TREND ANALYSIS OF CLIMATE CHANGE OVER NIGERIA: A MANN-KENDALL AND SEN'S APPROACH

ABSTRACT

This study investigates the long-term variations in temperature and precipitation across Nigeria's climatic zones, focusing on their impact on agriculture and water resources. Using data from Calabar, Ibadan, Kano, and Kukawa to represent the tropical monsoon, tropical savannah, semi-arid and desert climate, respectively, the research adopts the Mann-Kendall trend test, innovative trend analysis, and anomaly analysis to assess climate trends and their implications. The findings reveal significant warming trends across all locations, particularly in semi-arid and desert zones like Kano and Kukawa, with temperature increase of 0.0443°C/year and 0.0412°C/year, respectively. It was further observed that precipitation trends varied by region, with Calabar showing a monthly decrease of -1.26 mm/year, while Kukawa exhibited an unexpected significant increase, which suggest potential greening in the desert. The study underscores the need for region-specific climate adaptation strategies. For instance, increased warming in semi-arid zones calls for enhanced water conservation efforts, while the rising precipitation in desert regions raises concerns about flood risks and water management. The results highlight the importance of multi-scale and spatial analysis to better inform climate-related policy decisions. National and regional policymakers must adopt targeted agricultural practices, improve water resource management, and implement climate resilience strategies to mitigate the adverse effects of these climatic shifts.

Keywords: Climate change, temperature trends, precipitation variability, agriculture, water resources

1.0 INTRODUCTION

Climate change is a long term shift in regional or global climate patterns, often characterised by changes in average temperatures, precipitation patterns and increased frequency of extreme events [1]. These observations and impacts have been attributedto unfriendly human activities that compromises the earth's environmental integrity. The most compromising activity being the emission of greenhouse gases like Carbon dioxide(CO_2)from oxidising fossil fuels.

Nigeria, a nation located in West Africa, is susceptible to significant impacts of climate change due to its large population estimated to be exceeding 250 million and its overdependence on climatic sensitive sectors such as oil exploration and agriculture [2-3]. Moreover, the deprecatinginfrastructure and poor technological competencies in preparatoryapproachestargeted at mitigating against climatic risks are responsible for the nation's poor adaptive form to natural disasters and climate change emergencies.According to Haider [4], Nigeria's rainfall patterns has become more variable, where later onset and earlier cessation of the rainy season can be observed in many areas, outside of the norm. This has facilitatedmore frequent and intense extreme weather events like floods and droughts.Akpodiogaga-a &Odjugo [5] climatic projections suggest that sea levels may rise by 1 meter in 2100, threatening the residents of Nigeria's coastline areas; further corroborating, Akande *et al.* [6]asserts on the likelihood of more frequent and severe droughts floods, heat waves and possible storms.

The necessity of climatic studies is easily gleaned from the impact climatic change has had on Nigeria key sectors. First, agriculture is a main stay in the Nigerianeconomywith over 70% of the population depending on subsistence or commercial forms of farming and agricultural products for their livelihood [7]. Agricultural productivity is threatenedby climate change as follows: reduced and more variable rainfall affects crop rotations especially in

Northern Nigeria [8]; higher temperature and heat stress that wilts crops and affects livestock, respectively [9]; increased frequency of drought and floods is damaging to crops and fishing of riverine communities [10]; sea level rise and saltwater intrusion compromises coastline agriculture [11].Second, the water resources availability and quality are drastically affected by climate change. This is seen in the reduced rainfall and higher evaporation rates that are decreasing river flows and groundwater recharge [6]; more frequent floods contaminating fresh water sources and causesaltwater intrusion in coastalaquifers of local communities [11]. Third, socio-economic impacts would result in food security and jeopardised livelihoods [10]; displacement of coastal communities due todamages inflicted on coastal ecosystems [12][13]; and climate induced migration that would increase rural to urban migration pressures [14][15]. In the case of energy impacts, climate change influence over rainfall patterns would weaken the nation's hydro-power generation efficiency [16]; extreme weather conditions could damageenergy and powerinfrastructure [17][18]; energy demands and prices would skyrocket during extremely hot conditions in this region [19].

Pre-empting these results of climate change demands the organisation and implementation of robust contingency measures that accurately target the root causes of these problems. Nigerian government's consistent attack on irrelevant and proximate issues to climatic problems such as the Vice President's Kashim Shettima pledging to support the victims of the Alau Dam flood in Maiduguri of Borno State with 50 trucks of rice[20]is not suitable nor sustainable. Hence, the need to identify climate change patterns through trend analysis, as the insight obtained from such studies would help inform data-driven decisions on how best to approach climate change issues. Rain variation is currently the most critical climate change problem faced by Nigeria, as observed in the excessivefloods and droughts within irregular timeframes [10]. This buttresses the need for a study such as this, that employs the Mann-Kendall (MK) test and the Sen's slope estimator in effectively detecting and quantifying trends within Nigeria's climatic variables. The contribution of such methods is in their certified capabilities in examining temperature and precipitation fluctuations across various temporal scales [21][22].

Based on the above, the research aims to conduct a trend analysis of climate change over Nigeria using the Mann-Kendall (MK) test and Sen's slope estimator. This will be achieved by analysing 42 years (1981-2022) of monthly temperature and precipitation data from four locations representing different climatic zones in Nigeria

The specificobjectives include:

- Assess annual and seasonal trends in temperature and precipitation across Nigeria's climatic zones using the Mann-Kendall test.
- Quantify the magnitude of identified trends using Sen's slope estimator.
- Analyse temporal variations in temperature and precipitation within distinct climatic zones and identify extreme events.
- Elucidate the implications of observed climate change impacts on agriculture, water resources in Nigeria, and provide evidence-based policy recommendations for national and regional climate change adaptation and mitigation strategies.

2.0 LITERATURE REVIEW

Utilising both the Mann-Kendall (MK) test and Sen's slope estimator has helped unravel critical insights into regional and national climate patterns. Sam *et al*. [23] used both the MK test and Sen's slope in analysing rainfall and temperature trends in Nigeria from 1986 to 2015. Their study showcased MK test's versatility in employing different scales as applicable to monthly, seasonal and annual data sets. The result showed significant increasing trend in rainfall for March and May, with maximum temperatures identified in June and August. Their use of the Sen's slope facilitated a quantification of observed trends, further informing climate change adaptation strategies needed in Nigeria. Asgher et al., [24] examination of rainfall and temperature data in Pakistan from 1982 to 2017 revealed the importance of examining trends at multiple temporal scales. The results showed that while annual precipitation revealed no significant trend, the monthly analysis showed significant decreasing trends in March and May. Further, emphasising the importance in careful consideration of temporal resolution in climate trend analysis.

Simultaneously, the authors in [25] investigated the precipitation and temperature trends in the Yangtze River Basin from 1960 to 2015. The results presented spatial variability of climate trends, with different regions of the basin experiencing distinct warming and precipitation patterns. Additional validation of the study findings was enabled through a comparison of MK test results and the innovative trend analysis (ITA) method. Further highlighting the complimentary approaches of different statistical approaches in climate trend analysis. Meena [26]examined rainfall data in the Udaipur district of India from 1957 to 2016.The methods permitted trend detection at different spatial scales from the district level down to individual tehsils (sub-districts). The quantified trend using Sen's slope was an overall increasing trend of 3.4 mm/year for the district, a critical information that is helpful to their local water resource management strategies.

