Spatiotemporal Variations of Rainfall Over Nigeria from 1971 to 2020

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ABSTRACT

The impact of climate change on annual rainfall has received significant attention from scholars worldwide. Many studies have been conducted to demonstrate that changes in annual rainfall are becoming evident globally. This study focused on detecting trends in annual rainfall in six stations in Nigeria: Calabar, Lagos, Enugu, Abuja, Kano, and Maiduguri. Three different widely used nonparametric methods of Mann-Kendall, Innovative Trend Analysis, Sen's Slope Estimation, and a Linear Trend Analysis method were used on time series data for each of the stations for 50 years (1971 to 2020) to detect trends and estimate the magnitudes in annual rainfall at a 5% significance level. Water availability is essential for agriculture, industry, irrigation, power generation, and other human activities. Therefore, the amount of rainfall received in an area is crucial in assessing water availability. This study analysed trend values of annual rainfall and found that the Innovative Trend Analysis (ITA) is more effective in detecting trends than the Mann-Kendall (MK) method. The results obtained from ITA, Sen's Slope Estimation (SSE), and Linear Trend Analysis (LTA) showed good agreement. The Sen's slope estimator determined the magnitudes of the trends. All stations except Abuja showed statistically significant increasing trends. The linear trend plot also indicated a decreasing trend for Abuja, while the other five stations had an increasing trend that ranged from 0.44 to 1.02 mm/year. This agrees well with global climate model estimates which predict that increasing trends will continue throughout the 21st century in most West African countries.

Keywords: Rainfall trend, Mann-Kendall, Innovative Trend Analysis, Sen's Slope Estimation, Linear Trend Analysis, Climate Change.

INTRODUCTION

In recent years, the issue of climate change caused by global warming has become a significant concern. Various studies have revealed that changes in rainfall patterns are occurring both on a global scale (Hulme et al., 1998; Lambert et al., 2003; Dore, 2005) and a regional scale (Rodriguez-Puebla et al., 1998; Gemmer et al., 2004; Kayano and Sansigolo, 2008) due to global warming. It is expected that future climate change may cause changes in climate variability and modifications in averages (Mearns et al., 1996).

The climate of Nigeria is characterised by its uneven distribution of rainfall, which varies both temporally and spatially. Climate experts predict that Nigeria's rainfall patterns will change significantly as our planet continues to warm, leading to extreme weather events such as floods and prolonged droughts in some areas of the country. West Africa, including Nigeria, is particularly vulnerable to the effects of climate change, according to the IPCC's 2007 report. Therefore, it is critical to examine the spatial and temporal variations of rainfall trends to aid in disaster mitigation, agricultural production, water resource management and socioeconomic planning in the face of imminent global climate change. This study focuses on detecting rainfall trends at six stations in Nigeria from 1971 to 2020.

In many parts of Africa, the most urgent threat posed by climate change is widely recognised to be the increasing risk of floods and droughts. This has led to public discussions about the seemingly more frequent occurrence of extreme weather events, especially intensified rainfall (Sufiyan et al., 2018). Eludoyin and Adelekan, (2013) looked at monthly rainfall distribution in Nigeria from 1985 to 1994 and 1995 to 2004 and found some variations in most months. Akinsanola and Ogunjobi, (2014) investigated seasonal rainfall variability in the Guinea savannah region of Nigeria, concluding that rainfall variability is increasing due to climate change. The rise in global temperature over the last decade has impacted the world, increasing precipitation in various parts of the globe. Flooding, drought, and temperature trends are all influenced by the distribution of rainfall across regions (Sufiyan, 2020).

Various studies have explored the seasonal and temporal variations of rainfall in Nigeria. However, none has investigated the spatial and temporal distribution of rainfall trends in stations in the southern and northern regions of the country for upward of 50 years. This paper addresses this gap by analysing the spatial and temporal patterns of rainfall trends in six stations, three each from the south and the north of the country, spanning from 1971 to 2020. To detect trends in rainfall at the six stations, three nonparametric methods were employed, namely Mann-Kendall (MK), Innovative Trend Analysis (ITA), and Sen's Slope Estimator (SSE). The study analysed trends in mean annual rainfall in Nigeria over 50 years. The Mann-Kendall and ITA tests were used to analyse the rainfall data of the six selected stations to identify trends, while Sen's slope estimation method was used to determine the magnitude of change. The study's findings were confirmed using Linear Trend Analysis (LTA). The study examined how rainfall trends vary over time and space. The study also used the Sofa statistical package to create spatial maps to visualise the variations.

Climate of Nigeria and Study Area

Nigeria is located in West Africa and covers an area of about 923,768 sq. km. Its climate ranges from sub-tropical to semi-arid. Geographically, it is situated between 4°N to 14°N latitude and 2°E to 14°E longitude. Nigeria experiences a tropical climate marked by mainly wet and dry seasons. The dry season occurs from November to February in the south and from October to April in the north. The rainy season lasts from February to November in the South and May to September in the North. The average temperature in the country ranges from 28°C to 35°C in the south and as high as 45°C in the North. The minimum temperature drops as low as 8ºC in the north and ranges between 17–24ºC in the south during the dry harmattan season (December–February). The wet season starts around late May and ceases in September in the North with a single maximum. In the southern region, the rainy season begins in February and ends in November. It shows two peak periods. A marked interruption in the rains occurs during July/August in the south, resulting in a “little dry season” often locally called the “August break”. The mean annual temperature ranges between 29ºC to 32ºC and the mean annual rainfall is between 1500mm to 2000mm in the South. The middle belt occupies the central part of Nigeria with annual rainfall ranging from 2000mm to 1700mm and maximum temperature of 35-38ºC and minimum of 19-20ºC. In northern Nigeria, the annual average temperature ranges from 36-42°C, and the rainfall varies between 500mm to 1500mm (Eludoyin & Adelekan, 2013). Rainfall primarily occurs during the summer months due to the south-westerly moist wind from the Atlantic Ocean that sweeps across the country. The geographical location, size, and shape of Nigeria contribute to the variety of weather patterns in different ecological zones. This is representative of the most weather patterns prevalent in other West Africa countries (Oguntoyinbo and Odingo, 1979). Nigeria has four distinct climatic zones, namely tropical savanna climate, monsoon climate, warm semi-arid climate, and warm desert climate, according to the Koppen classification shown in Figure 1. The elevation of Nigeria ranges from 0 meters near the coast of the Atlantic Ocean in the south to 2419 meters in Chappal Waddi in the northeastern part of Nigeria (Shiru et al., 2018). The study area covered the 6 geopolitical zones representing different ecological zones of Nigeria as shown in Figure 2. One station each was selected as a sample to be surveyed. The selected stations and their coordinates are shown in Table 1. The stations are Maiduguri (representing North-East), Kano (representing North-West), Abuja (representing North Central), Enugu (representing South-East), Lagos (representing South-West), and Calabar (representing South-South).

