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Assessment of Temporal Trend in Surface Air Temperatures across Some Selected Eco-Climatic Zones in Nigeria

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Temporal trends in surface air temperatures across some selected eco-climatic zones in Nigeria from 1981 to 2018 were assessed using the Merra-2 reanalysis dataset. A total of 15 stations spread across the eco-climatic zones in Nigeria were used for this study. The Mann-Kendall (M-K) trend test was used to detect direction, significance, coefficients of time trends, while the linear regression and the Sen's slope trend tests were used to estimate the trend magnitudes. The M-K trend test showed that the surface air maximum temperature of 14 stations had monotonic increasing trends, of which 13 stations were statistically significant at the 0.01 significance level, and 1 station was statistically significant at the 0.05 significance level. However, the M-K trend test also showed that surface air minimum temperature for all the 15 stations (representing 100%), showed monotonic upward trends, statistically significant at the 0.01 significance level. The Sen's slope and linear trend tests showed higher trend magnitudes at most stations, particularly stations in the Guinea-wooded, Sudan and Sahel savannas. The estimated mean trend magnitudes of maximum and minimum air surface temperatures increased by approximately 0.035°C/year and 0.036°C/year, respectively. The estimated mean air surface temperature increased by approximately 0.036°C/year and approximately 1.4°C for Nigeria over the 38-year period. The study then presents a linear trend projection of mean air surface temperature increase in Nigeria of approximately 4.3°C by 2100. This is 0.2°C below maximum levels and within the range of approximately 1.5 to 4.5°C that global air surface temperature is projected to rise by 2100 in the Intergovernmental Panel on Climate Change (IPCC) 2007 report. The M-K and linear trend tests were fully consistent with the standardized time series anomaly plots. Mean annual values of the air surface temperatures showed latitudinal dependence. The manifestation of significant long-term trends at high confidence levels in the air surface temperatures over the period, provides a clear evidence that the climate of Nigeria is witnessing a possible human-induced radiative forcing and a strong tendency for the occurrences of climate-related extreme events and their resulting adverse implications.

Keywords: *Trend; Temporal, Maximum temperature; Minimum temperature; Radiative forcing; Nigeria*

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1. Introduction

A trend is generally a long-term movement in a chronologically ordered observation (*i.e.*, a time series), having a period exceeding the length of the time series. Stephenson [1] defines a trend as a long-term variation in the average level, a smooth regular component having a period exceeding the length of a time series. There is generally a basic tendency either for data to go upward, downward or remain stable over a considerable period of time. Most importantly, analyzing temporal trends and changes in air surface temperature can indirectly reveal the "health" of the environment. A rising and/or declining trend may be quite instructive for different segments of human and natural systems.

The detection of time series trends in hydroclimatic parameters has become the most popular technique for detecting local, regional and global climate change and variability, and spatial or temporal changes in climate parameters appear to be non-uniform. Yue and Hashino [2] pointed out that there may be considerable and significant spatiotemporal changes between regions with different climates.

Many researchers analyzed surface air temperature-time series from various climate change perspectives across a wide range of temporal and spatial scales. Their analysis indicates significant increases in surface air temperature in different parts of the world [3-5]. Climate change scenarios for Nigeria as examined by Abiodun *et al.* [3], using a 30-year data distribution that spanned from 1971-2000, reported upwards trends in surface air maximum and minimum temperatures. Many studies have shown positive trends in surface air temperatures, although the changes vary from one region to another [6-9]. Analysis of 30 years' data for temperature and rainfall variability in Nigeria spanning from 1971-2000 conducted by Akinsanola and Ogunjobi [10], indicated that surface temperatures and rainfall increased significantly at a considerable number of the sites they studied. Their results further suggested a sequence of alternately upward and downward trends in the two parameters. Oguntunde *et al.* [11] conducted a study to assessed the possible occurrence of trends in air surface temperature across Nigeria from 1901-2000. Their results showed that the change in the minimum air surface temperature was higher than the change in the maximum air surface temperature. Amadi *et al.* [12] conducted a trend and variation study of basic atmospheric parameters including but not limited to mean annual air surface temperatures. Their findings showed trends in the parameters across Nigeria from 1950-2012.

The contemporary focus of applied climate science is on enhancing knowledge at local, regional and global scales. The more limited this information is available, the more relevant it will be to most users of the application. Studying trends and changes in a region's weather and climate elements is critical for sustainable agriculture, water management, power generation, marine and aviation safety, and more. Most communities in Nigeria are vulnerable to the vagaries of climate change and variability since they are exposed to several environmental hazards associated with climate change and variability. The effective use of weather and climate information to manage climate-related risks and prepare adaptive and mitigation measures to face future challenges is very vital. According to the IPCC report [13], high temperatures leaves in its wake, incidences of heatwaves. High temperatures can trigger off incidences of diseases linked to high temperatures such as Cerebra-spinal meningitis, heat stroke etc. Also, changes in surface air temperatures influences quite a number of hydrological processes, including precipitation.

Some trend studies in Nigeria focus on individual towns over relatively short periods of time [14-18]. Most of these studies carried out in Nigeria focused on the last century, while others focused on small spatial scales, mostly using in-situ meteorological data. Therefore, there is a need to study current trends in annual mean air surface temperatures at representative stations of selected eco-climatic zones in Nigeria using an Integrated Earth System Analysis (IESA) approach using decades of global reanalysis data. Reanalysis is a process in which a data assimilation system provides a consistent reprocessing of meteorological observations, typically covering an extended period of the historical data record. Milestones in achieving the objectives of this study are: 1. Assessing the historical recorded trends of the selected parameters at the site and period studied; 2. Assessing the temporal trends and possible causes of spatial variation of the selected parameters.

2. Location and Brief Geography of the Study Area

Nigeria is sandwiched between latitudes 4° and 14°N and between longitudes 3° and 15°E of the Equator and Greenwich Meridian respectively. The climate of Nigeria is made up of various ecotypes and climate zones and is influenced by the interaction of the Tropical Maritime and the Tropical Continental air masses and their associated Planetary Winds-the South-east and the North-east trade winds respectively. The Tropical Maritime air mass emanates from the Sub-tropical High Pressure belt, centered about 30°S of the equator, and off the coast of Namibia while the Tropical Continental air mass emanates from the Sub-tropical High pressure belt., centered about 30°N, north of the equator and over the Sahara Desert [3] The Tropical Maritime air mass is warm and moist while the Tropical Continental air mass is cold and dry, even as it travels across the Sahara Desert, towards Nigeria. The interactions of these two air masses defines the Wet and Dry season pattern in Nigeria. Teleconnection influences on the Nigerian landscape are imposed by the strong North Atlantic Oscillation (NAO) during the dry season and the El Nino-Southern Oscillation (ENSO) during the wet season [11].

Adefolalu [19] has pointed out that Nigeria may be divided into five eco-climatic zones - the Mangrove-swamp rainforest, the Tropical rainforest, the Guinea, Sudan and the Sahel Savannas. The characteristic of the eco-climatic zones is essentially defined by the vegetation pattern. Other factors such as rainfall, relief, soil type and human activity, may have significant impacts. Fig. 1: shows the meteorological stations for the study and the eco-climatic zones.

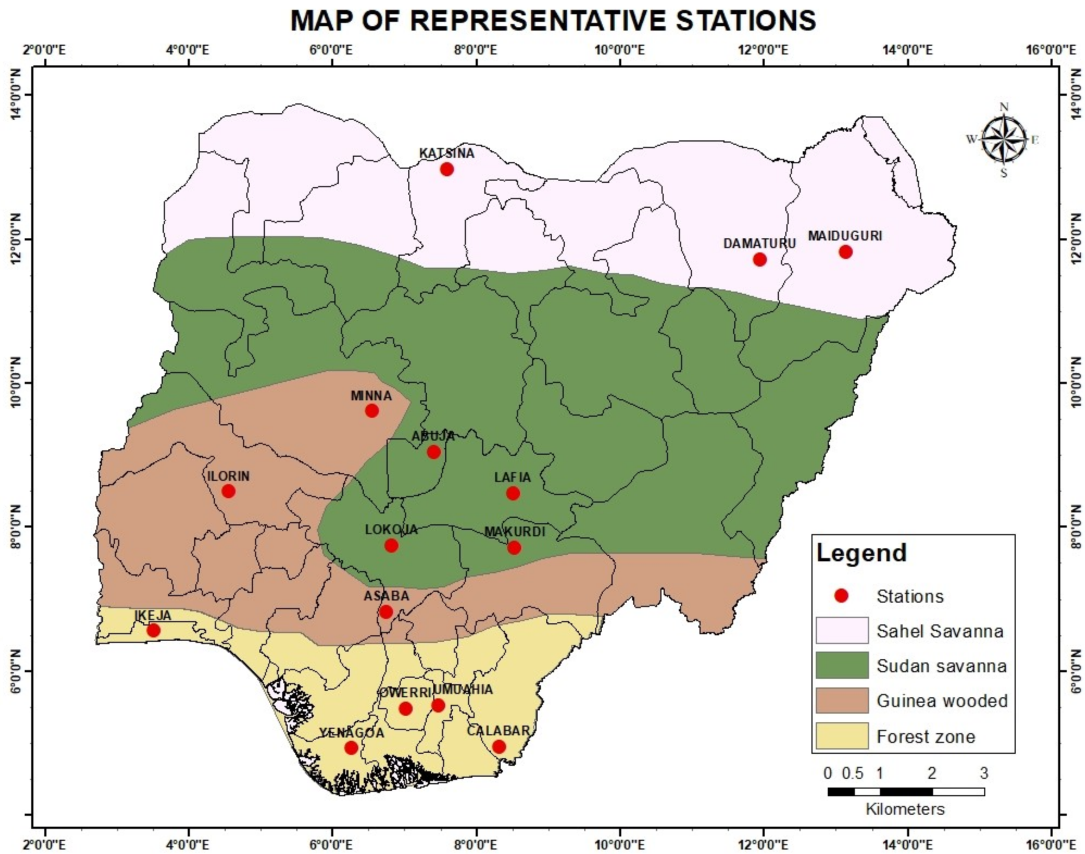


Fig. 1. Map of Nigeria showing the meteorological stations for the study and eco-climatic zones