Ali et al., [27] assessed streamflow trends in the Yangtze River from 1980 to 2015 and their study underscore the complexities associated with hydrological trends and the different patterns observed in mean annual flow, minimum flow and maximum flow. The results showed critical shifts in the Yangtze river's hydrological regime such as increasing winter flows and decreasing summer flows.Diress&Bedada [28]used both techniques in conjunction with the coefficient of variation (CV) in analysing rainfall variability in Rajasthan, India from 1957 to 2016). Examining 13 tehsils (sub-districts) showed that the CV for rainfall ranged from 30% to 42% across tehsils. The highest rainfall was observed between July and August and lowest rainfall was found to occur between November and February. Aditya *et al*.,

[29]examined annual and seasonal rainfall patterns in West Kalimantan of Indonesia, focusing on the Mempawah and Kubu Raya regions using data from 2000 to 2019. In addition to the use of MK test and Sen's slop estimator, the study employed the Pettitt's test in testing for homogeneity within the data series. The seasonal pattern results showed that highest rainfall occurred in the wet season of March to October, while the dry season lasted from November to February. Most monthly trends occurred between April to June and September to November, with significant upward and downward trends detected in eight locations

Alashan [30]employed both the modified MK (MMK) test, Sen's slope estimator and Sen's innovative trend analysis (ITA) in examining the monthly maximum temperatures from Oxford England for years between 1852 to 2017. The purpose of using modified forms of the existing approaches is for improved trend detection. This comparison of different approaches revealed significant increasing trends in maximum temperatures for most months. However, the MMK-ITA approach detected an increasing trend in April, which the MMK-SSE was unable to. Agbo *et al*., [31] assessment of Nigeria's climatic zones using the MK test, Sen's slope estimator and Sen's innovative trend analysis using data from 1981 to 2020. The findings revealed that no parameter showed significant monotonic trends across all climate zones. However, the ITA methods detected significant trends for non-monotonic variations. Moreover, high correlation was observed between refractivity, equivalent potential temperature, and related parameters

Lastly, in [32], the authorsemployedboth techniques in conducting a comprehensive analysis of meteorological parameters such as temperature, atmospheric pressure, relative humidity, and derived variables such as refractivity and equivalent potential temperature of Calabar, Cross River State using data obtained from 1986 to 2019. The multi-scale analysis used permitted an examination of trends at annual, seasonal and monthly temporal scales, with inclusion of derived variables such as refractivity and equivalent potential temperature extending the relevance of this study to telecommunications and atmospheric physics. The annual trends showed significant increasing trends in atmospheric pressure and maximum temperature. The wet seasonal trend showed significant decreasing trends in relative humidity and minimum temperature.

The use of MK test and Sen's estimator within the reviewed contemporary studies on analysis climatic variables strongly validates the robustness of both techniques as the non-parametric nature of both techniques gives them the distinct advantage of analysing non-normally distributed data, often a common feature of environmental time series [22]. Moreover, it is a more suitable approach to handling missing data and outliers. As with all techniques, it has its own inherent limitation such as its assumption that trends are monotonicallyincreasing or decreasing. However, this can be overcome by careful data pre-processing or even modifying key aspects of the tests as seen in later studies. Furthermore, as seen in [24], the trends detected at one temporal scale such as annual, would likely differ from those of another scale such as monthly. Thus, highlighting the significance of multi-scale analysis. The most employed solutions to such challenges include MK test and Sen's estimator integration with other methods such as comparisons with the innovative trend analysis (ITA) method [27];andconsidering multiplelevels of significance in p-values to facilitate a more nuanced analysis of climatic trends.

3.0 STUDY AREA AND METHODOLOGY

This study focuses on four key areas within each of Nigeria's climatic zones, namely, Calabar in tropical monsoon; Ibadan in tropical savannah; Kano in warm semi-arid; and Kukawa in warm desert climate

i. Calabar: Calabar is the capital of Cross-Rover State and encompasses two local government areas (LGA), namely, Calabar Municipality and Calabar South LGAs. Calabar lies within latitudes 4˚50'N and 5˚10'N and longitudes 8˚17'E and 8˚20'E and is wedged between the Great Kwa River and the Calabar river to the East and West, respectively. There has been a noticeable expansion in its physical boundaries, however expansion in its Southern part is hindered by the presence of mangrove swamps [33-36].

ii. Ibadan: Ibadan is situated on a hilly terrain with elevation of about 210 metres above the sea level. It les 145km north-east of Lagos state and is located within latitude 7° 05N and 7° 25N and longitude 32 °40 E and 32° 55 E. identified for its woodlands, secondary forests and tropic vegetation communities, most of its population are into mixed cropping and extensive agriculture [37].

iii. Kano: The city of Kano (differentiating it from the state) is the second largest urban agglomeration in Nigeria. Both the core city and its periphery number up to five million inhabitants as at the last national census. Urban Kano and its peripheries are located within latitudes 11◦50′and 12◦07′N and longitudes 8◦22′and 8◦47′E. Located 800km from the Sahara Desert to the north and about 1000km form the Atlantic Ocean to the South. As a critical urban centre in Nigeria’s northern region, the individuals largely engage in the services sector and some mid-tier manufacturing of goods such as leather works [38].

iv. Kukawa: Kukawa is one of the 27 local government areas (LGA) in Borno state. Located in the northern part of the state, it shares an international border with the nation of Chad, having the following coordinates 12^{0}55’33’’ North and 13^{0}34’12’’ East.The average elevation is estimated to be 277 metres. The population estimated to be 25,000 is largely dependent on farming and fishing; and the area is actively considered by the Nigerian National Petroleum Corporation (NNPC) as a potential crude oil prospecting area [39].

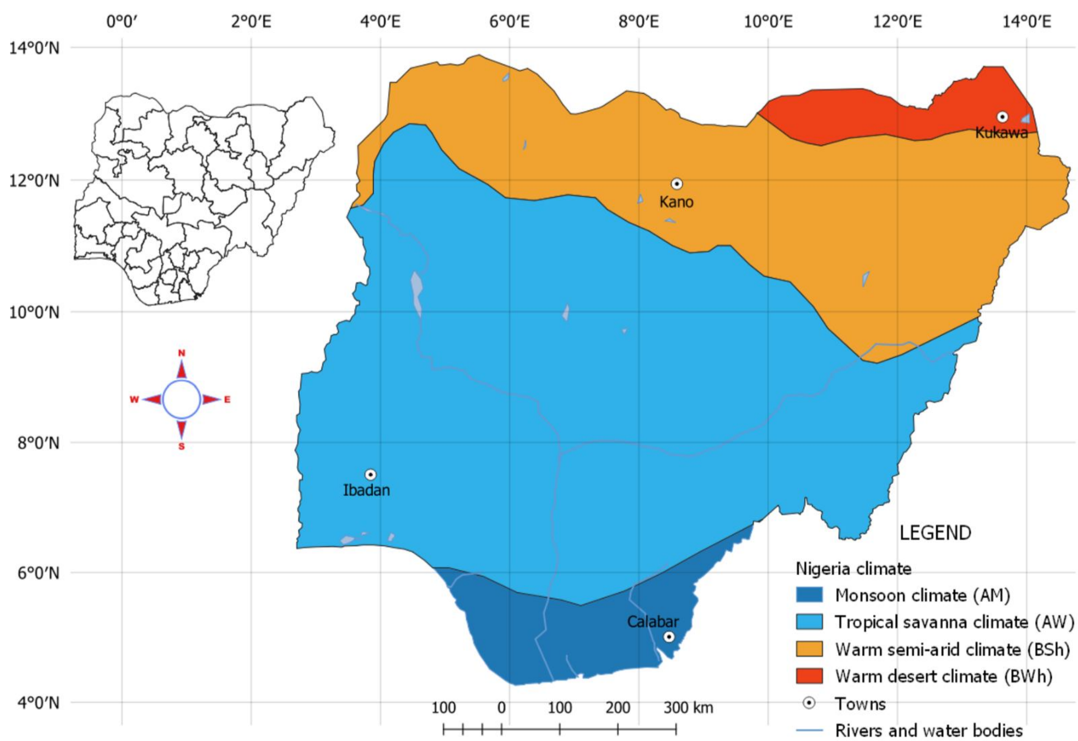

Figure 1: Map of Study Area, showing study locations.

