Nigerian Journal of Environmental Sciences and Technology (NIJEST)
www.nijest.com
ISSN (Print): 2734-259X | ISSN (electronic): 2734-2603
Vol 10, No. 1 March 2026, pp 53- 69

Spatio-temporal Analysis of Rainfall and Temperature Trends in the Sudano-Sahelian Zone of Nigeria Using Long-Time Data

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https://doi.org/10.36263/nijest.2026.01.12

ABSTRACT

Climate change has emerged as one of the most pressing environmental challenges of the twenty-first century, with significant impacts on temperature, rainfall variability, and hydrological processes across vulnerable ecological zones. This study examined the spatio-temporal trends of temperature and precipitation in the Sudano-Sahelian zone of Nigeria using long-term climate data spanning 1951–2023. The study focused on selected states within the region, including Niger, Adamawa, Jigawa, Kano, Kebbi, and Kogi States, with the aim of assessing inter-annual climate variability and identifying the hydrological and environmental factors influencing these changes. Secondary climate datasets were obtained from reputable sources such as NASA POWER, the World Bank Climate Change Knowledge Portal (CCKP), NiMet, and other validated climatological repositories. Analytical techniques including statistical trend analysis and Kernel Density Estimation (KDE) were employed to evaluate changes in temperature and precipitation distributions over time. The results revealed a consistent and accelerating warming trend across the Sudano-Sahelian region, particularly from the 1990s onward. Mean surface air temperatures increased by approximately 1.0–1.4°C over the study period, with recent decades exhibiting the highest rates of warming. Jigawa, Kano, and Kebbi States recorded especially rapid temperature increases, while Kogi State showed increased inter-annual temperature variability. Rainfall patterns displayed significant spatial variability, with declining and increasingly erratic precipitation in northern states such as Kebbi and Jigawa, whereas parts of Kogi experienced increasing rainfall intensity. The study further identified major drivers of climatic variability, including greenhouse gas emissions, land-use change, deforestation, rapid urbanization, and hydrological instability. These factors have intensified the occurrence of floods, droughts, soil degradation, and water stress across the region.

Keywords: Climate change, extreme climate events, temperature, precipitation, variability

1.0. Introduction

One of the greatest social and ecological challenges in the twenty-first century is climate change, and it's a global phenomenon (IPCC, 2021; United Nations, 2022).Climate change is known to be a long-term variation in temperature, rainfall, and other weather patterns, the variations can be as a result of human influence, natural variability including the El Niño phenomenon, or due to changes in sun's activity, tropical cyclones or large volcanic eruptions (IPCC, 2021; NASA, 2023).Since the 1800s, human activities have been the major driver of climate change, mainly through the burning of fossil fuels such as coal, oil, and natural gas. The combustion of these fuels release greenhouse gases into the atmosphere, where they form a heat-trapping layer around the Earth, leading to a rise in global temperatures (UNEP, 2022; IPCC, 2021). Methane and carbon dioxide are the two primary greenhouse gases responsible for climate change (Filonchyk *et al*., 2024).

These results, for instance, from using coal to heat a building or gasoline to operate a vehicle. Carbon dioxide can also be released through land clearing and forest destruction. The two main industries that emit methane are agriculture and oil and gas operations. Among the primary industries producing greenhouse gases are energy, industry, transportation, buildings, agriculture, and land use (Sokal & Kachel, 2025). Heatwaves, cold waves, heavy precipitation, droughts, tornadoes, and tropical cyclones are a few examples of extreme weather and climate occurrences. Beyond the limits of natural climate variability, human-caused climate change has resulted in widespread negative effects, as well as losses and damages to both people and the environment, including more frequent and intense extreme events (Pörtner *et al*., 2022). Extreme weather and climatic events have more detrimental effects because of their heightened intensity, duration, and spatial extent. Beyond what might be anticipated from a single extreme weather event, a series of extreme events can compound and have greater effects.

Nigeria's changing climate is evident in rising temperatures, irregular rainfall patterns, sea level rise, flooding, drought, desertification, land degradation, increased occurrences of extreme weather events, declining biodiversity, and pressure on freshwater resources. Prolonged and intense rainfall has also led to severe runoff and widespread flooding across many parts of the country (Ologunorisa *et al*., 2022; Umar & Gray, 2023). Variability in rainfall is expected to keep rising.
Rising sea levels and increased precipitation are predicted to worsen flooding and coastal land submersion in southern regions. Due to a decrease in precipitation and an increase in temperature, droughts have also become a regular occurrence in Nigeria and are predicted to persist in Northern Nigeria (Ayanlade *et al.,* 2018; NiMet, 2020).

The Intergovernmental Panel on Climate Change declared in its most recent Assessment Report (AR6), which was accepted by almost 200 nations in September 2013, that "it is extremely likely (with 95%-100% certainty) that human influence has been the dominant cause of observed warming since mid-20th century." In this context, "human influence" mostly refers to the rise in carbon dioxide emissions and how they affect the Greenhouse Effect (Sun *et al*., 2022).

The layer of natural gasses that surrounds the globe and traps heat from the sun's rays is known as the "Greenhouse Effect," which keeps the planet's temperature comparatively constant and "comfortable." The 1980s saw a sharp increase in temperature. According to climate estimates for the upcoming decades, temperatures will rise significantly throughout all-natural zones.

Therefore, this study provided information on rainfall and temperature inter-annual trend between 1951 and 2023, while also examining the hydrological and environmental factors that contribute to inter annual variability and change in climatic parameter over Sudan Sahelian zone (Bo *et al*., 2026).

2.0 Methodology

2.1 The Study Area

One of the largest ecological zones that occupies almost one third of the total land mass of the country is the Sudano-Sahelian zone which is located between latitudes 10°N and 14°N and longitudes 4°E and 14°E (Figure 1). This zone stretches from Sokoto plains through the Northern section of the high plains of Hausa land to the Chad Basin (Odekunle *et al*., 2008). The Central African Republic, Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Ghana, Guinea, Guinea-Bissau, Mali, the Niger, Nigeria, Senegal, the Sudan, and Togo are among its members. This zone experiences regular dry periods that can lead to severe and extensive droughts because of the significant inter-annual variability of rainfall (Alhassan *et al*., 2024; Adeyefa and Odekunle, 2022; Dogondaji and Isah, 2025).

