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Assessing Four Decades of Climate Variability in Kano City, Nigeria Using ERA5 Data: Trends in Temperature, Pressure and Humidity

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ABSTRACT
In recent years, climate change studies have become prominent globally because of its negative impact on the socio-economic lives of the citizenry and the need to mitigate against it. Investigating the degree of climate change variability in an urban city such as Kano becomes imperative. This study investigated temperature, pressure, and humidity variability in Kano, Nigeria, using ERA5 reanalysis data (1980–2021), processed via empirical and statistical methods. Annual averages were 303.00 K (temperature), 42.59% RH (humidity), and 1002.74 hPa (pressure). Correlation coefficients revealed long-term trends: temperature increased significantly with positive R of 0.66, pressure rose moderately with R of +0.16 and humidity with R of −0.22. Monthly analysis identified August as the coldest (300.79 K, 27.1°C) and April as the hottest (308.14 K, 34.99°C). A 7-year interval analysis (2015–2021) highlighted accelerated warming (49% increase), alongside humidity (26%) and pressure (73%) rises, aligning with Standardized Anomaly Index trends confirming intensified climate variability. These results underscore a clear climate shift, with temperature anomalies dominating recent years. The findings emphasize urgent mitigation strategies, particularly green energy adoption, to address escalating climate risks in urban Kano. This study provides actionable insights for policymakers and urban planners to enhance climate resilience in semi-arid regions.

Keywords:
Climate change,
Kano City, Standardized Precipitation index,
Atmospheric parameter analysis,
ERA5 reanalysis Data

INTRODUCTION

Climate change remains a critical global issue, significantly affecting environmental sustainability, particularly in areas such as biodiversity loss, water resource depletion, and economic development through disruptions in agriculture and infrastructure. The increasing frequency and severity of extreme weather events, changes in precipitation patterns, and rising temperatures highlights the urgent need for detailed climate studies at both global and regional levels. While extensive research has been conducted on climate variability worldwide, localized studies are essential to understanding the specific climate dynamics of individual regions, enabling the development of targeted mitigation and adaptation strategies. For instance, research on the Sahel region (Epule *et al*., 2017), has highlighted how localized climate shifts directly impact agriculture, water resources, and socio-economic stability, emphasizing the importance of region-specific assessments.

Kano City, located in northern Nigeria, is characterized by a semi-arid climate, making it particularly vulnerable to fluctuations in temperature, rainfall, humidity, and atmospheric pressure. Given the city's dependence on rain-fed agriculture and the socio-economic consequences of climate-sensitive industries, understanding long-term climate variability is vital. Recent studies have deepened our understanding of climate variability in Kano State, Nigeria, highlighting its significant impact on agriculture and livelihoods. For instance, Mohammed et al. (2015) analyzed a century's worth of rainfall data in Kano, revealing notable variability in both the amount and duration of the rainy season. Their findings indicated periods of drought in the 1970s and 1980s, followed by improved moisture conditions in subsequent decades. This underscores the dynamic nature of the region's climate and its potential implications for water resource management and agricultural planning.

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In the agricultural sector, Bichi et al. (2023) investigated rice farmers' perceptions of climate change in Kura Local Government Area of Kano State. They found that farmers possess a strong awareness of climate change and its adverse effects on rice yields, prompting considerations of alternative crops and adaptation strategies. Similarly, a study focusing on Ajingi Local Government Area reported that declining rainfall and its uneven distribution have led groundnut farmers to contemplate switching to alternative crops like soybean to sustain their livelihoods. These studies highlight the adaptive challenges faced by farmers in response to climate variability.

Further research (Fitto et al., 2021), examined the impact of climate variability on staple grain crops in Wudil Local Government Area. The study concluded that rainfall variability significantly affects crop yields, emphasizing the need for water-saving technologies and improved soil water use efficiency to mitigate the adverse effects of changing rainfall patterns.

Despite these valuable insights, there remains a scarcity of comprehensive analyses focusing on the long-term trends of multiple climatic variables, such as temperature, rainfall, humidity, and atmospheric pressure, in Kano City specifically. Existing studies often concentrate on single variables or specific local government areas, leaving a gap in understanding the broader climatic dynamics of Kano City over extended periods.

This study aims to fill this gap by conducting a detailed evaluation of historical climate data spanning 42 years (1980 - 2021), assessing long-term trends, and exploring their implications for agriculture, water resources, and economic stability in Kano City. The research specifically examines changes in temperature, humidity and atmospheric pressure by identifying long-term trends that suggest shifts in climatic conditions. The study also explores the mean climate values at seven-year intervals, comparing these with Kano's long-term climatology to assess the consistency and magnitude of fluctuations. This interval-based approach helps identify and evaluate the progression of climate change over time, offering a clearer view of how specific climatic elements have evolved. The Standardized Anomaly Index (SAI) methodology is employed to quantify climate patterns at seven-year intervals, providing a systematic framework to assess climate anomalies and their potential impacts on the region.

