IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 18, Issue 7 Ser. 2 (July 2024), PP 25-41
www.iosrjournals.org

An Assessment of the Long-Term Trends in Annual Mean Temperature using Three Nonparametric Methods and a Linear Trend Analysis in some selected Nigerian Cities.

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Abstract
The impact of climate change on annual mean air temperature has received significant attention from scholars worldwide. Many studies have been conducted to demonstrate that changes in mean yearly temperature are becoming evident globally. This study focused on detecting trends in annual mean temperature 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 trend magnitude at a 5% significance level. This study analyzed yearly mean temperature trend values 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. All stations, except Enugu, indicated statistically significant increasing trends. The Linear trend line plot also indicated increasing temperature trends ranging from 0.007 to 0.03 °C/year (0.07 to 0.3 °C/decade) range compared to the global annual mean temperature which has increased at an average rate of 0.08°C per decade since 1880 and more than twice that rate (0.18°C) since 1981 as reported by NOAA. Similarly, Sen's results indicated that the magnitude of the temperature trend ranged from 0.005 to 0.035 °C per year, or 0.05 to 0.35 °C per decade. Climate models predict that increasing trends will continue in the 21st century and slow down if greenhouse gas emissions are drastically reduced. Analyses of trends in West Africa averaged over all available land stations in the region over the past 50 years, revealed statistically significant increases in annual mean temperature indices. Specifically, the mean annual maximum temperature increased by 0.16°C per decade, and the mean annual minimum temperature increased by 0.28°C per decade (Barry, A.A. et al, 2018). The MK, ITA, and linear trend line indicated a decreasing trend of 0.01°C for Enugu.
Keywords: *Temperature trend, Mann-Kendall, Innovative Trend Analysis, Sen's Slope Estimation, Linear Trend Analysis, Autocorrelation, Climate Change.*

Date of Submission: 08-07-2024 Date of Acceptance: 18-07-2024

I. Introduction

One of the indicators of climate change is the fluctuation in temperatures. Despite Nigeria's challenges with drought and desertification, there has been limited research on spatiotemporal temperature variations ranging from 50 and above years, using data from northern and southern stations. Ragatoa et al (2018) analysed the temperature trend in some selected cities in Nigeria for only 35 years. This study examined the average annual and seasonal temperature trends using three nonparametric methods and a linear trend method from 1971 to 2020 for Calabar, Lagos, Enugu, Abuja, Kano, and Maiduguri. According to the Intergovernmental Panel on Climate Change, IPCC (2018), the world's temperature (from 2015 to 2019), which was 1.1°C higher than it was in pre-industrial times, is expected to continue warming through 2052 and is likely to reach 1.5°C higher.

Most of the time, the emission of greenhouse gases enhances global temperatures, which increases evapotranspiration and rainfall (Bates et al., 2008).

The IPCC Fifth Assessment Report (AR5) projected a sustained increase in global temperatures (IPCC 2007a) due to rising fossil fuel combustion and greenhouse gas (GHG) emissions, significant changes in land use/land cover resulting from industrialisation and urbanisation, and natural processes such as earthquakes (IPCC 2007b). These natural processes and human activities have also significantly contributed to the alteration of climate patterns worldwide (IPCC 2007a), leading to the intensification of El Niño events, a rise in extreme weather occurrences (Akinsanola et al 2014), an increase in the ocean and land surface temperatures (IPCC 2014), changes in the spatiotemporal pattern of temperature (Sylla et al. 2016), and sea level rise (IPCC 2014). The rising temperature trends in all world regions are attributed to changes in climate and weather patterns (Vincent et al., 2015).

Scientific evidence consistently indicates climate change already affects the planet, leading to increasing global temperatures, rising sea levels, and retreating glaciers. Since 1901, the average global surface temperature has been increased by 0.07°C per decade. This rate doubled or tippled to between 0.19°C to 0.28°C per decade since the late 1970s (US EPA). Changes in temperature and precipitation patterns have far-reaching effects on human health, water resources, agriculture, ecosystems, and biodiversity (Onoz and Bayazit, 2012). Higher temperatures can lead to heat waves, posing health risks to susceptible populations, and drought and desertification can lead to food crises. Furthermore, temperature changes can cause shifts in the original habitats of plant and animal species.

Analysis of temperature trends over West Africa for the past 50 years shows statistically significant increases of 0.16 °C/decade and 0.28 °C/decade for mean annual maximum and minimum temperatures, respectively, across all available land stations in the region (Vincent, et al, 2015). West Africa is expected to experience persistent and increased temperatures due to climate change exceeding the estimated mean worldwide temperature of 1.5°C by 2100 (Sylla et al., 2016).

Climate change poses varying challenges across different regions of Nigeria. An analysis of climate vulnerability reveals that northern states are more susceptible to climate change impact than those in the south, with the Northeast and Northwest being the most vulnerable areas. The acceleration of desert encroachment due to increasing temperatures and reduced rainfall has resulted in the loss of wetlands, rapid reduction of arable lands, and depletion of available surface water, flora, and fauna resources on land. According to Braganza et al. (2004), trends in maximum and minimum temperatures can be used to monitor climate change and variability. Studies by Vose et al. (2005) focused on global maximum and minimum temperatures, showing that maximum temperatures have been rising by approximately 0.1-0.15 °C per decade and minimum temperatures by about 0.1-0.2 °C per decade, as noted by Solomon (2007). It is expected that climate change will have a significant impact on biodiversity loss in the country by the end of this century. The current global warming is already impacting species and ecosystems, especially in vulnerable areas like the Niger Delta and the extreme northern regions.

II. Data And Methodology

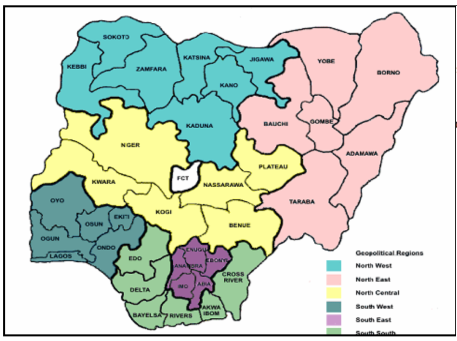
Study Area

Figure 2.1 shows the map of Nigeria, the study area, within the map of Africa and Figure 2.2 shows Nigeria within the West Africa map showing neighbouring countries. Figure 2.3 shows the map of Nigeria, which shows the six geopolitical zones and the six stations used in the study. Nigeria has a total landmass area of about 923,769 km^2 and a population of more than 230 million people (Oluwaseun et al., 2020). It is the most populous country in Africa and the world's sixth-most populous country. Nigeria comprises six geopolitical zones, 36 states and the Federal Capital Territory, Abuja. It is located between the Sahel to the north and the Atlantic Ocean to the south (Gulf of Guinea) which plays an important role in the weather patterns that affect the country. Nigeria lies between latitudes 4° and 16°N, and longitudes 2° and 15°E. Nigeria is bordered in the north by Niger, Chad in the northeast, Cameroon in the east, and Benin in the west. Omotosho and Abiodun (2007), and Abiodun et al. (2013), divided West Africa into three zones namely; Guinea coast, Savannah and Sahel with the latitudinal belt of 4°–8° N, 8°–11° N, and 11°–16° N respectively. Nigeria follows the same pattern of classification with three distinct climate zones: a tropical monsoon climate in the south, a tropical savannah climate in the central regions, and a hot, semi-arid Sahelian climate in the north.

Figure 2.1: African Map showing Nigeria   Figure 2.2: Map of Nigeria showing neighbours
Courtesy: Godswill Ofualagba and CCBY 2.0.

Climate of the Study Area

The climate in Nigeria is characterised by two major seasons: the rainy and the dry season. The amount and period of occurrence of rainfall varies from the coastal to the inland areas. The southern parts receive an annual rainfall of over 2000 mm, mostly between March and October, and the farthest northern parts receive an annual rainfall below 500 mm, mostly occurring between June and September. A marked interruption in the rains occurs during August in the south, resulting in a short dry season often locally called the little "dry season" or "August break". The average temperature ranges from 30–37°C in the south, and as high as 45°C in some parts of the north during the hot season (Eludoyin & Adelekan, 2013). The minimum temperature drops as low as 8°C in the north and ranges between 17–24°C in the south during the dry harmattan season (December–February). This represents the prevalent weather patterns in West Africa (Oguntoyinbo and Odingo, 1979). There are four distinct climatic zones: namely, tropical savanna climate, monsoon climate, warm semi-arid climate, and warm desert climate, according to the Koppen classification as shown in Figure 2.4. 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 six geopolitical zones representing different ecological zones of Nigeria as shown in Figure 2.4. One station each was selected as a sample to be surveyed from each political zone. The selected stations and their coordinates are presented in Figure 2.5 and Table 2.1. 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.



