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DECADAL CLIMATE VARIABILITY AND CHANGE IN EDO STATE, NIGERIA

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Abstract - This study examines the decadal variability of temperature and rainfall in Edo State, Nigeria. This is crucial for decision-making in various industries like infrastructure, water resources, agriculture, and energy. The study utilized gridded Climate Research data from 25 local communities between 1956 and 2016, cross-checked against Nigerian Meteorological Agency (NiMet) data, and applied various time series analysis methods. The results demonstrated that the state has experienced both abrupt and gradual increases in temperature, particularly during the decade spanning 1976–1985. The most probable time frame for a sudden temperature change was 1980. Changing by 0.14856 ^{0}C on average per ten years, 1986–1995 was the coldest decade, and 1976–1985 was the hottest, with the typical temperature difference of -0.01723 ^{0}C every ten years. Rainfall varied by an average of 61 mm/decade in the wettest decade (1986–1995) and 14.08 mm/decade in the driest (1976–1985). The spectral examination revealed that 15 years was the most significant frequency for both temperature and rainfall. The study found low rainfall and temperature variability of 9.66% and 1.315%, respectively. This study proposes strategies to mitigate and enhance adaptive capacity in response to the impacts of climate change, thereby raising awareness about its impact due to rainfall and temperature.

Keywords: decadal climate variability, time series, trend, abrupt climatic change, periodicity

1.0 INTRODUCTION

The Decadal Climate Variability (DCV) phenomenon can provide crucial information for water managers, aiding in short-term planning for reservoir management, water supplies, flood risk management, energy production, infrastructure planners, recreation, inland navigation, and irrigation. The decadal time scale is a key planning horizon for governments, businesses, and societal entities, recognized by the IPCC [1] and national initiatives. There have been changes in temperature and rainfall patterns over various time periods, according to numerous research studies conducted worldwide [2]. Decadal prediction, which focuses on time-evolving regional climate conditions for the next 10–30 years, falls between seasonal/inter-annual forecasting and longer-term climate change projections. It is essential to have the information portfolio needed to deal with and successfully adapt to climate change. According to [3–5], the district of Betul in Madhya Pradesh experienced an increase in seasonal and annual rainfall; however, the rate of increase was not statistically significant. In their investigation of the variations in rainfall in East and West Madhya Pradesh, [6] discovered that West Madhya Pradesh monthly trends showed a notable decline around June, but a significant rise in August. Using high-resolution gridded data, [7] examined Madhya Pradesh's long-term rainfall patterns. According to their findings, there has been a discernible decrease in winter, post-monsoon, yearly, and monsoon rainfall. discovered a decrease in the yearly, monsoon, post-monsoon, and winter rainfall in India [8], while a trend towards improvement in the pre-monsoon period was similar to [9, 10]. In the Himalaya, [11] evaluated the temporal and spatial trends in observed and modeled precipitation and showed that remote sensing products can be employed with reliability in inaccessible places where there is a lack of observational data or incomplete data over time. Nigeria's coastline, including Edo State, is facing rising sea levels due to human activity and oil contamination, increasing coastal flooding risk. Socioeconomic issues, such as low income and remoteness, exacerbate the situation. Rising temperatures and sea levels threaten livelihoods, impact hydropower, agriculture, and industrial output [12]. Understanding climate change and its unpredictability is crucial for developing adaptation strategies and managing water resources. However, information on current climate variability rates, coastal geomorphology, and socioeconomic advancements in Africa is scarce, making it essential to develop comprehensive measures [13]. Previous research on climate change in Edo State has been limited, with most available materials focusing on climate trends and their impacts, such as flooding or sea level rise. Due to low climatic data availability, researchers used point-based climatic data [14–16]. There is no information available about earlier studies on rural communities, which are less equipped to adapt to changes in extreme occurrences and are more susceptible to climate change.

2.0 MATERIALS AND METHODS

2.1. Area of Study

The study area is the Southern Senatorial District of Edo State, Nigeria (Figure 1). Twenty-five communities in the district were selected as representatives of other communities for coverage based on their population, land size, land use, and land cover. Each community formed the sites for which rainfall and temperature values were collected for the study.

Edo State is one of the thirty-six states of Nigeria, having a population of 3,233,366 as of 2014 [17] and a total land area of 19,794 square kilometers. The state lies between latitudes 5°44'N and 7'37'N and longitudes 5°44'E and 6^{0}43'E. Its borders are as follows: Kogi State to the north, the River Niger to the east, Ondo State to the west, and Delta State to the south. The study area covers seven local government areas out of the state's eighteen local government areas. It is located in southern Nigeria, in the oil-producing Niger Delta region. Benin City is the headquarters of the state. Edo State is mostly low-lying except for its northern border. There are two distinct seasons in the state's tropical climate: the dry season and the rainy season. The dry season lasts from early November to late March, whereas the rainy season starts in late March and finishes in early November. In most cases, the northern section of the state endures a longer dry season than the southern part, which receives nearly year-round rainfall.

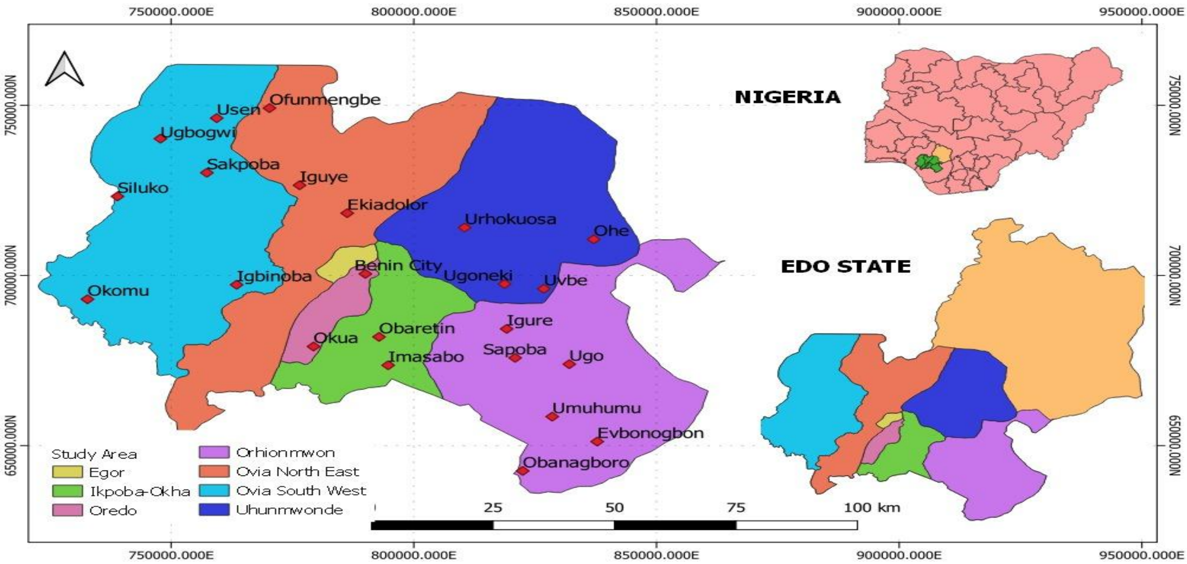


Figure 1 Map of study area (Source: Authors)

