ISSN: 3068-2789

Research Article

Journal of All Physics Research and Applications

Dynamics and Characteristics of Dry and Moist Heatwave across the Sahel and Coastal Climatic Zones of Nigeria

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ABSTRACT

The increasing frequency of heatwaves across Nigeria's diverse climatic zones has wide-ranging impacts on agriculture, human health, energy demand, and ecosystems. However, there is limited research comprehensively analysing the dynamics and characteristics of these heatwaves across Nigeria's climatic zones. Using observed average daily temperature and relative humidity data from synoptic stations across Nigeria for a period of twenty-nine years (1983-2012), this study examined the dynamics and characteristics of dry and moist heatwaves across the Sahel and Coastal climatic zones of Nigeria, comprising of Maiduguri, Sokoto, Ikeja and Calabar. Heatwave events were classified into wet and dry categories based on concurrent humidity levels. The Sahel region experienced higher temperatures and more frequent heatwaves, while the Coastal region experienced lower temperatures and less frequent heatwaves, but warming is still evident particularly in Ikeja. However, the data suggests increasing temperatures in all locations, with heatwaves becoming more prominent, particularly in the Sahel savannah. Sokoto had the highest number of dry heatwave days (13 days), indicating significant exposure to extreme heat without moisture, while Ikeja had the highest number of wet heatwave days (8 days), reflecting high temperature combined with high humidity.

Keywords: Heatwave, Temperature, Relative Humidity, Sahel Savannah, Coastal region, Mann-Kendall.

Received: June 10, 2026;
Accepted: June 17, 2026;
Published: July 24, 2026

Introduction

Nigeria's diverse climatic zones, from arid to tropical, have experienced an alarming increase in heatwaves in recent years, attributed to global climate change. Heatwave is a period marked by unusual hot weather over a region persisting for at least three consecutive days [1]. These heatwaves have wide-ranging impacts on agriculture, human health, energy demand, and ecosystems.

Abaje et al. stated that, concentration of greenhouse gases in the atmosphere has increased over the past few decades and this has resulted to changes in climatic condition [2]. There are different climate extremes that affect communities in different ways: storms, flooding, drought, and heatwaves. The latter may seem to be the less dangerous among them, but the recorded impacts worldwide have been dreadful compared to the other ones during the last decades [3-6]. From droughts to flooding rains and damaging frosts to heatwaves, it is obvious that climate extremes are very important and must be considered in every society; especially in tropics (direct hit of sunshine) where the West Africa countries are located [7]. Over the years, people's exposure to heatwave as a result of climate change have attracted a lot of concern due its frequent occurrence globally.

Heatwaves occur when high pressure builds up in the upper atmosphere, from 3000 to 7600m, gain strength and stays over an area for days and sometimes weeks in the same place. This physical process is frequently observed in summer (in each of the hemispheres) as the jet stream motion with the sun [8]. Anticyclones with low-level thermal low (transient anticyclones) can alter the jet stream's normal path and block synoptic weather systems and

Citation: Aisha Muhammad, Julia O Eichie, and Kingsley C Igwe (2026) Dynamics and Characteristics of Dry and Moist Heatwave across the Sahel and Coastal Climatic Zones of Nigeria. J All Phy Res Appli 2: 1-9.

allow heatwaves to build in an area. This is a complex system that includes many factors such as tropical convection [9].

Exposure to extreme heat is already a significant public health problem that is often related to cardiovascular problems and is a leading cause of weather-related mortality in Nigeria [10]. The World Meteorological Organisation distinguishes two types of meteorological heatwaves: dry and moist heatwaves. Dry heatwaves are characterised by stable conditions, clear skies, and a large input of solar radiation, whereas moist heatwaves are often accompanied by very oppressive, humid conditions during the day and night, often with nocturnal cloud cover [11]. Dry summer heatwaves, an example of a “compound extreme”, can have severe impacts on agriculture, ecosystems, water supplies, and local economies [12-14].

Exposure to heatwave causes severe symptoms, such as heat exhaustion and heat stroke-a condition which causes faintness, as well as dry warm skin, due to the inability of the body to control high temperatures. Other symptoms include swelling in the lower limbs, heat rash on the neck, cramps, headache, irritability, lethargy and weakness. Heat can cause severe dehydration, acute cerebra vascular accidents and contribute to thrombogenesis (blood clots). People with chronic diseases that take daily medications have a greater risk of complications and death during a heatwave, most especially older people and children [15].

