Spatio-Temporal Dynamics of Noon-Time Temperature in Selected Cities in Sudan Savanna and Tropical Rainforest Zones of Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. Author IMS designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors GNN and AAO managed the literature searches and corrected the draft manuscript. Author MM managed the analyses of the study. Author JM performed the statistical analysis. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

Urban centres in Sub-Saharan Africa have been undergoing unprecedented urbanization in the past decades at annual rates of almost 4%; with attendant impacts on the cities' thermal conditions. This study aimed at characterizing the noon-time maximum temperature of two selected cities each in the Sudan and Tropical Rainforest zones of Nigeria. The study utilized daily ERA Interim (European Reanalysis) grid-based 2 meter above ground daily noontime maximum temperature (°C) data of the European Centre for Medium-range Weather Forecasts (ECMWF) from 1990 to 2019. R Statistical package version 3.6.1 was employed to detect the trend and seasonality in the maximum noon-time temperature of the four cities using non-parametric Mann-Kendall trend and seasonal trend tests. The statistical properties of the data were first analyzed by graphical examination of the data, using time plots, and boxplots. Also, the normality test of Shapiro-Wilk (S-W test) was applied. Pettitt test was then employed to test for single change-point detection in the temperature series. The study revealed higher mean temperature values of

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27.49°C and 25.56°C respectively for Birnin Kebbi and Kano both in the Sudan, and lower temperature values of 24.08°C and 23.17°C respectively for Ibadan and Owerri located in the Tropical rainforest. The Tau statistics for Kano, Ibadan and Owerri are 0.07084, 0.09848 and 0.09113 and the corresponding p-values are 0.0447, 0.0053 and 0.0098 which are less than 0.05 alpha value; indicating significant trends for the three cities. The results also show significant seasonal increase at 0.05 significant levels in the maximum noon-time temperature series for all the locations. The study recommends urban landscape planning and design for optimization of outdoor thermal comfort and creation of heathier urban environments for the city dwellers.

1. INTRODUCTION

The last three or four decades have witnessed unprecedented urbanization, particularly in the developing countries [1]. Specifically, Sub-Saharan Africa is urbanizing quickly, with cities and towns growing at an annual rate of almost 4% over the last two decades [2]. Urbanization has been identified as the foremost anthropogenic activity with huge and irreversible consequences on contiguous ecosystems [3]. Most of the urban cities in Sub-Saharan Africa are characterized by unplanned, hasty, rapid urbanization processes which affect the ecology of the cities and often lead to negative environmental impacts, including elimination and fragmentation of native habitats, generation of anthropogenic pollutants, increase in Land Surface Temperature (LST) and reduced humidity [4,5]. Many scientific studies have shown that urbanization also results in changes in the micro climates of cities [6,7]. The consistent rise in urban atmospheric temperature results mainly from heat discharged by increased energy consumption, increased built-up surfaces which possess high heat capacities and conductivities, and decrease in vegetation cover [8,9]. Studies have already established negative relationships between cities and urban health globally, particularly; high ambient temperatures which are known to increase mortality or morbidity [10,11] and such fatalities have increased steadily over the past several decades [12,13]. Effective and coherent development of adaptation strategies to the rising urban climates requires a better understanding of the spatial and temporal variations in the local climate of these urban centres. This study therefore aimed at characterizing the noon-time maximum temperature of two selected cities each in the Sudan and Tropical rainforest zones of Nigeria from 1990 to 2019. The two selected cities in the Sudan Ecological Zone are Kano Metropolitan Area (Kano State) and Birnin Kebbi (Kebbi State) while those of the Tropical rainforest are Ibadan Metropolitan Area (Oyo State) and Owerri (Imo State). The temperature data grid points were extracted from the core areas of the four cities. The geographical coordinates of the grid points are indicated in Table 1.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Tropical Rainforest Ecological Zone corresponds to Koppen's tropical humid climate (Af) climate type. The zone occupies 9.7% of Nigeria's total land mass but is the most densely populated, source of Nigeria's bulk timber and a home to an enormous number of biodiversity plants animals [14]. The average annual rainfall of this ecological zone is about 2500mm at the south and about 1220 mm at the northern fringes of the zone, and a mean yearly relative humidity of about 76.05 % [15]. It is characterized by a long period of rainfall lasting between March/April and November, and a dry period lasting between December and March [15]. The zone has a monthly mean minimum temperature of about 22.49°C and a monthly mean maximum temperature of about 31.24°C. The average yearly temperature of the zone is about 26.6°C [15].