Monthly data for earth skin (surface) temperature and precipitation was gathered for 42 years (1981 - 2022) from the NASA POWER DATA archive for four locations; one from each climatic zone in Nigeria. The data will be received in CSV format, processed and cleaned utilizing tools like MS Excel and Python Programming language. The mean of the monthly data for each year will be calculated to obtain the annual data. The analysis will be carried out using Python programs such as *sklearn, matplotlib, seaborn, numpy, pandas, and pymannkendall*. MK and Sen's tests will be utilized to identify trends in the data. Results will be presented in tables and charts for ease of understanding.

Trend analysis with Mann-Kendall and Sen's estimator

We use the MK test to analyze time-series data. Since the test is non-parametric, the data do not have to fit into a particular distribution for it to be valid [40]. When a set of data shows a linear relationship, this test is applied. When examining meteorological, hydrological, and climatological time series, the test is typically used [41-43].

$$S = \sum_{k=1}^{n-1} \sum_{j=k=1}^{n} \operatorname{sgn}(x_j - x_k) \tag{1}$$

where;

$$\operatorname{sgn}\left(x_j - x_k\right) = \begin{cases} +1; & if\left(x_j - x_k\right) > 0 \\ 0; & if\left(x_j - x_k\right) = 0 \\ -1; & if\left(x_j - x_k\right) < 0 \end{cases} \tag{2}$$

From equation (1)

- n is the the number of data values; 42 (years) in our case.
- Having a positive S value denotes an upward trend, while a negative S value denotes a downward trend. This magnitude of the S value (either positive of negative) determines the magnitude of the upward or downward trend.

If the number of data points/values are more than 10; 42 (years) in our case, it is advised to also incorporating the normal approximation (Z-statistic) to the analysis. The equations below will guide this.

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p\left(t_p - 1\right)\left(2t_p + 5\right)\right] \tag{3}$$

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}}; & S > 0 \\ 0; & S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}}; & S < 0 \end{cases} \tag{4}$$

The variance of S *'VAR(S)'* in equation (3) is adopted in equation (4) to calculate the Z value. In order to understand the results, one can identify a declining trend when the Z value is negative and a rising trend when the Z value is positive. Both interpretations (rising or declining trends) can be seen as having significance when the null hypothesis (*Ho*) is rejected, i.e., if and when the data's p-value is smaller than the significance level (in this case, 5% or 0.05). Furthermore, *Ho* is accepted if the p-value exceeds the significance threshold, indicating that the trend is not significant.

4.0 RESULTS

4.1 Descriptive Analysis

Table 1: Descriptive Statistics of temperature and precipitation for all study locations

	TEMPERATURE				PRECIPITATION			
	Calabar	**Ibadan**	**Kano**	**Kukawa**	**Calabar**	**Ibadan**	**Kano**	**Kukawa**
Years	42	42	42	42	42	42	42	42
Mean	25.85	25.15	25.88	31.08	2923.85	1615.50	711.05	361.51
Std	0.38	0.30	0.87	0.68	715.20	301.71	291.68	130.36
Min	25.17	24.50	24.30	29.59	1592.58	996.68	200.39	158.20
25%	25.57	24.92	25.22	30.66	2452.15	1439.65	490.43	261.04
50%	25.86	25.15	25.66	31.06	2863.48	1597.85	725.10	329.59
75%	26.10	25.37	26.73	31.57	3160.11	1734.96	838.48	419.24
Max	26.52	25.81	27.33	32.35	5600.39	2391.54	1845.69	748.83

The descriptive statistics for all location have been presented in Table 1; they have also been represented in a Figures 2 and 3. The box plots in Figure 2 depict the temperature dispersion in four locations: Calabar, Ibadan, Kano, and Kukawa. Notably, Kukawa has the highest median temperature, around 31°C, with a narrow interquartile range (IQR), indicating low variability in temperature data. Kano has the largest distribution, with a lower median temperature of 27.5°C and a big IQR, indicating greater temperature variability. Ibadan and Calabar have lower median temperatures, approximately 26°C and 25°C, respectively, with very modest fluctuations. The wide variance in Kano reflects a more diverse environment in the semiarid region, whereas the consistency in Kukawa indicates more stable, higher temperatures.

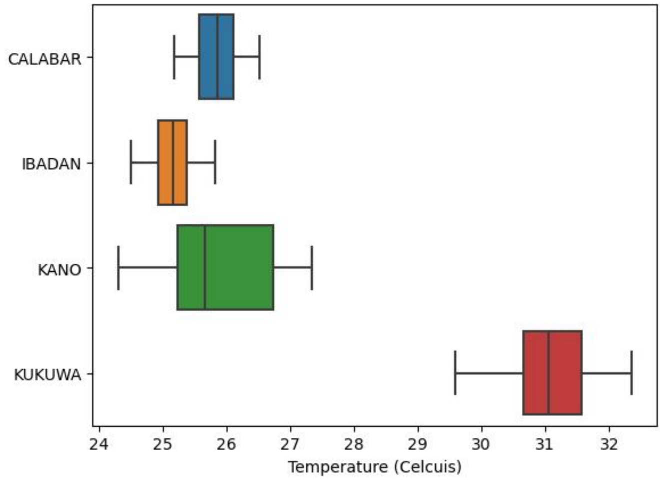

Figure 2: Box plots showing data distribution for temperature, across all locations

Figure 3 depicts significant variances in the distribution of precipitation data between regions. Calabar receives the most rainfall, with a median of roughly 3000 mm and a broad IQR, indicating substantial variability in precipitation. Outliers indicate that this place may see extreme rainfall. Ibadan gets modest rainfall, with a median of roughly 1300 mm, and there is some variability. Kano and Kukawa, both in semiarid zones, have substantially lower median precipitation levels (about 800 mm and 200 mm, respectively), with Kukawa showing very little variability.

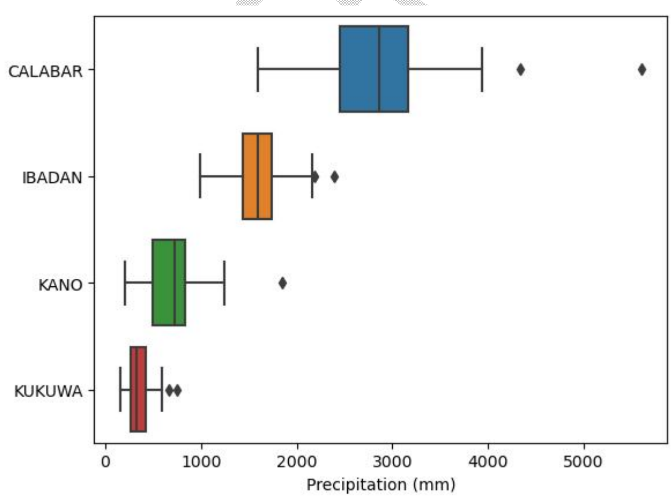

Figure 3: Box plots showing data distribution for precipitation, across all locations

The data offer crucial insights: locations like Calabar have more precipitation variability, heightening flood concerns, but Kano and Kukawa have lower and more variable rainfall, potentially exacerbating drought conditions. The unpredictability in Kano's temperature and precipitation indicates rising climatic stress, necessitating adaptive water resource management and agricultural methods.

