Decadal Rainfall Trends and Variability across Nigeria

Abstract

This work examined the decadal trends and variability of rainfall data over Nigeria from 1979 to 2021 (42 years). Observational monthly rainfall data was obtained from the Nigerian Meteorological Agency (NiMET). The data underwent statistical analysis to illustrate its spread and variability using metrics such as mean, standard deviation, and coefficient of variation, linear regression was applied to reveal the trends or changes over time, the coefficient of correlation was employed to assess the statistical relationships of rainfall across the distinct climate regions of Guinea, Savanna, and Sahel, respectively. There were varying levels of annual and seasonal rainfall across the regions, with Port Harcourt receiving the highest annual and seasonal rainfall in the Guinea region. Sokoto and Maiduguri exhibit the highest annual rainfall in the Sahel region. The decadal analysis highlights the fluctuations in rainfall anomalies, as some decades showed surplus rainfall while others displayed negative deviations, indicating the changing nature of regional rainfall patterns.

Keywords: Nigeria; rainfall; trend; variability; decadal.

1. Introduction

Climate is defined as the average weather condition of a place over a long period. The trend is the rate at which the climate variable changes over some time. It may be linear or nonlinear (Dennis, 2014). Climate trends are essential indicators of the Earth's changing climate system, providing insights into long-term patterns and shifts in temperature, precipitation, extreme events, and other climatic variables. Numerous studies have documented significant changes in global climate over the past centuries (Olaniran et al., 2017). The increase in greenhouse gas emissions from human activities, primarily from the burning of fossil fuels, is a major driver of this warming trend. Observational data from various sources, including surface temperature measurements, satellite records, and ice core analysis, all converge to show a consistent warming signal. Rainfall patterns have also shifted, resulting in more intense rainfall events and prolonged droughts in certain areas.

The primary driver of current climate trends is the increase in greenhouse gas concentrations, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), primarily emitted through human activities. These gases trap heat in the atmosphere, leading to the greenhouse effect. The burning of fossil fuels for energy production, transportation, and industrial processes is the largest contributor to CO_2 emissions. Deforestation and land-use changes also play a significant role in altering the balance of greenhouse gases in the atmosphere. Climate trends have far-reaching impacts on natural systems and human societies. Ecosystems face risks of biodiversity loss, altered species distributions, and disrupted ecological interactions. Changes in precipitation patterns affect water resources, leading to droughts in some regions and floods in others. Agricultural productivity is vulnerable to changing rainfall patterns, impacting food security. Human health is also at risk, with heat waves increasing the incidence of heat-related illnesses and the spread of vector-borne diseases (WHO, 2021)

Climate variability refers to the fluctuations and changes in climate patterns over time and has significant implications for ecosystems, human activities, and the overall well-being of the planet. Climate variability is influenced by a combination of internal and external factors. Internal factors include natural processes within the climate system, such as oceanic and atmospheric circulation patterns, interactions between different components of the climate system, and feedback mechanisms. External factors encompass various external forcings, including solar radiation, volcanic activity, and human-induced factors such as greenhouse gas emissions. Natural climate variability occurs due to a range of factors, including variations in solar radiation, volcanic eruptions, and natural cycles such as the El Niño-Southern Oscillation (ENSO), the Pacific Decadal Oscillation (PDO), and the Atlantic Multi decadal Oscillation (AMO). These phenomena cause fluctuations in temperature, precipitation patterns, and atmospheric circulation, leading to changes in regional and global climate conditions. It affects agricultural productivity, water resources, natural ecosystems, and human health. Extreme weather events, such as hurricanes, droughts, floods, and heat waves, can be intensified or influenced by climate variability, leading to increased risks and vulnerabilities. Climate variability is a natural occurrence, it is important to differentiate it from long-term climate change attributed to human activities. Climate change refers to shifts in average climate conditions over extended periods, primarily driven by greenhouse gas emissions and other anthropogenic factors. However, climate variability can interact with and amplify the impacts of climate change. Understanding climate variability is crucial for adaptation and mitigation efforts in the face of ongoing climate challenges (Ogolo and Nwadike, 2015).

Decadal climate trends and variability refer to the patterns of changes in weather and climate conditions that occur over ten years. It is the study of long-term changes and fluctuations in the climate of Nigeria over ten years.

Understanding the decadal rainfall trends and variability across Nigeria is important because it can provide insights into the long-term changes in rainfall that can affect various sectors of the economy, including agriculture, energy, health and water resources management. There are two general methods for rainfall downscaling, the statistical and dynamic methods. The statistical method has several advantages like cost-effectiveness, computation efficiency, and the provision of point scale climate variables from GCM scale output. It has been widely used over the past decades (Mohammed et al, 2019).

Nigeria is characterized by three distinct climate zones, a tropical monsoon climate in the south, a tropical savannah climate for most of the central regions, and a Sahelian hot and semi-arid climate in the north of the country (CCKP, 2021). The rainy season typically lasts from April to October, with peak rainfall occurring in July and August (NIHSA, 2020). The frequent and intense flooding from the south region to the north region across the country has affected the agricultural sector, food availability, food security and communities in Nigeria. This is a result of the existing gap in understanding rainfall trends and variability across Nigeria in past decades. There is a need to evaluate the trend of rainfall and to evaluate the variability of rainfall in different parts of Nigeria. This work studies the decadal trends and variability of rainfall across Nigeria over 42 years. The objectives are to, (i) evaluate the interannual trend and variability of rainfall across the climate zones of Guinea, Savanna and Sahel, respectively, (ii) determine the decadal rainfall anomaly across the climate zones of Guinea, Savanna and Sahel, respectively, (iii) evaluate the trend and variability of the seasonal (April to October) rainfall across the zones.