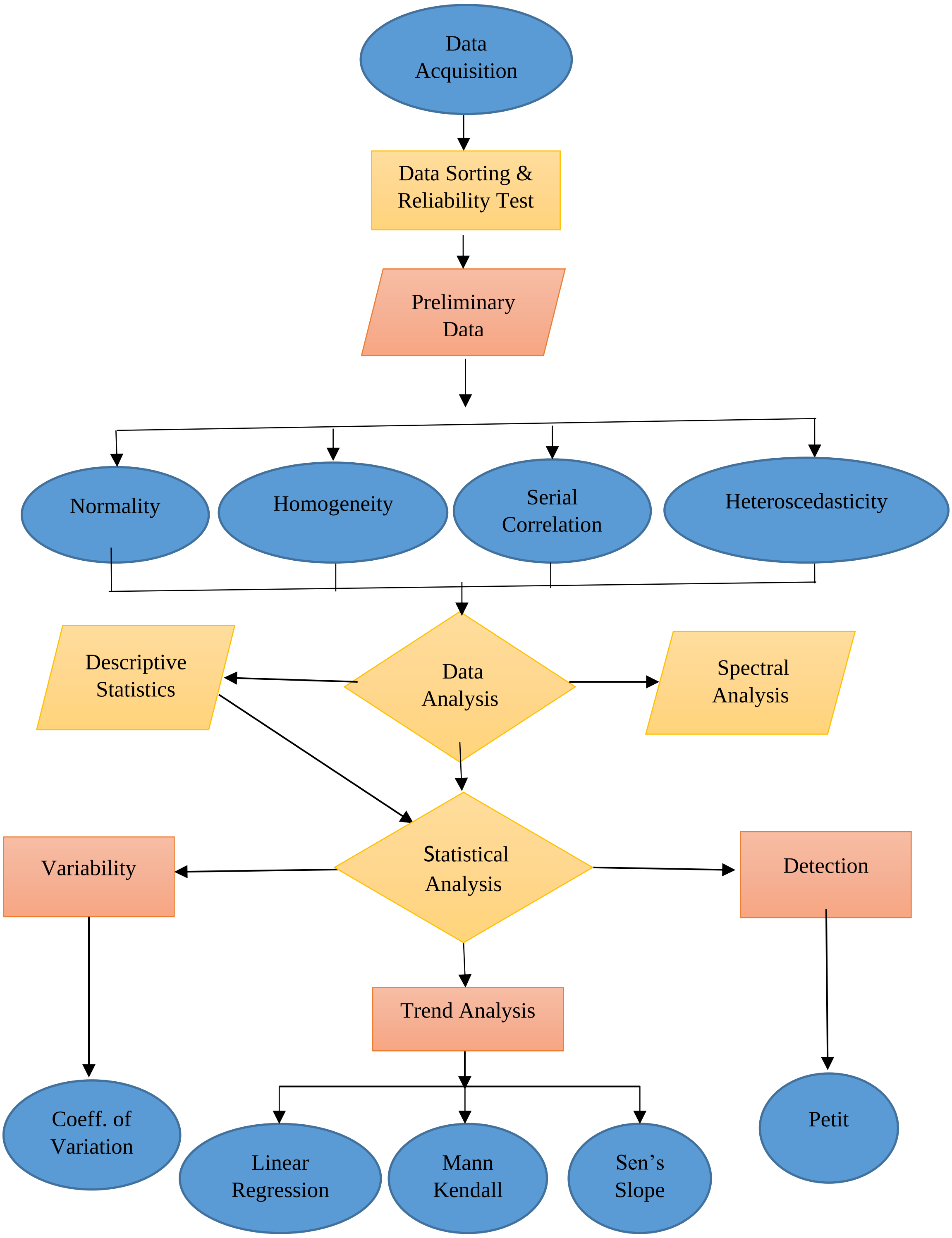


Figure 2 Flowchart of methodology for assessing decadal variability and climate change (Adapted from [18])

2.2. Data Collection

Archival mean monthly rainfall and temperature data for two distinct climate eras, 1956–1986 as well as 1987–2016, for 25 sites in each of the communities within the study area were collected in MS Excel format from Research Unit CRU TS 3.21 dataset (http://badc.nerc.ac.uk). They were classified according to annual rainfall and temperature series. They were compared with data from the Nigerian Meteorological Agency (NiMet).

2.3. Test for Reliability of CRU Data

Climate modeling faces difficulties due to the scarcity of genuinely trustworthy data for analysis and forecasts of climate change. For studies on hydrology, meteorology, climate change, and estimation, the data must be statistically reliable. Thus, they must be screened to guarantee data quality. The reliability of the CRU data was tested, validating the same using NIMET observed data. Two methods were adopted, namely: descriptive statistics and goodness-of-fit statistics. For the descriptive statistics method, the mean annual rainfall and temperature were computed for each of the states. To determine whether there were any differences between them, the simple t-test was employed. The degree of freedom (df=n-1) was calculated along with the Pearson correlation and the number of observations (n). The standard t statistics table provided the t statistics and t critical values for the one-tailed and two-tailed tests. The hypothesis was stated as:

The Null hypothesis: statistical variation in the average seasonal rainfall / Temperature distribution between the NIMET and CRU data does not exist.

The Alternate hypothesis: statistical variation in the average seasonal rainfall / Temperature distribution between the NIMET and CRU data do exist.

If $\mu_1 = \mu_2$ is the mean of Annual Rainfall /Temperature for NIMET and CRU data respectively, then, null hypothesis Ho: $\mu_1 = \mu_2$ and the alternative hypothesis is Ha: $\mu_1 \neq \mu_2$ i.e. $\mu_1 >. \mu_2$ or $\mu_1 < \mu_2$. Thus, the analysis included two-tailed testing.

Based on a simple t-statistic test statistic and the degrees of freedom, the P-values were determined. The P-value is the probability that a t statistic having n degrees of freedom is more extreme. The P-values were compared with the critical values at a significance level of 0.05 obtained from the standard t-statistics table. The decision is that if the P-value is greater than the critical value, alpha=0.05, Ho cannot be rejected

The second method, the Goodness-of-Fit statistics, used the Coefficient of Determination (R^2)

$$R^2 = \left[\frac{\sum_{i=1}^{n}(O_i - \overline{O})(P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n}(O_i - \overline{O})^2}\sqrt{\sum_{i=1}^{n}(P_i - \overline{P})^2}} \right] 0 \leq R^2 \leq 1 \qquad (1)$$

Where O_i is NiMet data, $\overline{O}$ is the mean of NiMet data, P_i is CRU data and $\overline{P}$ is the mean of CRU data

A perfect relationship is achieved when the value of R^2 falls between $0.8 < R^2 < 1$ [19].

If the R^2 values are greater than 0.80, there is an indication that there is a perfect relationship between NiMet data and the CRU data.

2.4. Preliminary Data Analysis

Descriptive statistics, including variance, kurtosis, skewness, minimum and maximum, range, mean, standard deviation, and associated standard error computations, were applied to the annual rainfall and temperature time series using the XLSTAT software. These figures provide a general idea of how the mean annual temperature and rainfall data sets were distributed and dispersed.

Three tests were used to determine the possibility that an underlying random variable would be normally distributed: the D'Agostino-Pearson, the Skewness, and the Shapiro Wilk Test (SWT). This was to ascertain whether or not a normal distribution could be used to characterize the dataset. This made it easy to execute tasks like data filtering, identification, explanation, validation of outliers, and variance descriptions among sub-populations.

To evaluate trend dependability and select appropriate time intervals for the research, homogeneity tests were carried out. The Standard Normal Homogeneity Test (SNHT), Von Neumann Ratio, Buishand's Test, and Pettit's Test were the homogeneity tests that were carried out using the XLSTAT software.

Serial correlation coefficients quantify the degree to which data within a sequence divided into different time periods are most likely to be comparable. According to [20], serial correlation must not exist in the time series prior to using the Mann-Kendall (MK) test as this could skew the genuine results of the trends. As a result, the Durbin Watson S Test was used to verify the serial correlation, and the XLSTAT program was used to implement it.

