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Climate variability and its long-term trends in central Taraba, Nigeria: implications for local ecosystems and rural livelihoods

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Abstract. This study examines the long-term trends of climate variability in Central Taraba, Nigeria, with a focus on analyzing temperature and rainfall patterns from 1980 to 2020. Central Taraba has witnessed notable shifts in climate patterns, characterized by increasing temperatures, erratic rainfall, and prolonged periods of drought and excessive rainfall. These climatic changes pose significant threats to local ecosystems and rural livelihoods, which rely heavily on rain-fed agriculture and natural resources. The research highlights significant fluctuations in both rainfall and temperature, underscoring the challenges posed by climate variability to the region's ecological and socio-economic systems. The primary objectives of this study are to examine the extent of climate variability on key ecosystem services, assess its impacts on local livelihoods, and identify sustainable management strategies to address these effects. Results show a clear upward trend in both minimum and maximum temperatures across the study area, with some towns experiencing more pronounced increases in minimum temperatures. Rainfall patterns reveal an erratic trend with periods of both drought and excessive rainfall, though a slight but statistically insignificant downward trend in rainfall was observed in most towns. These climatic shifts have profound implications for agriculture, water resources, and rural livelihoods, as communities in the region heavily depend on rain-fed farming and natural ecosystems for sustenance. The study also underscores the pressing need for adaptive strategies such as climate-resilient agriculture and improved water resource management to mitigate the adverse effects of climate variability. Recommendations emphasize strengthening community resilience and integrating climate data into regional development policies to safeguard local livelihoods and ecosystems from future climate-related risks.

Keywords. Central Taraba, climate variability, ecosystem services, provisioning services & rural livelihoods.

1. Introduction

Climate variability refers to the variations in climatic elements such as temperature, precipitation, and extreme weather events over a period of time, driven by both natural and anthropogenic factors. In recent decades, climate variability has become a critical issue affecting ecosystems and livelihoods globally, with significant impacts observed in sub-Saharan Africa, including Nigeria. Central Taraba, a region in northeastern Nigeria, has witnessed notable shifts in its climate patterns, especially in temperature and rainfall, with far-reaching consequences for agriculture, water resources, and the environment [1]. Understanding these long-term trends is essential for developing strategies to mitigate the adverse effects on local ecosystems and rural communities that rely on them.

Research has consistently shown that climate variability is becoming more pronounced, particularly in tropical regions like Nigeria. According to the Intergovernmental Panel on Climate Change [2], global temperatures have risen by approximately 1.1°C since the pre-industrial era, and this warming trend is more pronounced in tropical regions. The IPCC also warns that rainfall patterns in West Africa are becoming increasingly unpredictable, with alternating periods of extreme dryness and intense rainfall. This variability is particularly concerning for countries like Nigeria, where agriculture is predominantly rain-fed, and rural livelihoods are closely tied to the natural environment.

Central Taraba, located within the tropical grassland savanna ecological zones, has experienced significant climate variability over the past four decades. The region's climate, characterized by a wet season (May to October) and a dry season (November to April), has become increasingly unpredictable, with shifts in both rainfall intensity and duration. Historical climate data from 1980 to 2020 indicate rising temperatures and fluctuating rainfall patterns, which have direct implications for the region's agricultural productivity, water availability, and biodiversity. These climatic shifts are not isolated phenomena; they are part of broader global and regional changes driven by greenhouse gas emissions, deforestation, and land-use changes [3].

2. Statement of research problem

Climate variability has emerged as one of the most pressing environmental challenges globally, with significant consequences for regions heavily dependent on agriculture and natural resources, such as Central Taraba, Nigeria. Over the past four decades, this region has experienced notable shifts in both temperature and rainfall patterns, characterized by increasing temperatures, erratic rainfall, and prolonged periods of drought or excessive rainfall. These climatic changes have profound implications for local ecosystems and the livelihoods that rely on them for survival.

Rural communities in Central Taraba depend heavily on rain-fed agriculture, forestry, and natural water resources for their economic activities and sustenance. The disruption of rainfall patterns and rising temperatures are already threatening agricultural productivity, food security, and water availability. Crops, livestock, and natural ecosystems, which form the backbone of rural livelihoods, are increasingly vulnerable to these climatic shifts. As rainfall becomes less predictable, agricultural cycles are destabilized, leading to lower yields and heightened economic insecurity for farmers [3]. Rising temperatures also exacerbate water scarcity by increasing evaporation rates, compounding the challenges related to water access and usage for both agriculture and domestic needs [4].

Despite the observable impacts of climate variability, there is limited localized research on its specific patterns in Central Taraba and how these trends are affecting the region's ecosystems and socio-economic systems. Many studies on climate change in Nigeria tend to focus on broader regional impacts or sector-specific issues, leaving a significant knowledge gap in understanding how long-term climate variability is altering the natural environment and rural livelihoods in Central Taraba [5]. Furthermore, while global and regional climate models indicate that West Africa is likely to experience increasingly pronounced climate variability, there is insufficient localized data to inform effective adaptation strategies tailored to the unique environmental and socio-economic contexts of Central Taraba [2].

The lack of comprehensive, region-specific data on the impacts of climate variability complicates efforts to develop targeted, sustainable responses. Without a detailed understanding of the long-term trends in temperature and rainfall, policymakers, local communities, and development agencies are left without the critical insights needed to mitigate the risks posed by climate variability [6]. This knowledge gap also limits the ability to design adaptive strategies that would protect local ecosystems and secure the livelihoods of rural populations dependent on these ecosystems.

This research aims to address these gaps by providing a detailed analysis of the long-term trends in climate variability in Central Taraba, specifically focusing on temperature and rainfall patterns from 1980 to 2020. The study examines how these trends affect agricultural productivity, water resources, and ecosystem health, contributing to a more comprehensive understanding of the challenges facing rural communities in the region. By offering insights into how local ecosystems are responding to these climatic changes, this research will help inform the development of adaptive strategies to enhance the resilience of both human and natural systems to ongoing climate variability.

2.1 Research questions

i. To what extent do climate variability affected key ecosystem provisioning services in Central Taraba?
ii. What is the level and extent of the impact of changes in ecosystem services on local livelihoods and biodiversity
iii. How can sustainable ecosystem management be enhanced to mitigate the effects of climate variability?

2.2 Objectives of the study

i. Examine the nature and extensiveness of climate variability on ecosystem provisional services
ii. To Appraise the nature of the relationship between ecosystem changes and local livelihoods.
iii. To evaluate the adaptive responses by local communities to changes in ecosystem services.

3. Literature review

3.1 Climate variability and its global and regional context

Globally, climate variability has led to significant disruptions in ecosystems, with consequences for food security, water resources, and biodiversity. The increasing frequency and intensity of extreme weather events such as droughts, floods, and storms have posed a major threat to agricultural systems, especially in regions that rely on consistent climatic conditions for crop production [4]. The IPCC's Sixth Assessment Report [2] highlights that the impacts of climate variability are disproportionately felt in low- and middle-income countries, where limited resources and infrastructure exacerbate vulnerabilities.

In Africa, the effects of climate variability are particularly acute due to the region's reliance on natural resources and rain-fed agriculture. According to Niang [3], climate variability has caused shifts in rainfall patterns across much of West Africa, resulting in delayed planting seasons, crop failures, and reduced water availability. The African continent has also experienced rising temperatures, with some regions witnessing temperature increases above the global average. In Nigeria, these changes have had profound impacts on ecosystems and rural livelihoods, as the majority of the population depends on agriculture, fishing, and forestry for survival [5].

The impacts of climate variability on water resources are also critical. Water availability is highly sensitive to fluctuations in rainfall and temperature, with droughts leading to water scarcity and excessive rainfall causing flooding. In regions like Central Taraba, where water is essential for agriculture and domestic use, these climatic fluctuations directly affect the well-being of rural communities [7]. Research by Conway [8] underscores the importance of stable rainfall patterns for maintaining hydrological cycles, which in turn support ecosystems and human activities. As climate variability disrupts these cycles, water resources become more unpredictable, further stressing the resilience of ecosystems and communities.

