

Trend Analysis of Mean Annual Temperature in Sokoto Metropolis Between 1971 And 2020 Using Man-Kendall And Sen's Slope Estimator

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Abstract: Information on trends and changes in atmospheric conditions over a given region can enhance good policy making to develop strategies to curb heat waves and disaster risk management.

The time series temperature data between 1971 and 2020 (50 years) of Sokoto Metropolis was used in this study to identify the trend and slope magnitude in the series. The trend was analyzed using the Mann-Kendal non-parametric test and the Sen's slope estimator was used to estimate the degree or rate of increase or decrease. Linear regression was employed to evaluate the linear trend in the data and coefficient of variation, CV was used to estimate the level of variability.

The decadal trend analysis shows an increasing trend as indicated by the Mann-Kendall's tau and p-value of +0.48 and 7.8×10^{-5} (<0.001) respectively. Also, the Sen's slope estimator was positive and found to be +0.022 °C per year, representing the rate of increase in trend for yearly annual temperature. Furthermore, the results show that the analysis of monthly rainfall has a varied trend of temperature in the dry months. It also shows a positively increasing warming trend for the months of April, May and September while August and December show moderate warming. This study will help the government or policymakers to develop appropriate coping and mitigation strategies for the most vulnerable areas with regards to global warming and climate change.

Keywords: Atmospheric conditions, Mann-Kendall (MK), Sen's slope estimator, Decadal, Trend *analysis*.

Conflicts of Interest: The authors declare no conflicts of interest.

Contribution and Originality:

This study contributes to the existing literature with regards to the existence of trends and variability in temperature in Sokoto vis-a-vis Nigeria. It will help the government to introduce policies that will help in cushioning the effects of climate change.

I. Introduction

The weather condition of any given place is often described in terms of meteorological elements such as rainfall, relative humidity, cloud cover, evaporation, pressure, sunshine duration, temperature, winds, etc.

These factors influence the atmospheric condition and also respond to other phenomena like *El Nino*, *La-Nina*, direct and indirect release of energy to the atmosphere by humans, including effects of atmospheric pollution.

Temperature is defined as the degree of hotness or coolness of the body. It affects other meteorological parameters including air temperature, air vapours, atmospheric air pressure, dew point, and relative humidity. The situation observed has a wide range of measured variables for determining climate variation by affecting or controlling additional components of meteorological conditions (Geerts, 2003).

Temperature is also said to be a measure of the thermal state of matter and is widely measured to determine the change in the weather because it influences other elements of the weather, such as dew point, precipitation, relative humidity, cloud cover, and atmospheric pressure, Geerts, B, (2002). Impacts of changes in temperature extremes on the ecosystem and on human infrastructures have been recognized widely as being more important than changes in average values. Variability of the climate is also important as regards human perception of climate, (Rebetez, M. 2001).

The Nigerian Meteorological Agency (NIMET) reported there has been a significant increase in temperature in Nigeria over the past few decades with an average annual increase of 0.8°C since the 1960s. This increase has resulted in changes in rainfall patterns as well as increase in extreme weather events including flooding, droughts and heat waves across the country.

The importance of climate and weather information in agriculture, aviation, water resources management, health, electric power generation, road and marine transport etc cannot be over-emphasized. Though weather and climate has profound influence over human activities, it can be regulated reasonably through proper management of the environment.

Therefore, it is crucial to understand the trends in extreme temperature in any given region so as to develop strategies aimed at mitigating the effects. This study is aimed at evaluating seasonal and annual variations in temperature so as to identify the trends and its significance for the period under study.

A lot of studies have examined the trends and variability of temperature extremes in Nigeria over different time periods and spatial scales. They have employed various methods and indices in the analysis of extreme temperature and their impacts on the environment, on agriculture, and on human health. Change and variation in climate, for instance natural climate variability and anthropogenic climate change, are among the major factors influencing extreme temperatures in Nigeria, (Olaniran *et al.*, 2018).

A study of trends under local climate is indispensable given the highly variable nature of climate in space and time. There are different approaches on trend detection and so many researchers have employed linear regression method to study trends in many climatic time series, (Hutchinson 1995; Subbaramaya and Bhanu-Kumar, 1987). However, the Man-Kendall non-parametric test has been proven to be better than parametric tests in the study involving trend analysis, (Turkes *et al.*, 2009; Zhihua *et al.*, 2013; Brunetti *et al.*, 2001; Eris and Agiralioglu, 2012, Karaburun *et al.*, 2011; Ustaoglu, 2012, Karabulut *et al.*, 2008). A study undertaken by Gunduz and Zeybekoğlu (2024) on the analysis of temperature and precipitation series of the Hirfanli Dam Basin using the Mann-Kendall and Spearman's rho tests and innovative trend analysis, showed an increasing trend in temperature.

