Nigerian Journal of Environmental Sciences and Technology (NIJEST)
www.nijest.com
ISSN (Print): 2734-259X | ISSN (electronic): 2734-2603
Vol 9, No. 2 October 2025, pp 196 - 212

Trends in Hot Days and Tropical Nights (1989-2023) in Selected Central States of Nigeria

Adegun, O[1*]., Odunuga, S[1]., and Otusanya, O[2].

[1]Department of Geography, University of Lagos, Akoka, Lagos State, Nigeria
[2]Department of Geographical and Environmental Education, Lagos State University of Education, Lagos State, Nigeria
Corresponding Author: *oadegun@unilag.edu.ng

https://doi.org/10.36263/nijest.2025.02.40

ABSTRACT

The manifestation of warm weather extremes in the form of hot days and tropical nights is a major factor in the thermal stress experienced by humans and a contributory factor to reduced crop yield. This study analysed the frequencies and trends of warm weather extremes at Abuja, Lafia, Lokoja and Minna in the central region of Nigeria. Using daily maximum and minimum temperatures for the period 1989 to 2023, the frequencies and trends of hot days and tropical nights, days with maximum temperature > 35 °C and minimum temperature > 20 °C respectively were determined on an annual scale and for the hot season of the year. The modified Mann-Kendall trend test was used to assess the statistical significance of trends at a 0.05 level of significance, while the slope of the trends was computed using Sen's slope estimator. The results showed that the frequency of tropical nights was significantly higher in the region than the frequency of hot days. The results also revealed significant increasing trends of hot days at an annual rate ranging between 1.2days yr^{-1} and 2days yr^{-1}, while the trend of tropical nights varied between 0.94 nights yr^{-1} and 1.61nights yr^{-1} between the periods 1989 to 2023. The results suggest the need for climate adaptation to heat and hot weather in the region. Based on different mitigation measures that can be sustainably implemented in addressing some of the adverse consequences of hot extremes, a region-wide approach is therefore recommended to improve thermal comfort among residents.

Keywords: Hot extremes, High temperature, Mean temperature, Thermal condition, Heat stress.

1.0. Introduction

Warm extremes of temperature, which could lead to the occurrences of hot days, warm or tropical nights and heat waves, have profound impacts on human health and wellbeing, the environment, infrastructures, and different sectors of the economy (Abatan et al., 2017; Barriopedro et al., 2023). According to Herold et al., (2017), lower temperature variability in the tropical regions of the world means that smaller changes are needed for previous temperature extremes to be exceeded.

In different regions of Africa, including the West African sub-region, more incidences of warm extremes have been reported (Moron et al., 2016; Ringard et al., 2016; Engdaw et al., 2021). In West Africa, authors such as Ojo et al., (2021) have attributed such warming events to variability in radiation balance flux, climate sensitivity, and temperature extreme events. Furthermore, the climatic conditions of the West-African sub-region predispose the human population, ecosystems, and agricultural systems to heat waves, which are brought about by periods of continuous or successive days when temperatures are significantly hotter than normal (Langue et al., 2023).

In addition, the frequency of hot days and hot nights in the region is projected to increase at all global warming levels, with the frequency of extremely hot days (maximum temperature, TX > 40.6oC) increasing from 60 per annum between 1985 and 2005 to as high as 140 under RCP 8.5 in the 2060s and as high as 196 in the 2090s under the same scenario (Trios et al., 2022).

In the recent past, a number of studies have examined different indices of temperature extremes across various parts of Africa to derive a better understanding of extreme warm events across different spatio-temporal scales. For example, Engdaw et al., (2021) analysed the changes in temperatures and different indices of heat waves, including the number of hot days and tropical nights. The results of the study showed an earlier emergence of hot days and tropical nights, with trend signals in the number of hot days and tropical nights showing the earliest onset over the northern and eastern regions of the continent. The analysis of the spatio-temporal trends and patterns of various extreme temperature indices in Tanzania by Limbu and Makula (2023) showed increasing trends in the frequency of hot days and tropical nights for the study period. In a study that assessed the observed changes in high temperature extremes and associated meteorological conditions over Africa, Iyakaremye et al., (2021) showed that many parts of Africa generally experienced higher frequency and intensified hot days and nights, with a higher magnitude of change in the frequency of hot nights in most parts of the continent.

In Nigeria, Abatan et al., (2016) examined the trends in extreme temperature over Nigeria using percentile-based threshold indices for 1971 to 2012. The results of the study showed, among others, a statistically significant increase in the frequency of hot and cold extremes and an intense rate of night warming between June and November compared with December to May. In a similar study, Abatan et al., (2018) showed that the indices of warm extremes over the country mainly exhibited positive trends. The study also showed that the time series of the warm extremes bears similarities with those of the mean temperatures, with the trend in tropical nights generally higher than the trend in hot days.

Similarly, Gbode et al., (2019) utilised the temperature indices of the Expert Team on Climate Change Detection Indices (ETCCDI) to analyse trends of temperature extremes over Nigeria between 1971 and 2013. The outcome of the study showed increasing trends in the annual averages of daily maximum and minimum temperatures over the country. The study further revealed that while some parts of the country exhibited significant increases in hot days and warm nights, others exhibited declining trends.

Despite the existence of countrywide studies that have analysed the frequencies and trends of extreme temperature events in Nigeria, there is a need to assess occurrences and trends of these events in the more recent past at the sub-regional level in order for region-specific peculiarities to be analysed. This study therefore, aims to analyse the frequencies and trends of hot days and tropical nights in the central region of Nigeria.

The choice of the central region of Nigeria stems from a number of reasons. Firstly, several towns and cities in the region have witnessed rapid population growth and urbanisation in recent years. Based on the 1991 population census, the population of the Federal Capital Territory (FCT) Abuja, Lokoja (formerly located in Kogi Local Government Area [LGA] as at the time of the census) and Minna (located in Chanchaga LGA) was 371, 674, 82, 483, 143, 896, respectively. As at the 2006 population census, the population of the FCT had risen to 1, 406, 239, Lokoja to 196, 643 and Chanchaga LGA (Miina) to 202, 151. As of 2006, the population of Lafia was put at 329,992. (National Bureau of Statistics [NBS], 2011). In the same vein, the population projection for the FCT, Abuja, Nasarawa, Kogi, and Niger states for 2019 was put at 2,702,443, 2,632,329, 4,153,734 and 6,220,617, respectively (NBS, 2020). Secondly, the high rate of urbanisation has resulted in the urban heat island in places like Abuja (Adeyeri et al., 2017; Isioye, 2020; Goma and Kuku, 2024) and Lokoja (Ifatimehin, 2007). Thirdly, though there are a few countrywide studies, there is none that focuses specifically on the central region of the country.

In this present study, daily minimum and daily maximum temperatures for four meteorological stations located within the central region of Nigeria were used to examine frequency and trends of hot weather extremes between 1989 and 2023.

2.0 Methodology

2.1 Research methodology

The study locations (Fig.1), representing the central region of Nigeria, are located between longitudes 3° 45' E and 9° 40' E, and latitudes 6° 20' N and 11° 45' N.