3.2 Climate variability in central Taraba: an overview

Central Taraba is uniquely vulnerable to climate variability due to its ecological and socio-economic characteristics. The region is home to diverse ecosystems, including tropical rainforests, savannas, and wetlands, which provide essential ecosystem services such as water regulation, soil fertility, and biodiversity conservation [9]. However, these ecosystems are highly sensitive to changes in temperature and rainfall, with even small shifts in climate leading to significant disruptions in their functioning.

From 1980 to 2020, Central Taraba has experienced a consistent rise in both minimum and maximum temperatures, as well as erratic rainfall patterns. Historical data analyzed in this study show that while some years' experience droughts and reduced rainfall, others are marked by excessive rainfall that leads to flooding and soil erosion. These trends are reflective of broader regional patterns observed in West Africa, where climate variability is driven by factors such as ocean-atmosphere interactions, deforestation, and land-use change [3].

One of the most significant impacts of climate variability in Central Taraba is on agricultural productivity. Agriculture in the region is predominantly rain-fed, with smallholder farmers relying on stable seasonal rainfall to cultivate crops such as maize, rice, cassava, and yams. However, erratic rainfall patterns, coupled with rising temperatures, have disrupted planting and harvesting schedules, leading to lower crop yields and increased food insecurity [10]. Similar findings have been reported in other parts of Nigeria, where climate variability has reduced agricultural productivity and increased vulnerability to hunger and poverty [5].

Water availability is another critical issue linked to climate variability in Central Taraba. As rainfall patterns become more unpredictable, the availability of water for irrigation, livestock, and domestic use has become increasingly uncertain. Droughts reduce water levels in rivers and streams, while periods of excessive rainfall can cause flash floods that erode soils and damage infrastructure. These fluctuations in water availability have far-reaching implications for both ecosystems and rural livelihoods, as water is essential for sustaining agriculture, biodiversity, and human well-being [4].

The impacts of climate variability also extend to the region's biodiversity and forest ecosystems. Prolonged dry periods have contributed to the degradation of forest ecosystems, reducing the availability of non-timber forest products such as fruits, medicinal plants, and firewood, which are vital for rural livelihoods. Furthermore, increased temperatures and erratic rainfall have altered species composition and forest regeneration patterns, threatening the ecological balance of the region [11].

3.3 Implications for rural livelihoods

The socio-economic fabric of Central Taraba is closely tied to the health of its ecosystems, as the majority of the population relies on agriculture, forestry, and fishing for their livelihoods. Climate variability has heightened the vulnerability of rural households by disrupting the availability of essential resources such as food, water, and raw materials. As agricultural productivity declines and water resources become less reliable, rural communities face increasing challenges in sustaining their livelihoods.

In addition to direct impacts on food production and water availability, climate variability also affects the overall resilience of rural communities. Households that rely on a single source of income, such as farming, are particularly vulnerable to climatic shocks, as they lack the means to diversify their livelihoods in the face of crop failures or water shortages. This vulnerability is further compounded by limited access to credit, markets, and infrastructure, which hampers the ability of rural households to adapt to changing climatic conditions [6].

Thus, the long-term trends of climate variability in Central Taraba have profound implications for both ecosystems and rural livelihoods. As temperatures continue to rise and rainfall patterns become more erratic, the region's natural and socio-economic systems face increasing challenges. Understanding these trends and their impacts is essential for developing effective adaptation strategies that can mitigate the adverse effects of climate variability on the environment and local communities.

4. Methodology

4.1 Description of the study area

Taraba State Central senatorial zone/district is made up of five LGAs which include: Bali, Gashaka, Gassol, Kurmi and Sardauna Local Government Areas. The zone extends from latitude 6° 30'N to 8° 48'N of the Equator, and longitude 10° 01'E to 11° 50'E of the Meridian. This area is bounded by the Benue River to the west and shares borders with Adamawa State to the northeast and the Republic of Cameroon to the southeast. It also shares boundary with Karim-Lamido, Ardo-Kola, and Yorro LGAs to the North, Wukari and Donga LGAs, to the West and Ibi LGA to Northwest (Figure 1). The zone covers a total land area of 32,110.82 km². The zone is characterized by its diverse ecological zones and rich natural resources.

The study area is situated within the tropical grassland savanna ecological zones, characterized by distinct vegetation types that support a wide variety of wildlife and plant species. The Central Taraba zone is known for its rich biodiversity, including economically important species such as timber trees and non-timber forest products [12]. The region is predominantly used for agriculture and livestock grazing [11]. This ecological diversity enhances the region's capacity to provide essential ecosystem services, including food, water, and raw materials, critical for supporting rural livelihoods.

Central Taraba experiences a tropical climate, characterized by a distinct wet and dry season. The wet season typically occurs from May to October, with peak rainfall in July and August, while the dry season spans from November to April. The average annual rainfall ranges from 1,200 mm to 1,600 mm, with significant inter-annual variability [9]. Temperature in the region averages between 24°C and 30°C, with variations influenced by seasonal changes and elevation [9]. This climatic regime plays a crucial role in determining the agricultural cycles and the availability of water resources, which are essential for sustaining local communities.

The inhabitants of Central Taraba predominantly rely on agriculture, forestry, and fishing for their livelihoods.

Subsistence farming is a common practice, with crops such as maize, rice, cassava, and yams being cultivated. Additionally, the region's forests provide vital resources, including timber, fuelwood, and non-timber forest products, which are essential for both subsistence and income generation [12]. The socio-economic fabric of the region is intertwined with the health of its ecosystems, as these provisioning services directly influence food security and economic stability.

In recent years, Central Taraba has experienced significant climate variability, manifesting as irregular rainfall patterns, prolonged dry spells, and increased frequency of extreme weather events. These changes pose substantial risks to the ecosystems and the communities dependent on them, threatening agricultural productivity, water availability, and overall ecological balance [3]. The increasing pressure on ecosystem services from climate variability underscores the need for comprehensive research to understand the implications for rural livelihoods and sustainable management practices in Central Taraba.

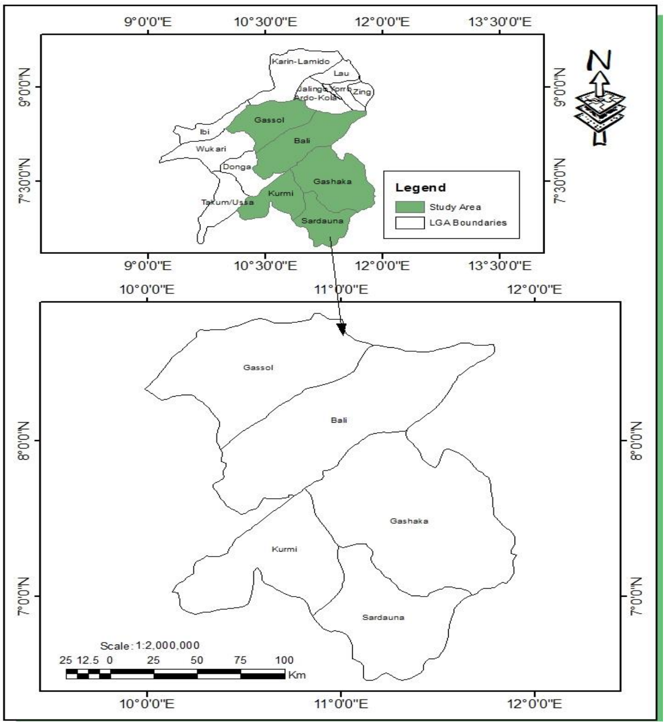

Figure 1. Map of Taraba central senatorial district.

5. Materials and methods

This study used secondary desk review of online materials and historical archival data obtained online to provide a holistic understanding of how climate variability affects ecosystem services, particularly those that support rural livelihoods. The study adopted a mixed-methods design, integrating both quantitative and qualitative approaches. This combination allows for the triangulation of data, enhancing the validity of the findings by providing multiple perspectives on the issue [13]. Quantitative data facilitated the analysis of relationships between climate variability and ecosystem service outputs.

This study utilized a novel geospatial approach, integrating Kriging interpolation with ArcGIS for high-resolution spatial pattern analysis of rainfall and temperature across Central Taraba. This method allows for the precise mapping of climate variability at a local level, enabling detailed identification of high-risk zones within the study area. Such spatial detail is particularly valuable in assessing the impacts of climate on ecosystem services, as it captures variations that might otherwise be missed in traditional analyses.