This methodology, which involves breaking the period into seven-year intervals, allows for a more nuanced understanding of climate trends by highlighting variations within shorter time frames. This approach is grounded in existing literature on climate variability, which suggests that examining climate trends in intervals facilitates a more precise detection of shifts and anomalies, especially in regions like Kano where climate variability may not be immediately apparent when assessed over longer periods.

MATERIALS AND METHODS

Study Area

This study was carried out in the city of Kano in Kano state Nigeria. It was formed in 1986 from Kano province, and in 1991 its northern-eastern portion was split off to form Jigawa state. It is bordered by the states of Jigawa to the north and east, Bauchi to the south-east, Kaduna to the southwest, and Katsina to the northwest. Kano consists of wooded savanna in the south scrub and vegetation in the north Awala-Hadejia river system. The state light sandy soils are excellent for growing peanuts (groundnuts), a major export. Other crops include cotton, onions, tobacco, wheat, and gum Arabic. Figure 1 illustrates the spatial distribution of population density across various districts of Kano City, highlighting densely populated clusters which may influence local climate variability and urban microclimates.

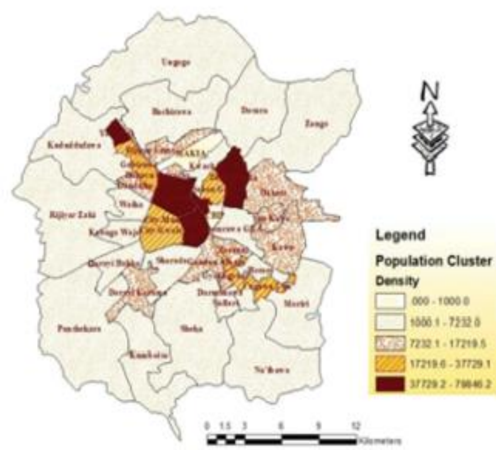


Figure 1: Population Cluster Density Distribution across Kano City (Ngwa, 2021)

Climatology of Kano

Kano city is located at an elevation of 468.5 meters (1537.07 feet) above sea level, Kano has a subtropical steppe climate. The city’s yearly temperature of 30.75ºC (87.35ºF) and it is 1.29% higher than Nigeria’s averages. Kano typically receives about 49.8 millimeters (1.96 inches) of precipitation and has 62.99 rainy days (17.2% of the time) annually. Kano city has an annual high temperature of 36.33ºC (97.39ºF), annual low temperature of 22.52ºC (72.54ºF), average annual precipitation of 49.8mm (1.96in). The city has the warmest month of April at temperature of 41.63ºC (106.93ºF). Coldest month of January with the temperature of 14.62ºC (58.32ºF), wettest month of August 272.2mm (10.72in), and relative humidity of 32.66%. The wet season occurs from Aprill to August with the highest rainfall amount in the month of August, while the dry season is from the month of November to

April. The intensity of rainfall is high in July and August, from about 60 mm to 99mm hour (Abaje *et al*., 2014).

Data Source

The data used in this study were obtained from the ERA5 reanalysis dataset provided by the European Centre for Medium-Range Weather Forecasts (ECMWF). ECMWF focuses on global climate monitoring and supplies high-resolution atmospheric data essential for climate research (Akinbolati and Abe, 2025; Sabiru *et al*., 2024)

Data Sorting and Processing

Following data acquisition, several sorting and organization techniques were applied to ensure effective analysis. These included time-based and variable-based sorting, data categorization, and visualization methods. These steps helped structure the data for subsequent statistical evaluation. To assess climate variability over the 42-year period, a combination of empirical and statistical tools was employed.

Statistical Analysis

Basic descriptive statistics, such as the mean, median, standard deviation, and range, were used to summarize the behavior of key atmospheric variables. These measures provided a foundational understanding of the data distribution and variability across the study period.

The Karl Pearson's Product Moment Correlation Coefficient good for continuous data analysis was conducted to evaluate the relationship among climatic variables over time. This helped reveal how the interactions between variables evolved throughout the 42-year period over Kano.