In linear regression, it is assumed that the residuals' distribution is constant throughout the plot (homoscedastic). To conduct and validate the Breusch-Pagan and White heteroscedasticity test, XLSTAT software was utilized. This was done in order to guarantee the safety of using the linear regression model for additional analysis. After we have identified data properties, we conducted a comprehensive data series analysis.

2.5. Data Analysis

The yearly rainfall data was analyzed using the Mann-Kendal and linear regression tests to detect trends. To ascertain the trend analysis's magnitude, the Thei-Sen Slope test was employed. The Petit test was employed to detect sudden changes in rainfall and temperature (step jumps). The flowchart of methodology for assessing decadal variability and climate change is presented in Figure 2.

2.6. Climate Variability (CV) Test

The coefficient of variation was used to assess the degree of variation in the mean distributions of environmental variables over an extended period of time. According to [21], the coefficient of variation represented by CV removes the unit of measurement from the standard deviation of a series of data by dividing it by the mean of this series of data. The formula for the coefficient of variation expressed as a percentage is:

$$CV = \frac{SD \times 100}{\overline{X}} \quad (2)$$

Where CV is the coefficient of variability .SD is the standard deviation and X is the mean. The degree of data variability in a sample with respect to the population mean is indicated by the coefficient of variation. The higher the CV, the more variable the year-to-year inter-annual rainfall of a locality is.

2.7. Change Detection-Pettit's Test (Non-Parametric Rank Test)

The Pettitt method is a rank-based test method which has been widely used to detect change point in the mean value of observed series.

The ranks $r_1...r_n$ of the $Y_1...Y_n$ was used to calculate the statistics.

$$X_k = 2\sum_{i=1}^{k} r_1 - k(n+1)\,, k = 1,2,\ldots,n \quad (3)$$

If an abrupt change occurs in year K, then the statistic is either maximal or minimal near the year k = K:

$$X_k = \max_{1\le k\le n} |X_k| \quad (4)$$

Equation (4) states that a transition point is reached when X_k approaches the maximum value of K in a series.

$$Ka = \left\{-1na\left(n_3 + \frac{n_2}{6}\right)\right\}\frac{1}{2} \quad (5)$$

where n is the number of observations and α is the level of significance.

The next step is to solve Equation (4)

Critical values for X_K for different data set lengths are given in Table1.

Table 1 Critical values of test statistics for different change point detection tests at different significance level

Number of observation	Pettit Test		SNHT		Buishand Range test ($R/\sqrt{n}$)		von Neumann Ratio test	
	1 %	5 %	1 %	5 %	1 %	5 %	1 %	5 %
20	71	57	9.56	6.95	1.60	1.43	1.04	1.30
30	133	107	10.45	7.65	1.70	1.50	1.20	1.42
40	208	167	11.01	8.10	1.74	1.53	1.29	1.49
50	293	235	11.38	8.45	1.78	1.55	1.36	1.54
70	488	393	11.89	8.80	1.81	1.59	1.45	1.61
100	841	677	12.32	9.15	1.86	1.62	1.54	1.67

2.8. The Mann-Kendall (MK)

The MK non-parametric test was used to look for patterns in the annual rainfall data series [22]. It verifies that statistic Z was derived from

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{V(S)}}, S > 0 \\ 0S \quad = 0 \\ \frac{S+1}{\sqrt{V(S)}}, S < 0 \end{cases} \quad (6)$$

Z_s is the typical statistic for the normal test for n > 10.

The statistic S's variance, V(S), was determined by:

$$V(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m}(t_k - 1)(2t_k + 5)}{18} \quad (7)$$

The number of groups that are connected and the number of ties for the specified amount are represented by the symbol m. A collection of samples with the same value is called a linked group. Z(α/2) = Z0.05=1.645 for α=0.1

If the upper Confidence level (*UC)* I > $Z_{0.05\ (1.645)}$, at the α significance threshold, the null hypothesis indicating no trend is rejected

2.9. Theil-Sen Analysis

Trend magnitude is measured using the Theil-Sen estimator. Hydrological time series data analysis has made extensive use of it. The estimator for Theil-Sen is calculated as [22]:

$$Q_{med} = median(Q),$$

$$Q = \frac{x_j - x_i}{j-i}, i < j, \quad (8)$$

where Q_{med} is the slope between the data points x_i and x_j, and x_i, x_j, and j are the data measurements at times i, j, and i, respectively.

2.10. Test for Linear Regression

For Linear Regression, the total number of observations, and the test statistic, T_O, have (n-2) degrees of freedom. The expression for regression is:

$$y = a + bx \quad (9)$$

The slope of regression is calculated using:

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{10}$$

Furthermore, the expected intercept is:

$$a = y - bx \tag{11}$$

The equation that describes the test-related statistic, that is the t-statistic (t) is:

$$T_o = b_1 SE \tag{12}$$

where SE is the slope's standard error and b1 is the model regression line's gradient.

$$SE = Sb_1 = \frac{sqrt\left[\sum \frac{(y_i - \hat{y}_i)}{(n-2)}\right]}{sqrt[\sum (x_i - x)^2]} \tag{13}$$

$$\frac{-t_a}{2}, n-2 < T_o < \frac{t_a}{2}, n-2 \tag{14}$$

For $\frac{-t_a}{2}, n-2 < T_o < \frac{t_a}{2}, n-2$ are the critically important values of the dual hypothesis, and the cumulative probability-corresponding important threshold as well as the percentile of the distribution.

2.11. The Spectral Analysis (Cycles and Periodicity)

Spectral analysis is used for the estimation of possible periodic cycles in a given time series. Atmospheric and climatic data show several periodicities such as the Quasi-Biennial Oscillation (2 - 3 years), El-Nino Southern Oscillation (5 - 7) years, Sunspot cycles (10- 15 years), and Atlantic Multi-Decadal Oscillation (30 years)

Periodicity in annual rainfall and temperature was investigated using a correlation analysis of the autocorrelation function. The Lomb-Scargle periodogram which has shown great promise in detecting peaks in unevenly sampled time-correlated data was used in this study. A mathematical technique called the Lomb Scargle periodogram is used to look for periodicities or oscillations in time series data that are unevenly spaced. For data with irregular sampling, it serves as an alternative to the more widely utilized Fourier analysis. The Lomb-Scargle periodogram was given by [23] as:

$$P_N(\omega) = \frac{1}{2a^2}\left\{\frac{\left[\sum_j\left(x_j - \bar{x}\cos(\omega(t_j - \tau))\right)\right]^2}{\sum_j \cos^2\left(\omega(t_j - \tau)\right)} + \frac{\left[\sum_j\left(x_j - \bar{x}\sin(\omega(t_j - \tau))\right)\right]^2}{\sum_j \sin^2\left(\omega(t_j - \tau)\right)}\right\} \tag{15}$$

The mean and variance of the time series respectively, $\tau$is a frequency-based time.

$$\tan(4\pi f\tau) = \sum_{n-1}^{N} \frac{\sin(4\pi f t_n)}{\cos(4\pi f t_n)} \tag{16}$$

$n - x^2$are delay given by spectral analysis, a method that is based on the Fourier transform, was applied using XLSTAT software to ascertain whether cycles characterize the series.

XLSTAT was utilized to implement the periodicity (cycles) that were identified by the spectrum analysis. This investigation found recurrent cycles with varying lengths in a time series that seemed like random noise at first. A periodogram is a graph that shows how each cycle's power or amplitude relates to its frequency or periods.