The Sudan Savanna Ecological Zone of Nigeria extends between latitudes 9° 30' and 12° 31' N and longitudes 4° and 14° 30' E. It occupies about 22.8 million hectares [15] and spans almost the entire northern states bordering the Niger Republic. It occupies over one quarter of Nigeria's total area. According to the Federal Department of Forestry [16], it stretches from the Sokoto Plains through the Northern section of the High Plains of Nigeria to the Chad Basin and includes areas around Sokoto, Kaduna, Kano and Borno States of Nigeria. The region has a unimodal annual rainfall range of between 600

and 1140 mm [14,17], falling over a period of 100-150 days. The relative humidity is generally below 40%, except for the few rainy months when this can rise to 60% [17]. Rainfall in the zone lasts from May/June to Septembe, while the dry period lasts between September and April. The zone has the largest population density in Northern Nigeria, produces important economic crops such as groundnuts, cotton, millet, and maize and has the highest concentration of cattle in the country [17]. The map of the study locations is presented in Fig. 1.

2.2 Data Used

Data used for this study is daily ERA Interim (European Reanalysis) grid-based 2 meter above ground daily noontime maximum temperature (^{o}C) data products of the European Centre for Medium-Range Weather Forecasts (ECMWF) from 1990 to 2019. Era-Interim is a global frequently used atmospheric reanalysis data. The spatial resolution of the data set is approximately 80 km on a default grid size of 0.75° x 0.75° latitude/longitude but was projected on 0.125° x 0.125° (14 km by 14 km) latitude/longitude grid. Maximum temperature was used because; being an hourly data there is no significant variation between the minimum and maximum values of the same hour.

2.3 Methods

The data which was downloaded in Network Common Data Form (NetCDF) format was extracted for the four selected cities using the Grid Analysis and Display System (GrADS) software into comma separated values (CSVs). To detect the trend and seasonality in the maximum noon-time temperature for Birnin Kebbi, Kano, Owerri and Ibadan Nigeria, non-parametric Mann-Kendall trend and seasonal trend tests were employed. In order to achieve these, statistical properties of the data were first analyzed by graphical examination of the data, using time plots, boxplots, density plots and Q-Q plots. Also, the normality test of Shapiro-Wilk (S-

W test) was applied. Pettitt test was employed to test for single change-point detection in the maximum temperature series. The brief discussions of the statistics are as follows:

2.3.1 Shapiro-wilk test for normality

The Shapiro-Wilk test is one of the most powerful tests for verifying if a climatic series are normally distributed [18,19]. Recently Shapiro-Wilk test has become one of the most preferred because of its good power properties as compared to a wide range of alternatives [20]. The S-W test is similar to computing a correlation between the quantiles of the standard normal distribution and ordered data points of the climatic series. The null hypothesis is that the population follows a normal distribution against the alternative which states that the population does not follow normal distribution. According to Shapiro and Wilk [21], the test statistic equation is given as follows:

$$SW = \frac{\left(\sum_{i=1}^{n} a_i y_{(i)}\right)^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \quad (1)$$

where, $y_{(i)}$ is the ordered sample values and a_i is the constant generated from the means, variances and covariances of the order statistics of a sample of size n from a normally distributed population [22].
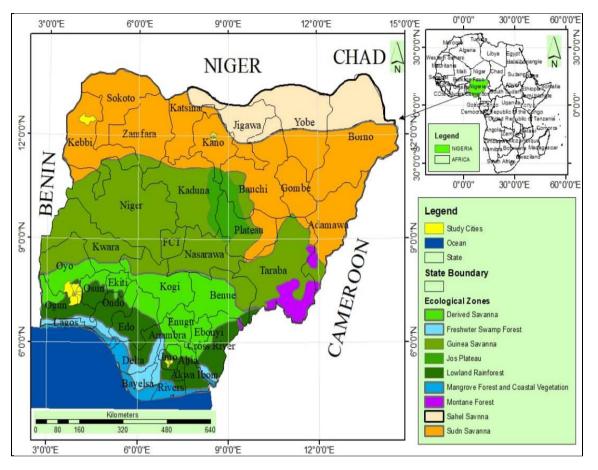
2.3.2 Mann-Kendall trend test

Mann-Kendall test is a non-parametric method which is widely employed to check the null hypothesis of no trend versus the alternative that there exists a monotonic increase or decrease in trend of a climatic time series data. The test statistic S is computed as follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}(X_j - X_k) \quad (2)$$

Table 1. Temperature data points for the study cities

Urban centre	Latitude	Longitude	Ecological zone
Birnin Kebbi	12° 22' 30"	4° 22' 30"	Sudan
Kano	12° 0' 00"	8° 30' 00"	Sudan
Ibadan	7° 22' 30"	3° 52' 30"	Tropical Rainforest
Owerri	5° 22' 30"	6° 52' 30"	Tropical Rainforest

Fig. 1. Nigeria showing selected cities in the Sudan Savanna and Tropical Rainforest zones

With,

$$\text{sgn}(x) = \begin{cases} 1 & if \quad x > 0 \\ 0 & if \quad x = 0 \\ -1 & if \quad x < 0 \end{cases}$$