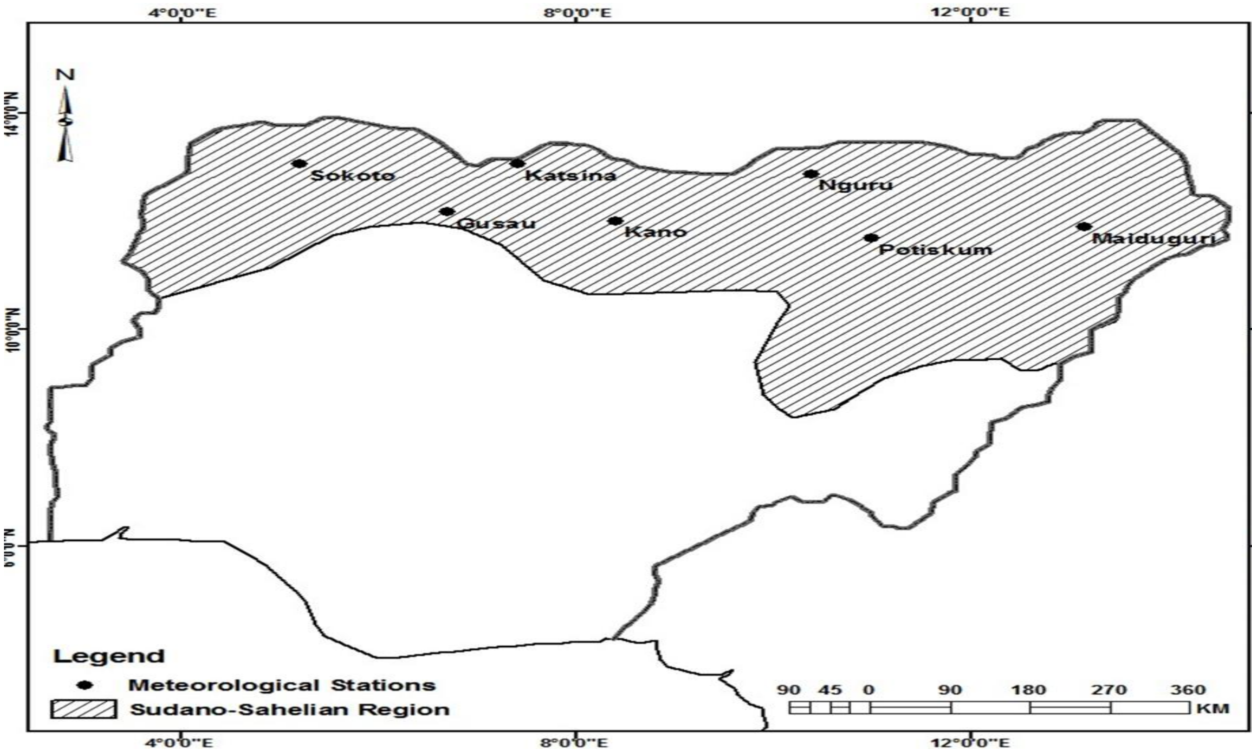


Figure 1: Map of the Study Area

The Sahel and the Sudan are the two natural regions that comprise the Sudano-Sahelian zone. To the south, the more humid savannah gives way to the desert in the Sahel. The Guinean zone to the south and the Sahelian zone to the north are separated by the Sudanian zone. The Savanna-type vegetation, which includes the Sudan and Sahel, has a diminishing tree and plant density as one move north (Abdulhamid *et al*., 2023). This region, which includes the majority of Nigeria's rangeland, has been referred to by numerous scholars as the country's dry land. Numerous cattle and other domestic animals are supported by Sudano-Sahelian zone since it serves as the primary source of feed and grazing land. This area is known for its camels and donkeys (Ilboudo *et al*., 2025).

2.2 Data sources

The methodology adopted for this study relied on the use of secondary data collection methods. Relevant data were obtained from various existing sources, including published research articles and academic journals, government reports and statistical publications, online databases and internet repositories, textbooks and scholarly materials, as well as reports and publications from non-governmental organizations (NGOs) and international organizations. The information received from these sources was credible and comprehensive enough for the study. The study also involved compiling the historical temperature and precipitation data from trusted repositories of global and regional climate data. These comprise data from satellites, including the POWER T2M grids from NASA, weather data from NiMet, Nigeria, and climatological re-construction data that have been collated and verified for reliability. The data are available on monthly, seasonal and annual scales in seven decades, allowing for comprehensive trend and variability analyses.

2.3 Data analysis

Data analysis is a process of logically interpreting collected data to get meaningful information. In this study, several statistics are used such as statistical trend analysis, kernel density estimation and distribution-based trend assessment. These analyses were based on historical climate data from the World Bank's Climate Change Knowledge Portal (CCKP). The CCKP offers detailed historical information and present climate data for assessing climate variability and long-term climate change. Climate data (historical and recent climate) included minimum, mean and maximum temperature data and precipitation data. The data were split into two broad time periods for comparison:

2.3.1 Historical period: 1903–1930, Recent period: 1990–2020

This temporal segmentation allowed investigation of the temperature and rainfall patterns evaluation as they evolved over time. CCKP offers regional, national and subnational climate data, which is what makes it unique. The analysis was enhanced by a detailed spatial knowledge of climatic behavior. The Sudano-Sahelian region (including Kano, Katsina, Jigawa, Borno, Yobe, Sokoto, and Zamfara) has the most vulnerable population. Changes in climate have been observed to increase flood occurrences in recent years, increasing hydrological instability.

The CCKP is rich in climatological data, including temperature trends, precipitation, and other variables and extreme events, providing a crucial tool for climate risk assessments and the development of adaptation strategies.

2.3.2 Kernel distribution estimation

Kernel density estimation (KDE) was used to assess the distribution characteristics of data in this study used for climatic analysis. KDE is a non-parametric method to estimate the probability density function of a variable (Guo *et al*., 2023). For the purpose of this study, the visualization of the effects of temperature was achieved using KDE. There is a change in the distribution of rainfall over time. The technique places smooth, overlapping "kernels" around each data point, producing a continuous surface that highlights the frequency and spread of climate values. This method enables a long-term trend in climatic behaviour to be exposed such as changes in averages and variability of the data.

3.0 Results and Discussion

3.1 Trend Analysus of the Selected States in the Study Area

3.1.1 Niger State, Nigeria (1951-2020)

The average annual temperature trend in Niger State showed a long term increasing trend as seen in Figure 2, with increase from 1951 to 2020. declined slightly around 1958, increased towards 1960, and thereafter maintained a generally upward trajectory until 2020. This study involved an analysis of the annual temperature variations and trends in the territory of Niger State over the period of the study. Overall, the annual temperature pattern indicates a progressive increase as the years advanced.

The observed variations in the average mean surface air temperature (MSAT) between 1951 and 2020 reveal a consistent warming trend, which aligns with the broader phenomenon of global warming. This may have been caused by several factors: The increase in global concentration of greenhouse gasses due to deforestation, land use change and more greenhouse emissions. The MSAT was measured at an average of 25.01°C in 1951 but by 1961 it had increased to rise to 26.26°C, an increase of about 0.32°C and rose further to 27.48°C in 1969.

The decadal analysis of temperature trends also shows the warming tendency in Niger State. The rate of temperature increase between 1951 and 1960 was comparatively small; this may be related to natural climatic fluctuations and relatively small amounts of industrial and economic activities that are linked to greenhouse gas emission. In the decade of the 60s and 70s, a moderate temperature rise was noticed, indicating the beginning of a significant warming pattern.

After World War II, there has been an increase in linked industrialization and global temperature rise. In addition, the increase between 1971 and 1980 was greater.

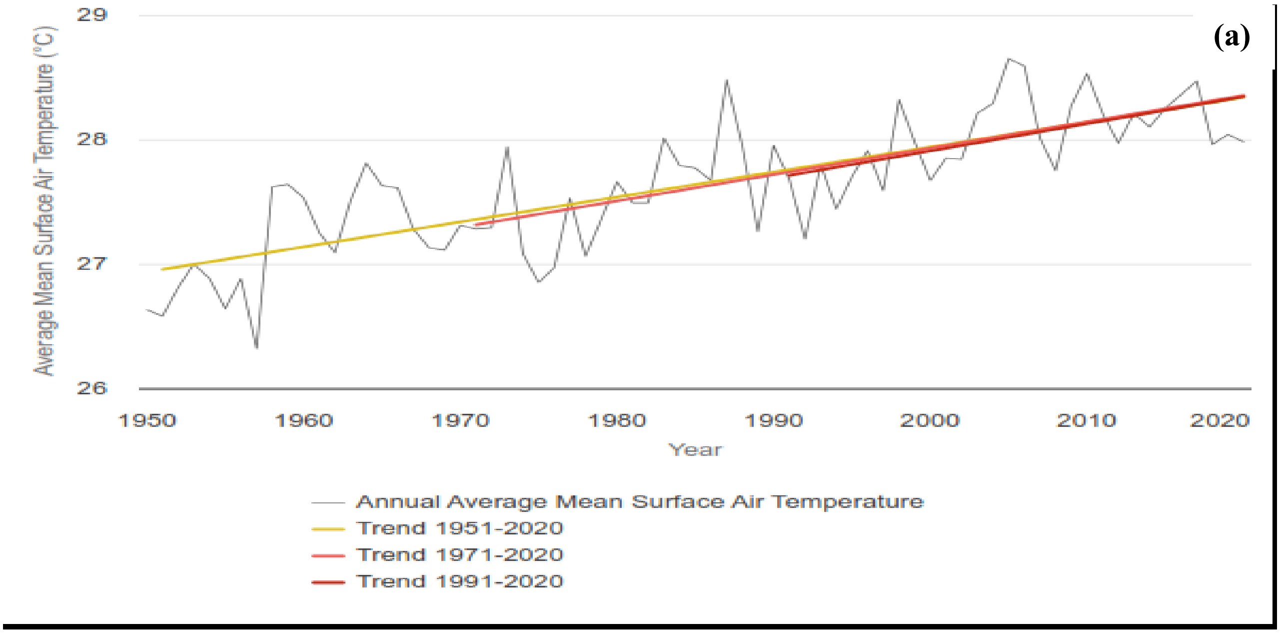
1981–1990: The 1980s continued the warming trend and the temperature increase became more pronounced, marking an intensified impact of human activities on global temperature patterns.

