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Temperature Variability Comparison Using Mann-Kendall Test

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Abstract: Climate change in terms of extreme temperature has been a global concern, and Nigeria has not been an exception. However, analysis of climatic trend comparison between the northern and southern part of Nigeria, especially in terms of temperature variability is rarely found among the available works of literature. Thus, this work therefore analyzed and compared the average temperature trends of six stations each from the far north and south of Nigeria for 30 years (1981 to 2010) using statistical analysis and the Mann-Kendall test, as a nonparametric procedure in assessing the temperature trends. However, from the results of the analysis, it was observed that at a 1% significance level, the Mann-Kendall test of the temperature trend in all the six stations considered from the south was rising significantly, while for those in the north there was no significant temperature rise in five of the six stations considered which nevertheless dropped to four stations at 5% significant level. Moreover, correlations were observed to exist only amongst stations with significant temperature trends. Hence, based on this observation, it can be concluded that the climate in the southern part of Nigeria is more prone to extreme temperature variation than that of the northern part.

Keywords: Climate change, temperature trends, temperature variation, correlations, mitigating efforts

1. Introduction

Climate change which has been one of the major problems being faced by the global community is a matter of great concern to scientists all over the world. It constitutes a threat to human development, especially with regards to his social and economic survival due to its potential to affect all-natural systems. This type of change is also believed might have a major impact on natural and social systems at local, regional, national, and global scales. Even, Nigeria is also believed to be highly vulnerable to the impact of climate change in that her economy is so dependent on fossil fuels, whose by-products have an impact on climate. Yet, Nigeria's qualitative response to climate change mitigation is extremely low. Moreover, it is believed that vulnerability, in terms of fluctuations or trends, is a natural attribute of climate. However, the degree of variability to which climate is subject, as well as the duration of such variability is very crucial [1]. There are diverse problems of adjustment by man, as his environment becomes very vulnerable due to the variations in climate that constitute a significant departure from the normal conditions. Also, there may be a prolongation in climate which could result in a new climate state. Likewise, the rapid variations in climate may also increase the vulnerability of man due to difficulty in adaptation. However, it must be noted that climate change could be easily deciphered in terms of rainfall and temperature. Yet, the temperature is the best and easiest of all documented weather parameters to show that the climate is changing [2].

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Temperature can be described as a physical quantity that expresses the degree of hotness or coldness of a place or an environment at a particular time. However, the temperature across the universe has been steadily increasing, over the years because of human activities [3]. Such activities include the burning of fossil fuels, land-use practices, deforestation and desertification which have a significant tendency to accumulate greenhouse gases, thereby causing global warming due to the greenhouse effect.

There have been indications of a warming rate of between 0.3^{o} - 0.6^{o}C from the long time-series of temperature analyses carried out on the hemispheric and global scale from the mid-19th century to the 20th century, due to either anthropogenic or astronomic causes [4, 5]. Thus, this steady rise in temperature across the entire globe has been attributed to be responsible for the current global warming being experienced, in which Nigeria is not an exception [6]. However, despite that some authors had affirmed that large-scale warming of the earth's surface had occurred over the last century [7]. Yet, others also reported that this warming up has brought about exceptionally cool temperatures in some parts of the world [8]. Nevertheless, it must be noted that regardless of the effect of temperature on global warming, the temperature is still an important factor in human life, in that it influences man's well-being in terms of his health, transportation and food supply [9, 10]. For example, whenever the physiological temperature (between 36.7^{o}C and 37^{o}C) is exceeded, heatwaves that threaten human health would be experienced [11, 12]. However, despite the effort made in several studies to analyze the trend of temperature in Nigeria, an extensive analysis comparing the northern and southern parts of the country is still lacking. Therefore, this study is an attempt to bridge the gap. Hence, this work is aimed at comparing the temperature trends between the northern and southern parts of Nigeria. Especially, since the northern part is close to the Sahara desert, while the southern part is so close to the Atlantic Ocean.