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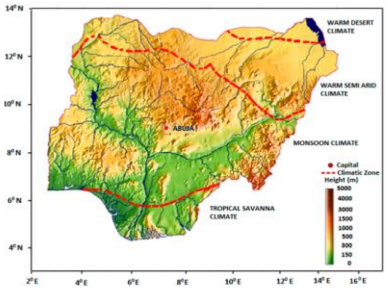

Figure 1: The topography and the climatic zones of Nigeria.

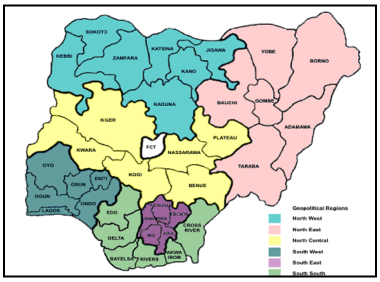

Figure 2: Nigeria map Showing 36 States/FCT and 6 Geo-political zones

Table 1: Coordinates and 50-Year Averages of Meteo. Stations of the Study Area

Station/ Name	Lat. (Deg)	Long. (Deg)	Altitude (m)	Rainfall (mm)	Tmax °C	Tmin °C	Tmean °C	Period (1971-2020)
Calabar	4.58	8.21	64	2952.728	30.8	23.1	27.0	50 years
Lagos	6.57	3.32	41	1459.229	31.3	23.1	27.2	50 years
Enugu	6.47	7.57	142	1785.256	32.3	21.9	27.1	50 years
Abuja	9.00	7.25	342	1394.997	33.0	21.6	27.3	50 years
Kano	12.03	8.51	476	957.780	33.6	20.0	26.8	50 years
Maiduguri	11.85	13.06	335	632.180	35.4	20.4	27.9	50 years

Source: Nigerian Meteorological Agency (NiMet), Abuja (2020)

RESEARCH METHOD

The nonparametric Mann-Kendall (MK) method (Yue & Wang, 2004), Innovative Trend Analysis (ITA) (Brunetti, M, 2001) and Sen's Slope Estimator (SSE) (Agarwal et al. 2021) were used to examine rainfall trends in this study. These methods are recommended by the World Meteorological Organisation (WMO) and they are commonly used for time series analyses of meteorological and hydrological data, such as precipitation, humidity and temperature data, water quality, stream flow etc. They are considered appropriate for climate change analysis and climate projections.

Data Collection and Analysis

The monthly rainfall data was collected from the data bank of the Nigerian Meteorological Agency as secondary data for 50 years (1971 – 2020). The monthly rainfall dataset for the 6 geopolitical zones was statistically analysed. The data were subjected to virtual quality assurance analyses. NiMet had carried out data quality assurance and control QA/QC. The randomness and homogeneity of the climate data were assessed using a simple autocorrelation test. The Sen's Slope Estimator (SSE) test was applied to estimate the magnitude of the slope in rainfall and temperature at all six stations. Mann-Kendall (MK) and Innovative Trend Analysis (ITA) were applied to detect the trends and confirm the significance of the changes. Finally, the results obtained using the MK and ITA methods were compared. The methodology of this study comprises four major steps:

i. Detecting the serial correlation effect
ii. Applying the Mann-Kendall (MK), Innovative Trend Analysis (ITA) and Sen's Slope Estimate (SSE), tests to detect trends

iii. Comparing the results of the three different nonparametric test methods to identify the most efficient method for detecting trends
iv. using Sen's Slope Estimate (SSE) to compute the magnitude of the slope (change per unit time) of the trends for future projections.

Estimation of Magnitude of Change

The Sen's Slope Estimator (SSE) method (Sen, 1968) was used for the magnitude estimation of annual rainfall trends from 1971–2020. The Sen's slope (β) is calculated as the median of all the slopes estimated between all the successive data points of rainfall time series (y) as:

$$\beta = median\ \frac{\Delta y}{\Delta t} \qquad \text{.............................. (1)}$$

Where Δy is the change in rainfall due to the change in the time, Δt is the time between two subsequent rainfall data. Sen's slope is a nonparametric test that is highly reliable for estimating change over time (Faiz et al., 2018). SSE (β) was calculated to obtain the trend and slope magnitude with the help of a nonparametric model. When β is positive, it implies an increasing trend, while the negative value of β implies a decreasing or downward trend in time series analysis. Similarly, a zero value represents no trend in the data. The unit of resultant β would be the magnitude of slope in original units per year or per cent per year (Salmi et al., 2002). Sen's slope test was developed to check for statistical linear relationships in long-term temporal data (Agarwal et al., 2021). It is a useful tool for calculating the magnitude of trends and is particularly effective in detecting linear relationships unaffected by outliers in the data (Ray et al., 2021).

Mann–Kendall Trend Test

There are numerous trend assessment tests available in the literature. However, the Mann–Kendall test is the most extensively used nonparametric test for assessing the trends in hydro-meteorological studies (Abghari et al., 2013; Hannaford and Buys, 2012; Piniewski et al., 2018; Ahmed et al., 2019; Hamed & Rao, 1998). The Mann-Kendall (MK) trend test was used to analyse data collected for consistently increasing or decreasing trends (monotonic) independent variables. It works for all types of distributions. The data doesn't have to meet the conditions of normality. However, the data should have no serial correlation. A simpler regression analysis should be used for a normal distribution (Ahmed, K 2017). The Mann-Kendall test is recommended and is often used because it is not particular about the data distribution, and it can cope very well with outliers (Mohamed and Shamsuddin, 2018; Sonali and Kumar, 2013). Other advantages of the non-parametric method include its ability to handle missing data, work with few assumptions, and be independent of data distribution (Dabanlı, ˙I, 2017). However, one major drawback is the potential influence of autocorrelation on test significance. While modifications have been proposed to address this through pre-whitening of data (Malik, A. et al., 2019; Su, B.et al.; 2006), recent studies have also suggested that they may not be sufficient to exclude the effect of long-term dependency on the data series (Zhang, Q. et al., 2008). Additionally, localised climate changes caused by changes in land use or earth-atmospheric phenomena may not always result in a unidirectional or monotonic trend (Noor, M.2007; Sen, P.K, 1968). Mann–Kendall test statistics (S) for rainfall was calculated using Equation (4). In Equation (2), n represents the sample size, whereas x_i and x_k are sequential data in series.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(x_i - x_k) \qquad (2)$$

where x_i *and* x_k *are sequential data in the series and*

$$\text{sign}\,(x_i - x_k) = \begin{cases} +1 & when \quad (x_i - x_k) > 0 \\ 0 & when \quad (x_i - x_k) = 0 \\ -1 & when \quad (x_i - x_k) < 0 \end{cases} \qquad (3)$$

The variance of S is estimated as,

$$\mathrm{Var(S)} = \frac{s(n-1)(2n+5)-\sum_{p-1}^{q} t_p(t_p-1)(2t_p+5)}{18} \quad (4)$$

Whereas t_p defines the ties of the p^{th} value, and q represents the number of the tied values. The standardised test static for the Mann–Kendall test (Z) can be calculated, as shown in Equation (5):

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & when \quad S > 0 \\ 0 & when \quad S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & when \quad S < 0 \end{cases} \quad (5)$$

The sign of Z indicates the direction of the trend. The negative value of Z indicates a decreasing trend and vice versa. At the 5% significance level, the null hypothesis of no trend is rejected if the absolute value of Z is higher than 1.64. The significance of the change in annual rainfall was estimated using the MK test. The MK method did not accurately estimate the magnitude of the trend, so Sen’s method was used for a more precise estimation. Sen's method assumes a linear trend in the time series and is commonly used to determine the magnitude of trends in hydro-meteorological time series.