1991–2000: This decade saw a clear and accelerating rise in temperature, with Niger experiencing higher-than average heat levels.

In Niger, the effects of climate change, like the rising frequency of droughts, were starting to show.

2001–2010: This decade saw one of the biggest temperature increases. This period was, like throughout the rest of the globe, a continuous warming period. Niger saw warmer-than-normal temperatures, affecting agriculture, water availability, and food security, like many other regions. The last 10 years (2011-2020) were the warmest decade on record, and the highest temperatures occurred in the warmest months. The regional warming that has been observed is the result of the combined impacts of sustained greenhouse gas emissions and the cumulative impacts of climate change.

To summarize, in Niger, the surface temperature has changed significantly over the last 70 years (1951-2020), warming by +1.0 °C per decade. Increasing sharpness of temperature rises since the 1980s. The pace of this warming has increased over the last few decades, similar to global climate change trajectories. Important policy makers should be aware of the widespread impacts these changes will have on public health, ecological systems, agricultural output, and freshwater availability, there's an urgent need to develop and establish successful climate mitigation and adaptation policies which can respond to the increased climate pressures in the region.



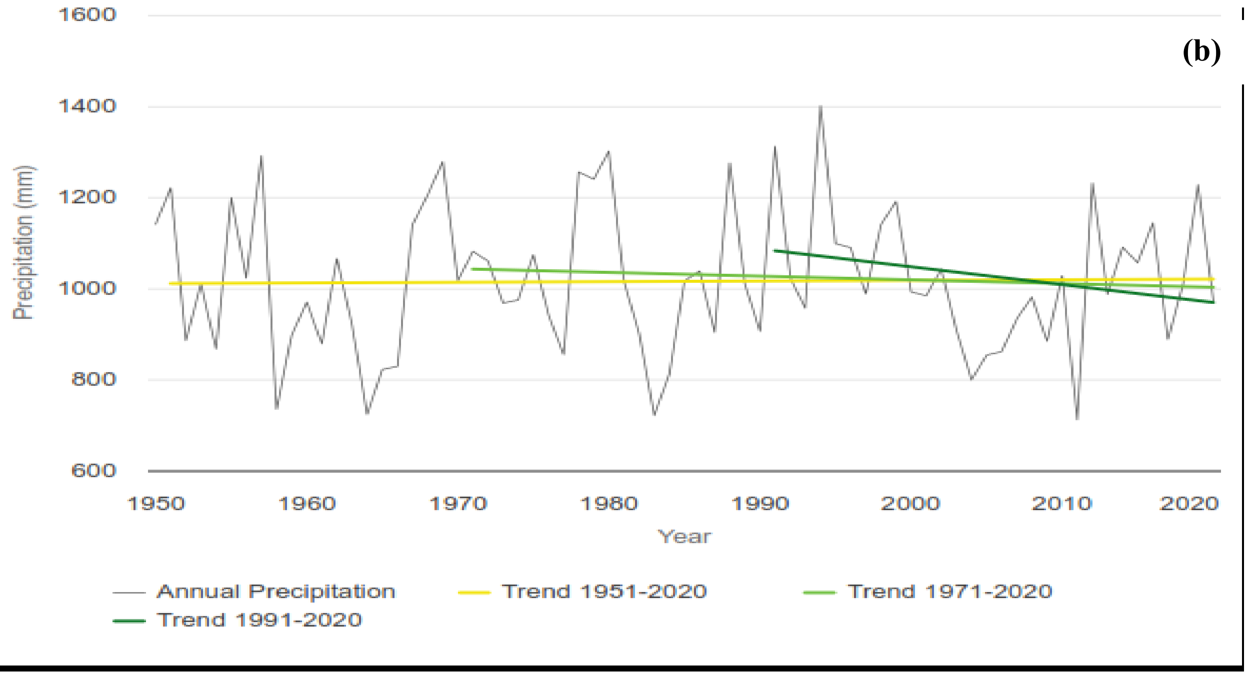


Figure 2: Average Mean Surface Air Temperature and Precipitation Annual Trends with Significant of Trend per Decade (1951-2020) in Niger State, Nigeria

3.1.2 Adamawa State, Nigeria (1951-2020)

The climate record, both observational and from peer-reviewed scientific literature, shows that since early 1950s, there have been measurable warming trend in Adamawa State with an increasing rate of temperature, accelerating considerably after 1990. Drawing on NASA POWER/MERRA-2 annual datasets and results of climate research in Nigeria, this chart shows the path of temperature change over the three overlapping time periods of 1951–2020, 1971-2020, and 1991-2020, while identifying environmental and anthropogenic influences underpinning these shifts.

The most recent three decades also include the state's hottest recorded year (2016, approximately 27.9 °C) as well as the sharpest annual temperature increase (a jump of about 0.4 °C from 2014 to 2015), is shown in Table 1.

Table 1: Decadal Trend Metrics

Period	Linear trends (^{0}C)/decade	Total Warming (start-2020)	Hottest Year (^{0}C)	Coolest Year (^{0}C)	Range (^{0}C)
1951-2020	+0.15^{0}C	≈+1.0 ^{0}C	2016 ≈27.9	1962≈26.0	1.9^{0}C
1971-2020	+0.20^{0}C	≈+1.0 ^{0}C	2016 ≈27.9	1984≈26.3	1.6^{0}C
1991-2020	+0.34^{0}C	≈+1.0 ^{0}C	2016 ≈27.9	1992≈26.8	1.1^{0}C

As shown in Figure 3, Adamawa State's average surface air temperature follows a pronounced upward trend. Each successive 30-year interval shows a stronger rate of warming than the one before it rising from roughly 0.15 °C per decade over 1951–2020 to more than 0.34 °C per decade during 1991–2020.

3.1.3 Jigawa State, Nigeria (1951-2023)

As shown in Figure 4, the graph shows the annual average mean surface air temperature from 1951 to 2023 in Jigawa, Nigeria. The black thin line represents the annual temperature values, which display considerable inter-annual variability with temperature fluctuations over the decades.