Table 1. Summary information on the meteorological stations [3, 19, 20]

Station name	Latitude (°N)	Longitude (°E)	Altitude (m)	Eco-climatic Zones
Katsina	12.98	7.60	163.91	Sahel Savanna
Maiduguri	11.83	13.15	331.51	
Damaturu	11.73	11.95	388.54	
Abuja	9.05	7.41	404.65	Sudan savanna
Lafia	8.48	8.52	163.91	
Lokoja	7.75	6.82	198.15	
Minna	9.62	6.55	346.62	Guinea-wooded Savanna
Ilorin	8.50	4.55	283.03	
Makurdi	7.72	8.53	139.21	
Asaba	6.83	6.75	136.69	Tropical rainforest
Umuahia	5.53	7.48	92.84	
Owerri	5.48	7.02	60.61	
Ikeja	6.56	3.51	55.68	Mangrove-swamp rainforest
Calabar	4.95	8.32	34.68	
Yenagoa	4.93	6.26	13.06	

3. Data and Methodology

3.1 Dataset

The data for the assessment of mean annual air surface temperatures for trends across some representative stations of the selected eco-climatic zones in Nigeria is MERRA-2, which is obtained from the National Aeronautics and Space Administration (NASA) database. The GEOS Atmospheric model and the Grid Point Statistical Interpolation analysis scheme are considered as the important components of this system [21-23]. Reanalysis products are increasingly used in climate monitoring because appropriate and careful consideration is given to their inherent uncertainties [20]. The stations are the representative stations of the selected eco-climatic zones in Nigeria. The data represents the mean monthly values of air surface temperatures remotely sensed at 2 meters above the ground surface from the space-borne observation systems, spanning from 1981 to 2018. The parameters of interest are the air surface maximum and minimum temperatures. Summary information on the representative stations, meteorological parameters measured at the representative stations are presented in Table 1.

3.2 Data Check and Smoothening

Data was checked for incompleteness, outliers, and homogeneity. The data had no missing values. Quality checks help to remove outliers (genuine freak events or single data errors) and their biases. According to Longobardi & Villani [24], long-term climate analysis should be based on homogenous data, since there is a large variability in space and time of climate variables. Climate datasets are homogeneous datasets with fluctuations/variations caused only by weather and climate changes. Non-climatic factors can introduce fluctuations/homogeneities that create progressive biases in the data distribution [12]. Hence, normality and homogeneity tests were conducted on the datasets.

3.3 Methodology

The original mean monthly datasets were converted to mean annual datasets. This study synergistically embraced the parametric linear trend test and the non-parametric Mann-Kendall (M-K) and Sen's slope trend tests. According to Kundzewicz & Robson [25] and Sonali & Kumar [26], multiple statistical tests should be used to accurately interpret the data and test hypotheses when each statistical test addresses a specific question.

The M-K trend test was used to evaluate the trend direction, significance of the trend and the M-K tau b. The linear regression model using the least squares method and the Sen's slope trend tests were used to estimate the magnitudes of the trend. Many authors have pointed out that non-parametric tests have statistical advantages over the parametric test. Therefore, non-parametric tests are superior because of the following advantages: they are insensitive to the presence of outliers (*i.e.*, being robust to rogue events and incomplete data) and they exhibit a degree of monotonicity [27-29].

In cases where the non-parametric tests showed disparity in results with the parametric linear trend test, the M-K and Sen's slope trend tests results were held superior to the parametric test.

3.3.1 The Mann-Kendall (M-K) Trend Test

The M-K trend test statistics is computed using the sign of differences between successive values rather than on the values of the randomly selected variables [35]. This non-parametric statistical tool has been widely used to assess trends in hydro-climatic data [30, 31, 36, 37]. Hence, it was adopted in this study.

Given a time series of n-sized dataset, such that n is greater than or equal to 10, the M-K test statistic (S) is computed with the formula [28, 32].

$$S = \sum_{k=1}^{n-1} \quad \sum_{j=k+1}^{n} sgn\left(x_j - x_k\right) \qquad 1$$

where x_j and x_k are the sequential data values for the j^{th} and k^{th} terms (j > k)

$$\text{Sgn}\left(x_j - x_k\right) = \begin{cases} 1 \; if \; x_j - x_k > 0 \\ 0 \; if \; x_j - x_k = 0 \\ -1 \; if \; x_j - x_k < 0 \end{cases} \qquad 2$$

An increasing (upward) trend (later values exceeding earlier values) is denoted by a large positive value of test statistic (*S*). A decreasing (downward) trend (later values not exceeding earlier values) is denoted by a large negative value of the test statistic (*S*). A small absolute M-K test statistic(*S*) value implies that a trend does not exist.

The variance of *S, VAR(S)* (σ2) where ties are not present (*i.e.,* j=k does not exist) is defined as

$$VAR(S) = \frac{n(n-1)(2n+5)}{18} \qquad 3$$

where ties are present, the variance of S is defined as

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p \; (t_p - 1)(2t_p + 5)\right] \qquad 4$$

From Eqn. 4, q denotes the number of tied (*i.e.*, j=k), t_p denotes the number of data values in the p^{th} group.

Computation of Z test statistic is done using the values of M-K test statistic(*S*) and the variance of the M-K test statistic *AR(S)* as follow

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} \; if \;\; S > 0 \\ 0 \qquad if \; S = \; 0 \\ \frac{S+1}{\sqrt{VAR(S)}} \; if \;\; S < 0 \end{cases} \qquad 5$$

An upward or downward trend is denoted by a positive or negative value of *Z,* respectively. For a two-tailed test, the null hypothesis H_o implies that a linear trend does not exist and that the data distribution is randomly ordered and independent. An alternative hypothesis H_1 implies that a linear trend does exists. For the null hypothesis H_0 to be rejected., the absolute value of Z evaluated using Eqn. 5 must be greater than the critical value $Z_{\alpha/2}$, at the selected significance level, for the null hypothesis H_0 to be rejected. Other than that, the null hypothesis is accepted.

3.3.2 The Linear Trend Test

The linear trend and Sen's slope trend tests were synergistically used in determining the trend magnitudes. A test for linear trend is given by the linear regression of y on time t.

$$y = \beta_0 + \beta_1 x + \varepsilon \qquad 6$$

The slope is denoted by β_1, and the intercept on y is denoted by β_0, which is the value of y at x = 0. The dependent variable is y, the independent variable is x, and ε is the error, residual, or bias, which can be positive, negative, or zero and is caused by random effects. The dependent variable y value corresponding to a given independent variable x value is estimated by finding the value of y from the least-squares line that fits the data.

The null hypothesis is that slope coefficient $\beta_1 = 0$ (*i.e.,* lack of linear dependence) and the alternative hypothesis is that slope coefficient $\beta_1 \neq 0$ (*i.e.,* linear dependence exists). A significant slope different from zero is the condition for rejecting the null hypothesis and accepting the alternative hypothesis that y has a linear trend over time with a ratio equal to β_1.

3.3.3 The Sen's Slope Trend Test

Estimation of trend magnitude in hydro-meteorological time series has been widely carried out using the Sens slope trend test [2, 18, 29].

Demonstration of the presence of a monotonic trend and the linearity of the trend allows for the estimation of the trend magnitude using the Sen's line. The non-parametric Sen's line models how the median data changes linearly with time, and the trend magnitude for the entire period covered by the study is obtained by multiplying the estimated slope per year by the total number of years involved. Following the method of Sen [33], the slope magnitude can be obtained as follows:

$$b_{sen} = Median\left[\frac{Y_i - Y_J}{(i-j)}\right] \text{for all j < i} \qquad 7$$

where Y_i and Y_j are data at time points i and j, respectively.

If the total number of data points in the series is *n*, then the corresponding slope estimates will be $\frac{n(n-1)}{2}$ and the test statistic b_{sen} will be the median of all slope estimates. Increasing or decreasing trend is shown by a positive or negative value of the test statistic respectively.

3.3.4 The p-value

The p-value defines a region in the probability distribution tail beyond the noticeable values of the selected test statistic. When the p-value is small, the corresponding selected test statistic value will be seen to be particularly high and when the p-value is large, the corresponding selected test statistic will be seen to be very small. The null hypothesis is rejected if the p-value is smaller than the selected significance level, assuming that the data is not consistent with the null hypothesis at the selected significance level and vice versa.

