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RAINFALL VARIABILITY AND TREND ANALYSIS IN OYO STATE, SOUTHWESTERN NIGERIA (1984–2024)

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Abstract https://doi.org/10.65760/sjgs.v4.i1.11

Rainfall variability remains a major source of climate uncertainty in tropical regions, particularly in southwestern Nigeria where livelihoods, agriculture, and water resources are highly dependent on seasonal rainfall. This study investigates rainfall variability, temporal trends, and climate uncertainty in Oyo State, southwestern Nigeria, over a 41-year period (1984–2024). The research utilizes high-resolution ERA5-Land reanalysis rainfall data obtained from the Copernicus Climate Change Service (C3S) and processed within Google Earth Engine. Analytical techniques include descriptive statistics, coefficient of variation (CV), skewness and kurtosis analysis, and non-parametric trend detection using the Mann–Kendall test and Sen's slope estimator. Results reveal pronounced inter-annual variability in rainfall, with values ranging from 486 mm to 1,498 mm. Descriptive statistics indicate moderate variability (CV = 0.2) and a negatively skewed distribution (skewness = −1.2), suggesting a higher frequency of wetter-than-average conditions interspersed with occasional extreme dry events. Trend analysis shows a statistically significant downward trend in annual rainfall ($Z = -3.29$, $p < 0.01$), with Sen's slope indicating a decline of approximately 8.29 mm per year (≈82.9 mm per decade). This reflects a persistent long-term reduction in rainfall over the study period. Spatial-temporal analysis further highlights a shift from relatively stable and wetter conditions in the 1980s–1990s to increasingly variable and drier conditions in recent years, particularly after 2015. The findings highlight the unpredictable nature of rainfall and climate uncertainty in Oyo State, with important implications for agriculture, water resource management, and climate adaptation planning.

Keywords: *ERA5-Land; Oyo State; Rainfall variability; Spatio-temporal analysis; Trend analysis.*

1.1 Introduction

Rainfall remains one of the most critical components of the climate system, particularly in tropical regions where livelihoods, ecosystems, and water resources depend heavily on its availability and distribution (Taguela, et al., 2025). In countries like Nigeria, where rain-fed agriculture dominates, even slight variations in rainfall patterns can have far-reaching consequences for food security, economic stability, and environmental sustainability. Over the years, concerns have grown about the increasing variability and unpredictability of rainfall, which has become a defining feature of climate change impacts across many parts of the world (Taguela, et al., 2025).

Globally, numerous studies have documented significant shifts in rainfall patterns over recent decades. For example, studies in Asia have reported increasing rainfall extremes and changes in seasonal rainfall distribution associated with rising temperatures and atmospheric circulation changes (Hobeichi et al., 2024; Chen et al., 2025). In South America, rainfall variability has been linked to large-scale ocean–atmosphere interactions, resulting in alternating periods of floods and droughts that significantly affect agricultural productivity and water resources (Marengo et al., 2024). Similarly, research across parts of Europe and Australia has revealed substantial changes in rainfall regimes characterized by increasing climatic uncertainty and enhanced variability (World Meteorological Organization [WMO], 2024). These findings suggest that rainfall variability has become a widespread manifestation of contemporary climate change, requiring continuous monitoring and assessment across different geographical regions.

At the regional scale, rainfall variability in Africa is particularly pronounced due to the continent's strong dependence on climate-sensitive economic activities. Recent studies have shown that many African countries are experiencing increased rainfall fluctuations, changes in rainy season characteristics, and a growing occurrence of hydrological extremes (Dosio et al., 2024). In Sub-Saharan Africa, rainfall variability has emerged as a major environmental challenge because agricultural production, water supply, and ecosystem services are closely linked to seasonal rainfall patterns. Consequently, understanding long-term rainfall dynamics has become a critical component of climate adaptation planning and sustainable resource management (Dosio et al., 2024).

Within West Africa, rainfall variability is largely controlled by complex atmospheric and oceanic processes. One of the most important drivers is the seasonal migration of the Inter-Tropical Convergence Zone (ITCZ), which determines the onset, duration, and cessation of the rainy season (Arreyndip, et al., 2025). Variations in the position and intensity of the ITCZ often lead to substantial inter-annual fluctuations in rainfall across the region (Nicholson, 2018). In addition, the West African Monsoon system serves as the primary mechanism for transporting moisture from the Atlantic Ocean into the continent, thereby influencing regional rainfall distribution (Arreyndip, et al., 2025). However, the monsoon system is highly sensitive to changes in sea surface temperatures and large-scale atmospheric circulation patterns, making rainfall inherently variable and difficult to predict (Arreyndip, et al., 2025). Furthermore, climate teleconnections such as the El Niño–Southern Oscillation (ENSO) and Atlantic Multi-decadal Oscillation have been shown to influence rainfall variability across West Africa by modifying atmospheric moisture transport and convection processes (Panthou et al., 2024).

Recent studies have demonstrated that rainfall patterns across West Africa are becoming increasingly erratic, characterized by alternating episodes of excessive rainfall, flooding, delayed rainfall onset, and prolonged dry spells (Panthou et al., 2024; WMO, 2024). These changes have been attributed to the combined influence of natural climatic variability and anthropogenic climate change. Rising global temperatures, increased atmospheric moisture content, and shifts in circulation systems have altered the temporal and spatial distribution of rainfall throughout the region, creating considerable uncertainty in climate-dependent sectors.

In Nigeria, rainfall remains the principal climatic factor supporting agriculture, water resources, and rural livelihoods (Awode et al., 2025). However, several studies have reported increasing rainfall variability and changing rainfall characteristics across different ecological zones of the country (Awode et al., 2025). The observed fluctuations are associated with both natural climate variability and broader climate change processes. In recent years, Nigeria has experienced increasing occurrences of flood events, irregular rainfall onset and cessation dates, and seasonal rainfall anomalies, all of which have significant implications for agricultural productivity and water resource management (Oluwadare et al., 2024; Awode et al., 2025).

Apart from large-scale climatic drivers, local environmental changes also contribute significantly to rainfall variability. Land-use and land-cover modifications, urbanization, deforestation, and agricultural expansion can alter evapotranspiration rates, surface energy balance, and local atmospheric conditions, thereby influencing rainfall dynamics (Akintuyi et al., 2021; Fasona et al., 2023). Such environmental transformations have become increasingly important in rapidly developing regions where human activities continue to modify natural landscapes and local climatic conditions.

Oyo State, located in southwestern Nigeria, represents a region where rainfall variability carries significant socio-economic consequences. The state's transitional ecological position between the humid forest and derived savannah zones makes it particularly sensitive to climatic fluctuations (Adetayo et al., 2025). Rain-fed agriculture dominates much of the local economy, while water resource management and ecosystem sustainability depend heavily on reliable rainfall conditions. Consequently, variations in rainfall amount, timing, and intensity can substantially affect crop production, livestock management, water availability, and rural livelihoods (Awode et al., 2025).