2. Materials and Method

2.1 Study area

Nigeria is located between the latitude of 4-14°N and the longitude 2-15°E on the western coast of Africa (Imoleayo et al, 2019). It has a total land mass area of 925, 796km². The climate of Nigeria is divided into two distinct seasons which are the rainy season and dry season. The major climatic zones in Nigeria shown in Figure 1 are divided latitudinally being the Sahel (11°- 14°N), Savanna (8°-11°N), Guinea (4°-8°N) (Ogungbenro and Morakinyo, 2014; Kingsley et al, 2020). Rainfall distribution and change detection show similar change points and transitions in all zones (Ogunrinde et al, 2019). The Sahel region experiences an annual rainfall of 434-969mm, the Savanna region having 897-1535mm and the Guinea region having 1575-2533mm (Kingsley et al, 2020). The southern part experiences annual rainfall which has a duration of eight months (March to October) with a break in July, while the northern part experiences a shorter duration of rainfall (May to September) (Ogunrinde et al, 2019). The annual amount of rainfall shows a gradient of declining rainfall amounts from the south (2600mm/year) to the north (110mm/year) (Nwokocha et al., 2018). Nigeria has a total of forty-four (44) station observing the weather, which provides measurements of rainfall amounts for different locations across the country (Stephen and Tobi, 2014).

2.2 Data acquisition

The monthly rainfall observation data were obtained for the period 1979-2021 (42year) from the Nigeria Meteorological Agency (NIMET). The study locations were selected across Nigeria from the three major climatic zones (i) the Guinea zone (Ibadan, Owerri, Port Harcourt), (ii) the Savanna zone (Minna, Makurdi, Abuja), and (iii) the Sahel zone (Sokoto, Maiduguri, Kano) shown in Figure 1. The choice of NIMET data is because they are by law responsible for the observing, analyzing, and accurate reporting of weather and climate information in Nigeria. Selecting the period has been based on when satellite data improved gauge observations.

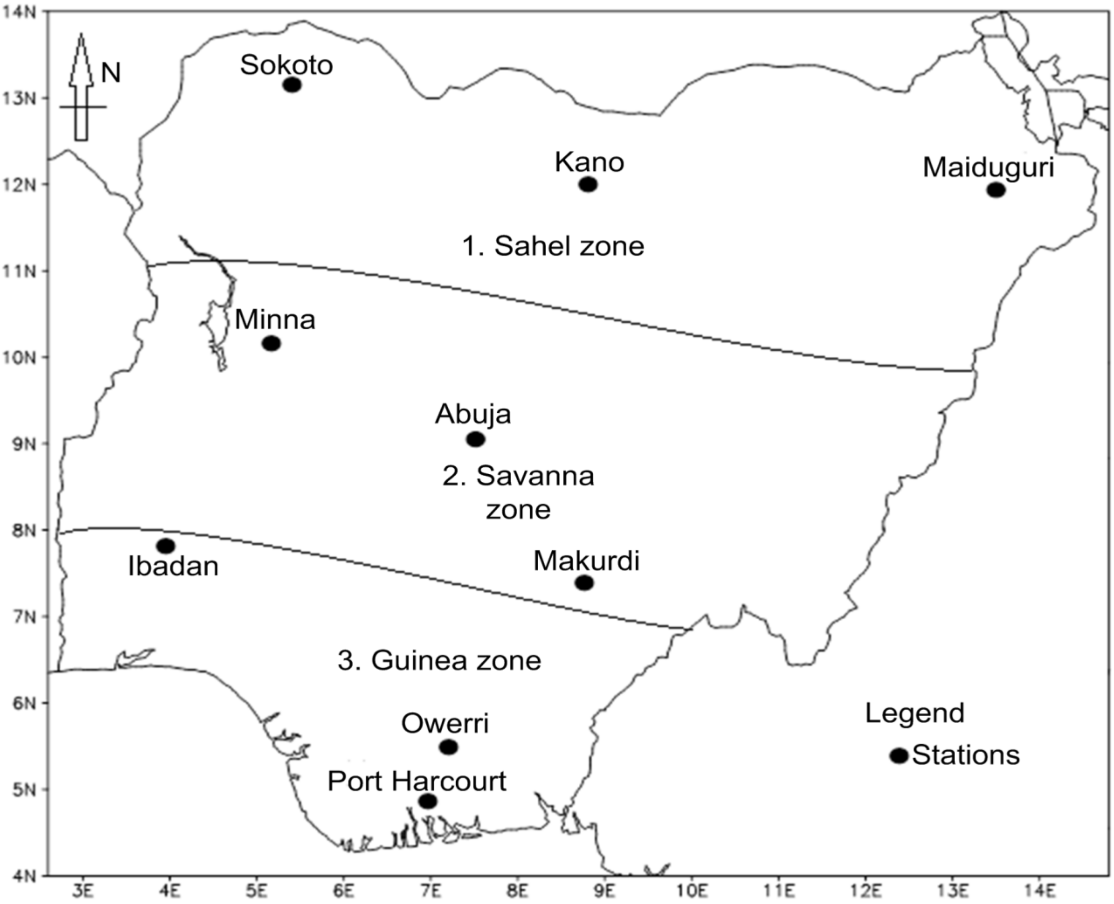

Figure 1. Map of Nigeria indicating the climatic zones and the study locations.

2.3 Data analysis

The data obtained were analyzed using basic statistics. The distribution of the annual and seasonal rainfall has been analyzed using the mean whereas the standard deviation indicated the variations during the period from the climatology. The coefficient of variation indicated the measure of the variability at the various locations. The linear regression indicated the measure of increase or decrease in decadal rainfall across the zones. The decadal average rainfall for each decade (10 years), by adding up the total rainfall values for each corresponding years within the 10 years and then dividing by 10. The rainfall anomaly is obtained by subtracting the obtained value from the overall climatology average of annual rainfall.