Three distinct trend lines (colored lines) indicate temperature trends computed for different starting decades to 2020:

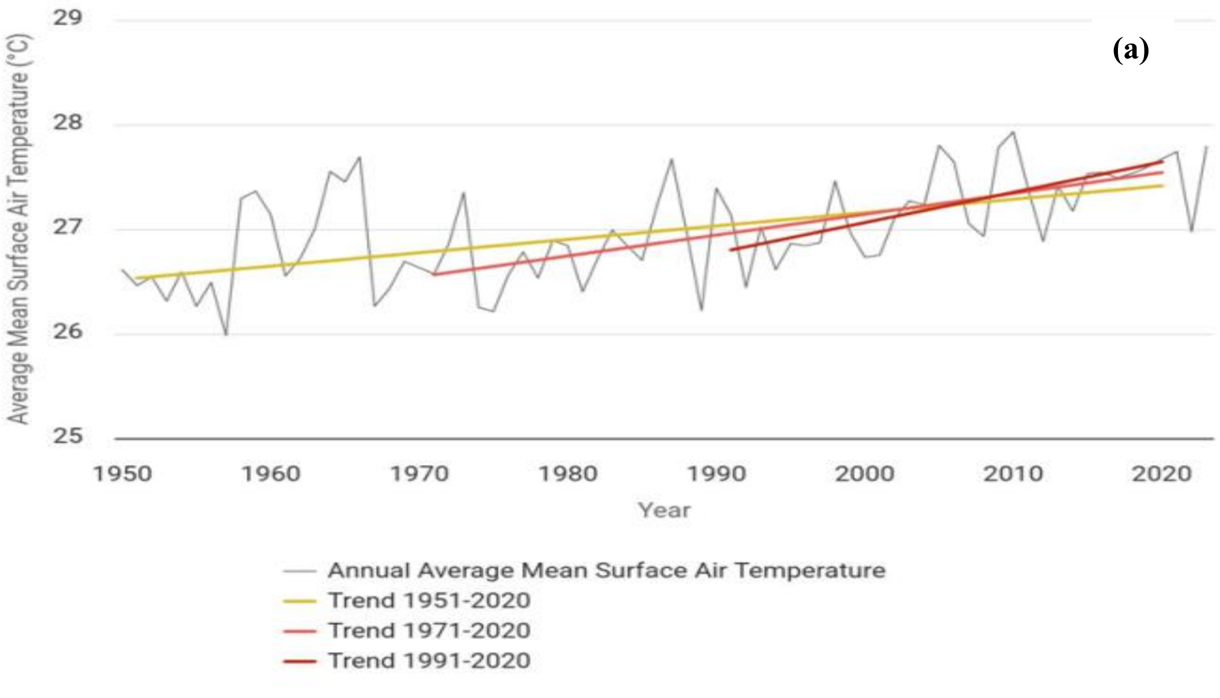
The Yellow line (trend 1951–2020) shows a gradual warming trend of about 0.3°C to 0.4°C per decade over this ~70year period, while the Orange-red line (trend 1971–2020) indicates a slightly steeper warming trend of around 0.4°C to 0.45°C per decade, reflecting the period of accelerated warming since the 1970s. The dark red line (trend 1991– 2020) displays the steepest warming trend of roughly 0.5°C per decade in more recent decades, showing a clear increase in the rate of warming.

This sequence illustrates an accelerating warming pattern in Jigawa's surface air temperature over the last seven decades.

Temperature highs: Peak average annual temperatures hover near 27.5°C to 28.0°C, most notably after the 2000s, corresponding to more frequent warm years.

Temperature lows: The coolest annual averages occurred in the earlier period around the 1950s and 1960s, close to 25.5°C to 26.0°C.

The amplitude of variation (difference between highs and lows) across the entire period is approximately 1.5°C to 2.0°C, showing meaningful warming, especially post-1990.



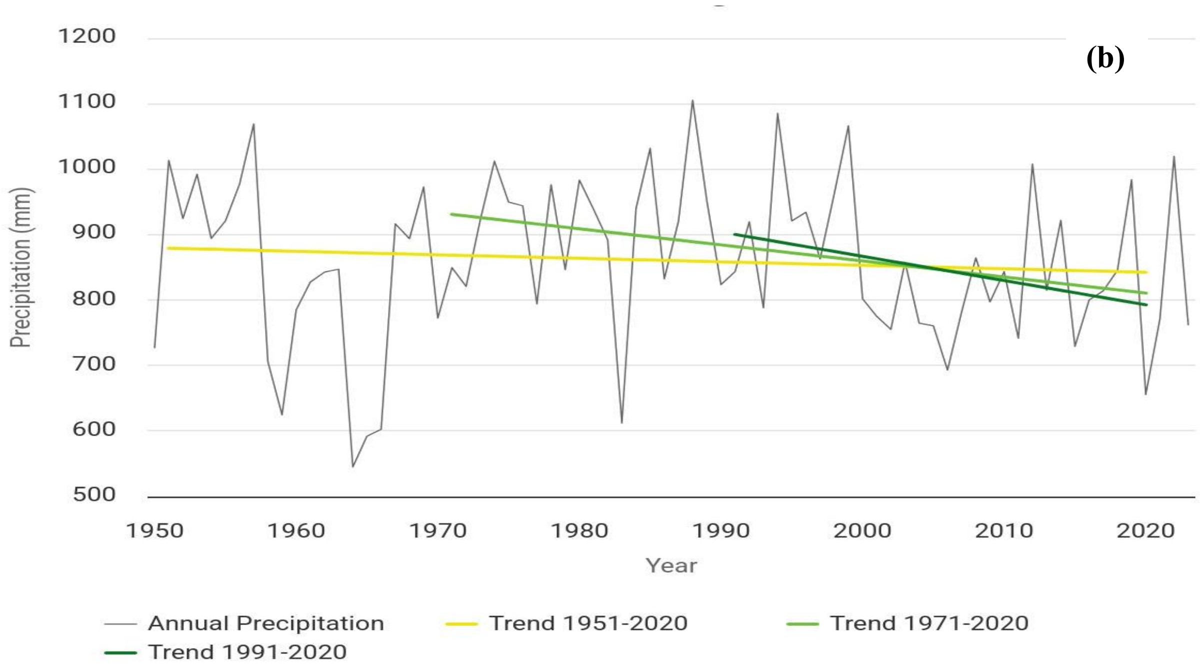
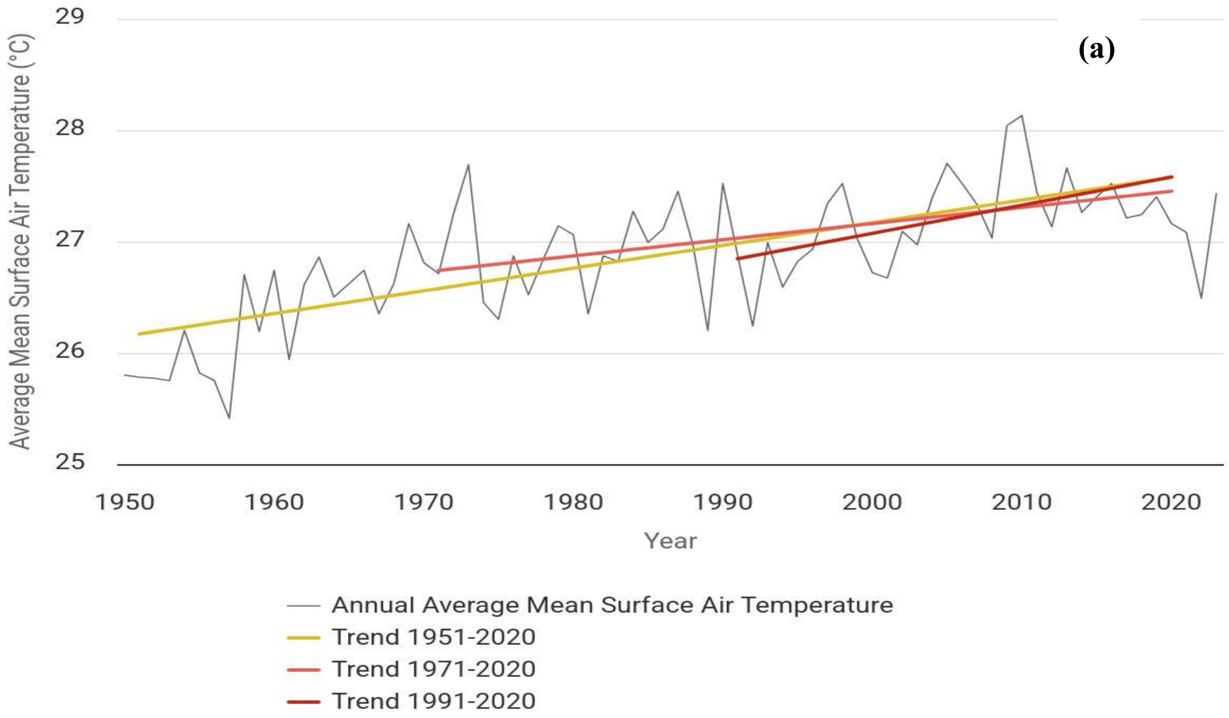


