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Anomalies and Trend Analysis of Temperature and Rainfall in Maiduguri, Borno State, Nigeria

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Abstract

This study examines the anomalies and trends of climatic variables (rainfall and temperature). The data were sourced from the Nigerian Meteorological Agency from 1974 – 2014. The data was subjected to normality tests; Rainfall Anomaly Index, Standardized Anomaly Index, Linear times series, and descriptive statistics. The results revealed that the Rainfall Anomaly Index indicates humid characteristics, there are more years of positive than negative anomalies for both rainfall and temperature. The trend of annual rainfall and mean temperature indicates an increasing pattern at the rate of 0.0361mm year^{-1}and 0.0248 ^{o}C year^{-1}respectively. There is no significant difference between maximum and minimum temperatures. The highest temperatures were recorded between April and May and the maximum rainfall was recorded between June and August. The trend of monthly rainfall indicates increasing trends except for April which revealed a decreasing trend at the rate of -0.25mm year^{-1} The study concludes that the rates of increase of rainfall series vary from one month to another, the month of July has the highest rate 2.14mm year^{-1} of increase for rainfall series during the study period. The study recommends that flood coping strategies should be adopted and also encourage urban tree planting to sequester carbon dioxide.

Keywords: Anomaly, Rate, Trend, Rainfall, Temperature

INTRODUCTION

The contemporary changes in the patterns of rainfall and air temperature are attributed to anthropogenic activities such as deforestation, burning fossil fuel, agriculture, and urbanization. The changes in patterns of climatic variables vary from one location to another depending on the prevailing circumstances. Some regions were experiencing increasing trends while others were experiencing declining trends of climatic variables. From the global perspective temperatures are increasing while rainfall is decreasing Intergovernmental Panel

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Climate Change IPCC (2007). Vinnikov and Grody(2003), observed an increasing temperature between 0.13°C and 0.22°C per decade in the lower troposphere. Hasanean (2001) observed positive and negative trends in air temperature in the east Mediterranean. There is an overall increase in temperature throughout the African continent with an approximate rate of 0.7^{o}C during the 20th century IPCC, (2007). Hulme *et al.*, (2001) the increased rainfall in the African continent is a result of warming conditions which may be associated with the changing climate.

The temporal air temperature trend in Nigeria has been increasing since 1983Aiyelokum (2016), air temperature has steadily increased in Nigeria, especially since the 1970s Odjugo (2010) and Ayuba (2007) noted increasing Temperature at the rate of 0.2^{o}C-0.3^{o}C per decade. Evidence from 28 meteorological stations proved that rainfall is declining Adefolalu (1986) and on the contrary, precipitation increases by about 2-3% for each degree of global warming in NigeriaAyuba (2007). Abaje, Sunday, Bello and Oyatayo (2023) revealed that the North-East region of Nigeria has been experiencing increasing wetness in recent years which is a result of the changing climate. Bello, Adebayo, and Bashir (2020) observed a significant increase in temperature in Gombe state. The anomalies of rainfall and temperature have been fluctuating over the years and in different locations. Liberty and Bello (2022) notice more years of positive anomalies than negative anomalies of rainfall and a few years of positive anomalies than negative anomalies of temperature in Dutsin-Ma.

In Maiduguri, there has been an uncertainty in the behavior of climatic variables over the years. These are attributed to increasing incidence of thermal discomfort, rapid loss of surface moisture leading to aridity, possible decline in arable land, and increased incidence of urban flood in Maiduguri. It is on this background that this study seeks to assess the behaviors of active climatic variables such as rainfall and temperature.

STUDY AREA

Maiduguri is the capital of Borno State, it is located between longitude 11° 46´ to 11° 54´ North and latitude 13° 06´ to 13° 14´ East Figure 1. The relief is relatively flat with a vast undulating plain that slopes gently toward Lake Chad. It has an average altitude of about 300 meters above sea level. The climate is characterized by a long dry season ranging from October to May and a short wet season raging from June to September. According to Waziri (2012), the mean monthly temperature for Maiduguri is above 20° C but the daily extremes vary in a wide range reaching up to 47°C in April. The dominant ethnic group is Kanuri and other indigenous ethnic groups include; Babur Bura, Shuwa Arab, Mandara, and Marghi while the non –non-indigenous groups include Hausa, Igbo, and Yoruba.