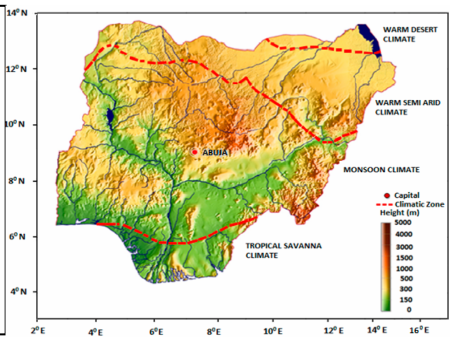


Figure 2.3: Nigeria map Showing 36 States/FCT and 6 Geo-political Zones
Figure 2.4: The topography and climatic zones of Nigeria. Source: (Shiru et al., 2018)

Figure 2.5: Digitized Satellite map of the Study Area showing the 6 Stations

Table 2.1: Coordinates of Meteorological Stations of the Study Area

Station/ Name	Lat.	Long.	Alt (m)	RF (mm)	Tmax °C	Tmin °C	Tmean °C	Period (1971-2020)
Calabar	**4.58**	**8.21**	**64**	**2952.73**	**30.8**	**23.1**	**27.0**	**50 years**
Lagos	**6.57**	**3.32**	**41**	**1459.23**	**31.3**	**23.1**	**27.2**	**50 years**
Enugu	**6.47**	**7.57**	**142**	**1785.26**	**32.3**	**21.9**	**27.1**	**50 years**
Abuja	**9.00**	**7.25**	**342**	**1395.00**	**33.0**	**21.6**	**27.3**	**50 years**
Kano	**12.03**	**8.51**	**476**	**957.78**	**33.6**	**20.0**	**26.8**	**50 years**
Maiduguri	**11.85**	**13.06**	**335**	**632.18**	**35.4**	**20.4**	**27.9**	**50 years**

Source: Nigerian Meteorological Agency (NiMet), Abuja (2020) (Ragatoa et al., 2018)

Methods

Historical data were obtained from six meteorological stations of the Nigerian Meteorological Agency (NiMet). The data comprised monthly maximum, minimum and mean temperature data for 50 years from 1971 to 2020. The data validation exercise was conducted virtually every month to identify and rectify missing and erroneous data. The data was obtained in MS Excel format and quality assessment was conducted by NiMet using QA/QC method. The mean annual and seasonal temperatures were analysed using the Mann-Kendall (MK), Innovative Trend Analysis (ITA), Sen's Slope Estimator (SSE), and linear Trend Analysis (LTA) tests for trends at a 5% significant level. Abuja had data for only 38 years instead of the 50 years obtained for the rest of the five stations. Abuja city was created as the country's new capital in 1976 and meteorological observation commenced in 1982. It was included in the study due to its significant role as the capital and the rapid urbanisation and population growth recorded in its very short existence. The randomness and homogeneity of the temperature data were assessed using a simple autocorrelation test. The SSE test was applied to estimate the magnitude of the slope in temperature at all six stations. Finally, the results obtained using the MK, ITA and SSE methods were compared. The software used for performing the statistical MK test is XLSTAT. The null hypothesis was tested at a 5% significant level for the six stations. In addition, to compare the results obtained from the nonparametric tests, linear trend lines were plotted for each station using Microsoft Excel.

Methodology

There are various nonparametric methods available for assessing trends, however, the Sen slope estimator (Sen, 2011), Innovative Trend Analysis and Mann-Kendall trend test (Tosunoglu, et al., 2017) are the most commonly used in hydrometeorological trend analysis (Tabari, 2011; Tabari, 2015; Demir and Kisi, 2016; Dabanlı, et al 2016). These nonparametric methods have several advantages, including handling missing data, requiring few assumptions, and being independent of data distribution (Dabanlı, et al., 2016; Wu, et al, 2017). Any data identified as spurious can be incorporated by assigning a common value smaller than the smallest measured value in the data set (Blackwell Publishing, Kendall's Tau). However, one major drawback is the potential influence of autocorrelation on test significance. 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, 2007; Sen, 2015).

The nonparametric Mann-Kendall (MK) method (Yue & Wang, 2004), Innovative Trend Analysis (ITA) (Brunetti et al., 2012) and Sen's Slope Estimator (SSE) (Agarwal et al. 2021) were used to examine temperature spatiotemporal trends. The nonparametric methods are also considered appropriate for climate change analysis and climate projections (Mavromatis and Stathis, 2011; Yue and Wang, 2004).

Mann–Kendall Trend Test

There are many trend assessment tests available in the literature. However, the Mann–Kendall test is the most extensively used test for assessing the trends in hydrometeorological data (Abghari et al., 2013; Hannaford and Buys, 2012; Piniewski et al., 2018; Ahmed et al., 2019; Hamed & Rao, 1998). The Mann-Kendall test, is recommended by the World Meteorological Organization (WMO) and is often used because it has several advantages: It considers the data distribution, and it can cope very well with the outliers (Mohamed and Shamsuddin, 2018; Sonali and Kumar, 2013). It works for all types of distributions i.e., the data doesn't have to meet the conditions of normality. However, the data should have no serial correlation. For a normal distribution, the simpler regression analysis should be used instead (Ahmed, et al., 2017).

The (MK) trend test was used to analyse the temperature data for consistently increasing or decreasing trends (monotonic) independent variables. Mann–Kendall test statistic for temperature was calculated using Equation (4). In Equation (1), n represents the sample size, whereas and are sequential data in series. According to the MK test, the null hypothesis H_0 assumes no trend, indicating that the data is independent and randomly ordered. The alternative hypothesis H_a implies the presence of a trend (Onoz and Bayazit, 2012). The computational procedure for the Mann-Kendall test considers the time series of n data points and $\mathscr{X}i$ and $\mathscr{X}j$ as two subsets of data where i = 1,2,3,…, n-1 and j = i+1, i+2, i+3, …, n. The data values are evaluated as an ordered time series. Each data value is compared with all subsequent data values. If a data value from a later period is higher than one from an earlier period, the statistic S is incremented by 1. On the other hand, if the data value from a later period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S (Drapela and Drapelova, 2011). The Mann-Kendall S Statistic is computed as follows:

where

sign ((2)

The variance of S is estimated as,

Var(S) =   (3)

Whereas tp defines the ties of the pth 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 (4):

(4)

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 temperature was estimated using the MK test. The MK test is a tool used to determine the presence or absence of a trend in a time series, however, it does not provide an accurate estimate of the trend's magnitude. On the other hand, Sen's method is based on the assumption of a linear trend in the time series. It is widely utilised to determine the magnitude of trends in hydrometeorological time series. Where $\mathscr{X}j$ and $\mathscr{X}i$ are the annual values in years j and i, j > i, respectively (Motiee and McBean, 2009). If n < 10, the value of |S| is compared directly to the theoretical distribution of S derived by Mann and Kendall. The two-tailed test is used. At a certain probability level, H_0 is rejected in favour of Ha if the absolute value of S equals or exceeds a specified value Sα/2, where Sα/2 is the smallest S with a probability less than α/2 to appear in case of no trend. A positive (negative) value of S indicates an upward (downward) trend (Drapela and Drapelova, 2011). For n ≥ 10, the statistic S is approximately normally distributed with the mean and variance as follows

Innovative Trend Analysis (ITA) Method

Sen initially proposed the concept of ITA (Brunetti, M, 2012) for trend detection in time series. Using this method, the data set is divided equally into two segments from the first entry to the last entry (Ali et al., 2019). 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 as shown in Figure 2.6. 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, 2018a and Khan et al, 2018b):

S_{ITA} =   (5)

