Trend and Variations of Surface Air Temperatures across Selected Eco-Climatic Zones in Nigeria

L.E. King,[1,*] S.O. Udo,[1] I.O. Ewona,[2] S.O. Amadi,[3] E.B. Ebong,[1] C.N. Emeka[4] and M.D. Umoh[5]

1: Dept. of Physics, Faculty of Physical Sciences, University of Calabar, Nigeria
2: Dept. of Physics, Faculty of Physical Sciences, Cross River State University of Science and Technology, Calabar, Nigeria
3:Dept. of Physics, Faculty of Physical Sciences, Alex Ekwueme Federal University, Ndufu -Alike Ikwu, Nigeria
4: Dept. of Geology, Faculty of Physical Sciences, University of Calabar, Nigeria
5: Dept. Of Research and Strategic Planning, Maritime Academy of Nigeria, Oron, Nigeria

Received April 23, 2024; Accepted May 9, 2024; Published May 29, 2024

The trends and variability in surface air temperatures over selected eco-climatic zones in Nigeria were assessed using Merra-2 datasets from 1981 to 2018. A total of 15 stations spread across the eco-climatic zones in Nigeria were used for this study. The Mann-Kendall, linear trend and Sen's slope trend test, time series plots and descriptive statistics were used. The coefficient of variation of the surface air maximum temperature showed a low variability for the Mangrove-swamp rainforest and a moderate variability for the Guinea-wooded, Sudan and Sahel savannas. Similarly, the coefficient of variation of the surface air minimum temperature showed a moderate variation for all the selected eco-climatic zones. The M-K trend test showed that 14 stations showed an upward trend, 1 station showed a downward trend, and the trends of the maximum atmospheric surface temperature at 13 stations were statistically significant. The minimum surface air temperature at all stations showed a clear upward trend. The maximum and minimum surface air temperatures are estimated to increase by about 0.035°C and 0.036°C per year on average, respectively. For Nigeria, the estimated average surface air temperature increase is about 0.036°C per year, while the average surface temperature over 38 years is estimated to have increased by about 1.4°C. This study gave a linear trend projection of an expected increase in the mean surface air temperature of about 4.3°C in Nigeria by 2100.

Keywords: Trend; Maximum temperature; Minimum temperature; Radiative forcing; Nigeria

Introduction

Surface air temperature is essentially an invaluable weather and climate element and an important indicator of climate change and variability. Assessing its character is very paramount towards having a clear insight about climate change and variability, which may be different at local, regional and global scales. The Inter-Governmental Panel on Climate Change report [1] and Malhi & Wright [2] have pointed out that worldwide, the earth's global atmosphere is experiencing a swift and human-driven change, with no previous antecedent in both its absolute potential magnitude and change

**Corresponding author:* lewisking72@yahoo.com,lewisking659@gmail.com

rate. Globally, the mean surface air temperature has increased by about 0.74°C and anticipated increase is projected to range between 1.6°C and 4.5°C by 2100 with its change rate being considerably different amongst regions [3].

In the last few decades, climate change has been adjudged as perhaps, a serious debilitating and unending environmental concern to the global community, especially in low- and medium-income nations of the world, where majority of their economic activities are seriously vulnerable to climate change. Rising ambient surface air temperatures has triggered off an increased frequency, intensity and duration of heat-related events, including heat waves in quite a number of regions. The rate and intensity of droughts have increased in some regions, and the intensity of heavy precipitation events has increased globally [4]. In recent decades, the global surface temperature rise has been very common, and the temperature rise in the high latitudes of the Northern Hemisphere has been more obvious. Heterogeneous land surface types and surface albedo, changing evapotranspiration rates, and carbon cycle influence climate in diverse ways and have been suggested to be culpable for the variations in the spatial distribution of surface air temperature [5-7].

The global energy budget of the earth is being influenced by variations in some factors, including but not limited to the concentrations of greenhouse gases (GHG's) and atmospheric aerosols, as well as by land surface properties changes. Radiative forcing expresses these changes as a pointer to the impact that a factor wields in changing the net balance of radiative flux between the down welling solar and the upwelling thermal infrared radiation from the earth's surface and lower atmosphere [3]. A radiative forcing of +2.30 W/m^2 has been pointed out to be due to the combined increases in carbon IV oxide, methane, and nitrous oxide, a radiative forcing of about –0.5W/m^2 due to atmospheric aerosols and a forcing of –0.7 W/m^2 due to indirect cloud albedo. A radiative forcing of about +0.35 W/m^2, +0.34 W/m^2, -0.2 and +0.1 W/m^2,+0.12 W/m^2 are due to changes in atmospheric concentrations of tropospheric ozone and halocarbons, changes in surface albedo as a result of land cover changes and deposition of carbon black on snow as well as solar irradiance changes, respectively [3].

Increased emission of greenhouse gases (GHG) through anthropogenic activities such as industrial activities, burning of fossil fuels, deforestation and urbanization are quite contributory to increase in surface air temperatures [3]. Greenhouse gases absorb some of the thermal infrared radiation given off by the earth's surface, and subsequently emit them back to the earth's surface, resulting in the increasing surface air temperature known as the greenhouse effect. Human activities have led to an increase in the concentration of greenhouse gases in the atmosphere, causing the Earth's surface to warm rapidly. In addition, greenhouse gases absorb thermal infrared radiation emitted by the Earth's surface and lower atmosphere, thereby exacerbating the greenhouse effect.

Verma *et al.* [8] has pointed out that the amount of radiation that can be altered by atmospheric aerosols depends primarily on the concentration, particle size distribution and composition of the atmospheric aerosols. Direct radiative forcing (DRF) results from perturbations to the Earth's atmosphere system due to direct interaction of atmospheric aerosols with the scattering or absorption of incident solar radiation. Fawole *et al.* [9] notes that emission of absorbed radiation by atmospheric aerosols alters the lifetime and micro-physical properties of clouds and this may eventually affect precipitation. Increasing population and industrialization has been pointed out to be culpable for the considerable increase in anthropogenic emissions of aerosols and gaseous pollutants in West Africa and a pattern expected to continue up to year 2030 [10]. Despite growing evidence that human-generated atmospheric aerosols have an impact on regional radiation budgets, there appear to be no strict regulations for emission standards in major African cities, and where they do exist, implementation and/or enforcement appear to be very weak [11].

The Earth-atmosphere system can be very responsive to land surface properties changes. Mounting evidence shows that land-use and land cover (LULC) changes may pose important climatic implications locally, regionally, and globally. The climate response to LULC changes in some instances may far outweigh the contribution from increasing greenhouse gases [12]. Natural and anthropogenic land use (*i.e.,* deforestation) and land cover changes (*i.e.*, desertification) can have a substantial impact on climate. Snyder *et al.* [6], notes that deforestation and desertification brings about an increase in sensible heat given off at the surface, with a reduced latent cooling compensating for the net radiation loss at the earth's surface resulting in a rise in surface air temperature, as the air is warmed by the sensible heat being convected and conducted from the surface.

Detection of trend in the time series of hydro climatic parameters has become the most sought-after technique to detect climate change and variability at local, regional and global basis and there appears to be no uniformity in the changes in the climatic parameters spatially or temporarily. Yue & Hashino [13] pointed out those considerable and significant temporal and spatial variations could exist amongst regions having different climates. Several statistical methods are been employed to evaluate trends in parameters of climatic interest [14-19]. They include but not limited to the Mann-Kendall's, least square linear regression and the Sen's slope trend tests etc. With a synergistic use of these methods, the possible trends in observed data can be adequately analyzed with respect to the direction, significance, Kendall's tau b and trend magnitude.

Many research studies have attempted to analyze surface air temperatures chronologically ordered observations (*i.e.*, time-series) from various climate change perspectives across a wider range of temporal and spatial scales. Their study indicated a significant increase of surface air temperatures in different parts of the world [20-22]. Climate change scenarios for Nigeria as examined by Abiodun *et al.* [20], 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 variously amongst regions [23-26]. Analysis of 30 years' data for temperature and rainfall variability in Nigeria spanning from 1971-2000 conducted by Akinsanola & Ogunjobi [27], indicated surface air temperatures and rainfall significant increase in quite a number of stations they studied. Their results further suggested a sequence of alternately upward and downward trends in the two parameters. Oguntunde *et al.* [28] conducted a study to assess the possible occurrence of trends in surface air temperature across Nigeria from 1901-2000. Their results indicated that surface air minimum temperatures changes are higher than changes in surface air maximum temperatures. Amadi *et al.* [17] conducted a trend and variation study of basic Atmospheric parameters including but not limited to mean annual surface air temperatures. Their findings showed trends in the parameters across Nigeria from 1950-2012. Some trend studies in Nigeria focused on individual towns for relatively short periods [16, 29-32]. 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.

Applied climate science attempts to embolden knowledge at local, regional and global scale. The more limited the scale at which such information is made available, the more important its relevance to users for most applications. The study of the trend and variability of weather and climate elements of a region is vital for sustainable agriculture, water resources management, power generation, marine and aviation safety etc. 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 [3], after the high temperature, there will be a heat wave. High temperatures can trigger off incidences of diseases linked to high temperatures such as Cerebra-spinal meningitis and heat stroke. Also, changes in surface air temperatures influence quite a number of hydrological processes, including precipitation.

The need then arises to study the current trend and variations in mean annual surface air temperatures across the representative stations of the selected eco-climatic zones in Nigeria with the Integrated Earth System Analysis (IESA) approach using a multi-decadal, 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.

The objectives of this study are:

1. To analyze the trend and variations in the historical records of the chosen parameters for the stations and period under study
2. To analyze the possible causes of the trend and variations of the chosen parameters.

Location and Brief Geography of the Study Area

Nigeria is located 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 typified by various ecotypes and climate zones and is influenced by the interplay 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) [33]. The Tropical Maritime air mass originates 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 [20]. 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 [28].

Adefolalu [34] 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 (Figure 1). 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.

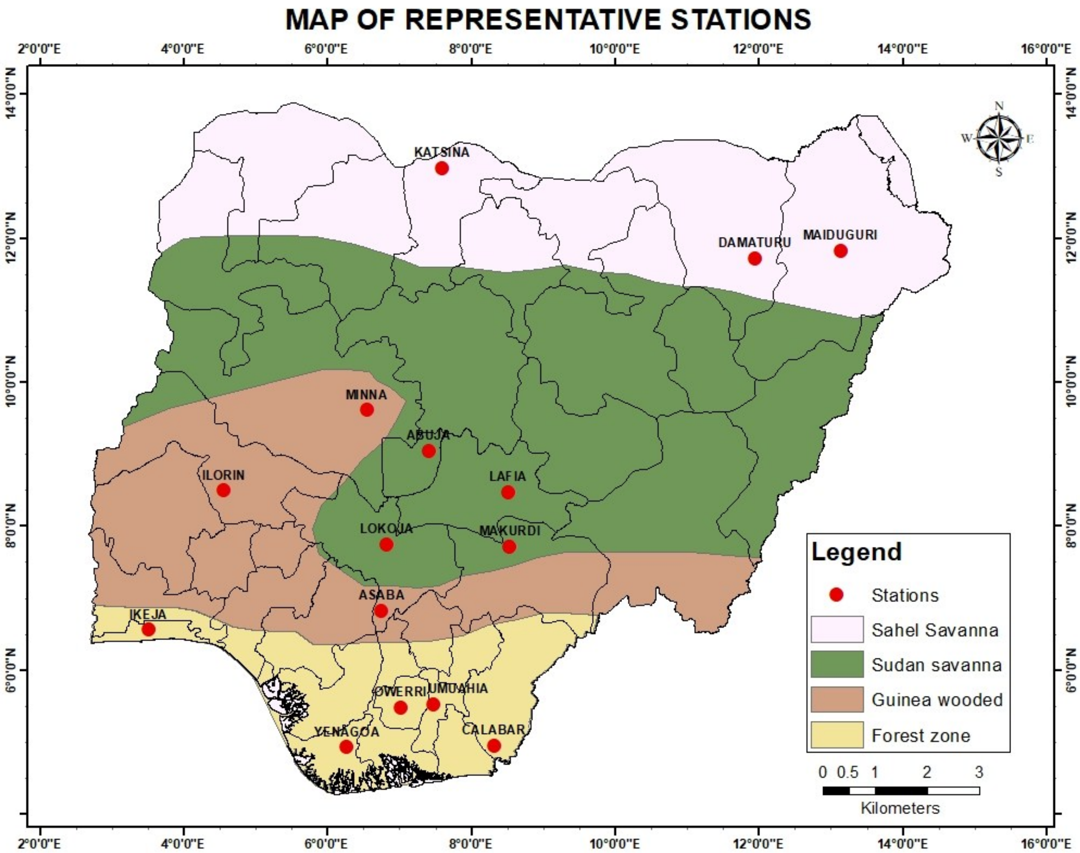

Fig. 1. The meteorological stations for the study and the eco-climatic zones

Data and Methodology

Dataset

The data for the analysis of mean annual surface air temperatures for trends across some representative stations of the selected eco-climatic zones in Nigeria is MERRA-2, obtained from the National Aeronautics and Space Administration (NASA) database. The GEOS Atmospheric model and the Grid Point Statistical Interpolation analysis scheme are considered important components of this system [36-38]. According to Gelaro *et al.* [35], reanalysis products are becoming increasingly used for climate monitoring.

The stations are the representative stations of the selected eco-climatic zones and the data represents the mean monthly values of surface air temperatures across Nigeria, spanning from 1981 to 2018. The parameters of interest are the surface air maximum and minimum temperatures. Detailed information on the stations, meteorological variables measured at the representative stations are presented in Table 1

Data Check and Smoothening

Data was checked for missing data, outliers and in homogeneities. The data had no missing values. Quality checks helps to remove outliers and their biases. Longobardi & Villani [39] pointed out that long-term climate analysis should be based on homogenous data, since there is large variability in space and time of climate variables. A homogeneous climate dataset is one having fluctuations/variations caused only by changes in weather and climate. Non-climatic factors introduce fluctuations/in homogeneities that produce gradual bias in the data distribution [17]. Thus, normality and homogeneity tests were conducted on the datasets.