1.1. Description of Study Area

Nigeria is the Federal Republic located in West Africa's Gulf of Guinea, between the eastern longitudes 3^{o} and 14^{o}, and northern latitudes 4^{o} and 14^{o}. It is divided into both the northern and southern parts, with the states grouped into six administrative divisions called geopolitical zones (3 each in the North and South): Northwest, Northeast, North Central, Southwest, Southeast and extreme South (Niger Delta). However, Nigeria is divided into seven (7) ecological zones: Mangrove Swamp and Coastal Vegetation, Freshwater Swamp Forest, Lowland Rain Forest, Derived Savanna, Guinea Savanna, Sudan Savanna and Sahel Savanna [13]. Also, these ecological zones could be broadly into classified four (4) zones: Mangrove, Rain Forest, Guinea Savanna and Sahel Savanna. In addition, Nigeria according to the Koppen classification has four climatic zones: warm desert climate (Northeast), warm semiarid climate (remaining parts of the north, except for Northeast), monsoon climate (Niger Delta) and the tropical savannah climate (middle belt and parts of the Southwest) [14]. However, two distinctive seasons can be recognized:

(i) Wet season (summer) is normally from April to October in the south, and June to September in the north.
(ii) Dry season (winter) is from November to March.

The southern part experiences extremely high annual rainfall, while the northern part experiences low annual rainfall. The temperature variance in Nigeria is determined by its two major seasons: the wet (i.e. rainy) season and the dry season. The rainy season is a period of cool weather conditions due to increased cloud cover that shields the sun rays. However, the dry season is a period of warm weather conditions.

2. Methodology

Monthly minimum and maximum temperature data for 30 years (1981 to 2010) were collected from the Nigerian Meteorological Agency, Lagos for six stations from the far south so close to the Atlantic Ocean (Benin, Ibadan, Lagos, Ondo, Owerri and Warri) which are mainly in the rain forest zone of Nigeria, and six other stations from the far north so close to the Sahara desert (Bauchi, Kano, Katsina, Maiduguri, Nguru and Sokoto) which are mainly in the Savanna (Guinea, Sudan and Sahel) ecological zone of Nigeria (Fig. 1). These monthly temperature data were statistically analyzed using the descriptive statistics methods of mean, standard deviation (SD) and coefficient of variation (CV) to measure the dispersion of temperature data sets. Also, the normality test was carried out to determine whether the temperature data utilized in this study are normally distributed or not by making use of the following statistical hypothesis:

H0: Null hypothesis (The data are normally distributed)
H1: Alternative hypothesis (The data are not normally distributed)

Thus, the skewness test was performed on the temperature data to validate the strength of the null hypothesis. However, for data normality, it is expected that the histogram for the temperature data should assume the bell-shaped configuration. Furthermore, the Mann-Kendall (MK) test was utilized in determining the trend, and the correlation matrix is finally investigating the dependence amongst the temperature parameter between stations.