Innovative Trend Analysis (ITA) Method

The concept of ITA was initially proposed by Sen (Brunetti, M, 2001) for detecting trends in time series. In this method, the data set is divided equally into two segments from the first to the last. Both segments are arranged in ascending order and presented in the X and Y axes. The first segment (Xi: i = 1, 2, 3, … n/2) is presented on the horizontal axis while the second segment (Xj: j = n/2 + 1, n/2 + 2, ….. n) is presented on the vertical axis in the Cartesian coordinate system. A bisector line at 1:1 (45^o) divides the diagram into two equal triangles. The upper triangle represents an increasing trend, while the lower one indicates a decreasing trend. For the estimation of the trend, the S_{ITA} statistic is computed as follows (Khan et al, 2018)

$$S_{ITA} = \frac{2(X_i - X_j)}{n} \quad (6)$$

where S_{ITA} is the slope based on the ITA method, n is the sample size, and X_i and X_j are the mean values of the first and second half of the series, respectively.

Autocorrelation

Autocorrelation is one method of measuring randomness. Autocorrelation plots were used to test for randomness in the datasets. These plots measured the autocorrelations of data values at different time lags to see if they displayed randomness. If a dataset is random, the autocorrelations should be close to zero for all time-lag differences. However, if a dataset is not random, one or more autocorrelations will be significantly non-zero. Autocorrelation plots also helped in identifying autoregressive and moving average time series models. It is however important to note that uncorrelated data does not always indicate randomness. Data exhibiting significant autocorrelation is not random. However, even data without significant autocorrelation could also display non-randomness in other ways. If the residuals from poorly fitting models show noticeable non-random patterns, autocorrelation can detect this. However, some applications need a more thorough test for randomness. In these cases, various tests, including autocorrelation checks, are used because data can deviate from randomness in subtle ways. If the autocorrelations are not close to zero, it indicates a failure of the randomness assumption.

RESULTS

In Figure 3, the results of autocorrelation analysis were used to assess the randomness of the annual rainfall dataset from six stations (Calabar, Lagos, Enugu, Abuja, Kano, and Maiduguri) between 1971 and 2020, with a significance level of 5%. The analysis revealed that subsequent correlations quickly approached zero after the lag-0 correlation and remained mostly within the significance level boundaries, depicted by the dashed blue lines in the diagrams. These results confirmed that the model residuals met the assumption of no autocorrelation, indicating randomness. All stations in Figure 3 displayed no autocorrelation.

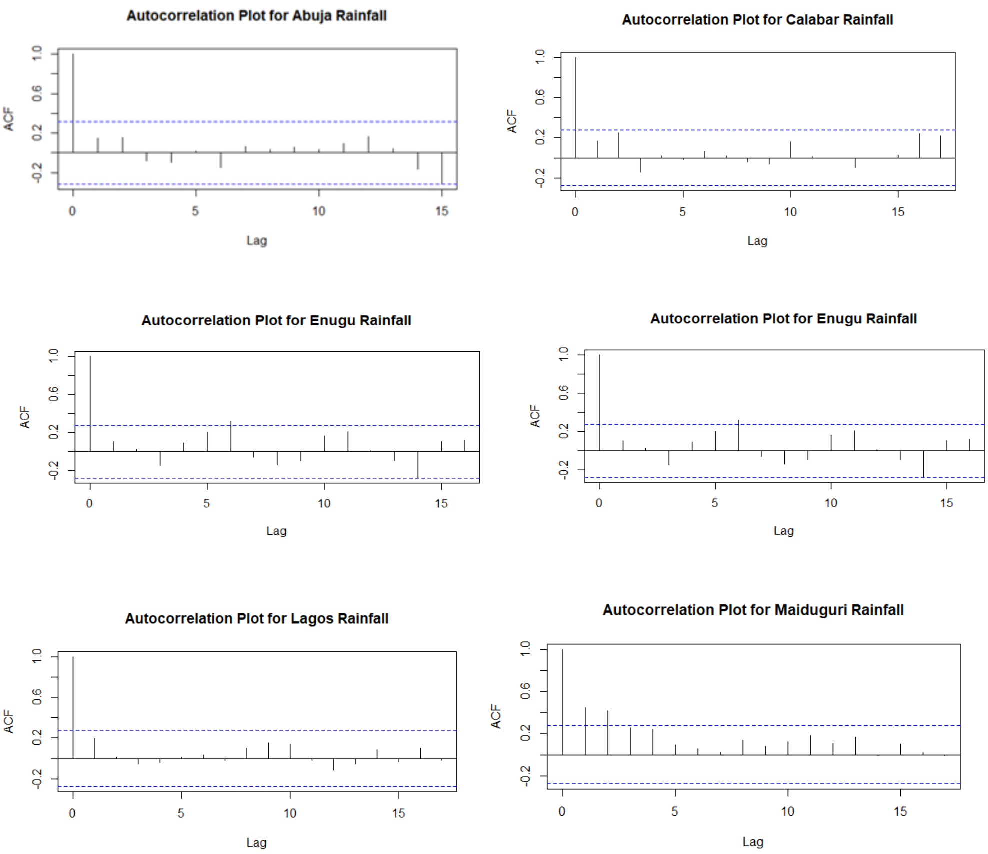

Figure 3.: Autocorrelation Plot for Rainfall in the Six Stations

Mann Kendall Analysis of Rainfall

Table 2 displays the results of the Mann-Kendall test conducted on rainfall data from six stations (Enugu, Abuja, Lagos, Kano, Maiduguri, and Calabar) over 50 years (1971-2020) at significance levels of 5%, 1%, and 10%. When the p-value is lower than the specified significance level (α alpha), the null hypothesis (Ho) was rejected. Rejecting Ho indicated the presence of a trend in the time series, while accepting Ho suggests that no trend was detected. At the 1% significant level, four stations (Calabar, Lagos, Enugu, and Abuja) representing 67% of the stations sampled accepted the null hypothesis, indicating that no trend was detected, while Kano and Maiduguri representing 33% rejected the null hypothesis, indicating increasing trends for the two stations. At the 5% significant level, Calabar, Enugu, Kano, and Maiduguri representing 67% rejected the null hypothesis, indicating trends were detected, while Lagos and Abuja representing 33% accepted the null hypothesis, indicating no trend was found in any of them. As expected, more stations (5 stations) at the 10% significant level, rejected the null hypothesis, indicating trends were detected in them, except Abuja, which indicated no trend. This represents 83% and 17% respectively. In summary, the two northernmost cities of Kano and Maiduguri showed increasing trends at all three significant levels, while Abuja indicated no trend at any significant level. The highest MK statistics (S) of 469 was recorded at Kano, with a tau of 0.368, indicating that the average rainfall was increasing at 0.368mm per year. The lowest S of -68 was recorded at Abuja, with a tau of -0.102 indicating a decrease of 0.102 mm per year. The high MK statistics (S) of 469 and

465 in Kano and Maiduguri, respectively, indicate stronger trends when compared to the lower S values of 233 and 273 in Lagos and Calabar, which suggest weaker trends.