Table 1. Summary information on the meteorological stations [20, 34, 35]

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	

Methodology

The mean monthly datasets were converted to mean annual datasets. This study synergistically embraced the parametric linear trend test, the non-parametric Mann-Kendall (M-K), Sen's slope trend tests and descriptive statistics. The literature [40, 41] has pointed out that more than one statistical test should be used to arrive at accurate interpretation of data and tests assumptions as each statistical test addresses a specific question.

The descriptive statistics showed the statistical characteristics of the mean annual values. The M-K trend test evaluated 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 estimated the magnitudes of the trend. According to many authors [42-45], nonparametric tests have statistical advantages over parametric tests because they are insensitive to the presence of outliers and incomplete data and exhibit a degree of monotonic dependence. The results of the nonparametric tests differed from those of the parametric linear trend test, while the results of the M-K and Sen slope trend tests were better than those of the parametric tests.

The Mann-Kendall (M-K) Trend Test

According to Houghton [46], the M-K trend test statistics is evaluated using the sign of differences between successive values rather than on the values of the randomly selected variables. This non-parametric statistical tool has been variously used to analyze trends in hydro- climatic data [47, 48]. Hence it was adopted in this study.

Given a time series of n-size dataset, such that, the M-K test statistic (S) is evaluated with the formula [44, 49]:

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

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

$$\mathrm{Sgn}(x_j - x_k) = \begin{cases} 1\ if\ x_j - x_k > 0 \\ 0\ if\ x_j - x_k = 0 \\ -1\ if\ x_j - x_k < 0 \end{cases} \quad 2$$

An upward trend (later values exceeding earlier values) is denoted by a large positive value of test statistic (*S*). A 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 connotes that a trend does not exist.

The variance of *S, VAR(S)* (σ^2) where ties are not present (*i.e.*, j=k does not exist) is denoted by

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

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

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

From Eqn. 4, q denotes the number of tied groups (where j=k), and 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 follows:

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

An upward or downward trend is indicated by a positive or negative value of *Z,* respectively. For a two-tailed test, the null hypothesis *Ho* 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 exist. 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 e rejected. Other than that, the null hypothesis is accepted.

The Linear Trend Test

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

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

The slope is denoted by β_1. 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 deviation which may be positive, negative or zero and are 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 $\beta_1 \neq 0$ (linear dependence exists). A significant slope different from zero is the condition for rejection of the null hypothesis and the alternative hypothesis that there is a linear trend in y over time with the rate equal to β_1 is accepted.

The Sen's Slope Trend Test

Determination of trend magnitude in hydro-meteorological time series has been variously executed using the Sen's slope trend test [13, 44].

The presence of a monotonic trend and the linearity of the trend allow for the estimation of the trend magnitude using the Sen's line. How the median data changes linearly with time is modeled by the non-parametric Sen's line. The trend magnitude for the time interval covered by the study is obtained by multiplying the estimated slope per year by the total number of years covered by the study.

According to Sen [49], the slope magnitude can be obtained as follows:

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

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.

The p-value

The p-value delineates a region in the tail of a probability distribution 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. When the p-value is smaller than the selected significance level, the null hypothesis is rejected on the assumption that the data is not consistent with the null hypothesis at the selected significance level and vice versa.

Results

Results of Mean Annual Surface Air Temperatures

Spatial Variability of Mean Annual Surface Air Temperatures

Table 2 shows that the mean annual surface air maximum temperature ranges from 28.15°C to 35.70°C. The highest value of the mean annual surface air maximum temperatures is noticeable in Maiduguri in the Sahel Savanna eco-climatic zone, while the lowest value is noticeable in Calabar in the Mangrove-Swamp rainforest eco-climatic zone. Table 3 shows that the mean annual surface air minimum temperature ranges from 19.84°C to 24.33°C. The highest value is observed in Calabar in the Mangrove-swamp rainforest eco-climatic zone, while the lowest value is observed in Katsina in the Sahel savanna eco-climatic zone.

The coefficient of variation for both mean annual surface air maximum and minimum temperatures are shown in Tables 2 and 3.The coefficient of variation for mean annual surface air maximum temperature range from 1.868 to 3.670. The highest value of coefficient of variation in mean annual surface air maximum temperature is noticeable in Abuja in the Sudan savanna eco-climatic zone, while the lowest value is noticeable in Calabar in the Mangrove-swamp rainforest eco-climatic zone. The coefficient of variation of mean annual surface air minimum temperature range from 1.563 to 3.367. The highest value in coefficient of variation of mean annual surface air minimum temperature is noticeable in Minna in the Guinea-wooded savanna eco-climatic zone and the lowest value in Calabar in the Mangrove-swamp rainforest eco-climatic zone.

For the mean annual surface air maximum temperature, all the 15 stations have positively valued coefficients of skewness. Thirteen (13) stations have negatively valued and two (2) stations positively valued coefficients of kurtosis (Table 2). For the mean annual surface air minimum temperature, ten (10) stations have negatively valued and five (5) stations positively valued coefficients of skewness and all the stations have negatively valued coefficients of kurtosis (Table 3)

Seasonal Variability of Mean Annual Surface Air Temperatures

Figures 2~6 show the variability of mean annual surface air maximum temperature across the representative stations. Figures 7~11 show the variability of mean annual surface air minimum temperatures across the representative stations.

Trend in Mean Annual Surface Air Temperatures

Tables 4 and 5 show the trend of mean annual surface air 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 surface air maximum temperatures across the selected eco-climatic zones in Nigeria. The highest trend magnitude in mean annual surface air maximum temperature is noticeable in the Lafia (*i.e.,* 0.073 °C/year), while the lowest value is observed in the Yenagoa (*i.e.,* 0.015 °C/year) (Table 4).

Tables 6 and 7 show the trend of mean annual surface air minimum temperatures. 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 surface air minimum temperatures across the selected eco-climatic zones in Nigeria. The highest trend magnitude in mean annual surface air 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 6).

Figs. 12~16 are the normalized time series anomaly plots for mean annual surface air maximum temperature, showing monotonic upward trends in the plots of 14 stations. A monotonic downward trend is shown by one station (*i.e.,* Ikeja). Figs. 17~21 are the normalized time series anomaly plots for mean annual surface air minimum temperature showing monotonic upward trends in all the 15 stations.

Table 2. Descriptive statistics for mean annual surface air maximum temperature

Station name	Number of years	Mean (°C)	Standard deviation	Coefficients Of variation	Coefficients Of skewness	Coefficients Of Kurtosis
Maiduguri	*38*	**35.70**	0.8078	2.263	0.120	- 0.860
Damaturu	*38*	**34.57**	0.8997	2.603	0.113	-0.580
Katsina	*38*	**33.90**	0.6331	1.868	0.375	-0.589
Ilorin	*38*	**31.98**	0.6962	2.177	0.196	-1.199
Lafia	*38*	**31.41**	1.0487	3.339	0.219	-1.169
Lokoja	*38*	**30.97**	0.9301	3.003	0.473	-0.191
Minna	*38*	**30.68**	1.0802	3.521	0.531	-0.387
Abuja	*38*	**30.59**	1.1228	3.670	0.396	-0.862
Makurdi	*38*	**30.53**	0.8467	2.773	0.310	-0.893
Asaba	*38*	**29.61**	0.5884	1.987	0.446	-0.452
Owerri	*38*	**29.17**	0.3152	1.081	0.244	-0.231
Umuahia	*38*	**29.10**	0.3397	1.167	0.258	-0.335
Ikeja	*38*	**28.88**	0.2936	1.017	0.708	1.023
Yenagoa	*38*	**28.73**	0.2794	0.973	0.154	-0.257
Calabar	*38*	**28.15**	0.3097	1.100	0.172	0.795

Table 3. Descriptive statistics for mean annual surface air minimum temperature

Station name	Number of Years	Mean (°C)	Standard deviation	Coefficient of variation	Coefficient of skewness	Coefficient of Kurtosis
Katsina	38	19.84	0.468	2.358	0.020	-O.497
Minna	38	20.32	0.684	3.367	0.433	-0.445
Abuja	38	20.34	0.661	3.249	0.220	-0.996
Damaturu	38	20.65	0.523	2.533	-0.274	-0.337
Maiduguri	38	21.19	0.493	2.327	-0.422	-0.180
Ilorin	38	21.48	0.472	2.197	-0.082	-0.957
Makurdi	38	21.59	0.567	2.626	0.035	-1.207
Lafia	38	21.79	0.648	2.973	0.135	-1.287
Lokoja	38	21.86	0.609	2.786	-0.008	-1.051
Asaba	38	21.86	0.499	2.283	-0.187	-0.875
Umuahia	38	22.15	0.472	2.131	-0.270	-0.974
Owerri	38	22.40	0.472	2.107	-0.276	-0.932
Yenagoa	38	23.38	0.446	1.908	-0.393	-0.715
Ikeja	38	23.51	0.391	1.663	-0.551	-0.323
Calabar	38	24.33	0.385	1.583	-0.273	-0.958

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

**Kendall's tau b is significant at the 0.01 level (2-tailed)
*Kendall's tau b is significant at the 0.05 level (1-tailed)
**Slope is significant at the 0.01 level (2-tailed)
*Slope is significant at the 0.05 level (1-tailed)

Table 5. Results of linear trend estimation for mean annual surface air 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 6. Mann-Kendall and Sen's slope trend tests for mean annual surface air 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 7. Results of linear trend estimation for mean annual surface air 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)

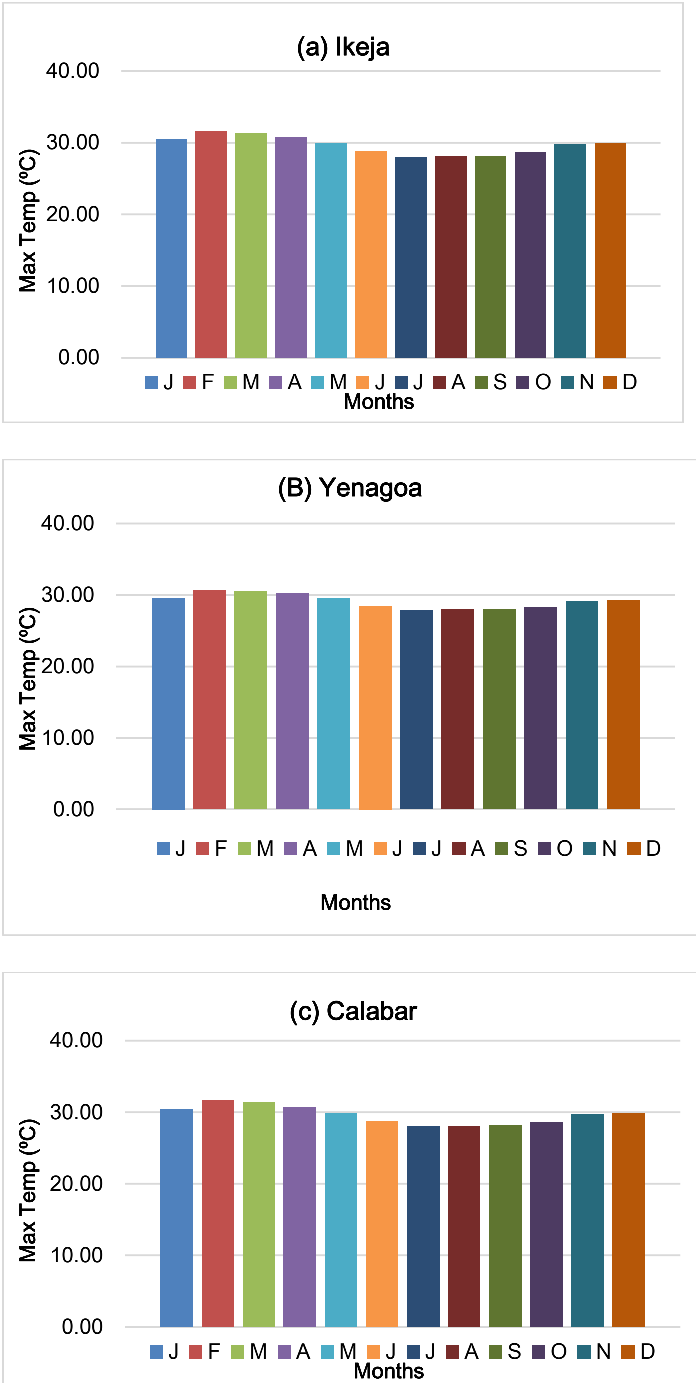

Fig. 2. Seasonal variation of mean annual surface air maximum temperature for representative stations (a: Ikeja, b: Yenagoa, and c: Calabar) of the Mangrove-swamp rainforest eco-climatic zone