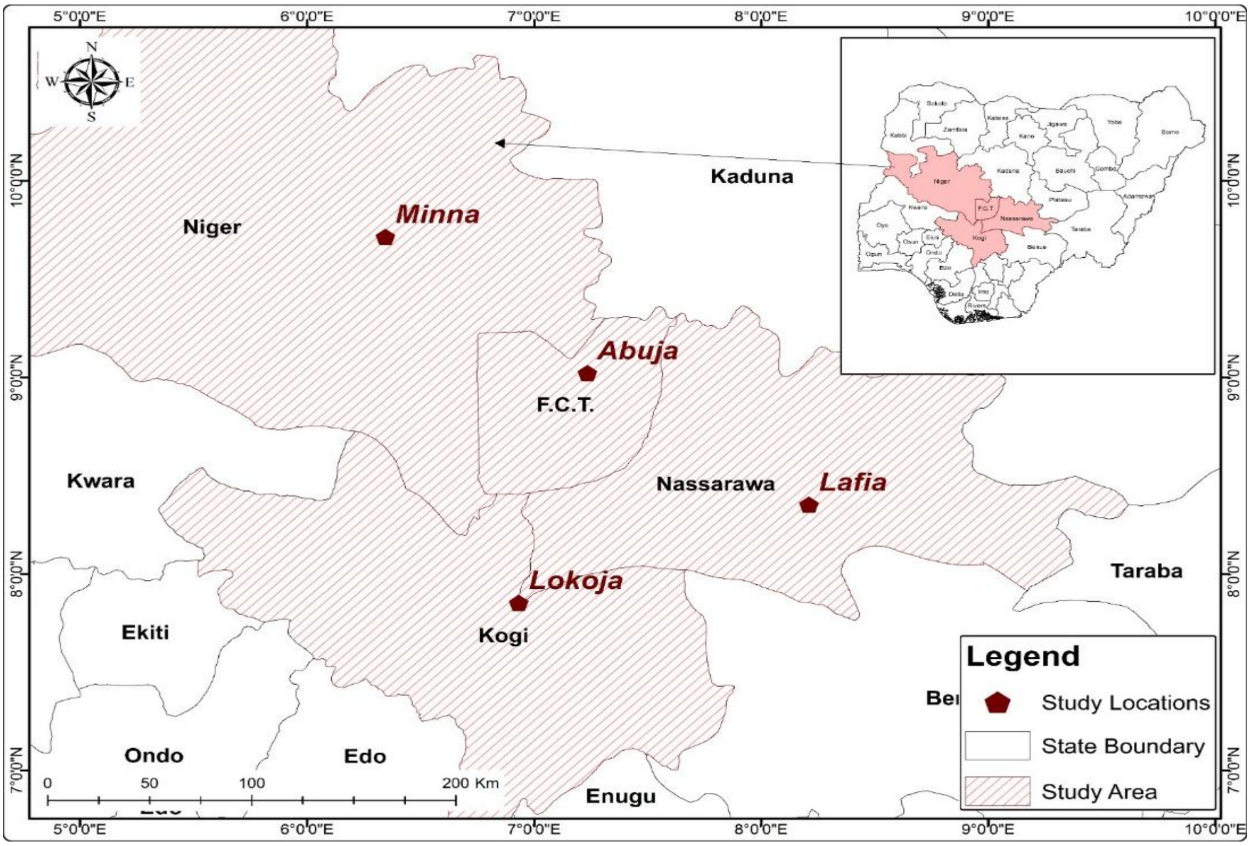

Figure1: The study locations within selected central states of Nigeria

The region is located within the Guinea Savannah Ecological Zone, where the dry season varies between 4 and 6 months and rainfall ranges between 1,020mm and 1,520mm (Nigeria Environmental Study Action Team [NEST], 1991). Between 1989 and 2023, annual mean maximum temperature at the four locations varied between 30 ºC and 34 ºC while annual mean minimum temperature varied between 21ºC and 26 ºC. The ecological belt where the study locations include trees such as *Afzelia Africana* and *Isorber Linia* ssp., while major grass species include Hyparrhenia spp., Andropogon spp., and Schizachyrium (NEST, 1991). Major rock formations in the region include Mount Patti, Zuma Rock, and Aso Rock.

2.2. Datasets and Methods

Datasets consisting of daily minimum temperature (TN) and daily maximum temperature (TX) for Abuja, Lafia, Lokoja, and Minna for the period from 1st of January 1989 to 31st of December, 2023, were obtained from the Nigerian Meteorology Agency (NIMET). Information on the four stations used for the study is shown in Table 1.

Table 1: Information on the Meteorological Stations used in the Study

Station Name	Station Abbrev	WMO ID No	Longitude (º E)	Latitude (º N)	Elevation a.s.l (m)	Data Availability
Abuja	ABJ	65125	7.00	9.00	343.1	100 Per cent
Lafia	LAF	65124	8.52	8.51	135.0	97.3 Per cent
Lokoja	LOK	65243	6.73	7.78	62.5	99.9 Per cent
Minna	MIN	65123	6.53	9.62	256.4	100 Per cent

The temperature datasets were subjected to quality control, which included the detection of possible outlier values and the filling in of missing temperature values. Outlier values were detected using the standard z-score method. Temperature data points with a z-score greater than 2 or 3 or minus 2 or 3 were flagged as outliers (Jamshidi et al., 2002). The outliers were replaced with values from the nearest non-outlier data point.

Missing daily maximum temperature data for 10 days at Lokoja for the year 2022 and daily minimum temperature for 350 days at Lafia in 2022 were filled using the closest station method, which is a nearest neighbour technique of filling in missing temperature values. The selection of the closest stations was based on the distance between the target station (station with the missing value) and its nearest neighbouring station. For Lafia station, 2.7 per cent of the values were filled, while 0.1 per cent of the dataset was filled for the Lokoja station.

The temperature data were used to assess the Hot Days (HotD) and Tropical Nights (TropN) on an annual scale and on a seasonal scale (the hot season) spanning March to May in the region. The computations were based on the values from cumulative days across the three months aggregated yearly. The period adopted as the hot season is in accordance with NIMET's subdivision of seasons on the basis of when peak maximum temperatures are recorded in the country. The hot season is a period of the year when daytime temperatures attain their highest values. It is a season characterised by increased solar radiation intensity, longer diurnal sunshine duration and a high level of thermal discomfort (NIMET, 2019; NIMET, 2024). In addition to earlier studies, for example, Musari et al., (2015) have shown that severe heat is usually experienced in the north-central region of Nigeria in the months of March, April and May.

In addition, to the assessment of the HotD and TrpN, the mean annual TX and TN were also assessed. In this study, Hot Days (HotD) are defined as days when TX>35 ºC and Tropical Nights (TropN) as days when TN>20 ºC as defined by (Moron *et al*., 2016; Abatan *et al*., 2018). Values of daily TX equal to 35 ºC and daily TN equal 20 ºC were not included in the analysis. A sensitivity test was conducted on the choice of the TX>35 ºC for HotD by conducting a trend analysis on an alternate HotD threshold of TX>33 ºC. The variation of the thresholds was done to determine if the choice of the thresholds used would produce a significant difference in the results obtained.

A modified version of the Mann-Kendall Trend Test (equations 1 to 6) by Hammed and Rao (1998) was used for the detection and assessment of the statistical significance of trends in the time series of the annual mean of TX, TN, and the indices of the hot weather extremes at a 5 per cent level of significance. The modified Mann-Kendall trend test was used to account for the inherent serial autocorrelation in the temperature time series.
The Mann-Kendall trend test is expressed as:

$$S = \sum_{i=1}^{n=1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \quad (1)$$

A positive S value indicates an increasing trend, and a negative value indicates a decreasing trend in the data time series. The sign function is expressed as:

$$Sgn\,(X_J - X_i) = \begin{cases} 1 \; if \; X_j - X_i \; > 0 \\ 0 \; if \; X_j - X_i \; = 0 \\ -1 \; if \; X_j - X_i \; < 0 \end{cases} \quad (2)$$

Where n is the number of data points, t_j is the ties of the sample time series, and m is the number of tied values. The test statistic, Z, is given as:

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

Where the variance of the test statistic is denoted by:

$$Var\,(S) = \frac{1}{18}\, n(n-1)\,(2n+5) \quad (4)$$

The modification of the variance in the classic Mann-Kendall trend test in equation 4 is expressed in equations 5 and 6 (Abatan *et al.,* 2016).

$$V^*\,(S) = Var\,(S).\frac{n}{n_s^*}\,\frac{1}{18}\, n(n-1)\,(2n+5).\frac{n}{n_s^*} \quad (5)$$

Where $\frac{n}{n_s^*}$ is a correction as a result of autocorrelation in the data and expressed empirically as:

$$\frac{n}{n_s^*} = 1 + \frac{nx}{1!} + \frac{2}{n\,(n-1)(n-2)}\ X \sum_{i=1}^{n=1} (n-i-1)(n-i-2)\ \rho s\ (i) \qquad (6)$$

Where $\rho s\ (i)$ is the autocorrelation function of the ranks of the data. The $\sqrt{Var}(s)$ in equation 3 is substituted with $V^*(S)$.

The null hypothesis (H_0) that there is no trend was tested against the alternative hypothesis (H_1) that there is a trend at $\alpha = 0.05$ level of significance. The magnitude and direction of trends were estimated using Sen's slope estimator expressed in equation 7 (Animashaun et al., 2020) as:

$$\beta = Median(\frac{x_{j} - x_k}{j-k}) \qquad (7)$$

The trend analysis was carried out using XLSTAT statistical software 2014 version.

The annual variability of mean annual TX and the mean annual TN are shown in Figures 2 and 3, respectively.