Standardized Anomaly Index (SAI)

To further assess climate variability, the Standardized Anomaly Index (SAI) was applied. SAI is a statistical metric (WMO, 2012; Hadgu *et al*., 2013) used to measure deviations of meteorological parameters such as rainfall and temperature from their long-term averages. It is particularly effective for identifying periods of anomalous wet or dry conditions. SAI operates on the assumption of a single gamma distribution and is calculated using the following formula:

$$SAI = \frac{(\chi - \mu)}{\delta} \quad (1)$$

Where: χ is the individual atmospheric variable, μ is the long-term mean, and δ is the standard deviation. The standard deviation is derived as (WMO, 2012; Hadgu et al., 2013):

$$\delta = \sqrt{Variance\ Deviation} \quad (2)$$

where:

$$\text{Variance Deviation} = \left(\frac{x - \mu}{n}\right)^2 \quad (3)$$

This method allowed for the classification of years as anomalously wet or dry based on their SAI values and provided insight into the magnitude and frequency of climatic anomalies over Kano (Table 1).

Table 1: Classification of Climate Conditions Based on Standardized Anomaly Index (SAI) Values (WMO, 2012, Hadgu, *et al.,* 2013).

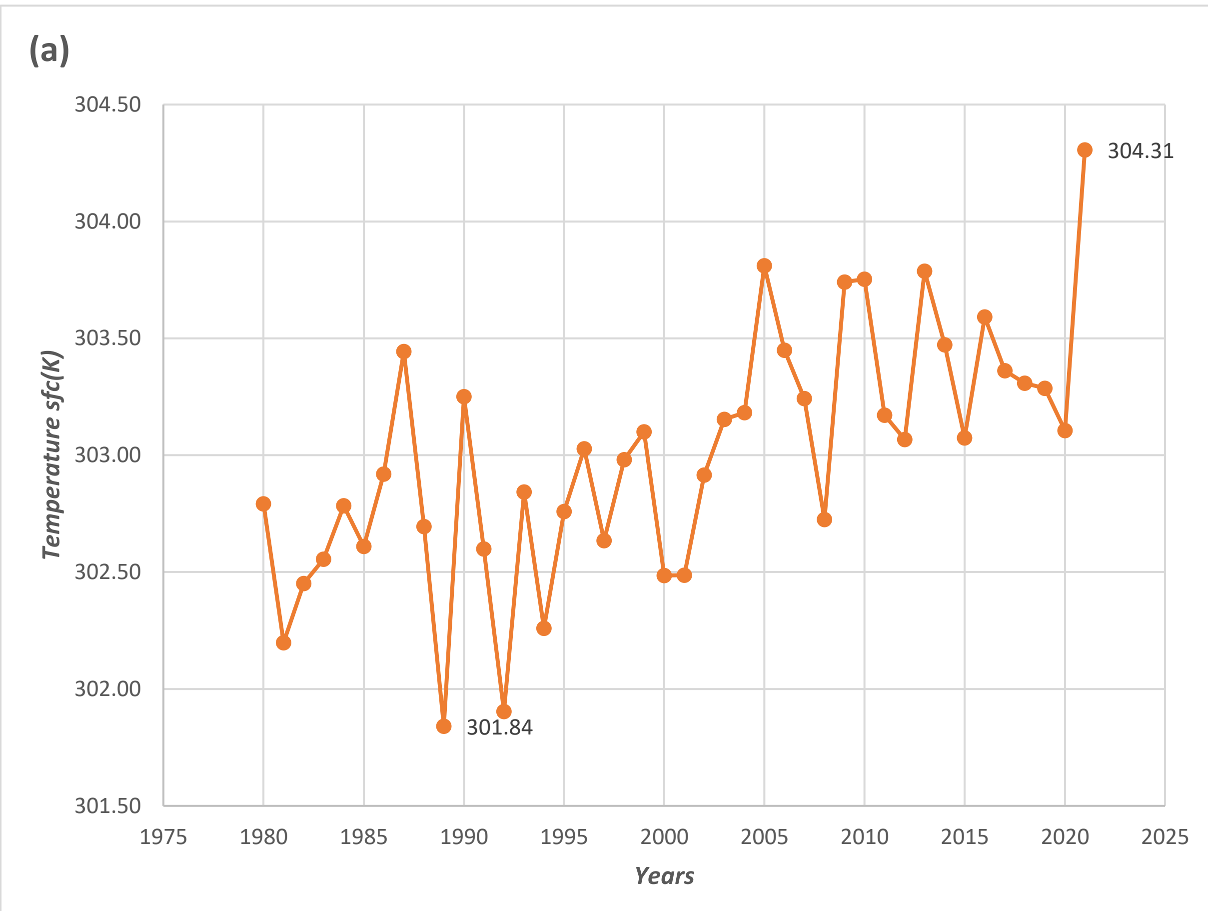
Index value	Standardized Anomaly Index (SAI) Interpretation
2.0	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-0.99 to +0.99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry
2.0	Extremely wet