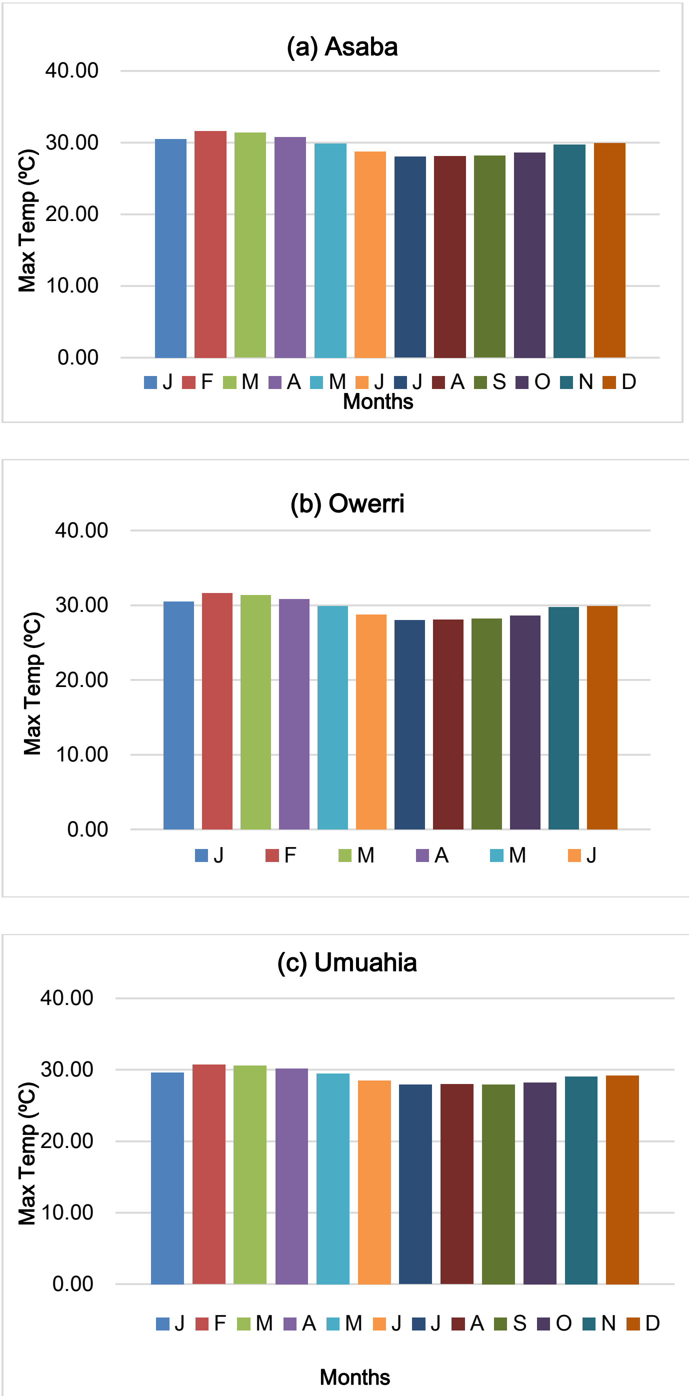

Fig. 3. Seasonal variation of mean annual surface air maximum temperature for representative stations (a: Owerri, b: Asaba and c: Umuahia) of the Tropical rainforest eco-climatic zone

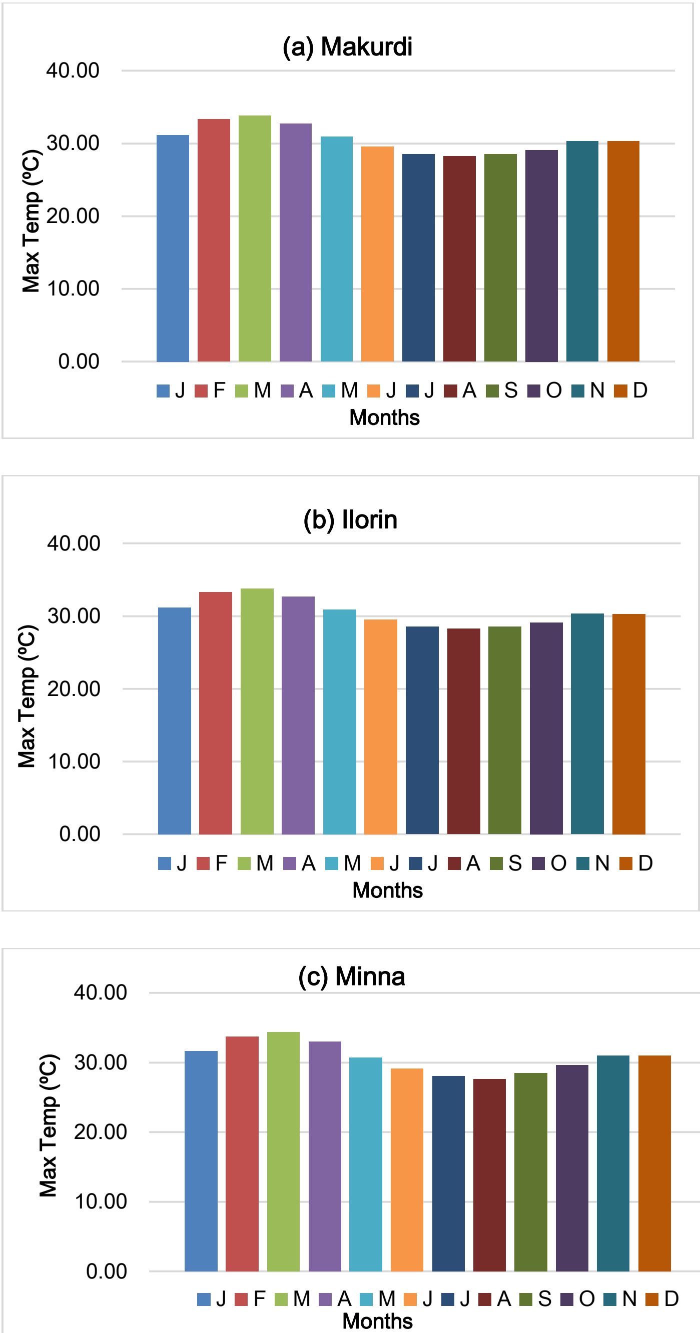

Fig. 4. Seasonal variation of mean annual surface air maximum temperature for representative stations (a: Makurdi, b: Ilorin and c: Minna) of the Guinea-wooded savanna eco-climatic zone

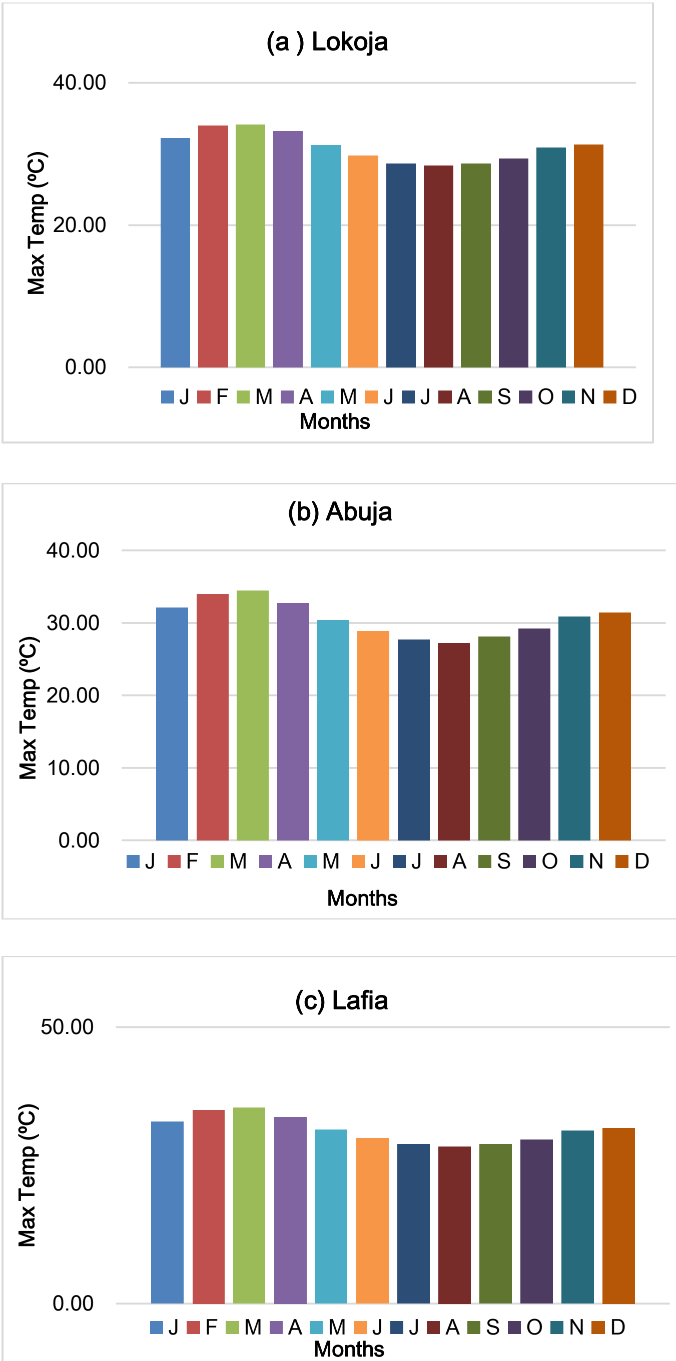

Fig. 5. Seasonal variation of mean surface air maximum temperature for representative stations (a: Lokoja, b: Abuja and c: Lafia) of the Sudan savanna eco-climatic zone

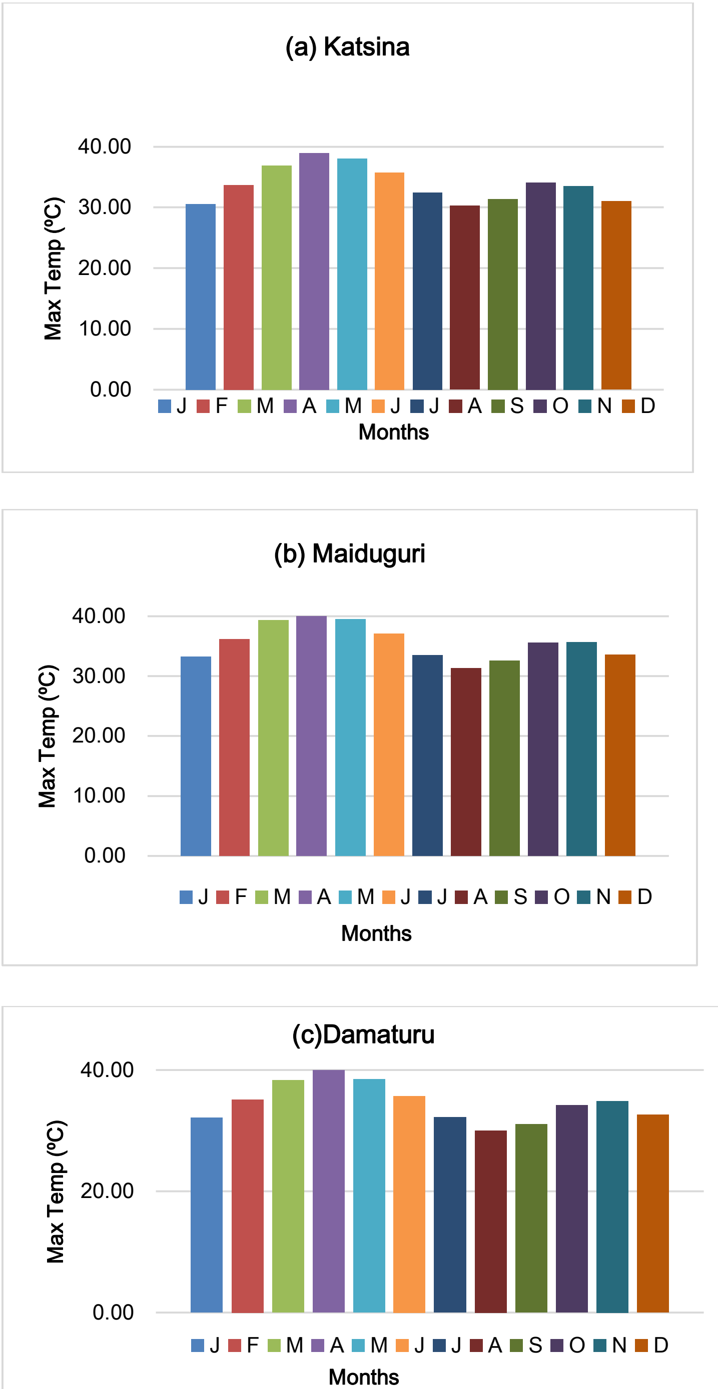

Fig. 6. Seasonal variation of mean surface airmaximum temperature for representative stations (a:Katsina, b:Maiduguri and c:Damaturu) of the Sahel savanna eco-climatic zone

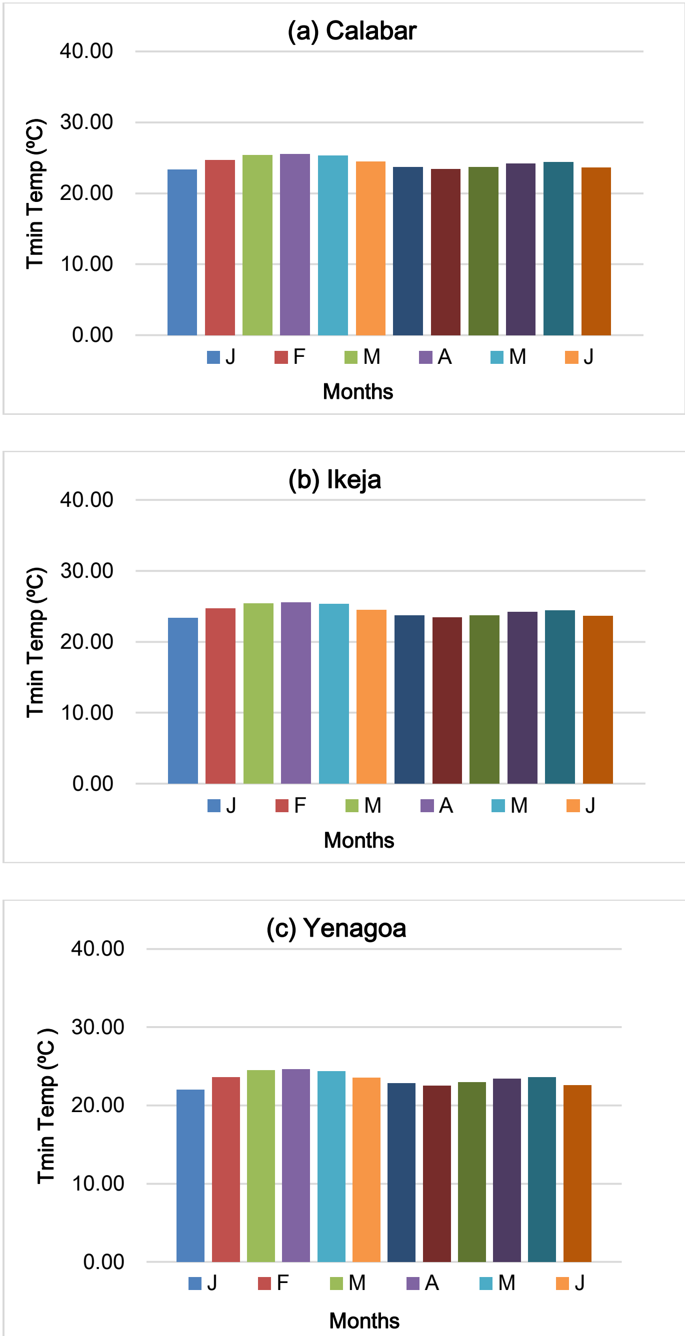

Fig. 7. Seasonal variation of mean surface air minimum temperature for representative stations (a: Calabar, b: Ikeja and c: Yenagoa) of the Mangrove-swamp rainforest eco-climatic zone