Figure 3: Average Mean Surface Air Temperature and Precipitation Annual Trends with Significant of Trend per Decade (1951-2020) in Adamawa State, Nigeria



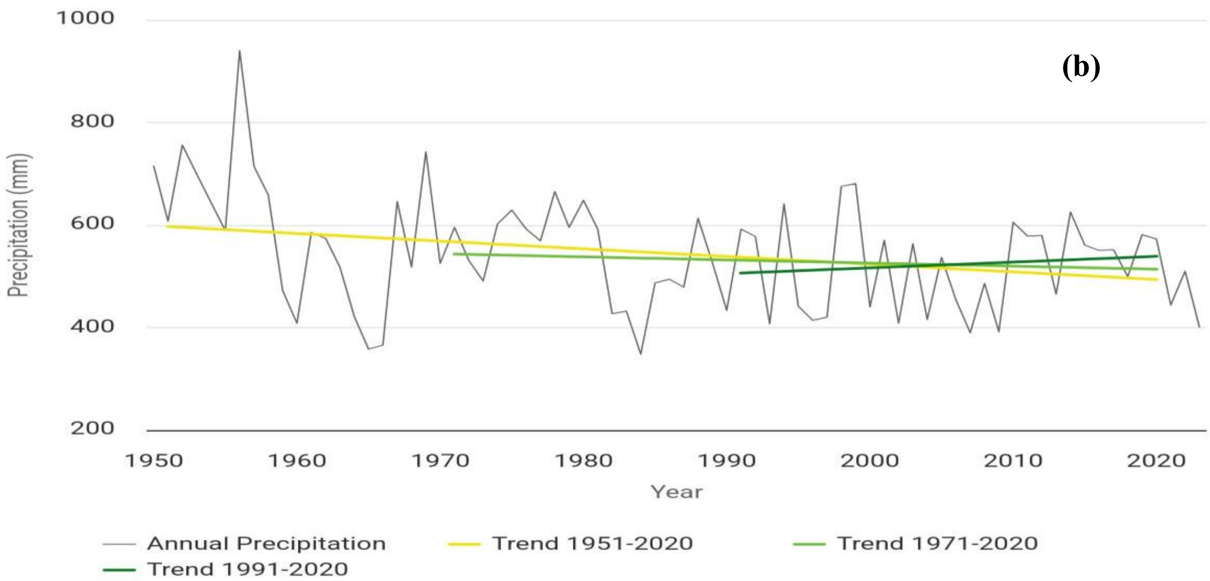


Figure 4: Average Mean Surface Air Temperature and Precipitation Annual Trends with Significant of Trend per Decade (1951-2020) in Jigawa State, Nigeria

Lows (around 1950s to 1970s): The cooler period reflected global mid-20th-century climate fluctuations, including possible aerosol cooling effects and weaker greenhouse forcing. Regional atmospheric circulation and variability in solar radiation also contributed to relatively lower temperatures during this time, less intense anthropogenic greenhouse gas emissions during the earlier decades.
Highs (post-1990s to 2023): Evident acceleration of global warming linked to increased CO_2 and other greenhouse gases from industrialization and population growth nationally and globally. Regional changes such as land use alterations (deforestation, urbanization) may exacerbate surface temperature increases by reducing evapotranspiration and increasing surface heat retention. Aerosol changes in regional atmospheric circulation, such as a weakening of the West African monsoon and lesser cloud cover, have increased the receipt of solar radiation, and warm and high surface temperatures throughout the region.

In Jigawa State, Nigeria, a significant warming trend has been observed over the last 70 years (from 1951 to 2023). The rate of warming increased from approximately 0.3°C per decade during the 1951–2020 period to around 0.5°C per decade between 1991 and 2020. Mean annual temperatures in the mid20th century ranged from 25.5°C to 26.0°C and have increased. Recently in the past few decades, it has been steadily exceeding the 27.5°C limit. This warming trend is in close agreement with both global and regional climate change patterns, mainly due to increased greenhouse gas concentrations and further amplified by area-specific land-use changes.

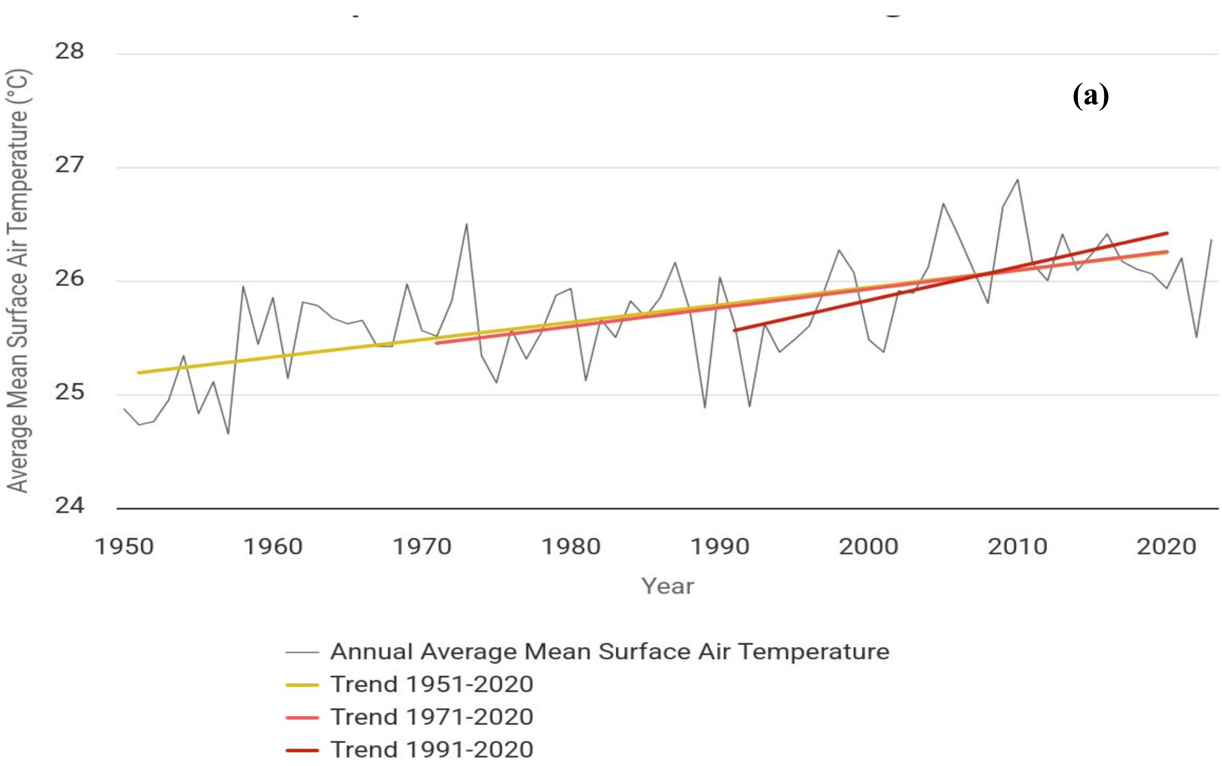
3.1.4 Kano State, Nigeria (1951-2023)

The available data unmistakably point to a sustained and progressively accelerating warming pattern in Kano between 1951 and 2023, as shown in Figure 5. The most pronounced temperature gains have occurred since the early 1990s, generating serious implications for crop productivity through increased heat stress, public health through a rise in heat-related conditions, freshwater availability, and broader community welfare.
Mean annual temperatures across the 72-year period have climbed steadily from approximately 24.5°C in the mid20th century to values consistently exceeding 26.5°C by the 2020s.
Decadal Rate of Warming: The 1951–2020 trend line reflects a relatively modest warming rate of around 0.2–0.3°C per decade. The 1971–2020 period records a somewhat faster pace of approximately 0.3–0.4°C per decade. The 1991–2020 period captures the most rapid warming, estimated at roughly 0.4–0.5°C per decade, underscoring the intensification of temperature rise in recent years.