Many studies on heatwaves have been carried out in Nigeria. However, heatwaves in Nigeria are still not well documented.

Agada and Yakubu investigated the impact of heatwaves in Yobe State, northeast Nigeria [16]. Time series analysis and basic statistical tools were used to analyse the data which was used to evaluate the trend of heatwaves and their impact in the study area. The results of the study showed that 2010 was extremely hot with an average maximum temperature anomaly of 2.18, while 2013 and 2015 have an average maximum temperature anomaly of 1.93 respectively and were very hot.

In a study using innovative trend analysis for Ibadan, Nigeria, for hydro-meteorological variables with data spanning a period of 45 years, the results obtained indicated an increasing trend with the highest being at a 10% significance level [17]. The results obtained from applying Sen slope and Mann-Kendall (M-K) tests for variability in evaporation and hydro-meteorological parameters in Ibadan, Nigeria, revealed a trend in which solar radiation, wind speed, and evaporation were significantly reduced while rainfall, temperature, and relative humidity did not indicate a significant change over the four decades interval being considered [18].

The Study Area

The study area comprises of some selected locations within the Coastal and the Sahel climatic zones of Nigeria, namely: Ikeja and Calabar (Coastal zone), Maiduguri and Sokoto (Sahel Savannah) as shown in Figure 1. The study areas were chosen due to the variation in their temperature patterns.

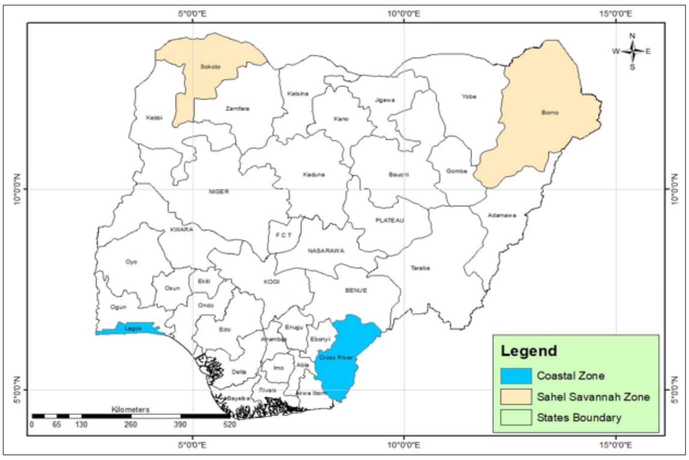

Figure 1: The selected locations

Background

Fundamentals of Temperature

Temperature is a measure of the thermal energy of an object, a critical variable in meteorology for determining atmospheric behaviour. In the context of heatwaves, temperature specifically refers to the prolonged periods where daily temperatures exceed normal or seasonal thresholds, often leading to severe ecological, agricultural, and human health impacts.

Temperature is a critical factor in understanding heatwaves, especially in the contrasting climates of Nigeria's Sahel and Coastal regions. The Sahel experiences high temperatures averaging 36-42°C, often exacerbated by low humidity, leading to severe heatwaves lasting 3-5 days [19]. In contrast, the Coastal areas are characterised by a hot and humid climate, where humidity significantly influences night-time temperatures and heatwave intensity (Langue et al., 2023). Recent studies indicate an increasing trend in heatwave frequency and intensity across both regions, driven by climate change and variability in sea surface temperatures [20].

Temperature variability across different climatic zones, such as the Sahel and Coastal regions of Nigeria, plays a crucial role in understanding the dynamics and characteristics of dry and moist heatwaves in these areas. Both regions experience unique climatic influences that shape the formation, intensity, and persistence of heatwaves, which are significant in the context of climate change and its associated risks.

Relative Humidity

Relative humidity (RH) is a critical concept in studying the dynamics and characteristics of dry and moist heatwaves, particularly across distinct climatic regions like the Sahel and Coastal zones of Nigeria. RH refers to the percentage of moisture in the air relative to the maximum amount of moisture that the air can hold at a given temperature. It is influenced by both temperature and the availability of moisture in the atmosphere, making it essential for understanding heatwave patterns in varying climates.