Several studies have reported that some locations across Nigeria has a marked increase in maximum temperatures, which has exceeded historical averages, (Edokpa, *et. al.*, 2023; Yahaya, *et. al.*, 2024; Okoduwa and Amaechi, 2024; Alhaji, *et. al.*, 2018). These higher temperatures have deadly consequences like heat stress on crops which reduces agricultural productivity, while increasing evaporation rates worsen water shortages. Increasing temperatures also poses health risks directly to the human population, particularly in urban centers as urban heat island effect increases the warming, (Jones and Thornton, 2003; WHO, 2022).

Cumulatively, increasing temperatures contribute to desertification through flora loss, which rapidly encroaches on fertile lands and constrains agricultural potentials more, (Yahaya, *et. al.*, 2024).

Most studies carried out recently with regards to climate change, for instance on temperature analyses as conducted by the Intergovernmental Panel on Climate Change (IPCC), has reported that the global mean temperature has risen from 0.3 °C to 0.6 °C in the last century (IPCC, 1990; Murat *et al.*, 1995) and a larger temperature increase has been projected in the IPCC's Third Assessment Report (IPCC, 2001) because it is projected that sulphur dioxide, SO₂ emissions will be controlled and the Fourth Assessment Report of the Intergovernmental Panel on Climate Change has affirmed that climate change is no longer a distrust but is now unambiguously noticeable as a result of evidence from scientific observations on increases in global average air and ocean temperatures, (IPCC, 2007).

Murat *et al.*, (1992), in his study carried out over Turkey reported that trends in annual mean temperature for Turkey, using a departure of 21-year running means from the normal for 1941- 1970, rose by approximately 0.5 °C between 1930 and the mid-1960's.

Adelekan *et. al.*. (2017) examined the potential impacts of temperature extremes on human health in Nigeria. They found that temperature extremes have contributed to increased morbidity and mortality in some parts of Nigeria. Olaniran *et al.* (2018) studied the trends and variability of extreme temperature and precipitation in the Upper Niger River Basin in Nigeria between 1961 and 2010 using the highest daily maximum temperature, lowest daily minimum temperature, and highest daily rainfall indices respectively. They showed that there has been an increase in extreme temperature significantly over the study period and that the greater increase was in maximum temperatures than in minimum temperatures. They highlighted the potential impacts of extreme temperature and precipitation on the management of agriculture, water resources as well as on human health in the basin.

II. Materials and Method

The Study Area

Sokoto is the capital city of Sokoto state and lies between latitude 5° 14' 02'' North and longitude 13° 03' 44'' East of the Equator. It is bounded by Wurno local government area to the north and Bodinga and Wamakko local government areas to the south. To the East, Sokoto is bounded by Goronyo and Gwadabawa local government areas and to the West by Wamakko local government area. Its total area is 85 square kilometers and on an elevation of 291 m above sea level. Sokoto is a very hot and dry area although bearable with an annual average temperature of 28.3 °C. It has a maximum daytime temperature below 40 °C for most time of the year, (Peel, *et. al.*, (2007). It has two seasons; the wet and dry seasons. The dry season commences from October and lasts till April in some parts and may extend to either May or June in other parts. The wet season on the other hand begins in most parts of the state in May and lasts up to September, or October.

Sokoto metropolis experiences high temperatures throughout the year, (Topographic Sheet, 1990). In Sokoto, the hot season lasts for about 3.2 months between February and late May with average daily temperature above 40 °C. April is the hottest month with an average high and low of 40 °C and 26.7 °C respectively.

The cool season in Sokoto lasts for about 4 months, between October and February with an average daily high temperature below 32.8 °C. The coldest month of the year is January, with an average low of 17.2 °C and high of 31.7 °C, (N-inf-G, 2020).

