Trend analysis and homogeneity tests in temperature and rainfall in Nigeria

Analyse des tendances et tests d'homogénéité de la température et des précipitations au Nigeria

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ABSTRACT: Climate change has significantly altered global weather patterns, with notable impacts in Nigeria. The main objective of this study was to examine the trends, variability, and homogeneity in temperature and rainfall in Nigeria. The study analysed temperature and rainfall trends from 1901 to 2021 using the variability test, trends test, and homogeneity tests. The results show that the north is the most unstable and the south most stable. The north experiences the least amount of rainfall each year, while the southern region experiences the highest amount of rainfall. The test results for Mann-Kendall (MK) showed that the temperature trend in Nigeria has considerably accelerated. Conversely, patterns of rainfall indicate a general decline, particularly in central and southern regions of the country. The Theil Sen's slope estimator (TSE) revealed that the two regions with the greatest shifts in rising temperature and decreasing rainfall are Sokoto (north) and Akwa Ibom (south). Homogeneity tests identified temperature change points occurring in northern Nigeria between 1981 and 1995, while southern Nigeria experienced abrupt warming around 1997–2000.

KEY WORDS: Change point detection, homogeneity, rainfall, temperature, trend, variability.

RÉSUMÉ: Le changement climatique a considérablement modifié les modèles météorologiques mondiaux, avec des impacts notables sur le Nigeria. L'objectif principal de cette étude était d'examiner les tendances, la variabilité et l'homogénéité des températures et des précipitations au Nigeria. L'étude a analysé les tendances de la température et des précipitations de 1901 à 2021 en utilisant le test de variabilité, le test de tendances et les tests d'homogénéité. Les résultats montrent que le nord est le plus instable et le sud le plus stable. Le nord connaît le moins de précipitations chaque année, tandis que la région du sud connaît la plus grande quantité de précipitations. Les résultats des tests pour Mann-Kendall (MK) ont montré que la tendance de la température au Nigeria s'est considérablement accélérée. Inversement, les régimes de précipitations indiquent une baisse générale, en particulier dans les régions du centre et du sud du pays. Le test de l'estimateur de pente (TSE) de Theil Sen a a révélé que les deux régions avec les plus grands changements dans la hausse des températures et la baisse des précipitations sont Sokoto (nord) et Akwa Ibom (sud). Les tests d'homogénéité ont identifié des points de changement de température se produisant dans le nord du Nigeria entre 1981 et 1995, tandis que le sud du Nigeria a connu un réchauffement brutal vers 1997–2000.

MOTS CLÉS: Détection du point de changement, homogénéité, précipitations, température, tendance, variabilité.

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1. Introduction

Trend analysis can be used to assess unknown events in previous weather parameters and forecast future weather events. Additionally, time-series homogeneity tests enable the identification of shifts across a data series. Therefore, change point detection is a crucial area in time series analysis with a wide range of applications. Here, it is necessary to find substantial departures from the expected behaviour in a system with measurable time series (Josserand, 2021). A single or several changes or variations in the climate data gathered over certain periods often go undetected until these events are identified using the correct statistical techniques (Beaulieu et al., 2012). A key component of climate studies is the identification, estimation, and forecasting of trends along with their statistical and physical importance (National Centre for Atmospheric Research, 2014).

Temperature and rainfall are the two most important variables usually used in climate science and hydrology to determine the size and scope of climate change, along with fluctuations (Intergovernmental Panel on Climate Change [IPCC], 2007; Aguilar et al., 2009; Shongwe et al., 2011). Extreme weather can have a considerable impact on ecosystems and the citizenry, and temperature and rainfall are two of the main climatic factors used to describe these events. Seneviratne et al. (2021) highlighted that a sequence of severe weather that lasts for years, for instance, a season, can be referred to as a severe climatic phenomenon. A severe weather phenomenon is defined as an incident that is exceptional in one specific area during a particular period of the year.

The various ongoing weather occurrences in Nigeria have demonstrated that the country's climate has changed from the norm. This is apparent in the manifestation of droughts in Nigeria, variations in rainfall patterns, desertification, rising sea levels, heat waves, flooding, soil erosion, and windstorms (Haider, 2019). Anthropogenic climate change would likely result in intensification in the incidence or the severity of severe weather events such as extreme heat and severe rainstorms (Durodola, 2019; United States Environmental Protection Agency [EPA], 2022). Warm temperature extremes are predicted to rise over the coming decades, whereas cold temperatures are expected to fall (IPCC, 2013; Hartmann et al., 2013). According to Dunne (2022), the number of people who lost their lives from these life-threatening weather conditions in Africa is an illustration of loss and damage. This is a term used to illustrate the adverse effects of global warming on people, particularly in highly fragile areas on a global scale. Since the regional climate and rainfall in West Africa have altered over time, the ecosystems and the connections between them have been negatively impacted (Bates et al., 2008; Wheeler & von Braun, 2013). Animashaun et al. (2020) analysed rainfall variability in 33 sub-basins of the Niger Central Hydrological Area (NCHA) in Nigeria from 1911 to 2015 using linear regression, Kriging interpolation and non-parametric tests such as Mann-Kendall [MK], Standard Normal Homogeneity Test [SNHT], and Pettitt's test [PET]. The results showed that rainfall trends are decreasing in all sub-basins except two (21 and 22), which have increasing trends. The study showed that the most significant change point in rainfall patterns occurred in 1969.

Akinsanola and Ogunjobi (2017) studied rainfall trends in Nigeria using data from 23 stations. The study used a modified version of the MK test to detect trends in rainfall data. The study used the slope estimator test developed by Theil and Sen to determine the amount of change over time. Rainfall was examined for homogeneity using Pettitt's test [PET], Standard Normal Homogeneity Test [SNHT], and Buishand Range Test [BRT]. The results show that annual rainfall increased, with nine stations having significant increases, with seven stations showing variations in the average rainfall. Meanwhile, 18 stations had homogeneous trends. Adeyeri et al. (2017) studied rainfall trends and homogeneity in the Komadugu-Yobe basin from 1979 to 2015. The study used the MK and TSE tests to detect trends and magnitude in rainfall data. PET, SNHT, and BRT were utilised to assess the consistency of the rainfall data. Annual and wet-season rainfall decreased, while dry-season rainfall increased. Homogeneity tests showed an overall homogeneous trend in rainfall across the basin. The change points were detected in 2005 for nine out of 15 grids in the annual and wet-season rainfall series.

Dan'azumi and Ibrahim (2021) studied the hydro-climate trends of Nigeria's Hadejia–Nguru Wetlands catchment from 1980 to 2016, using statistical techniques such as PET, MK trend, and TSE to test the homogeneity, trends and magnitude of the data. The results of the study show that there was an increasing trend in minimum, average, and maximum temperatures at all stations. The results for Bauchi and Kano stations show an increasing trend in monthly maximum temperatures. The monthly rainfall results show that no trend was detected in all the stations; however, mean annual rainfall shows that there was an increasing trend at Bauchi, Hadejia, and Nguru stations. Ishaku et al. (2024) studied rainfall and temperature patterns in northeastern Nigeria from 1981 to 2021. The study employed the MK test, inverse distance weighting (IDW) interpolation, and the TSE. The rainfall results show a decreasing trend in Akko, Billiri, Maiduguri, Numan, and Yola; however, the results show an increasing trend in Gombe, Abadam, Biu, and Mubi. Also, the results revealed that the maximum temperature has increased significantly across all stations, and the minimum temperature has decreased slightly but insignificantly.

Climate change has significantly altered weather patterns worldwide, with notable impacts on temperature and rainfall. In Nigeria, the situation is not different; the various climate parameters are experiencing significant variation, which has manifested itself as droughts, shifting trends in rainfall patterns, desertification, rising sea levels, heat waves, flooding, soil erosion, and windstorms. However, the changes that have occurred in the various weather parameters over the years have posed severe threats to ecosystems, agriculture, infrastructure, and human livelihoods. Despite numerous research studies undertaken in Nigeria relating to climate studies, critical gaps still exist in detecting and understanding climate trends, particularly in temperature and rainfall variability. The identification of change points in climate data is essential for assessing the magnitude and direction of these shifts. However, many climate variations remain undetected due to the lack of appropriate statistical techniques for trend analysis. Existing studies have applied various methods, including the MK test, Sen's slope estimator and Pettitt's test. Nevertheless, owing to inconsistencies in research undertaken across different regions in Nigeria, there is a need for further investigation. Therefore, in this study, we aimed to investigate the trends, variability, homogeneity, and change points in temperature and rainfall in Nigeria.

1. To investigate temperature and rainfall trends in Nigeria.
2. To assess temperature and rainfall variability in Nigeria.
3. To examine temperature and rainfall homogeneity in Nigeria.
4. To identify if there are any change points in temperature and rainfall in Nigeria.

2. Study area

Nigeria is located between latitudes 4° and 14° north and longitudes 3° and 15° east. Bounded by the Sahel (north) and the Gulf of Guinea (south), the country shares borders with Niger, the Benin Republic, Cameroon, Chad and Sao Tome (Figure 1). Because of Nigeria's large landmass, diverse topography, and vegetation, the country experiences a wide range of climatic conditions. Its climate is influenced by latitude, proximity to the Atlantic Ocean, and the interaction between the dry northeasterly trade winds and the moist south-westerly monsoon winds, which together result in significant regional and seasonal variations in temperature, rainfall, and humidity.