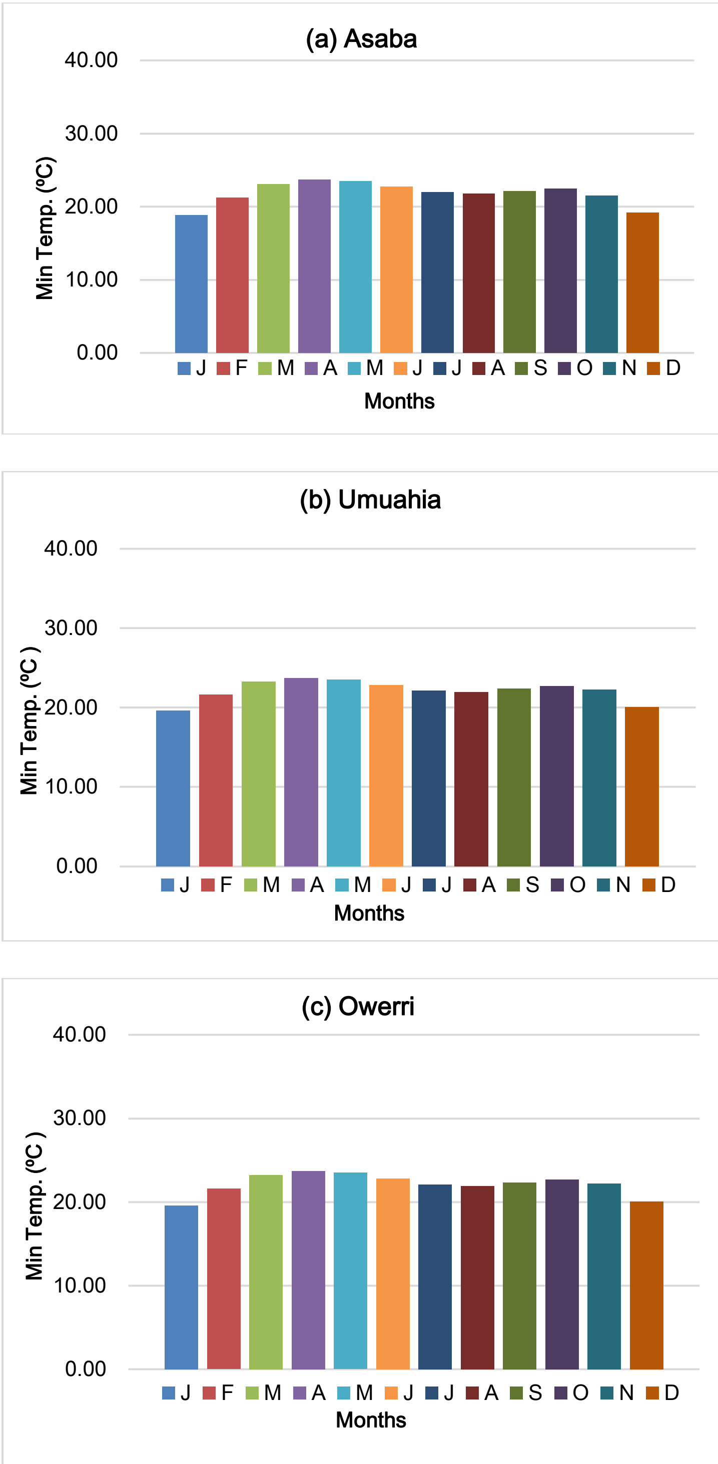

Fig. 8. Seasonal variation of mean annual surface air minimum temperature for representative stations (a: Asaba, b: Umuahia, and c: Owerri) of the Tropical rainforest eco-climatic zone

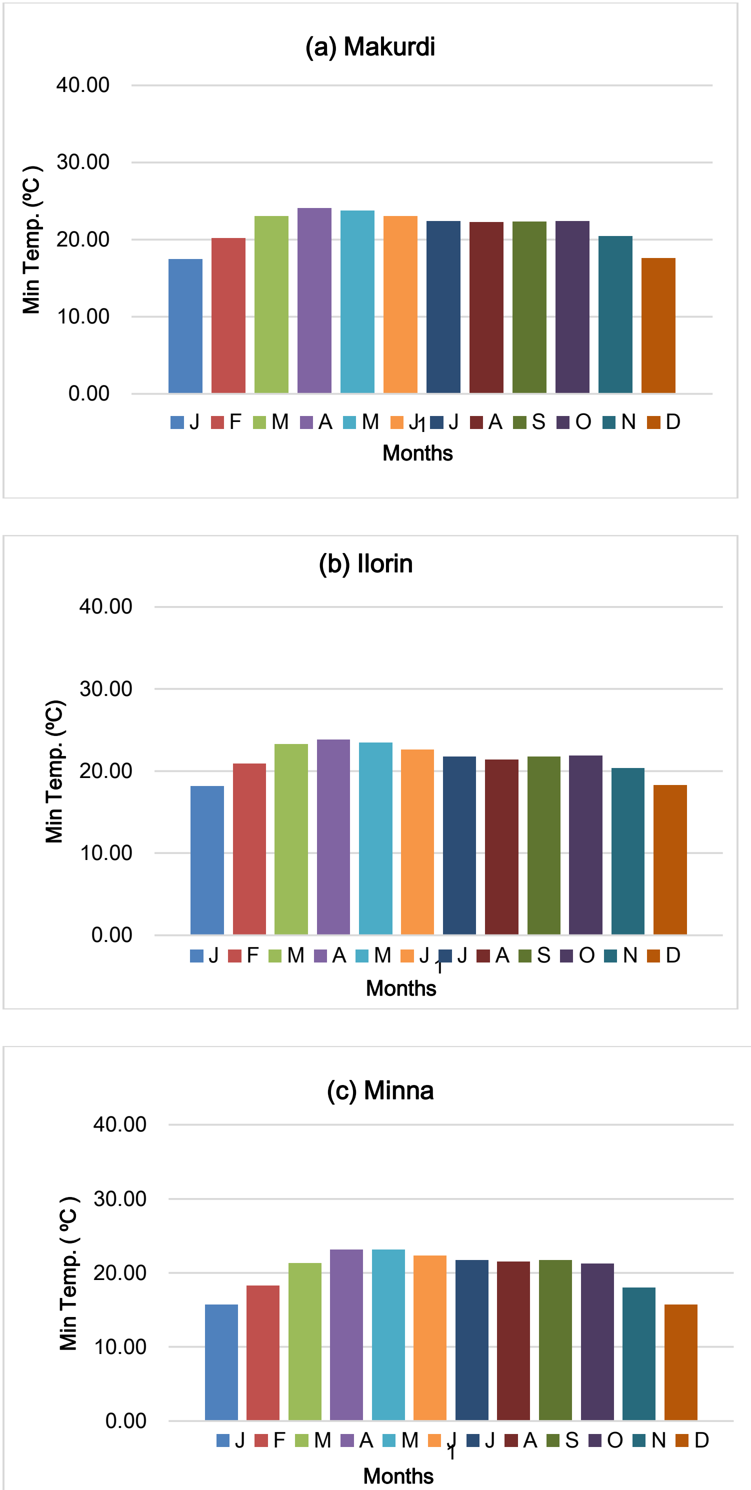

Fig. 9. Seasonal variation of mean annual surface air minimum temperature for representative stations (a: Makurdi, b: Ilorin and c: Minna) of the Guinea-wooded savanna eco-climatic zone

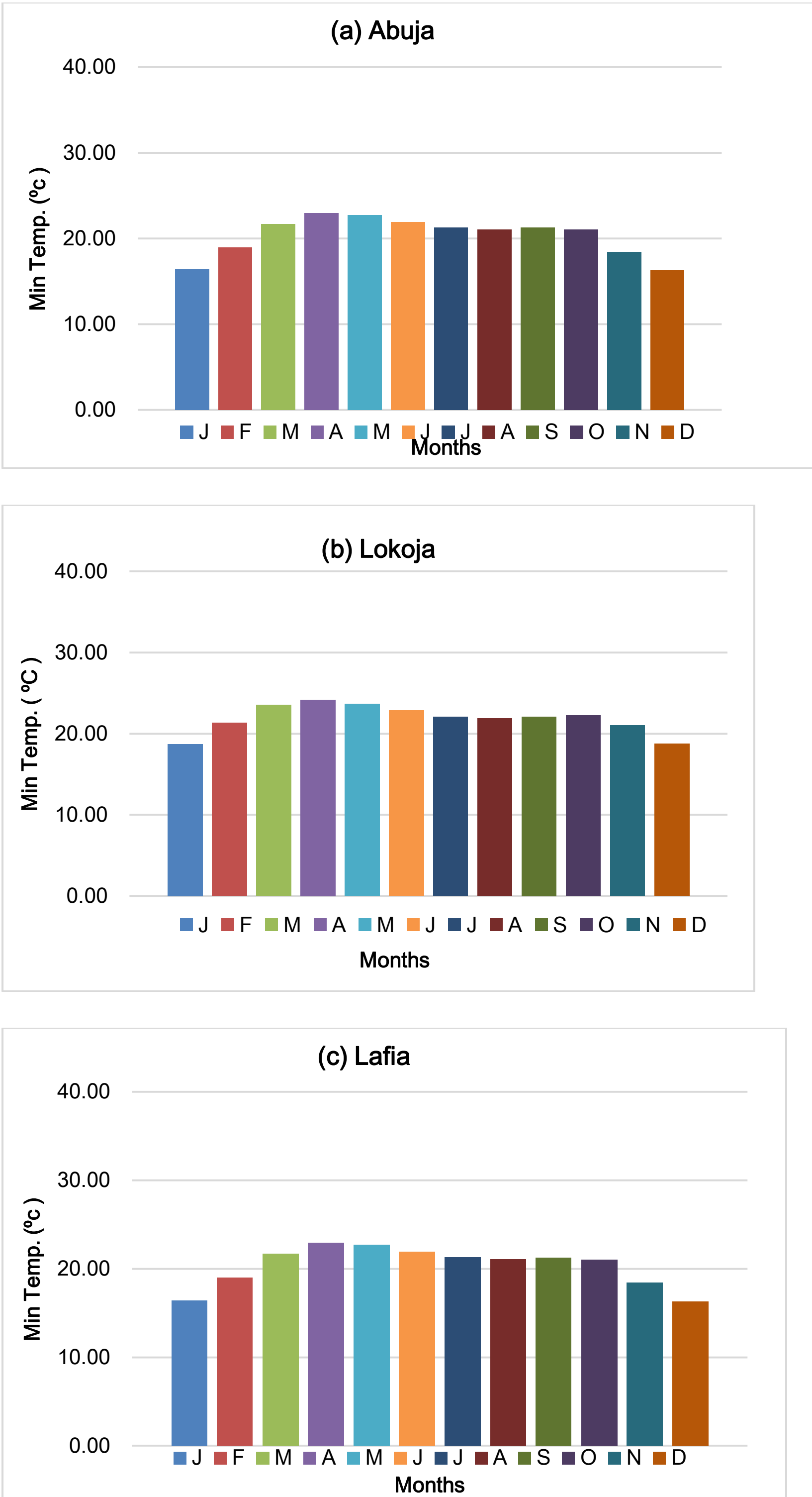

Fig. 10. Seasonal variation of mean annual surface air minimum temperature for representative stations (a: Abuja, b: Lokoja and c: Lafia) of the Sudan Savanna eco-climatic zone

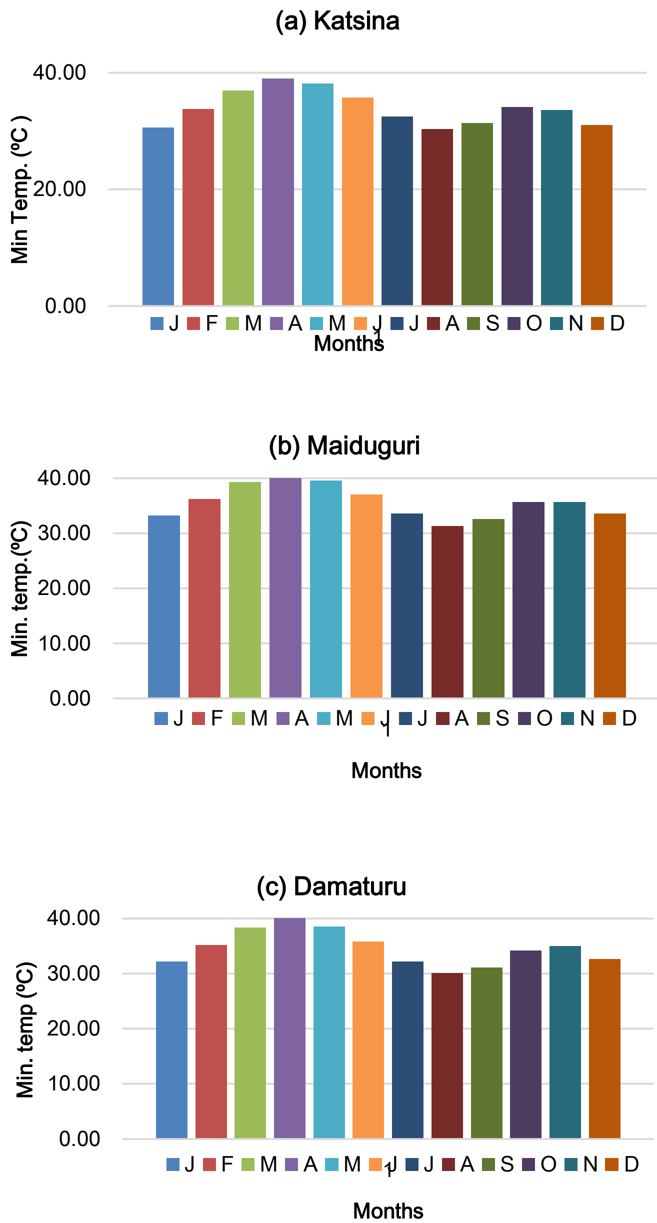

Fig. 11. Seasonal variation of mean annual surface air minimum temperature for representative stations (a: Katsina, b: Maiduguri and c: Damaturu) of the Sahel savanna eco-climatic zone