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

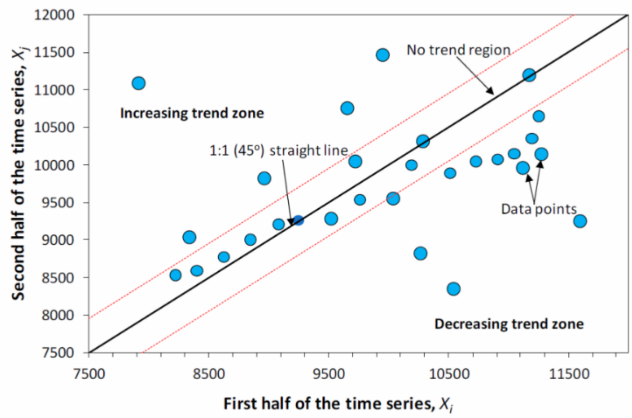


Figure 2.6: The Innovative Trend Analysis (ITA) Method showing Increasing and Decreasing Trend Zones. Source: (Ali et al., 2019)

The null hypothesis (H_0) of no significant trend cannot be rejected if the calculated slope value, s, remains below a critical value, s_{sci}. In contrast, the alternative hypothesis (Ha) of a significant trend in time series is applicable if s >s_{sci}. The null hypothesis's probability density function (PDF) is needed to calculate test significance. If the confidence limits of a standard normal PDF with zero mean and the standard deviation $_s$ is s_{sci}, at a significance level of, the confidence limit (CL) of the trend slope is:

$CL_{(1-)} = 0 \ \ s_{scis}$ (6)

where$_s$ is the slope standard deviation.

More details of the test can be found in Sen's method, (Dawood, 2017). The significance of the change in annual mean temperature was estimated using ITA. The ITA method was applied at 5% significance levels considering the rarity of significant temperature changes. Trend analysis was also used to ascertain the temperature trend in all 6 stations. Software SPSS was selected for trend analysis.

Estimation of Magnitude of Change

Sen's slope test was developed to check for statistical linear relationships in long-term temporal data (Agarwal et al., 2021; Sen 1968). 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).The Sen's Slope Estimator (SSE) (Sen, 1968) was used to estimate the magnitude of annual temperature for 50 years 1971–2020. The Sen's slope estimator (β) is calculated as the median of all the slopes estimated between all the successive data points temperature time series (*y*) as:

……………………….. (7)

Where is the change in temperature due to the change in the time, t is the time between two subsequent temperature data. Sen's slope Estimator is found highly reliable for trend magnitude estimation over time (Faiz et al., 2018). Finally, β has been calculated to obtain the trend and slope magnitude. 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).

Autocorrelation

The autocorrelation or serial correlation or the correlation of temperature data with itself over successive time intervals was tested before testing for trends. Autocorrelation increases the chances of detecting significant trends even if they are absent and vice versa. To consider the effect of autocorrelation, Hamed and Rao (1998) suggested a modified Mann-Kendall test, which calculates the autocorrelation between the ranks of the data after removing the apparent trend. The adjusted variance is given by:

$Var[S] = \ [N(N-1)(2N+5)\ ]$

Where

N is the number of observations in the sample, NS* is the effective number of observations to account for autocorrelation in the data, $p_s(i)$ is the autocorrelation between ranks of the observations for lag *i*, and p is the maximum time lag under consideration (Sinha and Cherkauer 2007).

III. Sources Of Error

It's important to note that the lack of consistency in temperature sensors used at the stations for 50 years may have impacted the accuracy of the recorded data. Different instruments were used over the years without any intercomparison. Furthermore, there's a lack of information regarding the number of temperature sensors used in each station for recording temperature data over 50 years. Additionally, the precise locations of the temperature sensors may have changed at some stations when the meteorological enclosure was relocated. The data was manually recorded and transmitted to the Headquarters, where the data bank is situated, leaving it susceptible to human error. Despite the implementation of quality control measures by NiMet, there is no guarantee of 100% accuracy.

IV. Results

Temperature Autocorrelation

Autocorrelation analysis was used to verify the randomness of mean annual temperature data from the six stations for 50 years, from 1971 to 2020, as shown in Figure 4.1. The analysis was tested at a significant level of 5%. The results indicated that after the lag-0 correlation, subsequent correlations rapidly approached zero and mostly remained within the significance level boundaries (represented by the dashed blue lines in all the diagrams). Therefore, the model residuals satisfied the assumption of no autocorrelation. All the stations in Figure 4.1 demonstrated no autocorrelation for temperature data, which confirms randomness.

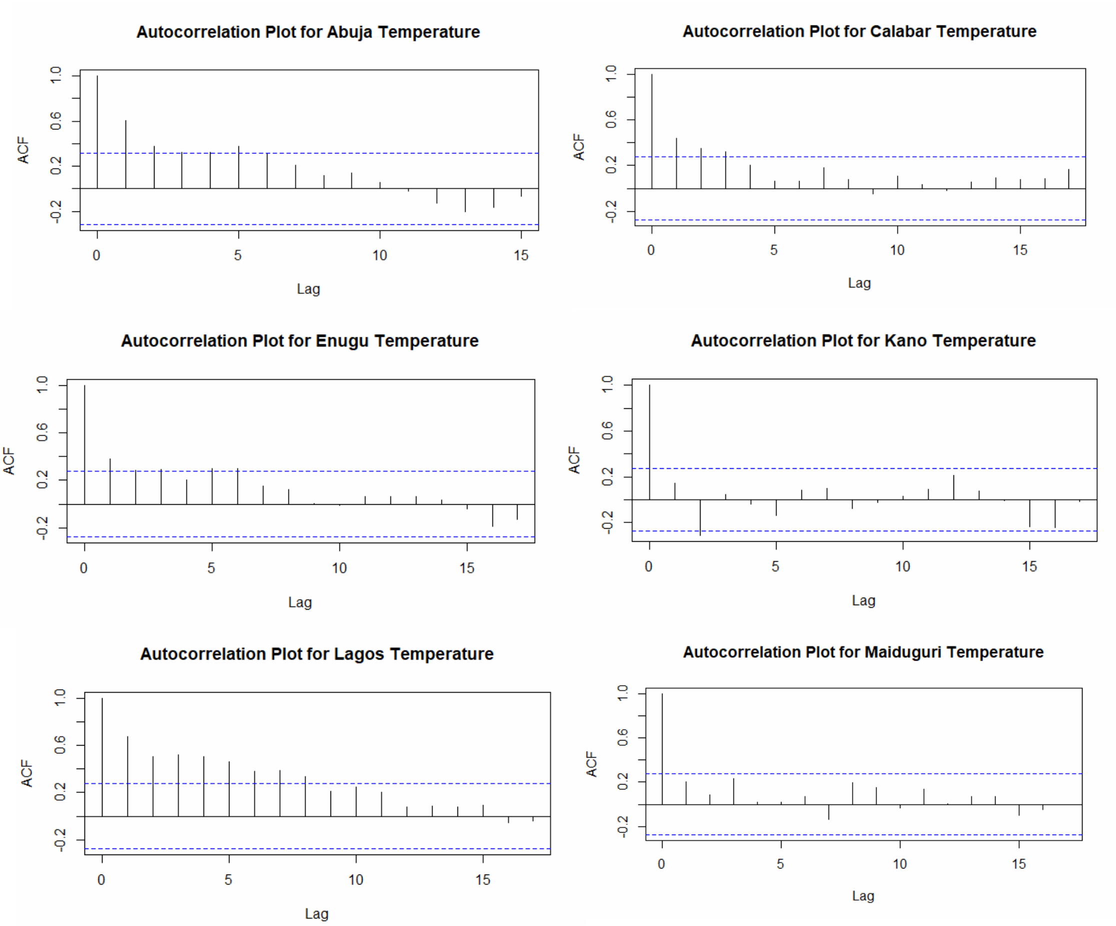


Figure 4.1: Autocorrelation Plot for Temperature at the Six Stations

Mann Kendall Analysis of Temperature

Table 4.1 shows the MK trend analysis of temperature values at the six stations. Calabar, Lagos, Abuja and Maiduguri showed increasing trends, implying that the null hypothesis was rejected for the stations. Enugu and Kano showed no trend. It is worth noting that the same increasing trend results were obtained at the three significant levels (SL) of 1%, 5% and 10% for Calabar, Lagos, Abuja and Maiduguri. Similarly, the same decreasing trend was obtained for Enugu and Kano at the three significant levels. The MK Statistics (S) has higher values in the Southern stations and lower values in the northern stations for all the stations with increasing trends. For Enugu and Kano where the null hypothesis is accepted which is also indicative of no trend have the lowest MK Statistics absolute values.