4.2 Annual Mann-Kendall test and Sen’s slope results

The annual trend results for the MK and Sen’s slope results have been presented in Table 2 for all locations. For the tropical monsoon location (Calabar), the results reveal a significant increasing trend in temperature, as indicated by the high Z-value (5.88) and the p-value (< 0.05) confirming the significance of the trend. The slope from Sen’s estimator (0.0268) indicates a modest but consistent annual increase in temperature, suggesting a warming trend in the tropical monsoon region. However, in spite of the high magnitude for precipitation in the tropical monsoon climate, no significant trend was detected for precipitation, as indicated by a Z-value of -0.271 and a p-value of 0.786. The slight negative slope (-2.11) does not suggest any meaningful changes. The absence of a trend implies that precipitation patterns in this humid region have remained stable, which may help maintain agricultural productivity. For the increasing temperature trend, the implications of this could include increased heat stress for both agriculture and human health (especially with the regions high magnitude of precipitation/rainfall), necessitating adaptation strategies in the region.

Table 2: Annual Mann-Kendall test and Sen’s slope results for temperature and precipitation, across all locations (1981 – 2022)

Test Parameters / Locations	**Calabar (Tropical Monsoon Climate)** *(Lat. 5.0118, Long. 8.4676)*		**Ibadan (Tropical Savannah Climate)** *(Lat. 7.507, Long. 3.8478)*		**Kano (Warm semiarid climate)** *(Lat. 11.9455, Long. 8.5884)*		**Kukawa (Warm Desert Climate)** *(Lat. 12.9566, Long. 13.6256)*	
Parameter	T	P	T	P	T	P	T	P

Z value	5.88	-0.271	0.987	1.6	3.4	-1.66	-0.249	3.74
Test Statistic (s)	543	-26	92	149	315	-154	-24	346
Slope	0.0268	-2.11	0.005	6.86	0.0443	-6.53	-0.00294	6.02
Intercept	25.3	2910	25	1450	24.8	859	31.1	206
p-value	4.18E-09	0.786	0.324	0.109	0.000666	0.0972	0.803	0.000184
Hypothesis	ACCEPT	REJECT	REJECT	REJECT	ACCEPT	REJECT	REJECT	ACCEPT
Trend	Increasing	No Trend	No Trend	No Trend	Increasing	No Trend	No Trend	Increasing

For the tropical savannah location in Ibadan, there was no statistically significant trend in both temperature (p-value of 0.324) and precipitation (p-value of 0.109). For the temperature trend, the slope (0.005) indicates only minimal variation over time. This suggests that the temperature in the tropical savannah zone has been relatively stable, although further monitoring might be necessary given the potential for future fluctuations due to climate change. Although the precipitation trend in the location is not statistically significant and cannot be confirmed, the Z-value (1.6) suggests a positive variation. The slope (6.86) indicates a potential increase in rainfall, but further observation is needed. Stable precipitation in the savannah could support rainfed agriculture.

For the warm semiarid climate of Kano, the results show a significant increase in temperature with a Z-value of 3.4 and a low p-value (0.000666). The slope (0.0443) shows a more substantial upward trend in comparison to Calabar. This increasing temperature could exacerbate drought conditions, stressing agriculture and water availability in northern Nigeria. It is also of no surprise that the test reveals no increasing trend in precipitation. The slightly negative Z-value (-1.66) means that precipitation is reducing annually, but this is not statistically significant according to the MK test, implying that there is no definitive trend in rainfall patterns. The negative slope (-6.53) suggests a tendency toward reduced precipitation, which, if it continues, could exacerbate water scarcity and desertification in this already dry region.

In contrast to the other locations, the warm desert climate of Kukawa shows no significant trend in temperature, with a negative Z-value (-0.249) and a p-value (0.803). Given the desert climate, stability in temperature trends may provide temporary relief, though the harsh environment remains vulnerable to other climate-induced stressors. Kukawa also shows a significant increasing trend in precipitation unlike other locations with a Z-value of 3.74 and a p-value of 0.000184. The positive slope (6.02) suggests a substantial annual increase in rainfall. This trend could signal a slight shift in desert climate patterns, potentially offering minimal relief from extreme dryness. This may be attributed to the precipitation arising from sea breeze in neighbouring water bodies like the lake Chad.

In conclusion, growing heat-related hazards to agriculture, water resources, and public health are highlighted by the rising temperatures in Calabar and Kano. Furthermore, long-term monitoring is still necessary despite the brief respite offered by the steady temperatures in Ibadan and Kukawa. For the precipitation variation, most locations appear to have stable rainfall patterns due to the lack of major increase in precipitation; nevertheless, Kukawa's desert environment has significantly increased, which may indicate substantial changes in weather patterns. The management of water resources and agriculture in that region may be impacted by this in both positive and negative ways.

4.3 Seasonal Mann-Kendall test and Sen's slope results

The combined seasonal analysis of temperature and precipitation trends across the four Nigerian climatic zones (Table 3 and 4) reveals significant regional variations, highlighting the impact of climate change on these parameters.

Table 3: Mann-Kendall test and Sen's slope results for temperature and precipitation for the Dry season, across all locations (1981 – 2022)

Test Parameters / Locations	**Calabar (Tropical Monsoon Climate)** *(Lat. 5.0118, Long. 8.4676)*		**Ibadan (Tropical Savannah Climate)** *(Lat. 7.507, Long. 3.8478)*		**Kano (Warm semiarid climate)** *(Lat. 11.9455, Long. 8.5884)*		**Kukawa (Warm Desert Climate)** *(Lat. 12.9566, Long. 13.6256)*	
Parameter	T	P	T	P	T	P	T	P
Z-value	8	-0.226	-0.0485	2.49	3.99	0.969	1.33	-1.32
Test Statistic (s)	1652	-47	-11	494	825	50	276	-33
Slope	0.0278	0	0	0	0.0343	0	0.012	0
Intercept	25.7	52.7	25.3	15.8	21.6	0	26.9	0
p-value	1.11E-15	0.821	0.961	0.0127	6.50E-05	0.333	0.183	0.187
Hypothesis	ACCEPT	REJECT	REJECT	ACCEPT	ACCEPT	REJECT	REJECT	REJECT
Trend	Increasing	No Trend	No Trend	Increasing	Increasing	No Trend	No Trend	No Trend

Table 4: Mann-Kendall test and Sen's slope results for temperature and precipitation for the Wet season, across all locations (1981 – 2022)

Test Parameters / Locations	**Calabar (Tropical Monsoon Climate)** *(Lat. 5.0118, Long. 8.4676)*		**Ibadan (Tropical Savannah Climate)** *(Lat. 7.507, Long. 3.8478)*		**Kano (Warm semiarid climate)** *(Lat. 11.9455, Long. 8.5884)*		**Kukawa (Warm Desert Climate)** *(Lat. 12.9566, Long. 13.6256)*	
Parameter	T	P	T	P	T	P	T	P
Z value	12.8	-2.02	7.1	1.86	7.39	-5.07	-1.35	4.41
Test Statistic (s)	3124	-494	1733	454	1805	-1233	-331	1020
Slope	0.0242	-1.26	0.0125	0.719	0.0412	-0.811	-0.00923	0
Intercept	25	348	24.7	180	27.1	90.8	33.2	21.1
p-value	0	0.0433	1.26E-12	0.0632	1.46E-13	3.97E-07	0.176	1.04E-05
Hypothesis	ACCEPT	ACCEPT	ACCEPT	REJECT	ACCEPT	ACCEPT	REJECT	ACCEPT
Trend	Increasing	Decreasing	Increasing	No Trend	Increasing	Decreasing	No Trend	Increasing

From Table 3, temperatures in the tropical monsoon climate zone (Calabar) increases significantly during both the dry and wet seasons. The dry season has a Z value of 8, a p-value < 0.001 and a Sen's slope value of 0.0278, demonstrating a consistently rising trend in temperature. Similarly, the wet season has a Z value of 12.8, a p-value close to zero, and a somewhat lower value for its Sen's slope (0.0242).