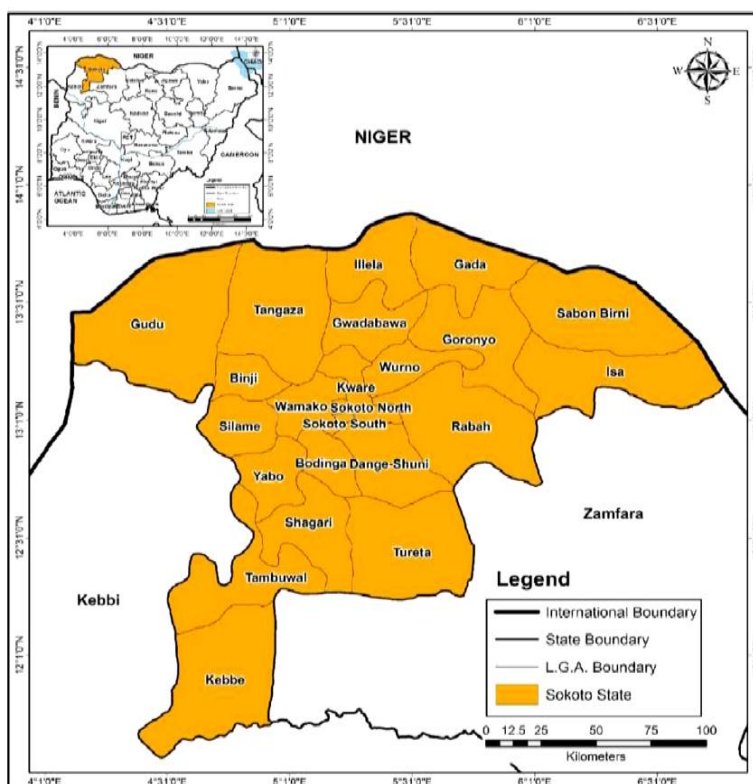


Fig. 1: Sokoto state showing the metropolis and other towns. Inset (top left): Map of Nigeria

Source: Administrative Map of Sokoto State 2022.

Data

Data Collection

Temperature data for Sokoto metropolis between 1971 and 2020, a period of 50 years was obtained from Historical Weather API.

Method of Data Analysis

The temperature data obtained over the period was analyzed using the Mann–Kendall test and Sen’s slope estimator. The Mann–Kendall statistical tool was used to ascertain whether there is a trend or not while the Sen’s slope estimator was used to estimate the degree or rate of change. These statistical tools have been adopted by many researchers to study the trends in various meteorological parameters, (Yaouba & Dieudonné, 2022).

Linear regression was also employed in the analysis to establish a relationship between the variables (dependent and independent). This was done by fitting a linear equation to the observed data. The data was also tested to find out whether a relationship exists between the variables or not. The coefficient of variation (CV) was also employed to measure the degree of variability of the data.

Mann-Kendall (MK) test

The Mann-Kendall test is non-parametric and is used widely in the detection of trends that are monotonic. It is superior to the parametric tests (Karaburun *et al.*, 2011; Ustaoglu, 2012; Karabulut, 2008). This is because it allows for missing values in time series data and does not require conforming to any particular distribution. It is robust to the effect of outliers (single data errors), (Turkes, 1999). The Mann–Kendall test method is frequently used globally to analyze trends, (Deumich, *et. al.*, 2020; Wang, *et. al.*, 2020; Mallick, *et. al.*, 2021; Pandey, *et. al.*, 2024; Muia, *et. al.*, 2024). That is, it is applied in testing for a decreasing or increasing trend in long-term temporal data, (Mallick *et. al.*, 2021) and is expressed as, (Kendall, M. G., 1975):

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

where n = number of data points, X_j and X_i = annual values in years j and i ; $j > i$

The sign ($X_j - X_i$) is calculated from:

$$\text{sign } (X_j - X_i) = \begin{cases} -1 & \text{for } (X_j - X_i) < 0 \\ 0 & \text{for } (X_j - X_i) = 0 \\ +1 & \text{for } (X_j - X_i) > 0 \end{cases} \quad \text{Equation 2}$$

The sign ($X_j - X_i$) simply implies the individual sign capability which takes on the values of +1, 0, or -1. A positive S value shows an upward or increasing trend, while a negative value indicates a downward or decreasing trend. A value of zero (0) indicates no trend.

The variance of the data is calculated in order to establish the probability of the Z value. In other words, when n is greater than 8, statistic S approximates to normal distribution and the mean of S is 0 while the variance of S can be computed as:

$$\text{Variance } (\text{Var } (S)) = \frac{(n(n-1))(2n+5)}{18} \quad \text{Equation 3}$$

where n is the number of data points.

The values of S and Variance, $\text{Var } (S)$ are used to compute the test statistics, Z which is obtained from the equation below:

$$Z = \begin{cases} \frac{S - 1}{\sqrt{\text{Var}(S)}}; & \text{if } S > 0 \\ 0; & \text{if } S = 0 \\ \frac{S + 1}{\sqrt{\text{Var}(S)}}; & \text{if } S < 0 \end{cases} \quad \text{Equation 4}$$

where S is the sign or the sum of the signs of all possible differences between later and earlier data points.

A value of $Z > 0$ indicates an increasing trend, while a value of $Z < 0$ gives a decreasing trend. Given a confidence level α , the sequential data would be supposed to experience statistically significant trend if $|Z| > Z(1-\alpha/2)$, where $Z(1-\alpha/2)$ is the corresponding value of $P = \alpha/2$ following the standard normal distribution. In this study, 0.05 or 95 % confidence levels were used. If the p -value is below 0.05, the trend is statistically significant and if greater than or above, it is insignificant.

The test statistics, (Kendall's tau) τ is obtained from the equation below:

$$\tau = \frac{S}{\frac{n(n-1)}{2}} \quad \text{Equation 5}$$

where n = number of data points and S is the sign. The tau shows the strength and direction of the trend. It has a range of -1 to +1 which is analogous to the correlation coefficient in regression analysis. That is, the Kendall's tau, τ is a correlation coefficient ranging between -1 (strong downward trend) and +1 (strong upward trend).