Table 4.1: Results of the Statistical Mann-Kendall Test for Temperature Data for the Six Stations from 1971 - 2020 at 5%, 1% and 10% Significant Levels.

Stations	M-K Statistic (S)	Kendall's Tau	Var (S)	P value (2tailed)	α	Result (5%)	α	Result (1%)	α	Result (10%)
Calabar	517	0.405	15158.33	< 0.0001	0.05	Reject null	0.01	Reject null	0.1	Reject null
Lagos	747	0.587	15154.33	< 0.0001	0.05	Reject null	0.01	Reject null	0.1	Reject null
Enugu	-206	-0.162	15155.33	0.10	0.05	Accept null	0.01	Accept null	0.1	Accept null
Abuja	310	0.465	5846	< 0.0001	0.05	Reject null	0.01	Reject null	0.1	Reject null
Kano	184	0.145	15153.33	0.14	0.05	Accept null	0.01	Accept null	0.1	Accept null
Maiduguri	360	0.282	15157.33	0.00	0.05	Reject null	0.01	Reject null	0.1	Reject null

(a)

For the MK test, 67% of the stations displayed increasing trends, while 33% showed no trend at all at the three significant levels. Lagos has the highest MK statistics value of 747 and corresponding tau of 0.587 while Kano has the lowest value of 184 with a corresponding tau of 0.145. Enugu has an S value of - 206 and a corresponding tau of -0.162.

Table 4.1b. Results for Mann Kendall's Test and Sen's Slope for Trend in Temperature at 5% Significant Level

Stations	M-K Statistic(S)	Kendall's Tau	Var (S)	P value (2-tailed)	alpha	M-K Result	Sen's slope (5%)	Sen's Result
Calabar	517	0.405	15158.33	<0.0001	0.05	Reject null	0.014 (0.009-0.019)	Increasing
Lagos	747	0.587	15154.33	<0.0001	0.05	Reject null	0.027 (0.020-0.033)	Increasing
Enugu	-206	-0.162	15155.33	0.096	0.05	Accept null	-0.008 (-0.016-0.001)	Decreasing
Abuja	310	0.465	5846.00	<0.0001	0.05	Reject null	0.035 (0.019-0.049)	Increasing
Kano	184	0.145	15153.33	0.137	0.05	Accept null	0.005 (0.002-0.013)	Increasing
Maiduguri	360	0.282	15157.33	0.004	0.05	Reject null	0.013 (0.005-0.018)	Increasing

(b)

Sen's Slope Estimation Test for Temperature

According to the data presented in Table 4.1b, all the stations, except Enugu, showed increasing trends at a 5% SL. On the other hand, Enugu showed a decreasing trend of 0.008°C per year at a 5% significance level. The SSE results agree with the MK results, except for Kano, which displayed no trend at 5% SL. The highest magnitude of the trend is observed at Abuja, with 0.035 ^{0}C per annum, while the lowest value is found at Kano, with a magnitude of 0.005 ^{0}C per annum. The 0.35^{o}C/decade recorded for Abuja is higher than the global average of 0.28 °C/decade for mean annual minimum temperature. Interestingly, there is no discernible latitudinal relationship among the slope magnitudes and it is worth noting that low values are recorded for Lagos, Kano and Maiduguri. Five out of the six stations showed an increasing trend representing 83%.

Table 4.2: Innovative Trend Analysis for Temperature in the Six Stations

State Name	Trend Slope	Trend Indicator	Slope Std deviation	Correlation	UCL at 90%	UCL at 95%	UCL at 99%	ITA Test Result
Calabar	0.011	0.10742	0.00048829	0.965340829	0.00080	0.00096	0.00126	**Increasing**
Lagos	0.023	0.21339	0.00075630	0.960542004	0.00124	0.00148	0.00195	**Increasing**
Enugu	-0.007	-0.06166	0.00087034	0.938913188	0.00143	0.00171	0.00224	No Trend
Abuja	0.028	0.20320	0.00108414	0.965076521	0.00178	0.00212	0.00279	**Increasing**
Kano	0.008	0.07700	0.00077718	0.961195919	0.00128	0.00152	0.00200	**Increasing**
Maiduguri	0.012	0.11431	0.00068522	0.96068073	0.00113	0.00134	0.00177	**Increasing**

Innovative Trend Analysis for Temperature

The Innovative Trend Analysis (ITA) for Temperature was conducted across the six stations as shown in Table 4.2 and Figure 4.2. The trend indicator column showed that five stations indicated increasing trends, representing 83%, while only Enugu showed a decreasing trend. This aligns with MK test results shown in Table 4.1b in all the stations except Kano which showed no trend for MK test results. Figure 4.2 shows all the data points above the diagonal line in all the stations except at Enugu where the data points are largely below the diagonal indicative of a decreasing trend.

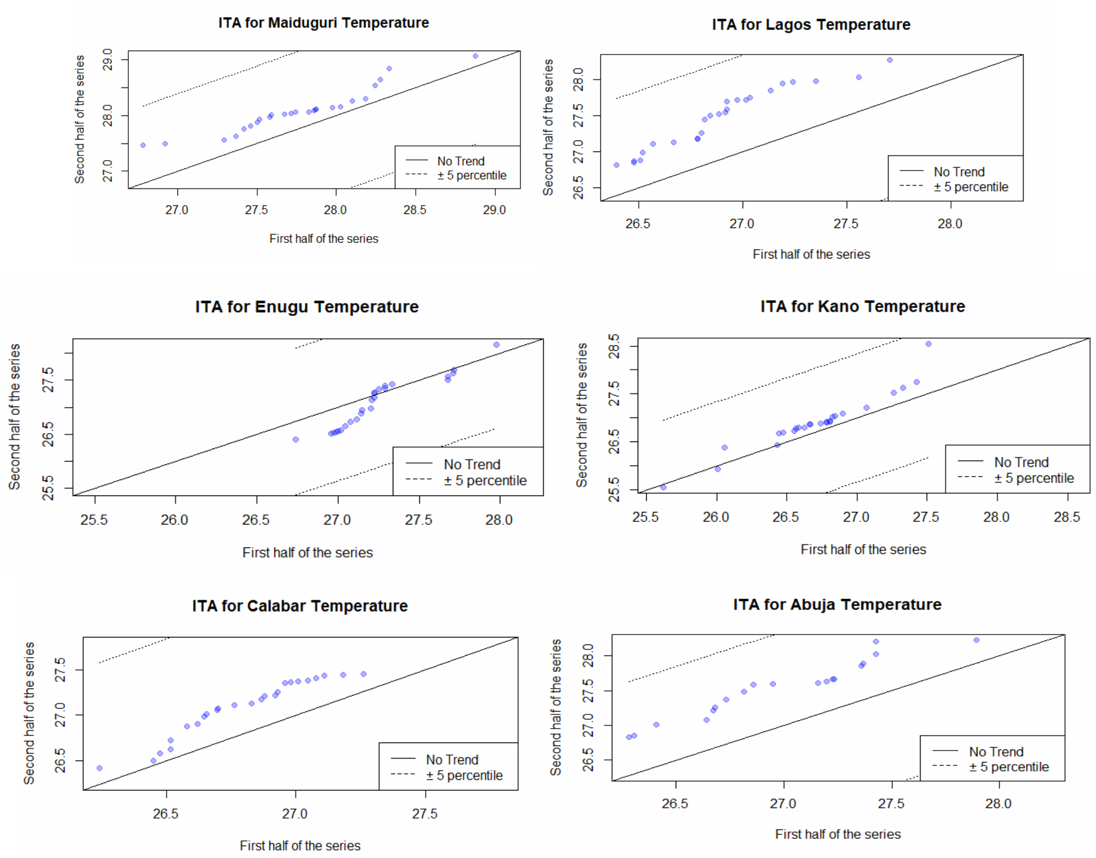


Figure 4.2: Innovative Trend Analysis for Temperature in the Six Stations

Linear Trend Analysis of Temperature

Figure 4.3 shows the time series of mean temperature with the linear trend lines in the six stations. Five stations showed increasing trends except Enugu which showed a decreasing trend and this aligns with the three nonparametric tests (MK, SSE and ITA). The slope of the trend lines in Calabar, Lagos, Abuja, Kano and Maiduguri are 0.01, 0.03, 0.03. 0.007 and 0.01°C per annum respectively. The latitudinal consideration showed an increasing slope magnitude up to the middle belt and decreasing strength at the far North. Enugu showed a decreasing trend with a value of 0.01°C per annum.