Mean annual rainfall data for a period of forty years (1980-2020) were obtained from DivaGIS climatic data. Two hundred and seventy-two (272) equidistant points covering the entire study area were generated using the fishnet module of ArcGIS 10.5. The generated points were used to extract the values of the rainfall data through the "extract by point" module of ArcGIS 10.5. The coordinates and the rainfall value of each of the points were used to interpolate the points using Kriging method of the Arctool box of ArcGIS 10.5. The output map was classified into four: high, moderately high, moderately low and low rainfall areas. Spatial pattern of rainfall shows the areas with high or low mean annual rainfall within the study area. The same procedures (using power.larc.nasa.gov/data-access-viewer climatic data instead of DivaGIS climatic data because of the non-availability of spatial data in power.larc.nasa.gov/data-access-viewer which is a point data) were used to generate the spatial patterns of mean temperature through kriging module of the ArcGIS 10.5.

The monthly climatic data for each of the forty years (1980-2020) period were obtained from power.larc.nasa.gov/data-access-viewer. Climatic parameters data for each of the months (January-December) were summed and were used to generate monthly mean records of the places using bar graph. The graphs show the mean of the climatic parameters of each month which was used to determine mean monthly records of the climatic elements according to the seasons in Nigeria; April-October and November-March.

The mean annual temperature was obtained by adding the values of minimum and maximum temperature of a particular point in a particular year and dividing the results by two using Microsoft Excel. The data were processed into line graphs while the trends, R^2 and other parameters were added in Microsoft excel environment.

In order to determine the trend in the time series of the annual rainfall and temperature in all the stations considered for the period 1980-2020, the simple regression analysis was used where by the values in the time series were regressed on time. The equation of the line of best fit was then computed using the Minitab statistical software. The equation is as follows;

$$Y = a - b\bar{x} + c$$

where *a*=intercept of the regression, *b*=regression of the coefficient and c=error term or residuals of the regression.

To determine whether the trend line in the time series analyzed is upward or downward, the simple correlation coefficient (r) was used and defined as follows;

$$r = \frac{\frac{\sum xy}{N} - \overline{xy}}{\sigma x - \sigma y}$$

where *r* is correlation coefficient, *N* is total number of observations in the series, *Y* is the observation in the series, *x* is the time in years, σx is the standard deviation of *x* and σy is the standard deviation of *y*. Where the value of (r) is positive, it indicates upward trend in the time series analysed and where the value of (r) is negative, it indicates down ward trend in the time series analyzed. The data were presented using tables, frequencies, figures and percentages.

To evaluate the accuracy of a forecasting model, three common error metrics are used: Mean Absolute Deviation (MAD): measures the average magnitude of errors (Lower values indicate better accuracy), Mean Square Error (MSE) calculates the average squared error (more sensitive to larger errors, lower values indicate better accuracy) and Mean Absolute Percent Error (MAPE) expresses errors as a percentage of actual values (Useful for comparing models with different scales, lower values indicate better accuracy). Therefore, Test of Mean Absolute Deviation (MAD), Mean Square Error (MSE), and Mean Absolute Percent Error (MAPE) for Moving Average (MA) were conducted on each moving average of maximum temperature and rainfall to determine the level of accuracy of the moving average for forecasting of the parameters.

6. Result and discussion

6.1 Variability in trend of rainfall in the study area

The result of the findings of the study on rainfall variability in the 5 LGAs of Taraba Central zone are presented in the figures below.

Figure 2 illustrates the annual mean rainfall patterns in Bali Town, Nigeria, from 1980 to 2020. The data reveals a noticeable variability in rainfall amounts over the years, with periods of higher and lower precipitation. While there is a slight downward trend suggested by the linear regression line (y=-1.2266x+1385). The annual change is not statistically significant due to the low R^2 value of 1.86%. This indicates a weak percentage contribution of change in years to changes in annual rainfall. In addition, the negative trend indicated that annual rainfall will decrease with increase in years. In another word, there is inverse relationship between annual rainfall and yearly increase. The 5-year moving average, however, offers a more smoothed representation of the rainfall trend. This line indicates a less pronounced downward trend compared to the annual data, suggesting a potential long-term pattern of decreasing rainfall.

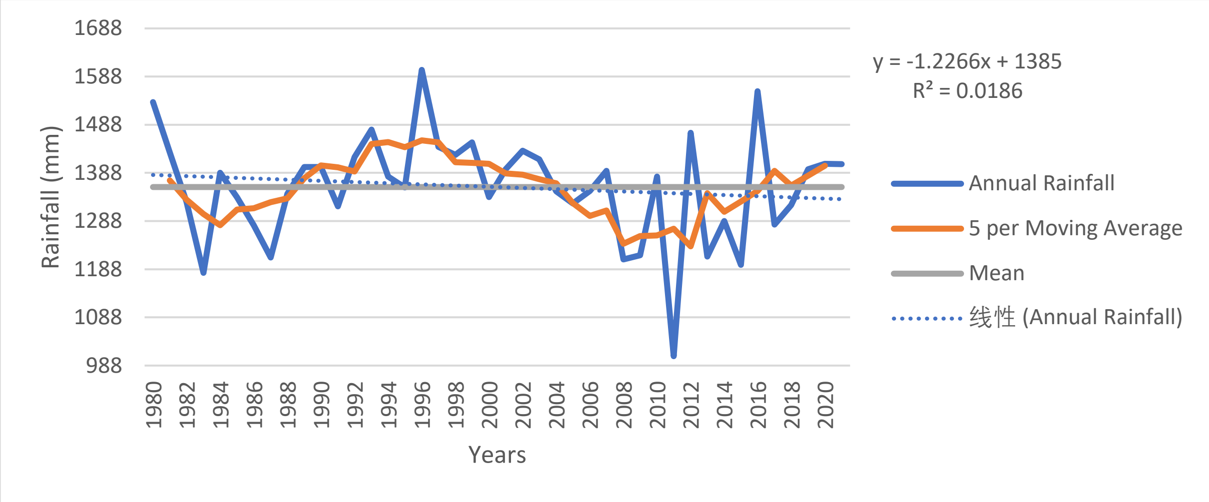

Figure 2. Trend in rainfall in Bali town (1980-2020).

Figure 3 illustrates the annual mean rainfall patterns in Gembu Town, Nigeria, from 1980 to 2020. The Figure 3 reveals fluctuating rainfall amounts, with periods of both high and low precipitation. While a slight decreasing trend is suggested by the linear regression line (y=-0.9669x+1743.6), it's not statistically significant due to the weak correlation (R^2=0.017). This indicates a weak relationship between the years and the rainfall amounts, suggesting that the observed decreasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced downward trend compared to the annual data, suggesting a potential long-term pattern of decreasing rainfall. These rainfall fluctuations can significantly impact ecosystem provisioning services in Central Taraba, such as agriculture, water resources, forestry, and biodiversity.

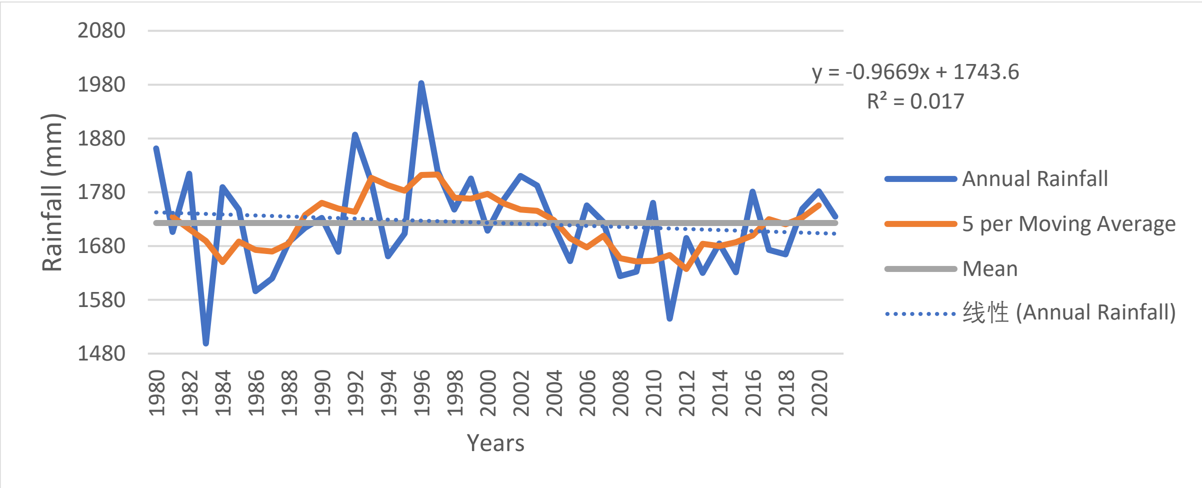

Figure 3. Trend in rainfall in Gembu town (1980-2020).