The mean of S is E[S] =0 and the variance σ^2 is

$$\sigma^2 = \frac{1}{18}\left(n(n-1)(2n+5) - \sum_{j=1}^{p} t_j(t_j-1)(2t_j+5)\right) \quad (3)$$

Where p is the number of the tied groups in the data set and t_j is the number of data points in the jth tied group. The statistic S is approximately normally distributed for data values greater than or equal to 10 and provided that the following Z-transformation is employed:

$$Z = \begin{cases} \dfrac{S-1}{\sigma} & if \quad x > 0 \\ 0 & if \quad x = 0 \\ \dfrac{S+1}{\sigma} & if \quad x < 0 \end{cases}$$

The significance of trend is usually assessed using Z critical value. A positive Z value indicates upwards or increasing trend while the negative Z value reveals downward or decreasing trend.

The statistic S is closely related to Kendall's τ as given as follows:

$$\tau = \frac{S}{D} \quad (4)$$

Where,

$$D = \left[\frac{1}{2}n(n-1) - \frac{1}{2}\sum_{j=1}^{p} t_j(t_j-1)\right]^{1/2}\left[\frac{1}{2}n(n-1)\right]^{1/2}$$

2.3.3 Sen's slope estimator

A simple non-parametric procedure to estimate the true slope and intercept if a linear trend is present in a time series was developed by [23]. The slope is calculated as follows:

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$$q_i = \frac{X_i - X_j}{i - j} \quad i = 1,2,3,\cdots,N \quad j > k \qquad (5)$$

For $\left(\left(1 \leq i < j \leq n\right)\right.$, where q is the slope, X denotes the variable, n is the number of data, and i, j are indices.

Sen's slope is then computed as the median from all slopes: b=median q_i. The intercepts are calculated for each time (t) as given by:

$$a_t = X_t - bt \qquad (6)$$

and the corresponding intercept as well the median of all intercepts.

The Sen's estimator of slope is the median of these N values of q_i. The N values of q_i are ranked from the smallest to the largest and Sen's estimator is:

$$q = \begin{cases} q_{N+\frac{1}{2}} & if \quad N \ is \ odd \\ \frac{1}{2}\left(q_{\frac{N}{2}} + q_{N+\frac{1}{2}}\right) \end{cases}$$

A $100(1-\alpha)$% two-sided confidence interval about the slope estimate is obtained by the non-parametric technique based on the normal distribution.

2.3.4 Pettitt's test for change-point detection

The Pettitt test is a non-parametric test after [24], used to detect a single change-point in climatic or hydrological series with continuous data. The null hypothesis is that the observations follow one or more distributions that have the same location parameter (no change) while the alternative hypothesis states that there exists a change point. The ranks $r_1, r_2, \ldots\ldots\ldots\ldots\ldots, r_n$ of $x_1, x_2, \ldots\ldots\ldots\ldots\ldots, x_n$ are used to calculate the statistics:

$$U_{(k)} = 2\sum_{i=1}^{k} r_i - k(n = 1), \quad k = 1,2,\ldots\ldots\ldots\ldots, n$$

The test statistic is the maximum of the absolute value given as:

$$K_T = \max\left|U_{t,T}\right|, \qquad (7)$$

Where,

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} \text{sgn}(X_i - X_j)$$

The change-point of the series is located at K_T, provided that the statistic is significant. The significant probability of K_T is approximated for $p \leq 0.05$ with:

$$p \approx 2\exp\left(\frac{-6K_T^2}{T^3 + T^2}\right),$$

2.3.5 Mann-Kendall seasonal test

The Mann-Kendall statistic for the gth season is given as follows:

$$S_g = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}\left(X_{jg} - X_{ig}\right) g = 1,2,\ldots.,m$$

The mean of S_g is $\mu_g = 0$ and the variance including the correction term for ties is:

$$\sigma_g^2 = \frac{1}{18}\left(n(n-1)(2n+5) - \sum_{j=1}^{p} t_{jg}(t_{jg}-1)(2t_{jg}+5)\right), \quad (1 \leq g \leq m)$$

According to [25], the seasonal Mann-Kendall statistic for the entire series is calculated as:

$$\hat{S} = \sum_{g=1}^{m} S_g \quad and \quad \hat{\sigma}_g^2 = \sum_{g=1}^{m} \sigma_g^2$$

The statistic S_g is approximately normally distributed, with:

$$z_g = S_g / \sigma_g$$

If continuity=TRUE then a continuity correction will be employed:

$$z = \text{sgn}(S_g)\left(\left|S_g\right| - 1\right)/\sigma_g$$

3. RESULTS AND DISCUSSION

The descriptive analysis of maximum noon-time temperature, the time plots for the four cities, trend analysis of the period 1990-2019 using Mann-Kendall, Sen's slope estimator, Pettitt tests for change point and Seasonal Mann-Kendall

test were investigated using R statistical package 3.6.1 version. The results and discussions are as follow:

3.1 Descriptive Statistics for the Maximum Noon-time Temperatures for the Four Cities

Table 2 shows the descriptive statistics of the maximum noontime temperature in Birnin Kebbi, Kano, Ibadan and Owerri. It shows that Birnin Kebbi had the highest mean temperature followed by Kano, Ibadan and Owerri respectively. The standard deviation and the coefficient of variation from the mean value were

higher for Kano than those of Birnin Kebbi, Ibadan and Owerri in that order.