Sen's slope estimator

The Sen's slope estimator is used to calculate the magnitude of trends in a long-term data, (Agarwal *et al.*, 2021). It is considered better to detect the linear relationship because it is not affected by outliers in the data, (Ray *et al.*, 2021). It is applied in this study to calculate the magnitude of the trend or the rate of change in the meteorological parameters under study and is expressed as:

$$Q_{ij} = \begin{cases} \frac{Y_j - Y_i}{j - i} & n = \text{odd} \\ \frac{1}{2} \left(Q \frac{N}{2} + \left(Q \frac{N+2}{2} \right) \right) & n = \text{even} \end{cases} \quad \text{Equation 6}$$

A positive value of Q_{ij} indicates an increasing trend, whereas a negative Q_{ij} shows a negative trend in the temporal data. The slope of the Sen estimator is the mean slope of such slopes' N values. The Sen's slope is:

$$\beta_1 = \text{median} \left(\frac{Y_j - Y_i}{X_j - X_i} \right) \quad \text{Equation 7}$$

where β_1 is the Sen's slope estimate; $i < j$ and $i = 1, 2, \dots, n-1$ and $j = 2, 3, \dots, n$; Y_j and Y_i are data values at time j and i respectively. In other words, computing the slope for all pairs of data that were used to compute S . The median of those slopes gives the Sen's slope estimator and it has the unit of slope magnitude per year.

Also, individual slopes, (Q_i) can be estimated by use of the following equation:

$$Q_{ji} = \frac{Y_j - Y_i}{j - i}; (j > i) \quad \text{Equation 8}$$

where $i = 1$ to $n - 1$ and $j = 2$ to n and Y_j and Y_i are data values at time j and i ($j > i$) respectively.

If there are N values of Y_j in time series, estimates of the slope will be:

$$N = \frac{n(n-2)}{2} \quad \text{Equation 9}$$

where n is the number of data points.

Linear regression analysis

Linear regression analysis is one of the parametric models used in detecting pattern in data series. This is achieved by fitting a linear equation to the data observed. Linear regression establishes a relationship between two variables, the dependent and independent variables. Correlation coefficient ranges from -1 to $+1$ and a value of ± 1 indicates perfect match. A value close to zero shows that the variables have a random, non-linear relation. The equation of linear regression model is generally expressed as:

$$Y = mX + C \quad \text{Equation 10}$$

where Y is the dependent variable (parameter values) and X , the independent variable (time in years), m is the slope and C is the intercept constant coefficient.

The coefficients (m and C) of the modal are determined using the Least-Squares method, which is the most commonly used method. The sign of the slope defines the trend variable direction – a positive value indicates an increasing trend while a negative indicates a decreasing trend, (Aswad, *et. al.*, 2020).

The regression analysis was used to establish a linear regression regarding time between the observed data results.

Coefficient of variation

The coefficient of variation (CV) is a measure of variability that indicates the size of a standard deviation in relation to its mean. It compares the size of standard deviation to the mean of variables. It is a standardized, unit-less measure that allows the comparison of variability between disparate groups and characteristics. It is expressed as (Statistics by Jim, 2019):

$$Cv = \frac{\delta}{\mu} \quad \text{Equation 11}$$

where δ is the standard deviation and μ , the mean.

A CV value below 0.1 (10 %) indicates low variability while that above 0.9 (90 %) shows high variability. A value of $CV \leq 0.4$ (40 %) shows stable climate after which it becomes unstable.

III. Results

The results obtained for trend analysis are given below: The Man-Kendall test for temperature from 1971 – 2020 in Sokoto was calculated using Equations 1 – 5 and the results are given on Table 1 while the Sen's slope estimator was obtained using Equations 6 – 9 and the results are also presented on Table 1.

The coefficient of variation, CV was calculated using Equation 11 and is presented on Table 1.

Table 2 is the result of monthly average temperature per decade while Table 3 gives the average annual temperature per decade.

Figures 2 – 7 gives the graphical presentation of temperature for the five (5) decades with the Sen's slope (in red) showing the trend line and the linear regression equation and R-squared value expressed on the top-right corner of the figures respectively.

Table I: Man-Kendall, Sen's slope and CV

S/N	Parameter	Year	Tau (τ)	P-value	Z-score	Sen slope (per year)	CV (%)
1	Temperature	1971 – 2020	0.44	0.0000768	1.95	0.022 °C	1.4

Table I presents Man-Kendall's tau = 0.44, p-value = 7.68×10^{-5} (<0.05 ; significant); Sen's slope estimator = 0.022 °C per year (a significantly increasing trend) and the CV of 1.4 %. The above values indicate an increase in temperature over the past five decades which is statistically significant ($p = 0.0000768$) and approximates to about 1.34 °C increase over the five decades.