3.0 Results and Discussion

3.1. Interannual trend and variability of rainfall across the climate zones

Figure 2 shows the annual rainfall in the Guinea region with the trend equations indicated. It indicates that Port Harcourt received more rainfall with an average of 2413.374mm/yr in the Guinea region whereas Ibadan received the least rainfall with an average of 1402.744 mm/yr. However, the Guinea region receives an average of 2030.665 mm/yr rainfall. The trend equations for each location indicate a decrease at the locations. Table 1 shows the summary at the Guinea region. Owerri and Port Harcourt have higher mean rainfall and similar standard deviations, indicating relatively consistent rainfall patterns. Ibadan has a higher coefficient of variation, suggesting greater variability in its rainfall. Owerri and Port Harcourt show a slight increasing trend, while Ibadan exhibits a decreasing trend over time.

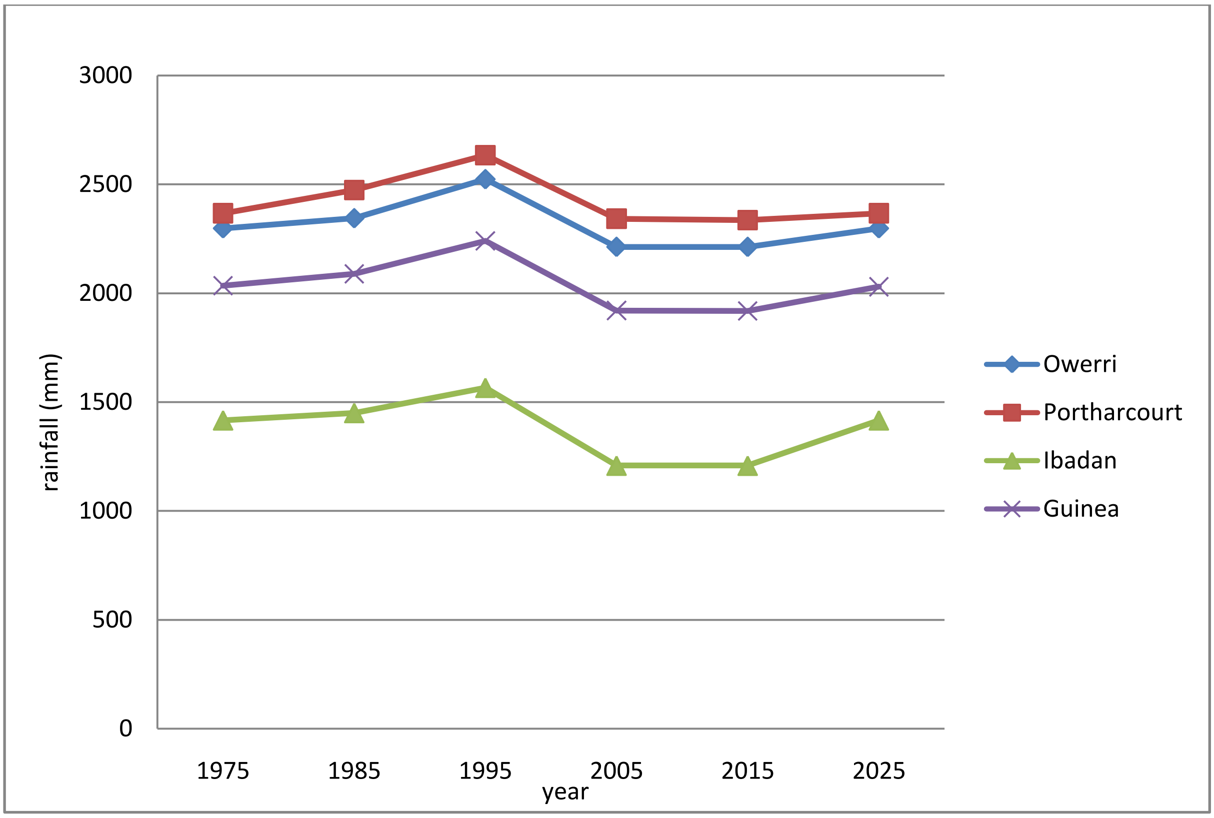

Figure 2. The annual rainfall in the Guinea region with the trend equations indicated.

Table 1. Variability and trend of annual rainfall in the Guinea region

Location	Mean Rainfall (mm)	Standard Deviation (mm/yr)	CV (%)	Trend (mm/yr)
Owerri	2259.440	193.510	8.550	-20.13
Port Harcourt	2357.080	175.070	7.420	-20.10
Ibadan	1505.830	339.310	22.537	-30.91
Guinea	2030.222	286.678	15.675	-24.39