3.2 Time and Box Plots of Maximum Noon-time Temperature for the Four Cities

Fig. 2a, b, c and d present the maximum temperature plots against the time (years) for the four cities. The graphs reveal that the maximum temperatures of the cities do not depict any temporal trend especially for Birnin Kebbi. Those of Kano, Ibadan and Owerri are not quite discernible, although trends are suspected to be present.

Table 2. Descriptive statistics for the maximum noon-time temperatures

Statistics	Birnin Kebbi	Kano	Ibadan	Owerri
Mean	27.49	25.56	24.08	23.17
Skew	0.39	-0.09	0.47	0.60
Kurtosis	-0.72	-0.69	-0.59	-0.06
Minimum	21.41	18.66	22.07	21.49
Maximum	33.12	31.84	27.51	26.67
Range	11.71	13.18	5.44	5.18
1st Quartile	25.69	23.54	23.04	22.32
Median	26.86	25.44	23.98	23.03
3rd Quartile	29.58	27.83	24.96	23.85
Standard Deviation	2.66	3.16	1.18	0.97
Coefficient of Variation	0.097	0.12	0.05	0.04

Table 3. Shapiro wilk normality test result

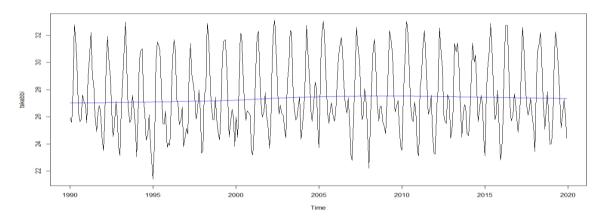| City	W-Statistic	P-Value
Birnin Kebbi	0.9591	1.8e-08
Kano	0.9801	7.15e-05
Ibadan	0.9620	4.7e-08
Owerri	0.9620	4.729e-08

Fig. 2a. Time plot of the time series observation of Birnin Kebbi in Nigeria against months for the period 1990 – 2019
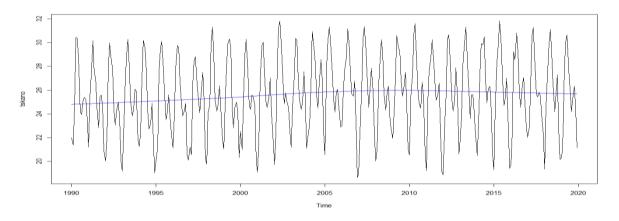
Fig. 2b. Time plot of the time series observation of Kano in Nigeria against Months for the period 1990 – 2019
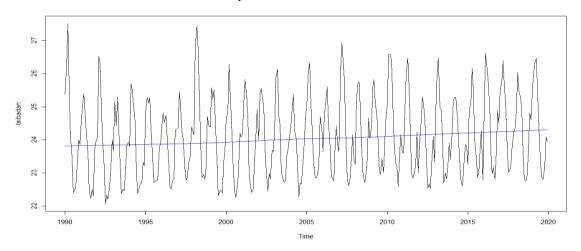

Fig. 2c. Time plot of the time series observation of Ibadan in Nigeria against months for the period 1990 – 2019
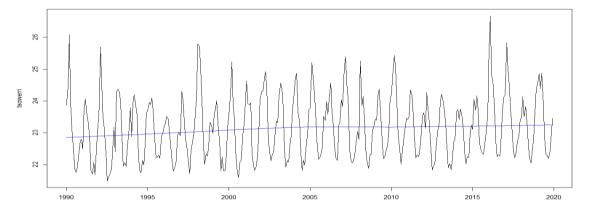

Fig. 2d. Time plot of the time series observation of Owerri in Nigeria against months for the period 1990 – 2019

The box plot for the four cities is shown in Fig. 3. It revealed five important statistics namely: minimum value, 25th percentile, median, 75th percentile, and the maximum value of the distribution as well as identification of potential outliers in the observations. From the boxplot below, it is apparent that only one observation was found to be above the upper adjacent value

in Owerri. No outliers were detected for every other city. The plot also reveals that more data is lying in the upper half of the range in Birnin Kebbi and Kano while those of Ibadan and Owerri are around the middle and lower half of the range respectively. In other words, the upper half of the maximum temperature is heavily weighted for Sudan Savanna cities (Birnin Kebbi and Kano) while those of Tropical Rainforest cities (Ibadan and Owerri) are otherwise.