It is worth noting that Abuja showed no trend at all three significant levels. The Mann-Kendall test (MK) gives an interesting insight into the annual average rainfall data for the six stations. Since the MK test is a nonparametric test with a better ability to detect trends in non-normal distribution data sets, the test results support increasing and decreasing trends observed from the linear time series plots.

Table 2: Results of the Statistical Mann-Kendall Test for Rainfall Data for the Six Stations from 1971 - 2020 at 5%, 1% and 10% Significant Levels.

Table 4.1. Results for Mann Kendall's Test for Trend in Rainfall											
Stations	M-K Statistic (S)	Kendall's Tau	Var (S)	P value (2-tailed)	α 5%	Interpretation At 5%	α 1%	Interpretation At 1%	α 10%	Interpretation At 10%	Sen's slope At 5%
Calabar	273	0.214	15158.33	0.027	0.05	Reject null	0.01	Accept null	0.1	Reject null	0.729
Lagos	233	0.183	15158.33	0.06	0.05	Accept null	0.01	Accept null	0.1	Reject null	0.410
Enugu	275	0.224	14291.67	0.022	0.05	Reject null	0.01	Accept null	0.1	Reject null	0.433
Abuja	-68	-0.102	5846	0.381	0.05	Accept null	0.01	Accept null	0.1	Accept null	-0.350
Kano	469	0.368	15158.33	0	0.05	Reject null	0.01	Reject null	0.1	Reject null	0.929
Maiduguri	465	0.365	15158.33	0	0.05	Reject null	0.01	Reject null	0.1	Reject null	0.595

Sen's Slope Estimation (β)

The slope values for Sen in Table 2 aligns well with the MK results at a 5% significance level. Abuja exhibits a negative value, signifying a decreasing trend, which supports the acceptance of the null hypothesis by the MK test. Kano and Calabar have the highest magnitudes at 0.929 mm/year and 0.729 mm/year, respectively. Conversely, Lagos and Enugu have the lowest magnitudes at 0.410 mm/year and 0.433 mm/year, respectively.

Table 3: Innovative Trend Analysis for Rainfall in the Six Stations

State Name	Trend Slope	Trend Indicator	Slope Std deviation	Correlation	UCL at 10%	UCL at 5%	UCL at 1%	ITA Test Result
Calabar	1.152	1.265788	0.0623299	0.94238364	0.10253	0.12217	0.16056	Increasing
Lagos	0.436	0.951693	0.0356118	0.9631275	0.05858	0.0698	0.09174	Increasing
Enugu	0.513	0.900036	0.0374948	0.94810056	0.06168	0.07349	0.09659	Increasing

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Abuja	**0.085**	**0.141779**	**0.0339354**	**0.97300654**	**0.05582**	**0.06651**	**0.08742**	**No Trend**
Kano	**1.559**	**6.646271**	**0.0373226**	**0.9726371**	**0.0614**	**0.07315**	**0.09614**	**Increasing**
Maiduguri	**0.627**	**3.675945**	**0.0219559**	**0.97339284**	**0.03612**	**0.04303**	**0.05656**	**Increasing**

Innovative Trend Analysis for Rainfall

Table 3 presents the Innovative Trend Analysis (ITA) results at 10%, 5%, and 1% significance levels. According to the trend indicator column, Calabar, Lagos, Enugu, Kano, and Maiduguri exhibit an increasing trend at the 5% significance level, while Abuja shows no trend. In terms of the magnitude of the trend indicator, Kano, Maiduguri, Calabar, Lagos, and Enugu have recorded values of 6.6, 3.7, 1.3, 1.0, and 0.9, respectively. On the other hand, Abuja, which shows no trend, has a trend indicator of 0.1. The trend slope column displays the magnitude of the detected trend at each station. Kano and Calabar exhibit the strongest trend slopes of 1.559 and 1.152, respectively, while Abuja has the lowest at 0.085, as shown in Table 3. These results are consistent across all six stations, as illustrated in Figure 4. It is crucial to assess trends in hydro-meteorological series for predicting long-term climate change and developing effective adaptation and mitigation strategies. The ITA method was further utilised to estimate the trend direction and eliminate the influence of autocorrelations and data cycles. This approach enhances the understanding of environmental changes and enables the reliable management of hydrometeorological data and ecosystems. Notably, the ITA method identified increasing trends in 5 out of the 6 stations, representing 83%.