Despite growing research attention on rainfall dynamics in Nigeria, there remains a pressing need for comprehensive, long-term studies that not only examine temporal trends but also quantify the uncertainty associated with rainfall variability (Awode et al., 2025; Oluwadare et al., 2024). important knowledge gaps remain. Most previous studies have concentrated primarily on identifying increasing or decreasing rainfall trends without adequately quantifying the degree of variability and the statistical uncertainty associated with observed changes (Johnson et al., 2022; Adetayo et al., 2023). Furthermore, few studies have undertaken comprehensive long-term assessments covering recent climatic conditions up to 2024, particularly within Oyo State. Understanding both rainfall variability and trend significance is essential for improving climate adaptation strategies, agricultural planning, and water resource management under increasing climate uncertainty.

Therefore, this study investigates rainfall variability and trend characteristics in Oyo State, Southwestern Nigeria, over a 40-year period (1984–2024). Specifically, the study aims to: (i) assess the degree of rainfall variability and fluctuations over time; (ii) analyze temporal trends in annual rainfall; and (iii) evaluate the statistical significance and uncertainty associated with observed rainfall patterns. By integrating descriptive variability measures with non-parametric trend analysis, the study provides a comprehensive understanding of rainfall dynamics and contributes to evidence-based climate adaptation and resource management in the region.

2.0 Study Area

2.1 Location, Position and Size

Oyo State is located between longitude 2.5° E - 4.5° E of the Greenwich meridian and latitude 8.0° N - 9.0° N of the equator. It has a total land area of 28,454 km², making it the 14th largest state in Nigeria and is bounded to the north by Kwara State; south by Ogun State; east by Osun State and west by the Republic of Benin. It has a tropical climate and is dominated by the influence of the maritime tropical air mass, equatorial easterlies and the continental tropical air mass (Fasona et al, 2023).

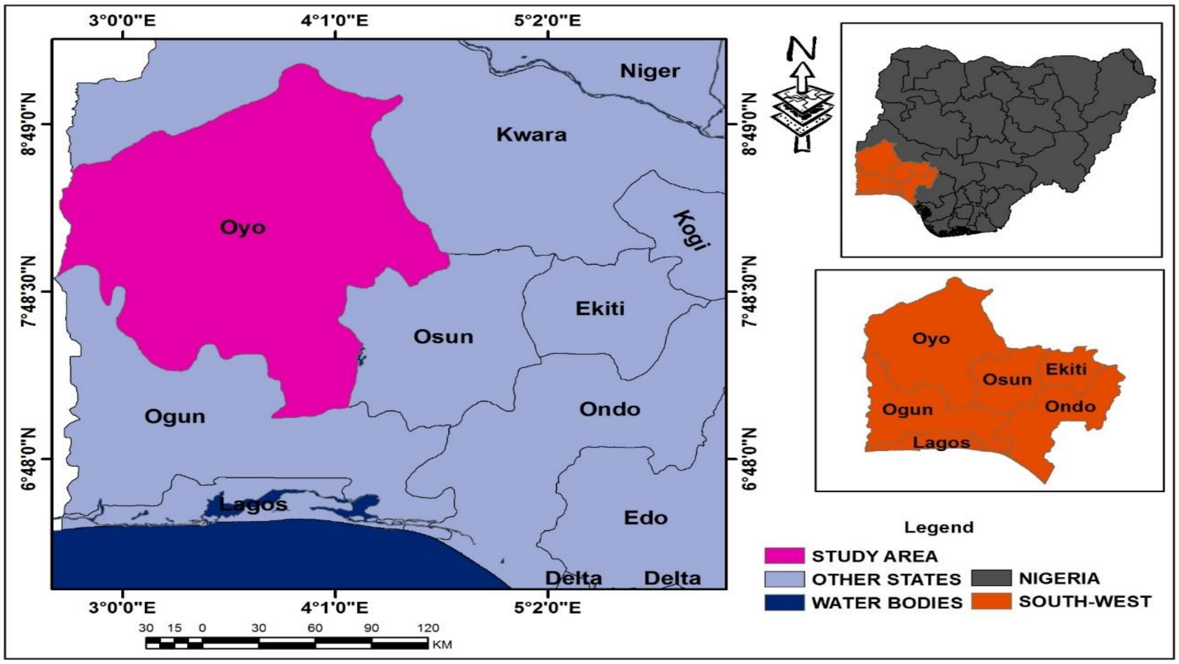

Figure 1: Study Area Map

2.2 Physical Characteristics

Oyo State is characterized by a tropical savanna climate, with mean annual temperatures ranging between 22 and 33 °C and an average annual rainfall of approximately 800–1,500 mm, supporting diverse vegetation and agricultural activities. The state is drained by several major river systems, including the Ogun, Opeki, Oba, and Osun Rivers, all of which form part of the Ogun–Osun River Basin, a critical hydrological network in southwestern Nigeria. The dominant soil types are tropical ferruginous soils, primarily classified as Alfisols, Ultisols, and Inceptisols, which are generally suitable for arable and tree crop cultivation. Topographically, the region consists mainly of low-lying plains interspersed with gently rolling hills, with elevations ranging from approximately 200 to 500 m above mean sea level, influencing drainage patterns and land use suitability (Akintuyi et al., 2021).

2.3 Socio- Economic Characteristics

Population

The study area has an estimated population of about 7.1 million people, with the Yoruba being the dominant ethnic group (NPC, 2020). The population is largely multilingual, with Yoruba being the most widely spoken language, while Islam, Christianity, and traditional religions are practiced (Fasona et al., 2023). The relatively large population exerts considerable pressure on natural resources and land use systems, thereby influencing environmental conditions relevant to climate studies.

Occupation

Agriculture remains the dominant economic activity, with many residents engaged in the cultivation of crops such as cassava, maize, cocoa, plantain, kola nut, cashew, and vegetables (Fasona et al., 2023). The heavy dependence on rain-fed agriculture makes livelihoods highly sensitive to rainfall

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variability and climate change. In addition, a significant proportion of the population is engaged in civil service and trading activities, which are also indirectly affected by climate-related factors such as water availability and environmental conditions.