Figure 4 illustrates the annual mean rainfall patterns in Mutum Biyu Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in rainfall amounts, with periods of both high and low precipitation. While a slight decreasing trend is suggested by the linear regression line (y=-0.9982x+1224.3), it's not statistically significant due to the weak correlation (R^2=0.013). This indicates a weak relationship between the years and the rainfall amounts, suggesting that the observed decreasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced downward trend compared to the annual data, suggesting a potential long-term pattern of decreasing rainfall. These rainfall fluctuations can significantly impact ecosystem provisioning services in Central Taraba, such as agriculture, water resources, forestry, and biodiversity.

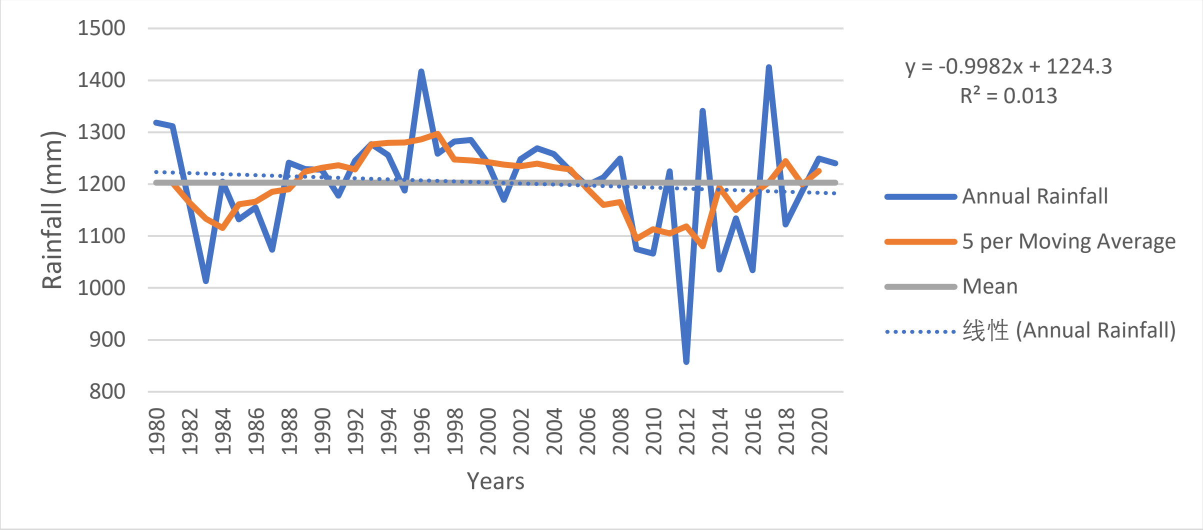

Figure 4. Trend in rainfall in Mutum Biyu town (1980-2020).

Figure 5 illustrates the annual mean rainfall patterns in Serti Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in rainfall amounts, with periods of both high and low precipitation. While a slight decreasing trend is suggested by the linear regression line (y=-1.6743x+1496), it's not statistically significant due to the weak correlation (R^2=0.0291). This indicates a weak relationship between the years and the rainfall amounts, suggesting that the observed decreasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced downward trend compared to the annual data, suggesting a potential long-term pattern of decreasing rainfall. These rainfall fluctuations can significantly impact ecosystem provisioning services in Central Taraba, such as agriculture, water resources, forestry, and biodiversity.

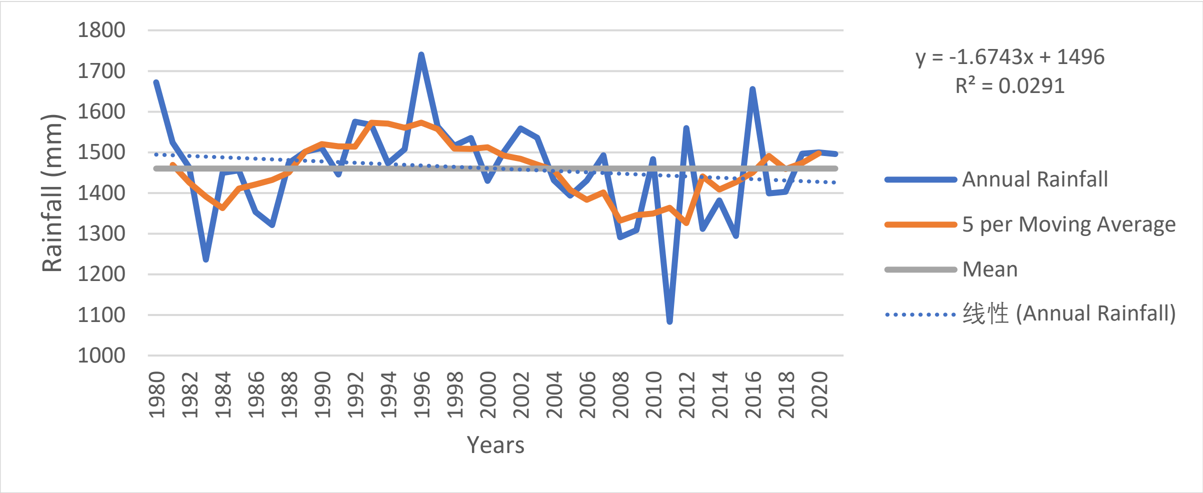

Figure 5. Trend in rainfall in Serti town (1980-2020).

Figure 6 illustrates the annual mean rainfall patterns in Baissa Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in rainfall amounts, with periods of both high and low precipitation. While a slight decreasing trend is suggested by the linear regression line (y=-0.4088x+1560.3), it's not statistically significant due to the weak correlation (R^2=0.0032). This indicates a weak relationship between the years and the rainfall amounts, suggesting that the observed decreasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced downward trend compared to the annual data, suggesting a potential long-term pattern of decreasing rainfall. These rainfall fluctuations can significantly impact ecosystem provisioning services in Central Taraba, such as agriculture, water resources, forestry, and biodiversity.

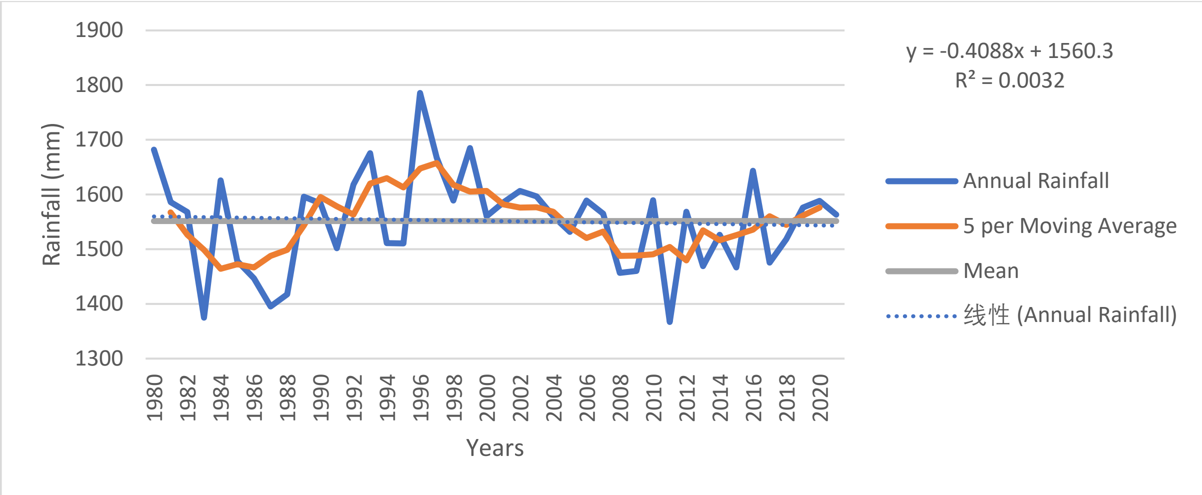

Figure 6. Trend in rainfall in Baissa town (1980-2020).