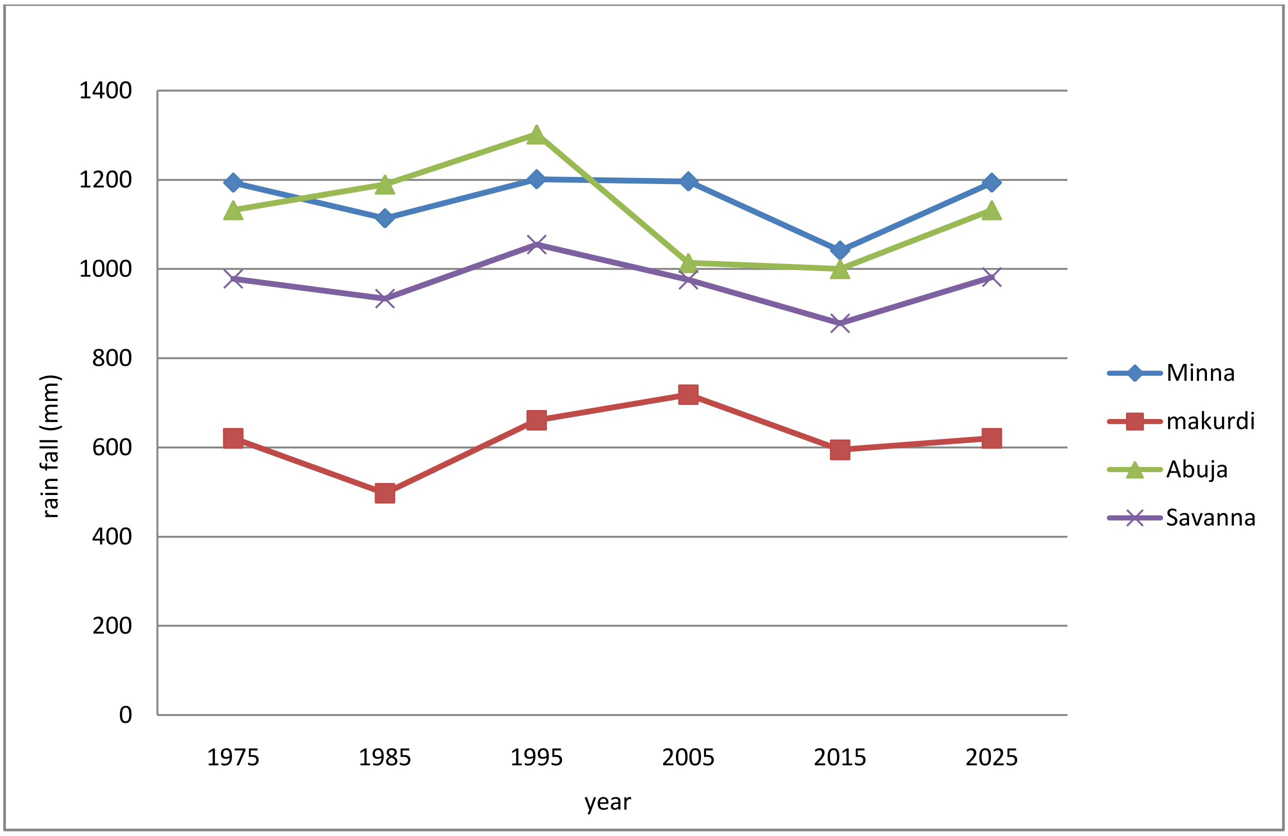

Figure 3. The annual rainfall in the Savanna region with the trend equations indicated.

Figure 3 shows the annual rainfall in the Savanna region. It reveals that Minna received more rainfall with an average of 1193.807 mm/yr whereas Makurdi received the least with an average of 620.6465 mm/yr. However, the Savanna region received an average of 982.292 mm/yr of rainfall. Minna and Abuja show higher mean annual rainfall compared to Makurdi. Table 2 shows the summary of the Savanna region. All three locations have relatively low coefficients of variation, indicating more stable rainfall patterns at the Savanna. The three locations show low positive trends in annual rainfall within the climatology.

Table 2. Variability and trend of annual rainfall in the Savanna region

Location	Mean annual rainfall (mm/yr)	Standard Deviation (mm/yr)	CV (%)	Trend (mm/yr)
Minna	1197.120	196.360	16.400	-6.35
Makurdi	663.630	67.880	10.240	9.69
Abuja	1105.050	79.230	7.160	-24.51
Savanna	982.2922	127.543	8.324	-6.39

Figure 4 is shows the annual rainfall in the Sahel region. Kano received more rainfall with an average of 692.1558 mm/yr in the Sahel region whereas Sokoto received the least with an average of 615.0256 mm/yr. However, the Sahel region received an average annual rainfall of 642.608 mm/yr. Table 3 shows the summary at the Sahel region. Sokoto and Maiduguri have similar mean rainfall, while Kano has higher mean rainfall. The standard deviation is higher for Sokoto, indicating more variability. The Sahel region shows relatively low coefficients of variation. All the locations exhibit positive trends in the annual rainfall over the climatology.

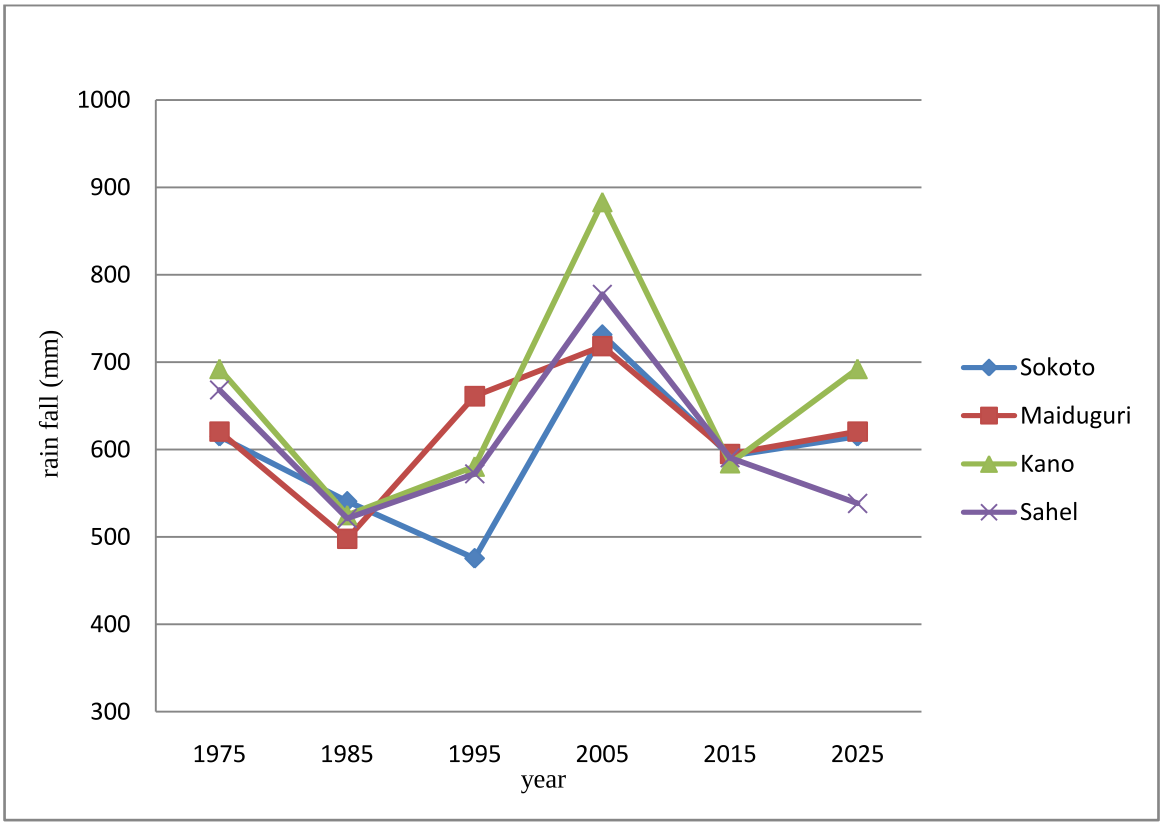

Figure 4. The annual rainfall in the Sahel region with the trend equations indicated.