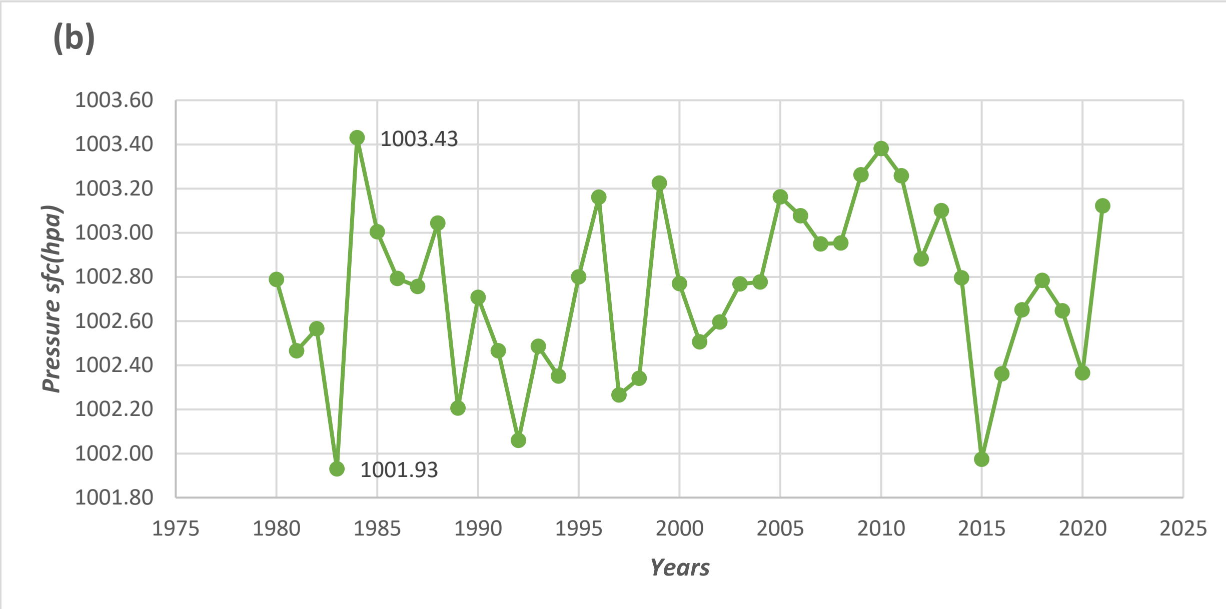
RESULTS AND DISCUSSION

Variations in Weather parameters

Temperature Variation

Figure 2a demonstrates a clear upward trend in surface temperature over the 42-year period. Starting from approximately 302.2 K in the early 1980s, the annual mean temperature consistently rises, reaching a peak of 304.31 K in 2021. The calculated overall mean temperature for the study period is 303.00 K, which, in comparison to early 1980s values, points towards an average increase of approximately 1.5 K over 42 years. This consistent warming pattern aligns with global and regional projections of rising temperatures due to climate change (IPCC, 2021; Abaje et al., 2014; Akinbolati et al., 2024). The increasing trend is statistically significant, indicating a long-term shift rather than a random fluctuation. Similar findings were reported by Olaniran and Sumaila (2019), who observed progressive warming in Northern Nigeria's semi-arid zone, driven largely by urban expansion and greenhouse gas emissions. The persistence of higher temperatures can intensify evapotranspiration and exacerbate water stress, especially in a region already vulnerable to desertification. Further insight is provided by monthly mean climatic variation in ambient temperature (Figure 3a). These data confirm a seasonal cycle dominated by hot-dry months (March to May), with warming more pronounced in post-2000 years. The correlation analysis in Table 3 reinforces this upward trend, with a positive correlation coefficient (R = 0.66) between surface temperature and study year, indicating a persistent year-on-year increase.