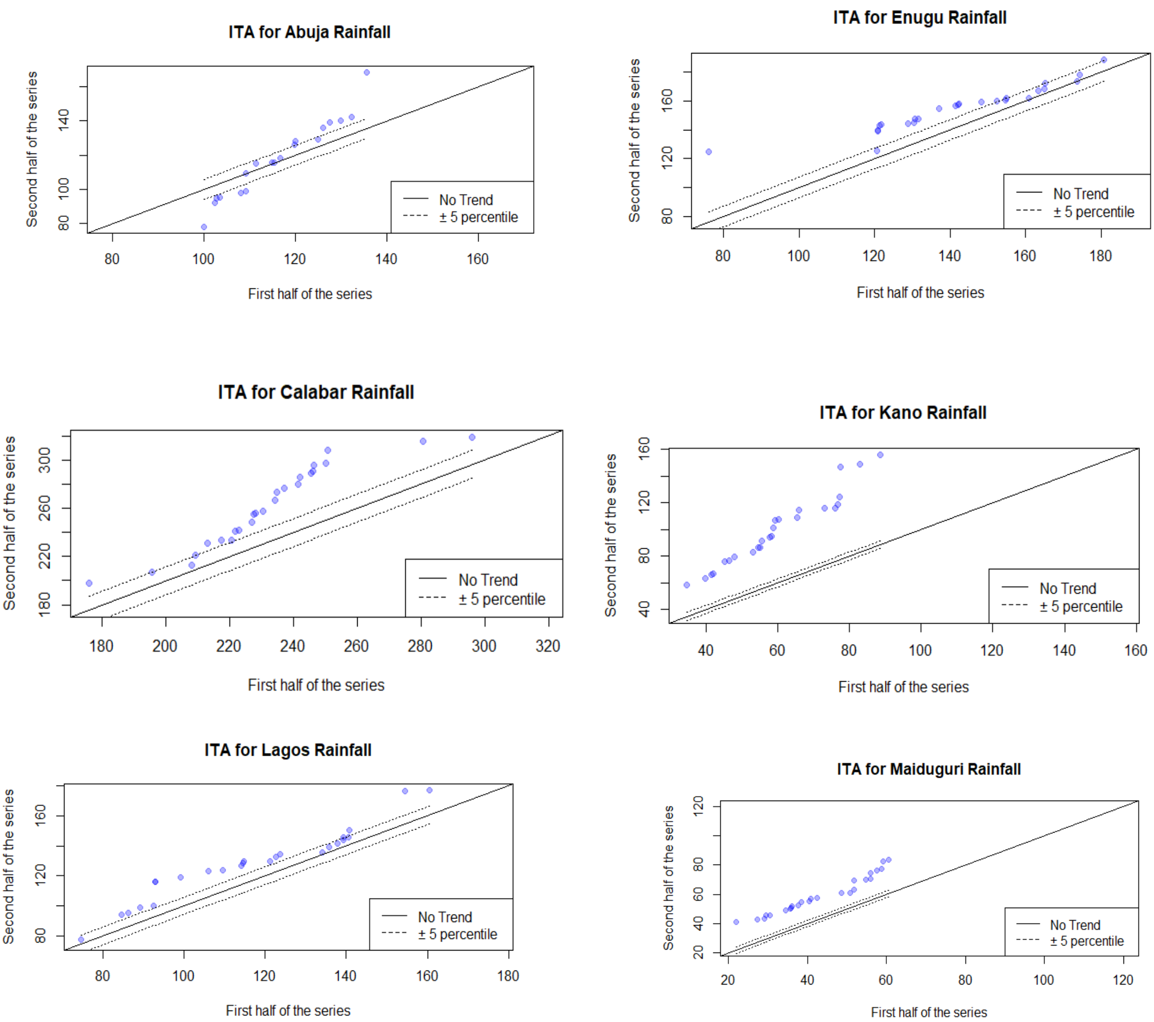

Figure 4: Innovative Trend Analysis for Rainfall in the Six Stations

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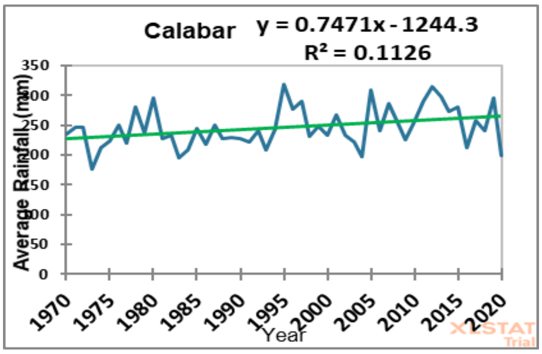
Linear Trend Analysis of Rainfall

The plots in Figure 5 indicate that most stations exhibited an increasing trend, except Abuja, which showed a decreasing trend. This observation aligns with the findings of the Mann-Kendall test at the 5% significance level and is consistent with the results derived from Sen's slope estimate and the ITA. The slopes of lines of the best fit for Calabar, Lagos, Enugu, Kano, and Maiduguri are 0.75, 0.48, 0.44, 1.02, and 0.65 mm per year, respectively. Notably, there is no discernible latitudinal correlation as anticipated. However, it can be argued that the trend was more pronounced along the coast and in the extreme north than in the middle belt region.

The MK test at a 10% significance level confirmed all the findings of the linear trend analysis with 100% correspondence. When the significance level was reduced to 5%, four out of six stations' MK results corresponded to the linear trend analysis, indicating 67% correspondence. At a 1% significance level, only Kano and Maiduguri stations exhibited increasing trends, representing a mere 33% correspondence. This analysis suggests that the MK analysis test is more likely to align with the linear time series analysis at lower confidence limits.



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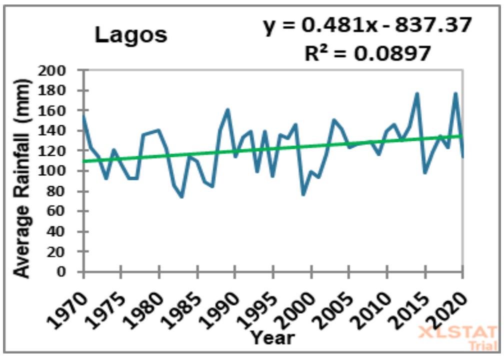

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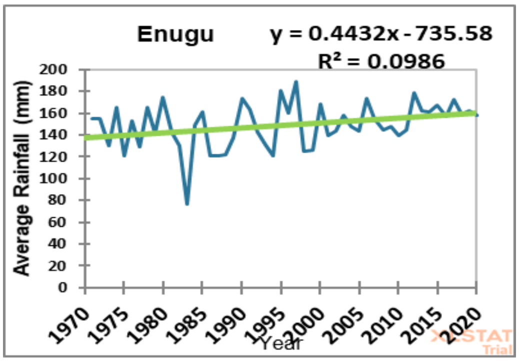

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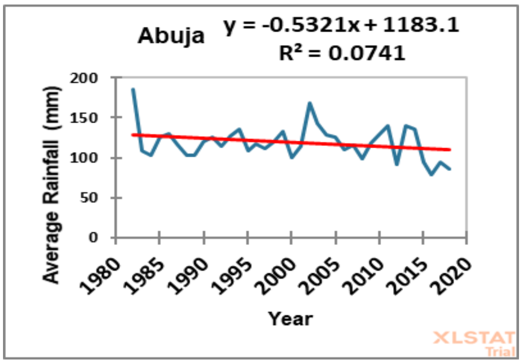

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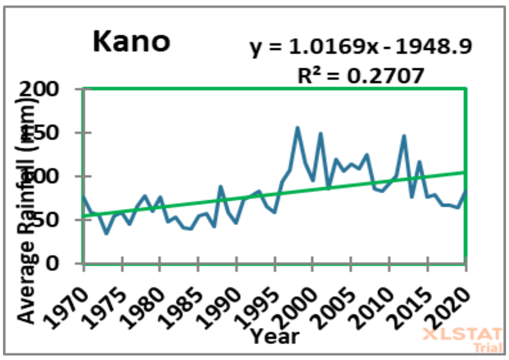

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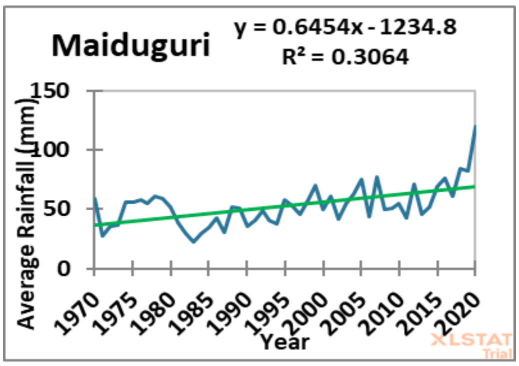