Temperature Extremes: Post-1990 records reveal heightened temperature variability, with a growing number of years registering mean annual values above 26.5°C, further reflecting the deepening warming trend across the region.

3.1.5 Kebbi State, Nigeria (1951-2023)

As shown in Figure 6, The color-coded trend lines depicted in this chart quantify the pace of temperature increase across distinct time intervals. The Yellow line, representing the 1951–2020 period, spans nearly seven decades and reflects the most gradual warming rate of the three trends. This extended timeframe encompasses earlier years when the regional influence of anthropogenic climate change was comparatively limited, resulting in a more subdued overall temperature trajectory. The Orange line, covering the 1971–2020 period over five decades, exhibits a visibly steeper slope, indicating that the rate of warming accelerated meaningfully during this more recent half-century window compared to the broader long-term trend.



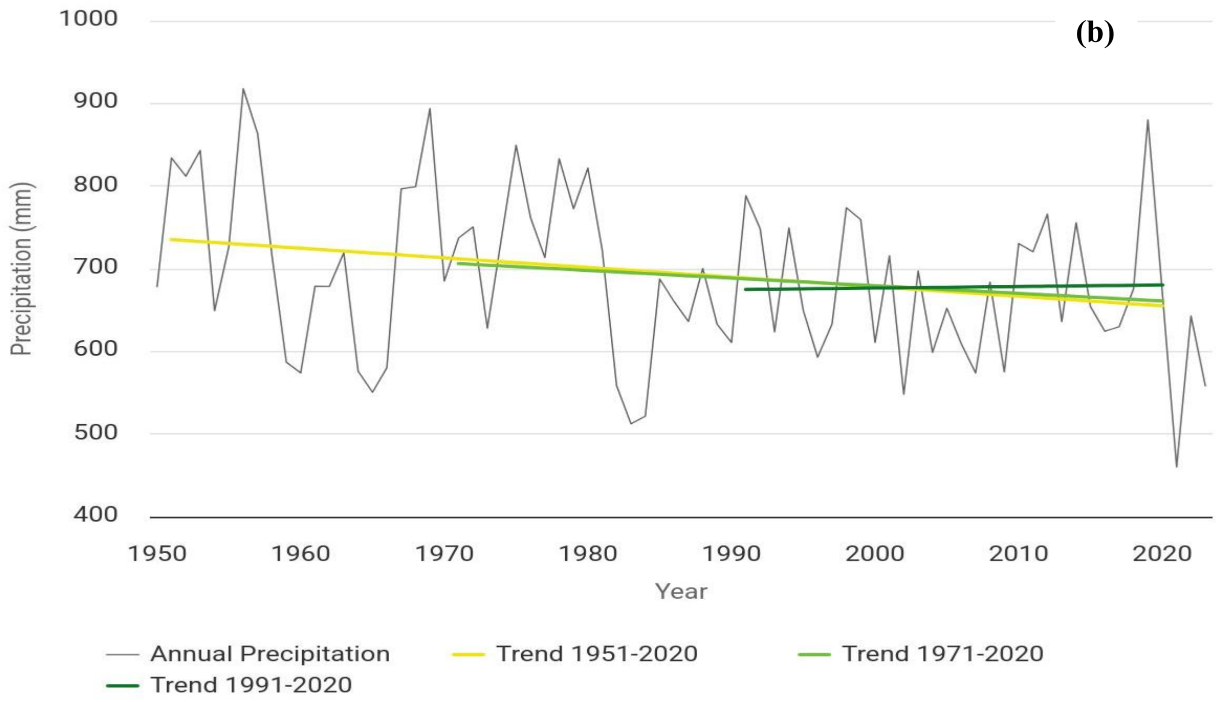
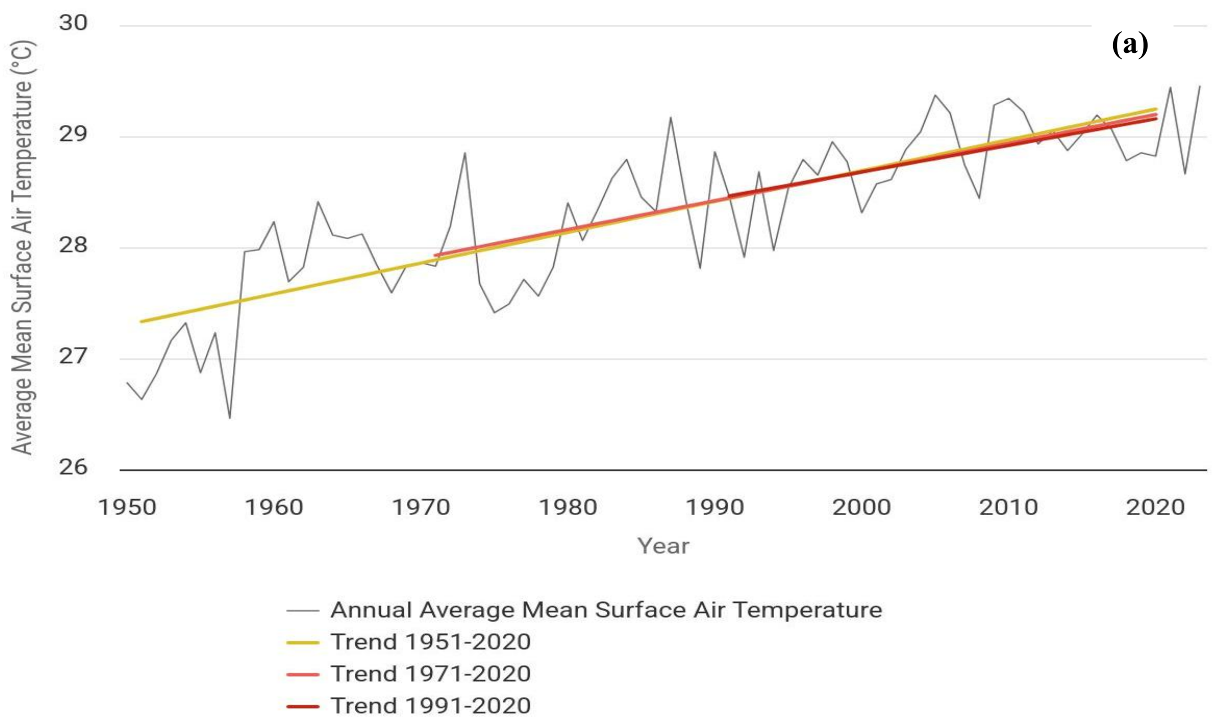


Figure 5: Average Mean Surface Air Temperature and Precipitation Annual Trends with Significant of Trend per Decade (1951-2020) in Kano State, Nigeria