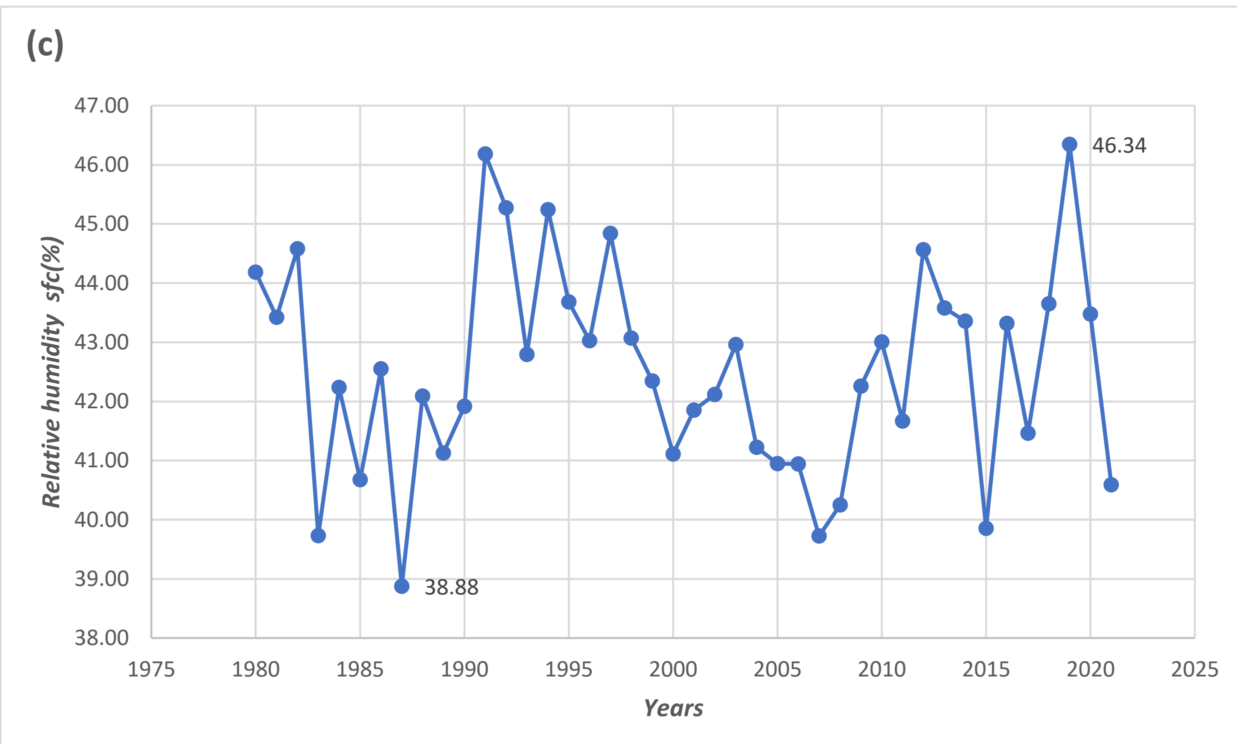
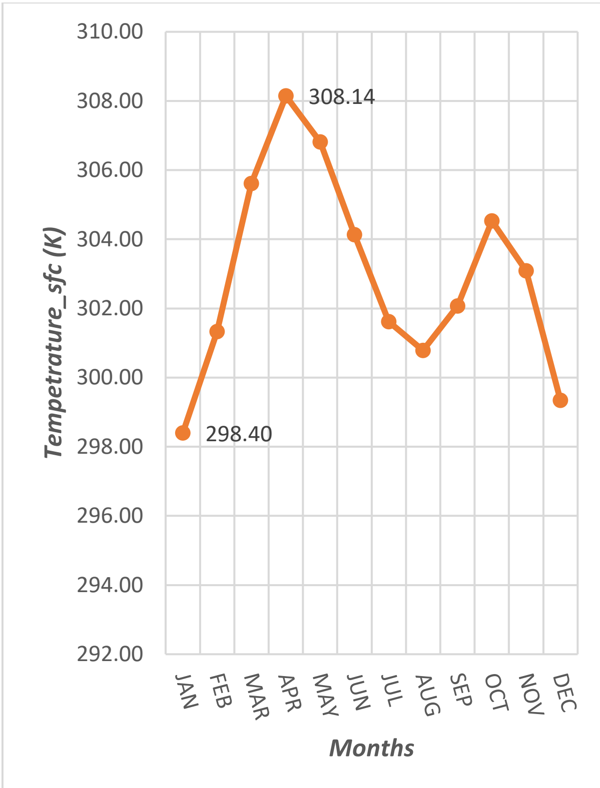


Figure 2: Annual Climatic Variation of (a) temperature (K) (b) pressure (hPa) and (c) relative humidity(%RH) for the years 1980-2021 over the city of Kano.