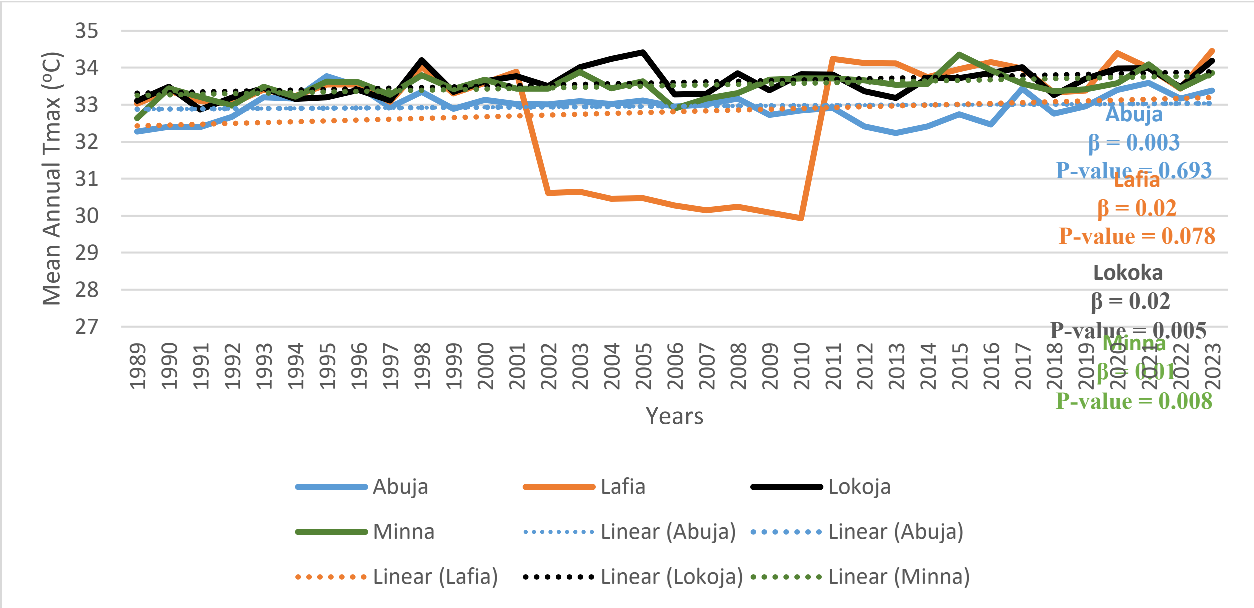

Figure 2: Mean Annual Maximum Temperature for the Study Locations

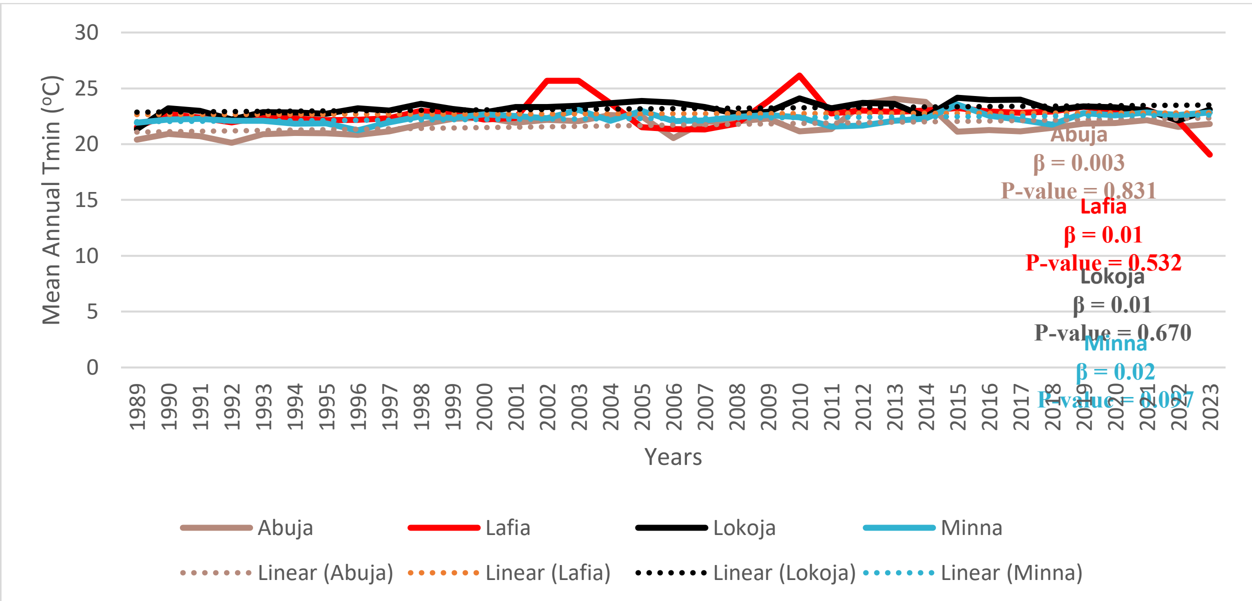

Figure 3: Mean Annual Minimum Temperature for the Study Locations

As shown in Figure 2, mean annual TX at Lafia between 2002 and 2010 were relatively lower in comparison with other locations during the same period, with values ranging between 30 ºC and 31 ºC. Conversely, three of these years (2002, 2003, and 2010) recorded relatively higher mean annual TN at Lafia when compared with the other locations. The lower values of the mean annual TX between 2002 and 2010 are because no days experienced TX>35 ºC. The thermal conditions exhibited at Lafia can be partly attributed to the general topography of Nasarawa state, which is partially characterised by hills which influence the daytime temperatures and contribute to thermal inversions at night.

3.2. Hot Extremes

3.2.1. Frequency of Hot Days

On an annual scale, the frequency of HotD at Abuja varied between 59 days in 1989 and 136 days in 1996 (long-term mean = 97 days). The HotD at Lafia varied between 69 days in 1997 and 175 days in 2020 (long-term mean = 91 days). Between 2002 and 2010 no HotD were experienced at Lafia. This indicates that during those periods, none of the days recorded maximum temperatures that exceeded 35 ºC. HotD at Lokoja was between 80 days and 141 days (long-term mean = 107) in 1997 and 2023, respectively, while it varied between 80 days and 169 days (long-term mean = 123) in 1992 and 2015, respectively at, Minna. Figure 4 shows the variation in the frequency of annual HotD at all the locations, while the long-term mean of the annual frequency is presented in Figure 8. The long –term means are means of annual counts over the 35-year study period.