3.3 Normal Probability Plots and Shapiro Wilk Normality Test of Maximum Temperature Series for the Four Cities

The normal probability plots of maximum temperature series for the four cities are depicted in Fig. 4. The plots reveal significant deviations from straight a line on the normal probability plots. Therefore, the series may not be normally distributed.

The results of Shapiro Wilk normality test presented in Table 3 is a further validation of non-normality of the maximum temperature series for Birnin Kebbi, Kano, Ibadan and Owerri from the normal probability plots. Since the p-values are all less than 0.05 significant value, the

null hypotheses that the series are normally distributed is rejected and it is concluded that the maximum temperature series collected for the period of 1990 to 2019 in for the four cities are not normally distributed.

3.4 Mann-Kendall and Sen's Slope Estimate Results of Maximum Temperature for the Four Cities

Mann-Kendall and Sen's slope estimate results of maximum noon-time temperature for the four cities are presented in Table 4. From the result, the Tau statistic for Birnin Kebbi is 0.045 and the corresponding p-value is 0.1976. Since the p-value greater than 0.05, we do not reject the null hypothesis of absence of trend in the maximum temperature for the city and concluded that there is no significant trend. However, the Tau statistics results for Kano, Ibadan and Owerri are 0.071, 0.098 and 0.091 and the corresponding p-values are 0.045, 0.005 and 0.010. Since the p-values are less than 0.05 alpha value, we reject the null hypotheses of the test and conclude that a trend is present in the data for Kano, Ibadan and Owerri respectively; with greater trends in the cities located within the Tropical Rainforest (Ibadan and Owerri).
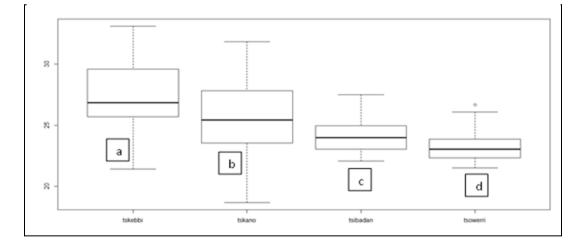

Fig. 3. Box plots of Maximum Noon-time temperature against time for Birnin Kebbi (a), Kano (b), Ibadan (c) and Owerri (d)

Table 4. Mann-Kendall trend and Sen's slope results of maximum noon-time temperature for Birnin Kebbi, Kano, Ibadan and Owerri

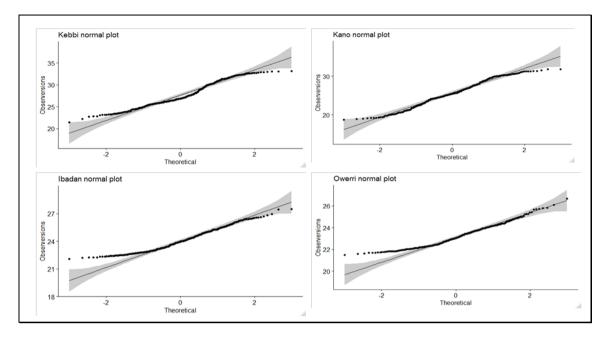| City	Tau	p-value	Sen's slope	p-value	95% Confident interval	
Birnin Kebbi	0.0455	0.1976	0.0013	0.2849	-0.0011	0.003703
Kano	0.0708	0.0447	0.0023	0.0609	-0.0001	0.006089
Ibadan	0.0985	0.0053	0.0015	0.0136	0.0003	0.002624
Owerri	0.0911	0.0098	0.0011	0.0224	0.0002	0.001979

Fig. 4. Normal probability plot of maximum noon-time temperature for Birnin Kebbi, Kano, Ibadan and Owerri

For the Sen's slope estimates, the slopes are all positive, indicating increasing trends over the years for the four cities. However, Ibadan and Owerri slopes showed significant differences at 5% significant level, Kano at 10% level, while slope for Birnin Kebbi is not statistically different from zero. These are further validated from the 95% confident interval reported. Any interval that contained zero is reported not statistically different from zero at 95%, indicating that the slope estimate is not statistically significant. The results are similar to those of Amadi [26] whose Mann-Kendall's test results for 20 synoptic weather cities across Nigeria (1950-2012) showed general warming trends across the locations and indicated that 17 cities had significant increasing trends in the minimum temperature at the 0.01 level of significance while 16 cities revealed significant increasing trends in the maximum temperature at the 0.01 and 0.05 significance levels.