4. Results

4.1 Results of Mean Air Surface Temperatures

4.1.1 Temporal Trend in Mean Annual Air Surface Temperatures

Tables 2 and 3 show the temporal trend for mean annual air surface maximum temperatures. The Mann-Kendall's test statistic (*S*) ranges from -113 to 398, the coefficients of time trends range from -0.161 to 566, and the trend magnitude increase ranges from 0.015° to 0.073°C/year for mean annual air surface maximum temperatures across the selected eco-climatic zones in Nigeria. The highest trend magnitude in mean annual air surface maximum temperature is noticeable in Lafia (*i.e.,* 073 °C/year) while the lowest value is observed in Yenagoa (*i.e.,* 0.015 °C/year) (Table 2). The temporal trend for mean annual air surface minimum temperatures are shown in Tables 4 and 5. The Mann-Kendall's test statistic (*S*) ranges from 280 to 446, the coefficients of time trends (*i.e.*, the Kendall's tau b) range from 0.398 to 0.634, and the trend magnitude increase ranges from 0.024° to 0.069 °C/year for mean annual air surface minimum temperatures across the selected eco-climatic zones in Nigeria. The highest trend magnitude in mean annual air surface minimum temperature is noticeable in Abuja (*i.e.*, 0.069 °C/year), while the lowest value is noticeable in Katsina and Ikeja (*i.e.*, 0.024 °C/year). (Table 4).

Figs. 2 to 6 are the standardized anomaly time series plots for mean annual air surface maximum temperatures, showing monotonic positive (upward) trends in the plots of 14 stations. A monotonic negative (downward) trend is shown by one station (*i.e.,* Ikeja).

Table 2. Results of Mann-Kendall's and Sen's slope trend tests for mean annual air surface maximum temperatures

Station name	S	Kendall's tau b	Z	Sen's slope estimates (°C/year)	p-value
Maiduguri	255	0.363**	3.1938	0.039**	1.404E-03
Damaturu	284	0.404**	3.5587	0.043**	3.727E-04
Katsina	196	0.279*	2.4529	0.020*	1.417E-02
Ilorin	129	0.184	1.6098	0.019	0.1074420
Lafia	398	0.566**	4.9914	0.073**	5.993E-07
Lokoja	320	0.455**	4.0114	0.051**	6.036E-05
Minna	365	0.519**	4.5762	0.065**	4.736E-06
Abuja	364	0.518**	4.5640	0.069**	5.019E-06
Makurdi	388	0.552**	4.8665	0.058**	1.136E-06
Owerri	316	0.450**	3.9632	0.019**	2.925E-04
Asaba	269	0.383**	3.3698	0.028**	7.522E-04
Ikeja	-113	-161	4.6035	-0.006	0.1587637
Umuahia	318	0.452**	3.9869	0.020**	6.695E-05
Yenagoa	284	0.404**	3.5594	0.015**	8.041E-03
Calabar	345	0.491**	4.3270	0.017**	1.511E-05

For Kendall's tau b, ** means that Kendall's tau b is significant at the 0.01 level (2-tailed), while means that *Kendall's tau b is significant at the 0.05 level (1-tailed). For Sen's slope, ** means that the slope is significant at the 0.01 level (2-tailed), while * means that the slope is significant at the 0.05 level (1-tailed).

Figs. 7 to 11 are the standardized anomaly time series plots for mean annual air surface minimum temperatures, showing monotonic positive (upward) trends in all the 15 stations.

Table 3. Results of linear trend estimation for mean annual air surface maximum temperature

Station name	Parameters	Slope estimates (°C/year)	Standard error	Students t-test	p-value
Maiduguri	Slope	0.039**	0.011	3.5862	4.77E-04
	Intercept	34.933	0.131	272..412	4.36E-02
Damaturu	Slope	0.048**	0.011	4.3837	8.50E-05
	Intercept	33.628	0.146	236.828	7.46E-03
Katsina	Slope	0.022*	0.009	2.4022	1.60E-02
	Intercept	33.465	0.103	330.044	5.58E-01
Ilorin	Slope	0.016	0.011	1.2883	1.25E-01
	Intercept	31.674	0.113	283.215	9.90E-01
Lafia	Slope	0.0075**	0.010	7.8234	2.01E-09
	Intercept	29.939	0.170	184.621	2.92E-07
Lokoja	Slope	0.052**	0.012	4.5241	3.71E-05
	Intercept	29.96	0.151	205.252	2.23E-03
Minna	Slope	0.069**	0.012	5.8302	6.22E-07
	Intercept	29.331	0.175	175.050	3.83E-05
Abuja	Slope	0.073**	0.012	6.0492	2.68E-07
	Intercept	29.157	0.182	167.914	1.54E-05
Makurdi	Slope	0..059**	0.008	7.1710	1.54E-08
	Intercept	29.384	0.137	222.263	4.90E-06
Asaba	Slope	0.028**	0.004	3.4982	6.87E-04
	Intercept	29.069	0.096	310.227	9.02E-02
Owerri	Slope	0.018**	0.004	4.7703	2.03E-05
	Intercept	28.3323	0.051	570.588	3.66E-01
Umuahia	Slope	0.020**	0.004	4.8984	1.21E-05
	Intercept	228.72	0.055	528.139	1.92E-01
Ikeja	Slope	-0.0069	0.044	-1.7697	1.11E-01
	Intercept	29.017	0.048	606.314	1.37E-07
Yenagoa	Slope	0.014**	0.004	3.8055	5.30E-04
	Intercept	28.468	0.045	633.952	8.00E-01
Calabar	Slope	0.018**	0.004	4.1381	8.17E-06
	Intercept	27.79	0.050	560.224	7.46E-01

**Slope is significant at the 0.01 level (2-tailed)
*Slope is significant at the 0.05 level (1-tailed)

Table 4. Mann-Kendall and Sen's slope trend tests for mean annual air surface minimum temperatures

Station name	S	Kendall's tau b	Z	Sen slope (°C/year)	p-value
Maiduguri	289	0.411**	3.6219	0.027**	2.925E-04
Damaturu	345	0.491**	4.3261	0.031**	1.518E-06
Katsina	280	0.398**	3,5089	0.024**	4.499E-04
Ilorin	366	0.521**	4.5906	0.029**	4.421E-06
Lafia	415	0.590**	5.2056	0.048**	1.934E-07
Lokoja	385	0.548**	4.8284	0.043**	1.132E-06
Minna	407	0.579**	5.1050	0.045**	2.735E-07
Abuja	364	0.518**	4.5640	0.069**	1.285E-07
Makurdi	388	0.552**	4.8673	0.038**	1.132E-06
Asaba	394	0.560**	4.9419	0.033**	7.735E-07
Owerri	410	0.583**	5.1439	0.033**	1.323E-04
Umuahia	391	0.556**	4.9038	0.033**	9.399E-07

Yenagoa	414	0.589**	5.1953	0.031**	2.043E-07
Calabar	446	0.634**	5.6340	0.030**	1.761E-08
Ikeja	348	0.495**	4.3651	0.024**	1.271E-05

**Kendall's tau b is significant at the 0.01 level (2-tailed)

**Slope is significant at the 0.01 level (2-tailed)

Table 5. Results of linear trend estimation for mean annual air surface minimum temperature

Station name	Parameters	Slope estimates (°C/year)	Standard error	Students t-test	p-value
Maiduguri	Slope	0.027**	0.006	4.2017	7.65E-05
	Intercept	20.671	0.08005	264.667	1.10E-02
Damaturu	Slope	0.031**	0.006	5.1639	6.93E-06
	Intercept	20.044	0.08490	243.210	1.25E-03
Katsina	Slope	0.024**	0.006	4.0525	1.33E-04
	Intercept	19.368	0.07586	261.603	1.32E-04
Ilorin	Slope	0.031**	0.005	5.49899	1.11E-06
	Intercept	20.903	0.07665	280.258	6.55E-04
Lafia	Slope	0.047**	0.006	7.9952	8.95E-10
	Intercept	20.876	0.10506	207.447	2.66E-07
Lokoja	Slope	0.041**	0.006	6.6786	4.39E-08
	Intercept	21.05	0.09876	221.315	1.18E-05
Minna	Slope	0.046**	0.007	6.5024	6.69E-08
	Intercept	19.418	0.11102	183.002	6.51E-06
Abuja	Slope	0.046**	0.006	7.0835	8.86E-09
	Intercept	19.44	0.10720	189.767	1.28E-06
Makurdi	Slope	0.039**	0.006	6.8273	3.24E-08
	Intercept	20.834	0.09194	234.822	1.28E-08
Asaba	Slope	0.034**	0.005	6.6422	5.06E-08
	Intercept	21.20	0.08097	269.966	4.5E-05
Owerri	Slope	0.033**	0.044	7.3927	6.52E-09
	Intercept	21.753	0.07659	292.493	1.51E-05
Umuahia	Slope	0.032**	0.005	6.8802	2.93E-08
	Intercept	21.52	0.07664	289.009	4.66E-05
Ikeja	Slope	0.025**	0.004	5.7450	1.23E-06
	Intercept	23.035	0.06338	370.915	4.62E-03
Yenagoa	Slope	0.031**	0.0042	7.4115	8.71E-09
	Intercept	22.768	0.0724	322.836	4.23E-05
Calabar	Slope	0.029**	0.004	8.8284	1.35E-10
	Intercept	23.767	0.6238	389.961	1.08E-05