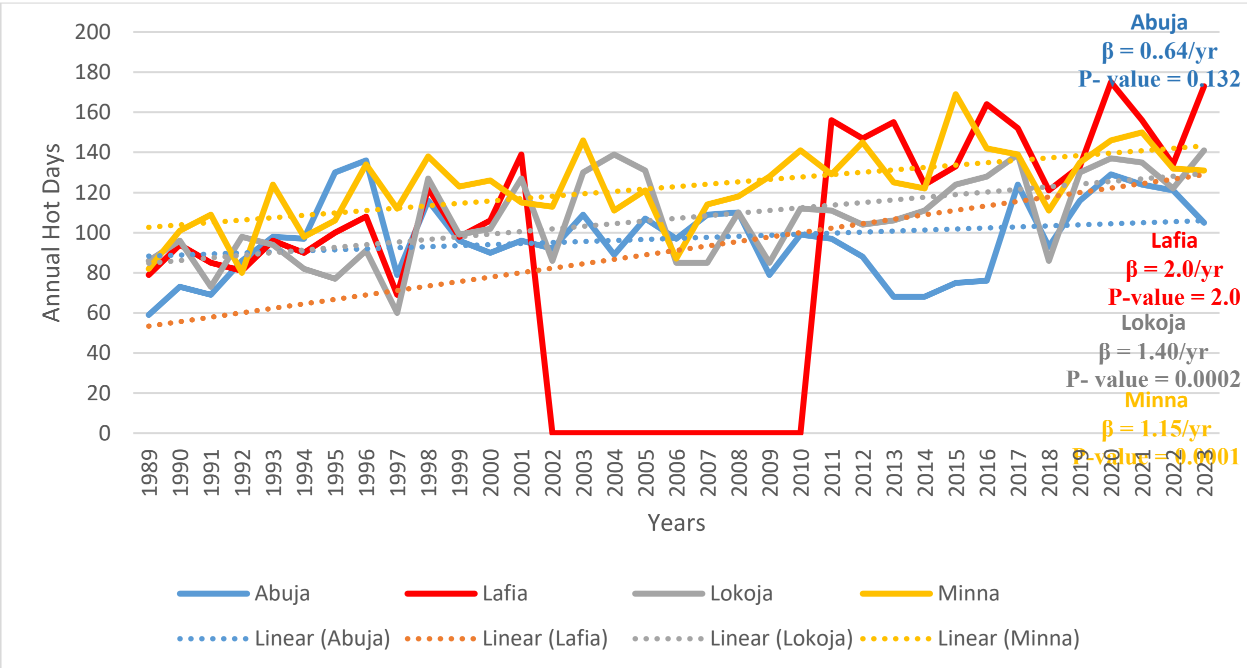

Figure 4: Variation in the Frequency of Annual HotD at the Study locations

During the Hot season, HotD varied between 22 days and 77 days (long-term mean = 45 days) in 1991 and 2007, respectively, at Abuja. At Lafia, HotD varied from 31 days in 1997 to 58 days (long-term mean = 35 days) in 2015. The observed number of HotD (long-term mean = 51 days) at Lokoja ranged between 24 days in 1997 and 74 days in 2003. At Minna, the number of HotD (long-term mean = 57 days) during the study period varied between a minimum of 26 days in 2008, and a maximum of 76 days in 2003 and 2015. This result is consistent with Abatan *et al.,* (2017) which showed that the frequency of HotD at locations outside the Sahelian eco-climatic region did not exceed 149 days. The variation of the frequency of HotD during the hot season is shown in Figure 5, while the long-term mean is shown in Figure 8.

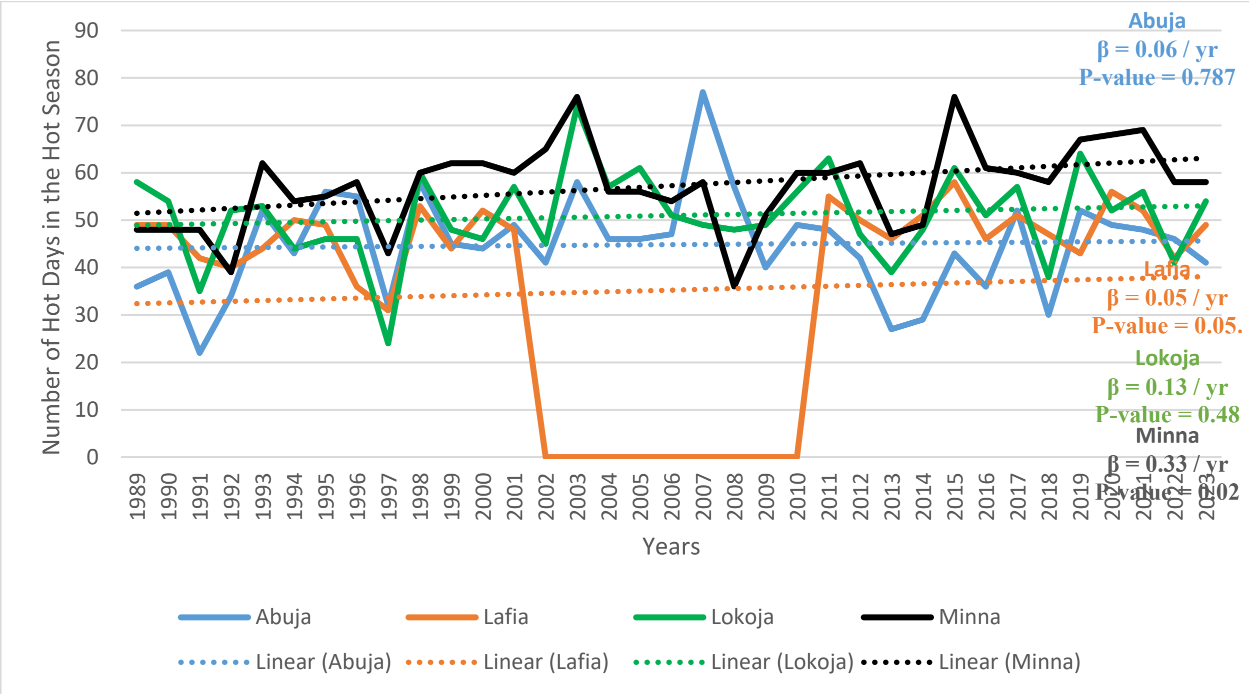

Figure 5: Variation in the Frequency of Annual HotD at the Study locations during the Hot Season.

High temperatures such as those experienced on hot days could have undesirable consequences for human beings as high temperatures have the ability to increase the core human body temperature, which could lead to heat stress, heat stroke and even death in extreme cases (Kunda et al., 2024). With the frequency of hot days in this region of the country, residents might likely need to increase their demand for electricity for cooling due to the heat stress they are subjected to. The heat stress that residents experience on these hot days, especially during the hot season, is likely to be exacerbated due to the frequent power outages that are prevalent in the hot season.

The frequency of hot days in the region could lead to heat-related water scarcity, reducing soil moisture availability, which could hamper nutrient uptake and which could eventually result in reduced crop yield or harvest failures especially, during dry season farming, if irrigation is not deployed to mitigate the negative effects of hot days in the region.

For example, the phenophases of certain crops (such as maize) which are cultivated within the region may be negatively affected due to the exceedance of their thermal tolerance level. According to Luo (2011), extremely high temperatures could have deleterious impacts on crop growth, development, and yield, especially during the phenophases. For example, the yield of maize, which is one of the major staple crops cultivated in the region, could be negatively affected under sustained excessively high temperatures, as studies such as Schoper *et al*., (1987) and Dupuis and Dumas (1990) have shown that maize pollen viability reduces when exposed to temperatures above 35 ºC.

Reduced crop yield or harvest failures occasioned by hot days also have negative economic implications, as this could lead to food shortages and higher food prices, which could affect the attainment of Sustainable Development Goal 2 (SDG 2), which aims to achieve zero hunger.

During the hot season, there is a higher likelihood of the outbreak of meningitis as studies (e.g., Ayanlade *et al.,* 2020) have shown that there is a strong relationship between temperature and the prevalence of Cerebrospinal Meningitis across the ecological zones of northern Nigeria.

3.2.2. Frequency of Tropical Nights

The frequency of TropN on the annual scale and during the hot season was significantly higher than the frequency of HotD on the same scales. This result is consistent with that of Iyakaremye (2021), who showed the frequencies of TropN are usually higher than the frequencies of HotD in many parts of Africa.

At Abuja (long-term mean = 272 nights), the annual frequency of TropN ranged between a minimum of 186 nights in 1992 and a maximum of 360 nights in 2013. The TropN at Lafia (long-term mean =298 nights) varied between 89 nights in 2023 and 365 nights between 2002 and 2004. At Lokoja (long-term mean = 313 nights), the frequency varied between 267 nights in 1989 and 344 nights in 2015, while at Minna (long-term mean = 296 nights), TropN varied between 222 nights in 1996 and 342 nights in 2021.

The high number of TrpN that mainly exceeds 200 nights is in line with the results obtained for the savannah regions in the study by Abatan *et al.,* (2018). The variation in the annual frequency of TropN at all the locations during the period of study is shown in Figure 6, while the long- term means are shown in Figure 8.

