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An Assessment of Rainfall Variability and Trends in Wukari, Nigeria from 1981 to 2021

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Abstract

This study assessed the trends and variability of rainfall in Wukari, Nigeria, from 1981 to 2021, using the ECMWF ERA5 reanalysis data sets. Rainfall trends and variations over the study period were analyzed using Mann Kendal trend test and the Theil Sen slope estimator. The assessment of monthly rainfall variation for the rainy months (May-October) showed an increasing trend for August, September, and October, with August having the highest increasing trend of magnitude 0.051 mmmonth-1. The result also showed an encroachment of the dry spell towards the rainy season and vice versa. This will create a variation in onset of rainfall and cessation in the coming decades, which will affect the farming season in Wukari in terms of the time of planting and harvesting of crops. A decline in annual rainfall of magnitude -0.005mm/ year was observed within the period 1981 to 2021. The rainfall pattern revealed a periodic trend on a decadal basis with an increasing trend been followed be decreasing trend in the next decade. The highest increasing trend of magnitude 0.73 mmdecade-1 was observed in the third decade, and the highest decreasing trend in the fourth decade, with magnitude -0.93 mmdecade-1. Based on the trend pattern, an increasing trend in rainfall amount is expected in next decade (2021-2030), with a higher increasing trend magnitude greater than that of the third decade. Therefore, it is recommended that Government Agencies and stakeholders in the agriculture sector should be proactive in educating/enlightening farmers on the likelihood of a change in the farming season and make adequate preparation to mitigate the effect of flooding in the area.

Keywords: Rainfall Trend; Rainfall Variation; Climate Change; Climate Change Impact; Rainfall Variability

INTRODUCTION

Weather and climate are described majorly by some atmospheric parameters, such as rainfall, atmospheric pressure, temperature, humidity, wind, and albedo. The weather of an area over a given period is referred to as the climate. It is a statistical analysis of relevant quantities and their variation over timescales ranging from months to thousands or even millions of years (IPCC, 2008). Unmistakable evidence of climate system warming has been provided by the tremendous changes that have been seen during the decades since the 1950s. Sea levels are rising, the ocean and atmosphere are warming, the amount of ice and snow is declining, and the concentration of greenhouse gases is rising. Global warming has lately altered the climate of the Earth, and it will likely continue to do so in the future. Even a simple glance at the current weather shows how much this transformation has occurred (Kevin et al., 2000). According to NAS and RAS (2014), the patterns that scientists anticipated to see are occurring because of increasing carbon dioxide levels and other changes brought on by anthropogenic activities that are consistent with the evidence of climate change. The impacts of climate change on the environment and humans are devastating. Locally and worldwide, the effects of climate change have been seen. Many scientists have been able to identify climate variations, trends, and changes in many different parts of the world using climatic indicators such air temperature, precipitation, evapotranspiration, and surface relative humidity.

It is easy to understand the climate of any region in terms of its yearly or seasonal variations in temperature and precipitation because temperature and precipitation are thought to be indicators of climate change (El Mallah, 2011). This variation can differ significantly from region to region, and there may be major spatiotemporal differences across places with various climates (Yue and Hashino, 2003).

Despite advances in technology, the weather and climate continue to determine what farming practices are possible (Ayoade, 2004). Rainfall variation under global warming is a major problem that could have a big influence on society and the environment regarding the availability of water supplies for domestic, industrial, and agricultural needs (Granados, 2017). This variability of climatic factors, such as rainfall, has an impact on farmers' ability to plan and the phases of crop growth, which impacts overall crop yield. Farmers decide when to plant crops and apply agricultural inputs during the growing season based on variations in the timing of seasonal rainfall (Bannaya, 2011). In recent years, it has also enhanced natural environmental hazards like drought and flood occurrences in Nigeria's climate, especially in the north's drier parts (López, 2015; Ishaku and Rafee, 2010). Recent decades have seen rainfall variability events and recurring extreme weather events in this area, which have had an impact on infrastructures, people, and agricultural output. With irrigation agriculture making up a smaller portion of the overall cultivated land, the state is primarily dependent on natural rainfall. As a result, the state's crop yields, and food production depend greatly on the quantity, timing, and distribution of rainfall as well as other climatic elements during the growing season. The rainfall regime in this area of the country is distinguished by high concentrations in a few months, with August/September serving as the peak month. These high concentrations are not only intermittent but occasionally at the extreme. As a result, the area is particularly susceptible to severe and dangerous weather, such as flooding. It is quite likely that the current level of climatic variability will rise and amplify in the coming years; storms, floods, and droughts are expected to become more frequent and severe (Oruonye, 2012, Oruonye and Adebayo, 2013). Therefore, this study aims to comprehensively assess rainfall variability and trends in Wukari, Taraba state, from 1981 – 2021 with a view to assisting farmers in the area with necessary information. The specific objectives include:

1. To assess the monthly distribution of rainfall variation in Wukari
2. To analyze the inter-annual rainfall trends in Wukari
3. To analyze decadal rainfall trends in Wukari

MATERIALS AND METHODS

The monthly mean rainfall data from the ERA-5 reanalysis of the European Centre for Medium-Range Weather Forecasts (ECMWF) was the meteorological parameters used in this study. Graph extraction and visualization were done using the R programming language to calculate the rainfall variation and trends using the monotonic Mann Kendall trend and the Theil Sen's slope tests.

Materials

The Study Area

Wukari is the Headquarters of Wukari Local Government Area of Taraba State; Taraba State is in Nigeria at latitude 7°51'N and longitude 9°47'E. It covers an area of 4,308 square kilometers (1,663 square miles). There are sixteen LGAs (Local Government Areas) in Taraba State. The 2006 National population Census estimates that there are 241,546 people living in Wukari (NPC, 2006).