3.0 RESULTS AND DISCUSSION

3.1. Descriptive Statistics About the Average Annual Temperature and Rainfall

Descriptive statistics about the average annual temperature and rainfall are tabulated in Table 2. XL. Statistic software was used to generate Table 1. According to Table 1, the average yearly rainfall changed from 182.99 mm during the First Climate Period to 185.66 mm during the Second Climate Period. The rainfall series has a normal distribution, according to skewness and kurtosis measurements.

Table 2 Mean annual rainfall descriptive statistics from 1956 to 1986 and 1987 to 2016

Climatic Type	Climatic period	Mean mm	SD mm	Min mm	Max mm	Range mm/	Sum (mm)	Skewness	Kurtosis
Rainfall	NIMET	191.734	128.381	0.55	413.37	413.37	412.825	-0.044	-0.75
Rainfall	CRU	170.348	117.344	16.55	335.84	335.84	319.286	-0.092	-1.60
Temp	NIMET	27.27	1.4263	2.035	25.068	29.068	4	-0.319	-1.39
Temp	CRU	30.447	1.838	3.378	27.507	32.729	5.22	-0.400	-1.34
Rainfall	First	182.991	108.158	20.274	334.582	314.309	2012.91	-0.217	-1.255
Rainfall	Second	185.668	116.391	15.556	337.091	321.535	2042.35	-0.295	-1.524
Temp	First	30.129	1.848	27.441	32.292	5.053	331.428	-0.206	-1.571
Temp	Second	30.614	1.970	27.573	32.965	5.393	336.755	-0.323	-1.535

3.1.1. Differences in NiMeT and CTU mean annual rainfall (1956-2016), (Simple T-Test)

Table 2 depicts the values of NiMeT and CTU Mean Annual Rainfall in the states where differences between them were determined using the student t-test. Displayed are the degree of freedom (df=n-1) and the number of observations (n) together with the Pearson correlation. Additionally provided are the calculated t statistics and the t critical values for the one-tailed and two-tailed tests.

The hypothesis is stated as follows:

The Null hypothesis: Statistical variation in the average seasonal rainfall / Temperature distribution between the NIMET and CRU data does not exist.

The Alternate hypothesis: Statistical variation in the average seasonal rainfall distribution between the NIMET and CRU data do exist.

Null hypothesis Ho: $\mu_{1=}\ \mu_2$

While the alternative hypothesis is Ha: $\mu_1 \neq \mu_2$ ie $\mu_{1>.}\ \mu_2$ or $\mu_{1<}\ \mu_{2.}$

Two-tailed tests are therefore employed in the study. We calculated the P-value using the degrees of freedom and the t-statistic test statistic. The likelihood that a t statistic with 11 degrees of freedom is more severe than 1.725 is known as the P-value. "More extreme" refers to a value larger than 1.725 or less than -1.725 in this two-tailed test. ie.

$$- 1.725 < T_O < 1.725 \quad (17)$$

$$\frac{-t_a}{2}, n-2 < T_o < \frac{t_a}{2}, n-2 \quad (14)$$

Table 3 Findings from the simple t-test comparing the rainfall data from CRU and NIMET

S/N	Simple t" test (To) Computed	Df (n-2)	Alpha	P-value (Two tail)	Decision
5	0.406	22	0.05	1.725	Cannot Reject H_o

Therefore, at a significance level of 0.05, there is no statistically significant difference in the mean of the seasonal rainfall distribution between the NIMET and CRU data. The CRU rainfall and temperature data for the sixty years (1956–2016) is very good and dependable, and it can be utilized for further investigation, according to the results of validation using NIMET observed data. Also, the study compared temperature and rainfall data from CRU and NIMET, revealing excellent data validity with R^2 values of 0.954 and 0.935, indicating that the data acquired from CRU is highly trustworthy and was utilized without risk for additional analysis in this research.

3.2. Three Common Normality Tests

To ascertain the P-values for rainfall, the normality tests Agostino-Pearson, Shapiro Wilk Test (SWT), and Skewness Test were employed. The results are 0.3706, 0.36169, and -0.09218, respectively. Also, the P-values for temperature were 0.2594, 0.2520, and 0.40085, respectively. The following is the formulation of the theories:

Null hypothesis = H_o: There is a normal distribution of the data.

Hypothesis alternative = H_i: There is no normal distribution in the data.

The aforementioned hypotheses were tested at the 0.05 significant level. The null hypothesis is not rejected when the p-value is greater than the significance level because there is not enough evidence to conclude that the distribution of the data is not normal. The results demonstrate that the distribution of the rainfall series is normal according to all three normality tests. The normal distribution assumption is essential for accuracy in parametric testing.

3.3. Homogeneity Tests

P-values for rainfall were found to be 0.316, 0.618, 0.895, and 0.10 for the standard normal homogeneity test (SNHT), Buishand's test (BRT), Von Neumann's ratio (VNR) test, and Pettitt test, respectively. The hypothesis is stated as follows:

$H_{0:}$ The distributions of the two populations are the same.

H_a: The distributions of the two populations are not the same.

Given that the calculated p-values are above the level of statistical significance, alpha = 0.05, the hypothesis H0: The distributions of the two populations are the same. —that is, the data is homogeneous. The data series were shown to be homogenous based on the findings of all four homogeneity tests. If all of the variations in a time series are due to changes in the climate, it is said to be homogenous [24]. The homogeneity test plot indicates that there are large, sudden variations in temperature and rainfall, as presented in Figure 3 and Figure 4.