Nigeria experiences two main seasons, namely, the rainy season and the dry season. The southern region has a longer rainy season than the north. The country has an annual mean temperature of 26.9°C, with monthly temperatures that vary from 24°C in December and January to 30°C in April. Nigeria has a mean annual rainfall of 1,165.0 mm, with Lagos State having a yearly mean relative humidity of 88% which decreases from the southern region to the northern region of the country (Eyefia, 2025). In relation to its diverse nature, Nigeria has been classified into three main climate zones, where the northern part of the country has a hot and dry Sahelian climate, the southern part is classified as a tropical monsoon climate and the central region as a tropical savannah climate (World Bank Group, 2021).

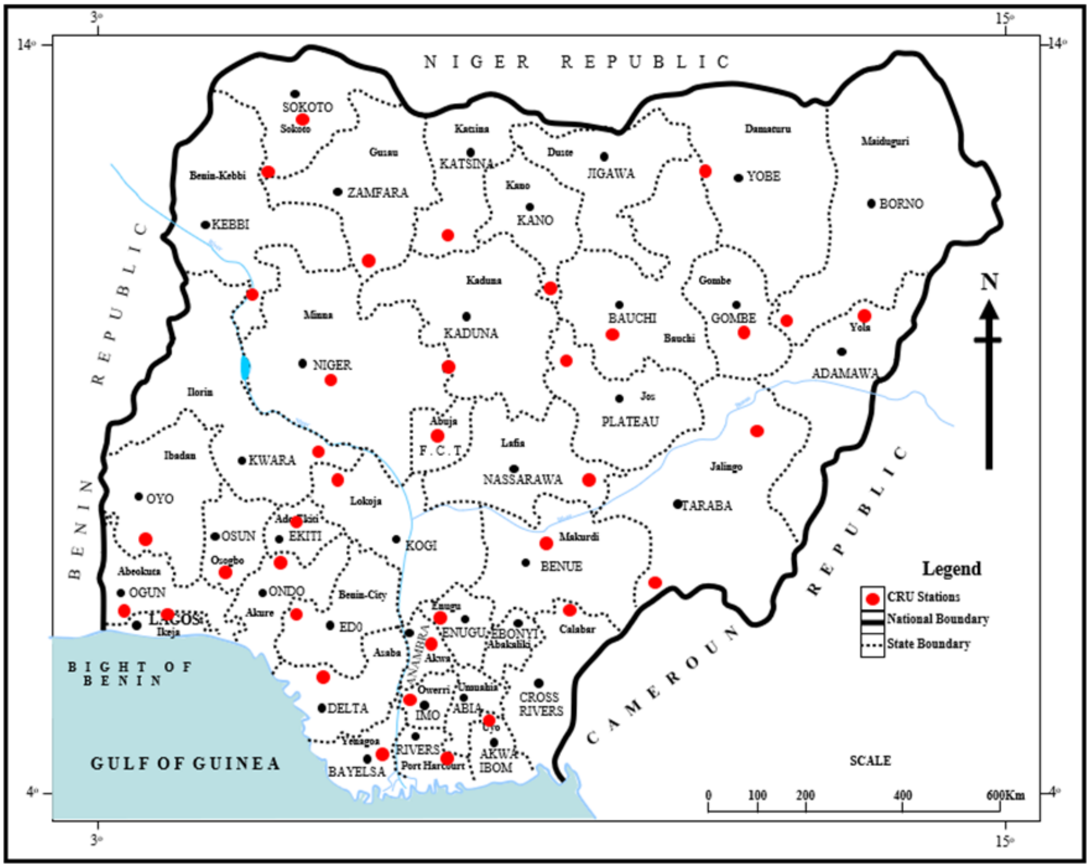

Figure 1 CRU Stations. Source: own study.

3. Methods

3.1. Data Source and Description

The study utilised gridded observational data on rainfall and temperature in Nigeria spanning 1901 to 2021. Mean monthly temperature and rainfall records were downloaded from the University of East Anglia's Climate Research Unit (CRU) gridded data CRU TS version 4.06 at 0.5° resolution using the Google Earth Interface covering the period January 1st 1901 - December 31st 2021 (Harris et al., 2020). The downloaded temperature and rainfall data were exported into Microsoft Excel sheets for data organisation, cleaning, visualisation, and analysis.

Table 1 Data Used for Variations, Trend, and Homogeneity of Temperature and Rainfall.

Data	Units	Resolution	Temporal resolution (TR)	Source
Temperature	Degree Centigrade	0.5° x 0.5°	Monthly	CRU = Climatic Research Unit at the University of East Anglia (UK)
Rainfall	Millimetre	0.5° x 0.5°	Monthly	CRU = Climatic Research Unit at the University of East Anglia (UK)

The CRU time series data set has been validated and extensively used in Nigeria, for example, Animashaun et al. (2020), Ujoh et al. (2019), Hassan et al. (2020), Shiru et al. (2020), Ndakara and Eyefia (2021) and Odigwe et al. (2021a, 2021b) have employed this time series data set in various research and achieved valid results.

To emphasise long-term climate trends and minimise the influence of short-term fluctuations, the monthly data were converted into annual mean temperature and rainfall totals. In the instances of missing or anomalies, the data underwent linear interpolation. To summarise the time series data, descriptive statistics such as minimum, maximum, mean and standard deviation (SD) were computed, while the Coefficient of Variation (CV) was employed to quantify the temporal variability of the dataset.

3.2. Trend Detection

3.2.1. Mann–Kendall (MK) Trend Test

In this study, the Mann–Kendall (MK) test (Gilbert, 1987) was used to detect the monotonic trends in temperature and rainfall data. The MK test is a non-parametric test that assesses the direction and magnitude of the data points, so it does not matter if the data follow a normal distribution or not. The standardised Z statistic tells us whether the trend is significant and whether it is an upward or downward trend, with $\alpha = 0.05$ as a threshold. The MK test was conducted for each climatic variable at all stations, assessing the significance and direction of long-term trends. Researchers in Nigeria, such as Oluleye and Adeleke (2012), Ilori and Ajayi (2020), Animashaun et al. (2020), Getahun et al. (2021), and Ndakara and Eyefia (2021) have applied the MK test to their climatological studies in different parts of the country with a valid result.

3.2.2. Theil–Sen Slope Estimator (TSE)

To validate the trends detected by the MK test, the Theil–Sen estimator (Sen, 1968; Wilcox, 2001) was used. This method calculates the slope between every possible pair of data points, then uses the median of these slopes as the estimate for the overall trend. The approach is very robust, whereby making outliers have little influence, and it does not depend on the data being normally distributed. When combined with the MK test, the Theil–Sen estimator offers a reliable measure of the rate of change. The TSE test has been widely utilised by Adeyeri et al. (2017), Akinsanola and Ogunjobi (2017), Dan'azumi and Ibrahim (2021), and Ishaku et al. (2024) in their climatological research.

3.3. Homogeneity and Change Point Detection

To check for homogeneity and detect a change point in the data, the Standard Normal Homogeneity Test (SNHT), Pettitt Test (PET), von Neumann Ratio (VNR), and Buishand Range Test (BRT) were conducted to ensure data reliability. The homogeneity tests help detect shifts or sudden inconsistencies, which can occur due to station relocation, instrument changes, or modifications in data processing. Each of these tests was used to assess whether the time series remained homogeneous, using $\alpha = 0.05$ as the significance threshold.

The Standard Normal Homogeneity Test [SNHT] (Alexandersson, 1986): This test was used to identify the abrupt mean shifts (change points) by comparing individual series to group averages.

Pettitt Test (Pettitt, 1979): This is a non-parametric, rank-based method for detecting a single significant change-point.

Von Neumann Ratio (von Neumann, 1941): This test was used to examine the randomness and serial correlation within the data.

Buishand Range Test: This test detects the systematic discontinuities by analysing the cumulative deviations from the mean.

3.4. Statistical Analyses

The Python programming language was used for every statistical computation since it provides robust modules for examining quantitative and climatological data. The following four statistical tools in Python were used:

1. The data transformation, cleaning, and the computation of descriptive statistics, such as maximum, minimum, mean and standard deviation, were computed using NumPy and Pandas.

2. The non-parametric trend analyses, such as the Mann-Kendall (MK) test and Theil-Sen's Slope Estimator (TSE), were carried out using SciPy to detect and quantify long-term trends in rainfall and temperature.

3. Climate trends and fluctuations throughout time and space were graphically represented using Matplotlib and Seaborn.

4. Custom Python scripts developed from accepted statistical procedures were used to perform homogeneity tests, such as the Pettitt test (PET), Standard Normal Homogeneity Test (SNHT), Buishand Range Test (BRT), and Von Neumann Ratio (VNR).

4. Results and discussion

Temperature: The summary statistical results of temperature trends across Nigeria are presented in Table 1. The results showed that Kebbi recorded the highest average temperature of 29°C, followed by Sokoto (28.7°C), Borno (28.1°C), and Adamawa (28.0°C). These high temperatures reflect the typical climate of northern Nigeria, which is characterised by abundant sunshine, dry winds, and sparse vegetation. Plateau State, on the other hand, records the lowest average temperature of 23.3°C; the lower temperature recorded can be attributed to the higher altitude and semi-temperate climate that play a significant role. Other elevated regions, such as Kaduna (25.4°C), Bauchi (25.8°C), and Abuja (25.4°C), also experience cooler conditions due to their elevation. The findings of this present study are consonant with the findings of the following researchers, such as Atedhor (2014), Ogolo et al. (2024), and Odunuga and Badru (2015), who earlier demonstrated that latitude and topography both significantly influence temperature patterns in various regions.