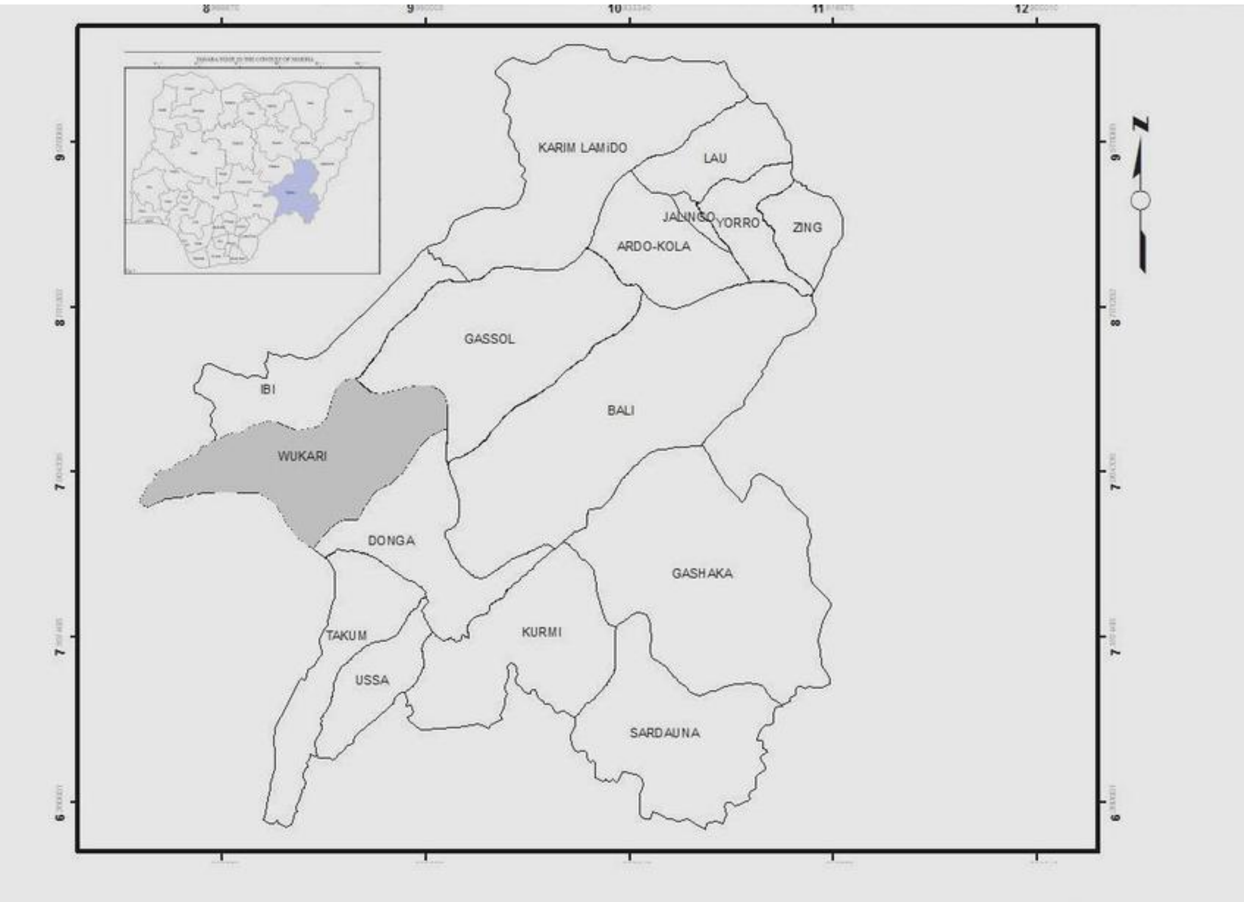

Fig 1: Map of study area, Source: Satellite map, 2015

Data Source

The observed surface data from rain gauges over Africa are known to have inadequate spatial coverage, missing data, and even to have been dropping recently. Due to the issues with point observations with an uneven spatial distribution or missing data, gridded-rainfall data from the European Centre for Medium-Range Weather Forecasts (ECMWF) fifth Generation (ERA5) model was used for this study. It has been proven suitable for climate monitoring (Sen and Habib 2000; Roy and Balling 2004; Boers et al. 2014a, 2015b and Dai et al. 1997). The fifth and most recent version of the ECMWF's global atmospheric reanalysis, ERA5, has been produced since 1979 with a latitude and longitude horizontal resolution of 0.25 by 0.25 degree. A file format called Network Common Data Form (NetCDF) is used to store multi-dimensional scientific data (parameters) including temperature, humidity, and precipitation). The Reanalysis data, which is in the NetCDF format, was extracted using R (version 4.2.1, an open-source application. In this research, monthly mean rainfall data from 1981 to 2021 from the ERA-5 reanalysis were employed. The yearly mean rainfall statistics were obtained by averaging the daily record of precipitation data with the monthly mean rainfall data. The seasonal means for the wet (April, May, June, July, August, September, and October) and the dry/harmattan (November, December, January, February, and March) seasons were also produced by averaging the monthly averages for each season.

Methods

Procedures of Data Analysis

i. From the daily measurements, the mean rainfall for each month, year, and decade was computed.
ii. A graph of monthly rainfall mean variations and decadal monthly rainfall variations were plotted to show rainfall patterns across the months of the year.
iii. Theil Sen's estimator and the Mann-Kendall trend test were used to analyze the monthly, annual, and decadal rainfall trends from 1981 and 2021.

Trend Analysis

To measure the significance of trends in meteorological time series, the Mann-Kendall statistical test has been widely used (Subash et al. 2011; Yue et al. 200). In this work, annual and seasonal rainfall time series data during a 41-year study period were subjected to the Theil-Sen estimator and Mann-Kendal test for trend analysis.