**Slope is significant at the 0.01 level (2-tailed)

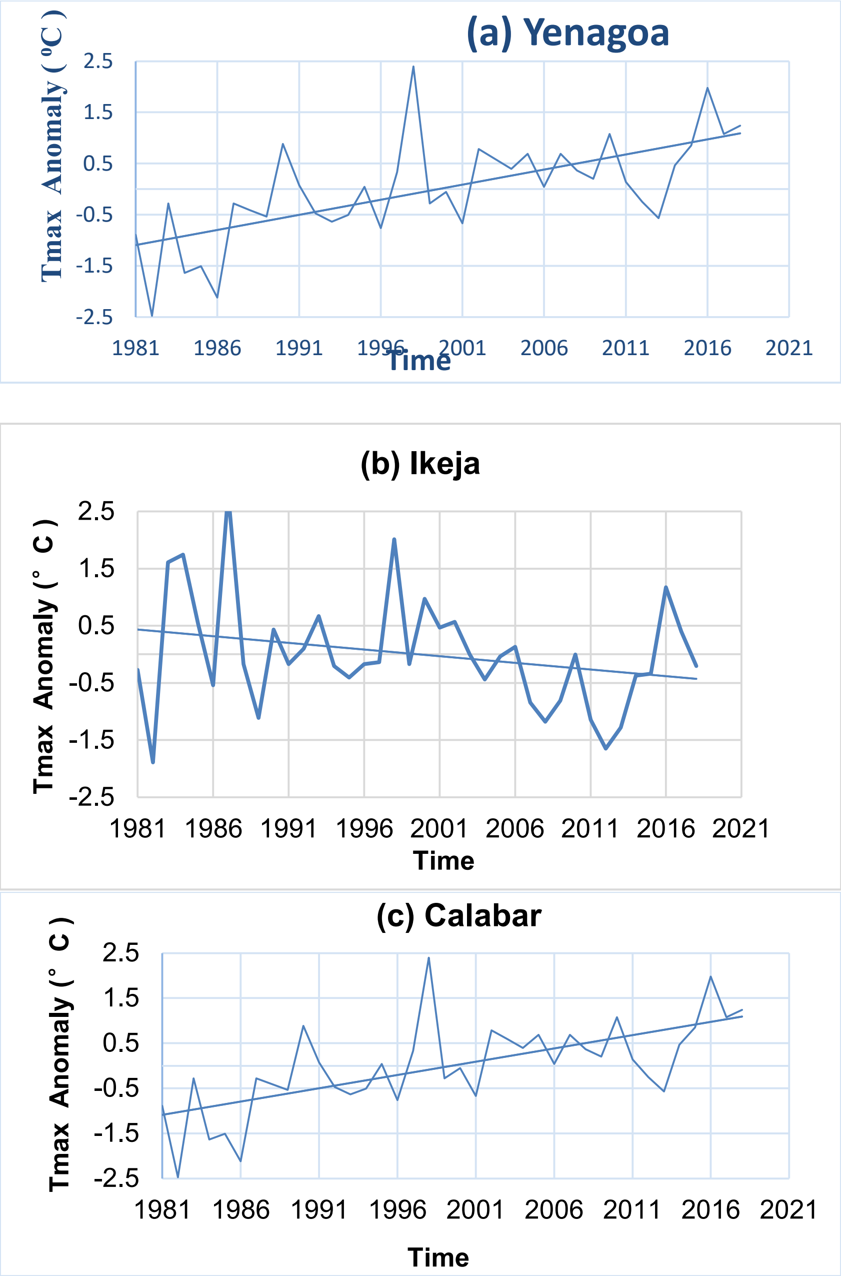


Fig. 2. Standardized anomaly time series plots for mean annual air surface maximum temperatures for representative stations (a: Yenagoa, b: Ikeja and c: Calabar) of the Mangrove-swamp rainforest eco-climatic zone

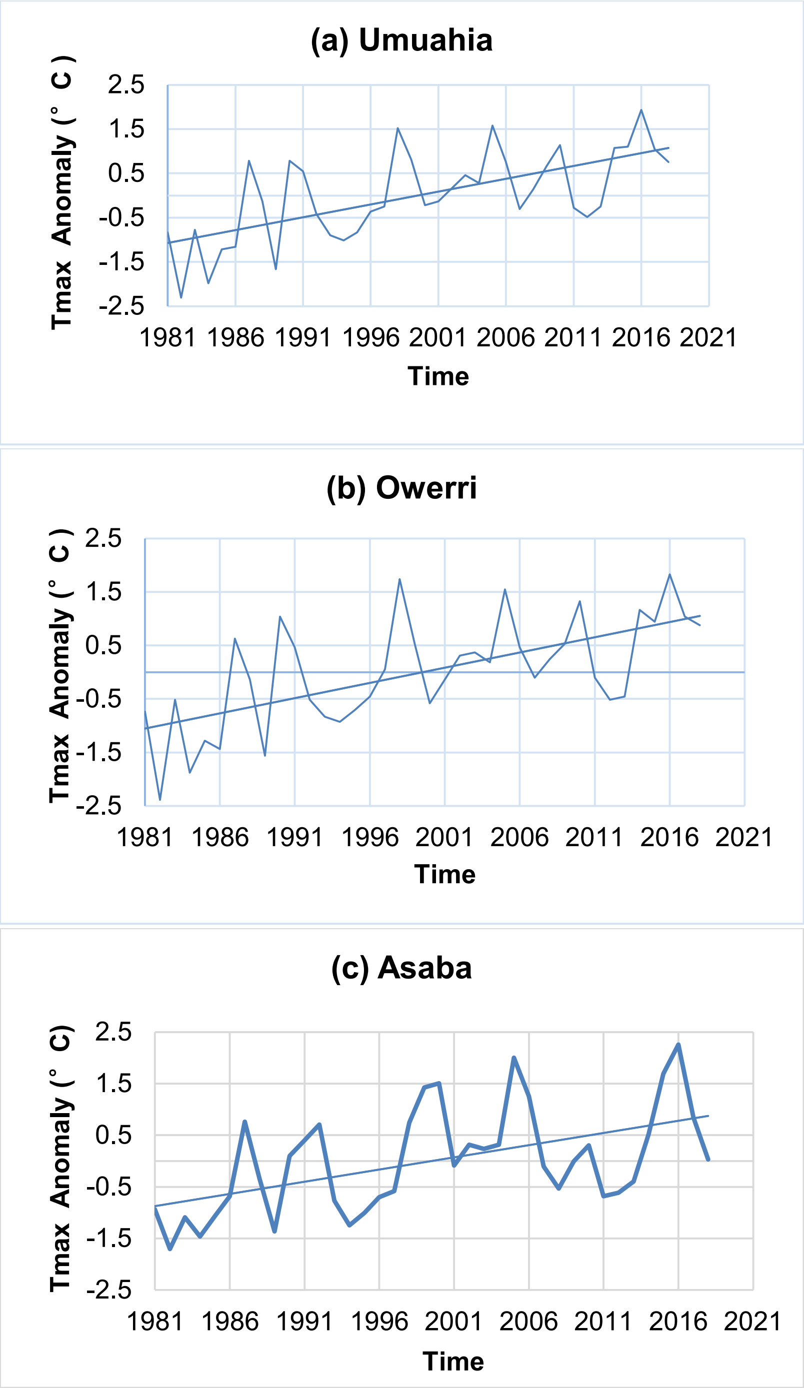


Fig. 3. Standardized anomaly time series plots for mean annual air surface maximum temperatures for representative stations (a: Umuahia, b: Owerri and c: Asaba) of the Tropical rainforest eco-climatic zone