The Mann-Kendall Correlation Test

The Mann-Kendall (MK) test can be used for heatwave analysis to assess the presence and direction of trends in heatwave occurrence. The MK test is a non-parametric test that does not require the assumption of normality, making it suitable for analysing heatwave data, which often does not conform to a normal distribution. In the context of heatwave analysis, the MK test can be applied to various heatwave indices, such as CTX90pct, CTN90pct, and EHF, which are used to measure different aspects of heatwaves, such as frequency, duration, and magnitude [21]. The test can help identify trends in the occurrence of heatwaves over time, which can be useful for understanding the impact of climate change on heatwave events and for developing strategies to mitigate their effects. The Mann-Kendell's test statistic (S) is calculated using the following equations:

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

where;

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 \; if x_j - x_k > 0 \\ 0 \; if x_j - x_k = 0 \\ -1 \; if x_j - x_k < 0 \end{cases}$$

The number of data values is denoted by the letter n. A positive S value denotes an upward trend, while a negative S value denotes a downward trend. A higher positive value in S on the other hand, indicates an upward pattern, while lower negative values indicate a declining trend. If the number of data values n is greater than 10, the normal approximation (Z statistic) is always utilised. It's also worth noting that when there are tied/equal values, the Z statistic's accuracy suffers if the data values are close to 10. The variance of S 'VAR(S)' is used to calculate the value of the Z statistic [22].

$$\operatorname{var}(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p+1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \quad (2)$$

Represents the number of tied groups in the series (showing that the test takes the tied or equal values into consideration). The number of data values in the p^{th} group is represented by *tp*. We can now obtain the test statistic Z, using the values of VAR(S) and S; [22].

$$Z = \begin{cases} \frac{s-1}{\sqrt{VAR(S)}} if S > 0 \\ 0 if S = 0 \\ \frac{s+1}{\sqrt{VAR(S)}} if S < 0 \end{cases} \quad (3)$$

To interpret results; when the Z value is negative, a falling trend is recognised, and when the Z value is positive, a rising trend is discerned. If and when the data's p-value is less than the significance level, both interpretations can be considered to have a significant trend and the null hypothecs (H_o) is rejected. If the p-value is greater than the level of significance, the trend is not significant and H_o is accepted [23,22].

Methodology

Data Acquisition

Observed average daily temperature and relative humidity data from synoptic stations across Nigeria for a period of twenty-nine (29) years (1983-2012) were acquired from the archives of the West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL) archives, FUT Minna, which were obtained from Nigeria Metrological Agency, Abuja (NIMET). The dataset for four stations was collected.

Data Analysis

The acquired data of temperature and relative humidity were sorted, filtered, and also the mean monthly and annual values were computed using Microsoft excel package. Afterwards, analysis of the data was carried out.

1. Statistical analysis: Time series analysis and basic statistical tools; the Mann-Kendell trend test was used to examine variations in mean monthly and annual atmospheric temperature and relative humidity.
2. Heatwave Characterisation: Heatwave events were defined based on temperature thresholds (days exceeding the 90th percentile of daily maximum temperatures) and their frequency, duration, and intensity were analysed accordingly:
3. Event Classification: Heatwaves were classified into wet and dry categories based on concurrent humidity levels. This involved analysing relative humidity data alongside temperature data to differentiate between event types. The frequency, duration and intensity of both wet and dry heatwaves was then calculated and analysed.

Results and Discussion

Variation of Mean Monthly Atmospheric Temperature and Relative Humidity in the Coastal Climatic Zone

Figure 2 shows the variation of mean monthly atmospheric temperature and relative humidity in Ikeja.

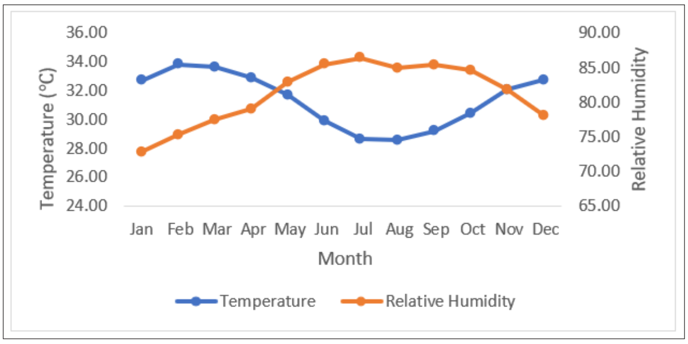

Figure 2: Mean Monthly Variation of Atmospheric Temperature and Relative Humidity in Ikeja (1983-2012)

Peak atmospheric temperature and relative humidity values of 33.81o C and 86.32 respectively, were observed in Ikeja in the months of February and July [24]. The correlation coefficient value of -0.875 signifies strong negative correlation between atmospheric temperature and relative humidity which indicates a classic dry heatwave, where extreme heat leads to very low humidity, increasing heat stress. This means that as temperature increases, relative humidity tends to decrease significantly [25].