The findings on maximum temperatures further reveal regional differences, with the highest values being recorded in Kebbi (30.4°C) and Sokoto (30.0°C), underscoring the extremely hot weather in northern Nigeria. Plateau's highland location is reflected in its lowest minimum temperature of 22.4°C. These findings are consistent with the findings of Yusuf et al. (2017), who reported similar north-south disparities, with moderate temperatures in central highland regions and warmer temperatures in the north. Standard deviation analysis of temperature variability showed that states like Cross River (0.26), Benue (0.28), Enugu (0.28), Ebonyi (0.27), Abia (0.28), Akwa Ibom (0.26), Imo (0.29), Rivers (0.27), and Yenagoa (0.30) had the least amount of variation. These low standard deviations are indicative of the consistent temperature patterns found in southern Nigeria's humid tropical and coastal rainforest climates. The study's findings also showed that Katsina (0.52), Kano (0.51), Jigawa (0.51), Kebbi (0.49), and Sokoto (0.50) have the highest levels of variability, highlighting how vulnerable northern states are to extreme temperature fluctuations and heat waves. The Sahelian, dry environment that prevails in most of the region is consistent with these findings.

Generally, the results show a noticeable heat gradient over Nigeria from north to south. While southern and highlands regions continue to be relatively steady and moderate, northern regions not only have higher average temperatures but also greater temperature variability. This geographical disparity confirms climate projections showing that northern Nigeria experiences increasing temperatures and a higher risk of extreme weather events. These findings are in line with earlier studies (Atedhor, 2014; Ogolo et al., 2024; Odunuga & Badru, 2015; Yusuf et al., 2017; Adejuwon & Dada, 2021).

Table 2 Temperature summary statistics for Nigeria.

Variable	Observations	Minimum	Maximum	Mean	Std. Deviation
Sokoto	121	27.458	30.025	28.682	0.496
Katsina	121	25.558	28.258	26.898	0.517
Kano	121	25.358	28.075	26.694	0.511
Borno	121	27.150	29.333	28.116	0.438
Kebbi	121	27.917	30.408	28.965	0.490
Jigawa	121	25.592	28.342	26.936	0.513
Bauchi	121	24.750	27.158	25.787	0.458
Taraba	121	26.408	28.258	27.120	0.364
Gombe	121	26.475	28.792	27.419	0.447
Zamfara	121	26.092	28.725	27.276	0.493
Yobe	121	25.417	27.642	26.360	0.458
Adamawa	121	27.367	29.158	28.035	0.373
Kaduna	121	24.475	26.708	25.390	0.446
Niger	121	26.742	28.875	27.706	0.440
Plateau	121	22.375	24.617	23.306	0.429
Abuja	121	24.642	26.617	25.416	0.381
Benue	121	26.342	27.875	27.009	0.284
Nasarawa	121	26.175	27.992	26.905	0.345
Oyo	121	25.858	27.842	26.872	0.405
Kwara	121	26.283	28.342	27.277	0.433
Kogi	121	26.425	28.042	27.239	0.337
Enugu	121	26.092	27.558	26.831	0.283
Lagos	121	26.008	27.950	27.001	0.385
Ondo	121	25.208	27.025	26.188	0.382
Edo	121	26.250	27.892	27.060	0.332
Delta	121	26.117	27.667	26.863	0.308
Cross River	121	25.767	27.117	26.433	0.255
Anambra	121	26.192	27.692	26.910	0.306
Ebonyi	121	26.150	27.575	26.880	0.270
Abia	121	25.825	27.267	26.532	0.275
Akwa Ibom	121	25.325	26.700	25.983	0.261
Imo	121	25.667	27.183	26.440	0.287
Rivers	121	24.775	26.208	25.467	0.272
Yenagoa	121	25.208	26.725	25.952	0.296
Ekiti	121	24.717	26.625	25.732	0.400
Osun	121	24.783	26.717	25.800	0.414
Ogun	121	26.325	28.300	27.328	0.416

Rainfall: Rainfall information for Nigeria was presented in Table 3. According to the results, Cross River in the southern region of Nigeria (2679.5 mm), Akwa Ibom (2624.1 mm), Rivers (2513.7 mm), and Delta (2453.5 mm) have the highest average annual rainfall. These numbers reflect both the region's closeness to the Atlantic Ocean and its humid rainforest climate. In contrast, Borno (631.3 mm), Sokoto (674.2 mm), Katsina (704.1 mm), and Yobe (811.2 mm) recorded the lowest average rainfall, which is consistent with the semi-arid and Sahelian climates of northern Nigeria.

As one of Nigeria's most humid regions, Cross River recorded the highest maximum rainfall (3296.1 mm), closely followed by Delta (3238.1 mm), Akwa Ibom (3196.2 mm), and Lagos (3185.5 mm). However, Yobe (60.4 mm), Zamfara (84.6 mm), and Niger (100.0 mm) had the lowest minimum rainfall amounts, which is an indication of northern Nigeria's prolonged dry seasons and fluctuating droughts.

Regional variations are further highlighted by rainfall variability, which is represented by the standard deviation. The areas with the least variability were Taraba (113.4 mm), Nasarawa (104.8 mm), and Bauchi (109.5 mm), suggesting more regular rainfall patterns. Ondo (187.6 mm), Lagos (317.1 mm), Delta (243.6 mm), Cross River (236.2 mm), and Akwa Ibom (246.2 mm) showed notable fluctuation, indicating erratic and intense rainfall events typical of the humid southern region.

On the whole, the rainfall distribution shows a clear north-south gradient, with rainfall amounts gradually declining from the arid north to the coastal south. A weakening of the Intertropical Convergence Zone (ITCZ) and decreased moisture input from the Atlantic Ocean as revealed by the results, which also shows a downward trend in typically wetter southern states, including Cross River, Akwa Ibom, Abia, Ebonyi, and Enugu. The findings of Omotosho and Abiodun (2007), Akinsanola and Ogunjobi (2014, 2017), Oguntunde et al. (2011), Adeyeri et al. (2017), and Agbo and Ekpo (2021) that documented declining rainfall totals, a delayed onset of the rainy season, and increased variability linked to deforestation, aerosols, and global warming are in line with the findings of this study.

Table 3 Rainfall summary statistics for Nigeria.

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
Sokoto	121	358.200	1088.700	674.146	135.305
Katsina	121	370.400	1078.300	704.135	128.971
Kano	121	517.300	1141.400	818.367	122.553
Borno	121	328.200	903.500	631.317	119.153
Taraba	121	709.000	1352.900	1136.885	113.421
Gombe	121	639.100	1122.600	903.188	97.631
Bauchi	121	779.100	1335.500	1064.037	109.446
Kebbi	121	507.100	1277.600	900.461	158.103
Jigawa	121	474.200	1142.600	806.007	124.193
Adamawa	121	581.100	1182.700	964.441	109.262
Yobe	121	60.408	1091.200	811.218	137.774
Zamfara	121	84.642	1421.300	1109.211	165.212
Plateau	121	940.600	1635.100	1257.179	127.037
Abuja	121	908.200	1558.600	1241.917	127.164
Benue	121	1322.100	2041.900	1651.557	125.141
Nasarawa	121	900.200	1411.400	1195.402	104.837
Oyo	121	951.800	2389.200	1463.788	234.554
Kogi	121	861.400	1603.600	1254.502	129.983
Kwara	121	810.600	1767.500	1205.797	151.042
Enugu	121	1442.700	2430.300	1967.984	157.905
Lagos	121	1131.700	3185.500	1787.959	317.116
Ondo	121	1148.800	2386.900	1567.424	187.599

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
Edo	121	1597.500	3000.000	2109.170	217.524
Delta	121	1878.300	3238.100	2453.487	243.592
Anambra	121	1431.200	2317.000	1944.997	163.547
Ebonyi	121	1626.700	2640.600	2158.600	172.392
Cross River	121	2092.200	3296.100	2679.496	236.193
Abia	121	1702.700	2810.900	2267.183	182.778
Akwa Ibom	121	1995.100	3196.200	2624.045	246.190
Owerri	121	1607.500	2728.500	2173.422	173.812
Bayelsa	121	1951.800	3028.300	2584.067	209.945
Rivers	121	1975.100	3090.900	2513.736	213.134
Ekiti	121	1024.900	2151.400	1423.521	175.335
Osun	121	978.000	2173.100	1398.335	191.693
Ogun	121	783.500	2085.800	1287.296	219.712
Niger	121	100.008	1478.600	1186.347	164.571
Kaduna	121	840.000	1494.800	1159.421	136.384
Mean	121	1011.118	1980.503	1488.65	165.6812

4.1. Coefficient of variation (CV)

Temperature: The findings for the Coefficient of Variation (CV) on the average yearly temperature in Nigeria are displayed in Figure 2. With a CV of 2.22%, the results show that Kano had the highest degree of temperature fluctuation, suggesting notable annual variations. Significant variability was also observed in Gombe (2.17%) and Bauchi (2.02%), which reflected erratic northern temperature patterns. On the other hand, the regions with the least amount of temperature fluctuation were Akwa Ibom (1.06%), Cross River (1.07%), and Rivers (1.13%), suggesting extremely steady and predictable thermal conditions typical of a humid southern region (Figure 2). Largely, the results showed that there is a north-south gradient in the distribution of temperature variability throughout the region, with northern states experiencing more considerable fluctuations and southern coastal states maintaining steady temperature trends because of their maritime influence and thick vegetation cover.