Calabar's dry season has no significant trend in precipitation, however, the wet season shows a significant decreasing trend, with a Z value of -2.02, a slope of -1.26, and a p-value of < 0.05. The decrease in wet-season rainfall is may be both advantageous and concerning because it may signify restricted water availability which will affect agricultural productivity in this area, or reduced floods in an area where rainfall is quite consistent.

Temperatures in Ibadan (tropical savannah), exhibit no significant trend during the dry season. However, during the wet season, temperatures rise significantly, with a Z value of 7.1, a slope of 0.0125, and a p-value of < 0.001. This increasing trend during the rainy season may cause increased heat stress throughout the agricultural growth season. This will lead to increased human discomfort and will have an effect on the kinds of crops grown there.

Precipitation in Ibadan varies with the seasons. During the dry season, there is a considerable increase in rainfall, as demonstrated by a Z value of 2.49 and a p-value of < 0.05. Although there is an increase in rainfall during the rainy season ($Z = 1.86$, slope = 0.719), the trend is not statistically significant ($p > 0.05$). Increased dry-season precipitation may alleviate water shortages, enhancing water security during usually dry months, but consistent wet-season rainfall predicts a low danger of drought throughout the rainy season.

Temperatures in Kano (warm semiarid zone) rise significantly during both seasons. The dry season has a Z value of 3.99, a slope of 0.0343, and a p-value < 0.001, while the wet season exhibits a more pronounced warming trend, with a Z value of 7.39, a slope of 0.0412, and a p-value < 0.0001. These data point to increased heat throughout the year, with especially high temperatures during the wet season. This could worsen water scarcity, increase human discomfort, and put a strain on agricultural systems that already have inadequate rainfall. Kano's precipitation shows no significant trend throughout the dry season. However, the wet season shows a significant decreasing trend for precipitation, with a Z value of -5.07, a slope of -0.811, and a p-value of < 0.0001 This decrease in wet-season rainfall could significantly limit water supply for both agricultural and human use, exacerbating the problems caused by rising temperatures and leading to more frequent and severe droughts.

Temperature trends in Kukawa (warm desert climate) do not vary significantly between the dry ($Z=1.33$, p-value >0.05) and wet seasons ($Z=-1.35$, and p-value >0.05); this shows general temperature stability over the four decades. However, precipitation trends vary with seasons. The dry season shows no significant trend, while the wet season has a substantial upward trend, with a Z value of 4.41, and a p-value < 0.001 Increased wet-season rainfall could improve water availability and lessen certain desertification pressures in this dry region, perhaps benefiting agricultural and local water supplies.

In conclusion, the combined analysis of the dry and wet seasons in the four locations demonstrates the various effects of climate change on temperature and precipitation over Nigeria. Increasing temperatures in Calabar, Ibadan, and Kano, particularly during the wet season, may exacerbate heat-related dangers, although steady temperatures in Kukawa indicate limited current impact. Precipitation patterns are more diverse, with considerable decreases in wet-season rainfall in Calabar and Kano, potentially exacerbating water stress, while Ibadan and Kukawa show increases in dry and wet-season rainfall, respectively, which may bring respite. These findings highlight the need of region-specific climate adaptation methods, notably in agriculture and water resource management, in mitigating the detrimental effects of the observed trends.

4.4 Annual Anomaly Analysis of Temperature

The temperature anomaly analyses for all study location, spanning from 1981 to 2022 (Figure 3), illustrates significant regional variations in Nigeria’s climatic zones.

In the tropical monsoon location of Calabar (Figure 4a), the temperature anomaly plot shows a predominantly negative trend until the mid-1990s. However, a notable shift occurred in the late 1990s, with a steady rise in both the annual anomalies and the 5-year moving averages. From the early 2000s to date, positive anomaly trends dominated, suggesting a warming trend that could affect local agriculture and ecosystems. Similarly, Ibadan (tropical savannah climate) shows large fluctuations (Figure 4b), with negative anomalies predominating in the 1980s and early 1990s. However, positive anomalies began to appear after 1990, showing a progressive warming trend, although they may not be of the same magnitude as that of Calabar. The persistence of these anomalies into the 2010s signals increasing heat stress, which could have ramifications for water supplies and agriculture, given the region's reliance on stable climatic conditions for food production.

For the warm semiarid climate of Kano (Figure 4c), negative anomalies observed in its early years, particularly in the 1980s. This trend abruptly reversed by the late 1990s, culminating in positive anomalies by 1999 and peaking in 2006. Despite recent cooling, the long-term warming trend in this semiarid region may raise concerns about drought, agricultural productivity, and water scarcity, all of which are exacerbated by rising temperatures. Finally, Kukawa (warm desert climate), showed significant temperature variability. While the early years had mixed findings, the 2000s saw a predominance of positive anomaly variations, which peaked in 2006. However, in recent years, temperature anomalies have reduced from the 42-year mean, with negative values reported in 2022.

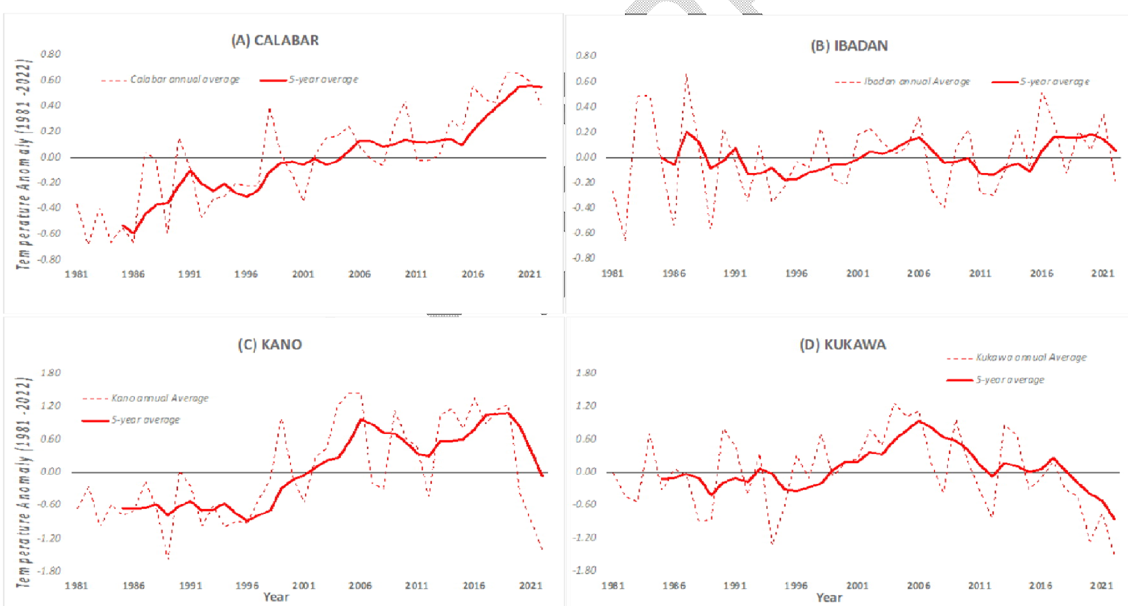

Figure 4: Annual temperature anomaly from 1981 – 2022, in ^{o}C for (a) Calabar – tropical monsoon (b) Ibadan – tropical savannah (c) Kano – warm semiarid (d) Kukawa – warm desert.