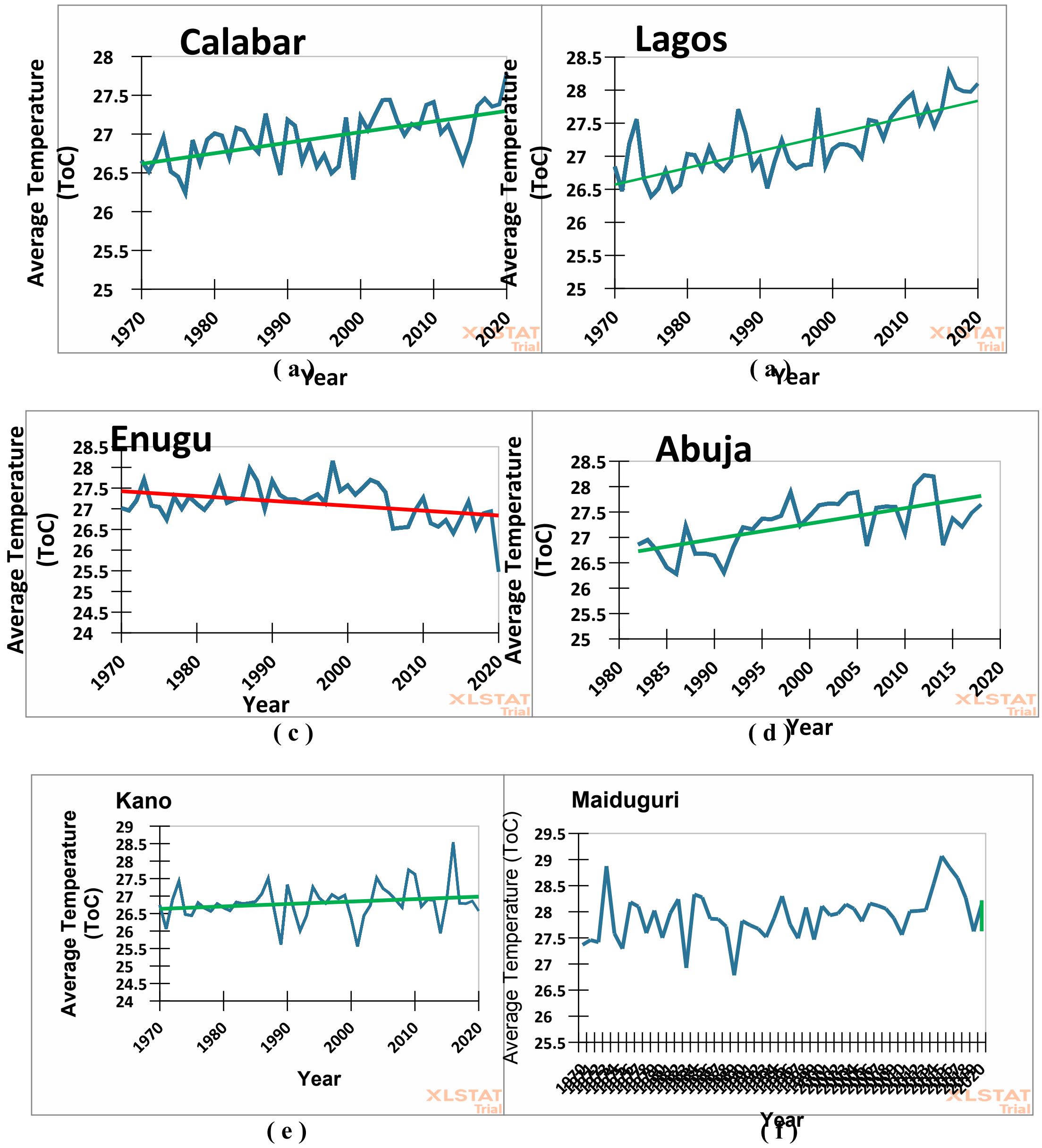


Figure 4.3: Linear Trend Lines Corresponding to Average Temperature Data for the Six Stations

Intercomparison of Temperature Trend Results from the Four Test Methods

The findings for the four types of analysis are presented in Table 4.3. It's worth noting that Calabar, Lagos, Abuja, and Maiduguri all produced identical results across all four tests, indicating a clear increasing trend in all stations. Kano's results across the four tests also displayed a trend increase in all but for the Mann-Kendall test, which showed no apparent trend. Enugu exhibited no trend with MK and ITA tests, but Sen's slope and linear trend analysis showed a decreasing trend. These results confirm the suitability of nonparametric tests for analysing hydrometeorological data sets, an observation widely reported in the literature. Overall, 79.2% of the trends across the four tests showed upward trends. The dominant characteristic of the upward trend throughout the stations can be interpreted to be due to global warming and anthropogenic activities. All the detected trends for temperature are in an upward direction except for Enugu, which indicated a downward trend. This serves as evidence of the effects of global warming that contribute to climate change. To maintain a liveable temperature, policymakers, private and government institutions, Nongovernmental Organizations (NGO), Faith Based Organizations (FBO), and the general public should actively promote and engage in tree planting and reforestation efforts while discouraging the reckless and indiscriminate felling of trees and land use. This approach will effectively address desertification and drought episodes in the northernmost regions. Additionally, the government should prioritise and promote well-planned urban development schemes.

Table 4.3: Intercomparison of Temperature Trend Results from the Four Tests at 5% Significant Level

Intercomparison of Temperature Trend Results from the Four Test Results								
Stations	**M-K Statistic S**	**Kendall's Tau**	**P value (2-tailed)**	**α at 5%**	**M-K Result (5%)**	**ITA Test Result**	**Sen's at 5%**	**Linear Trend Analysis**
Calabar	517	0.405	< 0.0001	0.05	Reject Ho	Increasing	Increase	Increasing
Lagos	747	0.587	< 0.0001	0.05	Reject Ho	Increasing	Increase	Increasing
Enugu	-206	-0.162	0.10	0.05	Accept Ho	No Trend	Decreasing	Decreasing
Abuja	310	0.465	< 0.0001	0.05	Reject Ho	Increasing	Increase	Increasing
Kano	184	0.145	0.14	0.05	Accept Ho	Increasing	Increase	Increasing
Maiduguri	360	0.282	0.00	0.05	Reject Ho	Increasing	Increase	Increasing