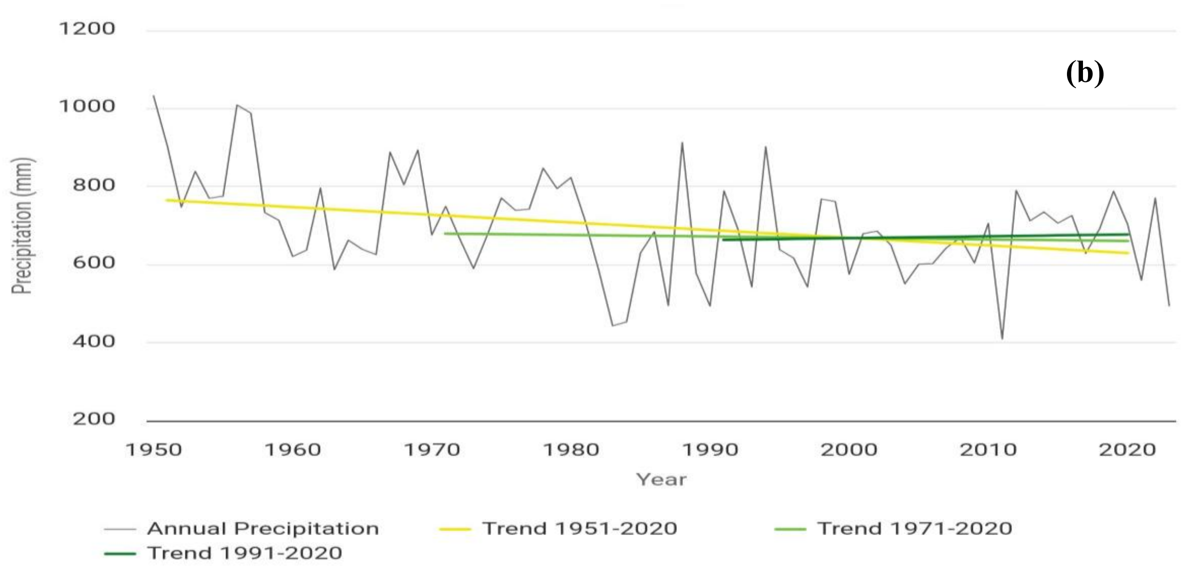


Figure 6: Average Mean Surface Air Temperature and Precipitation Annual Trends with Significant of Trend per Decade (1951-2020) in Kebbi State, Nigeria

It indicates that warming accelerated in the late 20th century, likely influenced by factors such as expanding urban areas, land-use changes, and the growing concentration of greenhouse gases worldwide.
Red Line (1991–2020 Trend): Representing the most recent 30 years, this is the steepest trend of all. It reflects the intensified effects of modern climate change, showing that temperatures in Kebbi have been climbing faster than at any previous time in the record. This suggests increasing climate-related risks in recent decades.

3.2 Evidence of Accelerating Warming

The progression from a gentle (yellow) to a steeper (orange) and then the steepest (red) trend line demonstrates that not only is Kebbi warming, but the rate of warming is increasing. The region has experienced markedly higher temperatures in more recent years.
This trend is consistent with global climate change, but it has local impacts, such as: Increased heat stress and health issues, Reduced agricultural yields (e.g, heat-sensitive crops), water stress, especially during dry seasons, Increased desertification or land degradation risk.

3.2.1 Kogi State, Nigeria (1951-2023)

As shown in Figure 7, the following were noted:

1. *Seasonal Temperature Cycle:* There is a distinct seasonal temperature cycle, with the highest temperature occurring in March and April (about 31–32°C) and the lowest temperature occurring in July and August (around 24– 26°C). With March to April marking the end of the dry season and the hottest months, and July–August marking the start of the rainy season, which brings cooling, this pattern mimics the normal wet-dry seasonal cycle of a tropical environment.
2. *Long-Term Warming Trend:* Over time, temperatures have clearly increased: Lower average temperatures are typically found in the first several decades (1951–1980), which are indicated by pale yellow to orange dots. The darker red to purple dots indicates the more recent decades (1991–2020), which have greater temperature values. This suggests that all months are seeing a long-term warming trend.
3. *Current Trends in Climatology (1991–2020):* The current climatological average (1991–2020) is shown by the black line. This trend line, which is above the majority of previous decades, confirms that average

temperatures have risen recently. As of right now, average temperatures are primarily above 28°C, reaching a peak of about 30.5°C in March and April.

4. *Increased Variability:* From 2001 to 2020, the dots' (scatter) distribution has widened, indicating: Greater inter-annual variability (some years are significantly hotter or cooler than others). Extreme temperatures are more common, particularly during the hot months.
There has been a noticeable increase in the average monthly surface air temperature in Kogi, Nigeria, between 1951 and 2020. Although the seasonal pattern is still present, recent decades have seen much higher temperatures with more dramatic and variable values than previous eras. This trend aligns with broader patterns of global and regional climate change.

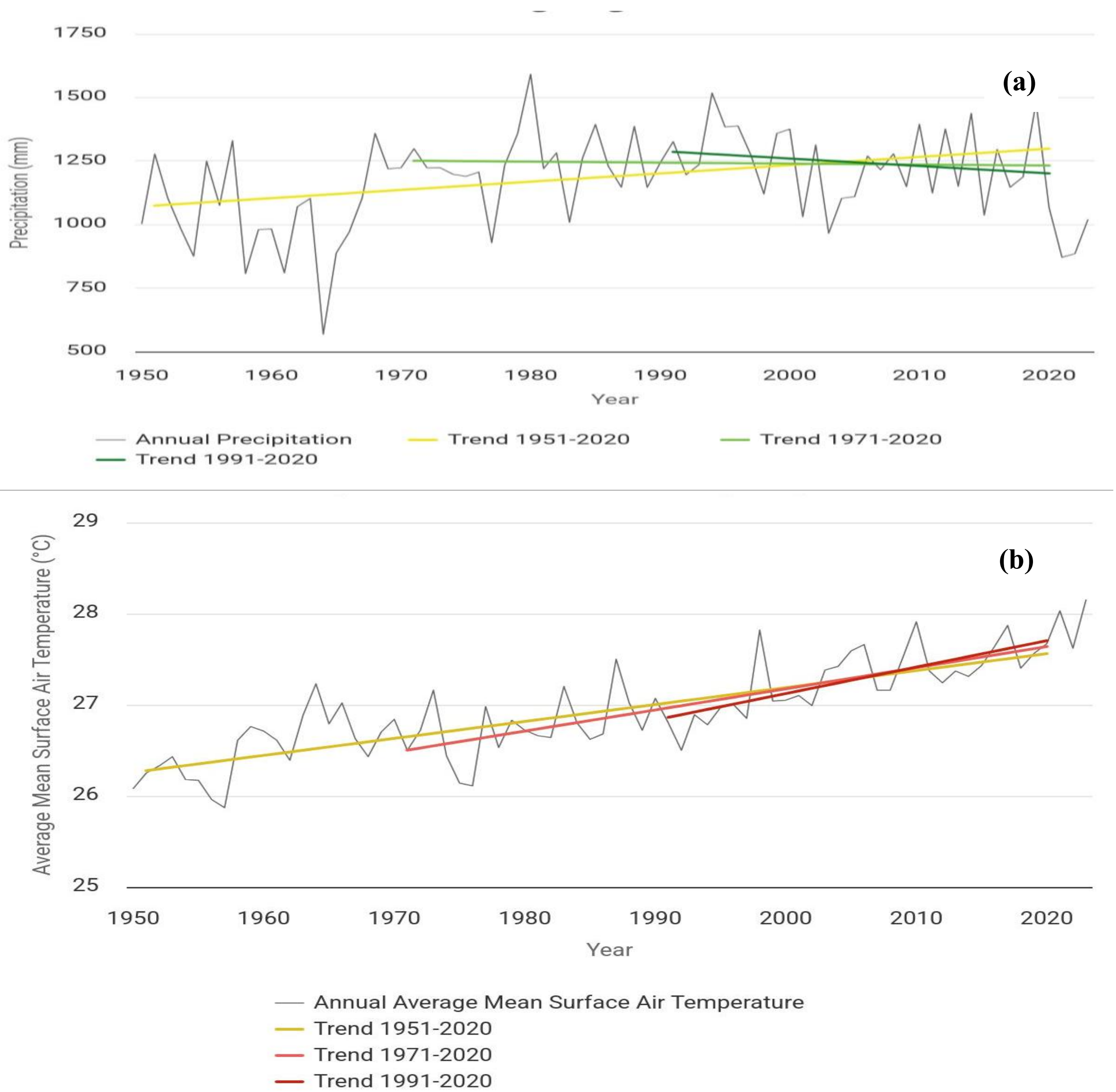


Figure 7: Average Mean Surface Air Temperature and Precipitation Annual Trends with Significant of Trend per Decade (1951-2020) in Kogi State, Nigeria