Man-Kendall Trend Analysis

The equation is given by;

$$S = \sum_{i=1}^{n-1} \sum_{j=1+i}^{n} sign(x_{j-} x_i) \quad (1)$$

Sign (xj - xi) is the sign function, and n denotes the number of data points. xi and xj are the values of the data in the time series i and j, respectively.

$$sign(x_{j\_}x_i) = \begin{cases} +1\, for\, x_i - x_j > 0 \\ 0\, for\, x_i - x_j = 0 \\ -1\, for\, x_i - x_j < 0 \end{cases} \quad (2)$$

The variance is calculated by;

$$Var(s) = \frac{n(n-1)(2n+5) - \sum_{i=1}^{p} t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

$$Zs = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, for\ S > 0 \\ 0,\ for\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, for\ S < 0 \end{cases} \quad (4)$$

Where P is the number of linked groups, t_i denotes the number of data values in the Path group, and n denotes the number of data points. The summation sign (Σ) denotes the summing over all tied groups. Positive Zs values show increase while negative Zs values show decrease in trend patterns. Trends are tested with a 5% degree of confidence.

The Sen's Slope Estimator

It is discovered that the Sen (1968) slope estimator is an effective tool for creating a linear relationship between two variables. The advantage of Sen's slope over the slope of the regression is that it prevents outliers and gross data series errors from affecting the size of the trend. The formula for calculating the Sen's slope is given below.

$$m_{ij} = \frac{Y_j - Y_i}{j-1} \quad (4)$$

Where Y_j and Y_i are the data values at time j and i respectively (j > i where i = 1 to n - 1 and j = 2 to n.

If in the time series there are n values of Y_j, estimates of the slope will be N= n(n-2)/2. The slope of the Sen Estimator is the mean slope of such slopes N values. The Sen's slope is

$$m = m_{\left[\frac{N+1}{2}\right]} \quad \text{if n is odd} \quad (5)$$

$$m = \frac{1}{2}\left[m_{\frac{N}{2}} + m_{\frac{N+2}{2}}\right] \quad \text{if n is even} \quad (6)$$

Sen's slopes that are positive or negative indicate an increasing or decreasing tendency, respectively.

Applying the Sen's slope estimator and Mann-Kendall on Wukari rainfall data computed using R Programming for data visualization, the study of trend for the monthly, annual, and decadal rainfall was obtained.

RESULTS

Analysis of monthly rainfall Variations and trends

The results of the descriptive statistics of monthly rainfall for the area of study are presented in table 1. The Man Kendal trend test was used to determine the trend, and the Teil Sen's estimator was used to determine the trend's size at a confidence level of 0.5, as shown in table 2. The month of March has an average rainfall record of 0.52 mm with 0.61 mm as the standard deviation, -0.01 $mmmonth^{-1}$ trend test value. The precipitation ranges between 0.22 mm to 4.38 mm with a standard deviation of 1.12 mm in April which serve as the onset of the rainy season with Mann Kendall trend test of -0.013 $mmmonth^{-1}$, within the study years. For the month of May, the rainfall values range from 2.00 mm to 10.97 mm, having a standard deviation of 1.98. Negative trend of magnitude -0.028 $mmmonth^{-1}$. Furthermore, the months of June, July, August, September, and October recorded an average rainfall of 7.12 mm, 8.75 mm, 11.18 mm, 10.35 mm, and 10.35 mm and 4.68 respectively. It's worth noting that the rainfall trend in July is significance at 5% confidence level (p-value is less than 0.05 as seen in table 2), compared to other months that are not significant. The trend tests revealed -0.029 $mmmonth^{-1}$ for June, -0.042 $mmmonth^{-1}$ for July, while August, September and October have magnitudes of 0.051 $mmmonth^{-1}$, 0.029 $mmmonth^{-1}$ and 0.005 $mmmonth^{-1}$ respectively.

Table 1: Monthly Rainfall Distribution in Wukari (mm) from 1981 - 2021

Month / Statistics	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Min	0.00	0.00	0.00	0.22	2.00	4.02	6.66	7.28	6.38	0.48	0.00	0.00
Max	0.00	0.00	2.29	4.38	10.97	14.76	12.14	16.90	14.96	10.28	0.00	0.00
Mean	0.00	0.00	0.52	2.24	5.48	7.12	8.75	11.18	10.35	4.68	0.00	0.00
S.D	0.00	0.00	0.61	1.12	1.68	1.98	1.44	2.12	1.73	2.00	0.00	0.00

Table 2: The monthly rainfall trend in Wukari from 1981-2021

Month / Statistics	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Kendall's tau	0	0	-0.212	-0.105	-0.148	-0.162	-0.248	0.16	0.122	0.025	0	0
P-Value	0	0	0.053	0.339	0.177	0.138	0.023	0144	0.266	0.822	0	0
Sen's Slope	0	0	-0.010	-0.013	-0.028	-0.029	-0.042	0.051	0.029	0.005	0	0