(f)

Figure 5: Linear Trend Line corresponding to Rainfall Data for the Six Stations

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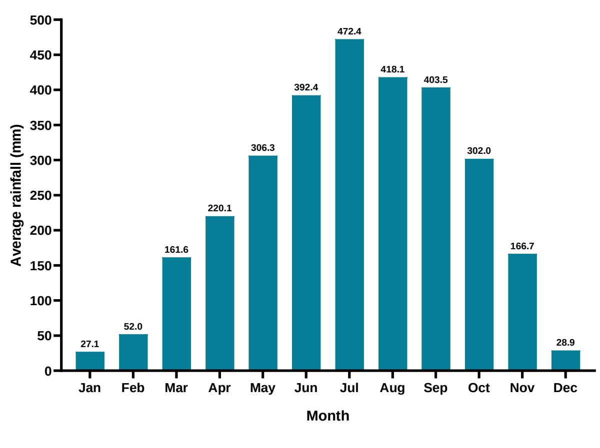
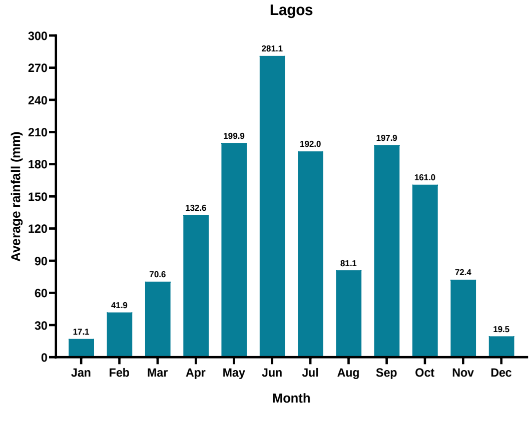
Intercomparison of Trend Results from the Four Test Methods for Rainfall

Table 4 summarises the three types of non-parametric tests conducted on the Rainfall dataset, with the linear trend plots depicted in Figure 5(a-f). In the plots, the green line represents an increasing trend, while the red line denotes either a decreasing trend or no trend. The results reveal that for Calabar, Lagos, Enugu, Kano, and Maiduguri, increasing trends are identified in the ITA. This corresponds with results obtained with Sen's slope estimation methods, and linear trend plots at a 5% significance level. Interestingly, Abuja exhibits no trend in all the test results, including the linear trend plots. Lagos demonstrates an increasing trend in all the tests at a 5% significant level, except for the MK test, which indicates no trend.

Table 4: Intercomparison of Rainfall Trend Results from Four Tests at a 5% SL

Intercomparison of MK, ITA Sens slope and Linear Trend results at a 5% Significant Level						
Stations	**P value (2-tailed)**	**α**	**M-K Test At 5%**	**ITA Test Result**	**Sen's slope At 5% (β)**	**Linear Trend Analysis**
Calabar	**0.027**	**0.05**	**Reject null**	**Increasing**	**Increasing (0.729)**	**Increasing**
Lagos	**0.06**	**0.05**	**Accept null**	**Increasing**	**Increasing (0.41)**	**Increasing**
Enugu	**0.022**	**0.05**	**Reject null**	**Increasing**	**Increasing (0.433)**	**Increasing**
Abuja	**0.381**	**0.05**	**Accept null**	**No Trend**	**Decreasing (-0.35)**	**Decreasing**
Kano	**0**	**0.05**	**Reject null**	**Increasing**	**Increasing (0.929)**	**Increasing**
Maiduguri	**0**	**0.05**	**Reject null**	**Increasing**	**Increasing (0.595)**	**Increasing**





a) Calabar **b) Lagos**

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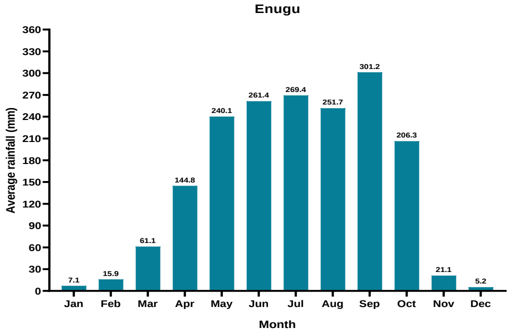
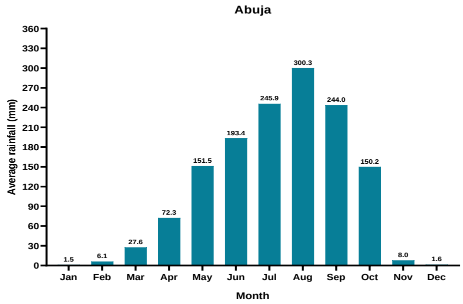
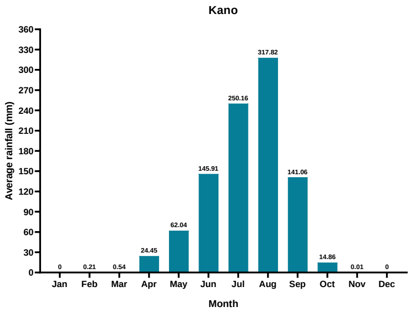
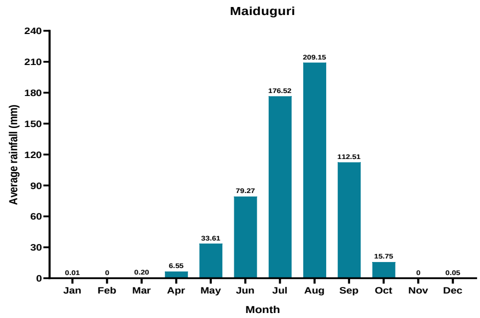




c) Enugu **d) Abuja**





e) Kano **f) Maiduguri**

Figure 6: Monthly Distribution of Rainfall Values in Six Stations

Monthly Rainfall Distribution

The data presented in Figure 6 illustrates the distribution of monthly rainfall across six stations. As expected, rainfall amounts decrease from the coastal region towards the inland area, aligning with the ecological zones. In the southeastern location of Calabar, a single peak in rainfall occurs in July. Unlike other southern stations lying above 4°N, Calabar does not exhibit a dual peak in the monthly rainfall distribution. Other stations exhibit double maximum rainfall amounts in June and September and a minimal amount in August. This pattern is in line with earlier studies by Ilesanmi (1981) and is referred to as the “little dry season” (LDS) or the "August break". This phenomenon is more prominent in the Southwest Region due to other prevailing synoptic features during the summer months. While this phenomenon is also present in the southeast stations, it tends to be weaker and of shorter duration. However, it is absent in the coastal areas below 4°N and not beyond 7°E (Hamilton and Archibold,1945).