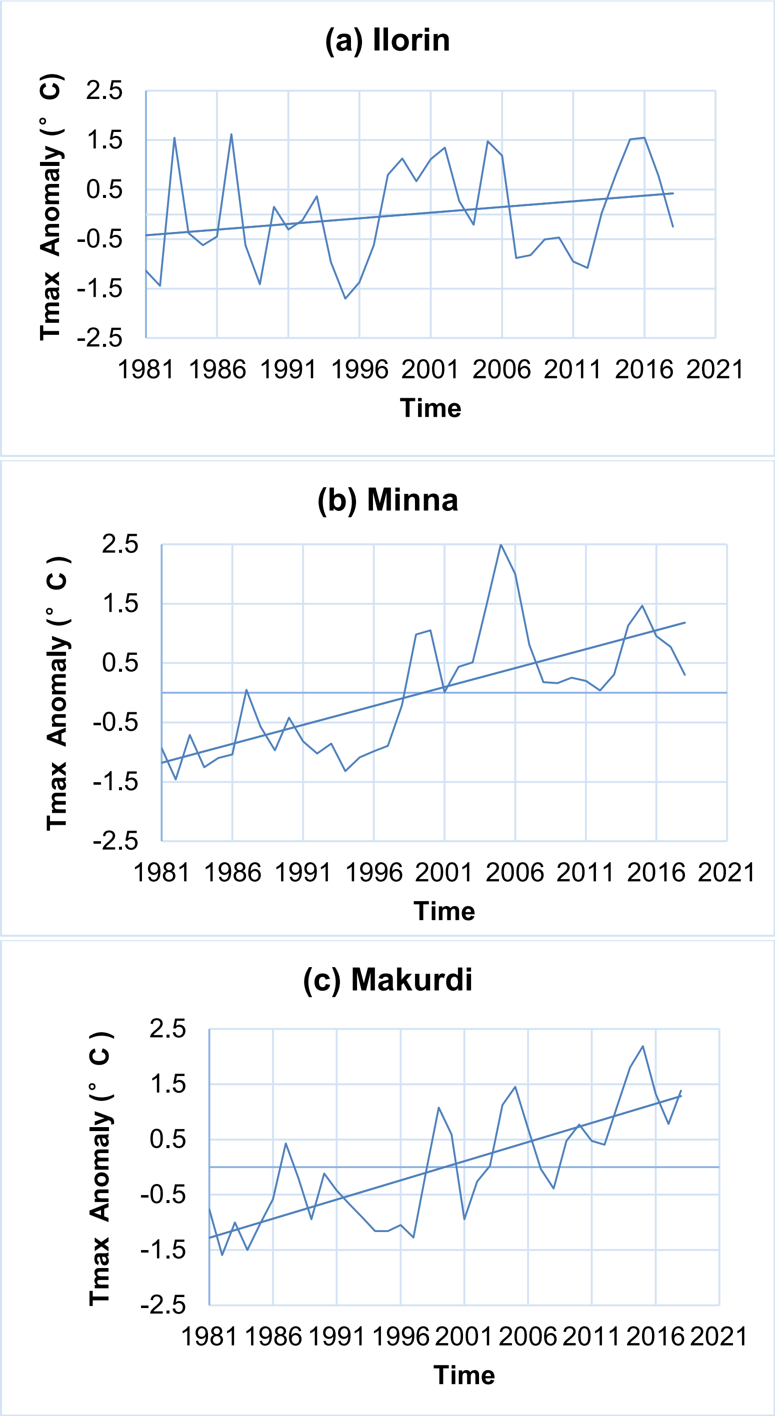


Fig. 4. Standardized anomaly time series plots for mean annual air surface maximum temperatures for representative stations (a: Ilorin, b: Minna and c: Makurdi) of the Guinea-wooded savanna eco-climatic zone

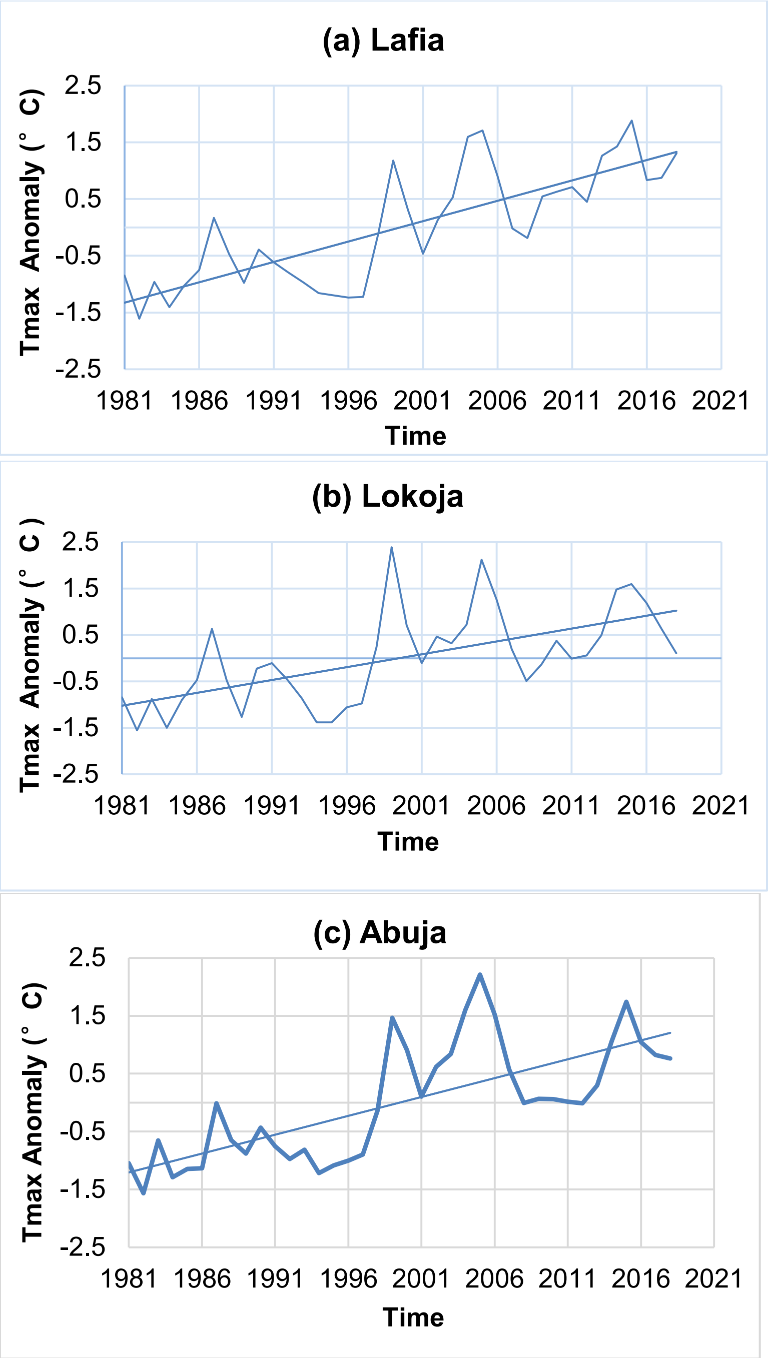
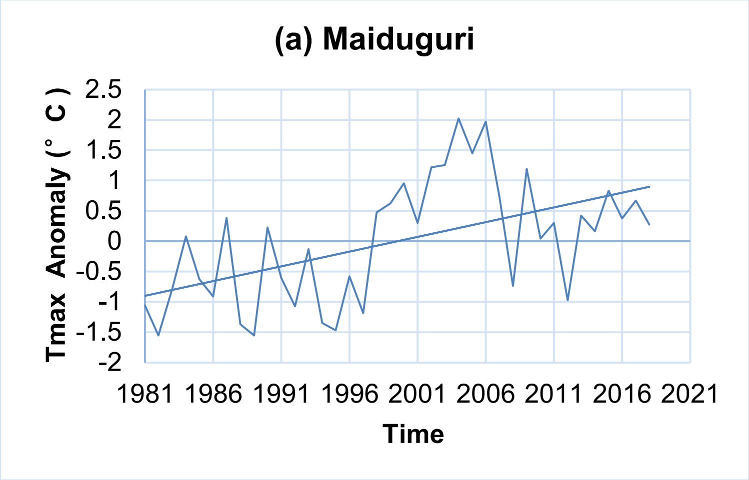
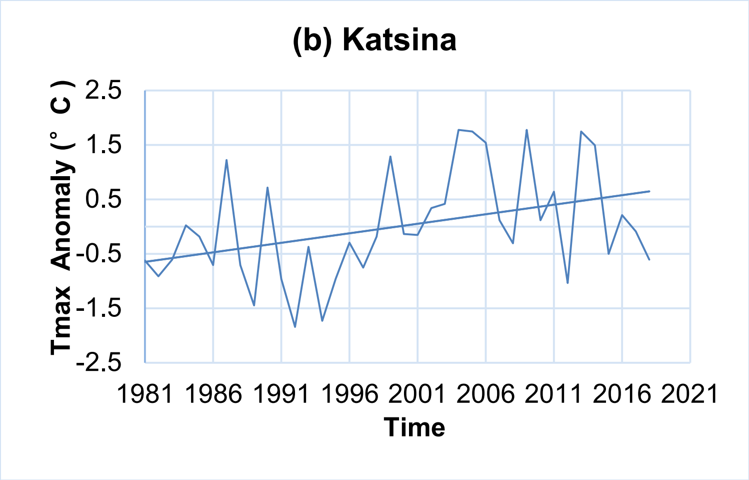


Fig. 5. Standardized anomaly time series plots for mean annual air surface maximum temperatures for representative stations (a: Lafia, b: Lokoja and c: Abuja) of the Sudan savanna eco-climatic zone