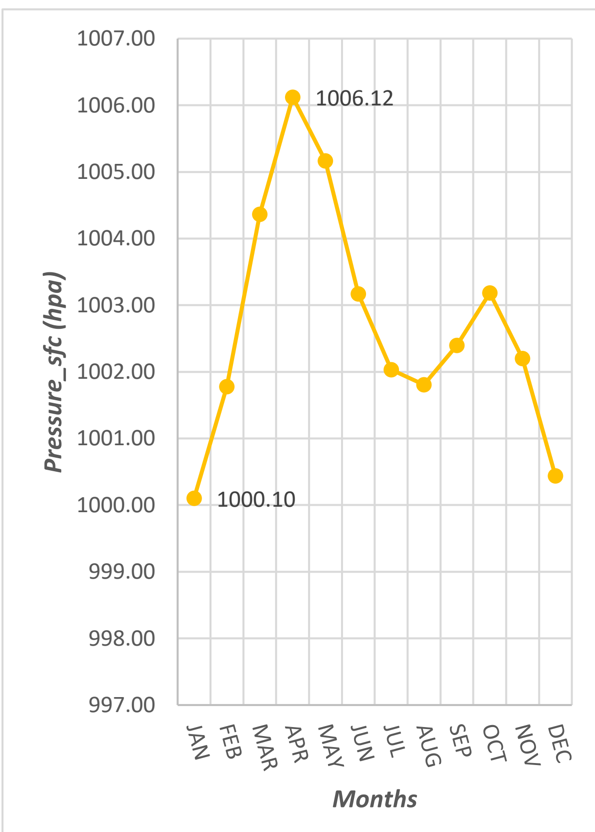


Fig. 3: Monthly atmospheric parameter variation of (a) temperature (K) (b) pressure(hPa) and (c) relative humidity (%RH); for the years 1980-2021 over the city of Kano.

Atmospheric Pressure Fluctuations

Surface pressure over Kano has remained relatively stable, with values centered around a mean of 1002.74 hPa (Figure 1b). While no pronounced long-term trend is observed, only modest fluctuations are observed, though slight increases occur after 2005. Table 3 indicates a low positive correlation (R = 0.16) between pressure and the study year, suggesting a mild upward trend, albeit less significant than temperature changes (Aremu, 2019). The pressure-temperature relationship also shows a moderate positive correlation (R = 0.54), implying that pressure may respond to warming dynamics in the region. Monthly mean variations in surface pressure, shown in Figure 2b, reveal a gradual but consistent decline, especially in the transitional months between dry and wet seasons. Such pressure dynamics can influence local weather conditions, including storm patterns and rainfall onset. While less evident than the temperature or humidity trends, these variations are indicative of changing synoptic-scale influences. Adefolalu (2007) reported similar findings, attributing them to broader synoptic weather pattern alterations driven by global atmospheric warming.

Relative Humidity Variation

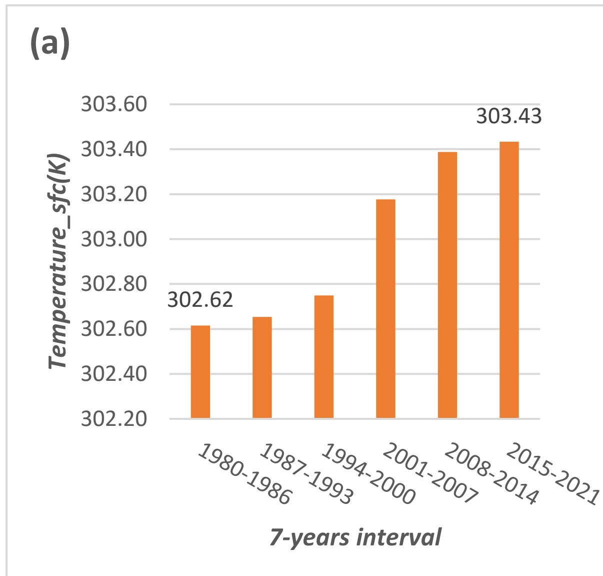
In contrast to temperature, the pattern in relative humidity (Figure 1c) shows greater variability and less consistent directional change. The values fluctuate between a minimum of 38.88% (1987) and a maximum of 46.34% (2019), with an average of 42.53%. Although a decline is observed in some decades, particularly the late 1980s and early 2000s, relative humidity tends to rebound in recent years. This instability suggests short-term climatic fluctuations potentially influenced by changing rainfall patterns, land use changes, or urbanization. Previous studies (Adefolalu, 2007), supports this variability, attributing changes in humidity to altered moisture transport systems and local deforestation trends around Kano. The monthly patterns in Figure 2c confirms this observation. Humidity levels are highest during the wet season (June to September), but lower values are becoming more persistent in the dry season months. This drying trend, combined with rising temperatures, indicates increasing aridity. The inverse relationship observed between rising temperature and declining humidity is consistent with Odjugo (2010), who noted that increased warming reduces atmospheric moisture retention in northern Nigerian cities, intensifying drought risks and affecting human health and ecosystems.