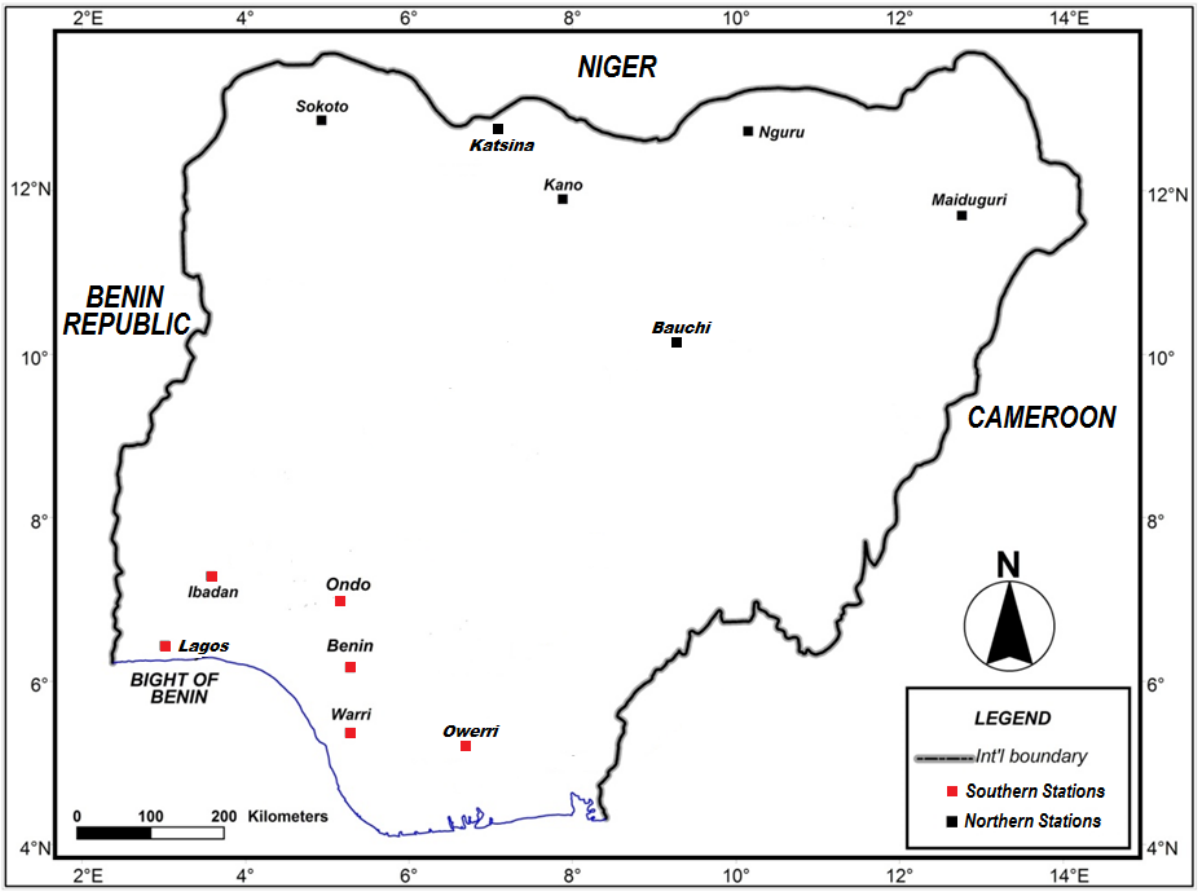

Fig. 1 - Selected temperature stations in Nigeria

2.1 Trend Detection Using Mann-Kendall (MK) Test

The Mann-Kendall (MK) test has been widely used in detecting trends of variables in various applications of atmospheric science- related research. It is a nonparametric ranked-based procedure so sensitive to the influence of extremely skewed variables, but employed in this study to estimate the presence of trends in the average temperature [15]. Moreover, the first step in the Mann-Kendall test was to compute the indicator function $sgn(x_j - x_k)$ as a time series x_1, x_2, x_3……., x_n of length n before the computation of mean *S* followed by that of variance, VAR *(S)* and finally computing the MK test statistic, Z.

In the MK test the number of positive differences minus the number of negative differences between the temperature data values, S is represented as eq. 1:

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

Where x_j and x_k are data values, n is the number of years understudy, and sgn is an indicator function that takes on the values 1, 0, or −1 according to the sign of $(x_j - x_k)$ as in eq. 2:

$$sgn(x_j - x_k) = \begin{cases} +1, & if(x_j - x_k) > 0 \\ 0, & if(x_j - x_k) = 0 \\ -1, & if(x_j - x_k) < 0 \end{cases} \qquad (2)$$

However, it must be noted that a positive (or negative) value of *S* indicates an increasing (or decreasing) temperature trend, as it is normally distributed with variance, VAR (S) [16, 17, 18] in eq. 3:

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

It is the VAR(S) that revealed whether the difference between the measurements at time j and k are positive, negative or zero.