Table II: Monthly decadal averages (°C)

Decade	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
1971 – 1980	26.6	29.7	33.4	34.9	34.7	33.0	29.2	28.9	27.0	30.3	30.4	29.4	30.7
1981 – 1990	26.9	30.3	33.8	35.4	35.2	33.8	29.5	29.3	27.4	30.8	30.5	30.2	31.1
1991 – 2000	27.0	30.3	35.6	35.3	33.3	30.8	27.3	30.2	35.6	29.4	29.0	30.9	31.2
2001 – 2010	27.5	31.2	34.1	35.8	35.6	34.0	29.9	29.4	28.1	31.4	31.3	30.6	31.6
2011 – 2020	27.9	31.6	34.4	35.9	35.9	34.2	29.9	29.6	27.8	31.3	31.4	30.4	31.7
Average	27.2	30.6	34.3	35.5	34.9	33.2	29.2	29.5	29.2	30.6	30.5	30.3	31.2

Table II above provides the average monthly temperature between 1971 and 2020. Each row shows the average monthly temperatures for each month of the year per decade. The last row shows the average monthly temperature per month per decade.

It can be observed from row five for instance that, between 2011 and 2020, the average minimum temperature in January was 27.9 °C while that in December was 30.4 °C and the average monthly temperature for the decade was 31.7 °C. The annual range of temperature has an 8.0 – 8.4 °C difference between warmest and coolest months.

Table III: Average decadal temperature and standard deviation

Decade	Mean annual temperature (°C)	Average	Standard deviation
1971 – 1980	30.7	30.7	2.8
1981 – 1990	31.1	31.1	3.0
1991 – 2000	31.2	31.2	2.9
2001 – 2010	31.6	31.6	2.8
2011 – 2020	31.7	31.7	2.9

The result (Table II) also shows that the mean annual average temperature throughout the period was 31.2 °C. The minimum temperature for the period under study was 26.2 °C which occurred in January between 1971 and 1980 while the maximum temperature was 35.9 °C and this was in April/May between 2011 and 2020. The mean standard deviation of 2.92 °C shows a low inter-annual variability and the CV value of 1.4% indicated a very stable warming trend throughout the period of study.

The warmest months in Sokoto occurred between March and May. That is, they have the strongest warming signals with monthly averages often $>33^{\circ}\text{C}$. More moderate warming trends are displayed from late June – August and December – February while the coolest months occur between July and September with monthly averages $\sim 27.0 - 29.6^{\circ}\text{C}$.

Table III gives the average decadal temperature and the standard deviation and from it, it can be observed that the period between 2011 and 2020 had the highest warming trend (31.7°C). It also shows that each decade was warmer than the last with the largest warming occurring after 2000. That is, each decade experiences a warming trend than the last. For instance, average decadal temperature increased from 31.2°C between 1991 and 2000 to 31.6°C between 2001 and 2010. This portrays a steady stable increase after the 2000s as shown by a CV of 1.4 % in Table I.

Most months show warming trends. The strongest warming trends were in April with $+0.0298^{\circ}\text{C}$ per year (amounts to $+1.49^{\circ}\text{C}$), May with $+0.0312^{\circ}\text{C}$ per year (amounts to $+1.56^{\circ}\text{C}$ over 50 years period and October with $+0.0276^{\circ}\text{C}$ per year ($\approx 1.38^{\circ}\text{C}$) over 50 years period. On the other hand, some months show more moderate warming, for instance October, November and December.