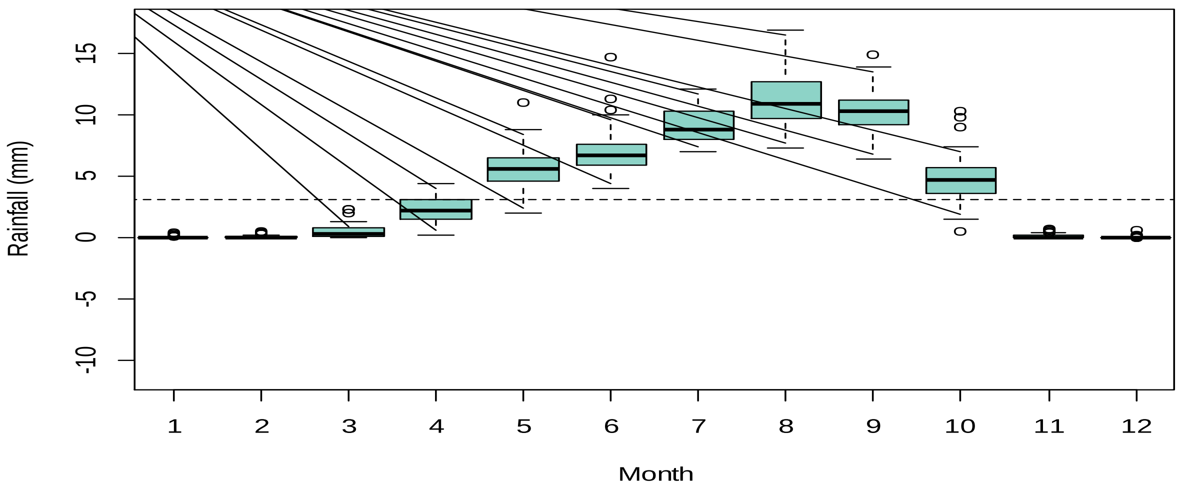

Figure 1: Monthly mean rainfall distribution in Wukari from 1981-2021

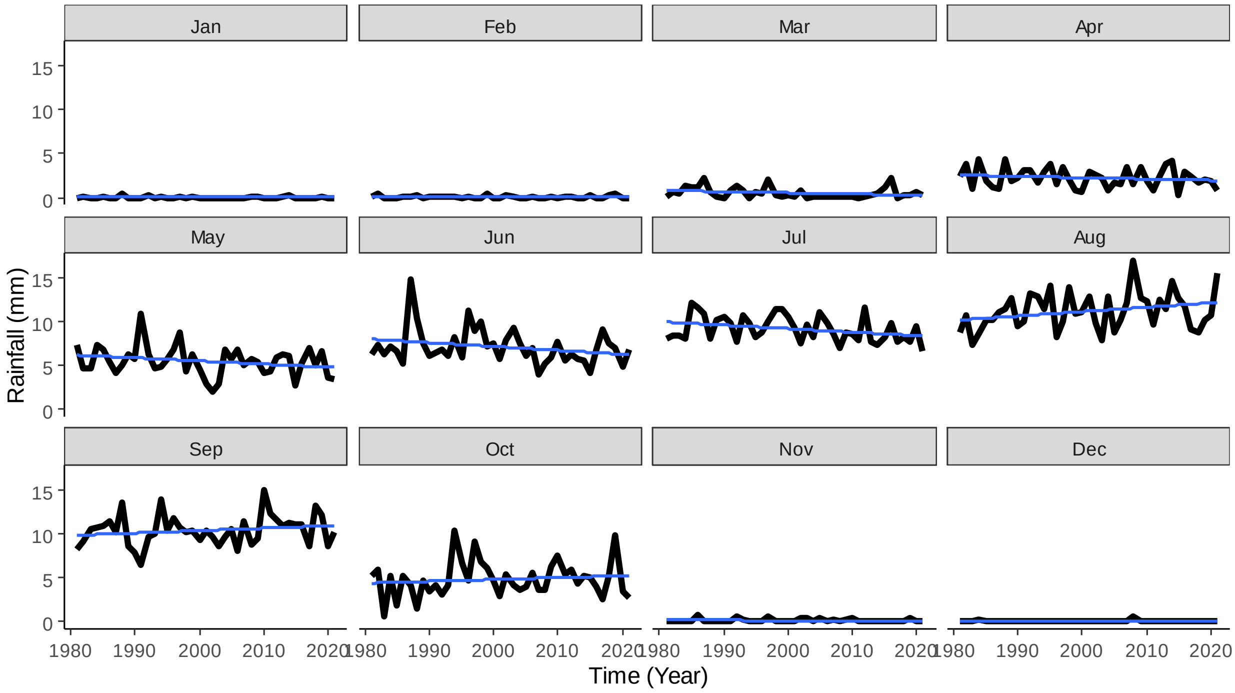

Figure 2: Monthly mean rainfall trend in Wukari from 1981-2021

Table 3: The annual rainfall trend in Wukari from 1981-2021

Location	Minimum	Mean	SD	Maximum	Kendall's tau	P-Value (5%)	Sen's Slope
Wukari	39.08	51.12	5.09	63.33	-0.091	0.405	-0.005

Annual Rainfall Trend

The trend of the annual mean rainfall for the study area within the study period across the years of study is shown in table 3. The line plot in figure 3 showed that rainfall has significantly peaked twice within the period of the study. The first peak was observed in the year 1987 with a value of 58.29 mm while it dropped in the year 1990 with a value of 45.25 mm. The second peak was in the year 1994 follow by 1997 with values of 61.55 mm and 63.33 mm respectively. In recent years, the highest peak observed was in the year 2019 with a value of 56.76 mm while the least occurred in the year 2020 with an average value of 42.88 mm. It is worth nothing that the year 1997 has the highest rainfall record while the year1983 has the lowest rainfall record within the study period with values of 63.33 mm and 39. 08 mm respectively. The trend test analysis showed a decreasing trend with Kendall value of -0.091, while -0.005 as the magnitude of the trend change as revealed by the Sen's slope estimator.

The p-value of tested at 5% confidence level was not significant, with a value greater than 0.05.