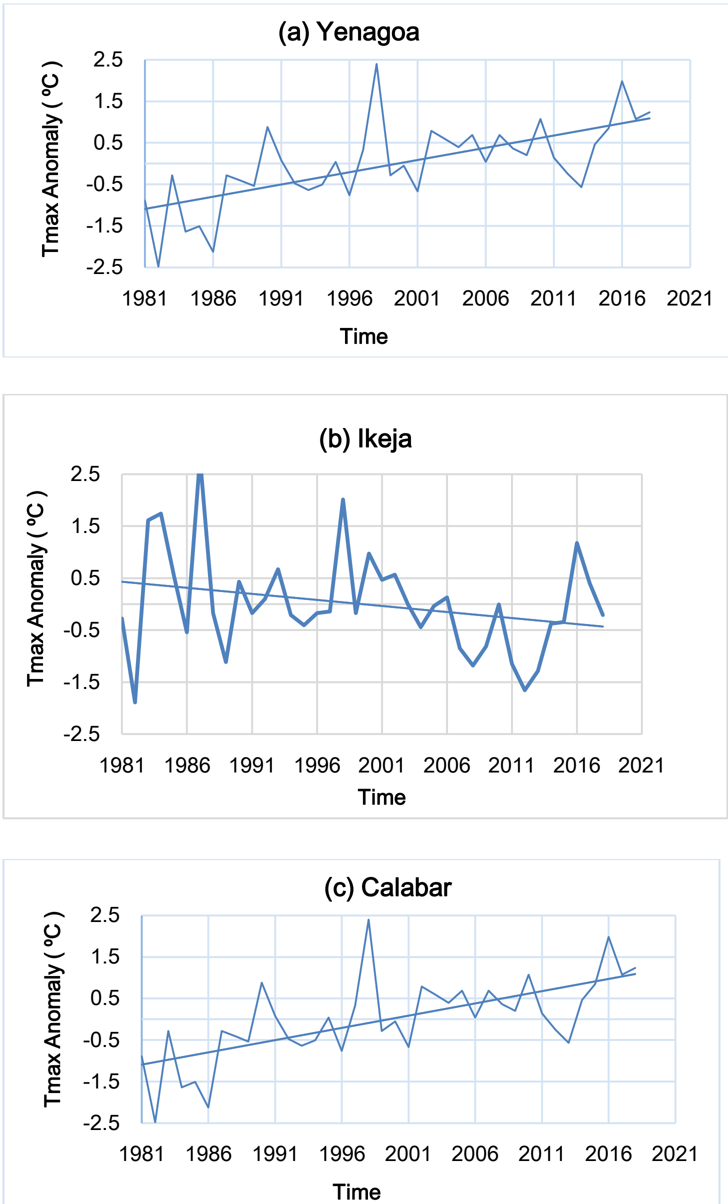

Fig. 12. Normalized time series anomaly plots for mean annual surface air maximum temperatures for representative stations (a: Yenagoa, b: Ikeja and c: Calabar) of the Mangrove-swamp rainforest eco-climatic zone

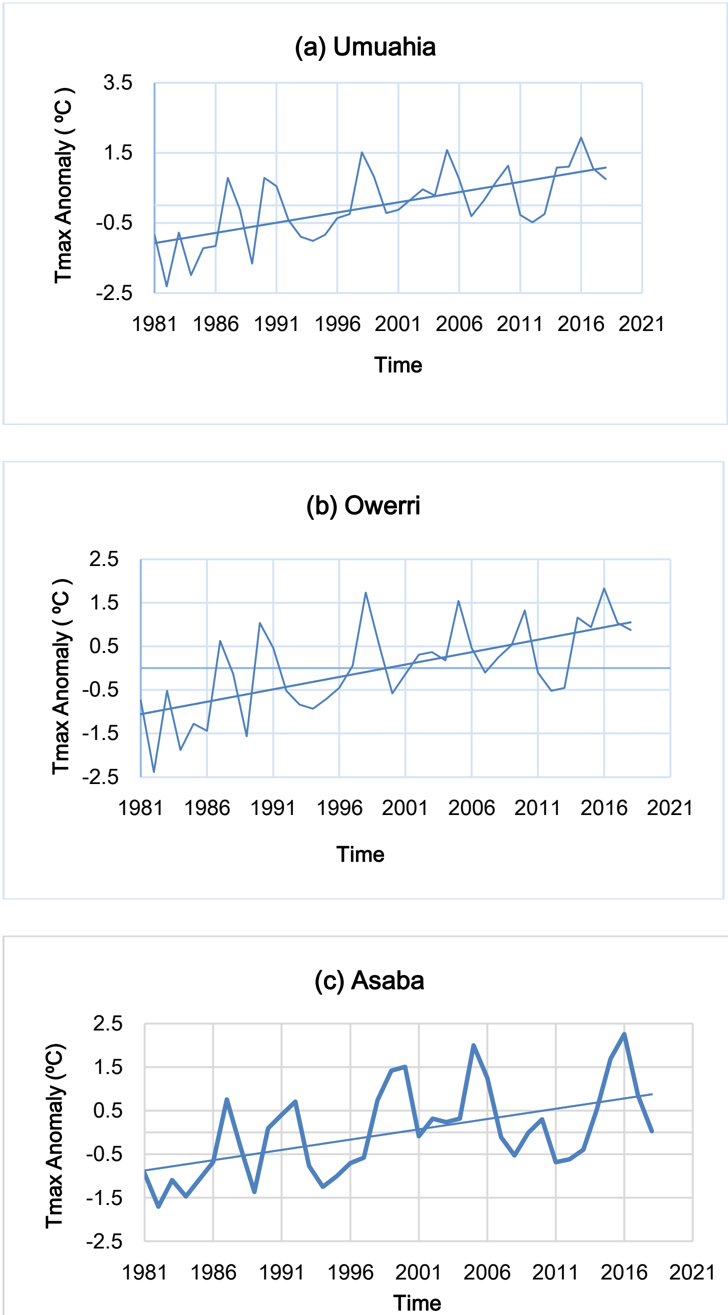

Fig. 13. Normalized time series anomaly plots for mean annual surface air maximum temperatures for representative stations (a: Umuahia, b: Owerri and c: Asaba) of the Tropical rainforest eco-climatic zone

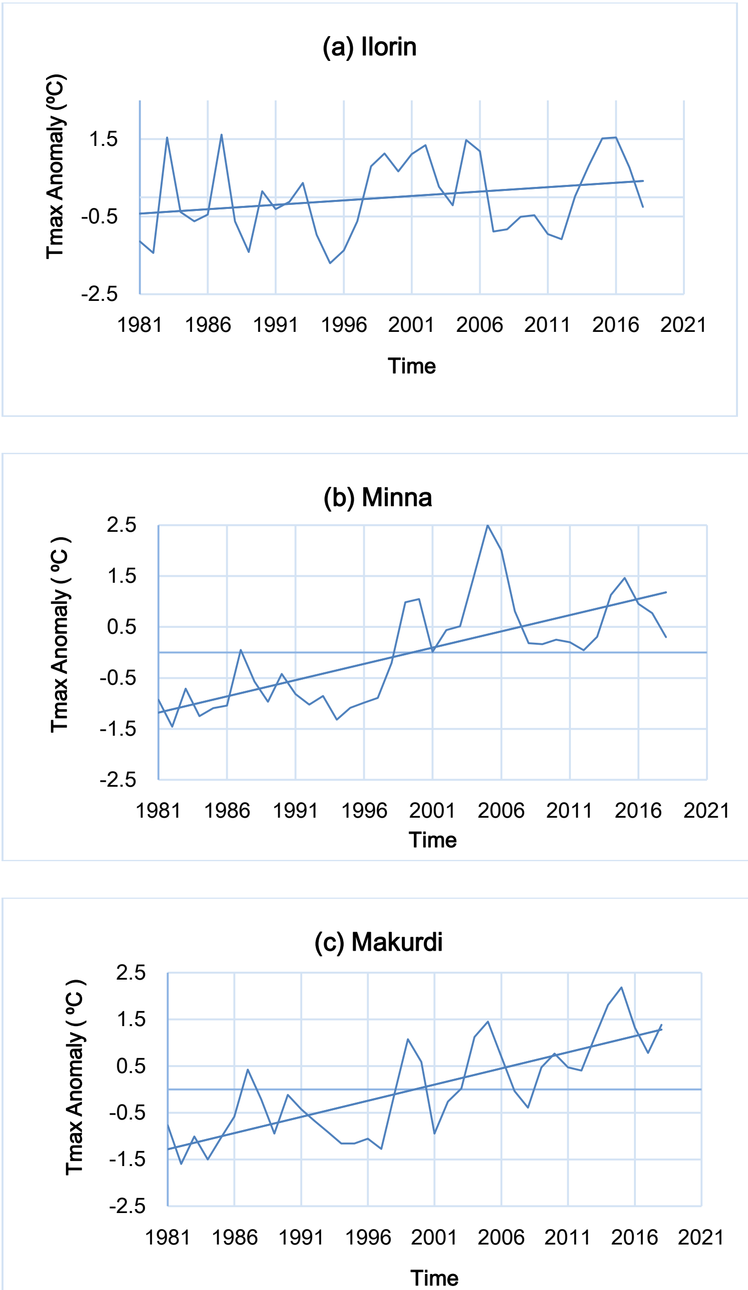

Fig. 14. Normalized time series anomaly plots for mean annual surface air maximum temperatures for representative stations (a: Ilorin, b: Minna and c: Makurdi) of the Guinea-wooded savanna eco-climatic zone

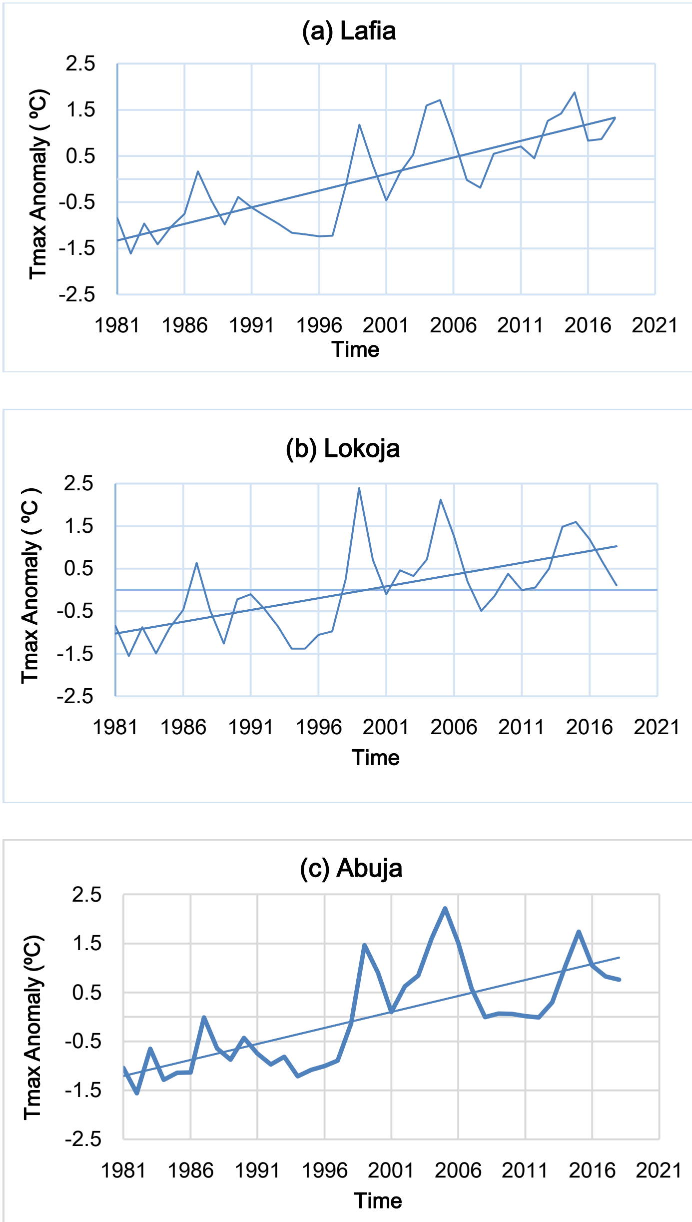

Fig. 15. Normalized time series anomaly plots for mean annual surface air maximum temperatures for representative stations (a: Lafia, b: Lokoja and c: Abuja) of the Sudan savanna eco-climatic zone