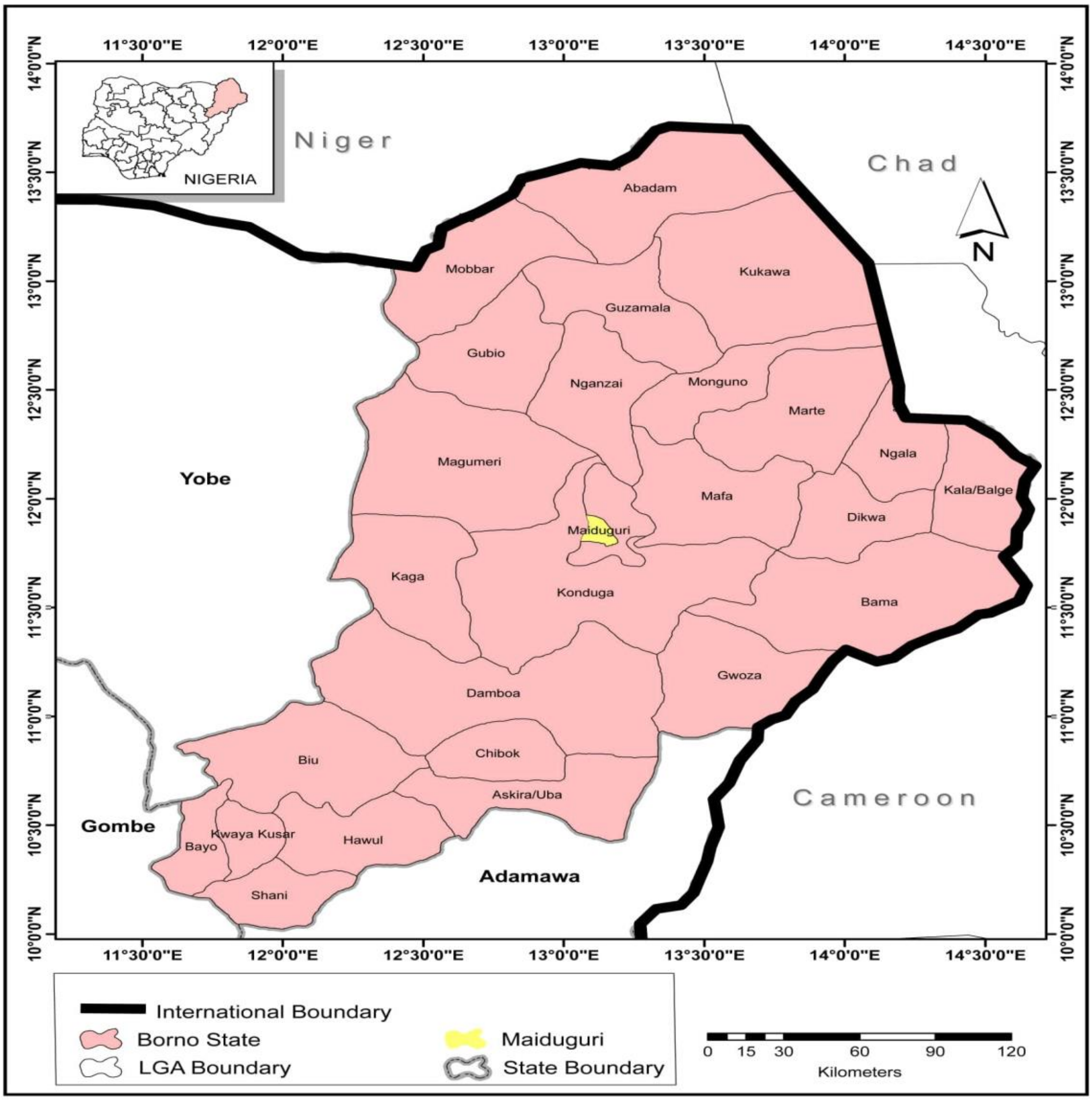

Figure 1: Study Area
Source: Borno State Ministry of Land and Survey

METHODOLOGY

The climatic data of temperature and rainfall were sourced from the Nigerian Meteorological Agency (NiMet) station in Maiduguri for the period 1974 to 2014 (41 years). The data were subjected to a normality test using the standardized coefficients of Skewness (Z_1) and Kurtosis (Z_2) statistics. The standardized coefficient of Skewness (Z_1) was calculated as:

$$Z_1 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^{3}/_{N} \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^{2}/_{N} \right)^{3/2} \right] \Big/ \left(6/N\right)^{1/2} \text{ ....}(Eq1)$$

and the standardized coefficient of Kurtosis (Z_2) was calculated as:

$$Z_2 = \left[\left(\sum_{i=1}^{N} (x_i - \bar{x})^{4}/_{N} \right) \Big/ \left(\sum_{i=1}^{N} (x_i - \bar{x})^{2}/_{N} \right)^{2} \right] - 3 \Big/ \left(24/N\right)^{1/2} \text{ ....}(Eq2)$$

If the result of the normality test of Z_1 and Z_2 for rainfall and temperature were less than 1.96 the data will be used without any transformation.

Linear Trend line analysis was used to determine the changes like rainfall and temperature series. To identify changes within the trends of annual rainfall totals, monthly volumes of rainfall from April to October, maximum, minimum, and diurnal range temperature series were analyzed, the formula is as follows;

$$Y_t = a+ bt+e_t \text{ ………………………………(Eq 3)}$$

Where $Y_{t=}$ the amount of rainfall
a = intercept
b= slope, which measures the rate of change in rainfall with time **t**
$e_{t=}$ random error component

Spearman's rank order correlation was used to determine the relationship between the rainfalls total and the number of rainy days. It is computed as:

$$\text{rho} = 1 - \frac{6\sum d^2}{N\,(N^2-1)} \text{ ………………………………(Eq4)}$$

Five (5) year running was used to smoothen the series.
Standardized Anomaly Index (SAI) was used to determine the average index of relative rainfall yield in the station using the annual rainfall totals. The formula is as follows:

$$Z = \frac{X - \overline{X}}{S} \text{………………………………………………………}(Eq5)$$

Where;
X: annual volume of rainfall for each year
$\overline{X}$: mean
S: Standard Deviation.

This statistic will enable us to determine the dry with negative values (-) and wet with positive values (+) years within the study period.
The Rainfall Anomaly Index (RAI) was used to analyze the frequency and intensity of dry and rainy years in the study area. RAI was developed by Rooy (1965) and is given by the equation

$$RAI = 3[(P - \overline{P})/(\overline{M} - \overline{P})] \text{………………………………………}(Eq6)$$

for positive anomalies and

$$RAI = 3[(P - \overline{P})/(\overline{X} - \overline{P})] \text{………………………………………}(Eq7)$$

Where p is the actual rainfall, $\overline{P}$ is the long-term average rainfall, $\overline{M}$ is the mean of the ten highest values of p on record and $\overline{X}$ is the mean of the ten lowest values of p on record. The arbitrary threshold values of +3 and – 3 have been assigned to the mean of the ten most extreme positive and negative anomalies respectively.

Table 1: Classification Table of Rainfall Anomaly Index (RAI)

	RAI Range	Classification
	Above 4	Extremely Humid
	2 to 4	Very Humid
Rainfall Anomaly Index (RAI)	0-2	Humid
	-2 to 0	Dry
	-4 to -2	Very Dry
	Below - 4	Extremely Dry

Source: Rooy (1965)

RESULTS AND DISCUSSION

The result of the normality test of Z_1 and Z_2 of rainfall was less than 1.96 therefore, the data was used without transformation while for temperature was more than 1.96 therefore the data was transformed before subjecting it to further analysis. The statistics for rainfall and temperature for the study period are presented in Table 2. The mean rainfall received during the study period was 569.9 mm, and the minimum and maximum volume of rainfall were 241.0mm and 924.1mm respectively. The Skewness and Kurtosis for rainfall were -0.001mm and -0.233mm respectively. The mean temperature for the study period was 24.92^{o}C, the maximum mean temperature and the maximum mean temperature were 20.20^{o}C and 26.75^{o}C respectively.