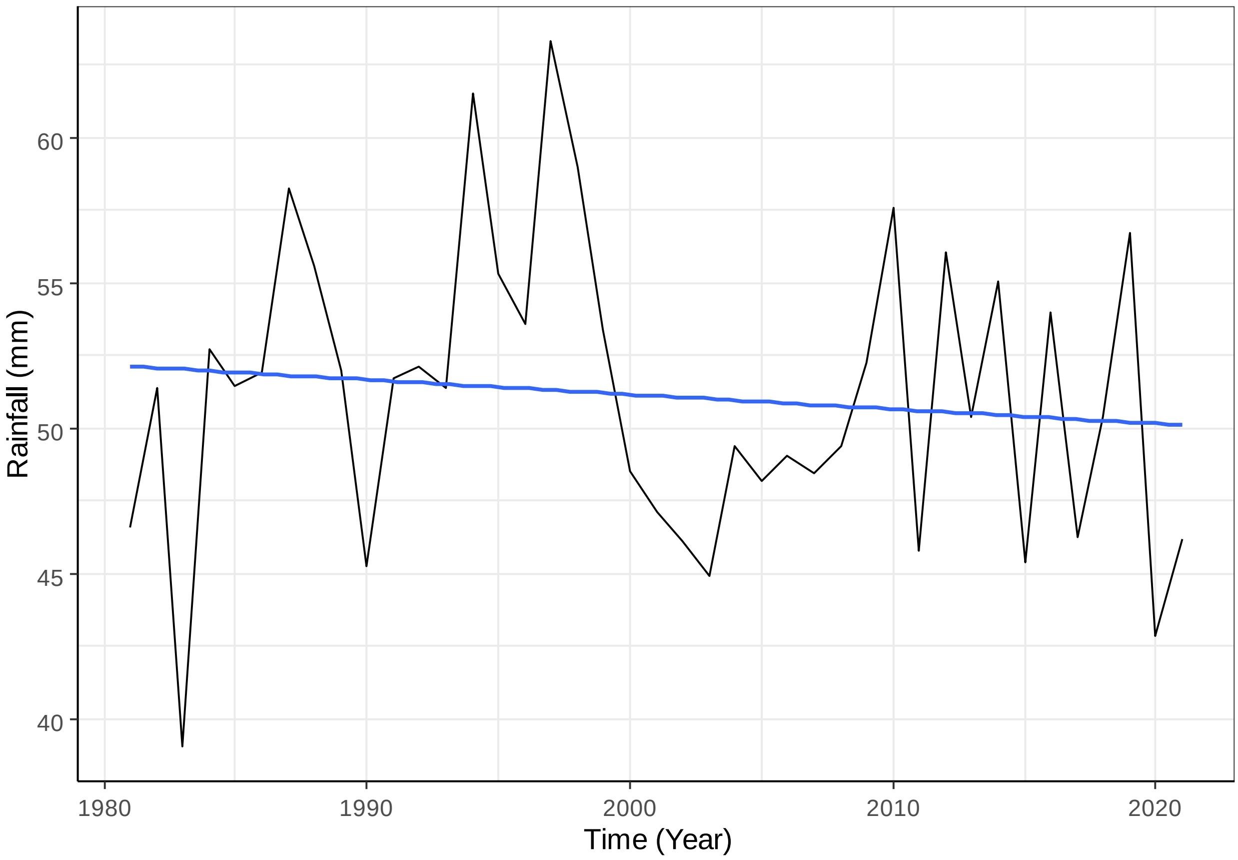

Figure 3: Annual averaged rainfall time series for Wukari from 1981 to 2021

Table 4: Decadal trend of rainfall over Wukari from 1982 to 2021

Decade	Min.	Mean	SD	Max.	Kendall's Tau	P-value	Sen's Slope	Trend description
1st	39.08	50.94	5.32	58.29	0.15	0.59	0.04	Increasing trend
2nd	47.16	54.55	5.33	63.33	-0.24	0.37	-0.55	Decreasing trend
3rd	44.95	49.13	3.66	57.61	0.41	0.12	0.73	Increasing trend
4th	42.88	50.34	4.97	56.73	-0.28	0.59	-0.93	Decreasing trend

Decadal Rainfall Trend

The analysis of decadal rainfall trend in Wukari is shown in table 4 and it is illustrated in Figures 5 to 7. For the first decade (1982-1991), the minimum rainfall value of 39.08 mm was recorded in 1983, with a mean value of 50.94 mm and maximum value of 58.29 mm in 1987. The trend test estimated an increasing trend as shown by the Kendall tau value of 0.156 with no significant p-value of 0.59. The second decade (1992-2001) has a higher rainfall than the first decade with minimum rainfall value of 47. 16 mm was recorded in 2001, a mean value of 54. 55 mm and maximum rainfall value of 63. 33 mm in 1997. The trend test estimated a decreasing trend value of -0.24. Furthermore, the third decade has a lower rainfall than the second decade with minimum rainfall value of 44.95 mm in 2003, a mean value of 49.13 mm and maximum rainfall of 57.61 mm in 2010. An increasing trend value of 0.41 was estimated. The fourth decade has a recorded minimum rainfall of 42.88 mm in 2013, a mean value of 50.34 mm and maximum rainfall of 56.73 mm in 2019, within the decade. The trend test also estimated a decreasing trend value of -0.28. The analysis of the magnitude of decadal change performed by the Sen's slope estimator, 0.04 mmdecade^{-1}, -0.55 mmdecade^{-1}, 0.73 mmdecade^{-1} and -0.93 mmdecade^{-1} for the first, second, third and fourth decades respectively, increases across the decades non-linearly, with the p-values greater than the 5% (0.05) tested confidence level.

It is worth noting that the periodic rainfall pattern in this area of study. An increasing rainfall decadal trend is followed by a decreasing trend in the next decade. Moreover, inter-decadal minimum and maximum rainfall show similar trends. The first, second, third and fourth decades have their minimum rainfalls in 1983, 2001, 2003 and 2013, maximum rainfalls in 1987, 1997, 2010 and 2019 respectively.

Table 5: Standardized precipitation index

Range (mm)	**Meaning**
2.0 and above	Extreme moisture
1.5 to1.99	Very moist
1.0 to1.49	Somewhat moist
-0.99 to 0.99	Almost normal
-1.0 to -1.49	Slightly drier
-1.5 to -1.99	Extremely dry

Source: Karabulut, G. (2015).

