for climate resilience with the following specific objectives: Analyze the rainfall pattern in Bida across three decades. In addition, determine the impact of temperature and humidity on rainfall and assess the environmental effects of these climatic changes and recommend appropriate coping strategies.

2. Methodology

2.1 Study Area

Bida is located in North-Central Nigeria, within Niger State, between latitudes 9.0797°N and longitudes 6.0097°E. The town covers an area of approximately 1,698 km². The region experiences a tropical savannah climate characterized by distinct wet (April–October) and dry (November–March) seasons. The local economy is driven by agriculture and livestock farming, both highly sensitive to changes in weather and climate patterns.

2.2 Data Collection

This study employed secondary climate data for rainfall (in millimeters), temperature (in degrees Celsius), and relative humidity (in percentage) from January 1991 to December 2020. The data were obtained from two reliable global climate databases:

a. ERA5 Reanalysis Dataset: Provided by the European Centre for Medium-Range Weather Forecasts (ECMWF), this source offers high-resolution global climate reanalysis data. It was used to obtain monthly and annual values for relative humidity.
b. NASA POWER (Prediction of Worldwide Energy Resources) Data Access Viewer: Managed by NASA's Langley Research Center, this tool supplies data to support agricultural, ecological, and energy research. It was used to collect rainfall and temperature data.

All data were downloaded in monthly time series format and subsequently aggregated to annual values. Each variable was carefully compiled into Microsoft Excel spreadsheets and categorized by decade for comparative analysis:

a. D1: 1991–2000
b. D2: 2001–2010
c. D3: 2011–2020

The collected data underwent a rigorous cleaning and pre-processing phase to ensure quality and accuracy. This included checking for missing or inconsistent entries, standardizing measurement units across datasets, and identifying outliers or anomalies using visual inspections and statistical summaries. Where necessary, missing monthly values were handled using linear interpolation or flagged for exclusion. The datasets were then organized in chronological order, verified against known seasonal patterns, and cross-checked with secondary sources for consistency. These steps ensured the data were reliable and ready for statistical analysis.

2.3 Data Analysis

Descriptive statistical methods were applied to examine the trends, variations, and seasonal behaviors of the climate variables across the three decades. The following key statistical tools were used:

2.3.1 Mean (Arithmetic Average)

The mean is used to determine the central tendency of the data as presented as equation 1:

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad (1)$$

Where: $\bar{X}$ = mean value, X_i = each data point and n = number of observations

2.3.2 Standard Deviation (SD)

The Standard deviation is a measure the dispersion or spread of data around the mean (equation 2):

$$SD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})^2} \qquad (2)$$

2.3.3 Coefficient of Variation (CV)

The coefficient of variation is a normalized measure of variability that allows for comparison across variables with different units as expressed mathematically below as equation 3:

$$CV(\%) = \left(\frac{SD}{\bar{X}}\right) \text{x } 100 \qquad (3)$$

2.3.4 Seasonal Classification

For clarity and better understanding of the intra-annual climatic variations, the dataset was divided into two seasons:

a. Dry Season: November to March
b. Rainy Season: April to October

Statistical summaries were generated per season, per decade, and across the full study period. Graphs and tables were used to display the comparative values across years and decades. All analyses were conducted using Microsoft Excel, with formulas and functions applied to automate calculations and produce visual outputs.

3. Results

This section presents the outcomes of the statistical analysis conducted on rainfall, temperature, and relative humidity data for Bida from 1991 to 2020. The results are grouped by decade to identify temporal patterns and variability. Each climate variable is analyzed with reference to its annual and seasonal trends using summary statistics including mean, standard deviation, and coefficient of variation. Tables are used to visualize and compare decadal changes in the climate parameters, helping to illustrate the evolving climatic conditions in Bida over the 30-year period.

3.1 Rainfall Variability

Rainfall is a critical climatic variable influencing agriculture, water availability, and overall ecosystem stability. Analyzing rainfall patterns over time can reveal the extent of climate variability and potential implications for food security and water resource planning. The following data in Table 1 summarize average annual rainfall across three decades, highlighting trends and changes specific to Bida.

Table 1: Decadal Rainfall Statistics in Bida (1991–2020) [NASA POWER]

Decade	Average Annual Rainfall (mm)	Highest Year	Rainfall (mm)	Lowest Year	Rainfall (mm)
D1 (1991–2000)	3.814	1995	5.00	1999	0.89
D2 (2001–2010)	3.038	2007	3.89	2005	2.08
D3 (2011–2020)	2.731	2012	3.82	2015	1.84

There was a total decline of 1.083 mm in average annual rainfall from D1 to D3 as shown in Table 1. The highest variability in rainfall occurred in D1 with a coefficient of variation (CV) of 28.77%. 2012 with 3.82 and 2015 with 1.84 . There was a total decline of 1.083 mm in average annual rainfall from D1 to D3. The highest variability in rainfall occurred in D1 with a coefficient of variation (CV) of 28.77%.