6.2 Trend of maximum and minimum temperature in the study area

Figure 7 illustrates the annual mean maximum temperature patterns in Bali Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in maximum temperatures, with periods of higher and lower values. While a slight increasing trend is suggested by the linear regression line (y=0.0068x+33.173), it's not statistically significant due to the weak correlation (R^2=0.0841). This indicates a weak relationship between the years and the maximum temperatures, suggesting that the observed increasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced upward trend compared to the annual data, suggesting a potential long-term pattern of increasing maximum temperatures.

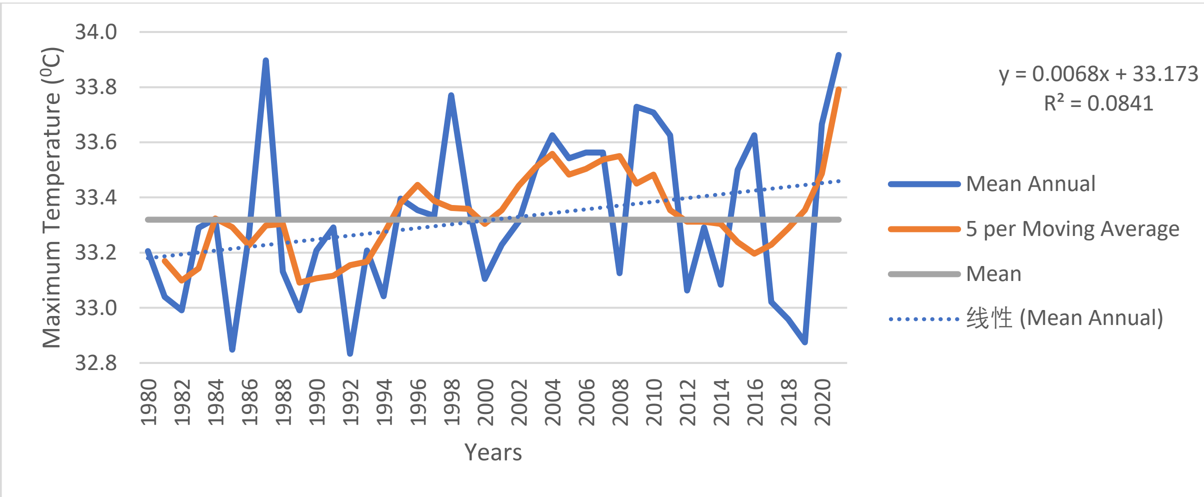

Figure 7. Trend of mean annual maximum temperature in Bali town (1980-2020).

Figure 8 illustrates the annual mean minimum temperature patterns in Bali Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in minimum temperatures, with periods of higher and lower values. While a slight increasing trend is suggested by the linear regression line (y=0.0217x+21.465), it's not statistically significant due to the weak correlation (R^2=0.5326). This indicates a weak relationship between the years and the minimum temperatures, suggesting that the observed increasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced upward trend compared to the annual data, suggesting a potential long-term pattern of increasing minimum temperatures.

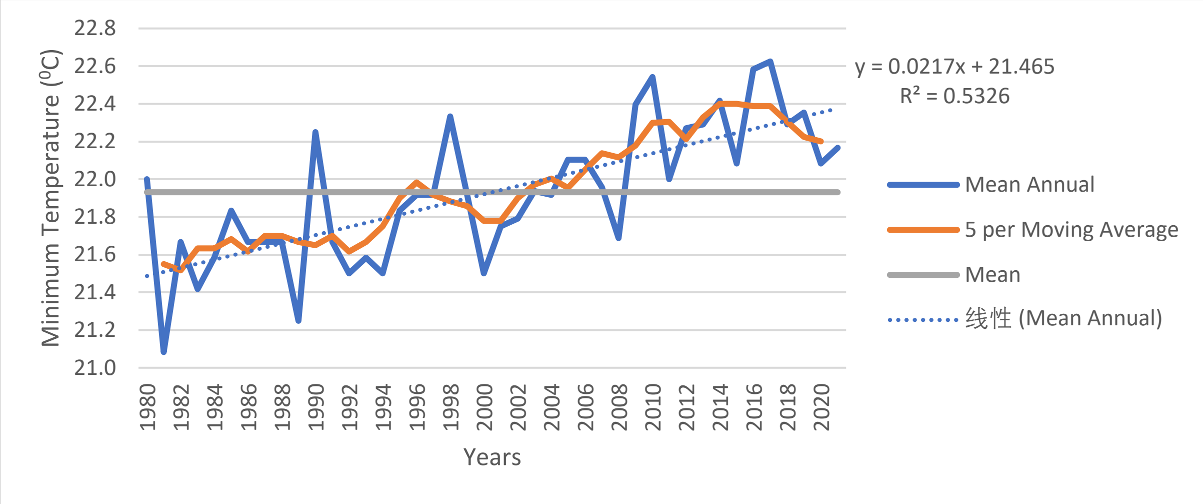

Figure 8. Trend of mean annual minimum temperature in Bali town (1980-2020).

Figure 9 illustrates the annual mean maximum temperature patterns in Gembu Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in maximum temperatures, with periods of higher and lower values. While a slight increasing trend is suggested by the linear regression line (y=0.0127x+26.935), it's not statistically significant due to the weak correlation (R^2=0.2104). This indicates a weak relationship between the years and the maximum temperatures, suggesting that the observed increasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced upward trend compared to the annual data, suggesting a potential long-term pattern of increasing minimum temperatures.

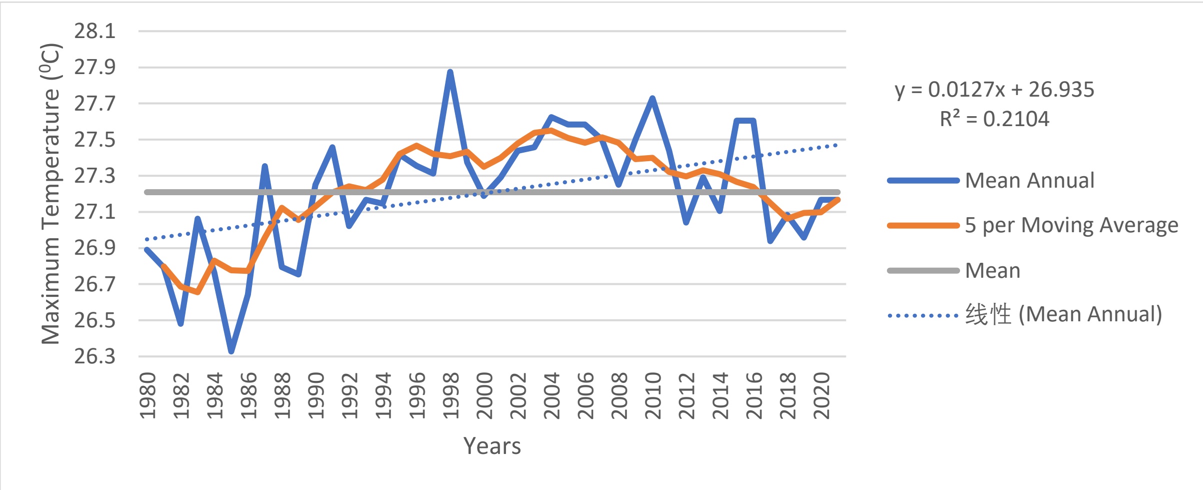

Figure 9. Trend of mean annual maximum temperature in Gembu town (1980-2020).

Figure 10 illustrates the annual mean minimum temperature patterns in Gembu Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in minimum temperatures, with periods of higher and lower values. While a slight increasing trend is suggested by the linear regression line (y=0.0456x+14.607), it's not statistically significant due to the weak correlation (R^2=0.7148). This indicates a weak relationship between the years and the minimum temperatures, suggesting that the observed increasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced upward trend compared to the annual data, suggesting a potential long-term pattern of increasing minimum temperatures.