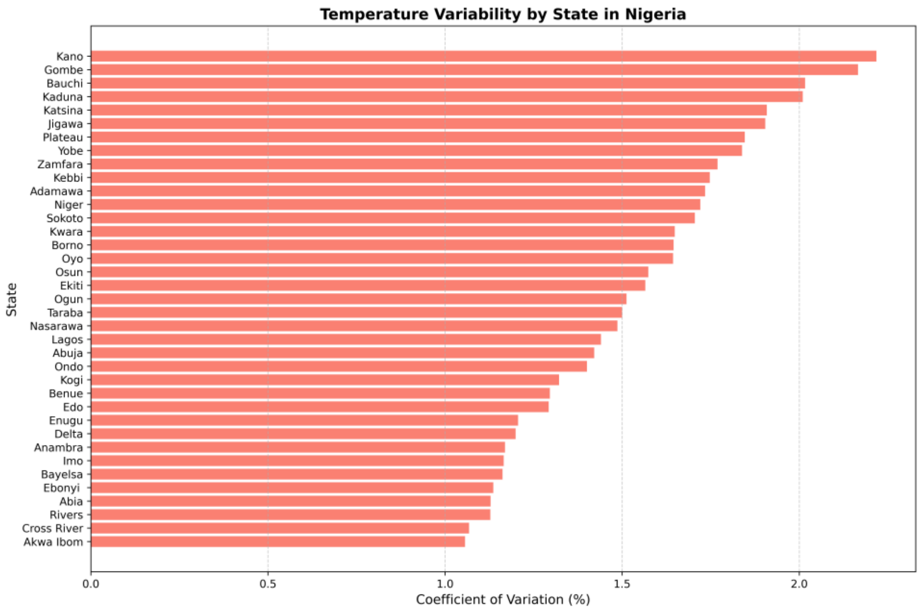

Figure 2 Temperature Variability (1901 – 2021).

Rainfall: The rainfall Coefficient of Variation (CV) for Nigeria is shown in Figure 3. The results show that the highest degree of rainfall variability occurred in Ogun (17.96%), indicating notable annual variations. Sokoto (17.71%), Lagos (17.45%), Yobe (17.38%), and Jigawa (17.03%) are other states that exhibit erratic rainfall patterns with comparable high variability. On the other hand, Abia (10.70%) had comparatively steady rainfall, but Bayelsa (8.86%) and Rivers (9.85%) had the least amount of variation (Figure 3), indicating the most reliable rainfall patterns across the nation.

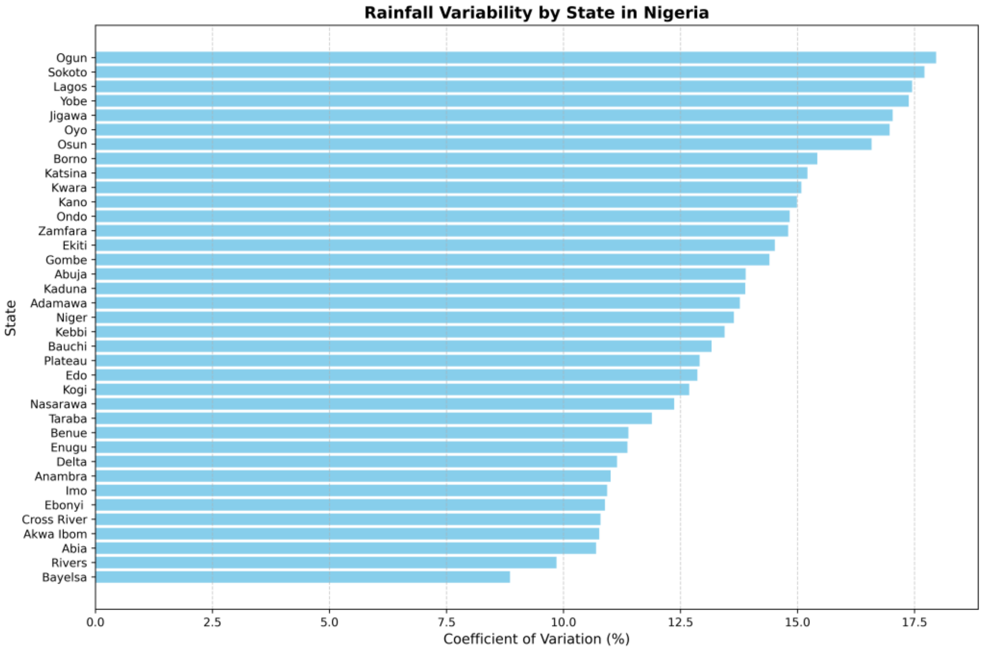

Figure 3 Rainfall Variability (1901 – 2021).

4.2. MK Test

Annual Temperature: The results of the Mann–Kendall (MK) test, which are displayed in Table 4, reveal that temperatures are rising steadily and statistically significantly across Nigeria, with upward trends observed at all stations. The greatest warming was observed in Rivers, Yenagoa, Akwa Ibom, Kebbi, and Cross River, indicating increased heat in both the north and the south. These temperature rises are consistent with forecasts of global warming that point to a rise in coastal heat stress and the advancement of northern desertification. While Kwara, Osun, and Ekiti showed the smallest but still significant warming trends, Kano, Kaduna, Benue, and Abuja (FCT) saw moderate temperature rises. At a significance level of 5% ($p < 0.05$), every station reported a statistically significant increase in temperature throughout Nigeria, confirming ongoing warming patterns. The p-values are incredibly low, generally below 0.001, indicating that these results are highly reliable and unlikely to be the product of chance variations. While the northern states are especially vulnerable to extreme temperature increases and desertification, the spatial distribution highlights that coastal areas are seeing rising temperatures.

Table 4 MK trend test for annual temperature.

Stations	Calculated z	P-value	Trend Direction	Significance
Sokoto	4.00350	0.0000312	Upward trend	Significant
Katsina	3.64005	0.0001363	Upward trend	Significant
Kano	3.74406	0.0000905	Upward trend	Significant
Kaduna	3.52717	0.0002100	Upward trend	Significant

Stations	Calculated z	P-value	Trend Direction	Significance
Borno	3.96157	0.0000372	Upward trend	Significant
Kebbi	4.64947	0.0000017	Upward trend	Significant
Jigawa	3.78668	0.0000763	Upward trend	Significant
Bauchi	3.95883	0.0000377	Upward trend	Significant
Taraba	3.71011	0.0001036	Upward trend	Significant
Gombe	3.68706	0.0001134	Upward trend	Significant
Niger	3.28017	0.0005187	Upward trend	Significant
Zamfara	3.43908	0.0002919	Upward trend	Significant
Yobe	3.48179	0.0002490	Upward trend	Significant
Adamawa	3.92938	0.0000426	Upward trend	Significant
Plateau	4.03992	0.0000267	Upward trend	Significant
Abuja	3.79809	0.0000729	Upward trend	Significant
Benue	3.71509	0.0001016	Upward trend	Significant
Nasarawa	3.98685	0.0000335	Upward trend	Significant
Oyo	3.35742	0.0003934	Upward trend	Significant
Kwara	3.19407	0.0007014	Upward trend	Significant
Kogi	3.40057	0.0003362	Upward trend	Significant
Enugu	4.11051	0.0000197	Upward trend	Significant
Lagos	3.68932	0.0001124	Upward trend	Significant
Ondo	3.29099	0.0004992	Upward trend	Significant
Edo	3.79147	0.0000749	Upward trend	Significant
Delta	4.09884	0.0000208	Upward trend	Significant
Cross River	4.53563	0.0000029	Upward trend	Significant
Anambra	4.03042	0.0000278	Upward trend	Significant
Ebonyi	4.10907	0.0000199	Upward trend	Significant
Abia	4.48244	0.0000037	Upward trend	Significant
Akwa Ibom	4.72365	0.0000012	Upward trend	Significant
Imo	4.38443	0.0000058	Upward trend	Significant
Rivers	4.87178	0.0000006	Upward trend	Significant
Yenagoa	4.84059	0.0000006	Upward trend	Significant
Ekiti	3.26658	0.0005443	Upward trend	Significant
Osun	3.22052	0.0006398	Upward trend	Significant
Ogun	3.36437	0.0003836	Upward trend	Significant

Annual Rainfall: The Mann-Kendall (MK) test results, which are shown in Table 5, show that annual rainfall has decreased statistically significantly throughout a sizable portion of Nigeria. The southern and central states, such as Cross River, Ebonyi, Akwa Ibom, Abia, and Enugu, saw the most noticeable declines, highlighting a persistent pattern of drying regions that had historically had high amounts of rainfall. Though they deviate from the findings of Akinsanola and Ogunjobi (2017), who observed localised increases at some Nigerian stations, the present results are in line with those of Adeyeri et al. (2017), Agbo and Ekpo (2021), Animashaun et al. (2020), Dan'azumi and Ibrahim (2021), and Ishaku et al. (2024). The study also shows that there was a noticeable decline in yearly rainfall across the country, as evidenced by statistically significant declining trends at a 5% significance level ($p < 0.05$) in 21 of 37 weather stations. Since the 16 remaining stations did not exhibit any discernible patterns, it is possible that natural variability rather than continuous climate change is to blame for changes in these regions. Additional evidence that the general decline is statistically significant and unlikely to be the consequence of random variability comes from the low p-values seen at the majority of the stations.