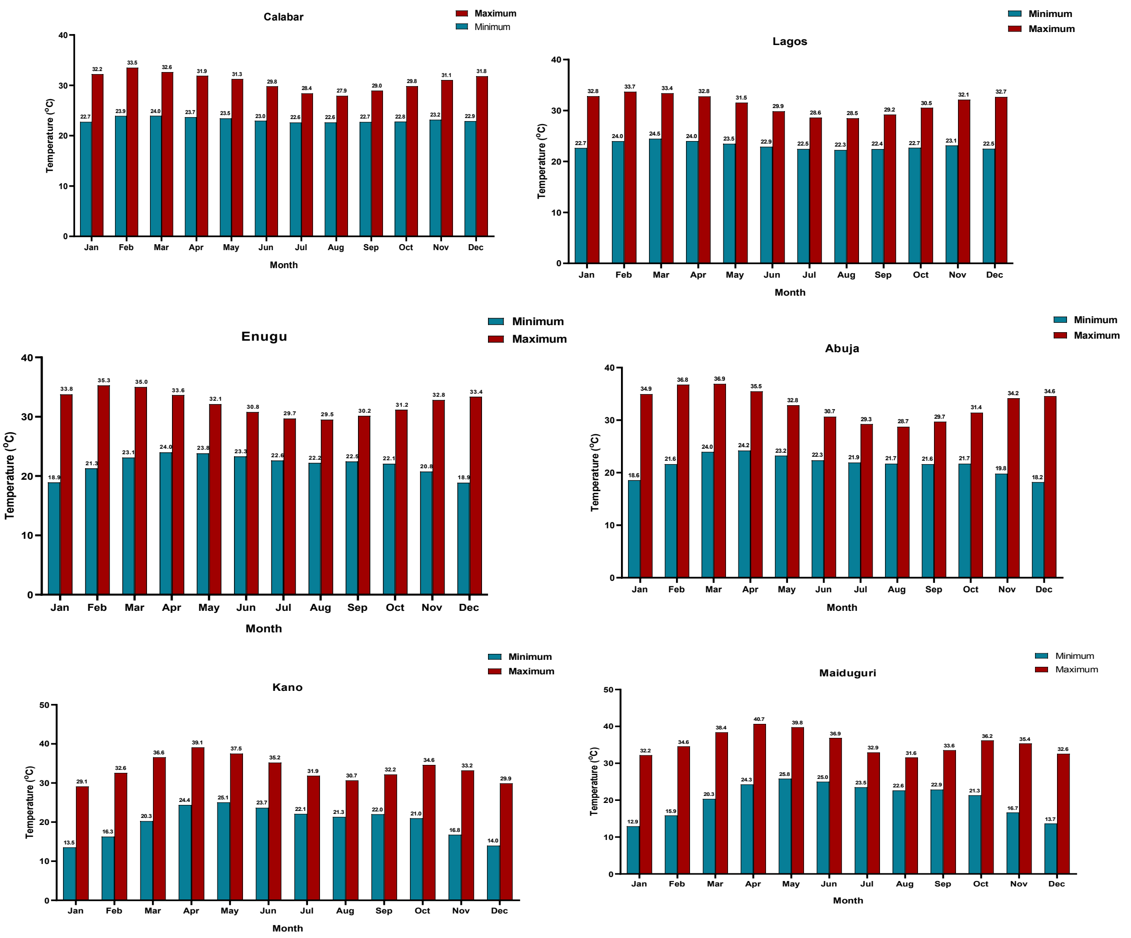


Figure 4.4: Monthly Distribution of Min. and Max. Temperature Values in Six Stations

Monthly Distribution of Maximum and Minimum Temperature

Figure 4.4 displays the monthly average distribution of minimum and maximum temperatures in the six stations. For Calabar, Lagos, Enugu, and Abuja, the highest maximum temperatures are recorded between January and March, and the second maximum in November and December. The values start decreasing in April and reach their lowest in July and August during the peak of the rainy season. This period corresponds to the little dry season with no precipitation and low clouds or those with little rain drops (Omotosho, 1988). The sky is usually overcast with low and medium clouds and the clouds prevent insolation penetration (Adefolalu, 1972).

The minimum temperatures followed the same pattern as maximum temperatures in the southern stations of Calabar, Lagos, and Enugu with a lower variation margin between January and December. However, a different pattern from the maximum temperatures is observed as the minimum temperature moved inland to Abuja, Kano, and Maiduguri. The lowest minimum temperatures are recorded in November, December, January, and February. This pattern is explained by the incursion of the midlatitude winter trough lines, bringing along cold and dusty dry winds from the mid-latitude temperate climate (Omotosho 1988).

March, April, and May recorded the highest maximum temperatures in Kano and Maiduguri. After June, the temperatures gradually decreased and reached their lowest point during July and August. May and June are the onset of the rainy season in the northernmost part of the country, which peaks in August. The rainy season in the North reaches its peak in July and August, coinciding with the lowest maximum temperature values. In September, the maximum temperature begins to rise again, reaching a second peak in October and November. In summary, Kano and Maiduguri experienced dual peaks in maximum temperature values in April and October, while Calabar, Lagos, Enugu, and Abuja had a single peak in February and March.

Table 4.4: Monthly Average Lowest Minimum Temp and Highest Maximum Temp for the Six Stations

STATIONS	LOWEST T_{min}	MONTH	HIGHEST T_{max}	MONTH	TEMP RANGE
Calabar	22.6°C	Jul & Aug	33.5°C	February	10.9°C
Lagos	22.3°C	August	33.7°C	February	11.4°C
Enugu	18.9°C	Dec & Jan	35.3°C	February	16.4°C
Abuja	18.2°C	December	36.9°C	March	18.7°C
Kano	13.5°C	January	39.1°C	April	25.6°C
Maiduguri	12.9°C	January	40.7°C	April	27.8°C

Table 4.4 shows the monthly average lowest minimum temperature and highest maximum temperature for the six stations. The lowest value is shown in blue, and the highest value is in red. It's worth noting that Kano and Maiduguri had the highest maximum temperatures at 39.1°C and 40.7°C, respectively, and the lowest minimum temperatures at 13.5°C and 12.9°C, respectively. The temperature range between the lowest minimum and highest maximum temperature increases with an increase in latitude from the coastal station of Calabar to the northernmost station of Maiduguri, with values of 10.9°C and 27.8°C recorded respectively. The wide temperature range in Kano and Maiduguri accounts for the wide range of cash and food crops grown in these areas. These extreme temperatures support the growth of mid-latitude crops such as cereals and Sahelian crop types like date palms.

Table 4.5: Temperature Trend Magnitudes from the Three Nonparametric Test Results

STATIONS	LINEAR PLOT °C/year	SEN'S SLOPE °C/year	1TA °C/year
CALABAR	0.014	0.014	0.011
LAGOS	0.025	0.027	0.023
ENUGU	-0.012	-0.008	-0.007
ABUJA	0.030	0.035	0.028
KANO	0.007	0.005	0.008
MAIDUGIRI	0.012	0.013	0.012

Temperature Trend Magnitudes from Three Test Results

The data contained in Table 4.5 shows the average annual temperature trends for the Linear trend plot, Sen's slope estimation and Innovative trend analysis. The trends in all three tests are similar, as further illustrated in Figure 4.5. The trends indicate that the mean temperatures are changing at varying rates of 0.014, 0.025, -0.012, 0.030, 0.007 and 0.012°C per year for the cities of Calabar, Lagos, Enugu, Abuja, Kano and Maiduguri respectively with LTA. The spatial pattern of temperature trends indicates increases in five cities except at Enugu. Enugu records a decreasing trend at 0.012°C per year. Coastal stations are experiencing more warming than inland stations. The rate of temperature change (magnitudes) aligns with the global trend (IPCC 2015). The highest temperature trend increase is recorded in Abuja, while Kano recorded the lowest.

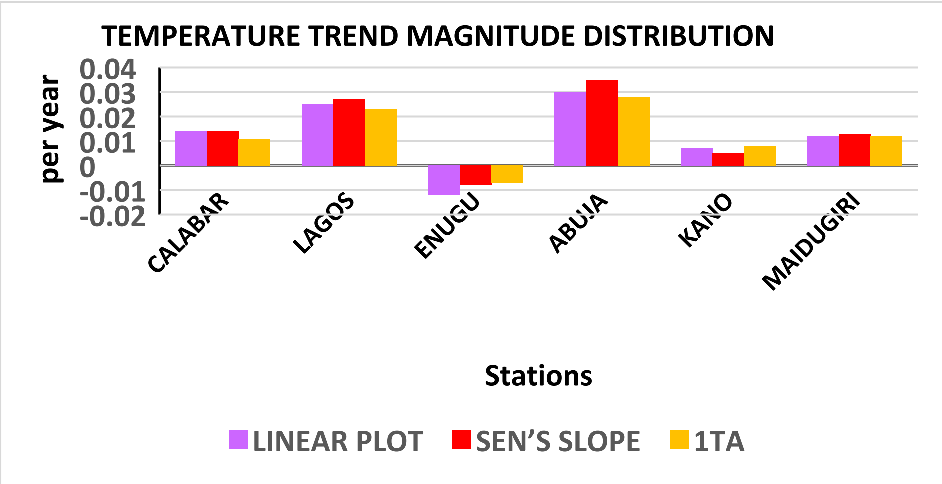


Figure 4.5: **Spatial Distribution of Temperature trend magnitudes**

Table 4.6: 50-Year Average Rainfall and Max & Min Temperature Values

STATIONS	RAINFALL mm	MAX TEMP °C	MIN TEMP °C	MEAN TEMP °C
Calabar	2952.73	30.8	23.1	27.0
Lagos	1459.23	31.3	23.1	27.2
Enugu	1785.26	32.3	21.9	27.1
Abuja	1395.00	33.0	21.6	27.3
Kano	957.78	33.6	20.0	26.8
Maiduguri	632.18	35.4	20.4	27.9