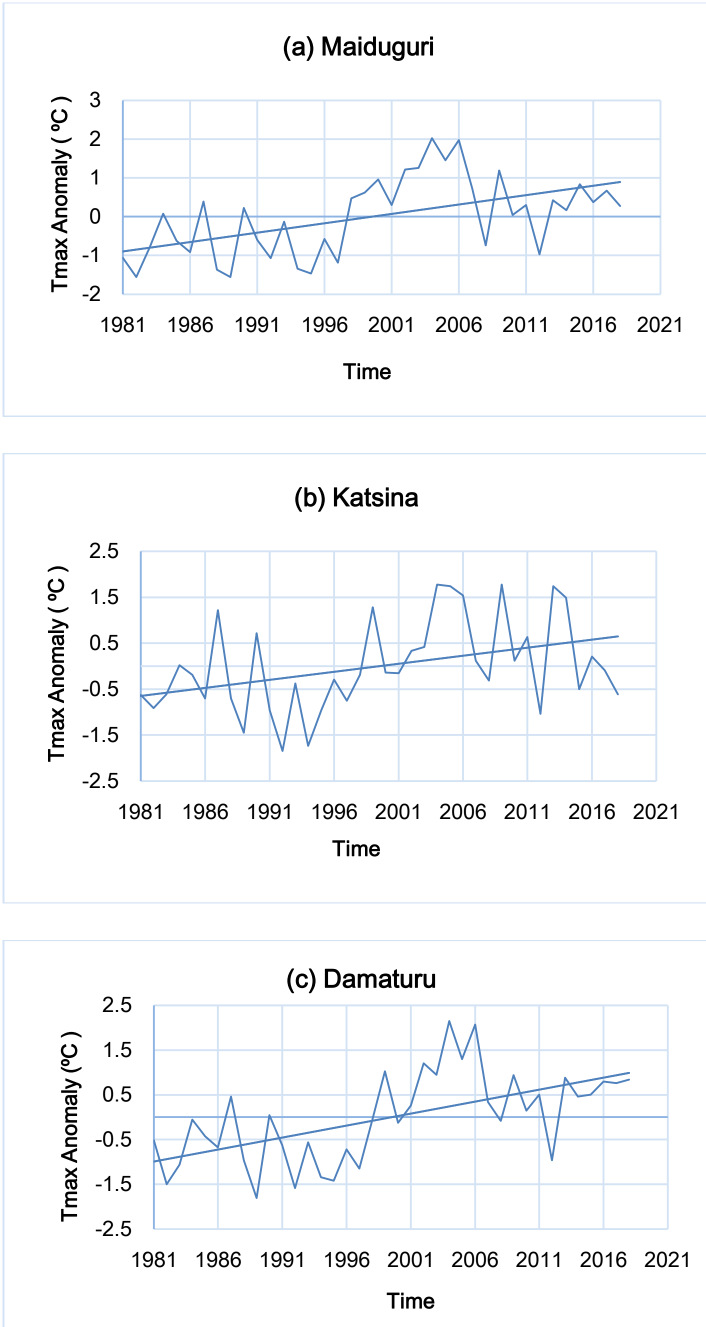

Fig. 16. Normalized time series anomaly plots for mean annual surface air maximum temperatures for representative stations (a: Maiduguri, b: Katsina and c: Damaturu) of the Sahel savanna eco-climatic zone

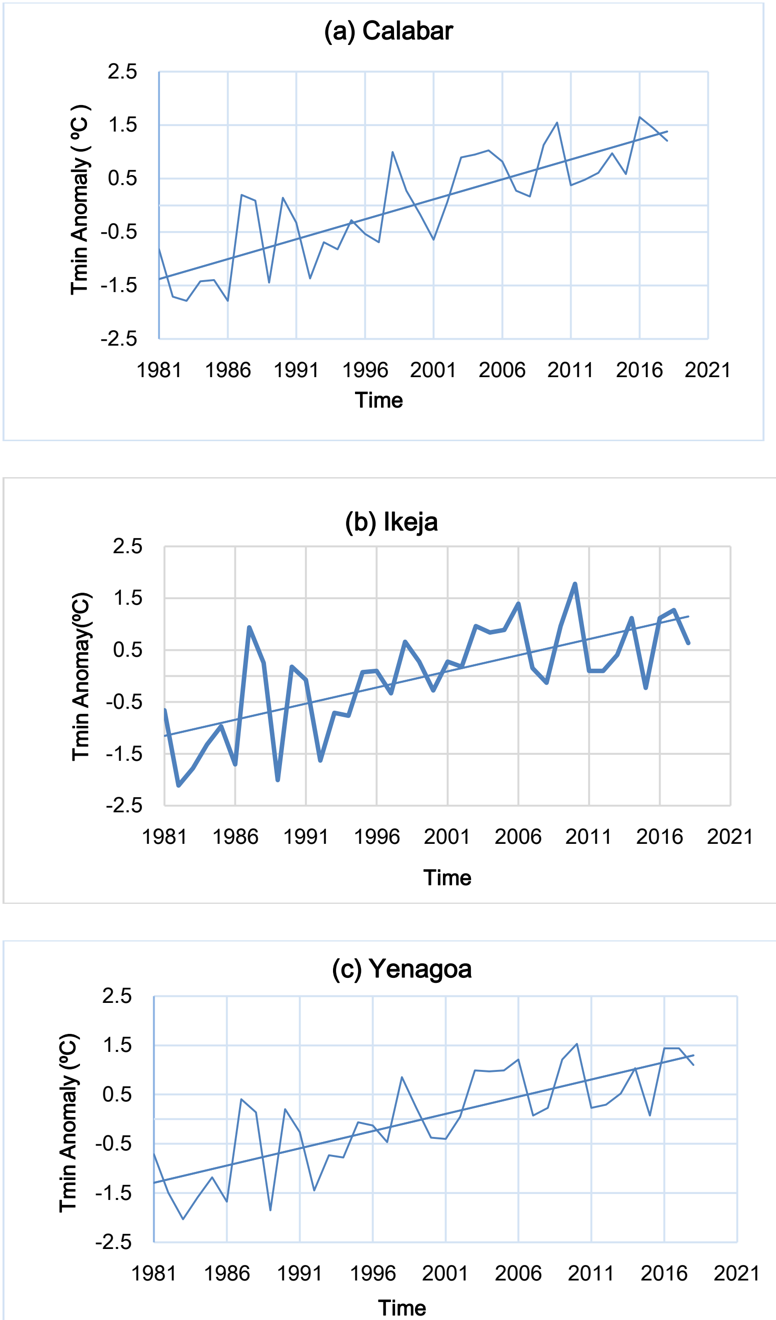

Fig. 17. Normalized time series anomaly plots for mean annual surface air minimum temperatures for representative stations (a: Calabar, b: Ikeja and c: Yenagoa) of the Mangrove-swamp rainforest eco-climatic zone

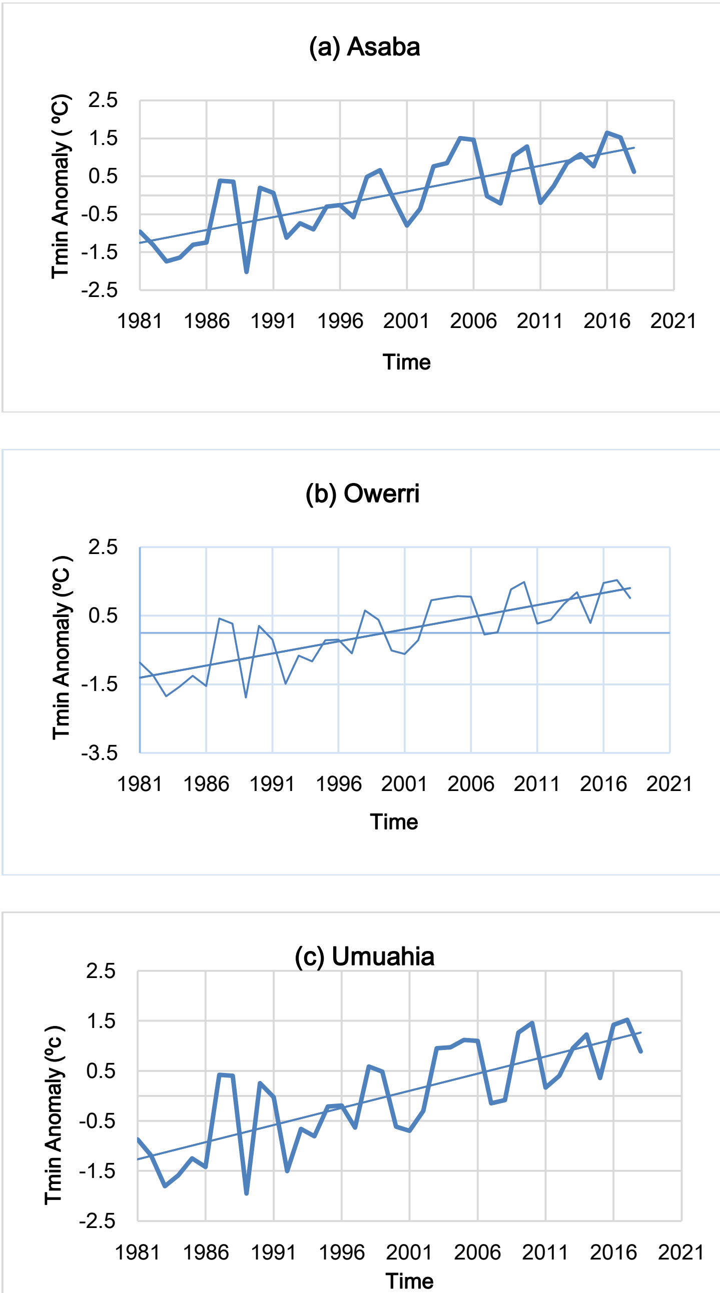

Fig. 18. Normalized time series anomaly plots for mean annual surface air minimum temperatures for representative stations (a: Asaba, b: Owerri and c: Umuahia) of the Tropical rainforest eco-climatic zone

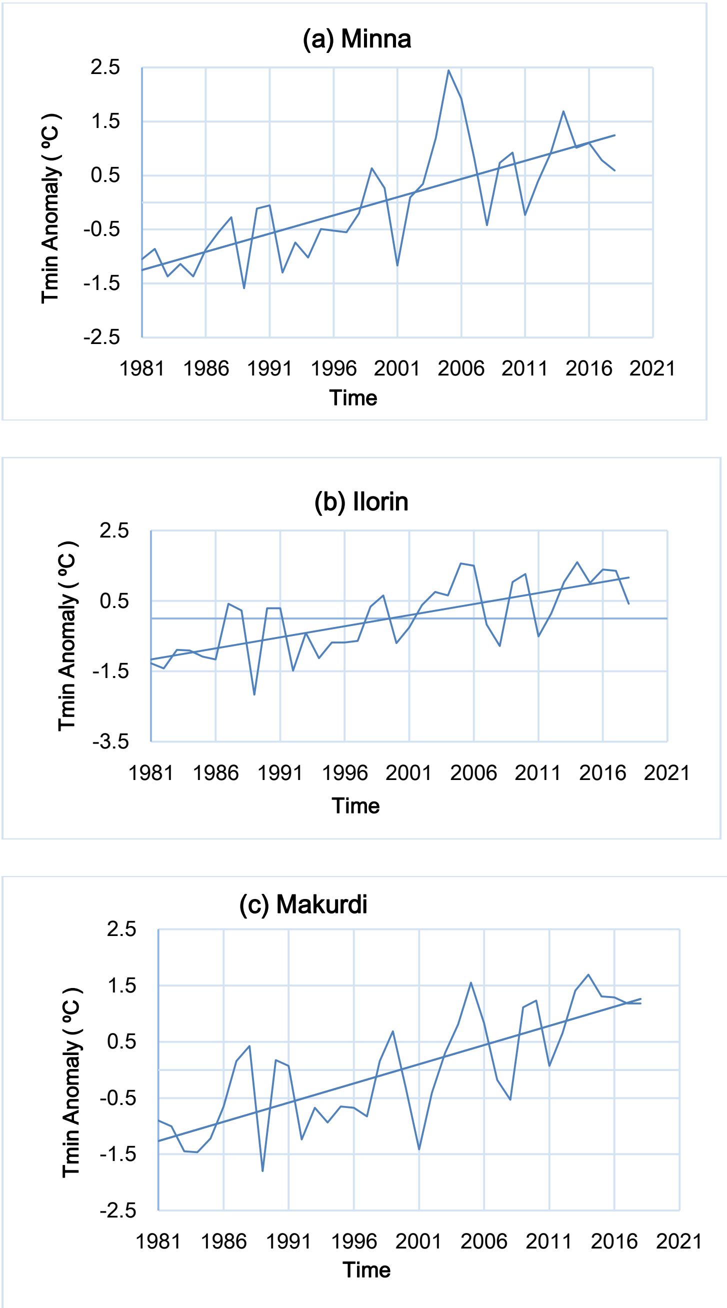

Fig. 19. Normalized time series anomaly plots for mean annual surface air minimum temperatures for representative stations (a: Minna, b: Ilorin and c: Makurdi) of the Guinea-wooded savanna eco-climatic zone

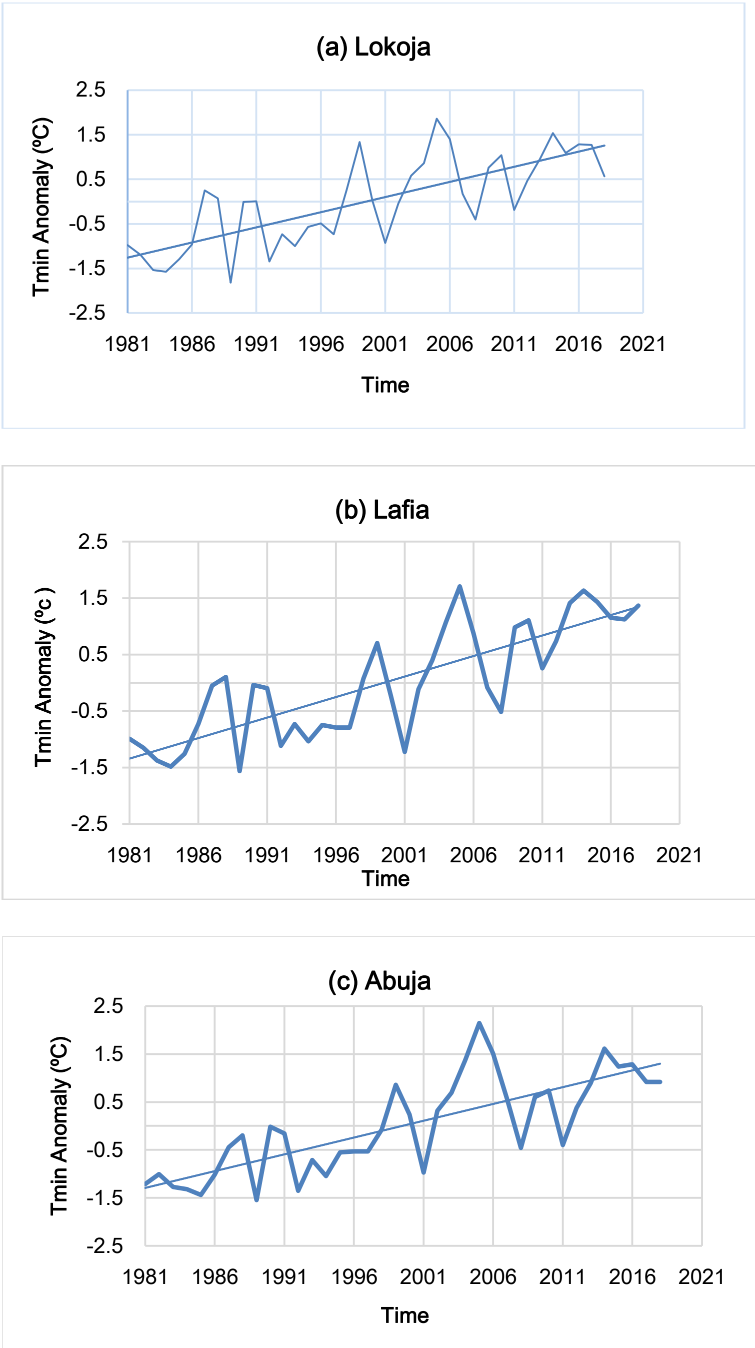

Fig. 20. Normalized time series anomaly plots for mean annual surface air minimum temperatures for representative stations (a: Lokoja, b: Lafia and c: Abuja) of the Sudan savanna eco-climatic zone