Although rainfall has historically been high in southern regions, the observed decreases raise concerns about possible food shortages, an increase in drought events, and more intense dry seasons. The central states, such as Plateau, Abuja (FCT), Adamawa, Taraba, and Benue, also experienced moderate but alarming declines; these areas are vital agricultural areas where future declines could endanger crop yields and water supplies. On the other hand, there were no notable long-term variations in the patterns of rainfall in Jigawa, Oyo, Borno, Ondo, Delta, Osun, and Ekiti, suggesting that rainfall in these areas was comparatively constant.

Table 5 MK trend test results for annual rainfall.

Stations	Calculated z	P-value	Trend Direction	Significance
Sokoto	−1.79331	0.962732	Downward trend	Significant
Kaduna	−2.03642	0.979146	Downward trend	Significant
Gombe	−1.81696	0.965388	Downward trend	Significant
Taraba	−3.08074	0.998968	Downward trend	Significant
Bauchi	−2.21566	0.986643	Downward trend	Significant
Kebbi	−1.71834	0.957133	Downward trend	Significant
Adamawa	−2.61220	0.995502	Downward trend	Significant
Yobe	−2.70180	0.996552	Downward trend	Significant
Plateau	−2.49121	0.993635	Downward trend	Significant
Abuja	−2.31423	0.989672	Downward trend	Significant
Benue	−3.17451	0.999250	Downward trend	Significant
Nasarawa	−2.48954	0.993605	Downward trend	Significant
Enugu	−3.66289	0.999875	Downward trend	Significant
Imo	−3.44558	0.99715	Downward trend	Significant
Cross River	−4.63964	1.00000	Downward trend	Significant
Abia	−4.07734	0.999977	Downward trend	Significant
Akwa Ibom	−4.18486	0.999986	Downward trend	Significant
Anambra	−1.84154	0.967228	Downward trend	Significant
Ebonyi	−4.24535	0.999989	Downward trend	Significant
Yenagoa	−2.72867	0.996821	Downward trend	Significant
Rivers	−3.57551	0.999825	Downward trend	Significant
Katsina	−1.56152	0.940800	Insufficient evidence	Not Significant
Kano	−1.40022	0.919276	Insufficient evidence	Not Significant
Borno	1.63319	0.0512148	Insufficient evidence	Not Significant
Jigawa	−0.938702	0.826058	Insufficient evidence	Not Significant
Niger	−1.32401	0.907250	Insufficient evidence	Not Significant
Zamfara	−0.436861	0.668894	Insufficient evidence	Not Significant
Oyo	0.497346	0.309473	Insufficient evidence	Not Significant
Kwara	−0.0112015	0.504469	Insufficient evidence	Not Significant
Kogi	−1.13609	0.972041	Insufficient evidence	Not Significant
Lagos	−0.226271	0.589504	Insufficient evidence	Not Significant
Ondo	1.04622	0.147731	Insufficient evidence	Not Significant
Edo	0.815466	0.207403	Insufficient evidence	Not Significant
Delta	0.853551	0.1966s77	Insufficient evidence	Not Significant
Ekiti	0.866993	0.192973	Insufficient evidence	Not Significant
Osun	0.598164	0.274865	Insufficient evidence	Not Significant
Ogun	0.0649686	0.474099	Insufficient evidence	Not Significant

Monthly Temperature: A statistically significant increase in the average monthly temperatures across Nigeria is indicated by the Mann–Kendall (MK) results, which are displayed in Table 6. The results indicate that every month showed positive z-values, supporting a consistent warming trend across the country, and the incredibly low p-values (mostly < 0.05 and < 0.001) indicate that these trends are not just the result of chance variations. March, April, June, and August were the warmest months, coinciding with the peak rainy season and the change from the dry to the wet season. Moderate but significant warming occurred in January, February, July, and October, which led to reduced seasonal cooling and a decline in harmattan. Despite having comparatively lower z-values, September, November, and December nevertheless showed encouraging patterns that suggested the cooler months were gradually declining.

While all months showed statistically significant warming at the 5% significance level ($p < 0.05$), some months, especially March, April, June, and August, showed very significant increases ($p < 0.001$). These findings are consistent with those of Babangida and Abubakar (2023), who reported comparable warming trends throughout Nigeria. This lends credence to climate change projections that state that heat stress will increase, agricultural vulnerability will increase, and water shortages will deteriorate.

Table 6 MK trend test results for monthly temperature.

Months	Calculated z	P-value	Trend Direction	Statistical Significance (α = 0.05)
January	2.65482	0.0039675	Upward trend	Significant
February	2.71319	0.0033319	Upward trend	Significant
March	4.01264	0.0000300	Upward trend	Highly Significant
April	3.62949	0.0001420	Upward trend	Highly Significant
May	2.41729	0.0078182	Upward trend	Significant
June	3.91185	0.0000458	Upward trend	Highly Significant
July	2.77397	0.0027689	Upward trend	Significant
August	3.62509	0.0001444	Upward trend	Highly Significant
September	1.67358	0.0471066	Upward trend	Significant
October	2.56098	0.0052189	Upward trend	Significant
November	1.96060	0.0249631	Upward trend	Significant
December	1.76143	0.0390828	Upward trend	Significant

Monthly Rainfall: The Mann-Kendall (MK) test results, which are displayed in Table 7, reveal that monthly rainfall has generally decreased in Nigeria, with several months showing significant drops and just one month showing a rise in rainfall. Significant decreases were seen in March, May, June, and November, indicating a contraction of the rainy season with a mid-season reduction (May–June), an early cessation (November), and a delayed onset (March). These patterns indicate increased drought risk and longer dry seasons in many regions. March, April, May, June, August, and November all exhibited statistically significant trends at the 5% significance level ($p < 0.05$), with November showing a noticeably larger decline in rainfall amount ($p < 0.01$).

On the other hand, August showed a notable increasing tendency, which was probably related to the August break effect, which is a brief interruption in rainfall during the wet season followed by a subsequent resumption. There were no notable changes in the other months, which were January, February, July, September, October, and December. A statistically consistent decrease in rainfall, particularly in the southern and central regions of Nigeria, is confirmed by the combined results of the MK and Theil-Sen's slope (TSE) results. These patterns are in accordance with the findings of Akinsanola and Ogunjobi (2017) and Animashaun et al. (2020), who connected these comparable decreases to elevated surface temperatures and less monsoon inflow, both of which enhance evapotranspiration. In the end, the results imply that Nigeria's rainfall patterns are becoming less consistent, with shorter wet seasons, more irregular rainfall, and a higher chance of drought and all of which are obvious signs of the continued effects of climate change.

Table 7 MK trend test results for monthly rainfall.

Months	Calculated z	P-value	Trend Direction	Statistical Significance (α = 0.05)
January	−1.29489	0.902321	Insufficient evidence	Not Significant
February	−1.58165	0.943135	Insufficient evidence	Not Significant
March	−1.93785	0.973679	Downward trend	Significant
April	−0.256737	0.994876	Downward trend	Significant
May	−2.42624	0.992372	Downward trend	Significant
June	−2.32318	0.989915	Downward trend	Significant
July	−1.10894	0.866273	Insufficient evidence	Not Significant
August	1.66454	0.048003	Upward trend	Significant
September	0.0560073	0.477668	Insufficient evidence	Not Significant
October	−0.123216	0.549032	Insufficient evidence	Not Significant
November	−2.63234	0.99576	Downward trend	Significant
December	−0.992449	0.839511	Insufficient evidence	Not Significant

4.3. TSE test

Temperature: Theil-Sen's slope (TSE) test results for mean yearly temperature fluctuation (°C year^{-1}) between 1901 and 2021 are shown in Figure 4. There were no indications of cooling (negative trends), and the results showed a statistically significant rising trend in temperatures ($p < 0.05$) in all the states in Nigeria. Even if the rate of warming varied by location, the fact that the confidence intervals for each state did not contain zero showed that the country's temperature was continuously rising. The study findings showed that Sokoto was the fastest warming region in the country, with the highest warming rate (around 0.006°C year^{-1}). The notable warming in other northern states, such as Jigawa, Katsina, Kano, and Kebbi, highlighted the sharp rise in temperature in the northwest.

The notable warming in other northern states, such as Jigawa, Katsina, Kano, and Kebbi, highlighted the sharp rise in temperature in the northwest. Significant rising trends were also observed in coastal states such as Rivers, Akwa Ibom, and Cross River, with an average annual temperature of 0.003°C, or almost half that of the northwest. This pattern draws attention to the two main warming regions in northern and coastal Nigeria.

The results of the study indicate that the statistically significant warming seen in every state supports a consistent and geographically consistent rise in temperature during the previous 121 years in Nigeria. These findings reinforce the evidence of long-term national warming connected to more general patterns of climate change, as demonstrated by the findings of Adeyeri et al. (2017) and Animashaun et al. (2020).