Table 2: Annual Statistics for Climatic Variables

Statistics	Rainfall Total (mm)	Mean Temperature (^{o}C)
Mean	569.9	24.92
Std. Deviation	157.6	1.119
Skewness	-.001	-2.671
Kurtosis	-.233	9.097
Minimum	241.0	20.20
Maximum	924.1	26.75

Anomalies and Trends of Temperature

The anomalies of rainfall are presented in Figure 2. There were 24 years of positive temperature anomalies and 17 years of negative temperature anomalies. These results did not agree with the findings of Liberty and Bello (2022) that temperature has a few years of positive anomaly and more years of negative anomalies in Dutsin-Ma. The pattern started with negative anomalies of -0.238 ^{o}C in 1974 and ended with negative anomalies of -0.061 ^{o}C in 2014. The maximum negative anomaly of -4.17 ^{o}C was recorded in 1979 while the maximum positive anomaly of 1.61^{o}C was recorded in 1981. There is a series of positive anomalyfrom 1998 – 2004. The mean annual temperature indicates an increasing trend at the rate of 0.024 ^{o}C and the coefficient of variation is 8.9%.

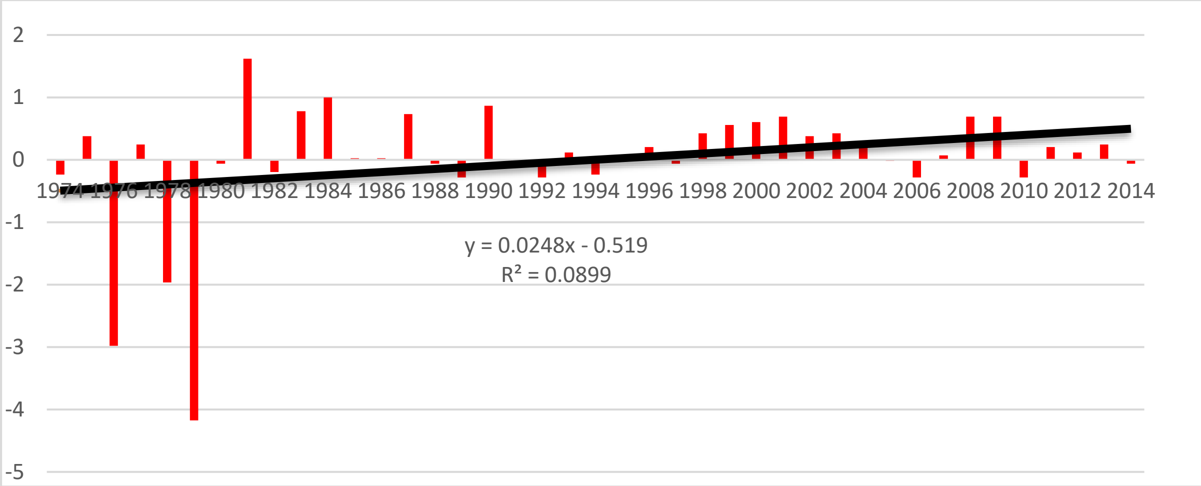

Figure 2:Temperature Anomalies

Results presented in Table 3 revealed trends of diurnal temperature, maximum temperature, and minimum temperature which show an increasing pattern at different rates. This finding is in line with Mayomi, Andrew, and Bello (2023) that, the temperature is increasing in Nafada and Shongom in Gombe state. Among the three (3) trends, maximum temperature has the highest rate of increase.

Table 3: Temperature Trends

Variable	Trend	R^2	Interpretation
Diurnal Temperature	Y= 0.0118x + 14.609	2.03	Diurnal temperature increases by 0.0118 °C at every annual increase and contributes 2.03% to the variation in diurnal temperature.
Maximum Temperature	Y= 0.0443x + 34.065	15.3	Maximum temperature increases by 0.0443 °C per year contributing 15.3% to the variation in maximum temperature.
Minimum Temperature	Y= 0.0332x + 19.46	24.5	Minimum temperature increases by 0.0332 °C per year contributing 24.5% to the variation in minimum temperature.