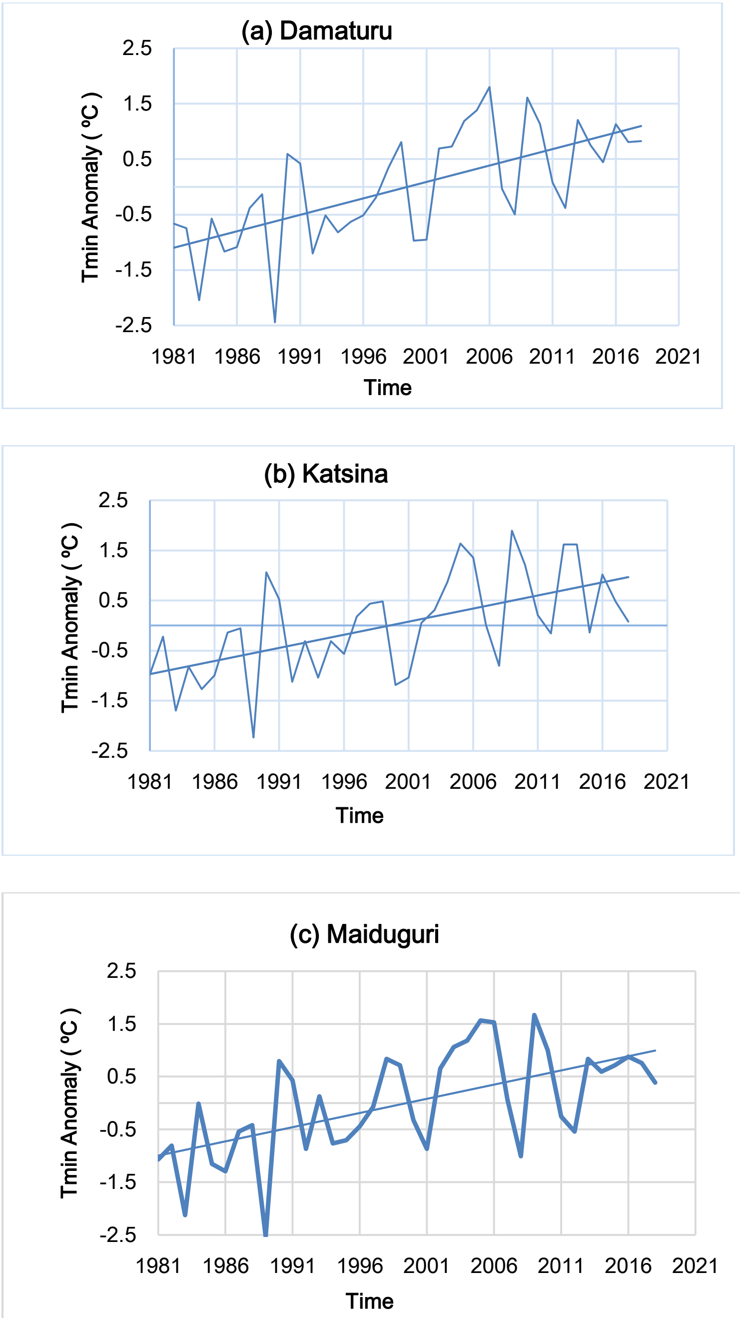

Fig. 21. Normalized time series anomaly plots for mean annual surface air minimum temperatures for representative stations (a: Damaturu, b: Katsina and c: Maiduguri) of the Sahel savanna eco-climatic zone

Discussion

The historical records of the studied variables showed long-term monotonic trends. The highlights of the findings are hereby presented.

Results of the analysis of the descriptive statistical features of surface air maximum and minimum temperatures are shown in Tables 2 and 3, respectively.

According to Durdu [50], the surface air temperature having a coefficient of variation (CV) of about <=0.1 (or 10%) indicates low variability. A CV of 0.1<CV<0.4 indicates moderate variability, and a high variability has a CV>0.4 (or 40%). Analysis of the coefficients of variation in Table 2 shows that mean annual surface air maximum temperatures in the Mangrove-swamp rainforest showed low variability, while that of the Tropical rainforest and the savannas (the Guinea-wooded, Sudan and the Sahel) showed moderate variability. Similarly, analysis of the coefficients of variation in Table 3 shows that mean annual surface air minimum temperature showed moderate variability in the eco-climatic zones in Nigeria covered by this study.

The variability of mean annual surface air maximum and minimum temperatures across the representative stations follow a well-defined pattern. Mean annual surface air maximum temperatures showed latitudinal dependence and are generally higher in the north and decreases towards the South in Nigeria (Table 2). Similarly, mean annual surface air minimum temperatures also showed latitudinal dependence, and are generally lower in the north, increasing towards the south in Nigeria (Table 3). This result is consistent with the findings of Aiyelabagan [51] that the maximum surface air temperature increases towards the north while the minimum surface air temperature decreases towards the north in Nigeria. This pattern of higher north-south coefficient of variation infers that surface air temperatures are more stable in the south than in the north. The nighttime cooling in the humid south is minimal due to radiative forcing from clouds, whereas the nighttime cooling in the drier north is substantial under cloudless skies.

Analysis of the coefficients of skewness in Table 2 shows that the mean annual values of surface air maximum temperatures for the 15 stations are above the central maximum for the data distribution. Similarly, analysis of the coefficients of skewness in Table 3 shows that the mean annual values of surface air minimum temperatures for 10 stations are below the central maximum and the mean annual values for 5 stations are above the central maximum for the data distribution.

Analysis of Figures 2~6 shows that mean monthly surface air maximum temperature varies seasonally along a well-defined pattern. Moving northward, the monthly mean maximum surface temperature begins to rise in January, reaches a maximum in March or April, and then gradually decreases, reaching a minimum in August. A rise to maximum values in October or November is observed again after August, dropping gently to a minimum value in December. In the South, the mean monthly surface air maximum temperature increases from January to peak at maximum values in February or March. During July or August, the values drop to their lowest values and then rise again to their maximum values during November or December. The maximum values observed around March is a consequence of increased surface air temperatures due to the arrival of insolation rather than in June to August when the on-set of the cool monsoon air lowers surface air temperatures. Similarly, the analysis of Figures 7~11 shows that the variation of mean monthly surface air minimum temperatures across the representative stations also follows a well-defined trend. The highest values in mean monthly surface air minimum temperatures are seen in April and May in the northern parts of Nigeria. In the South, the highest values in mean monthly surface air minimum temperatures are observed in March and April. Both sides of latitude 9°N, the lowest values in mean monthly surface air minimum temperatures record are observed in December and January. About this time, the Nigerian landscape is majorly under the influence of the Northeast trade wind and its associated air mass (*i.e.*, the Tropical Continental Air mass). Amadi *et al.* [17] notes that weather phenomena (such as early morning fog and mist) are associated with the dynamic processes of the trade wind due to radiation cooling at night under clear skies. Hence, low night temperatures characterize this period.

According to King *et al.* [33], the trend analysis of mean annual surface air maximum temperatures in Tables 4 and 5 reveals that 14 stations have monotonic upward trends in mean annual surface air maximum temperature. However, Ikeja shows a monotonic 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 surface air 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 surface air 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 at the 0.05 significance level.

The trend analysis of mean annual surface air minimum temperatures in Tables 6 and 7 shows that all the stations have monotonic upward trends in mean annual surface air minimum temperature [33]. 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 data in Table 4 with Table 6, it was observed that mean annual surface air minimum temperature has a higher change rate than the mean annual surface air maximum temperature.

The findings of this study's trend analysis agree with the findings of Oguntunde *et al.* [28] that the mean annual surface air minimum temperature has a higher rate of change than the mean annual surface air 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 surface air maximum temperature is noticeable in Lafia (*i.e.,* 0.073 °C/year), while the lowest value was noticeable in Yenagoa (*i.e.,* 0.015 °C/year). The highest trend magnitude in mean annual surface air 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).

According to King *et al*. [33], the mean estimated trend magnitude increase for mean annual surface air maximum temperature in Nigeria is about 0.035 °C/year and about 0.036 °C/year for the mean annual surface air minimum temperature. Thus, this study gives an estimated mean trend magnitude increase in mean annual surface air temperature of about 0.036 °C/year (*i.e.,*0.36 °C/decade) and an estimated mean annual surface air temperature increase in Nigeria of about 1.4°C from 1981-2018.

The normalized chronologically ordered anomaly plots for mean annual surface air maximum temperature show monotonic upward trends in 14 stations (Figures 12~ 16). 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). No significant long-term trends were observed in Ikeja (Figure 12b) and Ilorin (Figure 14a). The results of the plots align with the M-K and the linear trend tests results (Tables 4 and 5, respectively).

Similarly, the normalized chronologically ordered anomaly plots for the mean annual surface air minimum temperature showing monotonic upward trends in all the 15 stations were observed (Figure 17~21). The standardized anomaly time series plots also display the years with records of extreme events in mean annual surface air minimum temperatures during the period of this study. All the station's time series plots depict monotonic trends that align with the results of the M-K and the linear trend tests (Tables 6 and 7, respectively). The plots for the mean annual surface air temperatures depict chronologically ordered meteorological observations of surface air temperatures for the period covered by this study. The increasing trend in the annual mean maximum and minimum surface temperatures is shown by the Sen's slope (Tables 4 and 6) and the linear trend tests (Tables 5 and 7).

The combined use of more than one method to analyze the trends in mean annual surface air temperatures in Nigeria from 1981 to 2018 aligns with the findings of [40, 41]. According to them, proper care should be taken to arrive at correct interpretation of data and test assumptions during trend analysis using statistical tests. Those conclusions should be made by using more than one statistical test, as each statistical test addresses a specific question.

According to King *et al*. [33], increasing population, urbanization, increased evapotranspiration rates, severe drought, deforestation and desertification may be culpable for the high trend magnitudes in surface air temperature observed in the Guinea-wooded, Sudan and Sahel savannas. The study also pointed out that the trend magnitude and direction is in line with that of Akinsanola & Ogunjobi [27], who reported an increase of about 0.036 °C/year in mean surface air temperatures and upward trends in most stations in Nigeria, a decreasing g trend of about -0.02°C in Jos over the period 1971-2000 and a decreasing mean surface air temperature trend in Ikeja and Oshodi from 1991-2000. The same authors pointed out that the trend aligns with the result of Abiodun *et al.* [20], who found a trend in rising surface air temperature in Nigeria which are statistically significant at the 0.05 level of significance from 1971 to 2000.

King *et al.* [33] also pointed out that the trends observed in this study are partially consistent with the findings of [17]. They found that the annual mean surface maximum and minimum temperatures in Nigeria showed an increasing trend, which was statistically significant at the 0.05 and 0.01 significance levels. In most of the stations included in this study, the trend was statistically monotonic. The annual mean surface maximum temperature in Ilorin showed a decreasing trend, but the trend was not significant, while the annual mean surface maximum and minimum temperatures in Ikeja showed a significant monotonic increasing trend. The authors note that the difference in the maximum surface temperature results for Ilorin may be due to the difference in data length, while the difference in the annual average maximum surface temperature results for Ikeja may be due to the accumulation of a layer of air in the atmosphere over Ikeja, which tends to weaken the intensity of solar radiation reaching the Earth's surface but captures thermal infrared radiation emitted from the Earth's surface at night. The authors suggested that this may be culpable for the reducing surface air maximum temperature but increasing surface air minimum temperature observed in Ikeja. Therefore, further studies should be carried out to unravel the cause of the downward trend in surface air maximum temperature observed in Ikeja

CONCLUSIONS

This study aimed at analyzing the trend and variations in mean annual surface air temperatures across selected representative stations of some eco-climatic zones in Nigeria and the possible causes of the trend and variations. Mean annual surface air maximum temperatures in the Mangrove-swamp rainforest showed low variability, while that of the Tropical rainforest and the savannas (the Guinea-wooded, Sudan and the Sahel) showed moderate variability. Similarly, mean annual surface air minimum temperature showed moderate variability in the eco-climatic zones in Nigeria covered by this study. Surface air maximum and minimum temperatures mean annual conditions showed strong latitudinal dependence. The study revealed monotonic upward trends significant at the 99% and 95% confidence intervals 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 surface air maximum and minimum temperatures respectively. The estimated mean trend magnitude increases for mean annual surface air 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 surface air maximum temperature and an estimated increase in mean trend magnitude in mean annual surface air minimum temperature of about 0.036 °C/year, the estimated mean magnitude increase for both mean annual surface air maximum and minimum temperatures is about 0.036 °C/year. This study, also gives a projected estimated mean linear trend magnitude increase of about 4.3°C in mean surface air temperature by year 2100 in Nigeria.