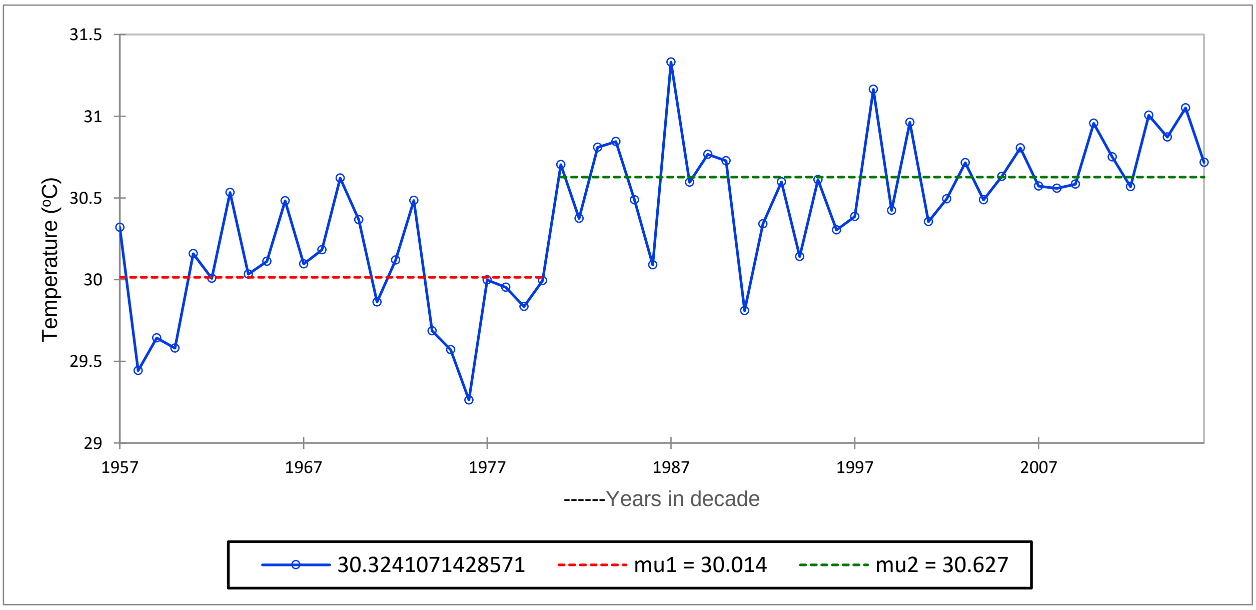


Figure 3 Homogeneity (Petit) Plot for Temperature with Decades in Benin City

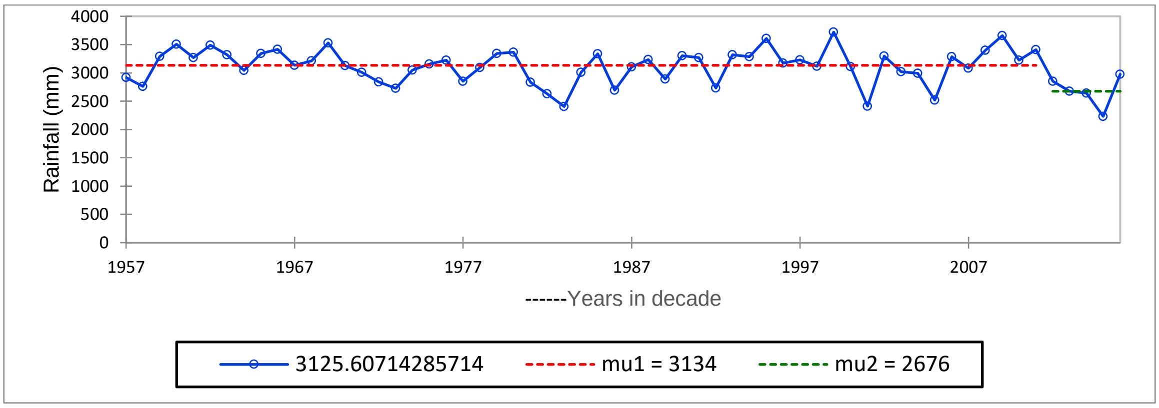


Figure 4 Homogeneity (Petit) Plot for rainfall Decades with in Benin City

The result of the serial correlation coefficients test showed data comparability between time periods. This ensured that time series were free of serial correlation and avoided misleading trends in Mann-Kendall tests [25]. The linear regression model was tested for safety and confirmed to be homoscedastic, indicating a constant distribution of residuals throughout the plot.

3.4. Abrupt Climate Change Analysis

The petit test plot shown in Figure 3 revealed that there was a significant abrupt change in Temperature which occurred in 1980 (Decade C). It can be seen in Figure 4 that mu2-mu1 =30.627-30.014=0.613 ^{o}C indicating a rising temperature. This was the year of increased industrialization in the state due to the policy of a new civil administration after military rule in Edo State. This led to increased burning of fossil fuels by machinery, equipment, and vehicles. Also, the increasing price of cooking gas led to an increase in the cutting down of trees in the forests for use as firewood. Overly dependent on electricity generators due to electric power outages as the national electric power grid collapsed several times. These are the identified drivers that increasingly influenced climate and consequent temperature rise in this study area. This added enormous amounts of greenhouse gases to those naturally occurring in the atmosphere, increasing the greenhouse effect and global warming.

The significance of changes in temperature can have noteworthy impacts on various aspects of our lives and the environment. Sudden or abrupt changes in temperature, both in terms of short-term fluctuations and long-term trends, can have far-reaching effects that can be felt across different sectors. Temperature fluctuations can disrupt ecosystems, affecting species survival and reproductive patterns, potentially leading to species loss due to shifts in plant and animal distribution. Climate and temperature conditions significantly impact agriculture, affecting crop yields, water availability, pests, diseases, and economic losses for farmers, as well as food supply and prices. Extreme temperature changes can significantly affect human health, air pollution, water availability, and biodiversity. They can also disrupt infrastructure, urban planning, and the business sector, leading to increased costs and logistical challenges, especially in urban areas and aquatic ecosystems. Climate change requires understanding and addressing drivers, reducing greenhouse gas emissions, enhancing resilience, and developing early warning systems while reducing fossil fuel use is crucial.

Also, there was a significant abrupt change in rainfall in 2013 (Decade F) with mu2-mu1 = 2676-3134 = -458mm, indicating a decreasing rainfall. This was after the extreme weather event of heavy rainfall and flooding that occurred in the whole country in 2012 [24]. The picture (Figure 5) shows some of the people who were displaced due to flooding that resulted in the loss of properties and submerged several square kilometres of land in general and farmlands in particular in the state. About 20,505 people were affected by the flood [26]. In Benin City, as in many other regions, drought conditions occurred following this period of heavy rainfall due to a combination of factors. The possible reason for this phenomenon is the impact of climate change. Changes in global climate patterns can lead to shifts in rainfall distribution, causing prolonged dry spells after periods of heavy rainfall. Additionally, increased temperatures associated with climate change can enhance evaporation rates, leading to the rapid loss of soil moisture and exacerbating drought conditions.

Figure 5 Situations during the 2012 flooding in Edo state (Source: [27])

Abrupt changes in rainfall patterns have significant implications for ecosystems, agriculture, societies, and economies. These changes can be the result of natural variability, such as El Niño or La Niña events, or human-induced factors like climate change. The implications of abrupt changes in rainfall are diverse and can vary depending on the region and the magnitude of the change.

Adapting to these changes requires a multi-faceted approach that includes improved water management, sustainable agricultural practices, early warning systems for extreme weather events, and community-based adaptation strategies. Addressing the underlying causes of abrupt changes in rainfall, such as climate change, is essential for long-term resilience and sustainability.

3.5. Variability Test

Using equation 1, we obtained the coefficient of variability for rainfall and temperature presented in Table 2. Decade E had the highest rainfall variability of 12.07% and Decade B had the lowest rainfall variability of 5.79%. The mean decadal rainfall variability was 9.66%. Decade C had the highest temperature variability of 1.67% and Decade F had the lowest rainfall variability of 0.68%. The mean decadal temperature variability was 1.315%. According to [28], CV is used to categorize rainfall and temperature events according to their degree of variability: low (CV < 20), moderate (20 < CV < 30), high (CV > 30), very high (CV > 40%), and CV > 70% indicate exceptionally significant inter-annual rainfall variability.

The state's low level of precipitation variability was revealed by the coefficient of variation (CV) of 9.66. The temperature's coefficient of variation (CV), which is 1.315 percent, indicates low variability. The implications of low variability of rainfall will not be significant and will not have a range of effects on agricultural production, water resources, and the overall well-being of communities. Farmers will not face difficulties in crop planning and management due to low rainfall variability, which will boost output and boost the economy. Droughts and floods are examples of extreme weather conditions that can be disastrous. Reduced rainfall variability will not have a major impact on water supplies, which could cause shortages, rivalry, and disputes over use in the industrial, drinking, and agricultural sectors. Low rainfall variability will not cause any major effects on biodiversity and services, especially in wetlands and forests, and it will not cause the extinction of any species or disturb natural ecosystems. Low rainfall variability will not hurt vulnerable populations, such as those in developing nations, and will instead boost the availability of food, water, and agricultural output. The Decadal Variability of Rainfall and Temperature Data are presented in Table 4.