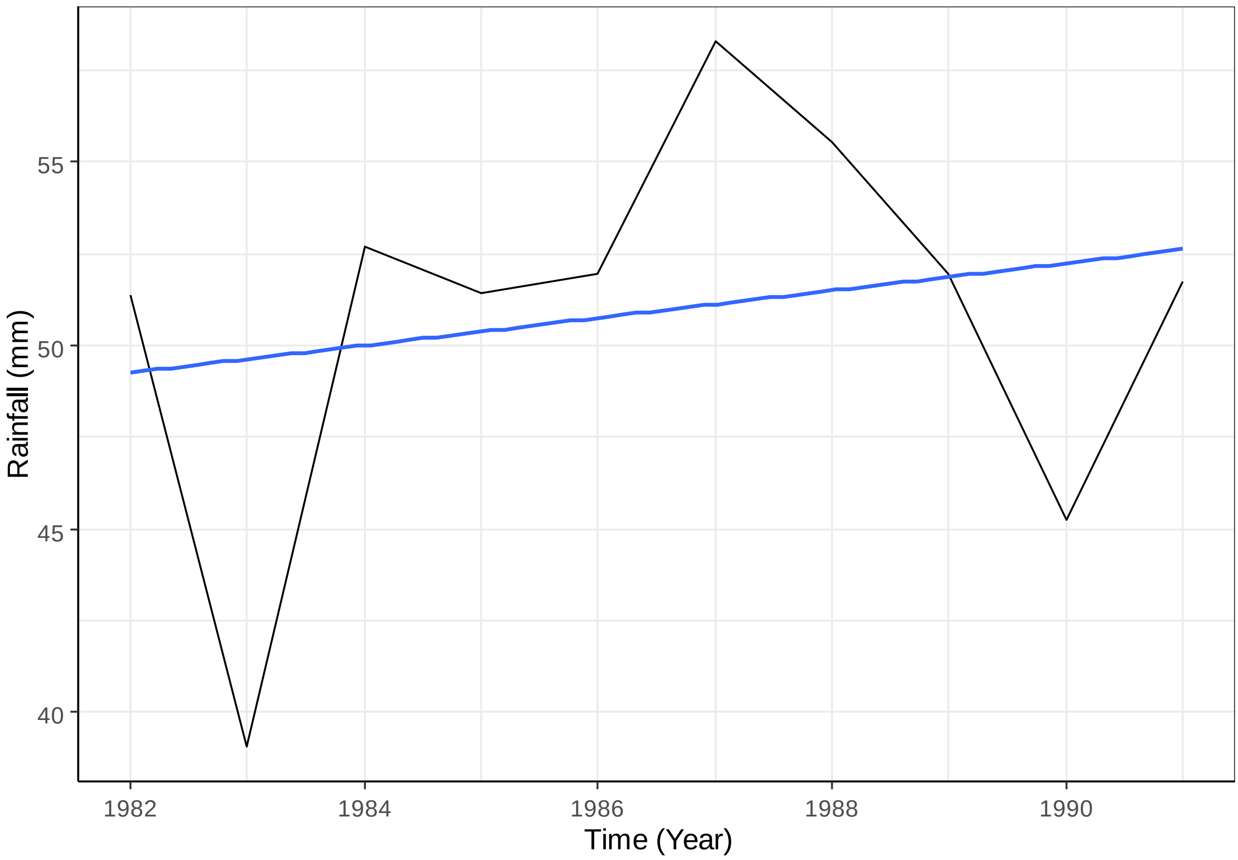

Figure 4: Decadal rainfall trend in Wukari from 1982 to 1991

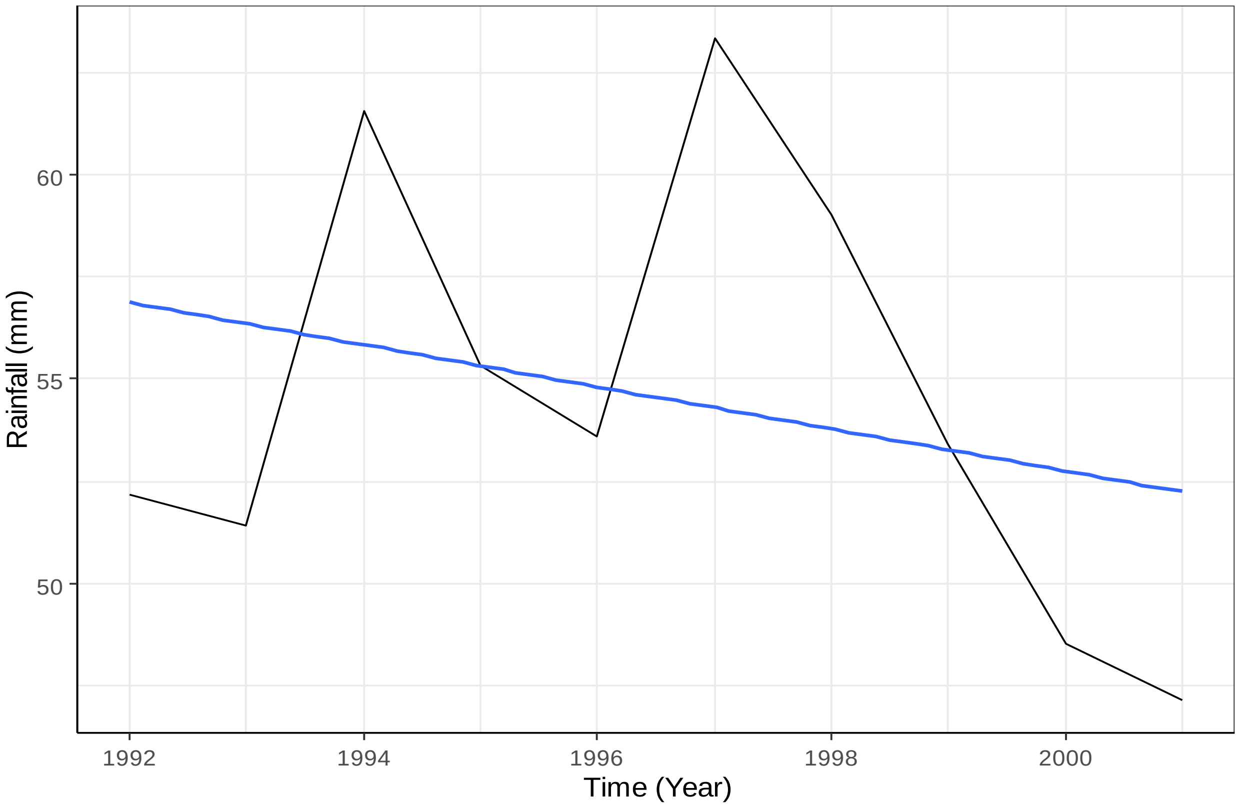

Figure 5: Decadal rainfall trend in Wukari from 1992 to 2001

DISCUSSION

According to the climatic distribution, the weather pattern in Wukari is classified under the semi-arid climate where rainfall occur between April and October, where the peak rainfall is in August, while little or no rain is from November to March, as depicted in figure 1. Therefore, the results of the monthly rainfall presented in table 1 show that the months of January, February, November, and December within the period did not receive rainfall except in trace amount while March and April did experience light rainfalls. Furthermore, the monthly rainfall analysis shows a high degree of variability in the study area during the period of study as depicted in figure 2. The magnitude of the trend is between 0.005±0.051 $mmmonth^{-1}$ with the least in October and the highest in August. It is also observed that all the rainy months show a gradual decrease in rainfall amount down the years except for August, September, and October. This shows an encroachment of the dry season towards the rainy season following the IPCC report on climate change. The month of July showed a significant decrease in rainfall among the rainy months. This shows that rainfall has dropped drastically in this month over time. This scenario will impact farming activities in the study area. The decreasing trend of rainfall will affect the onset of farming activities as farmers will have to wait for normalization of rainfalls before commencing planting of crops while the increasing trend around October, the transition month between the wet and dry seasons will also affect the harvest of some early maturing crops.

The results of the inter-annual rainfall trend for the study area show that rainfall has decreased on a long-time trend by -0.005 mmyear^{-1}. This could be attributed to the effect climate change where increase in dry spell is expected in some parts of the country, especially the semi-arid regions (Oruonye, 2012, Oruonye and Adebayo, 2013).Whereas, in the study conducted by Garba and Iliyasu (2021) who studied rainfall trends in same location from 1999-2018 with rainfall data collected from the archive of Nigerian Meteorological Agency (NiMet), a slight increase in rainfall on a long tern trend was observed. This result cannot be compared parallel with the result gotten from this study since they have different periods of study and different statistics was employed for the trend analysis.