Thus, using the mean *S* and the variance *VAR(S),* the test statistic, Z was used in performing the hypothesis test as in eq. 4:

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(S)}}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{S+1}{\sqrt{var(S)}}, & if s < 0 \end{cases} \quad (4)$$

The significance of the trend was verified by comparing the observed value of *Z* with the appropriate percentiles of the standard normal distribution (critical values), using a 0.05 significance level as the null hypothesis test to ensure that no monotonic trend is present, against the alternative hypothesis with an upward or downward monotonic trend.

3. Results and Discussion

The results of the mean temperature at the stations considered in the north showed a slightly higher value when compared with those from the south. The average mean temperature in the southern stations is 27.42ºC, while that of the northern stations is 27.49ºC. Moreover, three (3) stations (Ibadan, Lagos and Ondo) in the southern part of the country have each of their mean temperatures lower than that of the mean temperature for the entire southern stations considered. Also, three (3) stations (Bauchi, Kano and Katsina) in the northern part of the country have each of their mean temperatures lower than that of the mean temperature for the entire northern stations considered. However, it was observed that the closer the stations in the south are to the equator (i.e. based on their latitudinal positions), the warmer their mean temperature, except for Ondo (26.93ºC). While for the northern stations, their latitudinal positions did not follow the same warming trend as was observed in the southern stations. Thus, stations in the south seem warmer than those in the north, except those at Maduguri, Nguru and Sokoto (Table 1). Also, the SD values showed that the degree to which individual data sample differs from their sample mean is very low as a result of which all the samples cluster around their mean (i.e. values less than unity). Moreover, further analysis showed that CV values for southern stations are relatively smaller than those of the north (Table 2). However, the result of the normality test (Figs. 2 and 3) showed that the temperature data for both the northern part and southern part are not normally distributed (i.e skewed) since most climatic variables are stochastic. None of the stations is evenly skewed. Moreover, all the average temperatures from the southern stations are positively skewed except Lagos. While for the northern part, all the stations are negatively skewed except Kano and Bauchi. Hence, the southern stations tend towards positively skewed, while the reverse is the case for the northern stations which tend to be negatively skewed. Hence, since no temperature of any station is normally distributed it implies that the non-parametric test is very suitable for detecting and estimating the data trends. Thus, the usage of the Mann-Kendall test utilized in this work is justified.

Table 1 - List of stations used for this study

S/N	Station	Mean Temperature	Latitudinal and Longitudinal Locations	Location in Nigeria
1	Bauchi	26.36ºC	10.3010ºN, 9.8237ºE	North
2	Benin	27.54ºC	6.3350ºN, 5.6037ºE	South
3	Ibadan	27.24ºC	7.3775ºN, 3.9470ºE	South
4	Kano	26.79ºC	12.0022ºN, 8.5920ºE	North
5	Katsina	26.81ºC	12.9816ºN, 7.6223ºE	North
6	Lagos	27.31ºC	6.5244ºN, 3.3792ºE	South
7	Maiduguri	27.91ºC	11.8311ºN, 13.1510ºE	North
8	Nguru	28.05ºC	12.8775ºN, 10.4565ºE	North
9	Ondo	26.93ºC	7.1000ºN, 4.8417ºE	South
10	Owerri	27.83ºC	5.4891ºN, 7.0176ºE	South
11	Sokoto	29.03ºC	13.0059ºN, 5.2476ºE	North
12	Warri	27.67ºC	5.5544ºN, 5.7932ºE	South

Table 2 - Statistical analysis of the temperature data

Location in Nigeria	Stations	Mean	SD	CV (%)	Skewness
South	Benin	27.54	0.278	0.010	0.254
	Ibadan	27.24	0.316	0.012	0.146
	Lagos	27.31	0.450	0.016	-0.054
	Ondo	26.93	0.543	0.020	1.151
	Owerri	27.83	0.508	0.018	0.184
	Warri	27.67	0.383	0.013	0.339
North	Bauchi	26.36	0.766	0.029	0.687
	Kano	26.79	0.640	0.024	0.982
	Katsina	26.81	0.564	0.021	-0.240
	Maiduguri	27.91	0.438	0.016	-0.411
	Nguru	28.05	0.881	0.031	-2.264
	Sokoto	29.03	0.433	0.015	-0.202