Spatial Variation of 50-Year Average Annual Maximum & Minimum Temperature

Table 4.6 displays the 50-year average of maximum, minimum, and mean temperatures for the six stations. The maximum temperature has the lowest value of 30.8°C in Calabar and the highest value of 35.4°C in Maiduguri. The difference between the lowest and the highest value is 4.6°C. The maximum temperature increases with latitude and it is shown in Figure 4.6a. The highest minimum temperature 23.1°C is recorded in Calabar and Lagos and the lowest values of 20.0°C and 20.4°C are recorded in Kano and Maiduguri respectively. The difference between the two values is 3.1°C. The minimum temperature decreases as latitude increases, as illustrated in Figure 4.6b. The difference between the highest value and the lowest is 3.1°C. The mean temperature also increases with latitude and has the lowest value of 27°C at Calabar and the highest value of 27.9°C at Maiduguri. The difference between the two values is only 0.9°C. It is worth noting that the mean temperature varies by only 0.9°C from the coast to the northernmost part. The average temperature variation from the coast to the northernmost part over 50 years is minimal, as shown in Figure 4.7.

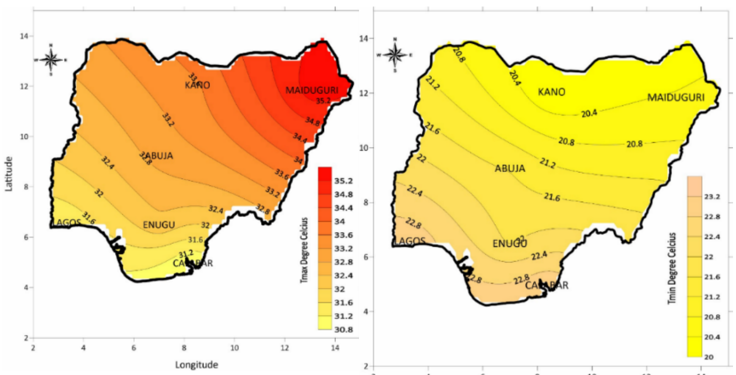


Figure 4.6: **Spatial Distribution of (a) Average Maximum Temperature and (b) Average Minimum Temperature**

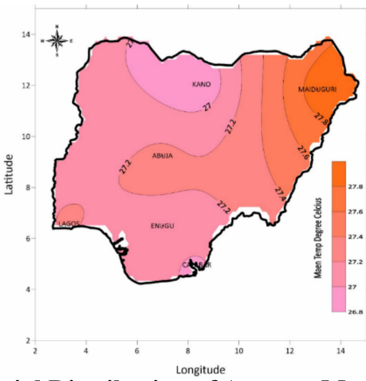
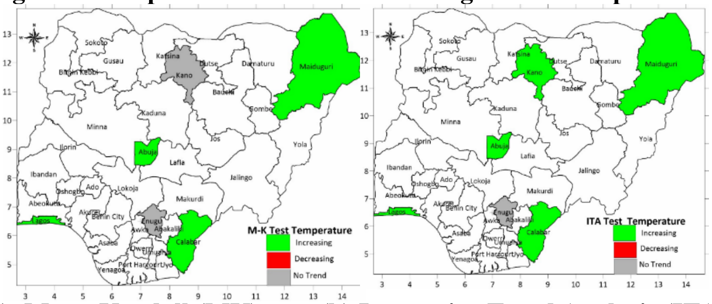
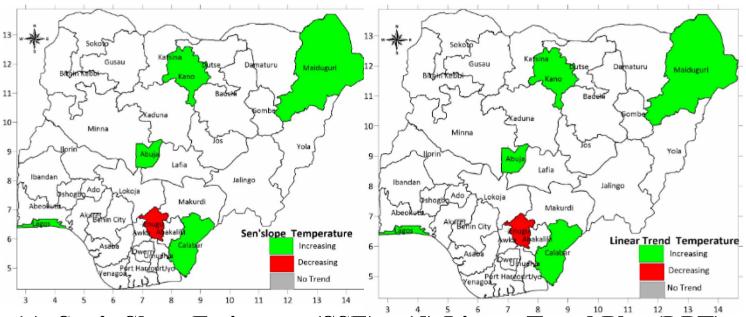


Figure 4.7: Spatial Distribution of Average Mean Temperature.



(a) Mann Kendall (MK) (b) Innovative Trend Analysis (ITA)



(c) Sen's Slope Estimator (SSE) (d) Linear Trend Plot (LPT)

Figure 4.8: Spatial Variations of Temperature Trend

Spatial Variations of Temperature Trends

Figures 4.8 (a), (b), (c), and (d) show the spatial analysis of the temperature trends from the results of MK, ITA, SSE, and LTP respectively. Kano and Enugu show no trend with the MK test but only Enugu maintained no trend or decreasing trend with the rest of the other three tests. It is also only the MK test that showed no trend in Kano but all the other three tests detected increasing trends for Kano. The four tests showed increasing trends for Calabar, Lagos, Abuja, and Maiduguri. This represents 66.7% of all the stations considered. The increasing trends observed at most stations indicate the effect of climate change. It is a result of increased greenhouse gas emissions, rapid land use changes, and uncontrolled urbanisation. Socioeconomic activities sensitive to higher temperatures should be planned with a focus on contingency mitigation and adaptation strategies.

V. Discussion

The MK, ITA, and SSE trend detection tests were individually conducted at various stations over an annual time series spanning 50 years (1971 to 2020) at a 5% significance level (Akinsanola et al., 2014). The MK and ITA tests were applied at 1% and 10% significance levels. These methods were applied to assess the annual mean temperature for all the stations. The reliability of the data was evaluated using autocorrelation analysis. Consequently, nonparametric methods (MK and ITA) were utilised to assess the trends in this study. The SSE and LTA results were used to confirm the results of the MK and ITA tests. Based on the findings, ITA outperformed the MK tests, and the SSE and LTA slope magnitudes aligned well. The results show that the methods produced statistically significant and consistent results for all the stations investigated. The minor discrepancies in the results may have arisen from the uncertainty and quality of the input data used. The sources of error have been outlined in section 3.0.

The nonparametric tests have shown an interesting insight into annual temperature data for the six stations studied. The temperature trend results do not follow any particular order on a latitudinal basis. Desertification and drought are already evident in the northernmost parts of the country, and these phenomena will likely worsen with further temperature increases. The country's northern regions are currently grappling with incessant conflicts between farmers and herders, which may worsen due to decreasing arable land and grazing reserves caused by rising temperatures. If temperature trends persist, the impact on ecosystems, wildlife, people, and habitats nationwide will vary across different zones. Shifts in temperature patterns are projected to alter ecological classifications and the habitats of forests, animals, birds, and insects, with potentially far-reaching implications for human health, food security, and productivity. Rising temperatures will also lead to more frequent heat waves and heat-related stress, presenting a significant challenge to vulnerable populations, including the elderly and outdoor workers such as construction workers, farmers, and sports enthusiasts.

Based on the above results, it is of immense importance to discuss the ecological, economic, and social impacts that could result if increasing temperature trends continue in these stations. It is crucial to comprehend how this trend might impact ecosystems and human life. Temperature changes will cause a shift in forest and insect habitats (Evans A. and Perschel R., 2009). Also, the temperature rise will result in intense heat waves that could be challenging for ageing and other vulnerable populations.