Figures 3 shows the variation of mean monthly atmospheric temperature and relative humidity in Calabar.

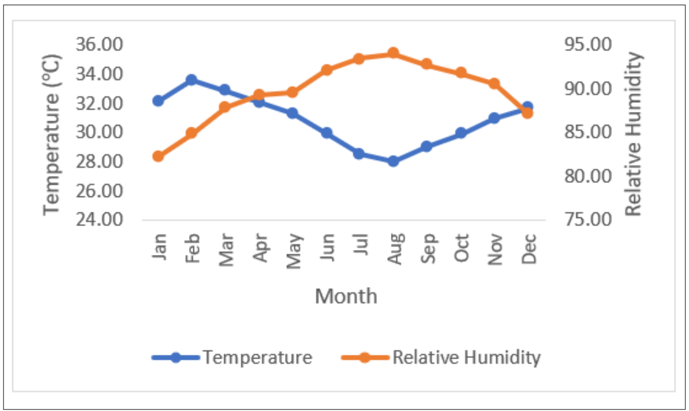

Figure 3: Mean Monthly Variation of Atmospheric Temperature and Relative Humidity in Calabar (1983-2012)

Maximum values of 33.59oC and 93.97 of atmospheric temperature and relative humidity respectively, observed in Calabar were in the month of February and August [26]. The correlation coefficient value of -0.86521 signifies a strong negative correlation between atmospheric temperature and relative humidity.

Variation of Mean Monthly Atmospheric Temperature and Relative Humidity in the Sahel Savannah

Figure 4 shows the variation of mean monthly atmospheric temperature and relative humidity in Maiduguri.

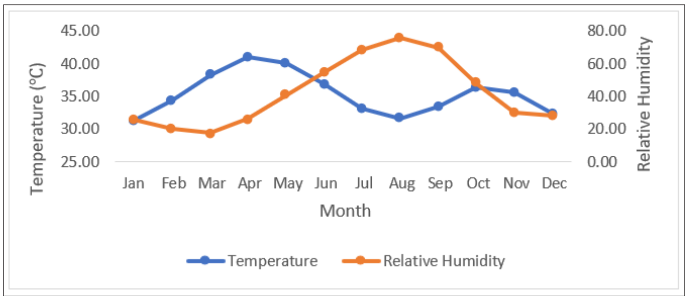

Figure 4: Mean Monthly Variation of Atmospheric Temperature and Relative Humidity in Maiduguri (1983-2012)

Peak atmospheric temperature and relative humidity values of 41.10oC and 75.66 respectively, were observed in Maiduguri in the months of April and August. The correlation coefficient -0.342 indicates a weak negative correlation between temperature and humidity, meaning that while there is a slight inverse relationship between temperature and humidity, it is not very strong. This weak correlation could be due to various external factors like strong winds, dust and cloud cover, affecting both variables, leading to more variability in the data.

Figure 5 shows the variation of mean monthly atmospheric temperature and relative humidity in Sokoto.

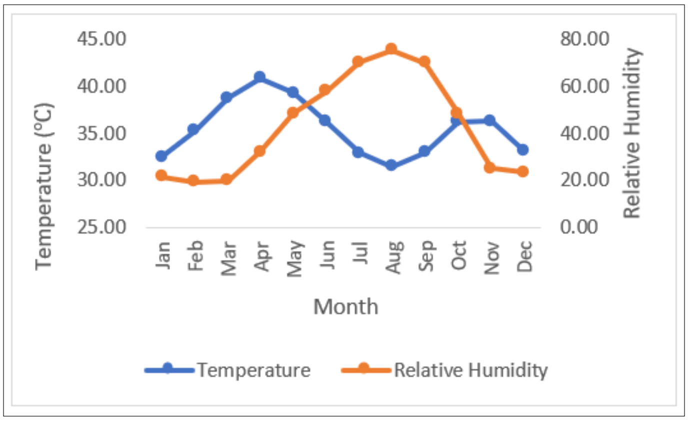

Figure 5: Mean Monthly Atmospheric Temperature and Relative humidity in Sokoto (1983-2012)

Maximum values of 40.86oC and 75.53 of atmospheric temperature and relative humidity respectively, observed in Sokoto were in the months of April and August. The correlation coefficient -0.373 indicates a weak negative correlation between temperature and humidity [27]. Meaning that while there is some inverse relationship, it is not reliable or predictive.