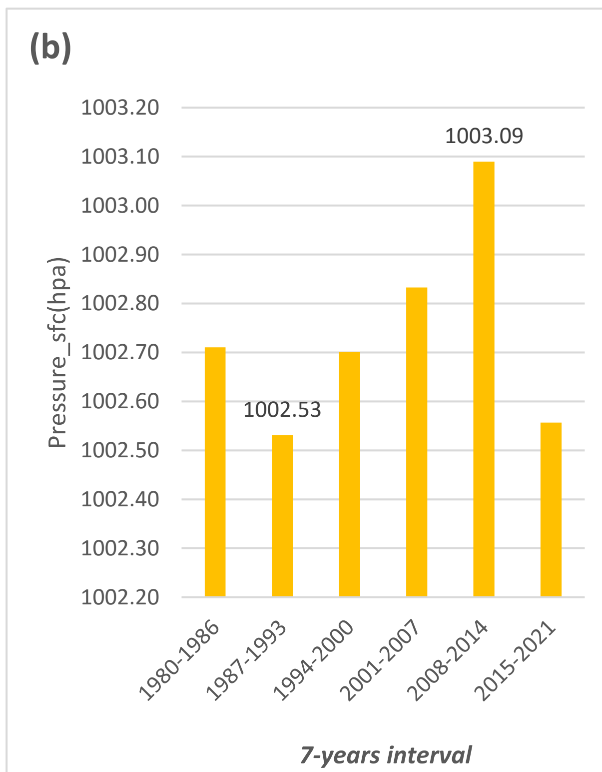
Synthesis of Climatic Variation Trends

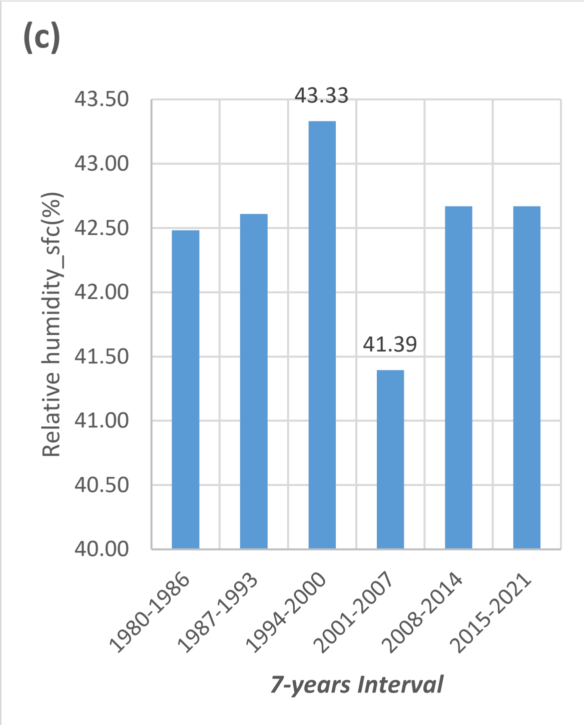
The results across annual and monthly scales confirm that Kano City is experiencing measurable climatic shifts. The dominant pattern is one of progressive warming, coupled with declining relative humidity and subtle changes in atmospheric pressure. These variations reflect both global climate influences and localized anthropogenic pressures such as deforestation, urbanization, and land degradation. The observed patterns align with regional climate assessments from the Intergovernmental Panel on Climate Change (IPCC, 2021) and recent empirical studies (Abaje et al., 2014; Abdusalam et al., 2018), all of which highlights the climate vulnerability of northern Nigerian cities.

Climatic Variation within Seven-Year Mean Intervals

There is a progressive increase in the seven-year mean values of annual average temperature from the early 1980s through to the most recent period. The temperature trend exhibits a near-linear upward trajectory, with more significant increases observed after the 1990s. This trend corroborates global climate observations and is consistent with studies indicating regional warming across northern Nigeria (Abdusalam, Bala, & Abdulhamid, 2014). Similarly, Adedayo and Obioha (2015) observed that the urban fabric and expanding anthropogenic activities in Kano have contributed to intensify warming, particularly in the post-1990 era. The consistent rise in temperature signals a gradual but persistent departure from Kano's traditional thermal regime. This change is likely driven by a combination of greenhouse gas accumulation, land surface modifications, and increased urbanization. Over time, such temperature increases may influence evapotranspiration rates, urban heat island effects, and energy demand patterns in the city. Table 2, further corroborates this relationship, with the highest correlation (R = 0.96) between temperature and the seven-year interval groupings, confirming a strong linear progression of warming over time.







Figures 4(a-c): depict the seven-year mean interval analysis of three core atmospheric parameters; temperature, pressure, and relative humidity, over a 42-year period in Kano City, Nigeria.

These figures illustrate clear trends and variations that offer insights into the extent and nature of climatic change within the region, when compared with established climatological norms.