3.2 Temperature Trends

Temperature trends offer insights into regional warming and potential stress on human health, crop productivity, and hydrological cycles. Table 2 shows the summaries of decadal temperature of the study area. This subsection presents the decadal averages and extremes in annual temperature to identify long-term shifts, with specific reference to observations made in Bida.

Table 2: Decadal Temperature Statistics in Bida (1991–2020) [NASA POWER]

Decade	Average Annual Temperature (°C)	Highest Year	Temperature (°C)	Lowest Year	Temperature (°C)
D1 (1991–2000)	26.33	1999	27.72	1994	25.80
D2 (2001–2010)	27.36	2005	28.55	2008	26.55
D3 (2011–2020)	27.36	2015	28.22	2011	26.09

From Table 2, the temperature has increased by approximately 1.03°C over the study period, with higher variability in D3 (CV = 2.72%) indicating more erratic climate behavior. 2015 with 28.22 and 2011 with 26.09. Temperature has increased by approximately 1.03°C over the study period, with higher variability in D3 (CV = 2.72%) indicating more erratic climate behavior.

Relative humidity showed modest variation, with a slight increase in peak values and greater variability observed in D3 (CV = 3.85%) as shown in Table 3. 2013 has 77.76 while, 2020 has 67.44. Relative humidity showed modest variation, with a slight increase in peak values and greater variability observed in D3 (CV = 3.85%).

3.3 Relative Humidity Trends

Relative humidity reflects atmospheric moisture content and influences evapotranspiration, precipitation, and human thermal comfort. The decadal relative humidity summaries are shown in Table 3. Analyzing long-term variations in humidity levels helps assess the hydrometeorological changes occurring in the study area. The data below show the decadal averages and extremes in relative humidity with contextual reference to Bida.

3.4 Seasonal Analysis

Seasonal analysis provides a more detailed view of intra-annual climatic fluctuations as shown in Table 4, offering insights into how dry and rainy seasons have evolved over time. By examining seasonal rainfall and temperature trends across decades, we can better understand the implications of climate change on agricultural cycles, water availability, and heat stress in Bida.

Table 3: Decadal Relative Humidity Statistics in Bida (1991–2020) [ECMWF]

Decade	Average Relative Humidity (%)	Highest Year	Humidity (%)	Lowest Year	Humidity (%)
D1 (1991–2000)	73.38	1999	77.04	2000	70.57
D2 (2001–2010)	73.59	2009	75.48	2008	71.23
D3 (2011–2020)	73.26	2013	77.76	2020	67.44

Table 4: Seasonal Rainfall Trends in Bida (1991–2020)

Decade	Dry Season Rainfall (mm)	CV (%)	Rainy Season Rainfall (mm)	CV (%)
D1	0.3316	104.54	6.2693	47.82
D2	0.2118	166.81	5.0324	56.90
D3	0.2062	153.89	4.5156	53.49

Table 5: Seasonal Temperature Trends in Bida (1991–2020)

Decade	Dry Season Temp (°C)	CV (%)	Rainy Season Temp (°C)	CV (%)
D1	25.84	8.11	26.69	5.09
D2	27.58	7.56	27.23	5.40
D3	27.54	8.04	27.36	6.16

These statistics shown in Tables 4 and 5 confirm that seasonal rainfall has declined and temperatures have risen, particularly during the dry season, intensifying heat stress and reducing water availability. 8.04 | 27.36 | 6.16|. These statistics confirm that seasonal rainfall has declined and temperatures have risen, particularly during the dry season, intensifying heat stress and reducing water availability.

4. Conclusion

This study establishes that Bida has undergone significant climatic changes over the last three decades. Key findings include declining annual and seasonal rainfall, leading to potential water scarcity and reduced agricultural productivity; increasing average temperatures, which may exacerbate drought conditions and reduce soil moisture; and fluctuating but generally high relative humidity, affecting thermal comfort and crop evapotranspiration. These changes are indicative of climate change impacts and pose challenges to local farming, water resource management, and public health. The data highlight the urgent need for climate-resilient policies and adaptive strategies in Bida and similar regions.

Recommendations

The combination of adaptation and mitigation strategies can help stakeholders reduce the negative impacts of climate variability and enhance resilience in Bida and beyond. Key recommendations include promoting climate-smart agriculture through the use of drought-resistant crops and sustainable farming practices; improving water management by enhancing rainwater harvesting and irrigation infrastructure; and supporting reforestation and afforestation efforts to strengthen local carbon sinks and combat desertification. Additionally, raising public awareness about climate change and adaptive strategies is essential, alongside integrating climate data into urban planning and agricultural extension services. Finally, establishing local meteorological stations for high-resolution data collection will support ongoing research and monitoring efforts.

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