Hypothetical analysis of Monthly Temperature using Mann-Kendall Trend Test

Table 1 shows the summary of analysis for monthly temperature trend test

Table 1: Analysis Summary for Monthly Temperature Trend Test

	Summary of Hypothetical Analysis Using Mann Kendall Trend Test							
Climatic Zone	**Climatic Station**	**Kendall Tau**	**Trend Direction**	**Mann-Kendall Statistic (S)**	**Var(S)**	**Test Statistic (Z)**	**P-value**	**Alpha**
Coastal Zone	Ikeja	-0.303	↓	-10	212.67	-0.61	0.19	0.05
	Calabar	-0.424	↓	-28	212.67	-1.85	0.06	0.05
Sahel Zone	Maiduguri	-0.151	↓	-10	212.67	-0.61	0.53	0.05
	Sokoto	-0.030	↓	-2	212.67	-0.06	0.94	0.05

Test Interpretation;

Ho: There is no trend in the series:

Ha: There is a trend in the series:

As revealed in the Mann-Kendall monthly trend test, the computed p-value for the stations, Ikeja (0.19), Maiduguri (0.53) and Sokoto (0.94) were much greater than the alpha value of 0.05, thus we fail to reject the null hypothesis Ho, meaning there is no significant trend in the data. The p-value for Calabar (0.06) is slightly greater than 0.05, meaning we fail to reject the null hypothesis at the 5% significance level. However, at a 10% significance level, the results suggest a possible downward trend in the data. The Kendall tau was low: Ikeja (-0.303) suggests a slight decreasing trend, but it is not strong enough to be considered statistically significant, Calabar (-0.424) suggests a moderate downward trend, Maiduguri (-0.151), and Sokoto (-0.030) suggests a weak decreasing trend. Thus, the magnitude of the monthly trend is very low.

Hypothetical Analysis of Annual Temperature using Mann-Kendall Trend Test

Table 2 shows the summary of analysis for annual temperature trend test

Table 2: Analysis summary for annual temperature trend test

		Summary of Hypothetical Analysis Using Mann Kendall Trend Test						
Climatic Zone	**Climatic Station**	**Kendall Tau**	**Trend Direction**	**Mann-Kendall Statistic (S)**	**Var(S)**	**Test Statistic (Z)**	**P-value**	**Alpha**
Coastal Zone	Ikeja	0.443	↑	112	3141.67	1.97	0.04	0.05
	Calabar	0.126	↑	55	3141.67	0.96	0.33	0.05
Sahel Zone	Maiduguri	0.318	↑	138	3141.67	2.44	0.01	0.05
	Sokoto	0.317	↑	138	3141.67	2.44	0.01	0.05

Test interpretation;
Ho: There is no trend in the series:
Ha: There is a trend in the series

As revealed in the Mann-Kendall monthly trend test, the computed p-value for the stations, Ikeja (0.04), Maiduguri (0.01) and Sokoto (0.01) were less than the alpha value of 0.05, thus we reject the null hypothesis Ho at the 5% significance level, meaning there is a statistically significant increasing trend in the dataset. The p-value for Calabar (0.33) is greater than the significance level 0.05, thus we fail to reject the null hypothesis, meaning there is no significant trend. The Kendall tau for Ikeja (0.443) suggests an increasing trend, Calabar (0.126) indicates a weak positive correlation, but it is not statistically significant given the p-value 0.33, Maiduguri (0.318), and Sokoto (0.317) indicates a moderate positive correlation over time. Thus, the data shows a weak to moderate increasing trend annually.

Hypothetical Analysis of Monthly Relative Humidity using Mann-Kendall Trend Test

Table 3 shows the summary of analysis for monthly relative humidity trend test

Table 3: Analysis Summary for Monthly Relative Humidity Trend Test

		Summary of Hypothetical Analysis Using Mann Kendall Trend Test						
Climatic Zone	**Climatic Station**	**Kendall Tau**	**Trend Direction**	**Mann-Kendall Statistic (S)**	**Var(S)**	**Test Statistic (Z)**	**P-value**	**Alpha**
Coastal Zone	Ikeja	0.318	↑	21	212.67	1.37	0.01	0.05
	Calabar	0.394	↑	26	212.67	1.71	0.08	0.05
Sahel Zone	Maiduguri	0.364	↑	24	212.67	1.57	0.11	0.05
	Sokoto	0.303	↑	20	212.67	1.30	0.19	0.05