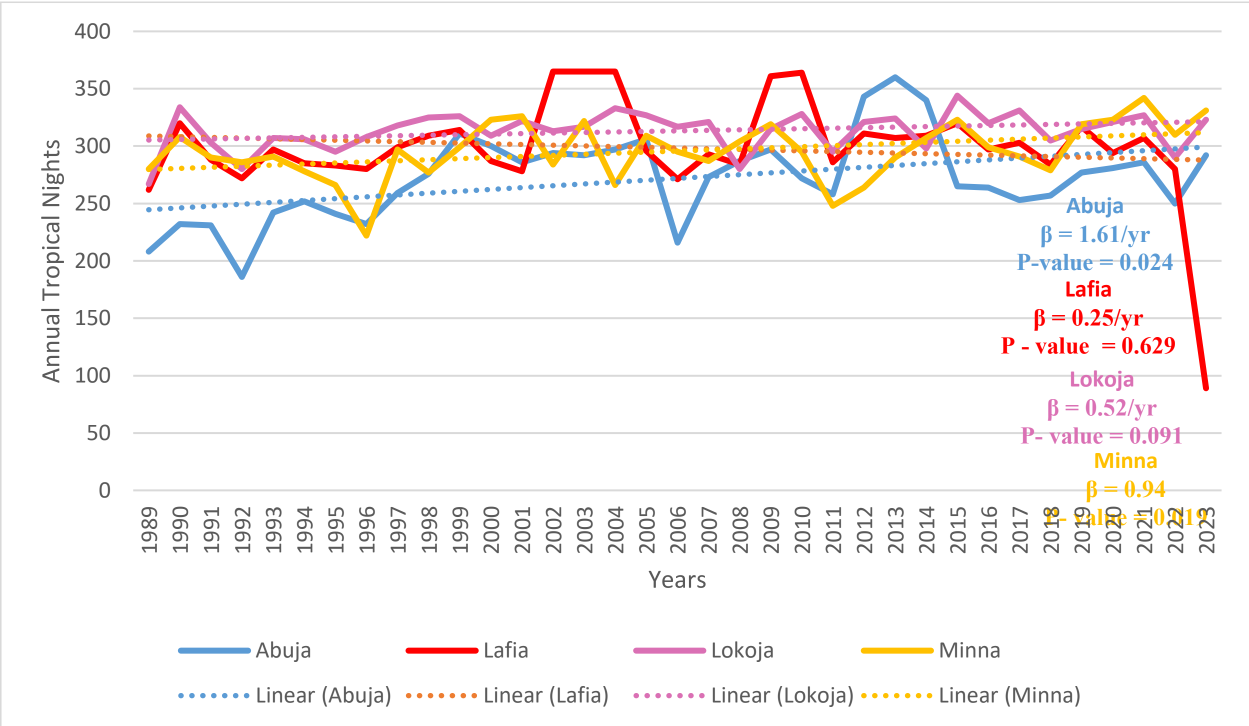

Figure 6: Variation in the Frequency of Annual TropN at the Study locations

During the hot season, the minimum number of TropN at Abuja, Lafia, Lokoja, and Minna was 71 nights, 76 nights, 81nights, and 80 nights, respectively. All the locations recorded a maximum of 92 nights, with Abuja recording these maximums between 2000 and 2002, Lafia between 1994 and 1996, 2002 and 2004, 2009 and 2014, and in 2016 and 2019. At Lokoja, 27 out of the 35 years of the study recorded the 92 nights of maximum TropN, while 12 years out of the study period at Minna recorded the 92 days of maximum.

The variability of TrpN during the hot season is presented in Figure 7 while, the long-term mean shown in Figure 8 was 88 nights, 89 nights, 91 nights, and 90 nights at Abuja, Lafia, Lokoja and Minna, respectively.

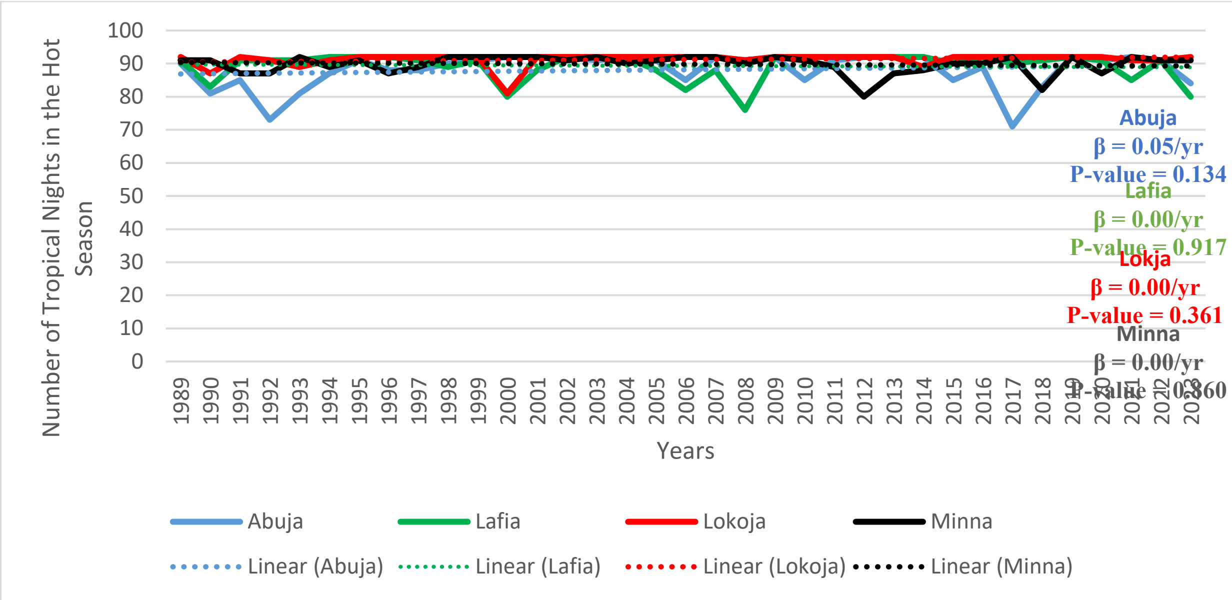

Figure 7: Variation in the Frequency of Annual TropN at the Study locations during the Hot Season.

The generally high frequencies of TropN at all the locations can negatively impact human efficiency and economic productivity due to sleep deprivation that could be brought on by night time heat stress. Sleep deprivation is likely to be exacerbated in densely populated low-income communities where access to cooling resources such as air-conditioners may be lacking. Warmer nights in some parts of Nigeria have been attributed to absorption and re-radiation of longwave radiation due to an increase in low and middle clouds (Abatan et al 2018).

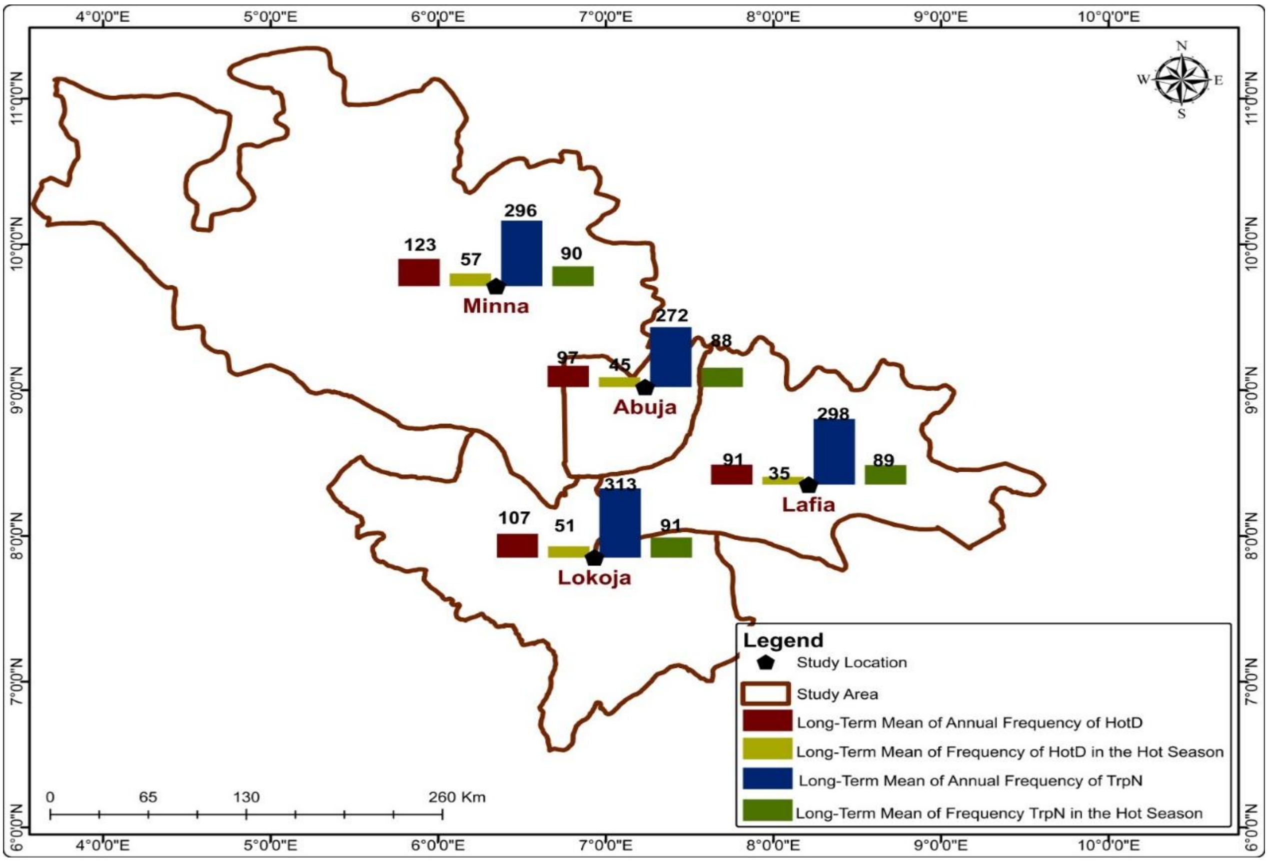

Figure 8: Long-term mean of (i) the annual frequency of hotD, (ii) the frequency of hotD during the hot season, (iii) the annual frequency of TrpN, and (iv) the frequency of TrpN during the hot season.