In summary, while each region exhibits individual climatic trends, the overall trend across these zones indicates rising temperatures over the decades. This is consistent with the broader implications of climate change, which could result in concerns such as water scarcity, agricultural stress, and ecosystem changes across Nigeria's different climates. Adaptation strategies will be critical for mitigating the effects of these trends and ensuring long-term sustainability in sensitive areas.

4.5 Annual Anomaly Analysis of Precipitation

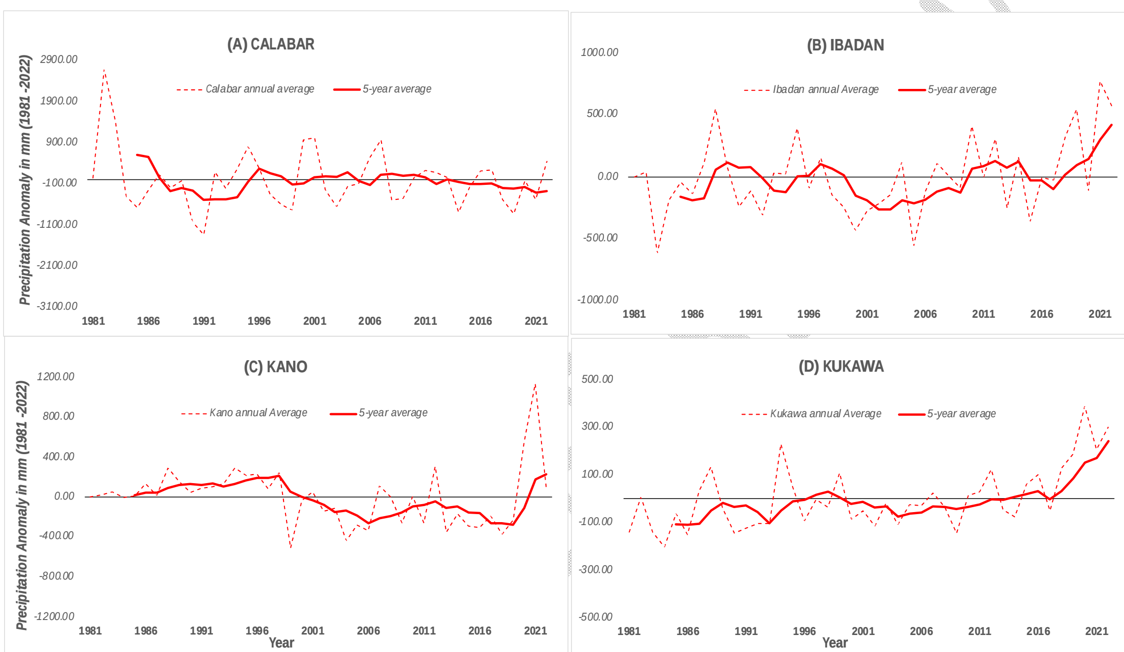

Figure 5: Annual temperature anomaly from 1981 – 2022, in mm for (a) Calabar – tropical monsoon (b) Ibadan – tropical savannah (c) Kano – warm semiarid (d) Kukawa – warm desert

The precipitation anomaly analysis in for all study locations (Figure 5) reveals significant regional heterogeneity in rainfall patterns between 1981 and 2022, with different consequences for agriculture and water management. Calabar experiences dramatic swings, with early positive anomalies (e.g., a 2676.54mm deviation from the 42-year average in 1982) followed by severe declines (e.g., -1331.27 in 1991) and recent negative anomalies from 2018-2022. These patterns point to increased precipitation variability, which affects agricultural output and flood hazards, necessitating improved water management and disaster preparedness.

Ibadan in the tropical savannah has severe negative anomalies in the early 1980s (e.g., -618.82 in 1983), followed by recovery periods in the late 1980s and early 1990s (e.g., 551.88 in 1988). Despite negative anomalies in the late 1990s and early 2000s, subsequent years (2018 forward) have shown a positive trend, with a peak of 776.04 in 2021. The unpredictability of rainfall highlights the need for adaptive strategies to prevent impacts on agricultural and water resources.

Kano, a warm semiarid location, saw positive anomalies in the late 1980s and early 1990s (290.90 in 1988 and 1994), followed by strong drops and a dramatic dip to -510.66 in 1999. However, from 2017, Kano has experienced a significant rebound, peaking at 1134.64 in 2021. The increased variability highlights the importance of good water resource management and adaptation to mitigate drought risks.

Kukawa, which is likewise warm semiarid, exhibits early negative anomalies (e.g., -203.31 in 1984), followed by a slow rebound beginning in the late 1990s (107.83 in 1999). A significant rising trend since 2010, peaking at 387.32 in 2020 and continuing through 2022, indicates improved rainfall conditions. While this trend may relieve drought difficulties, precipitation unpredictability remains a challenge for sustainable development.

Overall, the anomaly shows that precipitation variability has increased throughout different locations, with distinct patterns and implications. Effective water management, adaptable agricultural methods, and disaster preparedness are critical for mitigating the effects of shifting rainfall patterns.

5.0 DISCUSSION

The results and its implication will be discussed per location assessing for possible similarities and contrasts across the climatic zones; whilst stating the implications of the observed changes on agriculture and water reosurces.

5.1 Calabar (Tropical Monsoon Climate)

Calabar's temperature revealed a significant increasing trend in temperature for Calabar having a slope of 0.0268°C/year (annual) and 0.0242°C/year (monthly). These findings corroborate with [32] detection of significant increasing trends in maximum temperature for the same region. Precipitation annualtrendsrevealed no significant change;however, the monthly analysis indicated a decreasing trend of -1.26 mm/year. Such a discrepancy in trends strongly underscores the necessity of using different temporal scales as highlighted by [24]. Regarding temperature, a continuous warming trend could result in increased evapo-transpiration with adverse effects on local water resourcesand agriculture; and changes in monsoon pattern would alter rainfall distribution and intensity. Both resulting in heatstress for the entire Calabar ecosystem. The decreasing monthly precipitation trends might desire some changes to be made in the region's current agricultural practices in order to maintain maximum yields due to increased water stress during dry periods.

Critically, examining the region's temperature and precipitation anomalies revealed a clear increasing trending in temperature anomalies, with more positive anomalies occurring in the last five examined years. However, the precipitation anomaly graph depicts high variability but without any clear trends. The visuals for temperature anomalies supports [32]assessment and citing of implications such as, potential intensification of the monsoon system following increased land-sea contrasting temperatures and affected agricultural productivity. Since precipitation holds no clear trend, it is likely that there will be continued unpredictability in the region's rainfall pattern, which may be challenging to water resource management. This will affect agriculture and disaster preparedness in times of flood.

5.2 Ibadan (Tropical Savannah Climate)

Temperature results reveal no significant trend in annual temperature; however, there is a significant increasing trend of 0.0125°C/year on a monthly basis. Thus, underlying the importance of multi-scale analysis as emphasised by [27]. Regarding precipitation, the annual precipitation shows no significant trend, the monthly analysis shows an increasing trend (not statistically significant at $\alpha=0.05$, but close with $p=0.0632$); similar results with findings from the West Kalimantan study [29]. The precipitation results suggest an increased risk of flooding during intense rainfall events and altered agricultural patterns that will necessitate optimisation of water management.