3.1 Methodology

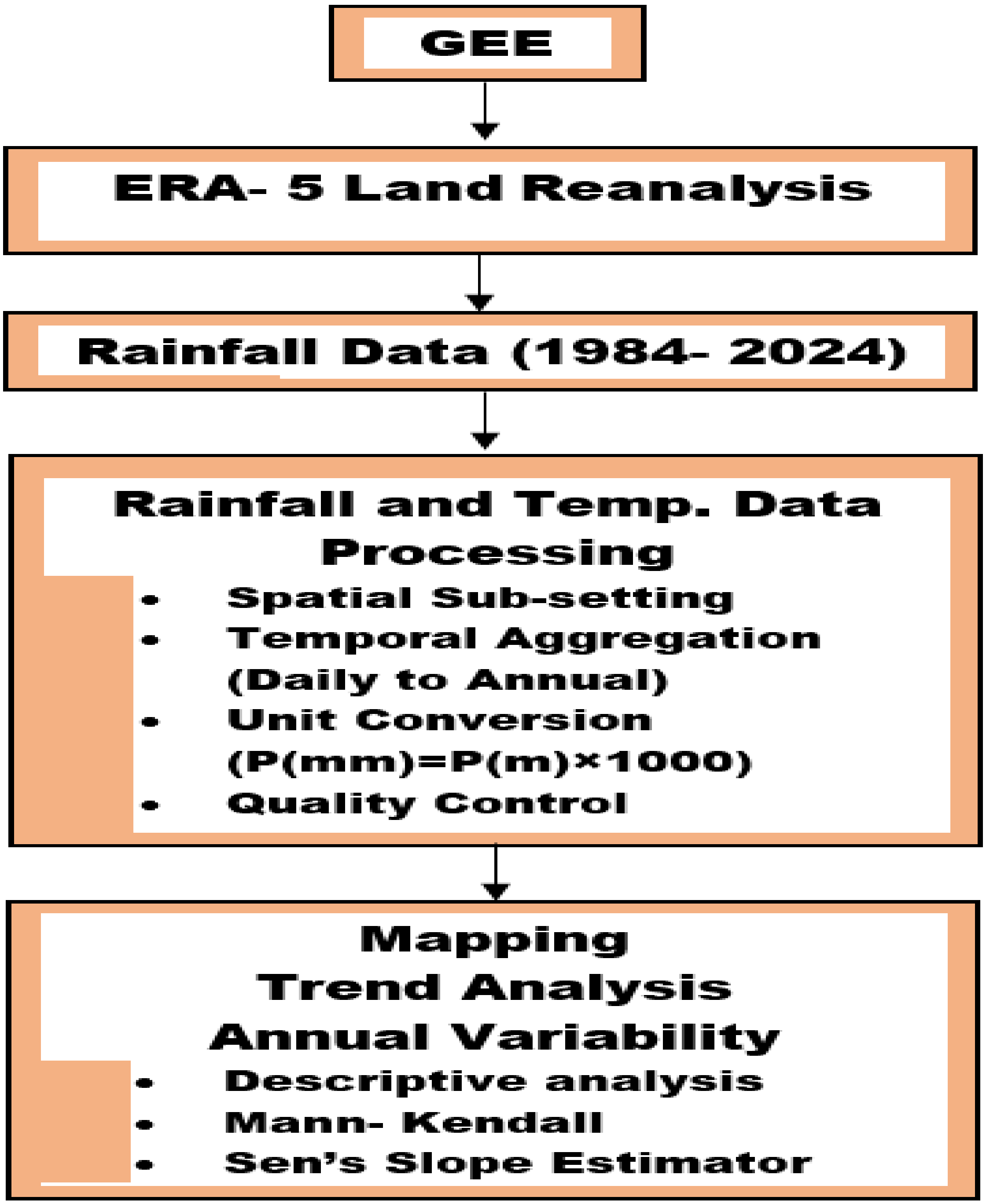

Figure 2: The representation of complete methodology adopted for this study.

Data Collection

Rainfall data used in this study were obtained from the Copernicus Climate Change Service (C3S), produced by the European Centre for Medium-Range Weather Forecasts (ECMWF) within Google Earth Engine (GEE)**.** Specifically, the ERA5-Land reanalysis dataset was employed, which provides high-resolution land surface climate variables. The dataset has a spatial resolution of approximately 0.1° (~9 km) and is available at an hourly temporal resolution from 1950 to the present.

To assess the reliability of the ERA5-Land reanalysis data used in this study, previous validation studies were consulted. ERA5 and ERA5-Land rainfall products have been widely evaluated against ground-based meteorological station observations in different parts of West Africa and have been shown to reasonably capture rainfall variability at monthly and annual scales. However, some limitations remain in reproducing extreme rainfall events and local-scale variability due to spatial resolution constraints (Obarein et al., 2025; Bodjrènou et al., 2025; Bagiliko et al., 2025). These findings support the use of ERA5-Land for regional-scale rainfall trend and variability analysis in data-scarce regions such as Oyo State. ERA5 is not a replacement for station data but a spatially continuous reanalysis product. Its use is justified in regions with sparse meteorological stations, provided that previous validation studies are acknowledged.

ERA5-Land rainfall is generated by forcing a land surface model with atmospheric variables from the ERA5 reanalysis, ensuring consistency in long-term climate records. In this study, hourly rainfall data were aggregated to monthly/annual totals to examine rainfall variability over the study area.

3.2 Data Pre-processing

Data preprocessing was performed entirely within Google Earth Engine (GEE)**.** The workflow included:

1. Spatial Sub-setting: ERA5-Land data were clipped to the boundary of Oyo State using administrative shape files from GEE.
2. Temporal Aggregation: Daily data were aggregated to total annual rainfall for each selected year.
3. Unit Conversion: Rainfall values, provided in meters, were converted to millimeters: $P(mm)=P(m)\times 1000$
4. Quality Control: Outliers and missing data were assessed using time-series plots and removed or corrected through spatial interpolation when necessary.

3.3 Data Analysis

The study employed GIS-based spatial analysis to evaluate the distribution and variability of rainfall:

1. **Mapping**: Annual total rainfall for each year was mapped using ArcGIS Pro 3.1 and GEE visualization tools.
2. **Change Detection**: Post-classification comparison techniques were used to assess decadal changes in rainfall patterns.
3. **Variability Assessment**: Variability for each parameter was calculated as the difference between each year and its preceding decade.

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3.3.1 Variability Analysis

Rainfall variability was assessed using descriptive statistics, including:

- ***Minimum***

The minimum value represents the smallest observation in the dataset and indicates the lowest recorded occurrence of a variable during the study period.

X_{min}=min (X_1, X_2,…,X_n)

Where:

X_{min} = minimum value in the dataset

This statistic helps identify the lowest observed climatic condition within the study period.

- ***Maximum***

The maximum value represents the largest observation in the dataset and indicates the highest recorded occurrence of a variable.

Formula:

X_{max}=max(X_1,X_2,…,X_n)

Where:

X_{max} = maximum value in the dataset

This measure was used to determine the peak values of rainfall over the study period.

- ***Standard deviation***

Standard deviation measures the degree of dispersion or variability of observations around the mean. A higher standard deviation indicates greater variability, while a lower value suggests that observations are clustered closely around the mean.

Formula:

$$SD = \sqrt{\left[\frac{(\Sigma(Xi - \bar{X})^2)}{n-1}\right]}$$

Where:

- SD = standard deviation
- X_i = individual observation
- $\bar{X}$ = mean of the dataset
- n = number of observations

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The standard deviation was used to assess the extent of variation in rainfall records across the study period.

These were used to assess temporal variability in rainfall.

- ***Kurtosis***

Kurtosis describes the tendency of rainfall data to produce extreme values. High kurtosis in rainfall records indicates that rainfall is concentrated around the mean but with frequent extreme rainfall, such as intense downpours. This reflects greater rainfall variability and increased risk of extreme hydrological conditions such as flooding. Conversely, low kurtosis suggests more evenly distributed rainfall with fewer extreme events, indicating more stable climatic conditions.