3.2.2 The hydrological and environmental factors that contribute to inter-annual variability and change in climatic parameter over Sudan Sahelian Zone

The Sudano-Sahelian region of Nigeria has long been considered a climate hotspot in terms of vulnerability, with its greater exposure to the changing precipitation patterns, coupled with increasing human activity and global warming, increasing the risks of frequent floods. This study has provided extensive analysis of long-term trends in temperatures and precipitation for the region, yielding critical insights into regional climate dynamics, human influences and hydrological responses. The results provide a strong scientific basis for comprehending the complex issues raised by flooding and for developing targeted actions that guarantee resilience and sustainable adaptation in this ecologically delicate area. Flooding is a common and increasingly severe environmental catastrophe in the Sudano-Sahelian region of Nigeria, which is an extremely sensitive ecological tract with a semi-arid climate, fragile soils and high climate variability. Through a methodical analysis of climate and hydrological changes in a variety of locales, this study has offered fresh perspectives on the region's multifaceted flood management options and problems. In-depth analysis of the available data between 1951 and 2020 has revealed that Sudano-Sahelian zone is experiencing significant warming, with a mean temperature rise of about 1.0 to 1.4 °C, especially since the 1990s. The primary results of the study indicate that Sudano-Sahelian zone sees a complex geo-spatial variability in precipitation, and a warming acceleration:
i. *Increased surface temperatures:* Surface temperature increases in the region were approximately 1.0 to 1.4ºC over the last 70 years (from 1951 to 2020), with the most significant warming observed in the pre-monsoon months (February-May). This warming effect worsens in fast urbanising regions such as Jimeta-Yola, and results in higher evapotranspiration and reduced soil moisture levels.

ii. *Modifying patterns of precipitation:* There is now increased geographical heterogeneity and instability in the rainfall regime.

a. In the northern parts, such as Kebbi and Jigawa States, there is significant decrease in annual rainfall and reduction in wet season, which increases the risk of drought and reduces agro-ecological production. The conflicting effect was observed in Kogi with a tendency towards increased precipitation, which indicates large regional variations likely due to complex interactions between oceanic teleconnections and monsoonal flux. In addition to this warming, there are increases in rainfall variability, including reduced rainfall and wet seasons in Northern States, such as Kebbi and Jigawa, leading to shorter and heavier rainy seasons and reduced average annual rainfall.

b. Intra-regional hydrological diversity and complex monsoon patterns can be seen as the annual rainfall increased in some regions, for example Kogi, while the premonsoon months (February – May) are warmer, with the increased warming leading to increased soil desiccation and evapotranspiration, which increases surface runoff and the risk of flooding when rains do occur.
c. Anthropogenic effects like urbanization (Jimeta-Yola's built-up area increased by 240% since 1990) and land-use change (loss of forest cover by over 50% since 1990) raise the likelihood of more frequent and intense floods.

iii. *Flood exacerbating factors:* These involve extensive loss of forest cover (>50%), accelerated urbanization (some cities had a 240% increase in built-up areas since 1990), and land-use changes that reduced the natural flood protection. These causes, compounded by global scale factors such as greenhouse gas emissions and oscillatory climatic phenomena increase the timing and intensity of floods.

iv. Seasonality and hydrological trends: While the overall seasonal rainfall volume exhibits declining trends or high variability elsewhere, peak rainfall months show notable intensification in some locations. The rainy season's shortening and shifting affects agricultural calendars and makes areas more susceptible to flooding. The combined data emphasizes that floods in this area are caused by a combination of climatic, environmental, and socioeconomic factors in addition to unusual rainfall.

3.3 Implications of Floods in the Sudano-Sahelian Region

In the Sudano-Sahelian region, floods have serious consequences:

i. *Food security and agricultural sustainability:* Flooding events disrupt the normal agricultural activities, reduce soil fertility and affect crops during critical growth phases. Unpredictability of rainfall adds to the difficulties of planting times, contributing to food shortages and putting at risk the rural livelihoods, especially in an area where agriculture is largely rain-fed.
ii. *Employment and Facilities:* Homes, roads, and drainage systems are all harmed by floodwaters, which results in financial losses, the destruction of assets, and displacement. Growing towns' safety and functionality are threatened by urban floods, which is exacerbated by impermeable surfaces and insufficient drainage.
iii. *Standing water from floods spreads water and vector-borne diseases, like cholera, typhoid and malaria.* Public health vulnerabilities are often made worse by the psychological strain and displacement brought on by flood catastrophes.
iv. *Degradation of Natural Resources:* Deforestation and overexploitation reduces the strength of natural flood barriers, making the flooding process destructive. The region's rural and urban communities are facing threats to their sustainability because of the increasing flood risks, if immediate and well-coordinated action is not taken.

4.0 Conclusion

This study has carried out a detailed evaluation of long-term temperature and precipitation trends across selected states within Nigeria's Sudano-Sahelian zone, revealing a clear and consistent pattern of climate change over the period 1951–2023. The results indicate that mean surface air temperature (SAT) increased at all studied locations and is increasing at an accelerating rate, especially since the 1990s. Decadal analyses also show that warming rates have accelerated with time, suggesting a change from moderate, over the past few centuries, to more pronounced and persistent over the last few decades. The study also shows an increased climatic variability, which includes more rainfall variability, besides the rise in temperature. There are also weak spatial patterns of hydrological responses, with some regions displaying decreasing and more variable precipitation trends that increase drought and agricultural stress, while others display increasing trends in some areas. This variability indicates the interaction between climatic drivers at a large scale and environmental conditions at a local scale. Global warming, changing precipitation patterns and anthropogenic land use changes (e.g. deforestation and accelerated urbanization) have greatly exacerbated environmental hazards in the region.
These changes have led to a rise in evapotranspiration, decreased soil moisture, and change in the duration of wet seasons in certain locations, while causing increased flood risk in other locations. This means that the Sudano-Sahelian region is facing a double climate-related challenge of both drought and flooding conditions in the region, which have significant impacts on agriculture, water resources, public health, infrastructure, and livelihoods. The evidence overall is that the climate change in the region is not only occurring, but is also getting more complicated in space and time, and is accelerating.

The findings highlight the necessity for ways to tackle adaptation that are more integrated, based on climate science, sustainable land management, better urban planning and better governance systems. Improving resilience in the Sudano-Sahelian zone will need to be done in a coordinated manner, taking into consideration both environmental and socio-economic factors driving vulnerability and ensuring long-term sustainability and climate risk reduction.

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Cite this article as:

Ayanlade O.S., Akinade O.E., Ayoola P.O., Muzhda Q.Q. and Oyewole O.O. (2026). Spatio-temporal Analysis of Rainfall and Temperature Trends in the Sudano-Sahelian Zone of Nigeria Using Long-Time Data. *Nigerian Journal of Environmental Sciences and Technology*, 10(1), pp. 53-69. https://doi.org/10.36263/nijest.2026.01.12