Test interpretation;
Ho: There is no trend in the series:
Ha: There is a trend in the series:

As revealed in the Mann-Kendall trend test, the positive S statistic and Kendall's Tau for Ikeja suggest an increasing trend. However, since the p-value (0.01) is less than 0.05, we reject the null hypothesis Ho, meaning there is a statistically significant increasing trend in the mean monthly relative humidity of Ikeja. For Calabar, since the p-value (0.08) is slightly above the typical significance level of 0.05, there is not enough strong statistical evidence to conclude a significant trend at the 95% confidence level. However, the positive S and Tau values suggest a moderate increasing trend in the data. A more relaxed significance level (e.g., 0.10) might indicate a weak but positive trend. Since the P-value (0.11) for Maiduguri is greater than the significance level (0.05), we fail to reject the null hypothesis. This suggests that there is no statistically significant trend in the data. However, the positive value of S and Tau indicates a weak increasing trend, though not strong enough to be considered statistically significant. The P-value (0.19) for Sokoto is greater than the common significance level (0.05), meaning that there is no statistically significant trend in Sokoto. However, the positive Kendall's Tau (0.303) and S value suggest a weak increasing trend.

Hypothetical analysis of annual Relative Humidity using Mann-Kendall trend test

Table 4 shows the summary of analysis for annual relative humidity trend test

Table 4: Analysis Summary for annual Relative Humidity Trend Test

		Summary of Hypothetical Analysis Using Mann Kendall Trend Test						
Climatic Zone	**Climatic Station**	**Kendall Tau**	**Trend Direction**	**Mann-Kendall Statistic (S)**	**Var(S)**	**Test Statistic (Z)**	**P-value**	**Alpha**
Coastal Zone	Ikeja	0.168	↑	73	3141.67	1.28	0.19	0.05
	Calabar	0.108	↑	47	3141.67	0.82	0.14	0.05
Sahel Zone	Maiduguri	0.278	↑	121	3141.67	2.14	0.03	0.05
	Sokoto	0.034	↑	15	3141.67	0.25	0.80	0.05

Test interpretation;

Ho: There is no trend in the series:

Ha: There is a trend in the series:

As revealed in the Mann-Kendall trend test, the positive S statistic and Kendall's Tau for Ikeja and Calabar respectively suggests an increasing trend. However, the p-value (0.19) and (0.14) are greater than 0.05, meaning the trend is not statistically significant at the 5% significance level. This implies that while there may be a slight upward trend in the data, it is not strong enough to be considered statistically significant. For Maiduguri, since p-value (0.03) is less than 0.05, we can conclude that there is a statistically significant increasing trend in the data at the 5% significance level. The positive S value (121) and Kendall's Tau (0.27) further support the presence of an increasing trend. Since the p-value (0.80) for Sokoto is much greater than 0.05, there is no significant trend in the data. The small Kendall's Tau (0.034) further suggests a very weak positive correlation. Therefore, we fail to reject the null hypothesis, meaning no statistically significant trend exists in Sokoto.

Heatwave Characterisation

Heatwave trend analysis for Ikeja and Calabar (1983-2012)

Figures 6 shows the heatwave trend analysis in Ikeja.

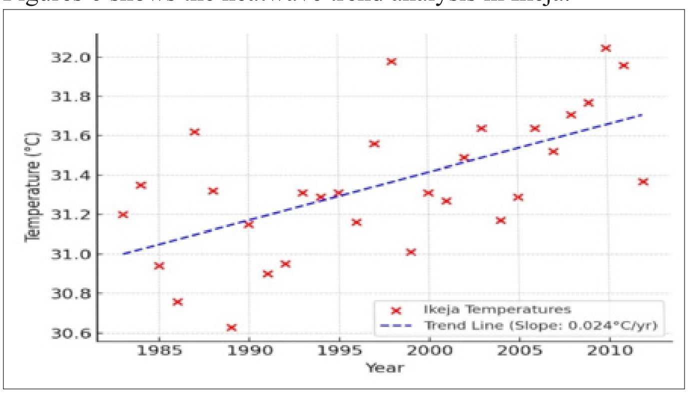

Figure 6: Heatwave trend analysis in Ikeja.