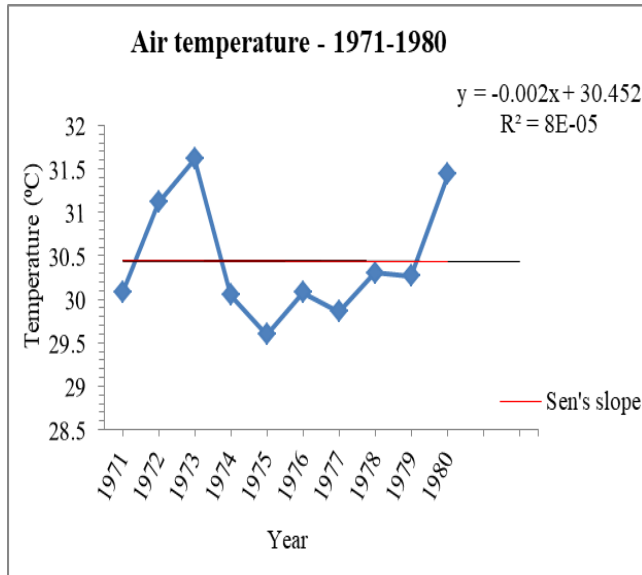


Fig. 2: Temperature in Sokoto – 1971 - 1980

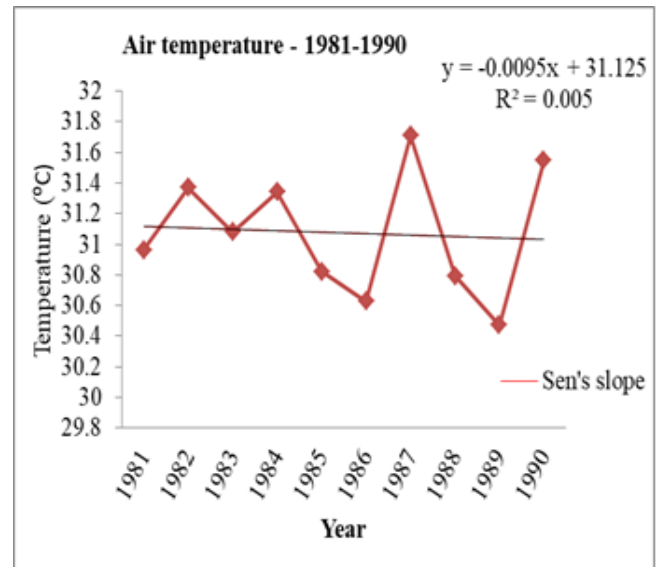


Fig. 3: Temperature in Sokoto – 1981 - 1990

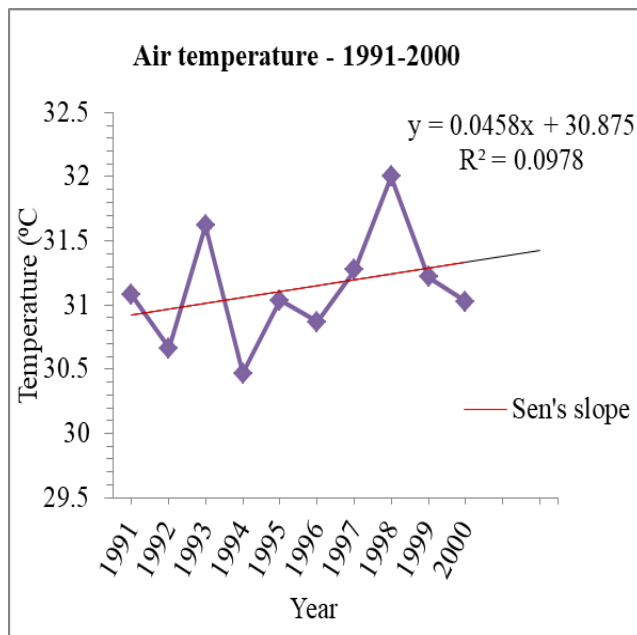


Fig. 4: Temperature in Sokoto – 1991 - 2000

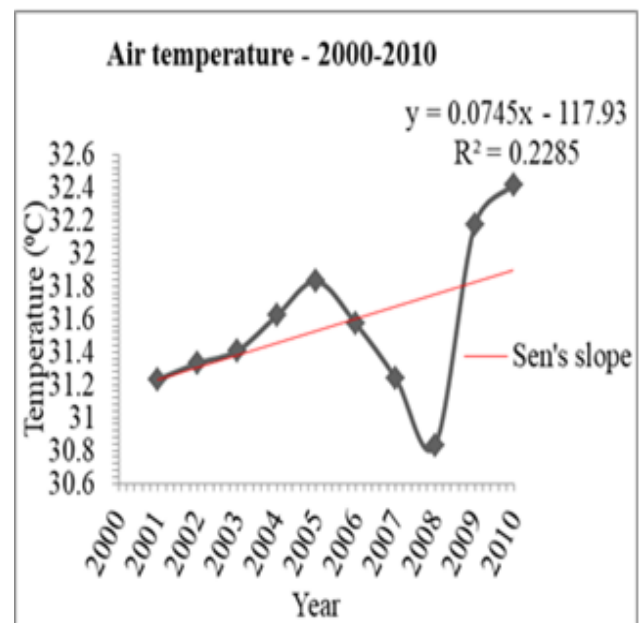


Fig. 5: Temperature in Sokoto – 2001 - 2010

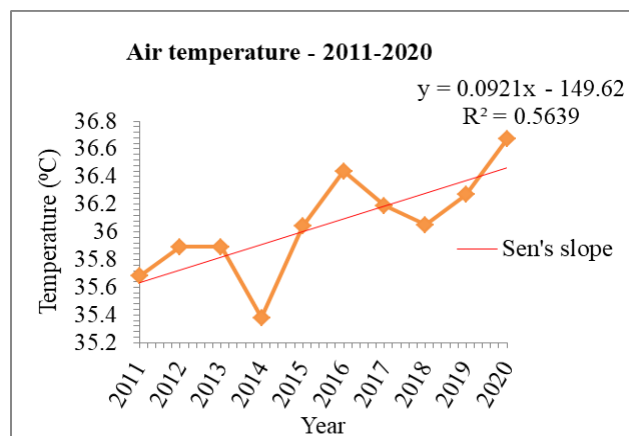


Fig. 6: Temperature in Sokoto – 2011 - 2020

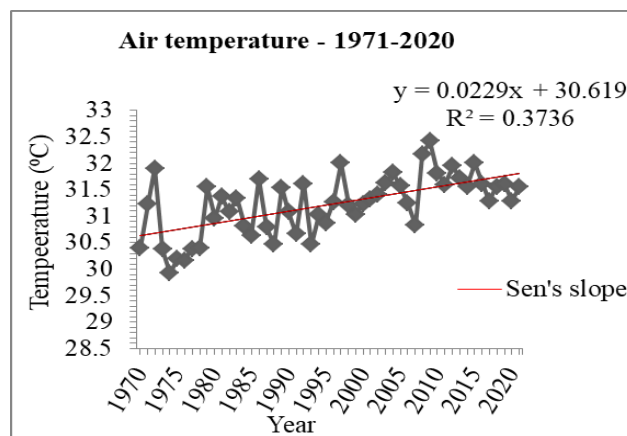


Fig. 7: Temperature in Sokoto – 1971 - 2020

IV. Discussion

Analysis of temperature data for Sokoto between 1971 and 2020 shows an increased rate at 0.022 °C per year. This increase aligns with regional and global patterns on a broader scale.

Fig. 1 is a map of Sokoto state showing Sokoto metropolis and other towns.

Fig. 2 shows the variation in temperature between 1971 and 1980. Here, 1972, 1973 and 1980 had the highest temperatures in the decade. The annual average temperature of the decade is 30.7 °C. This period, (1971-1980) in Sokoto was categorized as a drought decade as it faced a significant drought typical of the Sahel region which extended through the 1980s. Between 1970 and 1974, a Sahelian drought struck northern Nigeria as reported by Adamu, A., and Ma'aruf M., (2019) and Sokoto was not left out.

Fig. 3 shows the temperature between 1981 and 1990 in Sokoto. The decadal mean annual temperature is 31.1 °C. It shows that 1982, 1984, 1987 and 1990 had highest temperatures. 1987 was the driest year with the highest temperature and it came with experiences of both moderate and severe drought of 37.5 % and 62.5 % respectively. Locally between 1983 and 1987, there was extreme dryness and livestock loss as well as declining vegetation and socio-economic impacts. The decade was classified as a drought-dominated decade and was significant in terms of severity and persistence with drought covering about 63 % of Sokoto, (Fabeku, B. B and Okogbue, E. C. 2014).