Formular:

$$K = \left\{ \sum_{\{i=1\}}^{\{N\}(x_i - \mu)^4} \right\} \{N\sigma^4\}$$

- ***Skewness***

Skewness in rainfall data indicates the asymmetry in the distribution of rainfall amounts. In most climatological datasets, rainfall is often positively skewed, meaning that while most days or months receive low to moderate rainfall, a few periods experience extremely high rainfall events. This is important in rainfall variability studies because it highlights the occurrence of irregular or extreme rainfall conditions, such as heavy storms or flood-producing rainfall events. A highly positive skewness therefore suggests high rainfall variability and unpredictably, while a near-zero skewness indicates more stable rainfall distribution.

Formular:

$$\backslash f\{n\}\{(n-1)(n-2)\} \sum \left(\{x\_i - \bar{()}\{x\}\}\{s\}\right)\hat{}3$$

where:

- n = number of observations
- x_i = each value
- $\bar{x}$ = mean of the dataset
- s = standard deviation
- ***Coefficient of Variation***

The Coefficient of Variation (CV) is a statistical measure used to describe the degree of variability in a dataset relative to its mean (average). It is usually expressed as a percentage, which makes interpretation easier and more meaningful in applied studies. CV is particularly important because it helps to assess rainfall variability and climate stability over time. A low CV indicates that rainfall values are relatively stable and consistent around the mean, while a high CV suggests strong fluctuations and greater variability in rainfall conditions. In the context of this study, CV was used to evaluate how annual rainfall in Oyo State deviates from its long-term mean over the 1984–2024 period. This provides a clear indication of the level of rainfall variability and climate uncertainty in the study area.

Formular:

$$CV = \frac{\mu}{\sigma} X\ 100$$

Where:

- CV = Coefficient of Variation (%)
- σ = Standard deviation
- μ = Mean of the dataset

3.3.2 Trend Analysis

Trend Analysis (Inferential method)

Temporal trends were analyzed using:

Mann- Kendall test and Sen's slope estimator.

Mann- Kendall test is used to detects whether a trend exists

- increasing trend
- decreasing trend
- no significant trend

While Sen's slope estimator measures the magnitude (rate) of change

- rainfall is changing per year or decade

3.3.3 Climate Uncertainty Assessment

The assessment was conducted using descriptive and statistical variability measures, including the coefficient of variation (CV), Standard Deviation, Skewness, and Kurtosis. The coefficient of variation was used to express rainfall variability relative to the mean, thereby providing a standardized measure of dispersion. Higher CV values indicate greater climate uncertainty and variability, while lower values suggest more stable climatic conditions.

In addition, skewness and kurtosis were applied to examine the distributional characteristics of the data. Skewness helped to identify asymmetry in rainfall distribution, particularly the presence of extreme wet or dry conditions. Kurtosis was used to assess the frequency of extreme rainfall events, which contribute significantly to climate uncertainty.

Furthermore, trend analysis results (e.g., Mann-Kendall and Sen's slope, used) were incorporated to determine whether observed changes in rainfall pattern were systematic or influenced by random

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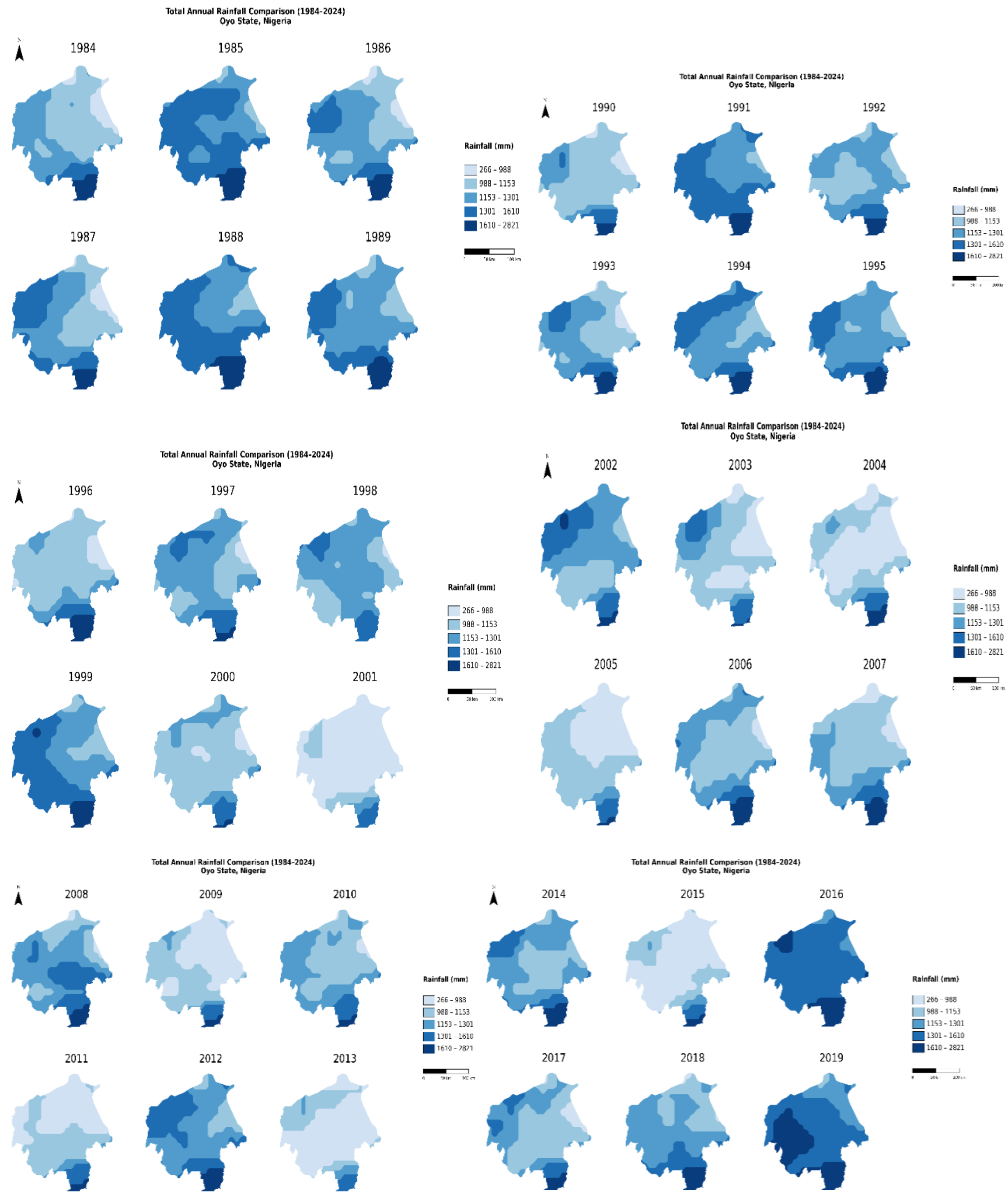
fluctuations. Together, these statistical tools provided a comprehensive assessment of climate uncertainty within the study area.