3.2.3. Consecutive Hot Days and Tropical Nights

The range of the annual maximum consecutive hot days and tropical nights is shown in Table 1. In the table, the annual maximum consecutive TropN was generally higher than the annual maximum consecutive HotD. The lowest numbers of consecutive HotD were recorded in the 1990s, with the lowest at Abuja, and Lafia recorded in 1990, while the lowest at Lokoja and Minna were recorded in 1992 and 1993, respectively. Similarly, the highest numbers of annual maximum consecutive hot days were recorded in 2001, 1998, 2003 and 2010 at Abuja, Lafia, Lokoja, and Minna, respectively.

The lowest numbers of consecutive TropN were recorded in 1992, 2023, 1992, and 2018 at Abuja, Lafia, Lokoja, and Minna, respectively. In addition, the highest numbers at Abuja were recorded in 2013, at Lafia, the highest numbers were recorded between 2002 and 2004, while at Lokoja and Minna, the highest were recorded in 2015 and 2000, respectively.

These results suggest that the population of these locations is subjected to a relatively modest number of days of uninterrupted high daytime temperatures and a significantly higher number of days of persistent elevated night time temperatures. This further suggests that tropical nights are an inherent feature of the climatology of central Nigeria. The consecutiveness of the hot extremes, especially the hot days, requires that several mitigation measures should be adopted by the populace of the region. Such measures include staying hydrated, limiting or avoiding outdoor activities during the peak heat hours between 12 pm and 4 pm, using sunscreen when going outdoors, and the use of Personal Protective Equipment (PPE) by construction workers.

Table 1: Annual Maximum Consecutive Hot Days and Tropical Nights

Station	Annual Max Consecutive HotD Range	Annual Max Consecutive TropN Range
Abuja	13 - 17	18 - 358
Lafia	11 – 87	66 – 365
Lokoja	18 – 107	86 – 312
Minna	20 – 82	28 - 296

3.3. Trends of Hot Extremes

Trends of Mean Maximum and Mean Minimum Temperatures

The results of the modified Mann-Kendall trend test for the mean annual TX and mean TX during the hot season are presented in Tables 2 and 3, while the results of the mean annual TN and mean TN during the hot season are presented in Tables 4 and 5.

Table 2: Trend of Mean Annual Maximum Temperature

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) ^{o}C yr^{-1}	Change Per Decade ^{o}C decade^{-1}
Abuja	0.055	33.0	0.693	0.003	0.03
Lafia	0.209	124.0	0.078	0.022	0.28
Lokoja	0.335	199.0	* 0.005	0.018	0.18
Minna	0.314	187.0	* 0.008	0.013	0.13
Sample Size	(n =35)				

An Asterisked P-value denotes a significant trend

Table 3: Trend of Mean Maximum Temperature during the Hot Season

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) ^{o}C yr^{-1}	Change Per Decade ^{o}C decade^{-1}
Abuja	0.025	15.0	0.831	0.003	0.03
Lafia	0.074	44.0	0.532	0.014	0.14
Lokoja	0.051	30.0	0.670	0.005	0.05
Minna	0.197	117	0.097	0.021	0.21
Sample Size	(n =35)				

Table 4: Trend of Mean Annual Minimum Temperature

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) ^{o}C yr^{-1}	Change Per Decade ^{o}C decade^{-1}
Abuja	0.324	193.0	*0.006	0.036	0.36
Lafia	0.185	110.0	0.118	0.022	0.22
Lokoja	0.232	138.0	*0.050	0.019	0.19
Minna	0.301	179.0	*0.011	0.018	0.18

Sample Size (n =35)
An Asterisked P-value denotes a significant trend

Table 5: Trend of Mean Minimum Temperature during the Hot Season

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) ^{o}C yr^{-1}	Change Per Decade ^{o}C decade^{-1}
Abuja	0.227	135.0	0.055	0.030	0.30
Lafia	0.182	108.0	0.125	0.021	0.21
Lokoja	0.138	82.0	0.244	0.014	0.14
Minna	0.083	49.0	0.486	0.007	0.07

Sample Size (n =35)

For the mean annual TX, Abuja and Lafia showed no significant changes, while Lokoja and Minna showed statistically significant positive trends of 0.018 ^{o}C yr^{-1} (0.18 ^{o}C decade^{-1}) and 0.013 ^{o}C yr^{-1} (0.13 ^{o}C decade^{-1}) respectively. This is an indication that Lokoja and Minna experienced an increase in peak daytime warming during the period of the study. For the hot season, none of the locations showed any significant changes. For the mean annual TN, all the locations except for Lafia showed statistically significant positive increases. For the hot season, none of the locations experienced any significant changes in overnight minimum temperatures.

3.3.1. Trends of Hot Days

The trends of HotD based on the TX>35 ^{o}C Threshold and the alternate threshold of TX>33 ^{o}C on both the annual and seasonal scales are presented in Tables 6 to 9. As shown in Table 6, the annual HotD based on the TX>35 ^{o}C threshold at Lafia, Lokoja and Minna exhibited significant positive trends of 2 days yr^{-1} (20 days decade^{-1}), 1.4 days yr^{-1} (14 days decade^{-1}), and approximately 1.2 days yr^{-1} (12 days decade^{-1}), respectively, while the change in Abuja was not significant. On the seasonal scale (Table 7), Minna was the only location that exhibited any significant trend, at an increasing magnitude of 0.3 days yr^{-1} (3.3 days decade^{-1}).

The results of the trend analysis based on the alternate threshold of TX> 33^{o}C for HotD (Tables 8 and 9) are similar to those obtainable from TX>35 ^{o}C Threshold. As shown in Table 8, no significant trend was recorded at Abuja during the study period, while the other three stations showed significant trends in the annual frequency of HotD at an increasing rate of 1.4 days yr^{-1} (14 days decade^{-1}) at both Lafia and Lokoja and a rate of 0.8 days yr^{-1} (8 days decade^{-1}) at Minna. For the hot season, the only significant change was recorded in Minna at the rate of 0.3 days yr^{-1} (3 days decade^{-1}).

Table 6: Trend of Annual Hot Days Based on TX>35 ^{o}C Threshold

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) days yr^{-1}	Change Per Decade days decade^{-1}
Abuja	0.179	106.0	0.132	0.643	6.43
Lafia	0.363	209.0	*0.003	2.000	20.00
Lokoja	0.449	265.0	*0.0002	1.400	14.00
Minna	0.459	273.0	*0.0001	1.154	11.54

Sample Size (n =35)
An Asterisked P-value denotes a significant trend

Table 7: Trend of Hot Days during the Hot Season Based on TX>35 ºC Threshold

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) days yr^{-1}	Change Per Decade days $decade^{-1}$
Abuja	0.032	19	0.787	0.061	0.61
Lafia	0.096	55	0.429	0.046	0.46
Lokoja	0.085	50	0.477	0.125	1.25
Minna	0.278	161	*0.022	0.333	3.33

Sample Size (n =35)
An Asterisked P-value denotes a significant trend

Table 8: Trend of Annual Hot Days Based on TX>33 ºC Threshold

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) days yr^{-1}	Change Per Decade days $decade^{-1}$
Abuja	0.210	124.0	0.078	0.60	6.0
Lafia	0.309	182.0	*0.009	1.44	14.4
Lokoja	0.502	297.0	*< 0.0001	1.41	14.1
Minna	0.464	273.0	* 0.0001	0.80	8.0

Sample Size (n =35)
An Asterisked P-value denotes a significant trend

Table 9: Trend of Hot Days during the Hot Season Based on TX>33 ºC Threshold

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) days yr^{-1}	Change Per Decade days $decade^{-1}$
Abuja	0.146	86.0	0.231	0.25	2.5
Lafia	0.069	40.0	0.567	0.00	0.0
Lokoja	0.214	126.0	0.073	0.21	3.1
Minna	0.293	170.0	* 0.015	0.30	3.0

Sample Size (n =35)
An Asterisked P-value denotes a significant trend

Similar studies (Abatan *et al.,* Gbode *et al.,* 2019) have reported increasing trends across different locations in different climatic regions of Nigeria. Furthermore, increasing trends in hot days are also consistent with increases found at some other locations in Africa. According to Nangombe *et al., (*2919), increases in hot days, including warm nights, have been observed in West Africa, with these increases linked to global warming.