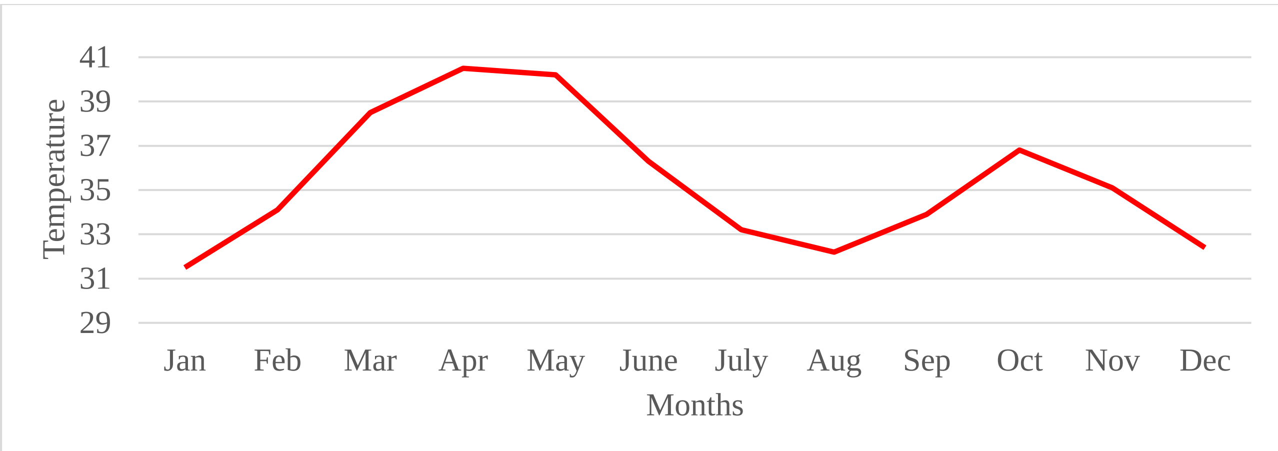

Figure 3: Temperature Pattern in Maiduguri

The pattern of temperature for Maiduguri is presented in Figure 3. The pattern indicates that the lowest peak temperature was recorded in January while the highest peak temperature was recorded in April. The higher temperatures were recorded during the Hot Dry Season (HDS) in March, April, and May, this high temperatures were the result of the absence of cloud cover during the period. Lower temperatures were during Warm Hot Season (WHS) and Cold Dry Season (CDS). During WHS in July, August, and September the temperatures were as a result of too much cloud cover during the wet season. During CDS the temperature drops due to excessive dust caused by the Harmattan winds in November, December, and January.

Annual Anomalies and Trends of MonthlyRainfall
The result from Rooy's (1965) RAI of the rainfall series is 1.119mm, This result revealed that the rainfall classification of Maiduguri is; Humid Table 1. Despite the situation in Maiduguri and its envious does not resemble humid, but the behavior of the metrological station shows humid-like characteristics.

The anomalies of rainfall are presented in Figure 4. The positive values represent rainy or we years and the negative values represent dry years with different degrees of intensity. The pattern began with negative variability in 1974 and 1975 then positive in 1976 and another drop in 1977 with two years of positive rise in 1978 and 1979. Another seven years drop from 1980 to 1987. From year 2007 – 2013 show seven years of positive anomalies. The maximum positive anomaly of 2.24mm was observed in the year 2007 and the maximum negative of -2.08mm was observed in 1982. The occurrence of 22 years of positive SAI and 18 years of negative SAI, implies that there are more years of positive anomalies than negative anomalies. This result does not agree with the findings of Bello, Msheliza, and Abaje (2020), who reported more years of negative anomalies than positive anomalies but agrees with Liberty and Bello (2022), who revealed more years of positive anomalies than negative anomalies.