Table 4 Decadal Variability of Rainfall and Temperature Data for Rainfall(mm) R and Temperature (^{O}C) T

		1956-1965 Decade A	1966-1975 Decade B	1976-1985 Decade C	1986-1995 Decade D	1996-2005 Decade E	2006-2015 Decade F	Mean Decade A- F
	Decadal Mean (Rm)	1968	1971.7	1877.2	1888.5	1841.8	1782.8	1888.3
1	SD	168.9	114.2	219.9	210.9	222.3	158.4	182.4
	CV (%)	8.6	**5.8**	11.7	11.2	**12.1**	8.9	9.7
	Decadal Mean (Tm)	30.23	30.25	30.36	30.65	30.75	30,96	30.54
2	SD	0.27	0.38	0.51	0.43	0.27	0.21	1.12
	CV (%)	0.9	1,3	**1.7**	1.4	0.9	**0.7**	1.3

3.6. Investigation of Deviation of Decadal Mean from Sample for Temperature as Well as Rainfall

Applying Theil Sen's slope evaluated for decadal rainfall, the values obtained are presented in Table 4 which shows the magnitude of trend analysis (mm/decade) of the rainfall trend. Table 4 also includes the percentage changes and the decadal mean. The Amount of Rainfall from Decadal Trend Analysis utilizing Theil Sen' Slope Analysis (mm/decade) and Deviation of Decadal Mean from Sample Mean for Rainfall(mm) and Temperature (^{O}C) are presented in Table 5.

Table 5 Amount of Rainfall from Decadal Trend Analysis utilizing Theil Sen' Slope Analysis (mm/decade) and Deviation of Decadal Mean from Sample Mean for Rainfall(mm) and Temperature (^{O}C)

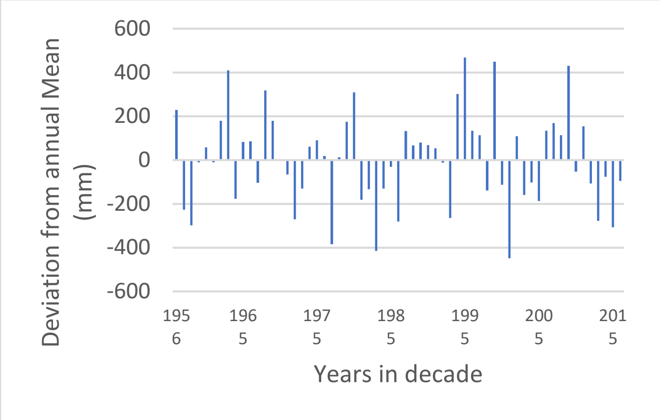
S/N	Climate	1956-1965 Decade A	1966-1975 Decade B	1976-1985 Decade C	1986-1995 Decade D	1996-2005 Decade E	2006-2015 Decade F
a	Rainfall (Theil Sen' Slope)	24.4	-58.2	**-14.08***	**61***	-34	-44.55
b	Temperature ‘’	0.06	-0.07	**0.11***	**-0.02***	0.11	0.02
c	Rainfall (Deviation of Decadal Mean)	0.13	0.09	-0.46	0.42	-0.19	0.09
d	Temperature ‘’	-9.38	-9.63	-5.88	-3.10	-6.22	-13.27

Note: The bold figures with * represent the extreme values.

Table 5 displays the percentage, mean, and decadal variability of the rainfall changes in Temperature (^{O}C). For the specific decade under consideration, the positive symbol indicates a lot of rain (wet)., whereas Low rainfall (dry is indicated by a negative value. It was observed that three decades A, B, D, and F representing 66.7 % were associated with much rainfall; while the remaining decades C and E representing 33,3 % had less rainfall. Table 5 showed that Decade D (1986-1995) was the wettest decade with an average rainfall deviation of 61mm and Deviation of Decadal Mean of 0.42(mm/decade). This is in agreement with [29] who carried out similar research at Ibadan about 300km from the study area. They stated that 1987 was the wettest year. Also, 1976–1985 was the driest decade, considering a change in average rainfall of -0.46 (mm/decade) and rainfall change of (mm/decade).

3.6.1. Deviation from annual rainfall and temperature

The deviation from annual rainfall and temperature for each state in the study area is presented in Figure 6 and Figure 7.



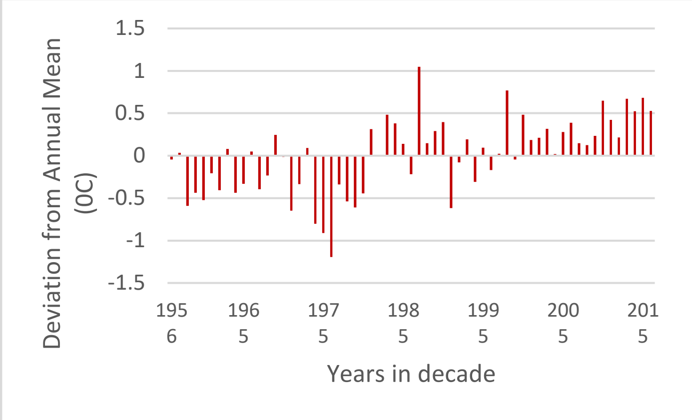


Figure 6 Deviation of mean rainfall from annual rainfall **Figure 7** Deviation of mean temperature from annual temperature

3.7. Trend Analysis - Mann-Kendal (Z-test)

The result of trend analysis using Mann-Kendal (Z-test) showed that the P-values for rainfall and temperature were -4.275 and 2.514 respectively.

Here is how the hypothesis is expressed:

The null hypothesis H_O: Tests show that the series does not exhibit any trends.

Three alternative hypotheses H_a: There is a negative, non-null or positive trend.

Alternative hypotheses H_a: There is a negative, non-null or positive trend. The trend is statically significant when the p-value is less than 0.05.

Since a negative or positive trend is present, the alternative hypotheses were accepted.

The MK test was employed in this work to determine the statistical significance of a trend in the annual and seasonal rainfall series. The p = 0.05 significance level was applied. Given that the calculated absolute value of the upper confidence level (UC) exceeds the standard normal distribution's critical point, i.e., UC > Z0.05 (1.645), the null hypothesis of no trend is rejected at the α significance level of 0.05. Hence, rainfall showed a significantly decreasing trend and temperature showed a significantly increasing trend. Table 6 displays the examination of rainfall trends gathered from 25 sites using linear regression analysis. The results of the linear regression analysis are also presented in Table 6 for temperature and rainfall trends. Eight locations showed a negligible increase in rainfall of various magnitudes, whereas seventeen sites showed a decrease in rainfall of various magnitudes.

3.8. Analysis of Rainfall and Temperature Trends Using Linear Regression

The results of the analysis of rainfall and temperature trends using Linear Regression are presented in Table 6.

Table 6 revealed that the temperature in all locations studied was continuously increasing. The rainfall pattern was not uniform as there were increases in 10 locations (40%) studied and decreases in 15 locations (60%) studied.

Rainfall patterns varied significantly even within relative proximity due to a variety of factors. One key factor is topography. Mountains or large hills cause orographic rainfall, where moist air is forced upwards and cools, leading to condensation and precipitation on the windward side. As a result, the windward side of a mountain may experience higher rainfall compared to the leeward side, which may be in a rain shadow. This can explain why rainfall might increase in one location and decrease in another nearby location.

Another factor is the presence of water bodies. Locations near rivers tend to have more moisture in the air, which can result in increased rainfall due to higher evaporation rates. In contrast, areas further inland may have less moisture available for precipitation, leading to lower rainfall.