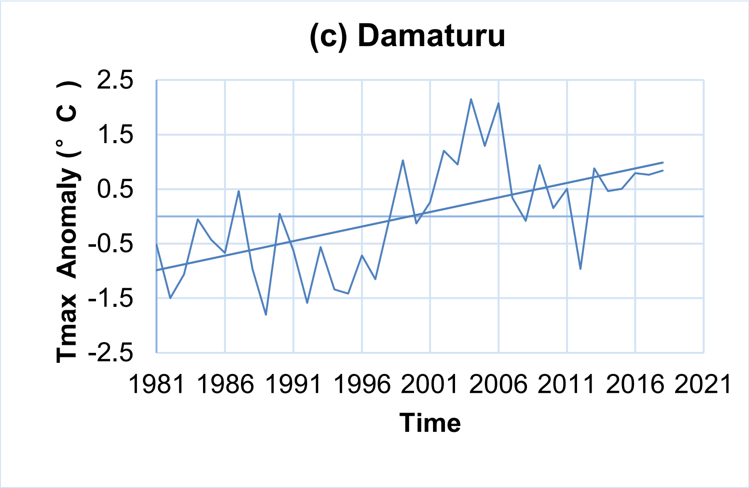
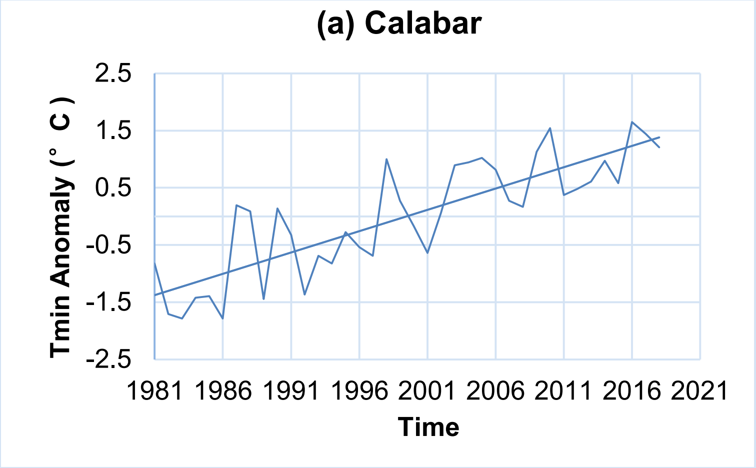
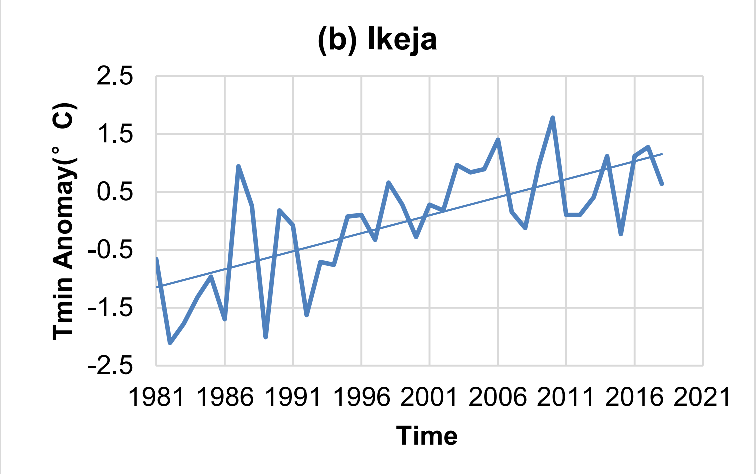


Fig. 6. Standardized anomaly time series plots for mean annual air surface maximum temperatures for representative stations (a: Maiduguri, b: Katsina and c: Damaturu) of the Sahel savanna eco-climatic zone





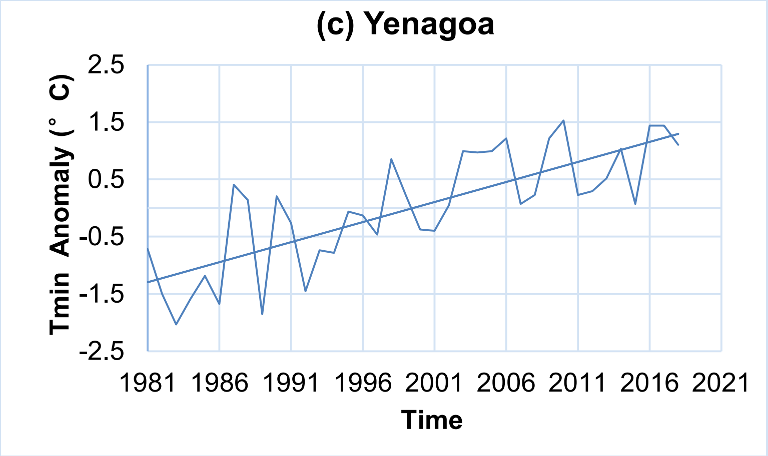
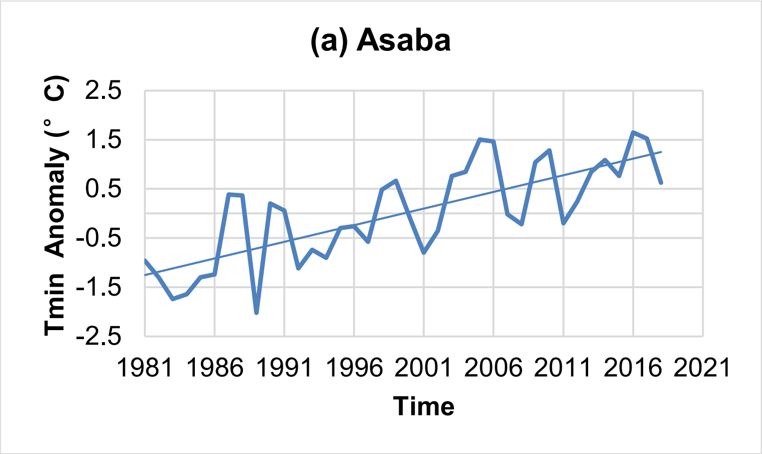
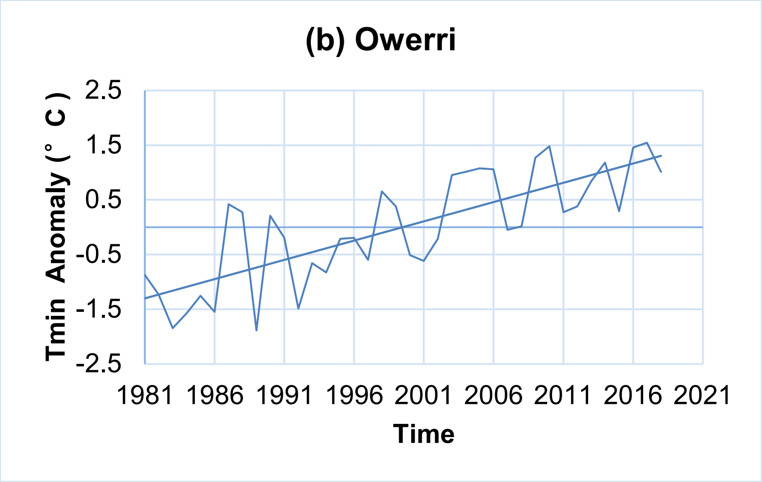


Fig. 7. Standardized anomaly time series plots for mean annual air surface minimum temperatures for representative stations (a: Calabar, b: Ikeja and c: Yenagoa) of the Mangrove-swamp rainforest eco-climatic zone





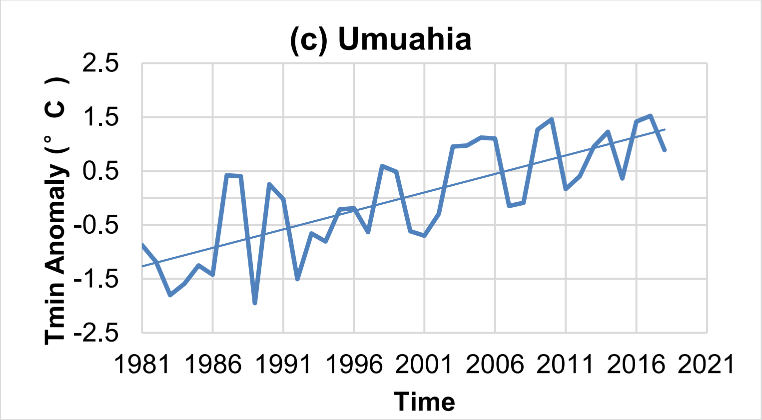
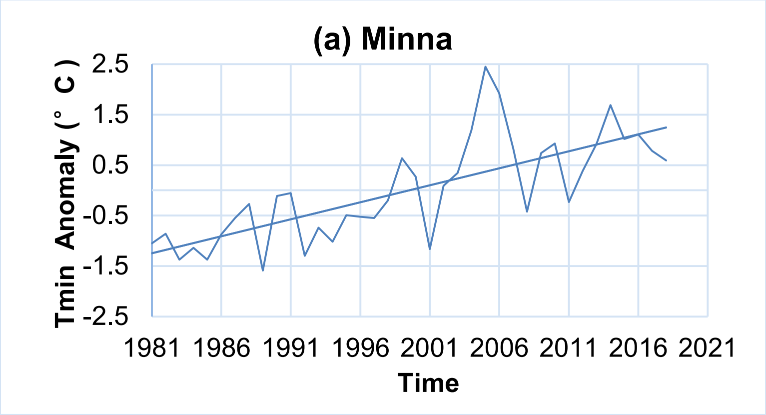
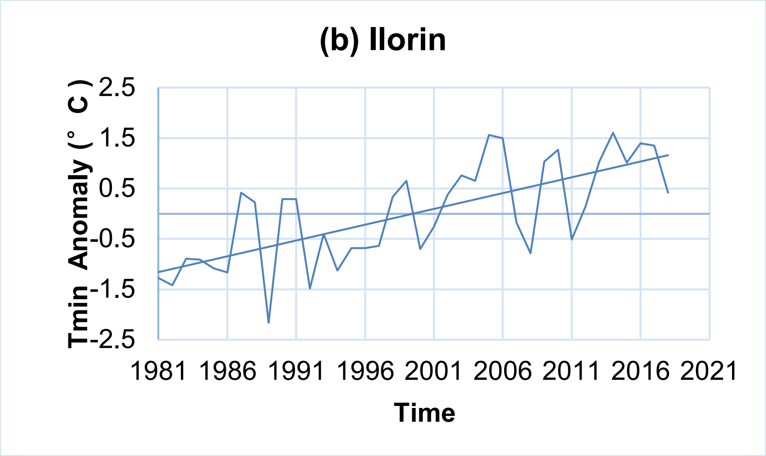