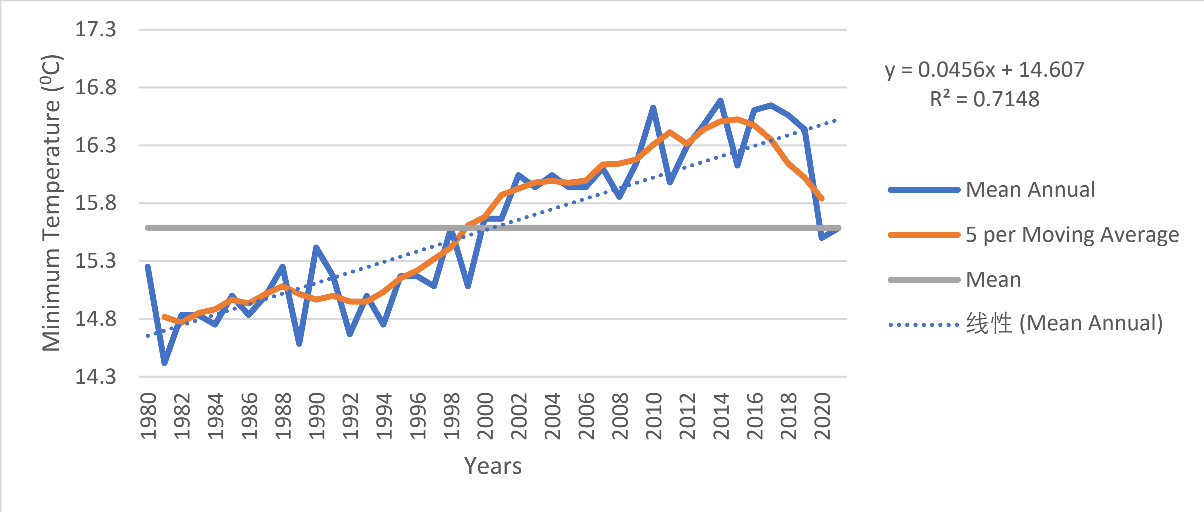

Figure 10. Trend of mean annual minimum temperature in Gembu town (1980-2020).

Figure 11 illustrates the annual mean maximum temperature patterns in Mutum Biyu Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in maximum temperatures, with periods of higher and lower values. While a slight increasing trend is suggested by the linear regression line (y=0.0084x+33.797), it's not statistically significant due to the weak correlation (R^2=0.1144). This indicates a weak relationship between the years and the maximum temperatures, suggesting that the observed increasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced upward trend compared to the annual data, suggesting a potential long-term pattern of increasing minimum temperatures.

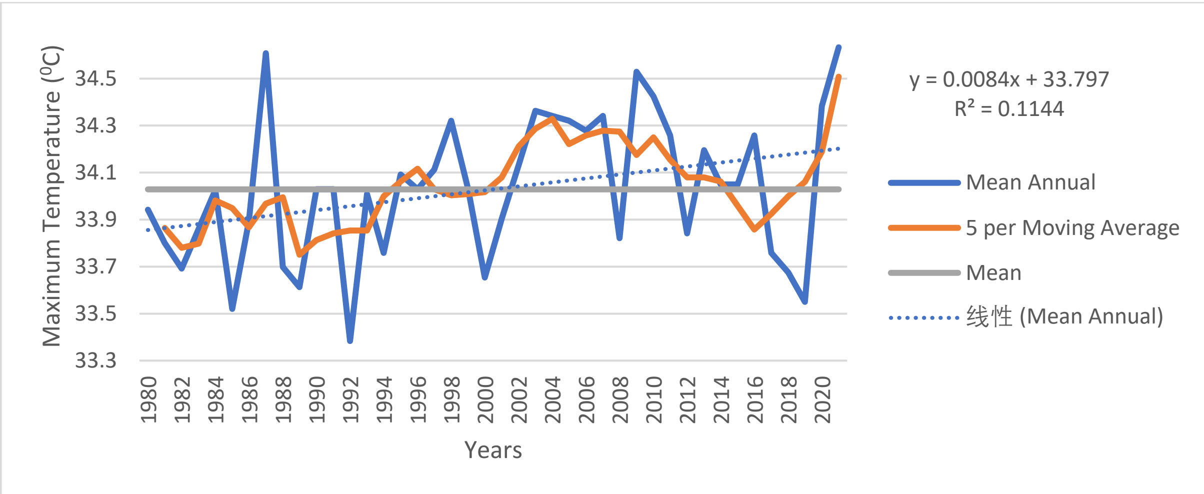

Figure 11. Trend of mean annual maximum temperature in Mutum Biyu town (1980-2020).

Figure 12 illustrates the annual mean minimum temperature patterns in Mutum Biyu Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in minimum temperatures, with periods of higher and lower values. While a slight increasing trend is suggested by the linear regression line (y=0.0183x+21.731), it's not statistically significant due to the weak correlation (R^2=0.4248). This indicates a weak relationship between the years and the minimum temperatures, suggesting that the observed increasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced upward trend compared to the annual data, suggesting a potential long-term pattern of increasing minimum temperatures.

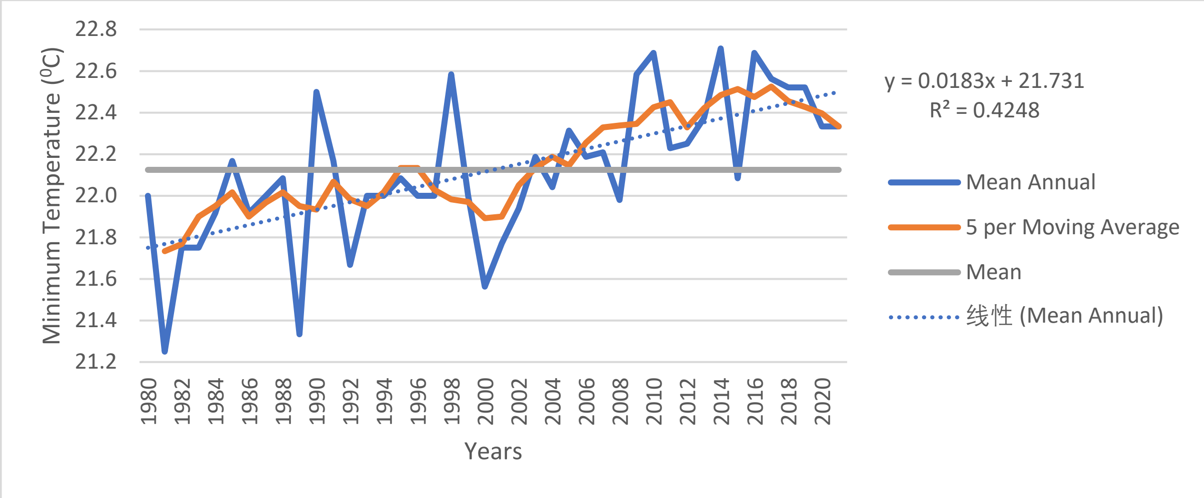

Figure 12. Trend of mean annual minimum temperature in Mutum Biyu town (1980-2020).

Figure 13 illustrates the annual mean maximum temperature patterns in Baissa Town, Nigeria, from 1980 to 2020. The data reveals a fluctuating trend in maximum temperatures, with periods of higher and lower values. While a slight increasing trend is suggested by the linear regression line (y=0.009x+32.032), it's not statistically significant due to the weak correlation (R^2=0.1528). This indicates a weak relationship between the years and the maximum temperatures, suggesting that the observed increasing trend could be due to random fluctuations in the data. The 5-year moving average indicates a less pronounced upward trend compared to the annual data, suggesting a potential long-term pattern of increasing minimum temperatures.