The temperature anomaly graph showed slight warming trends. If this increases it could result in potential shifts in the savannah ecosystem boundaries, and increased evapo-transpiration that affect water resources for rain fed agriculture. The precipitation anomaly graph reveals a high interannual variability with some extremely wet years; aligning with observation of increased rainfall variability in tropical regions [29].

5.3 Kano (Warm Semi-Arid Climate)

Both annual and monthly analyses show significant increasing trends0.0443°C/year and 0.0412°C/year, respectively. The implication is likely desertification if not mitigated and challenges to agricultural productivity and water resource. Precipitation annual trend showed no significant change; however, the monthly analysis indicates a significant decreasing trend of -0.811 mm/year. A study of Udaipur India showed similar results, where regions showed decreasing rainfall trends [26]. This signifies increased water scarcity and drought risk, with significant shifts in vegetation cover and ecosystem

The temperature anomaly analysis showsstrongwarming trends since the 2000s, a behaviour that is reflective of global warming patterns in the semi-arid regions. This poses risks of heat wave and associated health implications, and the potential acceleration of the region's desertification process. The precipitation anomaly graph reveals high variability with some extremely dry years and is suggestive of increase probability of prolonged droughts and water scarcity. Further emphasising a need for improved water conservation and management strategies.

5.4 Kukawa (Warm Desert Climate)

Annual temperature results show an increasing trend, however, thereis no significant trend in themonthly analysis of temperature data. This disparity highlights the complexity in climatictrends analysis and a cautious need for correct interpretation [30]. Regardingprecipitation, both annual and monthly analyses showed significant increasing trends. However, for a warm desert climate, this is quite unprecedented as it indicates potential greening of the desert if the trend continues, good opportunities for water resourcefulness and resource management. Nonetheless, in areas not used to significantprecipitation levels, this increases the flood risk during rainfall events.

Temperature anomaly graph shows high variability, with no clear trend. This requires more monitoring to better inform an understanding of the long-term trends in this complex desert climate and the variablenesshighlights the possibility for more frequent and intense heat waves [32].On the other hand, the precipitation anomaly graph shows several extremely wet years, in recent times. While it shows an opportunity for water harvesting during wet years that will support dry period, there is the potential for episodicfloodingevents in such a landscape that is not adapted to heavy rainfall.

Generally, the results demonstrate the significance of comprehending spatial variability even within the same country, and the discrepancies within the temporal scales highlight the importance of multi-scale analysis in climate studies. While, the increasing temperature trends in most locations support the general global warming patterns, it necessitates the implementation of heat adaptation strategies across different climate zones. More critical is the unexpected increasing precipitation trend in the desert climate of Kukawa, as this represents the counterintuitive nature of climate change impacts. Lastly, the varied precipitation trends indicate potential shits in water availability and require that the responsible agencies implement adaptive strategies towards water availability and agricultural practices.

6.0 CONCLUSION

This study investigated long-term trends in temperature, precipitation, and radio refractivity across Nigeria's climatic zones, and found significant geographical and temporal diversity. Key findings demonstrate rising temperatures in all regions, particularly in Kano and Calabar, which are consistent with global warming patterns and pose potential concerns to agriculture, water resources, and human health. However, precipitation patterns showed inconsistent results, with significant heterogeneity among periods and areas. The unexpected rise in precipitation in the desert region of Kukawa demonstrates the unpredictability of climate change, which presents both potential for water resource development and flood threats.

The repercussions of these developments are significant, particularly for agriculture, water management, and disaster preparedness. Effective adaptation techniques, such as drought-resistant agriculture, water conservation, and enhanced climate monitoring systems, are crucial for addressing these issues. To ensure long-term development, the study underlines the importance of specialized regional policies that handle the distinct climatic variations within each zone.

In conclusion, while the warming trend is uniform across Nigeria, the heterogeneity in precipitation patterns necessitates a region-specific approach to climate adaptation, with a focus on strengthening resilience in vulnerable sectors such as agriculture and water resource management.

7.0 RECOMMENDATIONS

- Use region-specific water conservation strategies, such as rainwater harvesting in semi-arid and desert zones (Kano, Kukawa), to reduce water scarcity and drought risks, while improving irrigation systems in tropical zones (Calabar, Ibadan) to manage increased rainfall variability.
- To ensure food security and sustainable farming, promote climate-resilient agricultural techniques such as drought-resistant crops in arid zones and enhanced irrigation systems in places with unpredictable rainfall.
- Set up early warning systems for heat waves and heat stress, particularly in places with rising temperatures such as Calabar and Kano, as well as promote urban greening and heat-resilient infrastructure to offset excessive temperature impacts.
- Create flood risk management frameworks, notably in Kukawa and Ibadan, to protect against episodic and unpredictable severe rains by providing effective drainage systems and emergency preparation.
- Enhance regional climate data monitoring and multi-scale analysis across zones to help inform policy decisions, enhance predictive models, and track changing climatic trends for future adaption efforts.

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REFERENCES

[1] Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., Church, J. A., Clarke, L., Dahe, Q., & Dasgupta, P. (2014). *Climate change 2014: Synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Ipcc.

[2] Adeoluwa Adeniyi, D., & F. Dinbabo, M. (2020). Stuck in a rut: A review of the interplay between agriculture, poverty and food security in Nigeria. *African Renaissance*, *17*(2), 129–160.

[3] Muftahu, M., & Jamil, H. (2020). The demographic shifts in West African Countries: Implications for access to higher education in Nigeria. *Asia Proceedings of Social Sciences*, *6*(3), 247–253.

[4] Haider, H. (2019). *Climate change in Nigeria: Impacts and responses*. https://opendocs.ids.ac.uk/articles/report/Climate_Change_in_Nigeria_Impacts_and_Responses/26429638

[5] Akpodiogaga-a, P., & Odjugo, O. (2010). General Overview of Climate Change Impacts in Nigeria. *Journal of Human Ecology*, *29*(1), 47–55.

[6] Akande, A., Costa, A. C., Mateu, J., & Henriques, R. (2017). Geospatial Analysis of Extreme Weather Events in Nigeria (1985–2015) Using Self-Organizing Maps. *Advances in Meteorology*, *2017*, 1–11.

[7] Apata, T. G., N'Guessan, Y. G., Ayantoye, K., Badmus, A., Adewoyin, O., Anugwo, S., Borokini, A., Sani, T., Aladejebi, O., & Ojedokun, S. (2018). Tenacity of small farms and poverty levels: Evidence of relationship among farming households in Nigeria. *Research on Crops*, *19*(4), 775–786.

[8] Ogbuabor, J. E., & Egwuchukwu, E. I. (2017). The impact of climate change on the Nigerian economy. *International Journal of Energy Economics and Policy*, *7*(2), 217–223.

[9] Ayanlade, A., Radeny, M., & Morton, J. F. (2017). Comparing smallholder farmers' perception of climate change with meteorological data: A case study from southwestern Nigeria. *Weather and Climate Extremes*, *15*, 24–33.

[10] Shiru, M. S., Shahid, S., Alias, N., & Chung, E.-S. (2018). Trend analysis of droughts during crop growing seasons of Nigeria. *Sustainability*, *10*(3), 871.

[11] Ebele, N. E., & Emodi, N. V. (2016). Climate change and its impact in Nigerian economy. *Journal of Scientific Research & Reports*, *10*(6), 1–13.

[12] Akinsemolu, A. A., & Olukoya, O. A. (2020). The vulnerability of women to climate change in coastal regions of Nigeria: A case of the Ilaje community in Ondo State. *Journal of Cleaner Production*, *246*, 119015.