Fig. 8. Standardized anomaly time series plots for mean annual air surface minimum temperatures for representative stations (a: Asaba, b: Owerri and c: Umuahia) of the Tropical rainforest eco-climatic zone





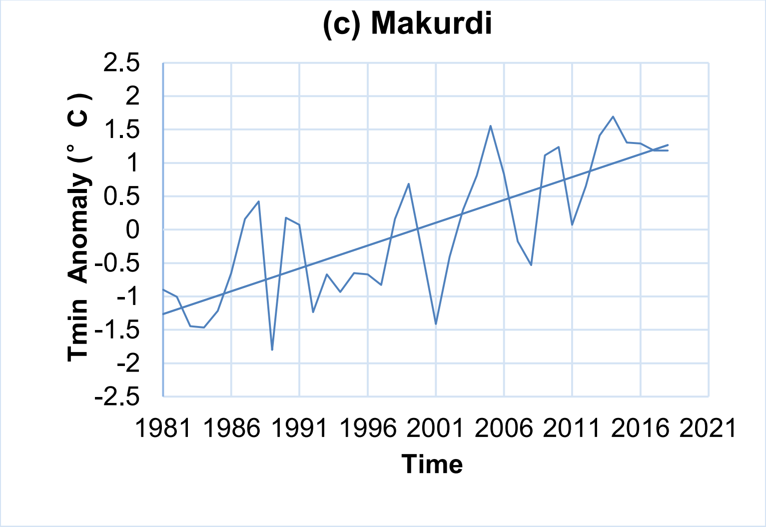


Fig. 9. Standardized anomaly time series plots for mean annual air surface minimum temperatures for representative stations (a: Minna, b: Ilorin and c: Makurdi) of the Guinea-wooded savanna eco-climatic zone

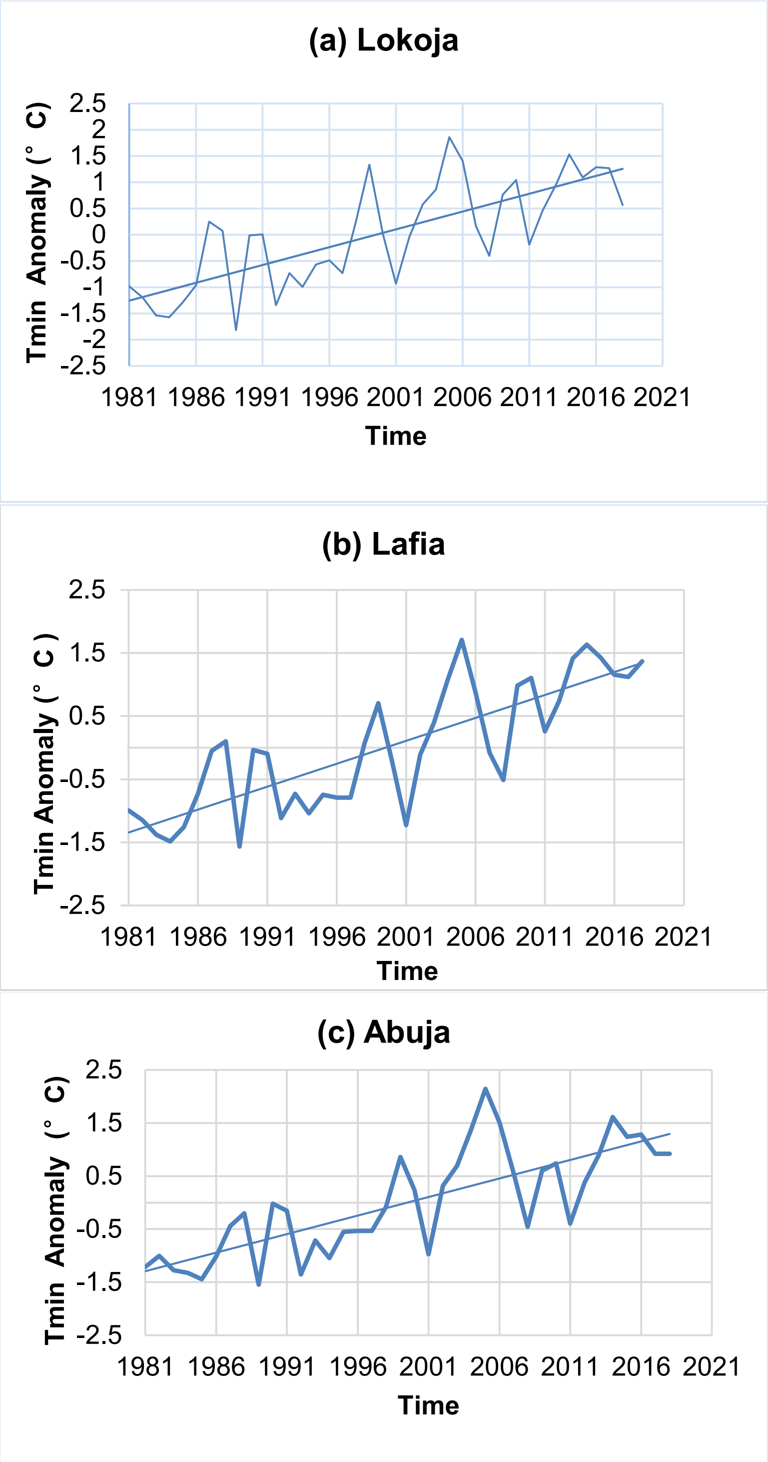


Fig. 10. Standardized anomaly time series plots for mean annual air surface minimum temperatures for representative stations (a: Lokoja, b: Lafia and c: Abuja) of the Sudan savanna eco-climatic zone

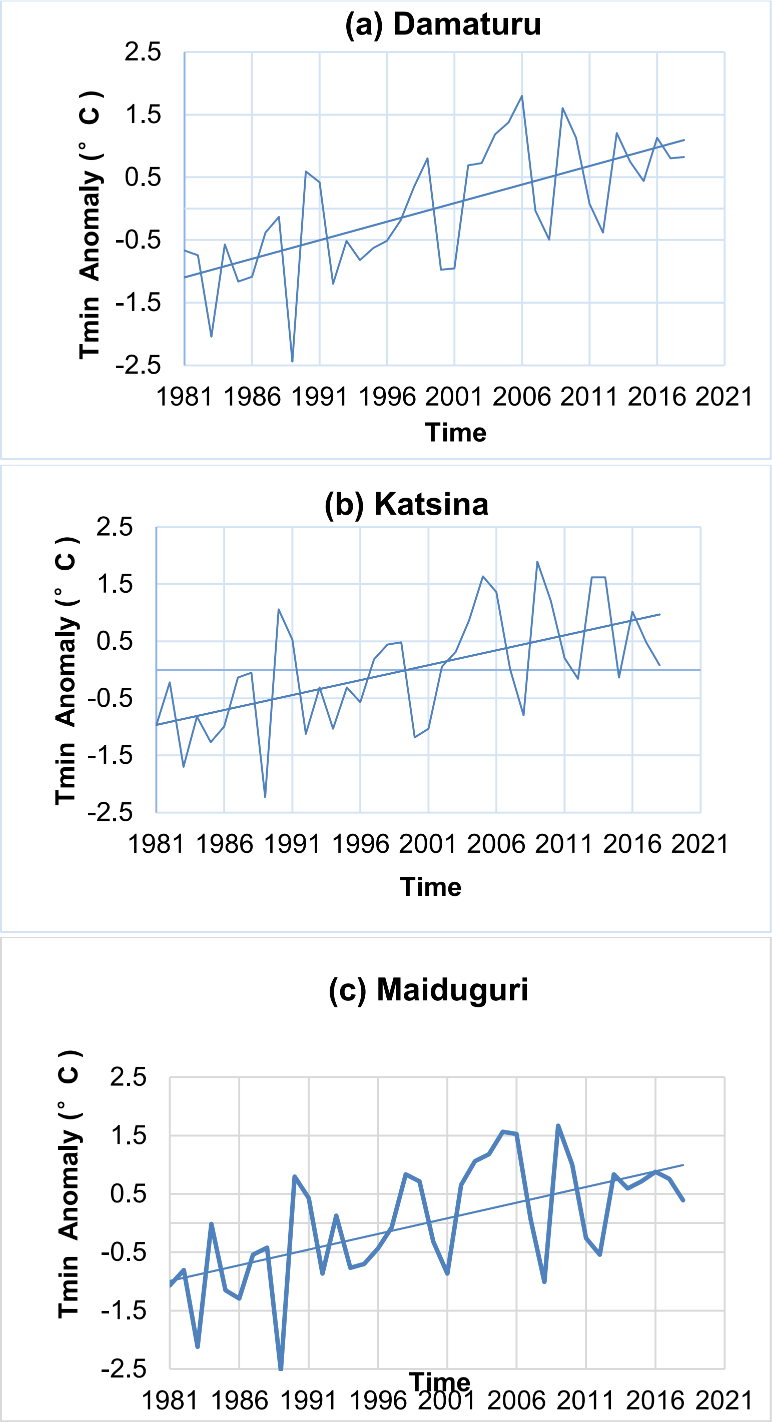


Fig. 11. Standardized anomaly time series plots for mean annual air surface minimum temperatures for representative stations (a: Katsina, b: Damaturu and c: Maiduguri) of the Sahel savanna eco-climatic zone

4. Discussion

Long-term monotonic trends were manifested in the historical records of the studied parameter. The highlights of the findings are hereby presented.