Table 6 Analysis of Rainfall and Temperature Trends Using Linear Regression

	Rainfall				Temperature			
Town	**Equation**	**R^2**	**Slope**	**Nature**	**Equation**	**R^2**	**Slope**	**Nature**
Benin city*	Y=-4.7271X+11.3	0.1133	-4.727	Declining	Y=0.0162X-1.17	0.3812	0.0162	Increasing
Ekiadolor*	Y=-0.8338X+3572.	0.0045	-0.8338	Declining	Y=0.0151X+0.39	0.3548	0.0151	Increasing
Evonogbon	Y=0.647X+488.1	0.0027	0.647	Increasing	Y=0.0138X+3.52	0.3081	0.0138	Increasing
Igbinoba	Y=2.2018X-2230.1	0.0228	2.2018	Increasing	Y=0.0156X-0.39	0.3658	0.0156	Increasing
Igueze	Y=0.2409X+1380.1	0.0004	0.2409	Increasing	Y=0.0148X+1.35	0.3386	0.0148	Increasing
Imasagbor	Y=0.2409X+1380.1	0.0004	0.2409	Increasing	Y=0.0158X-0.73	0.3814	0.0158	Increasing
Obanaghoro*	Y=-1.5826X+5462.7	0.0141	-1.5826	Declining	Y=0.0159X-0.84	03884	0.0159	Increasing
Obanisi*	Y=-1.0712X+4015.3	0.00109	-1.0712	Declining	Y=0.0146X+1.48	0.3489	0.0146	Increasing
Obaretin*	Y=-0.4686X+3122.4	0.0012	-0.4686	Declining	Y=0.0152X+0.41	0.3532	0.0152	Increasing
Ofunama	Y=0.4317X+1436.6	0.0007	0.4317	Increasing	Y=0.0156X-0.39	0.3611	0.0156	Increasing
Ogbombiri*	Y=-2.2147X+6820.9	0.0152	-2.2147	Declining	Y=0.0157X-0.75	0.368	0.0157	Increasing
Ohe	Y=0.5956X+697.	0.0033	0.5956	Increasing	Y=0.0147X+0.13	0.35	0.0147	Increasing
Okomu	Y=0.9561X+203.4	0.0042	0.9561	Increasing	Y=0.015X+0.69	0.3467	0.015	Increasing
Okua*	Y= -1.256X+4735.3	0.0078	-1.256	Declining	Y=-0.0157X-0.68	0.3741	0.0157	Increasing
Saforogbon	Y=1.7933X+3584.4	0.0127	1.7933	Increasing	Y=0.0146X+1.51	0.3446	0.0146	Increasing
Sakpoba*	Y=-0.7274X+3584.4	0.0039	-0.7274	Declining	Y=0.0155X-0.26	0.3769	0.0155	Increasing
Siluko	Y=0.8421X+270.24	0.0037	0.8421	Increasing	Y=0.014X+2.96	0.3174	0.014	Increasing
Ugbogui*	Y=-0.4095X+2579	0.0011	-0.409	Declining	Y=0.0143X+2.64	0.3174	0.0143	Increasing
Ugo*	Y=-0.1149X+2371	0.0001	-0.1149	Declining	Y=0.0153X-0.04	0.3787	0.0153	Increasing
Ugoneki*	Y=-1.8131X+5525.	0.027	-1.8131	Declining	Y=0.0154X-0.09	0.3748	0.0154	Increasing
Umuhumu*	Y=-0.7975X+3836.5	0.0049	-0.7975	Declining	Y=0.0154X-0.03	0.3787	0.0154	Increasing
Urhonigbe*	Y=-0.6482X+3169.5	0.0041	-0.6482	Declining	Y=0.014X+2.31	0.3309	0.014	Increasing
Urhokuosa*	Y=-0.2501X+2405	0.0005	-0.2501	Declining	Y=0.015X+0.50	0.3587	0.015	Increasing
Usen	Y=1.7708X-1750.7	0.0207	1.7708	Increasing	Y=0.0137X+3.67	0.2974	0.0137	Increasing
Uvbe*	Y=-4.0127X+9854.9	0.1273	-4.0127	Declining	Y=0.0151X+0.44	0.3711	0.0151	Increasing

Note: * denotes location with declining rainfall.

Local weather systems and atmospheric conditions also play a significant role. For example, the presence of weather fronts, temperature gradients, and air masses can create conditions conducive to rainfall in one area while leaving another area relatively dry.

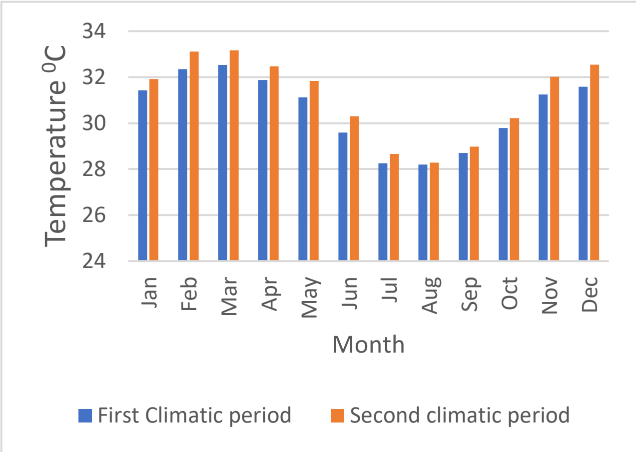
Human activities, such as deforestation, urbanization, and agriculture, can also influence local rainfall patterns. Deforestation can disrupt local ecosystems and reduce the amount of transpiration (water released from plants), which can in turn affect local rainfall patterns. Urbanization, with its concrete surfaces and reduced vegetation, can lead to increased runoff and decreased infiltration, altering natural water cycles.

Climate change is another important factor to consider. As global temperatures rise, the climate becomes more unpredictable, leading to changes in precipitation patterns. Some regions may experience more intense rainfall events, while others may experience more prolonged dry spells.

A combination of these factors could have resulted in varying rainfall patterns in these locations that are near each other.

3.9. Comparing the Seasonal Mean Rainfall and Temperature Patterns as a Measure of Climate Change

The period used as modern measures of the climatic period is 30 to 35 years [30]. To confirm climate change, data from two climatic periods were compared, forming an annual series of 30 years each**.** Figure 8 and Figure 9 show the findings for each of the 12 months in two climatic eras (1956-1986 and 1987-2016). Figure 8 and Figure 9 compare seasonal temperature and rainfall patterns in Benin City between two climatic periods. July experienced the most rainfall in the first two years, while January and December had the least.



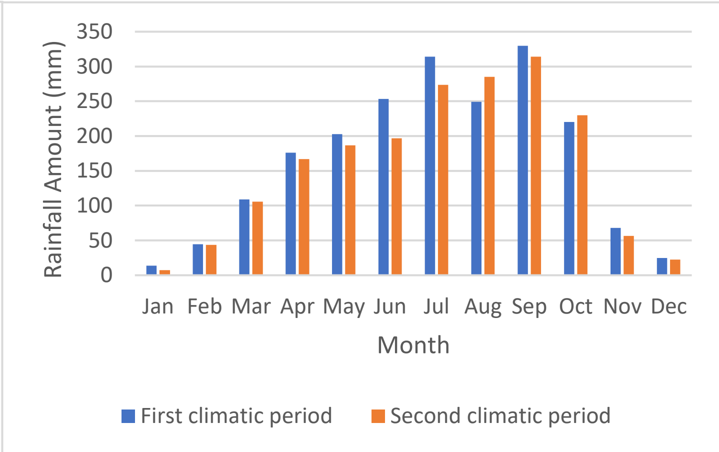


Figure 8 Comparison of seasonal temperature patterns in Benin city between two climatic periods

Figure 9 Comparison of seasonal rainfall patterns in Benin city between two climatic periods

Also, in all the months of the year, there were incremental changes in temperature whereas there were reductions in the amount of rainfall every except in August and October. The mean annual temperature increased significantly throughout the research area, as the values for the second climatic period were higher than those for the first. Also, the slope of the linear regression was positive, indicating a continuous, increasing trend. Nonetheless, there was no discernible variation in rainfall between the first and second climatic periods, according to the results of a regional examination of the study area's mean annual rainfall during 60 years.

3.9. The Spectral Analysis

The time series' cyclic component, both at high and low frequencies, was found by spectral analysis. The spectral analysis's output is displayed in Figure 10 to Figure 13.