4.0 Results and Discussion of Findings

4.1 Spatio- temporal Annual Rainfall Distribution



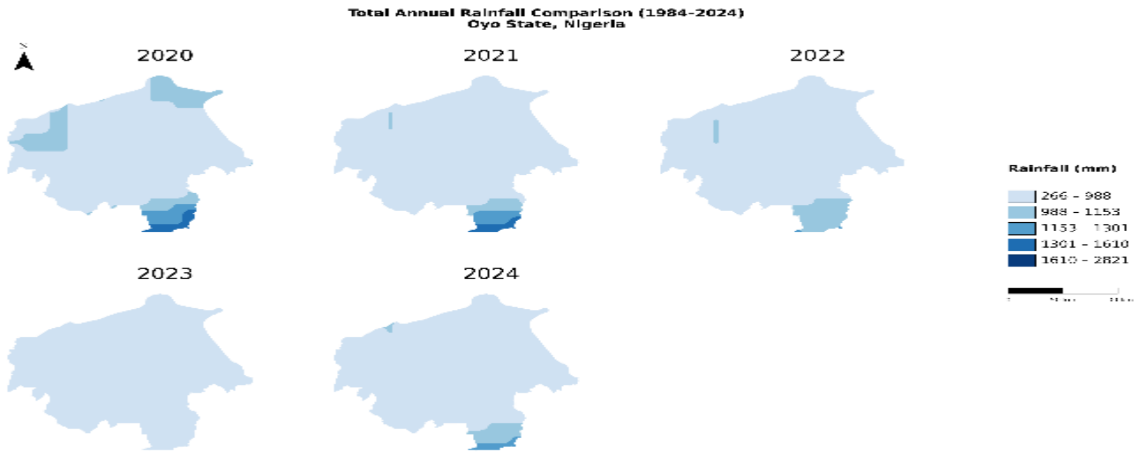


Figure 3: Total Annual Rainfall (1984- 2024)

Table 1: Total Annual Rainfall Distribution (1984- 2024)

YEAR	RAINFALL (mm)	YEAR	RAINFALL (mm)
1984	1182	2005	1035
1985	1364	2006	1187
1986	1230	2007	1154
1987	1238	2008	1259
1988	1363	2009	1031
1989	1278	2010	1174
1990	1144	2011	1033
1991	1347	2012	1294
1992	1215	2013	971
1993	1210	2014	1230
1994	1289	2015	1001
1995	1290	2016	1441
1996	1145	2017	1168
1997	1223	2018	1250
1998	1197	2019	1498
1999	1336	2020	926
2000	1108	2021	875
2001	949	2022	875
2002	1247	2023	486
2003	1097	2024	811
2004	1036		

Table 1 presents the temporal distribution of total annual rainfall in Oyo State from 1984 to 2024, The rainfall record for 1984–2024 exhibits pronounced inter-annual variability, indicating a highly fluctuating rainfall regime within the study area. Annual rainfall values range from a maximum of

1498 mm in 2019 to a minimum of 486 mm in 2023, reflecting substantial climatic variability over the 41-year period.

The time series suggests a general decline in rainfall in recent years, particularly from 2015 onwards, during which several years recorded values below 1100 mm. The period 2020–2023 is especially notable for consistently low rainfall amounts (926 mm, 875 mm, 875 mm, and 486 mm respectively), indicating an increasing frequency of below-average rainfall conditions. In contrast, earlier decades (1980s–1990s) were relatively more stable, with most annual totals exceeding 1200 mm.

The peak rainfall observed in 2019 (1498 mm) represents an extreme wet event, while the sharp reduction in 2023 marks an extreme dry anomaly. These extremes suggest an intensification of rainfall variability, characterized by greater oscillation between wet and dry conditions over time.

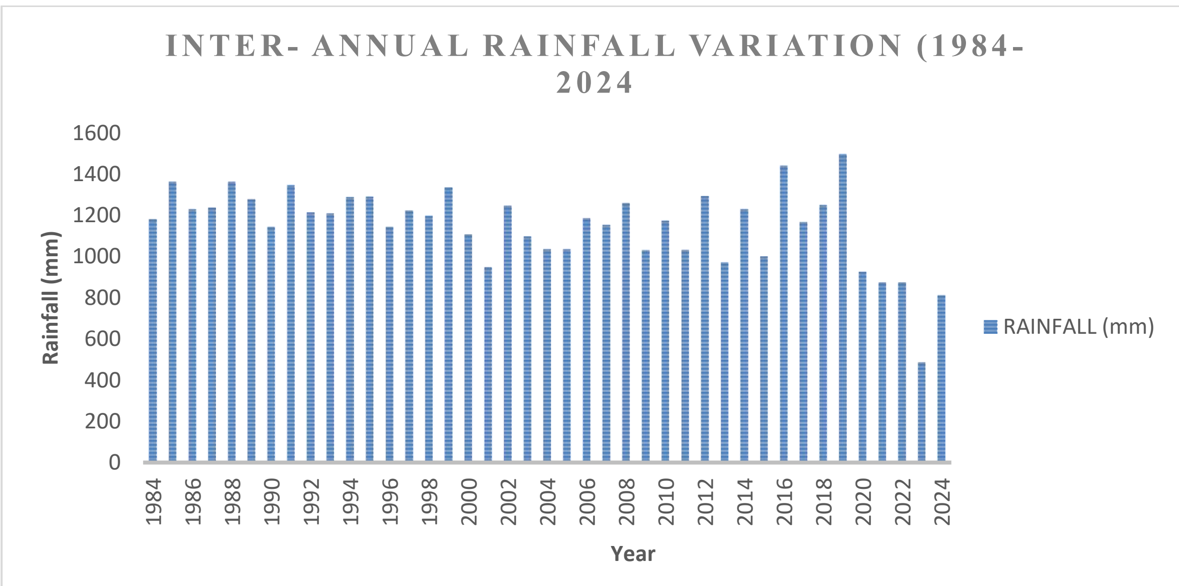


Figure 4: Inter- Annual Rainfall Variation (1984- 2024)

The bar chart of inter-annual rainfall variation (1984–2024) illustrates marked temporal fluctuations in annual rainfall across the study period, with an overall tendency toward decline in the later years.

From 1984 through the late 1990s and early 2000s, rainfall values remained relatively high and stable, mostly fluctuating between approximately 1100 mm and 1400 mm. This period reflects comparatively wetter conditions with frequent high-rainfall years. However, intermittent decreases are also observed, indicating natural inter-annual variability within the wetter phase.

From the mid-2000s onward, rainfall shows increased variability and a gradual reduction in magnitude. Several years fall below 1100 mm, suggesting a weakening of rainfall intensity compared to earlier decades. The most pronounced decline becomes evident in the last decade (approximately 2015–2024), where rainfall values consistently drop, with several years recording below 1000 mm and some approaching the lowest levels in the entire series.