The mean annual maximum noon-time temperature trends for the four cities are presented in Fig. 5. It shows higher temperature values in the two Sudan Savanna Cities (Birnin Kebbi and Kano) than the cities in the Tropical Rainforest (Ibadan and Owerri). According to Najib et al. [27], temperature in Nigeria had higher values in the far north, occasioned by the effect Sahara Desert, which is characterized by fewer cloud cover, resulting in more solar irradiation; while, lower temperature values in the south are attributable to much higher cloud cover and abundant vegetal cover.

3.5 Mann-Kendall Seasonal Trend Test Results

Mann-Kendall Seasonal Trend Test Results for the four cities are presented in Table 5. The results indicate a sufficient statistical evidence of a significant seasonal increase at 0.05 significant level in maximum noon-time temperature series for the four cities from 1990 - 2019.

Table 5. Seasonal Mann-Kendall trend test results of maximum noon-time temperature for Birnin Kebbi, Kano, Ibadan and Owerri

City	S	Var S	Z	p-value
Birnin Kebbi	695	37678.33	3.5753	0.0003498
Kano	1047	37677.00	5.3888	7.092e-08
Ibadan	1490	37659.33	7.6729	1.682e-14
Owerri	1259	37663.67	6.4822	9.042e-11

Fig. 5. Annual temperature trends across the four cities from 1990-2019

Table 6. Seasonal Mann-Kendall trend results for individual seasons (months)

Months	Birnin Kebbi		Kano		Ibadan		Owerri	
	Z(trend)	P-Value	Z(trend)	P-Value	Z(trend)	P-Value	Z(trend)	P-Value
January	-0.250	0.8027	-1.035	0.3007	0.464	0.6426	1.998	0.0457
February	1.106	0.2687	1.142	0.2535	0.375	0.7078	0.517	0.6048
March	0.786	0.4321	1.374	0.1693	0.928	0.3534	-0.553	0.5801
April	0.161	0.8724	0.000	1.0000	1.840	0.0657	1.588	0.1123
May	0.981	0.3263	2.481	0.0131	4.069	4.72e-5	1.481	0.1385
June	1.802	0.0715	1.945	0.0518	2.554	0.0106	1.304	0.1923
July	1.963	0.0496	4.158	3.2e-05	4.052	5.07e-5	3.194	0.0014
August	1.250	0.2114	3.248	0.0012	3.714	0.0002	2.588	0.0096
September	1.856	0.063	3.105	0.0019	2.534	0.0112	2.643	0.0082
October	1.802	0.0715	2.320	0.0203	3.676	0.0002	2.802	0.0051
November	0.607	0.5440	-0.518	0.6047	2.356	0.0184	2.644	0.0081
December	0.161	0.8724	0.339	0.7345	-0.143	0.8865	2.089	0.0366

In Table 6, the seasonal Mann-Kendall trend results indicates increasing trend in almost all the months of the year. For Birnin Kebbi, there are eleven months of increasing trend of which only July was statistically significant at 5% level, while the month of January witnessed a decrease in trend, although not statistically significant.

Kano witnessed a decreasing trend in the months of January and November, and increasing trends in the months of February - April and December but not statistically significant at 5% alpha level. However, from the months of May to October in Kano, there has been a significant increasing trend of temperature with the p-value <.05 alpha value. In Ibadan, December showed a decreasing trend over the years while, January to March is

increasing but not significant statistically. However, there has been significant increase in temperature from the months of April to November for the period under consideration. In Owerri, January, and July - December have witnessed increasing trends of temperature over the years and are statistically significant at 5% alpha value. The months of February to June witnessed increasing trend in temperature but not statistically significant.

A graphical representation of the mean monthly temperature of the four cities during the period under consideration is presented in Fig. 6. It shows that not only are temperature values higher in the two Sudan Savanna Cities (Birnin Kebbi and Kano); they are more variable seasonally compared to the two

cities in the Tropical Rainforest (Ibadan and Owerri).

Birnin Kebbi and Kano recorded the highest monthly mean temperature values between the months of March and June. The results are also in consonance with [26] whose study demonstrated latitudinal dependence of basic temperature characteristics; with the northern region of Nigeria showing higher temperature variability than the southern region. With low temperature values of 20.60°C and 21.17°C in the months of January and December for Kano and Birnin Kebbi respectively, Kano Metropolis particularly recorded temperatures much lower than those of the Tropical Rainforest which are generally characterized by lower temperatures. These lower temperatures in Kano city are attributable to the Harmattan season which occurs between the end of November and mid-March (Okeahialam, 2016) and is more severe in the Sudan ecological zone. The Harmattan dust is largely made up of dense silicon content which reduces radiation from the sun, and its attendant warmth, hence the associated low temperature [28]. For the cities in the Tropical Rainforest ecological zone, temperature peaks in March

(25.82 °C for Ibadan and 24.41°C in Owerri) and declines steadily till July from when a near uniform temperature is sustained until September, after which the temperature rises following the cessation of the rain season.