The most significant periodicity for rainfall was 15 years, with a P-value of 0.207. Fisher's Kappa, the examination statistic, was 4.699, according to the rainfall spectrum analysis's result. Moreover, the temperature spectrum analysis's result revealed that the most significant periodicity was 15 years, the P-value was 0.006, and Fisher's Kappa, the examination statistic, was 7.618%. These are sun sport cycles.

The significance of the 15-year periodicity of rainfall and temperature fluctuations lies in their potential impacts on various environmental and socio-economic systems. The periodicity suggests that there is a recurring pattern in the variation of rainfall and temperature over a 15-year cycle.

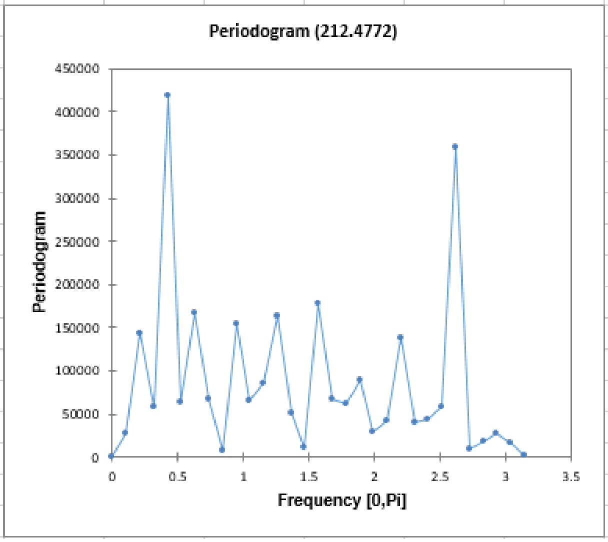


Figure 10 Spectrum analysis's result for Rainfall

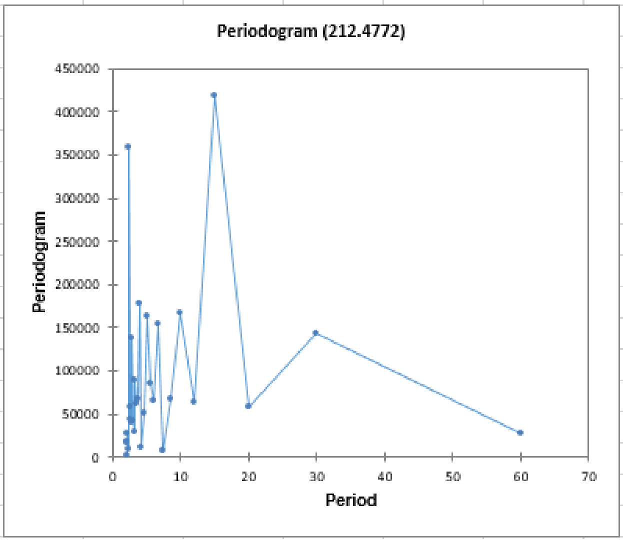


Figure 11 Periodogram Period Curve for Rainfall

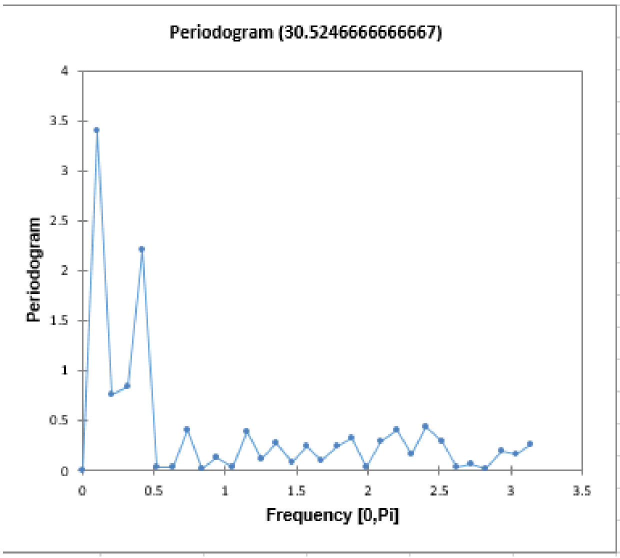


Figure 12 Spectrum analysis's result for Temperature

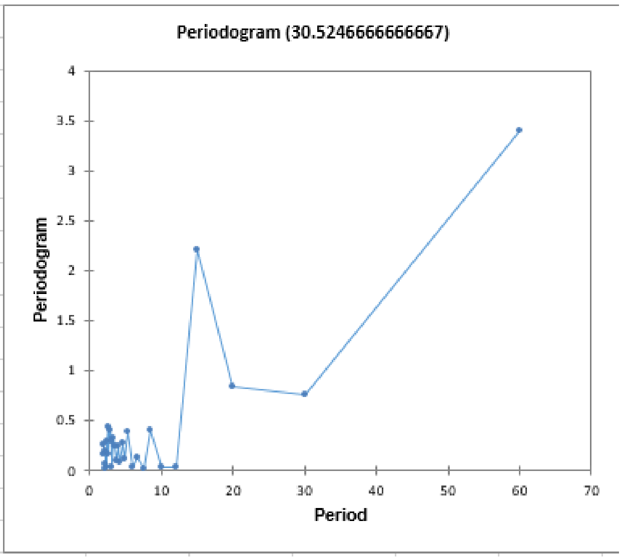


Figure 13 Periodogram Period Curve for Temperature

Understanding and acknowledging this pattern is crucial for several reasons: predictable weather patterns significantly impact agricultural productivity, affecting crop cycles, irrigation schedules, and land use patterns, with the 15-year periodicity of rainfall and temperature affecting crop suitability. Rainfall patterns, affecting water availability and distribution, can impact water sources like rivers, lakes, and groundwater aquifers, affecting water resource management strategies and infrastructure development.

Climate variability affects ecosystem dynamics, human settlements, infrastructure, and economic impacts. A 15-year periodicity in temperature and rainfall can have cascading effects on ecosystems, human settlements, and infrastructure. Understanding these patterns can help design resilient infrastructure, mitigate risks, and develop adaptive strategies for climate change adaptation. This understanding is crucial for industries like tourism, energy, and transportation.

Climate variability, including temperature and rainfall changes, can impact public health, leading to disease patterns and waterborne illnesses. Understanding the 15-year periodicity can help public health agencies prepare for these impacts. The significance of the 15-year periodicity of rainfall and temperature lies in its potential to inform various sectors, including agriculture, water resource management, ecosystems, human settlements, economics, climate change adaptation, and public health. Understanding this periodicity can aid in decision-making processes and long-term planning to build resilience and adapt to climate variability.

4.0 CONCLUSION

The results of this study demonstrate the existence of both climate change and variability in Edo State during the period under consideration. There have been changes in the temperature data due to the increased burning of fossil fuels and greenhouse gas (GHG) emissions, leading to global warming. This study confirmed that there was a considerable increase in temperature, with an abrupt change occurring in 1980. Heat stress was experienced because of rising temperatures and temperature extremes, especially in cities, even though temperatures in lowland rural areas were already above what is livable for humans. There were noticeable changes in rainfall, with a decreasing tendency and abrupt change that occurred in 2013. Variations in rainfall have an impact on the state's low aquifer replenishment, quality, and quantity of portable water availability, as well as coastal floods. This also resulted in a low yield of rain-fed crops. The findings of this study will help planners and policymakers to understand how rainfall and temperature in the research area are affected by climate change. From the identification of system vulnerabilities to the evaluation of mitigation solutions, this analysis will assist decision makers.

Conflict of Interest

The authors declare there are no conflicts of interest regarding the publication of this paper

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