From Fig. 4 is the temperature between 1981 and 1990. Here 1991, 1993, 1997 and 1998 had highest temperatures and the decadal mean annual temperature is 31.2 °C, indicating a gradual increase in mean temperature compared to previous decades. The period, 1991 - 2000 marked a transition from drought-dominated years to a hotter, wetter phase as the world experienced a shift in global and regional climate. This reveals the occurrence of more hot days and longer hot seasons extending beyond traditional dry periods and weather variability even as full-scale heat waves were rare. Also, this shows that Sokoto began experiencing early climate warming impacts from 1991 – 2000 and the decade was a pivotal transition period, thereby setting the stage for more climate impacts in the 2000s and beyond. Collins *et. al.*, (2011) reported that there has been a significant increasing trend in temperature for Africa, including the Northern Hemisphere Africa, Southern Hemisphere Africa, tropical and subtropical Africa.

Fig. 5 is a display of temperature between 2001 and 2010. It is very clear with the sharp increase as seen from the plot (Sen's slope line in red). The decadal mean annual temperature is 31.6 °C which is a very sharp increase from previous decades. This period witnessed a sharp increasing temperature (Figure 5) suggesting a more intense hot weather including heat waves and elevated temperature and warming trend more than past decades as shown on the figure. April – May were the hottest months. The sharp increase can lead to lengthening of the hot season and can be attributed to influences of climate change and anthropogenic factors as confirmed by an IPCC report which stated that there has been a detectable rise in global temperature since the beginning of the industrial period and an acceleration of warming since 1975. The mean global surface temperature has increased by about 1°C during the last century and has been more significant in the last 25 years, (IPCC, 2007).

Olusegun, *et. al.*, (2014) reported that Sokoto's minimum night time temperature increased at roughly 0.37 °C per decade from 1951 – 2010 and this trend continued into the 2010 – 2020 period. A study by Fabeku, B. B. and Okogbue, E. C. (2014) reported that the period between 1991 and 2000 in Sokoto was a drought-free period.

The trend in temperature between 2011 and 2020 is shown in Fig. 6. The decade had a mean temperature of 31.7 °C and this was the highest among the five decades. This indicates that temperature in Sokoto metropolis was on the increase.