Agriculture

Nigeria is a country that benefits from its naturally endowed diverse climatic conditions which range from dense rain forests in the south to the semi-arid zones in the north. Rainfed agriculture is the primary occupation of the people in the south. Some of the major cash and food crops are cassava, yams, cocoyam, sweet potatoes, cocoa, oil palm, rubber, and cola nuts. They grow well in the country due to its diverse climate. The increasing trend in temperature will lead to a decline in food production across the country. The impact of climate change on these crops has been thoroughly discussed in the literature (Adamaagashi,2023; Tajudeen, 2022). An increase in temperatures in the regions where these crops are cultivated will affect crop production and subsequently food security and the economy, which mainly depends on rainfed agriculture.

The detected increase in temperature trends across Nigeria will impact the economy negatively. The economy is already suffering from foreign exchange scarcity and further stress exacerbated by climate change will portend a more difficult time for citizens. Nigeria has a diverse range of agricultural products in the northern and southern regions. Unfortunately, climate change is having a noticeable impact on agriculture, particularly the climate-sensitive ones. This, in turn, will affect food security and lead to population migration in search of better opportunities.

Among the agricultural sectors that will be affected by high temperatures is the dairy industry. Heat stress will cause a decline in milk production and reproduction rate since cows are sensitive to heat above 23°C. The dairy industry, poultry farming, and other sectors are expected to experience negative impacts due to rising temperatures, especially in the North. The heat stress on birds will reduce milk and egg production, while the reproduction rates of cattle will significantly decrease. For example, cows are sensitive to heat above 23°C and once the ambient temperature reaches 29.5°C, chickens experience a decline in egg production. Chickens lay eggs best when the ambient temperature is between 11°C and 26°C. Heat stress will cause a decrease in egg production, while extreme temperatures, whether hot or cold, will also have a significant impact on egg production.

Water resources

Rising temperatures are expected to negatively impact the availability of water resources such as ponds, lakes, dams, and surface water. These sources are crucial for providing irrigation for dry-season farming and serving as drinking water for livestock, particularly in the northern regions where cattle rearing is a major occupation. Rising temperatures will increase water evaporation, increasing precipitation and a greater risk of flooding. Nonetheless, the increased rainfall will also positively affect groundwater recharge. The rising temperature patterns are projected to diminish groundwater recharge, potentially upsetting the equilibrium of water levels (Moser et al., 2008).

Coastal areas are expected to experience a rise in salinity intrusion as global temperatures increase. The temperature increase will consequently impact the fishing industry. The mangrove forests in the coastal Niger Delta will be severely affected by the temperature increase and may disappear entirely. As a result of climate change, new ecological features will emerge while established ones will disappear from the region. Climate change will further exacerbate the already-damaged biodiversity in the coastal and Southeast regions due to temperature increases. The frequency of extreme weather events such as flooding during the rainy season is also expected to rise. Responsible institutions and stakeholders must implement appropriate strategies to abate the severe impact of future extreme weather events and climate change in the country. Integrating the obtained results into model development will improve the accuracy of flood forecasting and groundwater balance management for effective control of hydrological events. The spatial trend analysis should always be a significant component of assessing groundwater availability to avoid adverse socioeconomic impacts on stakeholders.

Also, rising temperatures in coastal areas will lead to salinity intrusion negatively impacting fish production. The mangrove forest of the Niger Delta will be significantly affected by the rising temperatures (Nababa, 2020). Severe thunderstorms have already caused significant harm to the biodiversity of mangrove forests in the delta regions. It is expected that more frequent extreme weather events will occur due to rising temperatures (Sesan, 2024). Flooding during the rainy season is another consequence of global warming in Nigeria. Earlier studies suggest a clear link between temperature rise and the occurrence of floods, indicating that some regions of the country may experience more frequent flooding (Tabari, 2020). In conclusion, rising temperatures due to climate change, particularly in warmer regions, will likely lead to more climate change consequences in many sectors of the economy in the coming decades.

Health

The maps showing spatial trends should be correlated with the prevalence of climate-related diseases, such as malaria, heat stroke and zoonotic diseases. This is particularly crucial for the urban areas of Nigeria, where climate change is projected to significantly impact public health, particularly causing an increase in heat-related illnesses. To mitigate these adverse effects, various adaptation measures are recommended. This study provides valuable insights to guide experts, policymakers, and stakeholders in making climate-smart decisions that improve livelihoods and enhance productivity. These diseases increase with the rise in temperature, humidity, and rainfall. Generally, these weather conditions provide favourable breeding grounds for mosquitoes, rodents, reptiles, and other disease vectors. This can lead to outbreaks and rapid transmission of waterborne and zoonotic diseases. The increase in temperature will result in a rise in the number of biting insects an d rodents, leading to the transmission of vector-borne diseases such as dengue fever, malaria, and yellow fever. Moreover, due to the shifts in warmer climates, areas that have been hitherto free from such diseases may experience outbreaks. In Africa, malaria presents a significant health threat, with about 93% of global malaria-related fatalities occurring on the continent. Nigeria is especially affected by malaria, with an estimated 68 million cases and 194,000 deaths linked to the disease in 2021. Globally, Nigeria bears the highest malaria burden, representing nearly 27% of all cases (WHO, 2022). Additionally, the warming of the plateau highlands will enable malaria-carrying mosquitoes to survive at these elevated altitudes.

Jet Streams

Jet streams are narrow bands of strong winds in the upper atmosphere that flow west to east, but often have latitudinal movements depending on temperature difference. Omotosho, 1985 demonstrated that the jet stream plays a crucial role in generating large-scale convection in the subtropics. An increase in temperature increases the capacity of the atmosphere to hold precipitable water, which increases the chances of rainfall (Green et al., 2011). Another possible reason behind such a shift in storm development could be changes in the presence of the jet stream. The strength of these winds increases as the temperature difference between the two locations increases and the regions around 30° and 50°-60° Latitude are the regions where these winds are the strongest (NOAA). Research has further suggested that global warming will cause jet streams to rise in altitude and shift towards the poles (Lenoir et al., 2013). In a study conducted at the Carnegie Institution over 23 years (1979-2008), scientists found that jet streams in both hemispheres have risen in altitude and shifted toward the poles. This could have implications for the frequency and intensity of future storms, including tropical storms. As jet streams move away from the subtropical zone, where tropical storms form, the storm paths are likely to become stronger and shift poleward because their development is inhibited by the jet streams (Science Daily).

VI. Conclusions

This study analysed the average annual and monthly temperatures at six different stations across Nigeria from 1971 to 2020. The findings indicate that temperature is on the rise in all the stations except Enugu. This confirms the consequences of global warming and climate change at national and regional levels. Out of the six stations analysed for temperature series, only Enugu, representing 17%, showed no significant trend or a decreasing trend across the four tests. However, the remaining five stations, representing 83%, showed an increasing trend, except Kano, which also showed no trend with the MK test. The annual and monthly average temperature series mostly showed significant positive trends. It was also observed that different significant trend magnitudes were presented across all stations, confirming that different regions would be affected differently by global warming and climate change. The randomness of the dataset further validated the use of nonparametric methods. The findings confirmed the predicted impact of climate change in different zones.

Valuable insights and perspectives have been provided for policymakers and planners to proactively address the potential impacts of climate change on socioeconomic activities. It is important to always consider the local perspectives. The temperature trends observed at each station might have been influenced by local factors that do not necessarily reflect the broader regional effects, such as land use and urbanisation. Instituting timely measures and ensuring institutional changes can help mitigate the irreversible damages associated with climate change. The data from the 50-year analysis have provided the necessary red flag, making it imperative to take action sooner rather than later.

With good planning and ecosystem management, a significant reduction in climate change impact and associated risks can be achieved. It is therefore strongly recommended that strategic actions should be taken to create a good land use system and climate-friendly practices such as tree planting, smart agriculture and efficient energy utilisation. Institutions and knowledge systems should be encouraged to adapt quickly to changing conditions to avoid interruptions to the food security and comfort of the citizens. As climate change continues to have an increasingly significant socioeconomic impact, conducting more extensive research into temperature trends across various ecological zones has become imperative.

Limitations of the Study

The study used only one data point to represent each geopolitical zone, which may not provide an accurate representation. Data from multiple stations across an extended period for each geopolitical zone will produce more reliable conclusions. The data collected from the weather station in Abuja was only for 38 years, whereas the data from the other stations was collected for 50 years. It also didn't consider the effect of land use and urbanisation to recommend the impact of the increasing trend on livelihoods and socioeconomic activities.

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