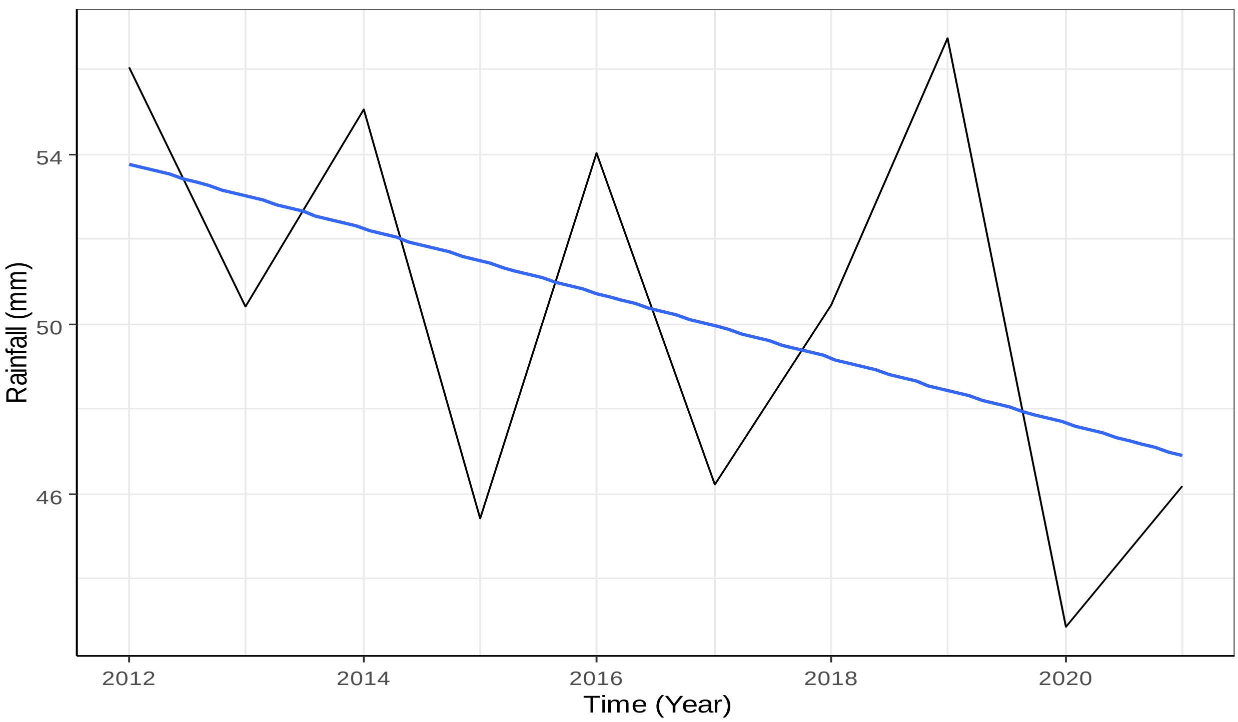

Figure 6: Decadal rainfall trend in Wukari from 2002 to 2011

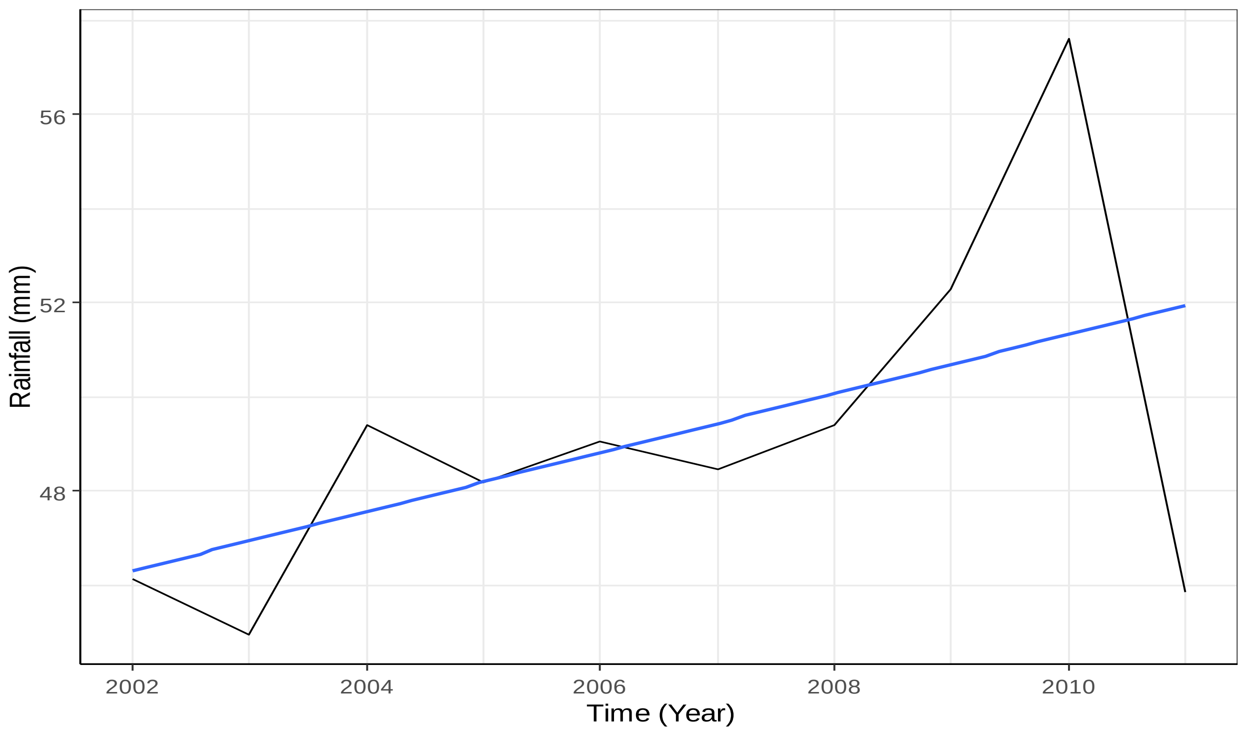

Figure 7: Decadal rainfall trend in Wukari from 2012 to 2021

The periodic pattern in the decadal rainfall observed in this study, where an increase rainfall trend is followed by a decreasing trend can be attributed to some solar activities, like increase or decrease in the number of sunspots. Also, it was observed from the study that a decade of increasing rainfall trend has a higher maximum rainfall amount that the last decade where an increasing trend was observed. Therefore, projecting from this trend analysis, Wukari is expected to experience an increase in rainfall over the next decade (2022-2031) with the maximum rainfall greater than 56.73 mm on average in the year 2027 as the peak of the decade while the minimum is expected in the year 2023 with rainfall amount less than 42.88 on average.

CONCLUSION

The assessment of rainfall variability and trend in Wukari, Nigeria between 1981 and 2021 showed high variability of rainfall in the area with trend indicating gradual decrease in rainfall amount in the months of April, May, June, July, and an increasing trend in the months of August, September and October which indicate an encroachment of dry season towards the raining season and likely extension of rains towards the dry season around October and

November. This scenario is observed to have a likely impact on the activities of farmers in the area with regards to onset of farming activities and harvesting of farm produces. Another likely implication of the increase in rainfall around August, September and October is the issue of flooding in the area. The area is likely to experience flooding in the next decade. The study also revealed that the decadal trend of rainfall in the area is periodic. An increasing trend in one decade is followed by a decreasing trend in the next decade. It is therefore projected that the fifth decade; 2022 to 2031 will experience higher amount of rainfall than the preceding decade 2012 to 2021, with the maximum rainfall expected to occur in 2027 with an annual rainfall greater 56.73 mm on average. It is therefore recommended that the stake holders and Government Agencies in the agriculture sector should be proactive in educating/enlightening farmers on the likelihood of a change in the farming season and make adequate arrangement to mitigate the effect of flooding in the area.

Declaration

Ethics approval and consent to participate

This manuscript is in compliance with ethics of the journal.

Consent to Publish

Data availability statement

Not Applicable

These data are accessible online at https://cds.climate.copernicus.eu/cds, the ECMWF Public Datasets website.

Competing Interest

The authors have no relevant financial or non-financial interests to disclose.

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Author's contribution

This research article is coined Moses Oluoke Omopekunola Masters' seminar paper. Jacob Abel is the first author's supervisor, Ahmed Abubakar and Augustina Achimugu edited the manuscript. All authors read and approved the final manuscript.

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