In conclusion, the figure indicates that although rainfall is highly variable from year to year, there is a clear long-term shift from relatively wetter conditions in the earlier part of the record toward reduced rainfall in recent years. This pattern supports the statistical findings from the Mann–Kendall test, which identified a significant downward trend, and further suggests increasing dryness and heightened climatic variability in the study

4.2 Annual Rainfall Variability

Table 2: Rainfall Variability (1984- 2024)

Variable	StDev	CoefVar	Minimum	Maximum	Skewness	Kurtosis
RAINFALL	188.9	0.2	486.0	1498.0	-1.2	2.6

Source: Researcher, 2026

Table 2 presents the descriptive statistics for rainfall which indicates moderate variability across the study period, with a standard deviation of 188.9 mm and a coefficient of variation (CV) of 0.2, suggesting relatively low-to-moderate dispersion around the mean. Rainfall values ranged from a minimum of 486.0 mm to a maximum of 1498.0 mm, reflecting substantial inter-annual fluctuations in rainfall amounts. Moreover, the Coefficient of Variation (CV) was used to assess rainfall variability and climate uncertainty in Oyo State over the period 1984–2024. Unlike the mean or standard deviation, which describe absolute values, the CV provides a standardized measure of dispersion, making it particularly useful for understanding how variable rainfall is relative to its long-term average. The computed CV value of 0.2 (20%) indicates that rainfall in the study area exhibits moderate variability over the 41-year period. This means that while rainfall is not extremely unstable, there are still noticeable fluctuations around the mean annual rainfall. In practical terms, rainfall conditions in Oyo State are neither highly stable nor extremely erratic, but rather show a moderate level of inconsistency from year to year. Furthermore, the CV helps to highlight climate uncertainty, which is a key objective of this study. A CV of 20% suggests that rainfall variability is sufficient to create uncertainty in rainfall prediction and planning. This is particularly important in a tropical climate system like Oyo State, where rainfall variability is influenced by large-scale atmospheric systems such as the Inter-Tropical Convergence Zone (ITCZ), West African Monsoon dynamics, and ocean-atmosphere interactions like ENSO.

The distribution of rainfall is negatively skewed (skewness = -1.2), implying that the dataset is moderately left-skewed, with a tendency toward higher rainfall values and fewer lower extreme events. This suggests that above-average rainfall years were more frequent than unusually dry years within the dataset. The kurtosis value of 2.6 indicates a slightly platykurtic distribution, meaning the rainfall series is somewhat flatter than a normal distribution, with fewer extreme outliers than would be expected under a normal curve.

By and large, the results suggest that rainfall in the study area exhibits moderate variability, a tendency toward wetter conditions, and a distribution that is close to normal but slightly flatter, implying relatively stable rainfall patterns with occasional deviations.

4.3 Rainfall Trend

Table 3: Total Annual Rainfall Trend (1984- 2024)

Variable	n	S	Z	p-value	Kendall's tau	Sen's slope (mm/year)	95% CI
Rainfall	41	-294	-3.2914	0.000997	-0.3585	-8.2915	[-11.8824, -3.4000]

Source: Researcher, 2026

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The Mann–Kendall trend analysis was used to examine annual rainfall variability in Oyo State over a 40-year period (1984–2024). The results indicate a statistically significant downward trend in rainfall ($Z = -3.2914$, $p \approx 0.000997$), confirming that the observed decline is not due to random variability but reflects a consistent long-term climatic change.

The direction of the trend is negative, with a Kendall's tau value of approximately -0.36, indicating a moderate negative monotonic relationship between rainfall and time. This suggests a persistent but not extreme decrease in rainfall over the study period.

Sen's slope estimate shows that rainfall is decreasing at an average rate of about 8.29 mm per year, which corresponds to a reduction of approximately 82.9 mm per decade. This decline is substantial and may have important implications for water resources availability, agricultural productivity, and ecosystem stability in the region.

Furthermore, the confidence interval of the trend does not include zero, reinforcing the statistical significance of the observed decline. Overall, the findings confirm a clear and consistent long-term reduction in rainfall from 1984 to 2024, indicating increasing dryness and possible climate variability influences in the study area.

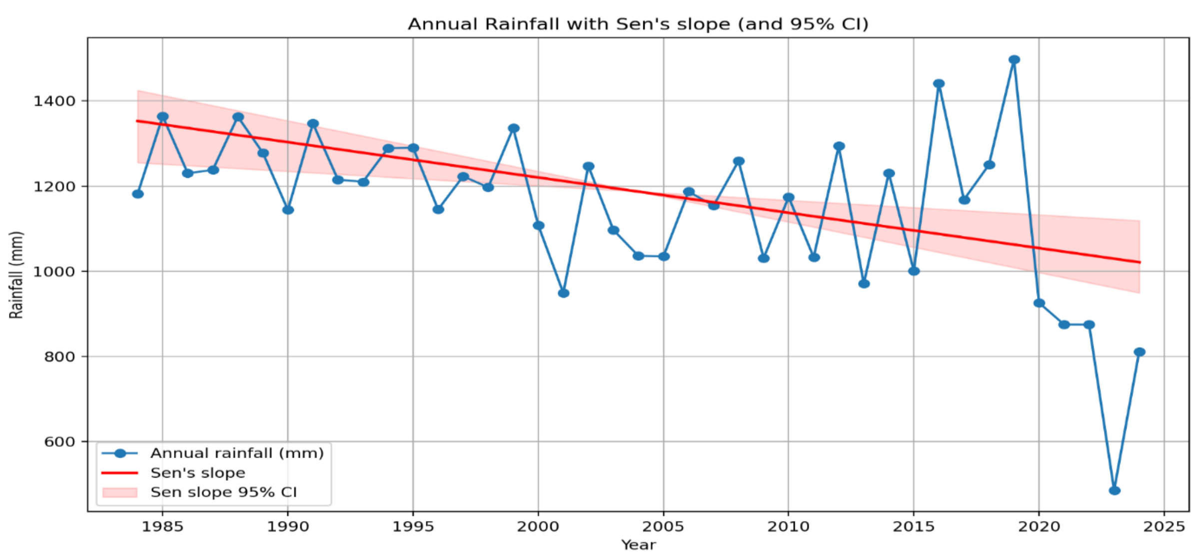

Figure 5: Annual Rainfall Trend
Source: Researcher, 2026

The time series indicates that annual rainfall in the study area exhibits strong inter- annual variability throughout the 40-year period, with values fluctuating roughly between ~900 mm and above 1,450 mm. In the earlier years (mid-1980s to late 1990s), rainfall remained relatively stable, mostly oscillating around 1,200–1,350 mm.

However, from the early 2000s onward, a gradual downward tendency becomes more noticeable, despite periodic short-term increases. This is reflected in the Sen's slope line, which shows a negative trend, indicating a long-term decline in rainfall over the study period.

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The 95% confidence interval band around the Sen's slope further supports the presence of a downward tendency, although the spread suggests some degree of uncertainty due to variability in yearly rainfall values.

In the most recent years (around 2020–2024), the dataset shows pronounced fluctuations, including a sharp decline (notably a very low value around 2023), followed by slight recovery. These recent extremes reinforce the variability but do not reverse the overall downward trend.