Table 3. Variability and trend of annual rainfall in the Sahel region

Location	Mean annual rainfall (mm/yr)	Standard Deviation (mm/yr)	CV (%)	Trend (mm/yr)
Sokoto	631.850	121.050	19.150	11.79
Maiduguri	629.880	122.850	19.480	9.96
Kano	692.380	134.100	19.360	13.71
Sahel	642.6080	211.723	19.380	4.3307

3.2 **The decadal rainfall anomaly across the climate zones.**

The decadal rainfall anomalies across the Guinea have been analyzed (Table 4). At Owerri, the 2019-2021 periods experienced a notable positive anomaly in Owerri, indicating higher-than-average rainfall. The 1979-1988 periods had a slightly negative anomaly, while the subsequent decades saw positive anomalies, suggesting an overall increasing trend in rainfall. Port Harcourt displayed positive anomalies in all decades, indicating generally wetter conditions. The 2019-2021 period saw a slight decrease in anomaly compared to the earlier decades, suggesting a trend toward more stable conditions. Ibadan showed a substantial negative anomaly in the 1979-1988 periods, followed by positive anomalies in the subsequent decades. The most recent period (2019-2021) displayed a significant positive anomaly, indicating notably wetter conditions. These anomalies underscore the varying trends in rainfall patterns across the Guinea climate regions. The positive anomalies in recent decades may be indicative of changing climate dynamics, underscoring the importance of monitoring and understanding such variations for sustainable planning.

Table 4. Decadal rainfall anomaly in the Guinea region

Decade	**Owerri (mm/yr)**	**Port Harcourt (mm/yr)**	**Ibadan (mm/yr)**
1979-1988	-4.430	54.980	-204.440
1989-1998	52.090	50.670	-175.810
1999-2008	47.690	59.080	-138.710
2009-2018	60.090	52.610	-97.580
2019-2021	80.720	45.610	138.720

Table 5 shows the decadal rainfall anomalies across the Savanna. In Minna, **t**he 1999-2008 and 2009-2018 decades experienced significant positive anomalies, suggesting wetter conditions. The most recent decade (2019-2021) saw a positive anomaly, indicating above-average rainfall. Makurdi exhibited substantial positive anomalies in all decades except for the 2019-2021 period, which saw a notable negative anomaly. This suggests a recent period of significantly reduced rainfall compared to the long-term average. Abuja displayed positive anomalies in all decades except for the 1979-1988 period, indicating an overall trend toward wetter conditions. The 2019-2021 period saw a positive anomaly, suggesting above-average rainfall. These anomalies highlight the varying patterns of rainfall across the Savanna climate regions. Positive anomalies are indicative of wetter conditions, while negative anomalies suggest drier periods. The fluctuating anomalies underscore the importance of understanding climate variability for effective water resource management and agricultural planning.

Table 5. Decadal Rainfall Anomaly of Savanna Region

Decade	Minna (mm/yr)	Makurdi (mm/yr)	Abuja (mm/yr)
1979-1988	-83.530	-71.560	16.070
1989-1998	70.530	122.070	32.820
1999-2008	146.470	243.480	59.060
2009-2018	161.080	162.830	87.220
2019-2021	50.630	-219.970	13.50

Table 6 shows the decadal rainfall anomalies across the Sahel. In Sokoto, the 1989-1998 and 2009-2018 decades exhibited positive anomalies, suggesting wetter conditions. The 2019-2021 period saw a positive anomaly, indicating above-average rainfall. Maiduguri showed substantial positive anomalies in all decades except for the 2019-2021 period, which displayed a notable negative anomaly. This suggests a recent period of significantly reduced rainfall compared to the long-term average. Kano exhibited positive anomalies in all decades except for the 1989-1998 period, indicating an overall trend toward wetter conditions. The 2019-2021 period saw a positive anomaly, suggesting above-average rainfall. These anomalies underscore the variability of rainfall patterns across the Sahel climate regions. Positive anomalies suggest wetter periods, while negative anomalies indicate drier conditions. The fluctuating anomalies emphasize the significance of understanding and managing climate variability for effective resource planning and agricultural strategies.

Table 6. Decadal rainfall anomaly of Sahel region

Decade	Sokoto(mm/yr)	Maiduguri(mm/yr)	Kano(mm/yr)
1979-1988	25.630	0.000	9.800
1989-1998	34.500	122.070	97.200
1999-2008	23.970	243.480	57.700
2009-2018	71.460	162.830	51.100
2019-2021	67.160	-219.870	26.200

3.3 Seasonal variability and trends across the regions

Figure 5 shows the seasonal rainfall in the Guinea region. Port Harcourt received more seasonal rainfall with the value of 2059.14mm in the Guinea region whereas Ibadan received the least with the value of 1980.33mm. However, the average in the Guinea region shows a seasonal rainfall of 2004.27mm (Table 7). Table 8 shows the summary of the decadal seasonal rainfall. The 2000's saw an increase in rainfall anomaly, indicating that the regions experienced more rainfall compared to the long-term average. In the 2010s, the anomaly returned to a negative value, indicating a decrease in rainfall compared to the average. These decadal anomalies can provide insights into the variations and trends in rainfall over time in the specified regions. In the 1980s, the rainfall in all three regions was lower compared to the entire period's average. This indicates a significant deviation from the average rainfall during that decade. During the 1990s, the decadal rainfall anomaly decreased, showing less deviation from the overall average rainfall. It is important to analyze the causes behind these variations, which could be related to climatic patterns, anthropogenic factors, or other environmental influences.