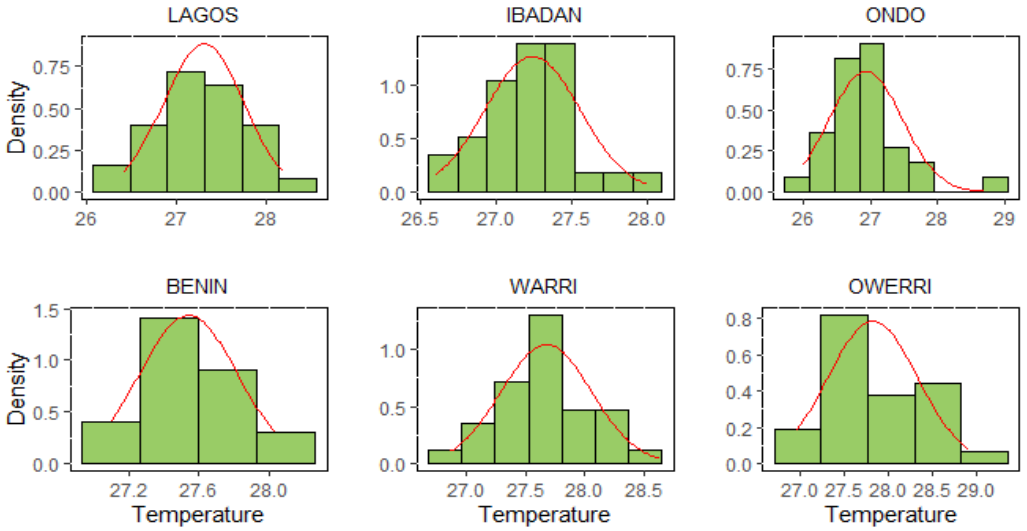

Fig. 2 - Normality test of the southern stations

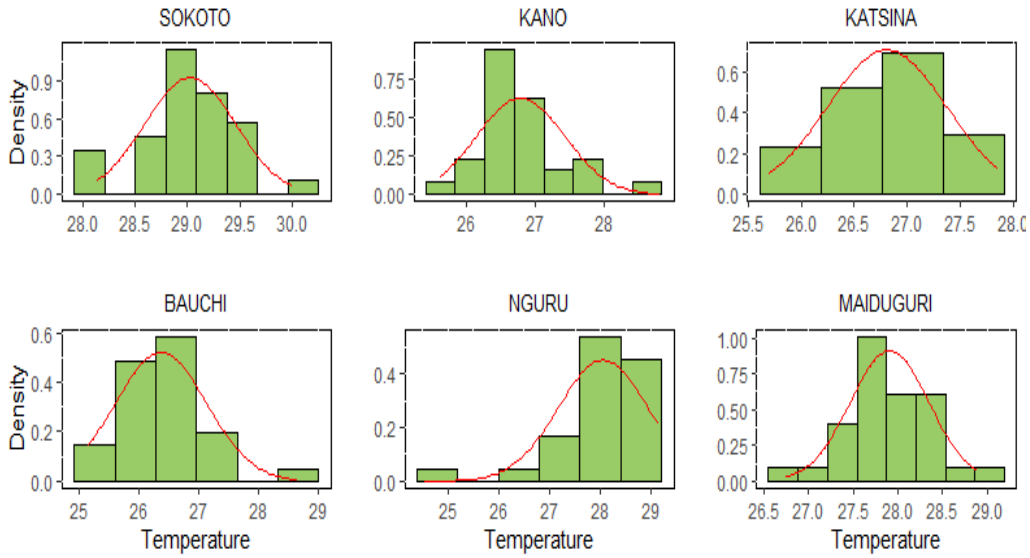

Fig. 3 - Normality test of the northern stations

The result of the MK test for the average temperature (Table 3) showed a significant positive temperature increase in the entire southern stations considered (Fig. 4). All the southern stations exhibit a significant rising trend which is consistent with similar findings of upward trends in monthly temperature [19].