Rainfall: A broad long-term decline in yearly rainfall based on the Theil–Sen's slope (TSE) analysis of rainfall trends across Nigeria was illustrated in Figure 5. The majority of states have negative slope values, which suggests that rainfall generally decreased throughout the study period. The results indicate that significant negative slopes were also seen in Ebonyi, Cross River, Imo, and Rivers, indicating a considerable decrease in rainfall in the southern and central regions. The largest drops in rainfall were recorded in Akwa Ibom (-0.221) and Abia (-0.155). Abuja (-0.037) showed a somewhat lower rainfall amount, indicating a less severe but still negative trend. On the other hand, a few states displayed slight positive slopes, suggesting that rainfall had increased locally. Borno, located in northeastern Nigeria, recorded the highest positive slope (0.018), reflecting the most significant warming trend, while Edo, Ekiti, Ondo, Osun, Oyo, and Yobe displayed lower positive slopes, indicating relatively weaker temperature rises. In light of the overall national drying trend, these findings point to some limited regional wetting.

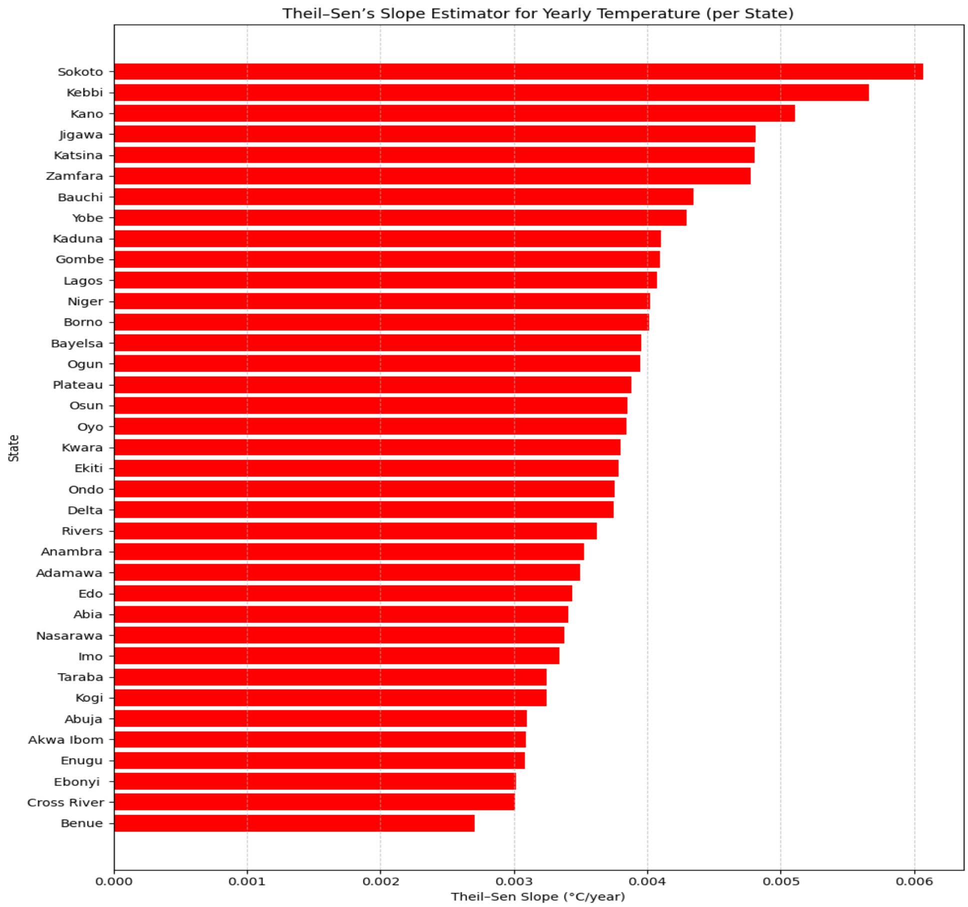

Figure 4 Temperature Sen's Slope (1901 – 2021).

The horizontal zero line in Figure 5 clearly distinguishes states with increasing and states with decreasing rainfall by separating positive (green) slopes from negative (red) slopes. While the red bars show decreasing rainfall, which is common in all the southern and central regions of Nigeria, the green bars show increasing trends, indicating an increase in rainfall over time.

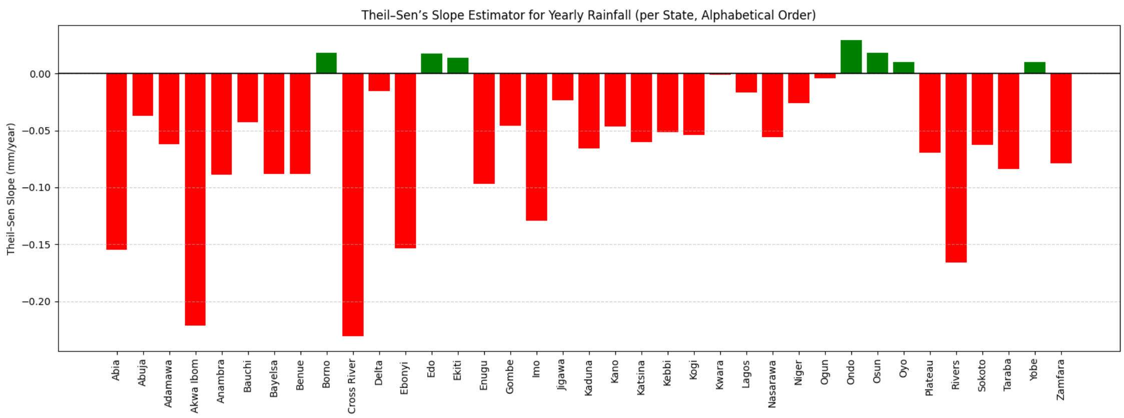

Figure 5 Rainfall Sen's Slope (1901 – 2021).

However, the TSE test results show that rainfall is declining in most Nigerian states, with just a small number showing modest rising trends. This spatial disparity, which is consistent with larger climate-induced drying trends seen throughout West Africa, highlights the widening regional variations in hydroclimatic conditions.

4.4. Homogeneity tests

Temperature: Four conventional homogeneity tests were used to assess the temporal consistency of temperature and rainfall time series data: the Von Neumann Ratio (VNR), the Pettitt Test, the Standard Normal Homogeneity Test (SNHT), and the Buishand Range Test (BRT). All four tests were evaluated at a 5% significance level ($\alpha = 0.05$). A non-homogeneous series is shown by a $p < 0.05$, which indicates the identification of a statistically significant change point, in accordance with accepted climatological norms.

Using a significance level of 5%, all four homogeneity tests showed statistically significant inconsistencies in the temperature data from most stations, particularly between 1981 and 1995 in northern Nigeria, and between 1997 and 2000 in the southern region. The significant results ($p < 0.05$) are highlighted in bold in Table 8, indicating confirmed change points and structural changes in the long-term temperature records.

The findings of this study collectively demonstrate that Nigerian temperature results are primarily non-homogeneous, suggesting continuous long-term warming shifts. The results of the BRT, VNR, SNHT, and Pettitt tests frequently show statistically significant changes, supporting the country's overall trend towards warming. Before the late 1990s, significant change points were noted in the northern states of Kano, Sokoto, Borno, and Katsina, which corresponded with the rise of heat waves and accelerating desertification. Between 1989 and 2002 (Figure 6), change points were noted in the central region of Nigeria, such as Taraba, Plateau, Benue, Abuja (FCT), Niger, and Nasarawa, indicating increased heat stress and unpredictable weather patterns in these regions. On the other hand, major change points occurred in the southern coastal states of Akwa Ibom, Lagos, Rivers, Delta, Bayelsa, and Cross River between 1997 and 2000 (Figure 6), indicating a rise in temperature linked to urbanisation, deforestation, and climate change.

The findings of this study demonstrate statistically significant inhomogeneities in temperature records across Nigeria, highlighting the broad and ongoing warming that is consistent with regional and global climate change indicators.

Table 8 Results from four different homogeneity tests for temperature in Nigeria.