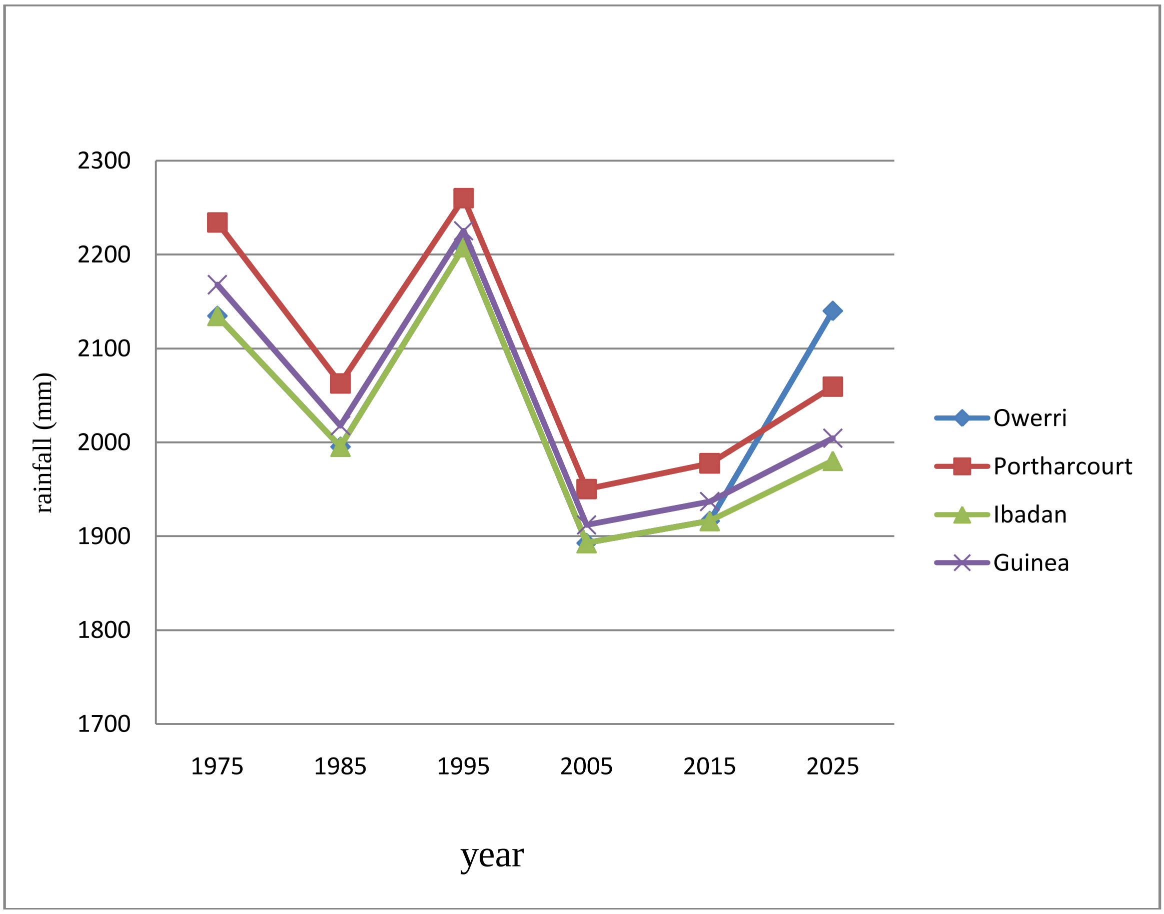

Figure 5. The seasonal rainfall in the Guinea region with the trend equations indicated.

Table 7. Variability and trend of seasonal rainfall in the Guinea region

Location	Mean seasonal rainfall (mm)	Standard deviation (mm)	Coefficient of variation (%)	Trend (mm/yr)
Owerri	1981.190	172.570	8.700	-15.02
Portharcourt	2059.140	189.320	9.200	-41.17
Ibadan	1980.330	123.430	6.230	-37.83
Guinea	2004.270	146.440	7.610	-39.28

Table 8. Decadal seasonal rainfall anomaly of Guinea region

Decade	Owerri (mm)	Port Harcourt (mm)	Ibadan (mm)
1980s	-124.850	-130.010	-124.850
1990s	-39.500	-38.040	-39.500
2000s	31.840	40.660	31.840
2010s	-67.240	-65.290	-67.240

Figure 6 shows the seasonal rainfall in the Savanna region. Makurdi received more seasonal rainfall with a value of 1248.361mm in the Savanna region whereas Abuja received the least with a seasonal rainfall of 1061.433mm. However, the Savanna region received a seasonal rainfall of 1158.860mm (Table 9). Table 10 shows the summary of the decadal seasonal rainfall in the Savanna. In Minna, there's a recent increase in rainfall, particularly notable from 2019 to 2021. Makurdi shows a rebound in precipitation from the 2000's, with a significant surge in the last decade. Similarly, Abuja experienced a recovery in rainfall from the 2000's onward, which intensified in the most recent period.