Although the changes in atmospheric pressure are relatively subtle, a general downward trend is evident, especially in the later decades. This mild reduction in pressure could reflect evolving regional air mass dynamics, possibly linked to the West African Monsoon system. Usman and Reason (2004) associated fluctuations in the monsoon and related rainfall patterns with changes in surface pressure regimes across northern Nigeria. While pressure changes may appear less pronounced than those of temperature, they still carry climatological significance. More detailed insights are provided in Table 2, where the seven-year interval analysis reveals an evolving pattern. Notably, the 2001–2007 and 2015–2021 periods show high positive correlations between pressure and time (R = 0.86 and 0.73, respectively), which may indicate increasing atmospheric mass during specific intervals, possibly driven by regional circulation changes. Meanwhile, the period from 1987–1993 reflects a negative correlation (R = -0.58), possibly tied to disrupted monsoon patterns during that decade. These mixed results suggest that pressure responds in complex, non-linear ways to climatic shifts, influenced by broader atmospheric systems, as noted by Aremu (2019). Declining pressure trends could suggest increased convective activity, which may influence rainfall variability and seasonality in Kano, a factor critical to the region's agricultural calendar and water resource planning. Table 2 presents the degree of relationship between temperature, relative humidity, pressure and the amount of rainfall for the interval of seven years between the years 1980-2021 over the city of Kano

Table 2: Correlation coefficient Table of atmospheric parameters for the 7-year intervals

	7-years interval	*Temp_sfc(K)*	*RH_sfc(%)*	*Pressure_sfc(hpa)*
7-years interval	**1**			
Temp_sfc(K)	**0.96**	**1**		
RH_sfc(%)	**-0.07**	**-0.25**	**1**	
Pressure_sfc(hPa)	**0.27**	**0.43**	**-0.20**	**1**

Figure 4c indicates a marked decline in the seven-year mean values of annual relative humidity, particularly after the year 2000. This decline suggests that the atmosphere over Kano is becoming drier, a condition that can exacerbate heat stress and reduce moisture availability for both ecological and human systems. This trend supports earlier observations by Oladipo (1993), who reported declining humidity across northern Nigeria with direct implications for crop productivity and human comfort levels. The reduction in atmospheric moisture may also be a function of rising temperatures, which increase the capacity of air to hold water vapor, often without a corresponding increase in moisture supply. Such a mismatch contributes to perceived dryness and can further degrade environmental quality, especially in semi-arid urban regions like Kano. The correlation coefficient between humidity and study year (R = -0.02) in Table 3, suggests a slight overall decline, consistent with the negative values observed in the seven-year interval analysis, particularly from 1994 to 2007 (R = -0.82 and -0.80 respectively), although fluctuations exist, the broader trend leans toward reduced atmospheric moisture.

Table 3: Degree of correlation coefficient (R) between the studied years and the atmospheric parameters

	Year	***Temp_sfc(K)***	***RH_sfc(%)***	***Pressure_sfc(hpa)***
Date	**1**			
Temp_sfc(K)	**0.66**	**1**		
RH_sfc(%)	**-0.02**	**-0.23**	**1**	
Pressure_sfc(hpa)	**0.16**	**0.54**	**-0.17**	**1**

This table established that, in the city of Kano all the weather parameters were increasing every year excluding relative humidity that is decreasing slightly within the studied period.

When compared with historical climatology, these seven-year mean intervals reveal a steady shift in Kano's climate regime. Traditionally, Kano exhibits a tropical continental climate with well-defined wet and dry seasons and relatively stable intra-annual variability (Adefolalu, 1986). However, the consistent warming, slight pressure decreases, and declining humidity levels observed in this analysis indicate a shift toward a hotter and drier regional climate. The implications of these shifts are far-reaching, affecting food security, water resources, public health, and urban sustainability.

CONCLUSION

This study investigated the degree of climate change over Kano City, Nigeria, using a forty-two-year dataset (1980–2021) of key atmospheric parameters: surface temperature, relative humidity, and surface pressure. The analysis revealed a statistically significant and persistent upward trend in surface temperature, confirming a clear warning signal consistent with global climate change projections and regional observations in the Sahel region. The annual mean temperature has increased by approximately 1.5 K, with the strongest correlation observed in recent decades, suggesting a continued trajectory of thermal intensification. Relative humidity, while exhibiting more variability, showed intermittent declines, particularly in the 1990s and early 2000s. These patterns reflect a potential reduction in atmospheric moisture content, likely influenced by rising temperatures, urbanization, and changing rainfall patterns. In contrast, surface pressure remained relatively stable, with only slight fluctuations and weaker correlations, indicating more complex or less direct responses to climatic shifts. Correlation analysis further confirmed the interdependence of these parameters. The inverse relationship between temperature and humidity supports the theory of intensified evapotranspiration and atmospheric drying under warmer conditions. Monthly and seven-year interval analyses reinforced the robustness of these trends, emphasizing the temporal evolution and interaction of weather variables in the study region. These trends have far-reaching implications for water resources, agricultural productivity, and urban planning. It is imperative that local authorities and policymakers integrate these insights into climate adaptation frameworks to enhance resilience against the growing challenges of climate variability and change in Northern Nigeria.

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