Station	PET Statistic	Shift	Shift year	SNHT Statistic	Shift	Shift year	BRT Statistic	Shift	Shift year	VNR Statistic	Shift	Remark Nature
Sokoto	1841.000	Yes	1983	31.092	Yes	1995	25.588	Yes	1994	0.936	Yes	**CP**
Katsina	1839.000	Yes	1983	30.045	Yes	1995	25.180	Yes	1994	0.935	Yes	**CP**
Kano	1885.000	Yes	1981	30.175	Yes	1995	25.212	Yes	1994	0.912	Yes	**CP**
Borno	1891.000	Yes	1982	30.145	Yes	1995	25.007	Yes	1994	0.913	Yes	**CP**
Kebbi	1995.000	Yes	1981	35.168	Yes	1995	27.044	Yes	1994	0.802	Yes	**CP**
Jigawa	1908.000	Yes	1981	29.747	Yes	1995	25.017	Yes	1994	0.904	Yes	**CP**
Bauchi	1837.000	Yes	1983	27.111	Yes	1995	23.871	Yes	1994	0.911	Yes	**CP**
Taraba	1745.000	Yes	1989	23.504	Yes	2004	22.176	Yes	1994	0.991	Yes	**CP**
Gombe	1757.000	Yes	1983	24.611	Yes	1994	22.825	Yes	1989	0.954	Yes	**CP**
Zamfara	1712.000	Yes	1994	24.093	Yes	1995	22.539	Yes	1994	0.967	Yes	**CP**
Yobe	1762.000	Yes	1994	28.577	Yes	2001	23.918	Yes	1994	0.925	Yes	**CP**
Adamawa	1756.000	Yes	1989	24.256	Yes	1996	22.644	Yes	1989	1.010	Yes	**CP**
Kaduna	1783.000	Yes	1981	27.219	Yes	2001	23.226	Yes	1994	0.903	Yes	**CP**

Station	PET Statistic	Shift	Shift year	SNHT Statistic	Shift	Shift year	BRT Statistic	Shift	Shift year	VNR Statistic	Shift	Remark Nature
Niger	1725.000	Yes	1995	29.433	Yes	2001	23.279	Yes	1995	0.821	Yes	**CP**
Jos	1841.000	Yes	1982	26.766	Yes	1995	23.711	Yes	1994	0.909	Yes	**CP**
Abuja	1776.000	Yes	1994	27.663	Yes	2001	23.036	Yes	1995	0.883	Yes	**CP**
Benue	1780.000	Yes	1994	27.115	Yes	2002	23.091	Yes	1994	0.958	Yes	**CP**
Nasarawa	1827.000	Yes	1981	26.645	Yes	2001	23.802	Yes	1994	0.847	Yes	**CP**
Oyo	1914.000	Yes	1997	40.701	Yes	2000	27.892	Yes	1997	0.691	Yes	**CP**
Kwara	1745.000	Yes	1997	31.304	Yes	2000	24.362	Yes	1997	0.772	Yes	**CP**
Kogi	1847.000	Yes	1997	37.395	Yes	2000	26.304	Yes	1997	0.751	Yes	**CP**
Enugu	2013.000	Yes	1997	47.912	Yes	2001	30.237	Yes	1997	0.728	Yes	**CP**
Lagos	1996.000	Yes	1997	44.779	Yes	2000	29.353	Yes	1997	0.643	Yes	**CP**
Ondo	1889.000	Yes	1997	39.254	Yes	2000	27.377	Yes	1997	0.704	Yes	**CP**
Edo	2033.000	Yes	1997	48.735	Yes	2000	30.551	Yes	1997	0.666	Yes	**CP**
Delta	2121.000	Yes	1997	55.612	Yes	2000	32.811	Yes	1997	0.642	Yes	**CP**
Cross River	2104.000	Yes	1997	52.417	Yes	1997	31.889	Yes	1997	0.870	Yes	**CP**
Anambra	2034.000	Yes	1997	49.395	Yes	2000	30.859	Yes	1997	0.689	Yes	**CP**
Ebonyi	2011.000	Yes	1997	46.903	Yes	2001	30.131	Yes	1997	0.770	Yes	**CP**
Abia	2090.000	Yes	1997	51.554	Yes	1997	31.625	Yes	1997	0.747	Yes	**CP**
Akwa Ibom	2118.000	Yes	1997	54.612	Yes	1997	32.549	Yes	1997	0.840	Yes	**CP**
Imo	2029.000	Yes	1997	51.351	Yes	1997	31.563	Yes	1997	0.705	Yes	**CP**
Rivers	2138.000	Yes	1997	55.451	Yes	1997	32.799	Yes	1997	0.768	Yes	**CP**
Bayelsa	2156.000	Yes	1997	56.659	Yes	1997	33.154	Yes	1997	0.679	Yes	**CP**
Ekiti	1846.000	Yes	1997	36.973	Yes	2000	26.537	Yes	1997	0.716	Yes	**CP**
Osun	1883.000	Yes	1997	38.766	Yes	2000	27.157	Yes	1997	0.701	Yes	**CP**
Ogun	1907.000	Yes	1997	40.702	Yes	1999	27.928	Yes	1997	0.692	Yes	**CP**

HG – homogeneous, CP – inhomogeneous (change point), DF – doubtful.

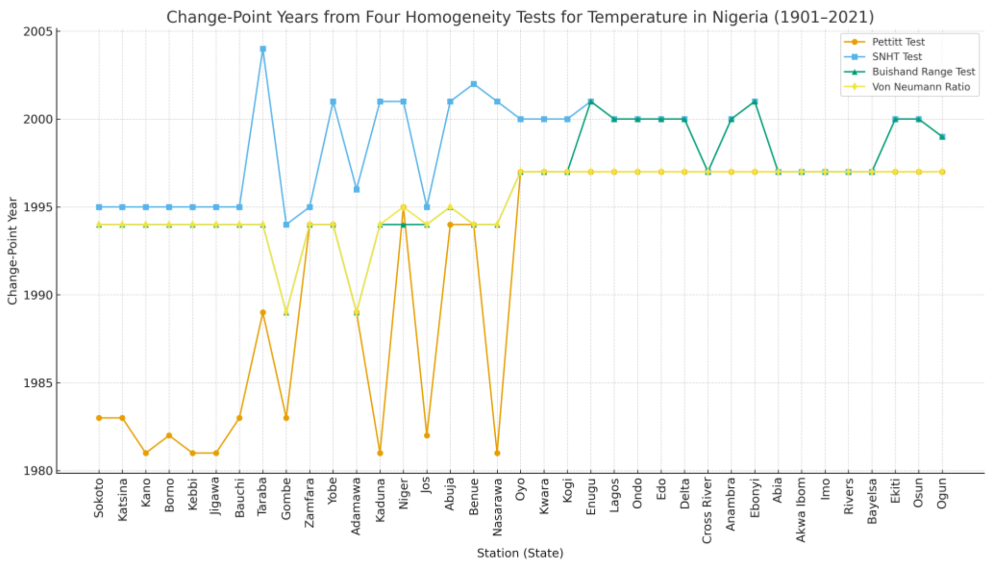

Figure 6 Change Point Years from Four Homogeneity Tests for temperature in Nigeria (1901 – 2021).

Rainfall: The summary of the results obtained from the Pettitt (PET), Standard Normal Homogeneity Test (SNHT), Buishand Range Test (BRT), and Von Neumann Ratio (VNR) on rainfall homogeneity in Nigeria is provided in Table 9. A 5% significance level (α = 0.05) was used for these results, meaning that $p < 0.05$ denotes inhomogeneity (a statistically significant change point was found) and $p \geq 0.05$ denotes homogeneity (no significant change was found).

At this level of confidence, the study results showed significant rainfall changes throughout Nigeria, suggesting a possible long-term drop in rainfall and climatic variability. The northern states, such as Katsina, Sokoto, Borno, Kano, and Kebbi, exhibited distinct shifts between 1966 and 1969, suggesting the onset of Sahelian desertification by showing early signs of declining rainfall and rising drought frequency. Additional change points were observed in Nasarawa, Abuja (FCT), Taraba, Plateau, Benue, and Niger between 1969 and 1981, indicating increased climate variability and potential delays in the commencement of the wet season in the central region.

Between 1969 and 1971, change points were identified in the southern coastal states of Lagos, Akwa Ibom, Cross River, Bayelsa, Edo, Rivers, and Delta. These were probably related to changes in coastal temperatures and deforestation. All things considered, these results confirm that rainfall fluctuation and decreases are common in many regions, with southern states showing later but more noticeable shifts than northern regions.

Across all the stations as indicated in Figure 7, the four homogeneity tests produced varying results at 5% significance level, as twenty stations (about 56%) were identified as inhomogeneous (CP), sixteen stations (roughly 44%) as homogeneous (HG), and one station (Anambra) as Doubtful (DF). The majority of change points are concentrated in the late 1960s to early 1970s, which corresponds with the Sahel drought phase and large hydroclimatic regime shifts throughout West Africa. The inhomogeneous stations are dispersed throughout northern, central, and southern Nigeria. Confidence in these results is reinforced by the stability of CP identifications across different tests, and HG stations show areas with statistically constant long-term rainfall from 1901 to 2021.

Table 9 Results of four different homogeneity tests for rainfall in Nigeria.