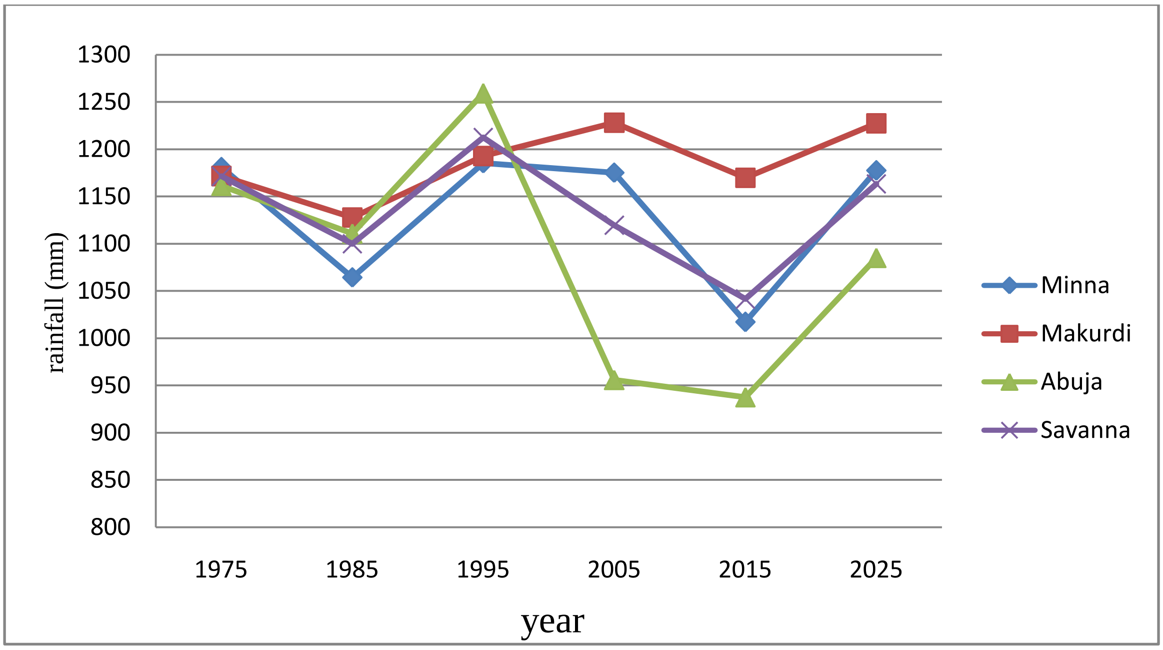

Figure 6. The seasonal rainfall in the Savanna region with the trend equations indicated.

Table 9. Variability and trend of seasonal rainfall in the Savanna region

Location	Mean seasonal rainfall (mm/yr)	Standard deviation (mm/yr)	Coefficient of variation (%)	Trend (mm/yr)
Minna	1164.787	138.729	11.900	-4.82
Makurdi	1248.361	59.966	4.800	12.58
Abuja	1061.433	97.196	9.160	-34.40
Savanna	1158.860	150.704	13.010	-8.78

Table 10. Decadal seasonal rainfall anomaly of Savanna region

Decade	Minna (mm/yr)	Makurdi (mm/yr)	Abuja(mm/yr)
1979-1988	-7.722	-137.766	-26.283
1989-1998	70.145	-29.155	69.662
1999-2008	57.061	-45.067	47.849
2009-2018	89.275	-0.610	91.285
2019-2021	198.632	77.266	114.632

Figure 7 show the seasonal rainfall in the Sahel region. Kano received more seasonal rainfall with value of 711.67 mm in the Sahel region whereas Sokoto received the least seasonal rainfall of 621.08 mm. However, the Sahel region received a seasonal rainfall of 653.53 mm (Table 11). Table 12 shows the decadal seasonal rainfall in the Sahel. Sokoto showed positive anomalies in the most recent decades (2009-2018 and 2019-2021) suggesting increased rainfall. Maiduguri also showed positive anomalies in 1989-1998 and 2009-2018 indicating wetter periods, while a negative anomaly in 2019-2021 signifies reduced rainfall. Similarly, Kano indicated positive anomalies in 1979-1988 and 2009-2018 point to wetter trends, while a negative anomaly in 2019-2021 indicates drier conditions.