A study by (Ogunjobi, *et. al.*, 2018) reported that a satellite data indicates that Land Surface Temperature, LST in Sokoto rose from approximately 36.9 °C in 1999 to ~38.6 °C in 2016 with a mean temperature in urban areas reaching 34.6 °C. Agidi, *et. al.*, (2021) also reported that there is an upward trend in temperature across ten stations in Nigeria including Calabar, Ikeja, Yelwa, Yola, Lokoja, Oshogbo, Minna, Zaria, Sokoto, and Maiduguri. A study by Xu *et al.*, (2017) showed that there has been an increase in temperature of 0.3 °C per decade in most areas in north China and between 0.1 and 0.3 °C per decade in most areas of south China. In the same vein, a positive trend in variations of temperature from 0.09 °C to 0.38 °C per decade over most part of Iran between 1961 and 2010 was reported by Ahmad (2010). The IPCC (Intergovernmental Panel on Climate Change) Climate Change 2014 Synthesis Report shows that the global mean temperature has increased at about 0.85 ± 0.2 °C from 1880 (IPCC, 2014). Similarly, Ragatao *et. al.*, (2018) found out that the general trend of minimum and maximum temperature in Nigeria is on the increase.

Fig. 7 is the overall temperature trend for the period between 1971 and 2020. It shows an increasing trend over five decades. This indicates a continuous steady rise in temperature in Sokoto metropolis and a clear indication of climate change in the metropolis which could bring about the urban heat island (UHI) effect - where urban areas experience significantly warmer temperatures than surrounding rural areas, especially at night.

Implications of the study

The analysis reveals a statistically significant increasing trend in average annual temperature in Sokoto over a 50-year period. This warming trend is consistent and accelerating and this indicates a clear signal of climate change and comes with implications as follows:

Agriculture

Agriculturally, higher temperatures can affect crop yields and alter growing seasons. It can also increase evapotranspiration rates, thereby leading to water stress for plants. It may also lead to increased crop water demand which may affect potential yield reductions for temperature-sensitive crops. Therefore, there should be adaptation and a shift to heat-tolerant and drought-resistant crop varieties and planting dates should be adjusted to avoid peak heat periods. Irrigation efficiency should be enhanced and water conservation practices promoted and upgraded as increasing temperatures may lead to higher evaporation rates and reduce water availability for irrigation and consumption.

Health

The continuous rise in temperatures can exacerbate heat-related illnesses like heat stroke, heat exhaustion, etc and affect the spread of vector-borne diseases such as malaria, etc. Therefore, there should be constant public awareness campaigns on heat stress prevention; healthcare systems should be strengthened to handle heat-related illnesses, and urban greening practiced to reduce urban heat island effects.

Energy production/demand

Due to increasing temperatures and subsequently increased solar radiation, emphasis should be laid on investment in renewable energy vis-a-vis solar power projects for increased solar energy production. Higher temperatures come with higher heat stress. Hence, there will be higher energy demand for heat cooling like air conditioning, refrigeration, etc. due to clear, hot days.

Urban design/planning

Urban design and planning should focus on planning and designing of buildings for passive cooling and heat mitigation. Increased green spaces/shading should be emphasized as this helps reduce evapotranspiration. Tall buildings and narrow streets should be reduced within the metropolis as these create urban canyons which trap heat and reduce airflow, thus amplifying warming.

Limitations

This study investigates and analyses the trends in temperature in Sokoto metropolis between 1971 and 2020 (50 years). Limitations are that there may be inconsistencies in weather reporting. That is, there may be differences in weather reports from different stations or they may use different methods for data collection and this may pose a challenge for comparing and aggregation of results. Another limitation is in the area of instrument calibration and errors. In other words, instruments used in measuring parameters such as humidity, temperature, and pressure can suffer from calibration issues, drift over time, or physical damage. These may lead to inaccurate readings.

V. Conclusion

This study has presented the trend analysis of mean annual temperature in Sokoto metropolis between 1971 and 2020 (50 years) using Man-Kendall and Sen's slope estimator. The results have shown that there has been an increase in temperature in the Metropolis over the past five decades and that each decade is warmer than the last with the largest warming occurring after 2000, (Table 3).

The result also showed that the mean annual average temperature throughout the period was 31.2 °C. The minimum temperature for the period under study was 26.6 °C which occurred in January (1971-1980) while the maximum temperature was 35.9 °C occurring in April and May (2011-2020) and that there is low inter-annual variability with mean standard deviation of 2.92 °C and a CV value of 1.4% indicating a very stable warming trend throughout the period of study.

The statistical analysis clearly demonstrates a significant warming trend over the past five decades. This information should inform proactive planning and management decisions by stakeholders to address both current impacts and future challenges associated with continued warming.

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