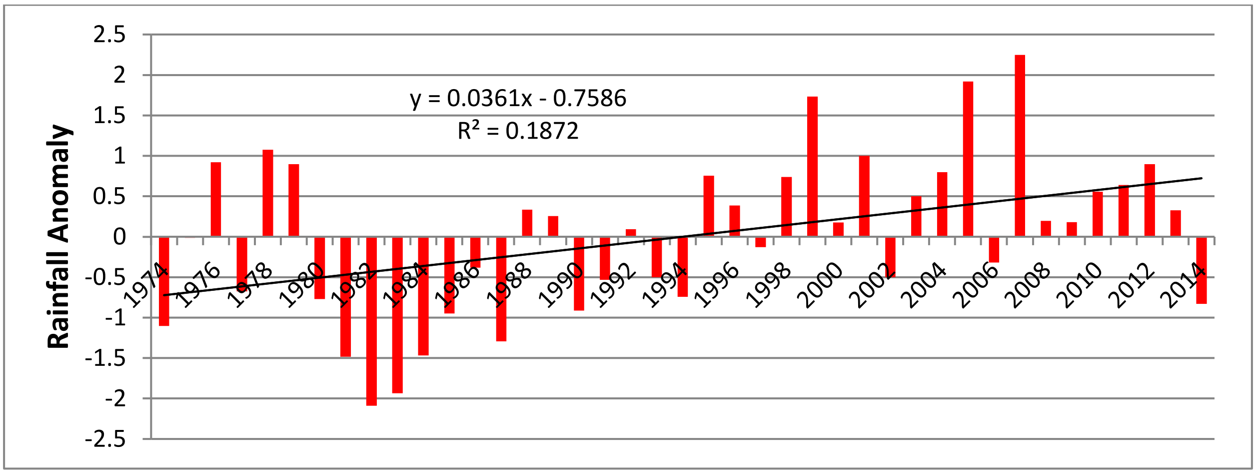

Figure 4: Rainfall Anomaly for Maiduguri

The inter-annual variability of rainfall anomalies from year to year in Maiduguri reveals that the coefficient of variation is 18.7% with an increasing rate of 0.036mm for every annual increase 4. The result of the present studies relates to the findings of Abaje, Achiebo, and Matazu (2018) who reported an increasing trend of annual rainfall yield in Kaduna state. The implication of this increasing pattern of rainfall is the occurrence of more urban floods which Maiduguri is experiencing today.

Table 4: Trends of Monthly Rainfall

Months	Rainfall Trend	R^2	Interpretation
April	Y= - 0.2508x + 9.528	9.01	Rainfall decreases by -0.25mm year^{-1} and contributes 9.01% to the model.
May	Y= 0.1912x + 28.24	1.03	Rainfall increases by 0.191mm year^{-1} and contributes 1.03% to the variation in Rainfall.
June	Y= 1.3052x + 51.38	6.17	Rainfall increases by 1.305mm year^{-1} and contributes 6.17% to the variation in rainfall.
July	Y = 2.1417x +127.2	11.9	Rainfall increases by 2.1417mm year^{-1} and contributes 11.95% to the model.
August	Y= 0.9811x + 157.9	3.47	Rainfall increases by 0.9811mm year^{-1} and contributes 3.47% to the variation in rainfall.
September	Y = 1.1528x + 65.94	5.49	Rainfall increases by 1.1528mm year^{-1}and contributes 5.49% to the variation in rainfall.
October	Y = 0.1917x + 9.372	1.30	Rainfall increases by 0.1917mm year^{-1}and contributes 1.30% to the variation in rainfall.

The trends of monthly rainfall presented in Table 4 revealed that rainfall in April indicates a decreasing pattern at the rate of -0.25mm year^{-1} while the remaining months indicate an upward pattern with July having the highest rate of 2.1417mm for every annual increase. This result disagrees with the finding of Abashiya et al., (2017) reported decreasing rainfall in July and September while August has the highest increasing rate.

CONCLUSION

The study concludes that RAI for Maiduguri indicates a humid climate. There are more years of positive SAI than negative SAI for both rainfall and temperature during the study period. The trends of both annual rainfall totals and mean temperature indicate increasing patterns. The monthly rainfall patterns revealed an upward trend except for April which revealed a downward trend at a rate of -0.2508mm per year and an increase in July at the rate of 2.1417mm per year during the study period. The trends of the diurnal range temperature are the least at the rate of 0.0118 ^{o}C for every annual increase. The maximum picks of monthly temperature were in April and October.

Recommendation

The study made the following recommendations;

i. The Inhabitance of Maiduguri should develop a coping strategy in dealing with the increasing flood incidence due to the increasing volume of rainfall.
ii. More urban tree plantations should be encouraged to sequester the carbon in the environment and to create a conducive microclimate.
iii. Inhabitance are encouraged to use clean sources of energy.

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