Figures 7 shows the heatwave trend analysis in Calabar.

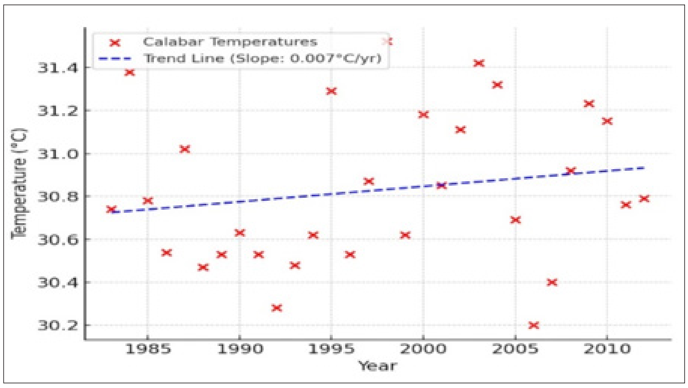

Figure 7: Heatwave trend analysis in Calabar.

Heatwave Trend Analysis for Maiduguri and Sokoto (1983-2012)

Figures 8 shows the heatwave trend analysis in Maiduguri.

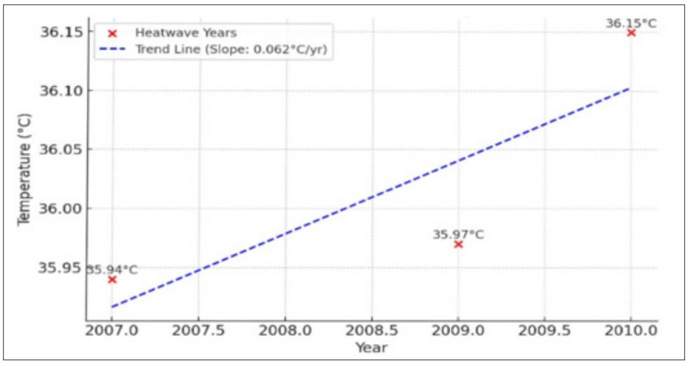

Figure 8: Heatwave trend analysis in Maiduguri.

Figures 9 shows the heatwave trend analysis in Sokoto.

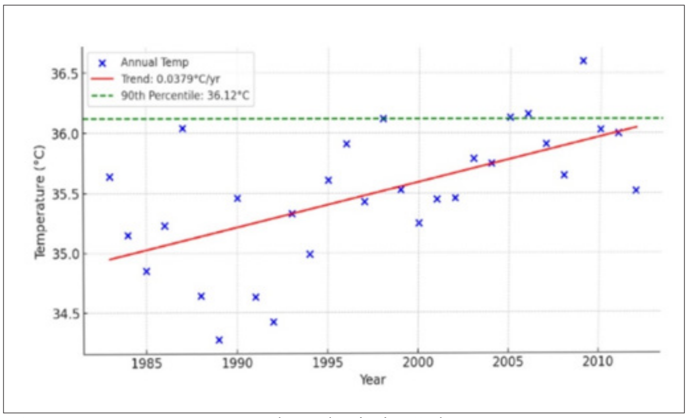

Figure 9: Heatwave trend analysis in Sokoto.

Heatwave Characterisation Summary for the Four Selected Locations

Figure 10 shows the summary of heatwave characterisation for the four locations.

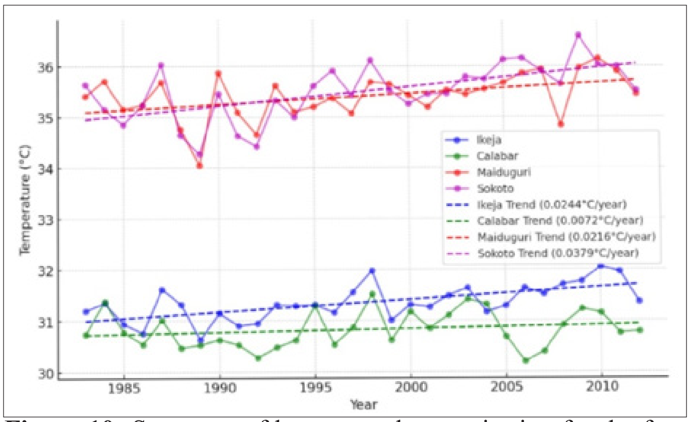

Figure 10: Summary of heatwave characterisation for the four locations.