The socio-economic consequences of hot days can be disadvantageous as they have the potential to adversely affect manual labourers, street traders, and other outdoor workers, as they are likely to experience more thermal stress, especially under conditions of combined high temperature and high humidity. Lack of Knowledge on the safety and health risks associated with working outdoors under extreme heat conditions is also likely to worsen the severity of thermal stress and other associated health conditions due to their inability to adopt proper adaptive strategies.

As reported by Moda *et al.,* (2024), more than 40 per cent of outdoor workers in a study conducted across five geopolitical regions of Nigeria had no source of information about adaptation strategies that can be employed under extreme heat conditions, the majority only relied on local knowledge of weather conditions within their domains.

3.3.2. Trends of Tropical Nights

For TropN (Table 10), no significant changes were recorded at Lafia and Lokoja, while at Abuja and Minna, significant positive trends of 1.6 nights yr^{-1} (16.1 nights $decade^{-1}$) and 0.94 nights yr^{-1} (16.1 nights $decade^{-1}$) were recorded on an annual scale. During the hot season (Table 11), none of the locations recorded any significant changes in the frequency of TropN.

Table 10: Trend of Annual Tropical Nights

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) nights yr^{-1}	Change Per Decade nights $decade^{-1}$
Abuja	0.268	159.0	*0.024	1.607	16.1
Lafia	0.058	34.0	0.629	0.250	2.5
Lokoja	0.2014	119.0	0.091	0.519	5.2
Minna	0.278	164.0	*0.019	0.940	9.4
Sample Size (n =35)					
An Asterisked P-value denotes a significant trend					

Table 11: Trend of Tropical Nights during the Hot Season

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) nights yr^{-1}	Change Per Decade nights $decade^{-1}$
Abuja	0.189	103.0	0.134	0.046	0.46
Lafia	-0.013	-7.0	0.917	0.000	0.00
Lokoja	0.125	49.0	0.361	0.00	0.00
Minna	-0.022	-12.0	0.860	0.00	0.00
Sample Size (n =35)					

The magnitude of change in the annual TrpN at Abuja when compared with the change at Minna may be due to the higher level of urbanisation in Abuja. As noted by Yavash and Erlat (2024), Urbanised areas generally exhibit higher nocturnal temperatures compared to rural or less urbanised areas due to variations arising from changes in land cover, alterations due to radiative and heat fluxes due to modified land cover and anthropogenic activities. Increasing trends in the frequency of TropN recorded at both locations could likely predispose people living in poorly insulated buildings, buildings that lack adequate ventilation, and those without air conditioning to increased nocturnal thermal stress.

3.3.3. Trends of Consecutive Hot Days and Tropical Nights

The results of the analysis for trends of annual maximum consecutive HotD and annual maximum consecutive TrpN are shown in Tables 12 and 13, respectively.

Table 12: Trend of Annual Consecutive Hot Days

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) days yr^{-1}	Change Per Decade days $decade^{-1}$
Abuja	0.085	50.0	0.478	0.167	1.67
Lafia	-0.004	-2.0	0.977	0.000	0.00
Lokoja	-0.044	-26.0	0.712	-0.103	-1.03
Minna	0.012	7.0	0.421	0.000	0.00
Sample Size (n =35)					

Table 13: Trend of Annual Consecutive Tropical Nights

Station	Kendall's Tau (τ)	Test Statistic (S)	P-Value Two-tailed	Sen's Slope (β) nights yr^{-1}	Change Per Decade nights $decade^{-1}$
Abuja	0.162	96.0	0.173	1.172	11.7
Lafia	0.051	30.0	0. 669	0. 313	3.1
Lokoja	0.249	148.0	*0.036	1.43	14.3
Minna	- 0.135	-80.0	0.256	-0.759	7.6
Sample Size (n =35)					
An Asterisked P-value denotes a significant trend					

As shown in Table 12, no significant changes were recorded for the annual maximum consecutive HotD during the study period. For the annual maximum consecutive TrpN, (Table 13), only Lokoja recorded any significant change at the rate of 1.4 nights yr^{-1} (14.3 nights $decade^{-1}$).

During periods of prolonged tropical nights, it is not uncommon for residents to sleep outdoors as a measure of alleviating the nocturnal heat stress they are subjected to. This could however, predispose such people to malaria due to increased mosquito populations and activities under such prolonged periods of high nocturnal temperatures. As noted by Lim *et al.,* (2021), high night-time temperatures favour the development, survival, and feeding activities of mosquitoes. In addition, Ebi et al., (2021) also noted that nocturnal heat stress triggered by high overnight temperatures is a leading factor dissuading the use of mosquito nets, thereby increasing the risk of diseases such as Malaria and Dengue fever in the tropics.

4.0 Conclusion

This study sheds light on the frequency and trends of HotD and TrpN at selected locations in central Nigeria between 1989 and 2023. Hot weather extremes pose significant challenges to human wellbeing as well as crop yield and productivity. The most vulnerable members of society, such as children, the elderly, pregnant women, and those with pre-existing health conditions, are most at risk of some of the deleterious impacts of hot extremes. These, however, underscore the need for climate adaptation to heat and hot weather in the region.

This will require a number of sustainable measures, such as the implementation of urban greening strategies, such as the planting of trees and other plants, to counter the thermal stress experienced by residents. This could involve planting of vegetation along transportation corridors, in private residences and public places. Construction of green walls (or vertical gardens) and green roofs in the urban centres of the region would assist in creating a microclimate that reduces the temperature of building envelopes and the amount of heat transferred from roofs into the interior. The capacity of the various ministries, departments and agencies in charge of the environment, ecological management and parks and gardens in various states within the region should be increased to enable them to improve existing urban greening strategies.

In order to enhance the country's preparedness and response in addressing adverse health effects associated with thermal extremes, NIMET should be given the required institutional backing to fully develop its existing heat-health early warning system for an effective and robust heat health action plan. This would help build resilience, proactive health responses, and increase public awareness.

Better management of Nigeria's electric power assets at the national and sub-national level is very important in ensuring proper functioning of the country's power grids to prevent power outages, especially during the hot season when there is a peak in energy demand. Relatedly, the abundant solar energy in the region can be harnessed for cooling through the installation of rooftop solar panels. This is because, beyond photovoltaic energy production, rooftop solar panels can prevent direct solar radiation from hitting the rooftops, thereby reducing heat transfer into the interior of buildings.

Due to losses that may be incurred due to reduced crop yield or harvest failures occasioned by hot weather extremes, there is a need for governments at the state and local government levels to provide farmers with heat-resistant crop varieties to ensure food security in the region and the country at large.

Going by the different measures that can be used in mitigating some of the undesirable impacts of hot extremes in rapidly urbanising towns and cities, such as those in central Nigeria, it is therefore recommended that region-wide approach should be adopted in providing solutions to this important climatic issue.

References

Abatan, A.A., Abiodun, B.J., Lawal, K.A., and Gutowski, W.J. (2016). Trends in extreme temperature over Nigeria from percentile-based threshold indices. *International Journal of Climatology,* 36, 2527 – 2540. DOI:10.1002/joc.4510.

Abatan, A.A., Abiodun, B.J., Adefisan, E.A., and Gutowski, W.J. (2018). Hot days and tropical nights in Nigeria: trends and associated large-scale features. *Theoretical and Applied Climatology.* https://doi.org/10.1007/s00704-018-2713-0.

Adeyeri, O.E., Akinsanola, A.A., and Ishola, K.A. (2017). Investigating surface urban heat island characteristics over Abuja, Nigeria: relationship between land surface temperature and multiple vegetation indices. *Remote Sensing Applications: Society and Environment*, 7, 57 – 68. https://doi.org/10.1016/j.rsase.2017.06.005.