Station	PET			SNHT			BRT			VNR		Remark
	Statistics	Shift	Shift year	Statistics	Shift	Shift year	Statistics	Shift	Shift year	Statistics	Shift	Nature
Sokoto	1612.000	Yes	1966	16.572	Yes	1966	22.390	Yes	1996	1.380	Yes	**CP**
Katsina	1764.000	Yes	1967	20.126	Yes	1967	24.633	Yes	1967	1.273	Yes	**CP**
Kano	1432.000	Yes	1966	12.479	Yes	1967	19.406	Yes	1966	1.474	Yes	**CP**
Borno	866.000	No	1949	5.078	No	1915	10.224	No	1949	1.469	Yes	HG
Kebbi	1302.000	Yes	1969	10.159	Yes	1969	17.428	Yes	1969	1.680	Yes	**CP**
Jigawa	1312.000	Yes	1967	10.688	Yes	1967	17.934	Yes	1967	1.462	Yes	**CP**
Bauchi	1433.000	Yes	1969	15.073	Yes	1969	21.229	Yes	1969	1.886	No	**CP**
Taraba	1434.000	Yes	1969	14.531	Yes	1981	19.808	Yes	1981	2.039	No	**CP**
Gombe	1303.000	Yes	1989	10.836	Yes	1969	18.000	Yes	1969	1.919	No	**CP**
Zamfara	1550.000	Yes	1966	9.409	No	1969	16.773	Yes	1969	1.935	No	HG
Yobe	1023.000	No	1968	7.759	No	1915	10.718	No	1968	1.799	No	HG
Adamawa	1266.000	Yes	1981	12.825	Yes	1981	18.608	Yes	1981	1.756	No	**CP**
Kaduna	1218.00	Yes	1966	10.526	Yes	1966	17.844	Yes	1966	1.870	No	**CP**
Niger	626.000	No	1969	4.929	No	1915	8.082	No	1915	2.068	No	HG
Jos	1439.000	Yes	1969	14.516	Yes	1969	20.834	Yes	1969	2.070	Yes	**CP**
Abuja	1046.000	No	1969	6.254	No	1901	13.384	No	1969	2.097	No	HG
Benue	1403.000	Yes	1969	13.464	Yes	1969	20.064	Yes	1969	1.904	No	**CP**
Nasarawa	1080.000	No	1972	7.576	No	1972	14.925	Yes	1972	2.076	No	HG
Oyo	380.000	No	1986	13.090	Yes	1901	4.780	No	1950	2.078	No	HG
Kwara	418.000	No	1935	13.945	Yes	1901	6.430	No	1969	1.787	No	HG
Kogi	604.000	No	1934	7.273	No	1901	7.464	No	1934	1.912	No	HG
Enugu	1592.000	Yes	1969	16.119	Yes	1969	21.953	Yes	1969	1.515	Yes	**CP**
Lagos	509.000	No	1970	7.274	No	1901	8.697	No	1970	1.950	No	HG
Ondo	662.000	No	1948	19.241	Yes	1901	7.251	No	1950	1.897	No	HG
Edo	612.000	No	1946	16.911	Yes	1901	8.055	No	1946	1.915	No	HG
Delta	578.000	No	1946	10.461	Yes	1901	7.969	No	1946	2.011	No	HG
Cross River	2108.000	Yes	1969	29.137	Yes	1969	29.516	Yes	1969	1.485	Yes	**CP**
Anambra	822.000	No	1971	12.479	Yes	1906	11.684	No	1969	1.742	Yes	DF
Ebonyi	1772.000	Yes	1969	20.171	Yes	1969	24.558	Yes	1969	1.582	Yes	**CP**
Abia	1725.000	Yes	1969	20.227	Yes	1969	24.592	Yes	1969	1.549	Yes	**CP**

Station	PET			SNHT			BRT			VNR		Remark
	Statistics	Shift	Shift year	Statistics	Shift	Shift year	Statistics	Shift	Shift year	Statistics	Shift	Nature
Akwa Ibom	2192.000	Yes	1971	32.358	Yes	1971	30.940	Yes	1971	1.331	Yes	**CP**
Imo	1470.000	Yes	1970	16.031	Yes	1906	20.148	Yes	1969	1.584	Yes	**CP**
Rivers	18.15.000	Yes	1969	23.650	Yes	1969	26.592	Yes	1969	1.445	Yes	**CP**
Bayelsa	1196.000	Yes	1969	10.405	Yes	1906	15.821	Yes	1969	1.779	No	**CP**
Ekiti	636.000	No	1950	17.377	Yes	1901	6.512	No	1950	1.903	No	HG
Osun	472.000	No	1950	16.471	Yes	1901	5.547	No	1950	2.031	No	HG
Ogun	403.000	No	1935	7.973	No	1901	6.042	N0	1935	1.885	No	HG

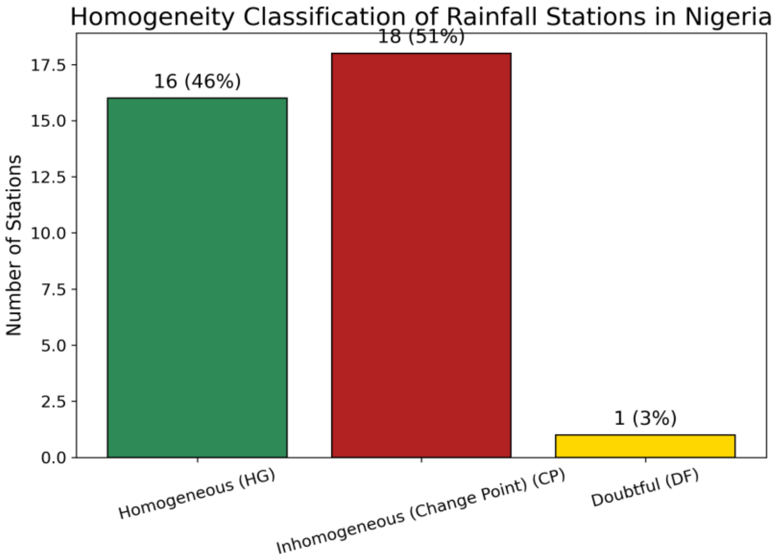

Figure 7 Homogeneity Classification of Rainfall Stations in Nigeria.

5. Conclusion

This study examines the trend analysis and homogeneity tests in temperature and rainfall in Nigeria from 1901 to 2021. The data were summarised using descriptive and inferential statistics such as maximum, minimum, mean, standard deviation, the Coefficient of Variation (CV), the Mann–Kendall (MK) trend test, Theil–Sen's slope estimator (TSE), and four homogeneity assessments (Pettitt, SNHT, Buishand Range, and Von Neumann Ratio test).

The findings indicated a statistically significant and persistent increase in temperature in all regions, confirming that the country is experiencing a warming trend. The highest average annual temperatures were recorded in Kebbi (29°C), Sokoto, Borno, and Adamawa, reflecting the hot, semi-arid conditions found in northern Nigeria, whereas Plateau (23.3°C) remained the coolest location due to its elevated terrain. Southern states such as Cross River, Akwa Ibom, Rivers, Imo, and Abia displayed the least variability (SD = 0.26–0.30; CV ≈ 1%), showcasing stable thermal patterns in coastal and rainforest regions.

The MK and TSE assessments verified significant warming trends ($p < 0.05$) across all states, with the most pronounced temperature increases observed in Rivers, Yenagoa, Akwa Ibom, Cross River, and Kebbi, and moderate warming observed in Benue, Kaduna, and Abuja (FCT). While Sokoto experienced the most rapid warming rate (~0.006°C/year), temperatures in southern states increased at roughly half that rate (~0.003°C/year).

Rainfall trends showed a mixed pattern but were largely decreasing, especially in southern and eastern states, particularly in Cross River, Akwa Ibom, Abia, Ebonyi, and Enugu, where significant reductions in annual totals were observed. Central states such as Plateau, Benue, Nasarawa, Taraba, and Abuja faced moderate declines, while northern states exhibited lower or inconsistent changes. Monthly evaluations highlighted significant reductions in March, May, June, and November, indicating increased irregularity in rainfall patterns.

Homogeneity tests identified temperature change points between 1981–1995 in northern Nigeria, 1997–2000 for the southern region, and 1966–1971 for rainfall trends, signifying important structural shifts in the long-term climate records of Nigeria. Collectively, these results substantiate ongoing national warming, regionally diverse reductions in rainfall, and distinct temporal shifts in the country's climate behaviour over the past 121 years.

Recommendations

The study found significant patterns in increasing temperatures and decreasing rainfall across Nigeria, with change points indicating long-term climate shifts. These findings demonstrate the pressing need for data-driven climate policies and flexible approaches to improve resilience nationwide.

1. It is recommended that the Nigerian Meteorological Agency (NiMet) should improve and broaden Nigeria's meteorological Stations network in collaboration with educational institutions and research groups, especially in areas with limited monitoring. The accuracy of trend detection and early warning systems will be improved by routinely calibrating and digitising historical data.

2. The National Climate Change Policy (NCCP), National Adaptation Plan (NAP), and Vision 2050 are important national plans that should use information regarding climatic trends to guide the advancement of energy, development of infrastructure, and agriculture.

3. Climate disparities between the north and south of Nigeria need to be considered in mitigation strategies. The northern regions need to prioritise tree planting, soil moisture conservation, and heat-resistant agriculture. While holistic administration of water resources and optimising agricultural production using rainwater ought to represent the central region's top priorities, the southern regions require improved flood control, coastal defences, and erosion control.

4. Promote the extension of irrigation systems, flexible planting schedules, and the use of crop cultivars tolerant to heat and drought. To offset decreased rainfall, water agencies should improve watershed conservation, groundwater replenishment, and reservoir management.

5. To support adaptive decision-making, incorporate climate knowledge into school curricula and strengthen community capacity and local governance through seminars, training sessions, and extension services.

6. Use seasonal forecasts, GIS-based risk assessments, and real-time monitoring to improve early warning systems (EWS) for droughts, heat waves, and floods.

7. To provide unified and efficient climate governance, the Federal Government of Nigeria should harmonise the efforts of key institutions in Nigeria, such as the NiMet, the National Water Resources Institute (NWRI), the Federal Ministry of Environment, and the National Emergency Management Agency (NEMA).

Policy Implications

Growing variability in the climate in Nigeria is suggested by persistent increases in temperatures and declining variations in rainfall. The northern and coastal areas are projected to warm most rapidly, while the southern and central regions are expected to experience considerable fluctuations in rainfall. Seasonal patterns have changed, as evidenced by shifts in rainy seasons and a decrease in harmattan severity. There is a need for adaptable, region-specific climate solutions since a decrease in rainfall during the critical wet months (March, May, June, and November) could cause planting to be delayed and raise the risk of crop failure.

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