Table 5: Monthly Average Rainfall Data for June, July, August, and September and LDS occurrence

Calabar	**4.9757° N, 8.3417° E**	**392.40**	**472.40**	**418.10**	**403.50**
Lagos	**6.5244° N, 3.3792° E**	**281.10**	**192.00**	**81.10**	**197.10**
Enugu	**6.4483° N, 7.5139° E**	**261.40**	**269.40**	**251.70**	**301.20**
Abuja	**9.0765° N, 7.3986° E**	**193.40**	**245.90**	**300.30**	**244.00**
Kano	**12.0022° N, 8.5920° E**	**145.91**	**250.16**	**317.82**	**141.06**
Maiduguri	**11.8311° N, 13.1510° E**	**79.27**	**176.52**	**209.15**	**112.51**

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The monthly distribution of rainfall in Lagos exhibits a clear double maximum pattern, with peaks in June (281.1mm) and September (197.1mm), and lower amounts in July (192.00mm) and August (81.10mm). Enugu also demonstrates a similar pattern, with peaks in July (269.40mm) and September (301.20mm) and reduced rainfall in August (251.70mm), although not as pronounced as in Lagos. In the Southeast, the period of reduced rainfall is shorter than in the Southwest, which experiences more than two months of low rainfall in July and August. Calabar experiences a single maximum in July, with a value of 472.4mm. Abuja, Kano, and Maiduguri each show a single peak of 300.30mm, 317.82mm, and 209.15mm, respectively, only in August. These findings are consistent with previous studies by Adefolalu (1972) and Omotosho (2008). The 50-year average shows that Calabar, Lagos, and Enugu records some amount of rainfall every month from January to December. However, rainfall in Abuja begins in February and ends in November, while in Kano and Maiduguri, it starts in April and ends in October.

Table 6: Rainfall Trend Magnitudes from the Three Tests

STATIONS	LINEAR PLOT mm/year	SEN'S SLOPE mm/year	1TA mm/year
CALABAR	0.747	0.729	1.152
LAGOS	0.481	0.410	0.436
ENUGU	0.443	0.433	0.513
ABUJA	-0.532	-0.350	0.085
KANO	1.017	0.929	1.559
MAIDUGIRI	0.645	0.595	0.627

Rainfall Trend Magnitudes from Three Test

The comparison of average annual rainfall trend magnitudes from the linear trend plot, Sen's slope estimation, and innovative trend analysis is presented in Table 6. Figure 7 illustrates that the results from the three tests are quite similar. The linear trend plot showed rainfall trend rates of 0.747, 0.481, 0.443, -0.532, 1.017, and 0.645 mm per year for Calabar, Lagos, Enugu, Abuja, Kano, and Maiduguri, respectively. The spatial pattern of rainfall trends reveals an increase in annual rainfall trend in all the stations except Abuja, where a decreasing trend in rainfall occurrence was observed. These findings are consistent with previous research in the country, demonstrating generally increasing trends. With the highest magnitude, Kano's rainfall trend stands out, while Lagos has the lowest, closely followed by Enugu.

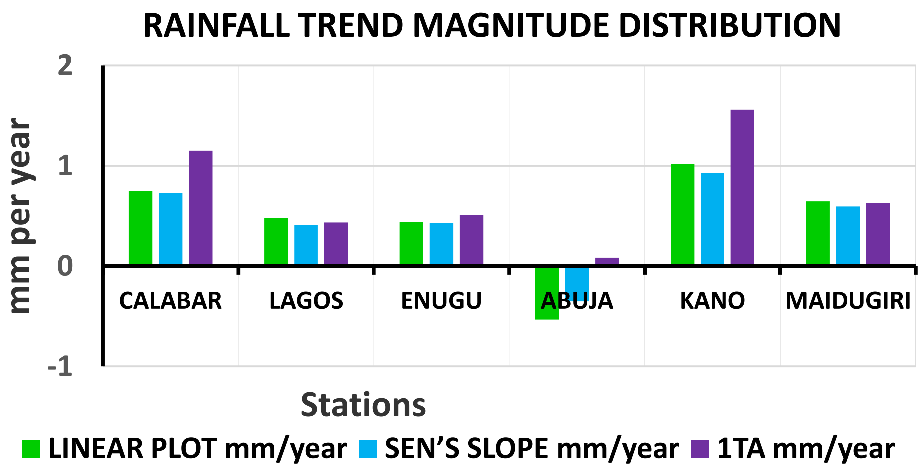

Figure 7: Spatial Distribution of Rainfall Trend Magnitudes

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Spatial Variation of 50-Year Average Annual Rainfall

Table 7 shows the 50-year average rainfall values for the six stations. Calabar has the highest rainfall of 2952.73mm and Maiduguri has the lowest value of 632.18mm. The rainfall values decrease with increasing latitude as shown in Figure 8.

Table 7: 50-Year Average Rainfall Value

50-YEAR AVERAGE RAINFALL						
Stations	Calabar	Lagos	Enugu	Abuja	Kano	Maiduguri
Rainfall mm	**2952.73**	**1459.23**	**1785.26**	**1395.00**	**957.78**	**632.18**

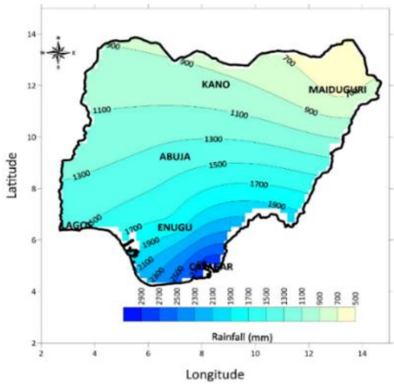
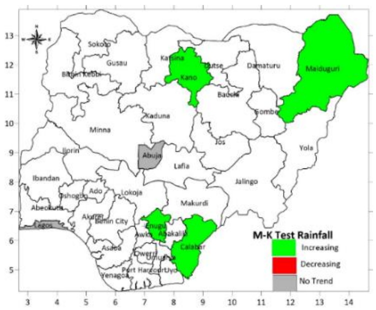
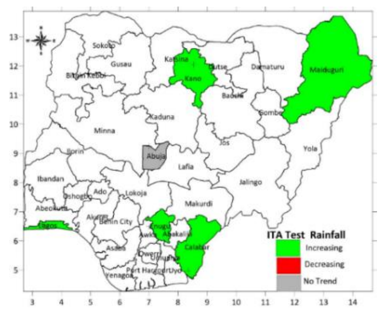


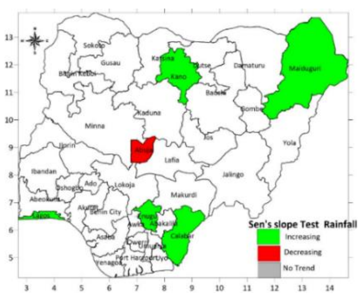
Figure 8: Spatial Distribution of 50-Year Annual Average Rainfall.