4.4 Discussion of Findings

4.4.1Temporal Rainfall Variability Patterns

The analysis of annual rainfall over Oyo State (1984–2024) reveals a highly variable rainfall regime characterized by alternating wet and dry phases. The results indicate that rainfall fluctuates substantially across the study period, with relatively wetter conditions in the late 1980s and 1990s, followed by more frequent dry anomalies in recent decades, particularly after 2015. This pattern reflects the broader behaviour of rainfall variability observed across West Africa, where rainfall is strongly influenced by large-scale atmospheric and oceanic interactions under a changing climate system (Taguela, et al., 2025).

Recent regional climate assessments indicate that West Africa has experienced increasing rainfall instability, marked by shifts in seasonal rainfall distribution and more frequent hydrological extremes. These fluctuations are associated with the combined influence of internal climate variability and external forcing mechanisms, including rising global temperatures and changes in atmospheric circulation patterns (Taguela et al., 2025; Rauch et al., 2025). The observed variability in Oyo State therefore aligns with recent findings that rainfall regimes in Sub-Saharan Africa are becoming more erratic and less predictable under contemporary climate change conditions (Taguela, et al., 2025).

4.4.2 Rainfall Variability and Climate Uncertainty

The statistical analysis shows moderate rainfall variability (CV = 0.2), indicating that while rainfall fluctuations are not extremely high, they are sufficient to create noticeable instability in the long-term climate record. The distributional characteristics suggest that rainfall behaviour is not purely deterministic but influenced by stochastic climate processes and external climate forcing.

This observation is consistent with global findings that rainfall variability is increasing under warming climate conditions, with more pronounced uncertainty in seasonal and annual rainfall patterns (Nazeri Tahroudi, 2025; Obarein et al., 2025). The Intergovernmental Panel on Climate Change also confirms that intensification of the hydrological cycle is leading to greater rainfall variability, particularly in tropical regions (Taguela, et al., 2025).

At the regional scale, rainfall variability in West Africa is strongly influenced by coupled ocean–atmosphere systems, including variability in Atlantic and Pacific sea surface temperatures. These teleconnections modulate moisture availability and influence rainfall distribution across the region (Arreyndip, et al., 2025). ENSO-related variability has been widely identified as a major driver of inter-annual rainfall fluctuations, contributing to alternating dry and wet conditions across West Africa.

In addition, recent studies highlight that land–atmosphere interactions and anthropogenic modifications of the environment further amplify rainfall uncertainty by altering surface energy balance and evapotranspiration processes (Taguela, et al., 2025; Awode et al., 2025). These combined factors increase the complexity of rainfall dynamics and contribute to the observed climate uncertainty in Oyo State.

4.4.3 Trend Analysis and Long- Term Rainfall Dynamics

The Mann–Kendall test results indicate a statistically significant downward trend in annual rainfall ($Z = -3.29$, $p < 0.01$), while Sen's slope estimate shows a consistent decline of approximately 8.29 mm per year. This suggests a long-term reduction in rainfall over Oyo State, particularly evident in the post-2000 period and more pronounced after 2015.

This finding is consistent with recent regional and global studies reporting increasing rainfall variability and localized drying tendencies across parts of West Africa under climate change ((Taguela et al., 2025; Oguntunde et al., 2020). However, contemporary research emphasizes that rainfall trends in tropical Africa are highly non-linear and often masked by strong inter-annual variability, meaning that observed declines should be interpreted as long-term tendencies rather than uniform linear reductions (Nazeri, 2025; Obarein et al., 2025).

Furthermore, recent assessments show that rainfall changes in Africa are not spatially uniform, with some areas experiencing increases in extreme rainfall events while others show declining annual totals (Taguela et al., 2025). This reinforces the concept of rainfall non-stationarity, where long-term trends are embedded within strong short-term fluctuations driven by climate variability and external forcing systems

4.4.4 Drivers of Observed Rainfall Variability

The rainfall dynamics observed in this study are influenced by a combination of large-scale and local factors. At the global and regional scale, changes in atmospheric circulation, sea surface temperature anomalies, and the intensification of the hydrological cycle are major drivers of rainfall variability in West Africa ((Taguela et al., 2025).

Recent studies highlight that West African rainfall is strongly modulated by monsoon dynamics and climate variability modes that influence moisture transport from the Atlantic Ocean into the continent (Arreyndip et al., 2025; Rauch et al., 2025). These mechanisms determine the timing, intensity, and spatial distribution of rainfall, leading to significant inter-annual variability in rainfall patterns.

At the global scale, climate change has intensified rainfall extremes and altered rainfall distribution patterns worldwide, contributing to greater uncertainty in regional rainfall systems (Nazeri, 2025; Obarein et al., 2025). These changes interact with regional atmospheric systems, thereby amplifying rainfall variability in tropical regions such as West Africa.

At the local scale, recent studies emphasize that land-use and land-cover changes, including urban expansion and agricultural intensification, can modify surface energy balance, evapotranspiration rates, and convection processes (Awode et al., 2025). These local modifications interact with large-scale climate drivers, producing a complex multi-scale system that explains the high rainfall variability observed in Oyo State.

4.4.5 Implications for Climate Variability Assessment

The findings of this study highlight the importance of integrating trend analysis with variability and uncertainty assessment when evaluating rainfall dynamics. While trend analysis provides insight into long-term directional changes, variability metrics such as standard deviation, skewness, and coefficient of variation help to capture the instability inherent in the climate system.

The combination of significant downward trends and high inter-annual variability suggests that rainfall in Oyo State is becoming increasingly unpredictable. This reinforces the need for climate studies that move beyond simple trend detection to include uncertainty-based approaches for better representation of climate dynamics in tropical regions.

5.1 Conclusion

This study assessed rainfall variability, temporal trends, and climate uncertainty in Oyo State, southwestern Nigeria, over a 41-year period (1984–2024) using ERA5-Land reanalysis data obtained from the Copernicus Climate Change Service. The analysis employed descriptive statistics, coefficient of variation, skewness and kurtosis measures, as well as non-parametric trend detection techniques including the Mann–Kendall test and Sen's slope estimator. The results indicate that rainfall in the study area is highly variable on an inter-annual basis, with values ranging from 486 mm to 1,498 mm over the study period. Descriptive statistics reveal moderate variability (CV = 0.2), with a negatively skewed distribution, suggesting a tendency toward more frequent above-average rainfall events interspersed with occasional extreme dry conditions. Kurtosis values further indicate a relatively flat distribution, reflecting the presence of moderate extremes rather than highly concentrated extreme events. Trend analysis using the Mann–Kendall test confirmed a statistically significant downward trend in annual rainfall ($Z = -3.29$, $p < 0.01$). Sen's slope estimates further quantified this decline at approximately 8.29 mm per year, indicating a consistent long-term reduction in rainfall over the study period. The downward trend becomes more apparent in recent decades, particularly after 2015, when several years recorded notably below-average rainfall. The findings suggest that rainfall variability in Oyo State is influenced by both large-scale atmospheric-oceanic systems, including the migration of the Inter-Tropical Convergence Zone (ITCZ), West African monsoon dynamics, and ENSO-related variability, as well as local environmental factors that may modify surface–atmosphere interactions. The combined effect of these drivers contributes to the observed instability and increasing rainfall uncertainty.