The results of the northern part at 1% significant level revealed that all the northern stations exhibit no significant trend except Sokoto, while at 5% level Bauchi becomes significant also with Sokoto (Fig. 5). From the correlation matrix of the southern stations with their northern counterparts (Table 4), it was observed that correlations only exist between stations with significant trends. Stations with no significant trend do not correlate with those of significant trends. Although Lagos and Bauchi have significant trends with each other, but Lagos does not correlate with any other station from the north. However, Bauchi correlated with the southern stations at a 5% significant level, except for Ondo and Warri.

Table 3 - Mann-Kendall test analysis of the average temperature

Location in Nigeria	Stations	MK (Z)	P-value	Trend
South	Benin	3.61	0.00031	rising
	Ibadan	4.33	0.00002	rising
	Lagos	2.57	0.01000	rising
	Ondo	4.28	0.00002	rising
	Owerri	3.75	0.00018	rising
	Warri	4.24	0.00002	rising
North	Bauchi	2.25	0.02458*	rising
	Kano	0.61	0.54410	No trend
	Katsina	1.03	0.30080	No trend
	Maiduguri	1.68	0.09343	No trend
	Nguru	0.93	0.35350	No trend
	Sokoto	3.46	0.00054	rising

* No trend at 1% significant level

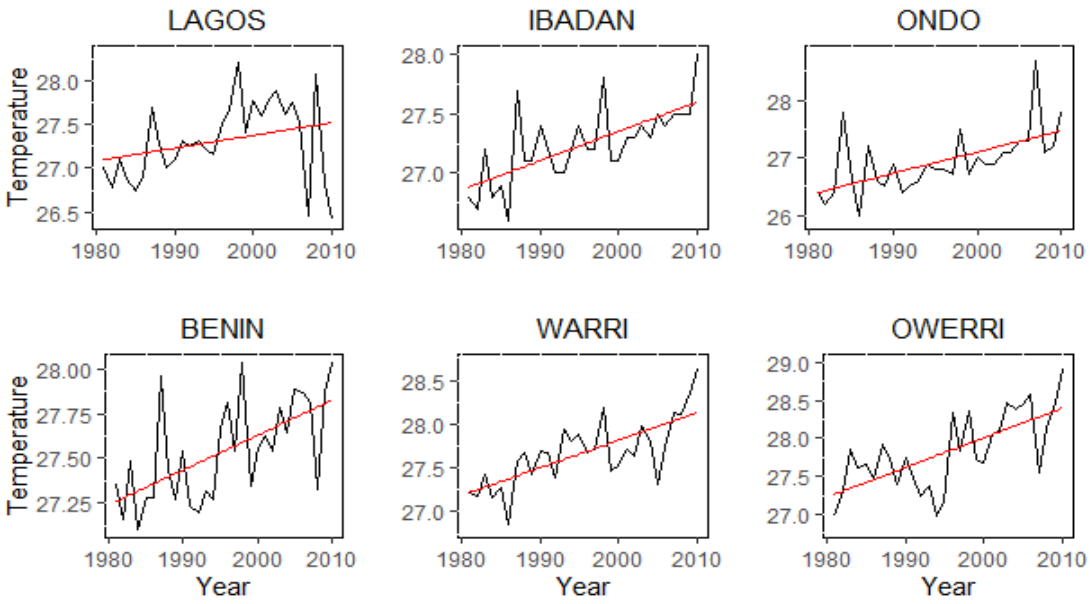

Fig. 4 - Trend of the southern stations

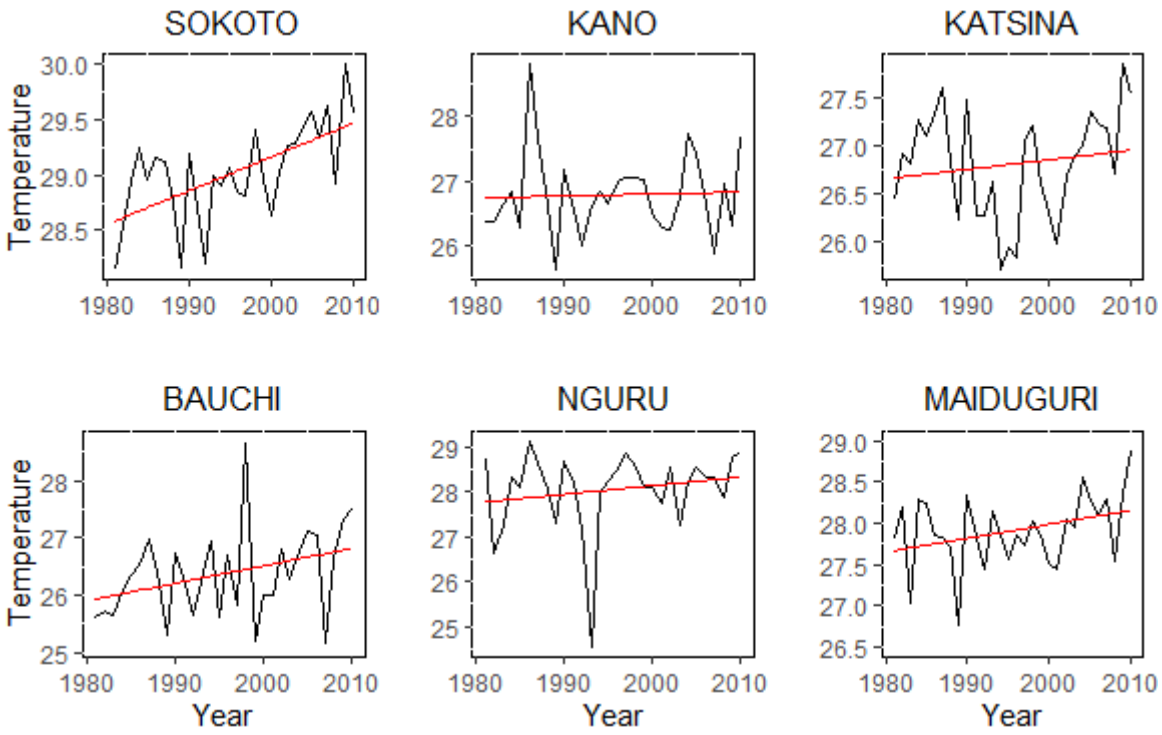

Fig. 5 - Trend of the northern stations

Table 4 - Correlation matrixes of the southern stations with the northern stations

Location	Bauchi	Kano	Katsina	Maiduguri	Nguru	Sokoto