Table 5 shows the summary of heatwave characterisation for the four selected locations

Table 5: Heatwave Characterisation Summary for the four selected locations

Climatic Zones	Location	90th Percentile (°C)	Trend Slope (°C/ Year)	Heatwave Years	Observations
Coastal Zone	Ikeja	31.789°C	0.024	1998, 2010, 2011	Gradual increase in temperature; heatwaves becoming more frequent.
	Calabar	31.326°C	0.007	1984, 1998, 2003	Slight temperature increase; heatwaves occur but are less severe.
Sahel Zone	Maiduguri	35.86°C	0.062	1990, 2007, 2009, 2010, 2011	Strong warming trend; most frequent and intense heatwaves.
	Sokoto	36.12°C	0.0379	2005, 2006, 2009	Increasing temperature trend; heatwaves present but less frequent than Maiduguri.

Summary of Heatwave Classification Across the Four Selected |Locations

Table 6 shows the summary of heatwave classification across the four selected locations

Table 6: Summary of heatwave classification across the selected locations

Locations	Wet Heatwave Frequency	Dry Heatwave Frequency	Wet Heatwave Intensity (°C)	Dry Heatwave Intensity (°C)
Maiduguri	3	11	0.25	0.28
Sokoto	3	13	0.39	0.40
Ikeja	8	2	0.24	0.26
Calabar	6	4	0.24	0.30

Duration Analysis of Heatwaves Across the Selected Locations

Definition of Duration Metrics

- Short Heatwave: Lasts 1-2 days
- Moderate Heatwave: Lasts 3-4 days
- Prolonged Heatwave: Lasts 5 or more days

Summary of Heatwave Duration Across the Selected Locations

Table 7 shows the summary of heatwave duration across the four locations

Table 7: Heatwave duration summary

Locations	Short Heatwaves (1-2 days)	Moderate Heatwaves (3-4 days)	Prolonged Heatwaves (5+ days)
Maiduguri	6 dry, 2 wet	4 dry, 1 wet	1 dry, 0 wet
Sokoto	7 dry, 2 wet	4 dry, 1 wet	2 dry, 0 wet
Ikeja	3 dry, 6 wet	1 dry, 2 wet	0 dry, 0 wet
Calabar	2 dry, 4 wet	1 dry, 2 wet	1dry, 0 wet

Conclusion

The findings showed that different climatic zones have different temperature and relative humidity. Maiduguri had the highest mean monthly temperature of the value 41.10oC in the month of April and Sokoto had the highest mean annual temperature of the value of 36.60oC in the year 2009, while Calabar had the least mean monthly and mean annual temperature of the values 28.05oC in the month of August and 30.20oC in the year 2006 respectively.

Calabar had the highest mean monthly and mean annual relative humidity of values 93.97 in the month of August and 92.10 in the year 2010 respectively. While Maiduguri had the least mean monthly and mean annual relative humidity of values 17.54 in the month of March and 34.98 in the year 2012 respectively. Using the Mann- Kendall trend test. Both the Sahel and Coastal climatic zones experienced downward trends for the mean monthly temperature trend test and upward trends for the mean annual temperature trend test. Mean monthly and mean annual relative humidity showed upward trends also in all locations.
The Sahel region (Maiduguri and Sokoto) experienced higher temperatures and more frequent heatwaves, likely due to their arid climate and geographical positioning. The Coastal region (Ikeja and Calabar) experienced lower temperatures and less frequent heatwaves, but warming is still evident, particularly in Ikeja. However, the data suggests increasing temperatures in all locations, with heatwaves becoming more prominent, particularly in the Sahel savannah.

The Sahel region experienced more frequent and prolonged dry heatwaves due to low humidity, which are more intense and pose severe health risks. While the Coastal region experienced more wet heatwaves linked to persistent high humidity, which can exacerbate heat stress due to the reduced cooling effect of sweat evaporation. Sokoto had the highest number of dry heatwave days (13 days), indicating significant exposure to extreme heat without moisture, while Ikeja had the highest number of wet heatwave days (8 days), reflecting high temperature combined with high humidity. More dry heatwaves last longer than wet heatwaves, which aligns with global climate change trends in arid regions. The correlation analysis showed that dry heatwaves are strongly linked to low humidity, while wet heatwaves have a positive relationship with humidity.

Acknowledgment

The authors appreciate the West African Service Centre for Climate Change and Human Habitat (WASCAL CC HH), Federal University of Technology, Minna for the provision of data for this research.

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