The observed trend and variations in this study indicates changes in the net balance between the incoming solar and the outgoing thermal infrared radiation from the earth's surface and the lower atmosphere due to the radiative forcing caused by increasing concentrations of greenhouse gases (GHG's) and aerosols, land surface properties changes, urbanization and increasing population.

The significant long-term trends in the mean annual surface air temperatures at 0.01 and 0.05 significance levels over the period covered by this study provides a strong evidence that the climate of Nigeria is witnessing a possible human-induced climate change and a strong tendency for the on-set of climate-related hazards and their resulting adverse impacts. The results have serious implications for Nigeria. There is cogent need to devise appropriate and adequate mitigation and adaptive strategies by the relevant authorities; so that potential problems could be tackled before they become critical.

ACKNOWLEDGMENTS

The authors acknowledge the positive contribution of the National Aeronautics and Space Administration (NASA) for providing the reanalysis data.

CONFLICTS OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

1. IPCC. (2002). *Climate Change 2001: The Scientific basis*, Cambridge. Cambridge University Press.
2. Malhi, Y., Phillips, O. L., Malhi, Y., & Wright, J. (2004). Spatial patterns and recent trends in the climate of tropical rainforest regions. *359*(1443), 311-329. doi:https://doi.org/10.1098/rstb.2003.1433
3. IPCC. (2007). Summary for Policymakers. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge.
4. IPCC. (2019). Summary for Policymakers. In: *Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.* Cambridge University Press, Cambridge.
5. Meissner, K. J., Weaver, A. J., Matthews, H. D., & Cox, P. M. (2003). The role of land surface dynamics in glacial inception: a study with the UVic Earth System Model. *Climate Dynamics, 21*(7), 515-537. doi:https://doi.org/10.1007/s00382-003-0352-2
6. Snyder, P. K., Delire, C., & Foley, J. A. (2004). Evaluating the influence of different vegetation biomes on the global climate. *Climate Dynamics, 23*(3), 279-302. doi:https://doi.org/10.1007/s00382-004-0430-0.
7. Dang, H., Gillett, N. P., Weaver, A. J., & Zwiers, F. W. (2007). Climate Change detection over different land surface vegetation classes. *27*(2), 211-220. doi:https://doi.org/10.1002/joc.1397
8. Verma, S., Prakash, D., Srivastava, A. K., & Payra, S. (2017). Radiative forcing estimation of aerosols at an urban site near the thar desert using ground-based remote sensing measurements. *Aerosol and Air Quality Research*, *17*(5), 1294-1304.
9. Fawole, O. G., Cai, X., Pinker, R. T., & MacKenzie, A. R. (2019). Analysis of radiative properties and direct radiative forcing estimates of dominant aerosol clusters over an urban-desert region in West Africa. *Aerosol and Air Quality Research*, *19*(1), 38-48.
10. Liousse, C., Assamoi, E., Criqui, P., Granier, C., & Rosset, R. (2014). Explosive growth in African combustion emissions from 2005 to 2030. *Environmental Research Letters*, *9*(3), 035003. doi:https://doi.org/10.1088/1748-9326/9/3/035003
11. Doumbia, E. H. T., Liousse, C., Galy-Lacaux, C., Ndiaye, S. A., Diop, B., Ouafo, M., Assamoi, E. M., Gardrat, E., Castera, P., Rosset, R., Akpo, A., & Sigha, L. (2012). Real time black carbon measurements in West and Central Africa urban sites. *Atmospheric Environment, 54*, 529-537. doi:https://doi.org/10.1016/j.atmosenv.2012.02.005
12. Mahmood, R., Pielke Sr., R. A., Hubbard, K. G., Niyogi, D., Dirmeyer, P. A., McAlpine, C., Carleton, A. M., Hale, R., Gameda, S., Beltrán-Przekurat, A., Baker, B., McNider, R., Legates, D. R., Shepherd, M., Du, J., Blanken, P. D., Frauenfeld, O. W., Nair, U. S., & Fall, S. (2014). Land cover changes and their biogeophysical effects on climate. *34*(4), 929-953. doi:https://doi.org/10.1002/joc.3736
13. Yue, S., & Hashino, M. (2003). LONG TERM TRENDS OF ANNUAL AND MONTHLY PRECIPITATION IN JAPAN. *39*(3), 587-596. doi:https://doi.org/10.1111/j.1752-1688.2003.tb03677.x

14. De Luís, M., Raventós, J., González-Hidalgo, J. C., Sánchez, J. R., & Cortina, J. (2000). Spatial analysis of rainfall trends in the region of Valencia (east Spain). *20*(12), 1451-1469. doi:https://doi.org/10.1002/1097-0088(200010)20:12<1451::AID-JOC547>3.0.CO;2-0
15. VICENTE-SERRANO, S. M. (2006). Spatial and temporal analysis of droughts in the Iberian Peninsula (1910-2000). *Hydrological Sciences Journal, 51*(1), 83-97. doi:https://doi.org/10.1623/hysj.51.1.83
16. Ewona, I. O., & Udo, S. O. (2008). Trend studies of some meteorological parameters in Calabar, Nigeria. *Nigerian Journal of Physics, 20*(2)*,* 283-289.
17. Amadi, S. O., Udo, S. O., & Ewona, I. O. (2014). Trend and Variation of Monthly Mean Minimum and Maximum temperature data over Nigeria for the period 1950-2012. *International Journal of Pure and Applied Physics, 2*(4), 1-27.
18. Subarna, D. (2017). Analysis of Long-Term Temperature Trend as an Urban Climate Change Indicator. *Forum Geografi*, *31*(2), 196-208.
19. Wang, J., Xu, C., Hu, M., Li, Q., Yan, Z., & Jones, P. (2018). Global land surface air temperature dynamics since 1880. *International Journal of Climatology, 38*(S1), e466-e474. doi:https://doi.org/10.1002/joc.5384
20. Abiodun, B. J., Salami, A. T., & Tadross, M. (2011). *Climate Change Scenarios for Nigeria: Understanding the Biophysical lmpacts.* A Report by the Climate Systems Analysis Group, Cape Town, for Building Nigeria's Response to Climate Change (BNRCC) Project, lbadan, Nigeria.
21. Thomas, T., Sudheer, K. P., Ghosh, N. C., & Gunte, S. S. (2013). Spatio-temporal variation of temperature characteristics over Narmada basin - is the consistent warming trend a possible climate change signal? In *Proceedings - 20th International Congress on Modelling and Simulation, MODSIM 2013*, *December*, pp.2416-2422.
22. Magawata, U. Z., & Yahaya, A. A. (2019). Trends and Variations of Monthly Solar Radiation, Temperature and Rainfall Data over Birnin Kebbi Metropolis for the Period of 2014-2016. *Journal of Geography, Environment and Earth Science International*, *21*(4), 1-10.
23. Peterson, T. C., & Vose, R. S. (1997). An overview of the Global Historical Climatology Network temperature database. *Bulletin of the American Meteorological Society*, *78*(12), 2837-2850.
24. Abatzoglou, J. T., Redmond, K. T., & Edwards, L. M. (2009). Classification of regional climate variability in the state of California. *Journal of Applied Meteorology and Climatology*, *48*(8), 1527-1541.
25. Liu, X., Yin, Z. Y., Shao, X., & Qin, N. (2006). Temporal trends and variability of daily maximum and minimum, extreme temperature events, and growing season length over the eastern and central Tibetan Plateau during 1961-2003. *Journal of Geophysical Research Atmospheres*, *111*(19), 1-19. doi:https://doi.org/10.1029/2005JD006915
26. Abudaya, M. (2013). Seasonal & Spatial Variation in Sea Surface temperature in the South-East Mediterranean Sea. *Journal of Environmental and Earth Science, 3*(2), 42-52.
27. Akinsanola, A. A., & Ogunjobi, K. O. (2014). Analysis of rainfall and temperatures variability over Nigeria, 1971-2000. *Global Journal of Human-Social Science: B Geography, Geo-sciences, Environmental Disaster Management, 14(3)*, 1-17.
28. Oguntunde, P. G., Abiodun, B. J., & Lischeid, G. (2012). Spatial and temporal

temperature trends in Nigeria, 1901-2000. *Meteorology and Atmospheric Physics*, *118*(1-2), 95-105. doi:https://doi.org/10.1007/s00703-012-0199-3
29. Ogolo, E. O., & Adeyemi, B. (2009). Variation and trends of some meteorological parameters at lbadan, Nigeria. *The Pacific Journal of Science and Technology, 10*(2), 981-989.
30. Ewona, I. O., & Udo, S. O. (2011). Climatic parameters of Calabar as typified by some meteorological parameters. *Global Journal of Pure and Applied Sciences, 17(*1), 81-86.
31. Oruoye, E. D. (2014). An assessment of the trends of climatic variables in Taraba State, Nigeria. *Global Journal of Science Frontier Research: H Environment & Earth Science, 14*(4), 1-13.
32. Agbo, E. P., & Ekpo, C. M. (2021). Trend Analysis of the Variations of Ambient Temperature Using Mann-Kendall Test and Sen's Estimate in Calabar, Southern Nigeria. *Journal of Physics: Conference Series, 1734*(1), 012016. doi:https://doi.org/10.1088/1742-6596/1734/1/012016
33. King, L. E., Udo, S. O., Ewona, I. O., Amadi, S. O., Ebong, E. D., & Umoh, M. D. (2024). Assessment of Temporal Trend in Surface Air Temperatures across Some Selected Eco-Climatic Zones in Nigeria. *Trends in Renewable Energy, 10*, 132-158. doi:http://dx.doi.org/10.17737/tre.2024.10.1.00169
34. Adefolalu, A. D. (2002). Climate of Nigeria. In *Atlas of Nigeria, (65)*, Paris: Les Editions J.A.
35. Gelaro, R., McCarty, W., Suárez, M. J., Todling, R., Molod, A., Takacs, L., ... & Zhao, B. (2017). The modern-era retrospective analysis for research and applications, version 2 (MERRA-2). *Journal of climate*, *30*(14), 5419-5454. doi:https://doi.org/10.1175/JCLI-D-16-0758.1
36. Rienecker, M. M., & Coauthors, G. (2008). *The GEOS-5 Data Assimilation System-Documentation of versions 5.0.1,5.1.0 and 5.2.0.T technical Report series on Global Modeling and Data Assimilation, vol.27,* NASA TECH REP. NASA/TM-2008-104606,118pp.
37. Molod, A., Takacs, L., Suarez, M., & Bacmeister, J. (2015). Development of the GEOS-5 atmospheric general circulation model: evolution from MERRA to MERRA2. *Geosci. Model Dev., 8*(5), 1339-1356. doi:http://dx.doi.org/10.5194/gmd-8-1339-2015
38. Wu, W. S., Purser, R. J., & Parrish, D. F. (2002). Three-dimensional variational analysis with spatially inhomogeneous covariances. *Monthly Weather Review, 130*(12), 2905-2916.
39. Longobardi, A., & Villani, P. (2009). Trend analysis of annual and seasonal rainfall time series in the Mediterranean area. *International Journal of Climatology, 12*(4), 23-31.
40. Kundzewicz, Z. W., & Robson, A. J. (2004). Change detection in hydrological records - A review of the methodology. *Hydrological Sciences Journal*, *49*(1), 7-19. doi:https://doi.org/10.1623/hysj.49.1.7.53993
41. Sonali, P., & Nagesh Kumar, D. (2013). Review of trend detection methods and their application to detect temperature changes in India. *Journal of Hydrology, 476*, 212-227. doi:https://doi.org/10.1016/j.jhydrol.2012.10.034
42. Rossi, R. E., Mulla, D. J., Journel, A. G., & Franz, E. H. (1992). Geostatistical tools for modeling and interpreting ecological spatial dependence. *Ecological Monographs*, *62*(2), 277-314. doi:https://doi.org/10.2307/2937096

43. Turkes, M. (1999). Vulnerability of Turkey to desertification with respect to precipitation and aridity conditions. *Turkish Journal of Engineering and Environmental Science*, *23*(5), 363-80.
44. Helsel, D. R., Hirsch, R. M., Ryberg, K. R., Archfield, S. A., & Gilroy, E. J. (2020). Statistical methods in water resources techniques and methods 4 -A3. *USGS Techniques and Methods, 1*(13), 15-25.
45. Houghton, R. A. (2003). Revised estimates of the annual net flux of carbon to the atmosphere from changes in land use and land management 1850-2000. *Tellus, Series B: Chemical and Physical Meteorology*, *55*(2), 378-390.
46. Yue, S., & Wang, C. (2004). The Mann-Kendall Test Modified by Effective Sample Size to Detect Trend in Serially Correlated Hydrological Series. *Water Resources Management, 18*(3), 201-218. doi:https://doi.org/10.1023/B:WARM.0000043140.61082.60
47. Wang, H., Zhang, M., Zhu, H., Dang, X., Yang, Z., & Yin, L. (2012). Hydro-climatic trends in the last 50years in the lower reach of the Shiyang River Basin, NW China. *CATENA, 95*, 33-41. doi:https://doi.org/10.1016/j.catena.2012.03.003
48. Rai, R. K., Upadhhyay, A., & Ojha, C. S. P. (2010). Temporal variability of climatic parameters of Yumuna River Basin: Spatial analysis of persistence, trend and periodicity. *The Open Hydrology Journal, 4,* 184-210. doi:http://dx.doi.org/10.2174/1874378101004010184
49. Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of American Statistic Association, 63*, 1379-1389. doi:https://doi.org/10.1080/01621459.1968.10480934
50. Durdu, O. F. (2009): Effects of Climate Change on Water Resources of the Buyuk Menderes River Basin; WesternTurkey. *Turkish Journal of Agriculture*. *34,* 319-332.
51. Aiyelabagan, A. T. (2014). Latitudinal dependence of some meteorological parameters in Nigeria. *International Journal of Technical Research and Application, 2(*6), 7-10.