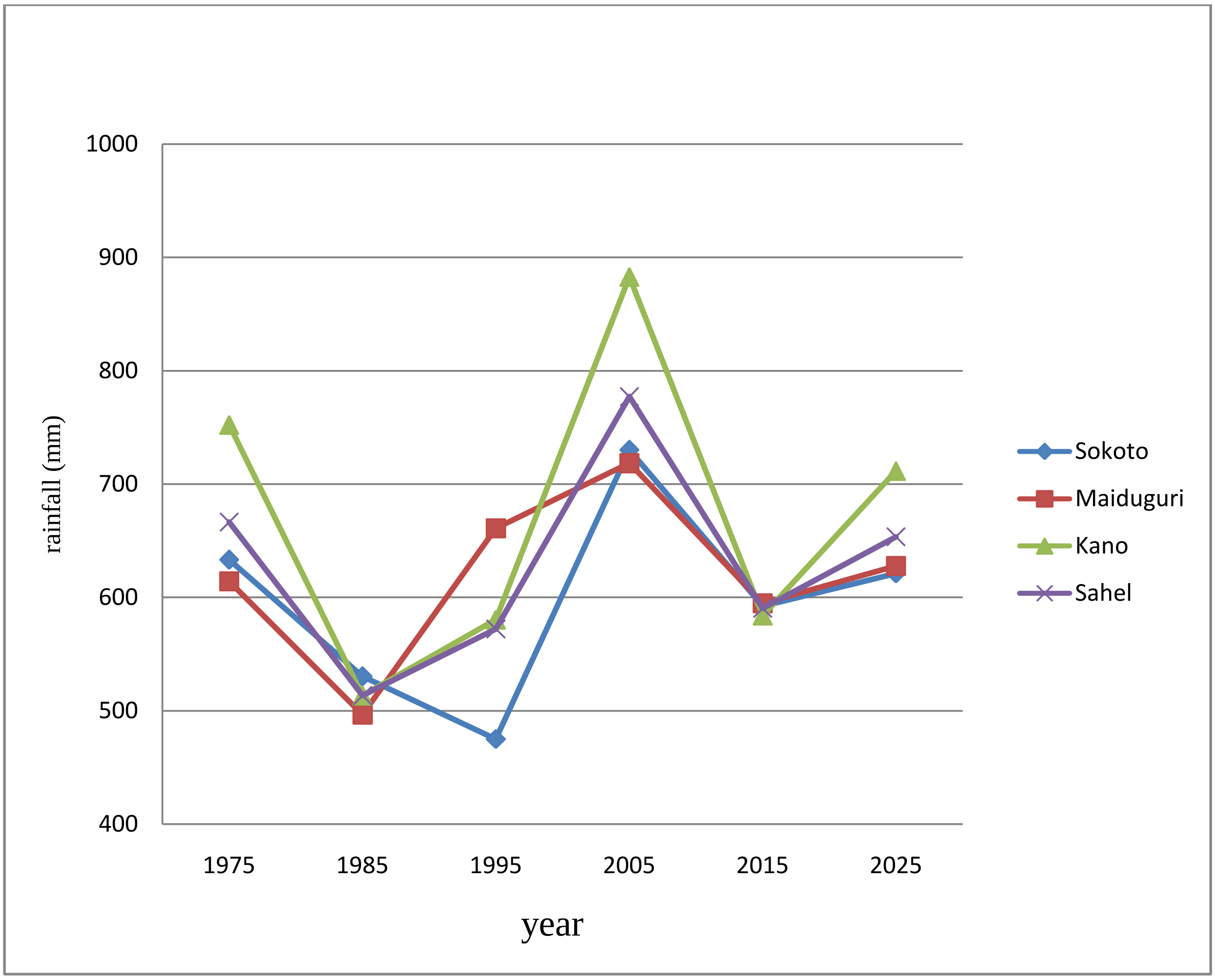

Figure 7. The seasonal rainfall in the Sahel region with the trend equations indicated.

Table 11. Variability and trend of seasonal rainfall in the Sahel region

Location	Mean Rainfall (mm)	Standard Deviation (mm/yr)	Coefficient of Variation (%)	Trend (mm/yr)
Sokoto	621.080	129.510	20.860	12.02
Maiduguri	627.830	144.900	23.060	10.49
Kano	711.670	156.810	22.020	8.88
Sahel	653.530	129.960	19.850	10.59

Table 12. Decadal seasonal rainfall anomaly of Sahel region

Decade	Sokoto(mm/yr)	Maiduguri(mm/yr)	Kano(mm/yr)
1979-1988	-14.866	-92.058	57.188
1989-1998	66.636	49.344	-8.366
1999-2008	-50.456	93.044	-40.224
2009-2018	-14.502	33.812	43.034
2019-2021	107.054	-72.48	-133.867

Scientifically, this study on decadal rainfall trends and variability across Nigeria is crucial for understanding the regional impacts of climate change. Nigeria's diverse ecosystems, agriculture, and water resources are highly sensitive to shifts in rainfall patterns. Such research provides valuable data for climate scientists and meteorologists to enhance climate models and predictions (Viloria et al. 2023; Paredes et al. 2023). Comparing this with studies in tropical agricultural territories of Latin America underscores the need for region-specific assessments (Parra et al. 2012; Olivares and Hernandez, 2019), considering the unique climatic and geographical features that affect each region's vulnerability to climate variability (Rodríguez et al. 2013; Olivares et al. 2013; Olivares et al. 2018).

Socially, in Nigeria, where agriculture is a primary livelihood for a significant portion of the population, understanding decadal rainfall trends is paramount for ensuring food security and economic stability. The findings can guide policymakers and farmers in implementing adaptive strategies to minimize the impact of droughts or excessive rainfall on crop yields. In Latin American tropical agricultural territories, such research is equally vital (Olivares and

Zingaretti, 2018), as it can inform sustainable agriculture practices (Hernandez et al. 2018; Montenegro et al. 2021), disaster preparedness, and resource management (Hernández and Olivares, 2019), benefiting the livelihoods of local communities and enhancing resilience to climate-related challenges (Guevara et al. 2012; Guevara et al. 2013; Olivares and Hernández, 2020).

Comparing these studies underscores the global relevance of climate research. While Nigeria and Latin American territories face distinct climate challenges, both regions share the common goal of mitigating climate-related risks to secure food production (Olivares and Zingaretti, 2019), water resources (Zingaretti et al. 2017), and the overall well-being of their populations (Parra et al. 2017). International collaboration and the exchange of knowledge between these regions can lead to more effective climate resilience strategies and contribute to a broader understanding of climate variability in tropical areas (Olivares et al. 2017; Cortez et al. 2016).

4. Conclusion

This work aimed to examine the decadal trends and variability of rainfall over Nigeria from 1979 to 2021 (42 years) to understand the long-term climate changes and fluctuations. The results present a comprehensive analysis of annual and seasonal rainfall trends and variability across distinct climate zones. The research focused on both interannual and decadal patterns of rainfall. The varying levels of annual and seasonal rainfall across these regions, with Port Harcourt consistently receiving the highest annual and seasonal rainfall in the Guinea region, while Sokoto and Maiduguri exhibit the highest annual rainfall in the Sahel region has been presented. Additionally, decadal analyses highlight fluctuations in rainfall anomalies, with some decades showing positive deviations from the average and others displaying negative deviations, emphasizing the dynamic nature of regional rainfall patterns.

The work fills a crucial gap in the understanding of rainfall patterns and trends within specific climate zones of the region. The project's investigation into interannual and decadal variations in rainfall provides a deeper comprehension of the complex climate dynamics at play. Additionally, the focus on regional climate sub-divisions allows for a more precise assessment of localized climate phenomena, which is valuable for effective decision-making in various sectors. Overall, the project's insights aid in anticipating and planning for climate-related challenges, thus advancing understanding in the field and informing adaptation strategies. These results provide insights into the rainfall patterns and trends in these regions, aiding in understanding and planning for climate-related impacts on agriculture, water resources, and other sectors.

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