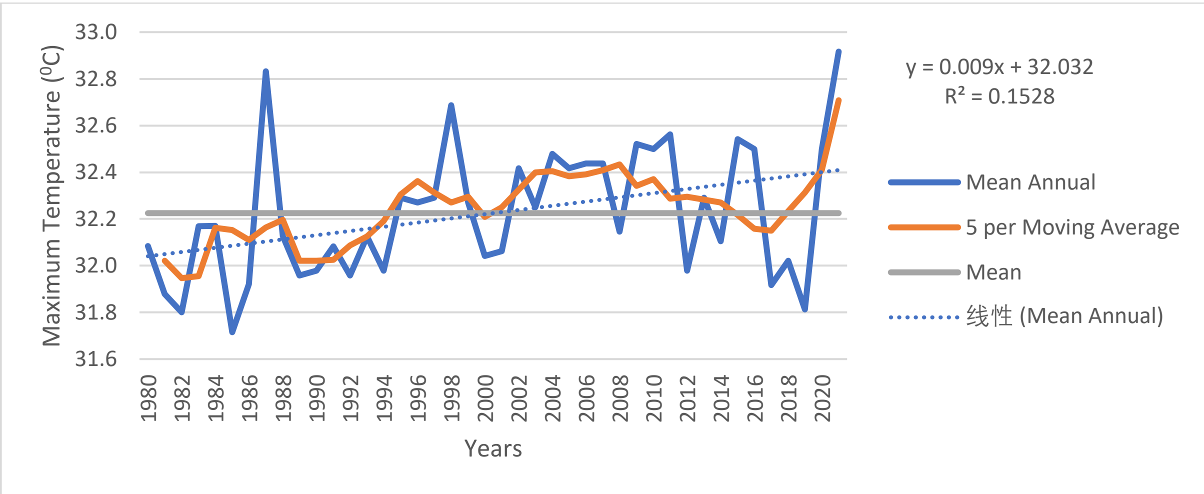

Figure 13. Trend of mean annual maximum temperature in Baissa town (1980-2020).

Figure 14 depicting the variability in the trend of minimum temperature in Baissa town reveals a clear upward trend over the study period (1980-2020). This trend is evident from the regression equation y=0.0247x+21.012, with an R^2 value of 0.629, indicating a moderately strong positive correlation between time and minimum temperature. The linear trend line, represented by the dashed line, visually confirms this upward trajectory. The mean annual minimum temperature, as shown by the blue line, fluctuates around the overall trend line, suggesting short-term variations within the long-term upward trend. The 5-year moving average, represented by the orange line, smooths out these fluctuations, providing a clearer picture of the general trend.

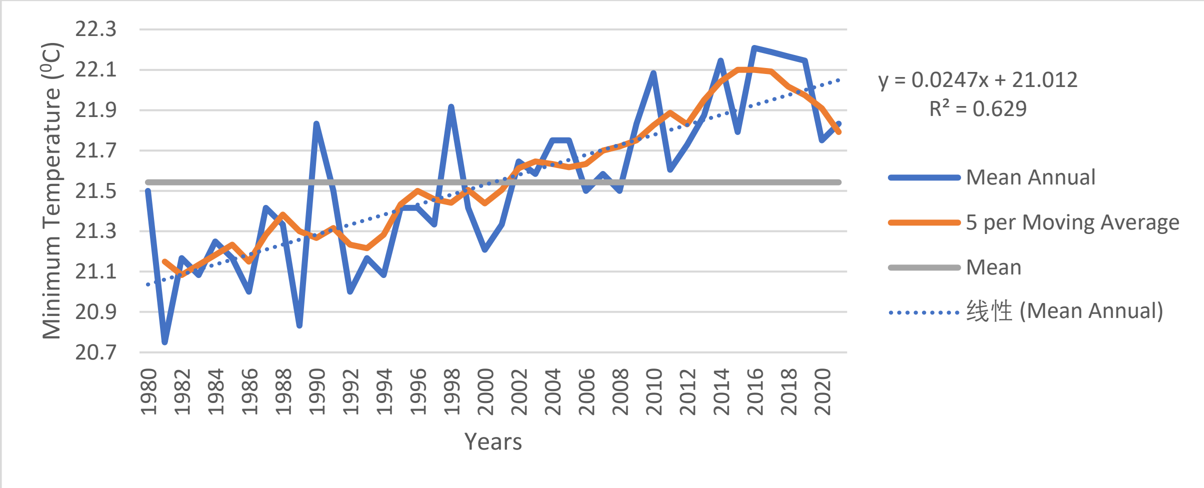

Figure 14. Trend of mean annual minimum temperature in Baissa town (1980-2020).

Figure 15 depicting the variability in the trend of maximum temperature in Sert town reveals a slight downward trend over the study period (1980-2020). This trend is evident from the regression equation y=-0.0031x+32.207, with an R^2 value of 0.0105, indicating a very weak negative correlation between time and maximum temperature. The linear trend line, represented by the dashed line, visually confirms this downward trajectory, although the trend is not as pronounced as the upward trend observed in Baissa town. The mean annual maximum temperature, as shown by the blue line, fluctuates around the overall trend line, suggesting short-term variations within the long-term downward trend. The 5-year moving average, represented by the orange line, smooths out these fluctuations, providing a clearer picture of the general trend.

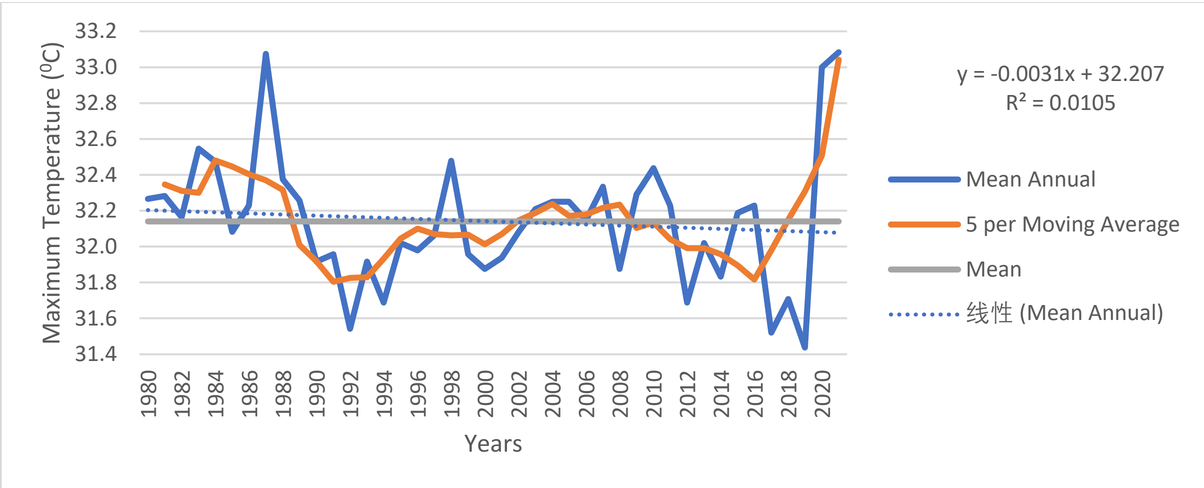

Figure 15. Trend of mean annual maximum temperature in Serti town (1980-2020).

Figure 16 depicting the variability in the trend of minimum temperature in Sert town reveals a slight upward trend over the study period (1980-2020). This trend is evident from the regression equation y=0.0171x+20.579, with an R^2 value of 0.3529, indicating a moderately weak positive correlation between time and minimum temperature. The linear trend line, represented by the dashed line, visually confirms this upward trajectory. The mean annual minimum temperature, as shown by the blue line, fluctuates around the overall trend line, suggesting short-term variations within the long-term upward trend. The 5-year moving average, represented by the orange line, smooths out these fluctuations, providing a clearer picture of the general trend.