The temporal trend analysis of mean annual air surface maximum temperature in Tables 2 and 3 reveals that 14 stations have monotonic positive (upward) trends in mean annual air surface maximum temperature as shown by the positive values of the M-K test statistic (*S*). Ikeja however, shows a monotonic negative (downward) trend as observed by the negative value of the Mann-Kendall's test statistic (*S*). The highest value in the M-K test statistic for mean annual air surface maximum temperature was observed in Lafia, while the lowest value was observed in Ilorin. The M-K coefficients of time trend (*i.e.*, Kendall's tau b) for mean annual air surface maximum temperature for 12 stations are statistically significant at the 99% confidence interval (*i.e.*, 0.01 significance level) and one station (*i.e.*, Katsina) is statistically significant at the 95% confidence interval (*i.e.*, 0.05 significance level).

Similarly, the long-term temporal trend analysis of mean annual air surface minimum temperature in Tables 4 and 5 shows that all the stations have monotonic positive (upward) trends in mean annual air surface minimum temperature as revealed by the positive values of the M-K test statistic(*S*). The highest value was observed in Calabar, while Katsina revealed the lowest value. The trends for all the stations are statistically significant at the 0.01 significance level as revealed by the coefficients of time trends values. Comparing Tables 2 and 4, it was observed that mean annual air surface minimum temperature has a higher change rate than mean annual air surface maximum temperature. The results of this study long-term temporal trend analysis are in line with the findings of [11], in which mean annual air surface minimum temperature has a higher rate of change than mean annual air surface maximum temperature. Majority of the stations in the Guinea-wooded (*i.e.,* Makurdi and Minna), Sudan (Abuja, Lafia and Lokoja) and Sahel savanna (*i.e.,* Maiduguri and Damaturu) zones have higher trend magnitudes. The highest trend magnitude in mean annual air surface maximum temperature is noticeable in Lafia (*i.e.,* 073 °C/year), while the lowest value was noticeable in Yenagoa (*i.e.,* 0.015 °C/year). The highest trend magnitude in mean annual air surface minimum temperature was noticeable in Abuja (*i.e.,* 0.069 °C/year), while the lowest value is noticeable in Katsina and Ikeja (*i.e.,* 0.024 °C/year). Mean estimated trend magnitude increase for mean annual air surface maximum temperature is about 0.035 °C/year and about 0.036 °C/year for mean annual air surface minimum temperature. Thus, this study gives an estimated mean trend magnitude increase in mean annual air surface temperature of about 0.036 °C/year (*i.e.,* 0.36 °C/decade) and an estimated mean annual air surface temperature increase in Nigeria of about 1.4°C from 1981-2018.

The standardized chronologically ordered anomaly plots for mean annual air surface maximum temperature show monotonic positive (upward) trends in 14 stations (Figs 2 a-c to 6 a-c). Extreme temperature events such as that of 1998 are shown in some of the standardized anomaly time series plots (*i.e.,* Calabar, Owerri, Umuahia and Yenagoa). The outstanding years (*i.e.,* 2005, 2009 and 2010) which are amongst the 10 warmest years in the global record relative to the 1961-1990 reference period [34], were observed in the plots of some stations. No significant long-term trends were observed in Ikeja (Fig. 2b) and Ilorin (Fig. 4a). The results of the plots are in line with the M-K and the linear trend tests results (Tables 2 and 3 respectively)

Additionally, the standardized chronologically ordered anomaly plots for mean annual air surface minimum temperature showing monotonic positive (upward) trends in all the 15 stations were observed (Figs. 7 a-c to 11 a-c). The standardized anomaly time series plots also displays the years with records of extreme events in mean annual air surface minimum temperatures during the period of this study. All the station's time series plots depict monotonic trends that are in complete agreement with the results of the M-K and the linear trend tests (Tables 4 and 5, respectively). The plots for the mean annual air surface temperatures depict chronologically ordered meteorological observations of air surface temperatures for the period covered by this study. The trend line fitted into the plots shows that mean annual air surface maximum temperature had increased monotonically for 14 stations as shown by the positive (upward) trend lines. Excerpt one station (*i.e.,* Ikeja) where the mean annual air surface maximum temperature had decreased monotonically as shown by the negative(downward) trend line over the period covered by this study. Similarly, the plots for mean annual air surface minimum temperature shows that mean annual air surface minimum temperature had increased monotonically across all the representative stations of the eco-climatic zones over the period covered by this study. The magnitudes of the increase in both mean annual air surface maximum and minimum temperatures are shown by the Sen's slope (Table 2 and 4) and the linear trend tests (Tables 3 and 5).

The synergistic use of more than one method to analyze the trends in mean annual air surface temperatures in Nigeria from 1981 to 2018, in this study is in line with the findings of [25, 26]. According to them, proper care should be taken to arrive at correct interpretation of data and test assumptions during trend analysis using statistical tests, and the conclusions should be made by using more than one statistical test as each statistical test addresses a specific question.

This study suggests that increasing population, urbanization, increased evapotranspiration rates, severe drought, deforestation and desertification may be culpable for the upward and high trend magnitudes in air surface temperature observed in the Guinea-wooded, Sudan and Sahel savannas. The result of this study trend magnitude and direction is in line with that of Akinsanola & Ogunjobi [10], who reported an increase of about 0.036 °C/year in air surface temperatures and upward trends in most stations in Nigeria, a decreasing trend of about -0.02°C in Jos over the period 1971-2000 and a decreasing air surface temperature trend in Ikeja and Oshodi from 1991-2000. The result of this study is also in line with the findings of Abiodun *et al.*, [3], who found a trend in increasing mean annual air surface temperature in Nigeria which are statistically significant at the 95% confidence interval (*i.e.,* 0.05 significance level) from 1971 to 2000 historical record.

This research results agrees in part with that of Amadi *et al.* [12], which found upward trends in mean annual air surface maximum and minimum temperatures in Nigeria which are statistically significant at the 95% and 99% confidence intervals (*i.e.,* 0.05 and 0.01 levels of significance) and monotonic positive (upward) trends, in most of the stations covered by this study, a statistically non -significant downward trend in mean annual air surface maximum temperature in Ilorin and a significant, monotonic positive (upward) trend in both mean annual air surface maximum and minimum temperatures in Ikeja. The disagreements in Ilorin mean annual air surface maximum temperature result could be as a result of differences in data length. The disagreements in Ikeja's mean annual air surface maximum temperature result could be as a result of the possible build-up in the atmosphere over Ikeja, of a layer of air that tends to attenuate the intensity of the downwelling solar radiation reaching the earth's surface but traps the thermal Infrared radiation upwelling from the earth's surface and lower atmosphere at night. This study suggests that this may be culpable for the reducing mean annual air surface maximum temperature but increasing mean annual air surface minimum temperature noticeable in

Ikeja. Therefore, further studies should be carried out to unravel the cause of the downward trend in mean annual air surface maximum temperature noticeable in Ikeja.

5. CONCLUSIONS

This study provides an invaluable insight on the temporal trend in mean annual air surface temperatures across the representative stations of the selected eco-climatic zones in Nigeria. The study revealed monotonic positive (upward) trends significant at the 0.01 and 0.05 significance levels across the representative stations whose estimated mean trend magnitude increase over the 38-year period is 1.3°C and 1.4°C for mean annual air surface maximum and minimum temperatures respectively. The estimated mean trend magnitude increase for mean annual air surface temperature in Nigeria is about 1.4°C for the period 1981-2018. With an estimated increase in mean trend magnitude of about 0.035 °C/year for mean annual air surface maximum temperature and an estimated increase in mean trend magnitude in mean annual air surface minimum temperature of about 0.036 °C/year, the estimated mean magnitude increase for both mean annual air surface maximum and minimum temperatures is about 0.036°C/year (*i.e.,* 0.36 °C/decade). This study, then gives a projected estimated mean linear trend magnitude increase of about 4.3°C in mean annual air surface temperature by year 2100 in Nigeria. This is 0.2°C less than the highest regime and within the range of the projected global increase of about 1.5 to 4.5°C in air surface temperature up to year 2100 by the IPCC 2007 report.

The observed trends in this study indicates changes in the net balance between the downwelling solar and the upwelling thermal infrared radiation from the earth's surface and lower atmosphere due to radiative forcing caused by increasing concentrations of greenhouse gases (GHG's) and aerosols, land surface properties changes, urbanization and increasing population. The manifestation of long-term significant temporal trend in the mean annual air surface temperatures at the 99% and 95% confidence intervals (*i.e.,* 0.01 and 0.05 significance levels, respectively) over the period covered by this study provides a clear evidence of possible future increase in air surface temperature and a strong indication of the tendency for the occurrence of climate-related hazards and their resulting adverse impacts in Nigeria. The results have serious consequences for Nigeria, a developing country with a large population. There is cogent need to respond proactively rather than reactively, so as to tackle the attendant resulting adverse impacts of increasing air surface temperatures in Nigeria before they become overwhelming.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this paper.

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