3.6 Pettitt Test for Single Change-Point in Temperature for the Cities

Results for the Pettitt Test for Single Change-Point in temperature for the four cities are presented in Table 7and Fig. 7. The results reveal that the general rising trend began in the month of February 2002 for Birnin Kebbi and Kano, both located in the same ecological zone.

However, Birnin Kebbi is not statistically significant at 5% level. For Ibadan and Owerri both in the same ecological zone, an increasing trend was experienced in the month of November. The change in trend in Owerri was earlier (2001), while that of Ibadan occurred later. Also, an increasing change point was observed in November 2004 and 2001 in Ibadan and Owerri. The results for Ibadan and Owerri were statistically significant only at 10% significance level with p-values of .058 and .051 respectively.
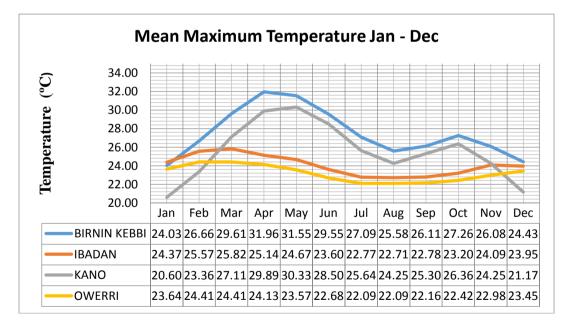

Fig. 6. Mean monthly noon-time temperature of the cities from 1990 to 2019

Table 7. Pettitt test for single change-point in maximum temperature for the cities

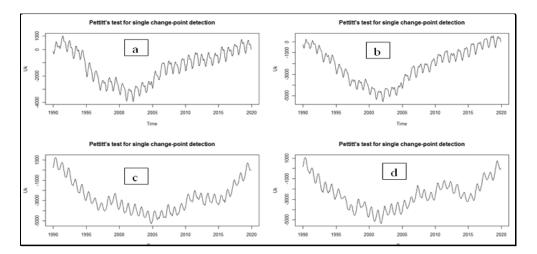| City	U	p-vale	K	Year-Month
Birnin Kebbi	3943	0.2723	146	February, 2002
Kano	5544	0.0388	146	February, 2002
Ibadan	5251	0.0583	179	November, 2004
Owerri	5342	0.0515	143	November, 2001

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Fig. 7. Pettitt's test for single change-point detection in maximum temperature for Birnin Kebbi (a), Kano (b), Ibadan (c) and Owerri (d) for the period 1990-2019

4. CONCLUSION

This study examined the spatio-temporal dynamics of noon-time urban temperature in selected cities in the Sudan Savanna and Tropical Rainforest Ecological zones of Nigeria between 1990 and 2019. The study adopted time plots, Mann-Kendall, Sen's slope estimator, Pettitt and Seasonal Mann-Kendall tests to investigate noon-time temperature trends and changes in four selected cities in the two ecological zones. The study revealed comparatively higher mean temperature values for the cities in the Sudan than those in the Tropical rainforest during the study period. It also shows that temperature is rising in all the cities with significant trends in three out of the four cities; with the Tau statistics results of 0.071, 0.098 and 0.091 and corresponding p-values are 0.045, 0.005 and 0.010 for Kano, Ibadan and Owerri respectively. The results also show significant seasonal increase at 0.05 significant levels in the maximum noon-time temperature series for all the locations; with greater seasonal increase in the cities located in the Tropical rainforest ecological zone. The observed rising trends is likely to have negative effects on the thermal comfort index of the cities, which should necessitate urban landscape planning and design for optimization of outdoor thermal comfort and creation of heathier urban environments for the city dwellers.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Farrel K. The Rapid Urban Growth Triad: A New Conceptual Framework for Examining the Urban Transition in Developing Countries. Sustainability. 2017;9:1407. DOI:10.3390/su9081407
2. Henderson JV, Storeygard A, Deichmann U. Has Climate Change Driven Urbanization in Africa? Journal of Development Economics. 2017;12:60–82.
3. Usman MB, Sanusi YA, Musa D. Physical and commuting characteristics of selected peri-urban settlements in Kaduna, Kaduna State, Nigeria. Journal of Geography and Regional Planning. 2017;10(11):317-329. DOI: 10.5897/JGRP2017.0641
4. Salim R, Rafiq S, Shafiei S. Urbanization, Energy Consumption and Pollutant Emission in Asian Developing Economies: An Empirical Analysis. ADBI Working Paper. 718. Tokyo: Asian Development Bank Institute; 2017.
5. Li Y, Zhang J, Sailor DJ, Ban-Weiss GA. Effects of urbanization on regional meteorology and air quality in Southern

California. Atmospheric Chemistry and Physics 2019;19:4439–4457.
Available:https://doi.org/10.5194/acp-19-4439-2019