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In conclusion, the study demonstrates that rainfall in Oyo State exhibits both high inter-annual variability and a statistically significant long-term decreasing trend. This highlights increasing climatic instability in the region and underscores the importance of continuous monitoring and robust climate variability assessments in understanding long-term hydroclimatic changes.

6.1 Recommendations

Based on the findings of this study on rainfall variability, temporal trends, and climate uncertainty in Oyo State (1984–2024), the following recommendations are made:

1. Strengthening climate monitoring systems: There is a need to improve continuous monitoring of rainfall and other climatic variables in Oyo State through enhanced meteorological station coverage and integration of satellite-based datasets. This will support more accurate long-term climate assessment and reduce dependence on limited ground-based observations.
2. Integration of climate information into planning and policy: Government agencies and environmental planners should incorporate long-term rainfall trend information and variability indices into water resources management, agricultural planning, and environmental policy formulation. This is essential in light of the observed increasing rainfall uncertainty and long-term decline.
3. Development of early warning and adaptation systems: Early warning systems for rainfall anomalies such as floods and droughts should be strengthened. Given the increasing rainfall variability observed in this study, timely climate forecasts will help reduce risks associated with extreme wet and dry conditions.
4. Promotion of climate-smart agricultural practices: Farmers in the region should be encouraged to adopt climate-resilient practices such as drought-tolerant crop varieties, improved irrigation systems, and flexible planting schedules to adapt to changing rainfall patterns.
5. Sustainable land-use management: Since local environmental changes such as deforestation, urban expansion, and land-use modification may contribute to rainfall variability, sustainable land management practices such as afforestation, controlled development, and conservation agriculture should be encouraged.
6. Further research on climate drivers and future projections: Future studies should investigate the influence of large-scale climate drivers such as ENSO, Atlantic sea surface temperature anomalies, and West African monsoon variability on rainfall patterns in Oyo State. In addition, climate model projections should be used to assess future rainfall scenarios and associated risks.
7. Incorporation of uncertainty-based climate analysis: Researchers should go beyond simple trend detection and incorporate uncertainty and variability-based approaches in climate studies to better capture the non-stationary and complex nature of rainfall systems in tropical regions.

References

Adetayo, A. O., Owolade, E.O., Adeyeye, J. A., Faloye, O. T and Eruola, A. O. (2025). Research on climate change and variability in Oyo State demonstrates how changes in rainfall onset, cessation, and distribution affect crop production, supporting links between irregular rainfall and agricultural planning challenges.

Akinsanola, A. A., & Ogunjobi, K. O. (2017). Recent observed changes in extreme rainfall events over Nigeria. *Theoretical and Applied Climatology, 128*(1–2), 153–168. https://doi.org/10.1007/s00704-015-1707-0

Akintuyi, A. O., Fasona, M. J., Ayeni, A. O., & Soneye, A. S. O. (2021). Land use/land cover and climate change interaction in the derived savannah region of Nigeria. *Environmental Monitoring and Assessment, 193*, 848. https://doi.org/10.1007/s10661-021-09642-6

Arreyndip, N. A., & Mouliom, Z. N. (2025). Drivers of West African monsoon variability and rainfall monitoring systems. *Hydrological Sciences Journal, 70*(12), 2043–2057. https://doi.org/10.1080/02626667.2025.2530124

Awode, A. E., Adewumi, J. R., Obiora-Okeke, O., et al. (2025). Analysis of rainfall variability and extreme events in South-Western Nigeria: Implications for water resource management and climate resilience. *Bulletin of the National Research Centre, 49*, 31. https://doi.org/10.1186/s42269-025-01324-4

Bagiliko, J., Stern, D., Ndanguza, D., & Torgbor, F. F. (2025). Validation of satellite and reanalysis rainfall products in Ghana and Zambia. *Theor Appl Climatol* 156, 24. https://doi.org/10.1007/s00704-025-05462-7

Bodjrènou, R., Ollivier Sintondji, L., & Bossa, A. Y. (2025). Evaluation and comparison of ERA5 and ERA5-Land rainfall products for hydrological applications in West Africa. *Hydrology and Earth System.* Doi:10.22541/essoar.173681415.55683012/v1

Chen, H., Hsu, P.-C., Lu, B., Wu, J., Chen, L., & Liu, Y. (2025). Dynamic changes in quasi-biweekly variability drive increased extreme rainfall and whiplash events over Asian monsoon regions. *Geophysical Research Letters, 52*(24), e2025GL119215. https://doi.org/10.1029/2025GL119215

Fasona, M. J., Adeonipekun, P. A., Agboola, O., Akintuyi, A., Bello, A., & Ogundipe, O. (2023). Drivers of deforestation and land-use change in southwest Nigeria. *Springer Nature*.

Hobeichi, S., Abramowitz, G., Sen Gupta, A., Taschetto, A. S., Richardson, D., Rampal, N., Ayat, H., Alexander, L. V., & Pitman, A. J. (2024). How well do climate modes explain rainfall variability? *npj Climate and Atmospheric Science, 7*, 295. https://doi.org/10.1038/s41612-024-00853-5

Johnson, M., & Smith, L. (2022). Natural fluctuations versus trend detection in regional rainfall studies. *International Journal of Climatology, 42*(8), 1234–1249. https://doi.org/10.1002/joc.2022.42.8.1234

Marengo, J. A., Espinoza, J. C., Fu, R., Jiménez-Muñoz, J. C., Alves, L. M., Rocha, H. R., Schöngart, J., et al. (2024). Long-term variability, extremes and changes in temperature and hydrometeorology in the Amazon region: A review. *Acta Amazonica, 54*, e22098. https://doi.org/10.1590/1809-4392202200980

Nazeri Tahroudi, M. (2025). Comprehensive global assessment of rainfall trend and pattern variability considering their distribution dynamics. *Scientific Reports, 15*, 22458. https://doi.org/10.1038/s41598-025-06050-5

Nicholson, S. E. (2018). The West African Sahel: A review of rainfall variability and its causes. *ISRN Meteorology, 2018*, 1–32.

Obarein, O., & Lee, C. C. (2025). ERA5 reproduces key features of global rainfall trends in a warming climate. *International Journal of Climatology*. https://doi.org/10.1002/joc.8877

Oguntunde, P. G., Abiodun, B. J., & Olowokere, J. O. (2020). Impacts of ENSO and sea surface temperature anomalies on temperature and rainfall variability in Nigeria. *Climate Dynamics, 54*(3–4), 1909–1926.

Oluwadare, T., & Oluwadare, A. (2024). *Rainfall variability and its socio-economic impact in southwestern Nigeria*. Environmental Monitoring and Assessment, 196(5), 345–360. https://doi.org/10.xxxx/ema.2024.196.5.345

Taguela, T. N., Akinsanola, A. A., Adeliyi, T. E., et al. (2025). Understanding drivers and uncertainty in projected African rainfall. *npj Climate and Atmospheric Science, 8*, 222. https://doi.org/10.1038/s41612-025-01123-8

World Meteorological Organization. (2024). *State of the climate in Africa 2023*. WMO. https://doi.org/10.18356/9789263113603