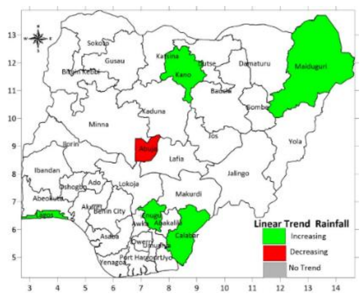
(a) Mann Kendall (MK)



(b) Innovative Trend Analysis (ITA)



(c) Sen's Slope Estimator (SSE)



(d) Linear Trend Plot (LTP)

Figure 9: Spatial Variations of Rainfall Trends

Spatial Variations of Rainfall Trends

Figures 9 (a), (b), (c), and (d) show the spatial analysis of the rainfall trends from the results of Mann Kendall (MK), Innovative Trend Analysis (ITA), Sen's Slope Estimator (SSE) and Linear Trend Plot (LTP) respectively. Abuja and Lagos showed no trend with the MK test and only Abuja continued with no trend or decreasing trend with the other three tests. Only the MK test accepted the null hypothesis which means no trend at Lagos but all the other tests indicated increasing trends for Lagos. The four tests indicated increasing trends for Calabar, Enugu, Kano and Maiduguri. This represents 66.7% of all the stations considered.

SUMMARY

The global impact of climate change on annual precipitation has been the subject of extensive research by scholars worldwide. This study focused on detecting trends in annual precipitation data from six stations in Nigeria for over 50 years (1971-2020) and the spatial analysis of the trends. To achieve this, three non-parametric statistical tests were utilised namely; the modified Mann-Kendall test, Innovative Trend Analysis, Sen's slope estimation, and linear trend line plotting. All the tests were conducted at a 5% significance level, except for the M-K test which was run at an additional 1% and 10% significant levels. The time series, spatial distributions of annual and monthly rainfall values and monthly average rainfall distribution for each of the six stations were also analysed. The resulting Mann-Kendall test statistic (S) provided insight into the direction and magnitude of trends in precipitation at each station.

The analysis revealed that there were statistically significant increasing rainfall trends in all the stations, except Lagos and Abuja, which did not show statistically significant trends at the 5% significance level for the MK test. The linear trend line plot indicated a decreasing trend for Abuja, with a rate of 0.532mm/year, while the other five stations displayed increasing trends ranging from 0.0443 to 1.0017 mm/year. It's worth noting that there is no consistent pattern in the variation of trend magnitudes with latitude. The Innovative Trend Analysis method is more efficient in detecting rainfall trends than the Mann-Kendall method. The rising trend in rainfall has both favourable and unfavourable impacts. On the positive side, this trend promises improved rainfall in the upcoming years, leading to higher agricultural productivity and an adequate water supply, especially groundwater. However, it also brings the risk of flooding, erosion, land degradation, ocean saltwater intrusion, coastal inundation, and other associated calamities.

CONCLUSIONS

The study concluded that, except for Abuja, the rainfall trend is increasing in all other stations analysed. The nonparametric tests, Mann-Kendall, Innovative Trend Analysis (ITA), Sen's Slope Estimation, and Linear Trend Plot, all produced similar results. The randomness of the dataset further validated the use of nonparametric methods. The study's findings confirmed the predicted impact of climate change, due to the projected increasing rainfall trends in five out of six stations analysed.

It is crucial to note that the detected increasing trends, will provide enough rainfall for irrigation for dry-season farming and water sources for animal consumption, particularly in the North where cattle rearing is the major occupation. It will also enhance groundwater recharge. The findings of this study offer valuable insights and perspectives for policymakers and planners to proactively address the potential impacts of climate change. Local perspectives must always be considered when interpreting and applying the findings. It is important to note that the observed rainfall trends at each station may have been influenced by local factors such as land use and urbanisation which may not necessarily reflect broader regional effects. Nigeria enjoys diverse climatic conditions, with the southern region receiving high rainfall and having more forested areas supported by abundant precipitation and short dry seasons. Rainfed agriculture is the primary occupation in the south, with cash crops like cassava, yams, cocoyam, potatoes, cocoa, oil palm, rubber, and cola nuts thriving due to the abundant rainfall. The increasing rainfall trend will boost food production across Nigeria and aid groundwater recharge.

Coastal areas are expected to face increased salinity intrusion with rising rainfall, resulting in the emergence of new ecological features and the disappearance of established ones due to climate change. The coastal and southeast regions will receive increased rainfall, causing further challenges such as severe thunderstorms, erosion, landslides, and land degradation, which will further impact the already vulnerable biodiversity. The frequency of rainfall-induced extreme weather events, such as flooding is expected to rise. Government institutions and stakeholders should adopt appropriate mitigation strategies to avert the destructive consequences of projected rainfall-induced extreme weather events and associated climate change in the years to come.

RECOMMENDATIONS

Based on the findings of this study, the following measures are hereby recommended;

i. A more comprehensive study is needed to establish the connection between observed rainfall trends and the impact of climate change in the areas under investigation. This can be done by collecting data from more weather stations spread across the country and over a longer period. The predictions of the regional climate model should be compared with the projected trend. Based on the available data and analysis, some indicative conclusions on the effect of climate change on the weather and climate of the study area can be better predicted.

ii. The maps showing spatial trends should be correlated with the prevalence of hydrometeorological disasters and climate-induced diseases like malaria and zoonotic diseases. These diseases are more prevalent in areas with higher humidity and rainfall, as these weather conditions create ideal breeding grounds for mosquitoes, rodents, reptiles, and other disease vectors. The above weather condition leads to outbreaks and rapid transmission of waterborne and zoonotic diseases.

iii. Government institutions, private sector organisations, and policymakers should use the results when planning and managing agricultural farms, dams and artificial lakes, monitoring and controlling drought, desertification, land degradation, floods, and erosion. The results can also be used for global warming and climate change studies to address the impacts of climate change on socio-economic activities.

iv. To better understand the ecological impact of changing rainfall trends, it is important to conduct vulnerability and risk assessments based on obtained trend data. This will help identify areas with high vulnerability or resilience to climate change and allow for targeted management interventions to enhance biosphere resilience.

v. Integrating obtained results into model development will improve the accuracy of flood forecasting and groundwater balance management for effective control of hydrological events.

vi. The spatial trend analysis should always be a significant component of assessing groundwater availability to avoid adverse socioeconomic impacts on stakeholders.

vii. Dairy and poultry farmers in the extreme north such as Kano and Maiduguri regions, where the difference between the minimum and maximum temperatures is broad, should adopt remedial strategies during extreme weather conditions. The aim is to provide additional heating during the harmattan season and cooling during the hot season. This will help prevent heat-related stress that could reduce animal and poultry production.

Limitations of the Study

i. The study relied on a single data point for each geopolitical zone, which may not accurately represent the entire area. To ensure more reliable conclusions, it is recommended to analyse data from multiple stations over a longer period for each geopolitical zone.

ii. The data collected from the weather station in Abuja only spans 38 years, whereas data from other stations covers 50 years. The station was established in 1982 and was included in the study due to the city's importance as the country's capital and one of the fastest-growing cities in Africa.

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