Animashaun, I.M., Oguntude, P.G., Akinwumiju, A.S., and Olubanjo, O.O. (2020). Rainfall analysis over the Niger Central Hydrological Area, Nigeria: variability, trend, and change point detection. *Scientific African,* 8, e00419. https://doi.org/10.1016/j.sciaf.2020.e00419.

Ayanlade, A., Sergi, C., and Aynalande, O. (2020). Malaria and meningitis under climate change: initial assessment of climate information service in Nigeria. *Meteorological Applications*, 2020; 27:e1953. https://doi.org/10.1002/met.1953.

Barripedro, D., Herrera-Garcia, R., Ordonez, C., Miralles, D.G., and Salcedo-Sanz,S. (2023). Heatwaves: physical understanding and scientific challenges. Reviews of Geophysics, 61, e2022RG000780. https://doi.org/10.1029/2022RG000780.

Dupuis, I., and Dumas, C. (1990). Influence of temperature stress on in vitro fertilizer and heat shock protein synthesis in maize (Zea mays L.) reproductive tissues. *Plant Physiology*, 94, 665-670.

Ebi, K.L., Capon, A., Berry, P., Broderick, C., de Dear, R., Havenith, G., Honda, Y., Kovats, R.S., Ma, W., Malik, A., Morris, N.B., Nybo, L., Senevirantne, S.I, Vanos, J., Jay, O. (2021). Hot weather and heat extremes: health risks. *Lancet*, 398, 698-708.

Engdaw, M.M., Ballinger, A.P., Hegerl, G.G., and Steiner, A.K. (2021). Changes in temperature and heat waves over Africa using observational and reanalysis datasets. *International Journal of Climatology*, 42, 1165 – 1180. DOI:10.1002/joc.7295.

Gbode, I.E., Adeyeri, O.E., Menang, K.P., Intsiful, J.D.K., Ajayi, V.O., Omotosho, J.A., and Akinsanola, A.A. (2019). Observed changes in climate extremes in Nigeria. *Meteorological Applications*, 26, 642-654. https;//doi.org/10.1002/met.1791.

Goma, D., and Kuku, Y.I. (2024). Assessment of urban heat island in Abuja municipal area council, FCT-Abuja. *Jalingo Journal of Social and Management Sciences*, 6(1), 136-151.

Hamed , K.H., and Rao, A.R. (1998). A modified Mann-Kendall test trend for autocorrelated data. *Journal of Hydrology*, 204, 182-196.

Herold, N., Alexander, L., Green, D., and Donat, M. (2017). Greater increases in temperature extremes in low versus high income countries. *Environmental Research Letters,* 12, 034007. https://doi.org/10.1088/1748-9326/aa5c43.

Ifatimehin, O.O. (2007). An assessment of urban heat island of Lokoja town and surroundings using LANDSAT ETM data. *FUTY Journal of the Environment*, 2(1), 100-108.

Iyakaremye, V., Zeng, G., Ullah., I., Gahigi, A., Muno, R., and Ayugi, B. (2021). Recent observed changes in extreme high temperature events and associated meteorological conditions over Africa. *International Journal of Climatology*, 2022, 1-6.

Isioye, O.A., Ikwueze, H.U., and Akomolafe, E.A. (2020). Urban heat island effects and thermal comfort in Abuja municipal area council of Nigeria. *FUTY Journal of Environment*, 14(2), 19-34.

Jamshidi, E.J., Yusup, Y., Kayode, J.S., Kamaruddin, M.A. (2022). Detecting outliers in a univariate time series datasets using unsupervised combined statistical methods: a case study on surface water temperature. *Ecological Informatics*, 69:101672. https://doi/10.1016/j.ecoinf.2022.101672.

Kunda, J.J., Gosling, S.N., Foody, G.M. (2024). The effects of extreme heat on human health in tropical Africa. *International Journal of Biometeorology*, 68, 1015-1033. https://doi.org.1007/s00484-024-02650-4.

Langue, C.G.N., Lavaysse, C., Vrac, M., and Flaman, C. (2023). Heat wave monitoring over West African cities: uncertainties, characterisation, and recent trends. Natural Hazards and Earth System Sciences, 23, 1313 – 1333. https://doi.org/10.5194/nhess-23-1313-2023.

Lim, A.H., Gheong, H.K., Chung, Y., Sim, K., and Kim, J.H. (2021). Mosquito abundance in relations to extremely high temperatures in urban and rural areas of Incheon metropolitan city, South Korea from 2015 to 2020: an observational study. *Parasites and Vectors,* 14:559. https://doi.org/10.1186/s13071-021-05071-z.

Limbu, P.T.S., and Makula, E.K. (2023). Investigation of temporal trends and spatial patterns of extreme temperatures and their relationship to climate circulation indices in Tanzania. *Journal of Geographical Association of Tanzania,* 43 (2), 67-85.

Luo, Q. (2011). Temperature thresholds and crop production: a review. *Climate Change*, 109: 583-598. DOI: 10.1007/s/0584-011-0028-6.

Moda, H.M., Zallani, M.B., Rangaranjan, R., Hickey, P., Abubakar, M., Maina, J., and Makarfi, Y.I. (2024). Safety awareness and adaptation strategies of Nigerian construction workers in extreme heat conditions. *PLOS Climate*, 3(4):e0000380. https://doi.org/10.1371/journal.pclm.0000380.

Musari, A.A., Sojobi, O.A., Abatan, O.A., and Egunjobi, A.I. (2015). An estimate of thermal comfort in north-central region of Nigeria. *IOSR Journal of Applied Physics*, 7(1), 60-66. DOI:10.9790/4861-07116066.

Nangombe, S.S., Zhou, I., Zhang, W., Zou, L., and Li, D. (2019). High temperature extreme events over Africa under 1.5 and 2°C of global warming. *Journal of Geophysical Research: Atmospheres*, 124, 4413-4428. https://doi.org/10.1029/2018JD029747.

National Bureau of Statistics. (2022). Demographic statistics bulletin. Demographic Statistics Division.

National Bureau of Statistics. (2011). Annual abstract of statistics 2011. Federal Republic of Nigeria.

Nigerian Environmental Study Action Team. (1991). Nigeria's Threatened Environment. A National Profile. NEST Publications, Ibadan, Nigeria, pg. 148.

Nigerian Meteorological Agency. (2019). 2018 Climatic Review Bulletin.

Nigerian Meteorological Agency. (2024). 2023 State of the Climate in Nigeria.

Ojo, S.O., Emmanusl, I., Adeyemi, B., Ogolo, E.O. (2021). Effect of the radiation balance on warming occurrence over West Africa. *Scientific African*: e00700.https//doi.org/10.1016/j.sciaf.2021.e00700.

Ringard, J., Dieppios, B., Rome, S., Diedhiou, A., Pellarin, T., Konare, A., Diawara, A., Konate, D., Dje, B.K., Katiellou, G.L., Seidou Sanda, I., Hassane, B., Vischel, T., Garuma, G.F., Mengistu, G., Camara, M., Diongue, A., Gange, A.T., Descroix, L. (2016). The intensification of thermal extremes in West Africa, 129, 66 -77. *Global and Planetary Change*, 139, 66-67. https://doi.org/10.1016/j.gloplacha.2015.12.009.

Schoper, J., Lambert, R., and Vasilas, B. (1987). Pollen viability, pollen shedding, and combining ability for tassel heat tolerance in maize. *Crop Science,* 27, 27-31.

Trisos, C.H., Adelekan, I.O., Totin, E., Ayanlade, A., Efitre, J., Gemeda, A., Kalaba, K., Lennard, C., Masao, C., Mgaya, Y., Ngaruiya, G., Olago, D., Simpson, N.P., and Zakieldeen, S. (2022): Africa. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 1285–1455, doi:10.1017/9781009325844.011.

Yavash, D.D., and Erlat, E. (2024). Tropical nights in the Mediterranean: a spatiotemporal analysis of trends from 1950 to 2022. *International Journal of Climatology*, 44(5), 1472-1488. https://doi.org/10.1002/joc.8394.

Cite this article as:

Adegun, O., Odunuga, S., and Otusanya, O. (2025). Trends in Hot Days and Tropical Nights (1989-2023) in Selected Central States of Nigeria. *Nigerian Journal of Environmental Sciences and Technology*, 9(2), pp. 196-212. https://doi.org/10.36263/nijest.2025.02.40