6. Jiang Y, Han X, Shi T, Song D. Microclimatic Impact Analysis of Multi-Dimensional Indicators of Streetscape Fabric in the Medium Spatial Zone International Journal of Environment Research and Public Health. 2019;16:952.
DOI:10.3390/ijerph16060952

7. Ali SB, Patnaik S, Madguni O. Microclimate land surface temperatures across urban land use/ land cover forms. Global J. Environ. Sci. Manage. 2017;3(3):231-242.
DOI: 10.22034/gjesm.2017.03.03.001

8. Chaithanya VV, Binoy BV, Vinod TR. Estimation ofthe Relationship betweenUrban Vegetationand Land Surface Temperature of Calicut City and Suburbs, Kerala, India using GIS and Remote Sensing data. International Journal of Advanced Remote Sensing and GIS. 2017;6(1):2088-2096.

9. Paranunzio R, Ceola S, Laio F, Montanari A. Evaluating the effects of urbanization evolution on air temperature trends using nightlight satellite data. Atmosphere. 2019;10:117.
DOI:10.3390/atmos10030117

10. Péres WE, Ribeiro AFS, Ruso A, Nunes B. The Association between Air Temperature and Mortality in Two Brazilian Health Regions. Climate. 2020;8:16.
DOI:10.3390/cli8010016

11. Sanderson M, Arbuthnott K, Kovats S, Hajat S, Falloon P. The use of climate information to estimate future mortality from high ambient temperature: A systematic literature review. PLoS ONE. 2017;12(7):0180369.
Available:https://doi.org/10.1371/journal.pone.0180369.

12. Mirzaei M, Verrelst J, Arbabi M, Shaklabadi Z, Lotfizadeh M. Urban Heat Island Monitoring and Impacts on Citizen's General Health Status in Isfahan Metropolis: A Remote Sensing and Field Survey Approach. Remote Sensing. 2020;12:1350.
DOI:10.3390/rs12081350

13. Ahima RS. Global warming threatens human thermoregulation and survival. Journal of Clinical Investigation. 2020; 130(2):559-561.

14. Adaohuru AR, Obiefuna JC, Ibeawuchi II, Okoli NA. Evoking the knowledge of tree tenure in the humid tropics: A review of dimensions in agro-plantation system in Nigeria. Journal of Agriculture and Social Research (JASR). 2012;12:(1):171-182.

15. Adepoju KA, Salami AT. Geospatial assessment of forest fragmentation and its implications for ecological processes in tropical forests. Journal of Landscape Ecology. 2017;10(2):19-34.

16. Federal Department of Forestry. National Forest Reference Emission Level (FREL) for the Federal Republic of Nigeria. Federal Department of Forestry Federal Ministry of Environment Federal Republic of Nigeria; 2019.

17. Butu AW, Emeribe CN. Spatial patterns of climatic variability and water budget over Sudan Savannah Region of Nigeria. African Journal of Environmental Science and Technology. 2019;13(12):464-480.

18. Shapiro SS. How to Test Normality and other Distributional Assumptions. In: The ASQC Basic References in Quality Control. Statistical Techniques. 1980;3:1–78.

19. Gilbert, RO. Statistical Methods for Environmental Pollution Monitoring. John Wiley and Sons, New York; 1987.

20. Mendes M, Pala A. Type 1 Error Rate and Power of Three Normality Tests. Pakistan Journal of Information and Technology. 2003;2(2):135-139.

21. Shapiro SS, Wilk MB. An Analysis of Variance Test for Normality (complete samples), Biometrika. 1965;52(3–4):591–611.

22. Pearson ES, Hartley HO. Biometrika Tables for Statisticians; 1952. University Press, Cambridge. 1972;Vol. 2

23. Sen PK. Estimates of the Regression Coefficient Based on Kendall's Tau. Journal of the American Statistical Association. 1968;63:1379-1389.

24. Pettitt AN. A non-parametric approach to the change-point problem. Journal of the Royal Statistical Society. 1979;28(2):126-135. Techniques of trend analysis for monthly water quality data. Water Resources Research. 1982;18(1):107-121.

25. Hirsch RM, Slack JR, Smith RA. Techniques of trend analysis for monthly water quality data. Water Resources Research. 1982;18(1):107-121.

26. Amadi SO, Udo SO, Ewona IO. Trends and variations of monthly mean minimum and maximum temperature data over nigeria for the period 1950-2012. International Journal of Pure and Applied Physics. 2014;2(4):1-27

27. Najib Y, Okoh D, Musa I, Adedoja S, Said R. A study of the surface air temperature variations in Nigeria. The Open Atmospheric Science Journal. 2017;11:54-70.
   DOI: 10.2174/1874282301711010054

28. Enete JC, Obienusi EA, Igu IN, Ayadiulo R. Harmattan dust: Composition, characteristics and effects on soil fertility in Enugu, Nigeria. British Journal of Applied Science and Technology. 2012; 2(1):72–81.

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