[13] Ndimele, P. E., Ojewole, A. E., Mekuleyi, G. O., Badmos, L. A., Agosu, C. M., Olatunbosun, E. S., Lawal, O. O., Shittu, J. A., Joseph, O. O., & Ositimehin, K. M. (2024). Vulnerability, resilience and adaptation of Lagos coastal communities to flooding. *Earth Science, Systems and Society, 4,* 10087.

[14] Ibrahim, B., & Mensah, H. (2022). Rethinking climate migration in sub-Saharan Africa from the perspective of tripartite drivers of climate change. *SN Social Sciences*, *2*(6), 87.

[15] Lenshie, N. E., Ojeh, V. N., Oruonye, E. D., Ezeibe, C., Ajaero, C., Nzeadibe, T. C., Celestine, U. U., & Osadebe, N. (2022). Geopolitics of climate change-induced conflict and population displacement in West Africa. *Local Environment*, *27*(3), 287–308.

[16] Owebor, K., Diemuodeke, E. O., Briggs, T. A., & Imran, M. (2021). Power Situation and renewable energy potentials in Nigeria–A case for integrated multi-generation technology. *Renewable Energy, 177*, 773–796.

[17] Okon, E. M., Falana, B. M., Solaja, S. O., Yakubu, S. O., Alabi, O. O., Okikiola, B. T., Awe, T. E., Adesina, B. T., Tokula, B. E., & Kipchumba, A. K. (2021). Systematic review of climate change impact research in Nigeria: Implication for sustainable development. *Heliyon*, *7*(9).

[18] Shiru, M. S., Shahid, S., Shiru, S., Chung, E. S., Alias, N., Ahmed, K., Dioha, E. C., Sa'adi, Z., Salman, S., & Noor, M. (2020). Challenges in water resources of Lagos mega city of Nigeria in the context of climate change. *Journal of Water and Climate Change*, *11*(4), 1067–1083.

[19] Tambari, I. T., Dioha, M. O., & Failler, P. (2020). Renewable energy scenarios for sustainable electricity supply in Nigeria. *Energy and Climate Change*, *1*, 100017.

[20] Pulse Nigeria. (2024). *VP Shettima sympathises with Maiduguri flood victims with bags of rice*. Pulse Nigeria.

[21] Agbo, E. P. (2021a). The role of statistical methods and tools for weather forecasting and modeling. *Weather Forecasting. IntechOpen*, 3–22.

[22] Agbo, E. P., & Edet, C. O. (2022). Meteorological analysis of the relationship between climatic parameters: Understanding the dynamics of the troposphere. *Theoretical and Applied Climatology*, *150*(3–4), 1677–1698.

[23] Sam, M. G., Nwaogazie, I. L., & Ikebude, C. (2022). Climate change and trend analysis of 24-hourly annual maximum series using Mann-Kendall and Sen slope methods for rainfall IDF modeling. *Internat. Jour. Environ. Climate Change*, *12*(3), 44–60.

[24] Asgher, S., Ahmad, M., Kumar, N., & Kumari, M. (2021). Trend analysis of temperature and rainfall using Mann Kendall test and Sen's slope estimator in Bhaderwah Tehsil of Doda District. *Research Journal of Agricultural Sciences*, *12*(3), 1021–1026.

[25] Ali, R. O., & Abubaker, S. R. (2019). Trend analysis using Mann-Kendall, Sen's slope estimator test and innovative trend analysis method in Yangtze River basin, China. *International Journal of Engineering & Technology*, *8*(2), 110–119.

[26] Meena, M. (2020). Rainfall statistical trend and variability detection using Mann-Kendall test, Sen's slope and coefficient of variance—A case study of Udaipur district (1957–2016). *Appl. Ecol. Environ. Sci*, *8*(1), 34–37.

[27] Ali, R., Kuriqi, A., Abubaker, S., & Kisi, O. (2019). Long-term trends and seasonality detection of the observed flow in Yangtze River using Mann-Kendall and Sen's innovative trend method. *Water*, *11*(9), 1855.

[28] Diress, S. A., & Bedada, T. B. (2021). Precipitation and temperature trend analysis by Mann Kendall test: The case of Addis Ababa methodological station, Addis Ababa, Ethiopia. *African Journal of Land Policy and Geospatial Sciences*, *4*(4), 517–526.

[29] Aditya, F., Gusmayanti, E., & Sudrajat, J. (2021). Rainfall trend analysis using Mann-Kendall and Sen's slope estimator test in West Kalimantan. *IOP Conference Series: Earth and Environmental Science*, *893*(1), 012006.

[30] Alashan, S. (2020). Combination of modified Mann-Kendall method and Şen innovative trend analysis. *Engineering Reports*, *2*(3), e12131.

[31] Agbo, E. P., Nkajoe, U., & Edet, C. O. (2023). Comparison of Mann–Kendall and Şen's innovative trend method for climatic parameters over Nigeria's climatic zones. *Climate Dynamics*, *60*(11–12), 3385–3401.

[32] Agbo, E. P., Ekpo, C. M., & Edet, C. O. (2021). Analysis of the effects of meteorological parameters on radio refractivity, equivalent potential temperature and field strength via Mann-Kendall test. *Theoretical and Applied Climatology*, *143*, 1437–1456.

[33] Awuh, M. E., Officha, M. C., Okolie, A. O., & Enete, I. C. (2018). Land-use/land-cover dynamics in Calabar metropolis using a combined approach of remote sensing and GIS. *Journal of Geographic Information System*, *10*(4), 398–414.

[34] Ettah, E. B., Nwabueze, G. N., & Ekah, U. J. (2024). Comparative Analysis of Current-Voltage Characteristics of Photovoltaic (PV) Systems in Selected Climatic Regions in Cross River State, Nigeria. *Journal of Energy Research and Reviews*, *16*(4), 29-37.

[35]Akonjom, N. A., Umuji, J. I., & Ekah, U. J. (2021). Performance evaluation of polycrystalline photovoltaic modules in a Guinea Savanna and Mangrove swamp.World Journal of Advanced Engineering Technology and Sciences, 4(1): 11–21

[36] Okono, M. A., Agbo, E. P., Ekah, B. J., Ekah, U. J., Ettah, E. B., & Edet, C. O. (2022). Statistical analysis and distribution of global solar radiation and temperature over southern Nigeria. *Journal of the Nigerian Society of Physical Sciences*, 588-588.

[37] Olatunji, S., Yoade, A., & Adeyemi, S. (2021). Evaluation of Infrastructure in Ibadan Metropolis, Nigeria. *Ghana Journal of Geography, 13*(1), 81–102.

[38] Barau, A. S., Kafi, K. M., Mu'allim, M. A., Dallimer, M., & Hassan, A. (2023). Comparative mapping of smellscape clusters and associated air quality in Kano City, Nigeria: An analysis of public perception, hotspots, and inclusive decision support tool. *Sustainable Cities and Society, 96*, 104680.

[39] Allamin, I. A., Dungus, F. B., Ismail, H. Y., Ismail, G., Bukar, U., Shettima, H., & Faruk, A. U. (2021). Biodegradation of hydrocarbon by Enterobacter sp IAA-01 isolated from hydrocarbon exploration site soil of Kukawa Northeastern Nigeria. *African Journal of Environmental Science and Technology*, *15*(9), 384–389.

[40] Agbo, E. P. (2021b). The role of statistical methods and tools for weather forecasting and modeling. In *Weather Forecasting* (pp. 3–22).

[41] Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the Econometric Society*, 245–259.

[42] Kendall, M. G. (1975). *Rank correlation methods*. Griffin.

[43] De Luca, D. L., Petroselli, A., & Galasso, L. (2020). A transient stochastic rainfall generator for climate changes analysis at hydrological scales in Central Italy. *Atmosphere*, *11*(12), Article 12.