Benin	0.562*	0.234	0.387	0.338	0.387	0.654*
Ibadan	0.564*	0.131	0.299	0.261	0.293	0.586*
Lagos	0.341	0.143	-0.187	-0.257	-0.010	-0.011
Ondo	0.274	-0.036	0.382	0.480	0.270	0.655*
Owerri	0.621*	0.311	0.492	0.414	0.305	0.669*
Warri	0.429	-0.066	0.148	0.329	0.019	0.524*

*significant at 5% level

4. Conclusion

From the results of the analysis, it was observed that the MK tests of temperature trend in all the six stations considered from the south were significantly rising. While for those in the north, there was no significant rising temperature in five of the stations, amongst the six considered at 1% significant level, but at 5% level the number of stations with insignificant trend became four. Yet, it was in the northern stations that the highest temperatures were recorded (Nguru and Sokoto). In conclusion, this result showed that the rising temperature is more pronounced in the south than in the north. However, despite that, the climate of southern Nigeria is more prone to extreme temperature than the northern part as obtained in this study; there is a tendency of the southern part to become as warm as the north. Although it is recommended that further work should still be carried out in this area as soon as up to date data is available. Nevertheless, this result is a wake-up call that adequate mitigation effort should be intensified for the negative consequences associated with a rise in temperature to be averted in the southern part of Nigeria.

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