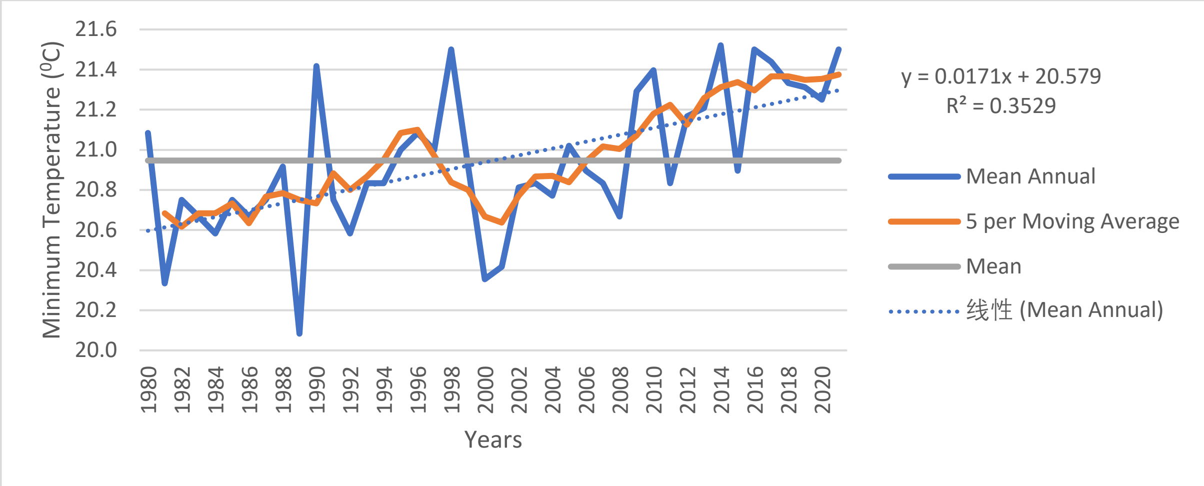

Figure 16. Trend of mean annual minimum temperature in Serti town (1980-2020).

6.3 Mean absolute deviation, mean square error or mean absolute percent error on moving average

Test of MAD, MSE, and MAPE for Moving Average (MA) were conducted on each moving average of maximum temperature to determine the level of accuracy of the moving average for forecasting of the parameter (Table 1). Following the result of the analysis, it was observed that MAD of all the selected stations is less than one (MAD<1).

Table 1. Mean absolute deviation, mean square error or mean absolute percent error on each moving average (maximum temperature).

	Maximum Temperature		
	Mean Absolute Deviation (MAD)	Mean Square Error (MSE)	Mean Absolute Percent Error (MAPE) (%)
Bali	0.184547	0.05569	0.554043
Gembu	0.168206	0.045305	0.618572
Mutum Biyu	0.18907	0.060236	0.557379
Kurmi	0.17077	0.050847	0.529573
Serti	0.208862	0.080657	0.650391

This clearly implies that the moving average model showed an excellent accuracy for temperature forecast in all the selected stations. In the same vein, the measure of average square differences (MSE) between actual and forecasted value of temperature displayed a very low value of less than 0.1 in all the stations of the study area. It therefore showed that the moving average model used for forecasting is accurate for the forecasting of temperature in the study area. Test of MAPE also showed a low percentage value in all the stations. It displayed a value of less than five percentage (MAPE<5%). This revealed that the level of the accuracy showed a low level of percentage error which is accurate for the forecasting of temperature in the area.

Following all the results presented (Table 2), it is clear that the moving average model is more accurate in forecasting temperature of Kurmi station based on the fact that it has low error level compared to other stations. It also implies that the model is fit for forecasting of temperature in the study area.

Table 2. Mean absolute deviation, mean square error or mean absolute percent error on each moving average (minimum temperature).

	Minimum Temperature		
	Mean Absolute Deviation (MAD)	Mean Square Error (MSE)	Mean Absolute Percent Error (MAPE) (%)
Bali	0.699856	12.03124	3.16629
Gembu	0.561958	5.98061	3.60771
Mutum Biyu	0.168648	0.056106	0.764161
Kurmi	0.17467	0.061741	0.835495
Serti	0.162051	0.041967	0.753231

Table 3 provides rainfall data for five different locations: Bali, Gembu, Mutum Biyu, Kurmi, and Serti. (Please note that this part was taken back to methodology in page 5 above).

Table 3. Mean absolute deviation, mean square error or mean absolute percent error on each moving average (rainfall).

	Rainfall		
	Mean Absolute Deviation (MAD)	Mean Square Error (MSE)	Mean Absolute Percent Error (MAPE) (%)
Bali	99.91351	56627.83	7.433884
Gembu	101.1278	79078.44	5.873851
Mutum Biyu	95.1787	46432.61	8.050982
Kurmi	106.9277	63756.96	7.441104
Serti	93.17334	64491.95	6.022927

Table 3 summarizes the rainfall analysis using key error metrics: Mean Absolute Deviation (MAD), Mean Square Error (MSE), and Mean Absolute Percent Error (MAPE). Table 3 reveals that Bali MAD 99.91, indicating an average deviation of about 99.91 units from the mean rainfall, MSE: 56,627.83, suggesting higher variability in data due to the squaring of deviations and MAPE: 7.43%, showing relatively low percentage errors compared to others.

For Gembu, MAD: 101.13 shows the highest among the locations, reflecting greater average deviation, MSE: 79,078.44, also the highest, indicating substantial data variability and MAPE: 5.87%, the lowest, suggesting Gembu's forecast has relatively smaller percentage errors despite high variability.

The Table 3 reveals that Mutum Biyu has MAD: 95.18, the lowest, showing smaller deviations from the mean rainfall, MSE: 46,432.61, the smallest, suggesting less variability in the dataset and MAPE: 8.05%, the highest percentage error, implying potential inaccuracies in percentage-based measures.

Kurmi has MAD: 106.93, indicating higher average deviations, MSE: 63,756.96, reflecting significant data variability and MAPE: 7.44%, relatively comparable to Bali. Serti has MAD: 93.17, showing relatively low deviations from the mean, MSE: 64,491.95, slightly higher variability compared to Mutum Biyu and MAPE: 6.02%, relatively moderate accuracy compared to others.

The findings of study in Table 3 reveals Serti and Mutum Biyu have the smallest MAD values, indicating more consistent rainfall patterns, while Mutum Biyu demonstrates the least variability (MSE), followed by Bali, suggesting more predictable rainfall. In terms of MAPE, Gembu shows the most accurate percentage error, while Mutum Biyu has the highest percentage error, indicating potential biases or inconsistencies in its forecast.

7. Discussion of findings

The results of this study highlight the significant variability in climate patterns observed in Central Taraba, Nigeria, from 1980 to 2020, with a focus on trends in rainfall and temperature. These findings are consistent with broader research on climate variability across West Africa, which has similarly documented erratic rainfall patterns and increasing temperatures [2, 3]. The analysis reveals fluctuations in both annual rainfall and temperature, with long-term trends indicating a slight but discernible decline in rainfall and an increase in both minimum and maximum temperatures. These climatic shifts have profound implications for the region's ecosystem provisioning services, including agriculture, water resources, and biodiversity, as well as the livelihoods of local communities reliant on these services.

7.1 Rainfall variability

The study's findings on rainfall trends show a general decline in rainfall amounts across the five local government areas (LGAs) of Central Taraba, albeit with notable fluctuations in specific years. In Bali, Gembu, Mutum Biyu, Serti, and Baissa towns, there is a consistent pattern of erratic rainfall, marked by alternating periods of drought and excessive rainfall. This variability is reflected in the regression analyses, which indicate weak correlations between rainfall and time in all LGAs. The low R^2 values, as observed in rainfall trends for towns such as Bali (R^2=1.86%) and Gembu (R^2=0.017%), suggest that annual changes in rainfall are driven largely by random climatic fluctuations rather than a strong long-term trend.

These findings align with broader regional studies that have reported similar trends of rainfall variability across West Africa. Ayanlade [5] reported that erratic rainfall patterns in southwestern Nigeria have disrupted agricultural cycles, leading to food insecurity. Furthermore, Niang [3] found that climate variability has caused delays in the onset of the rainy season, reducing the growing season for crops and increasing the likelihood of crop failures. The decreasing rainfall trends observed in this study indicate a potential long-term risk to rain-fed agriculture in Central Taraba, which is the primary source of livelihood for the region's rural communities.

7.2 Temperature variability

The study also reveals a clear upward trend in both minimum and maximum temperatures in Central Taraba. While the trends for maximum temperatures in towns like Mutum Biyu and Baissa show weak correlations, the minimum temperature trends are more pronounced. For example, in Baissa, the upward trend in minimum temperatures is statistically significant, with an R^2 value of 0.629, suggesting a moderate correlation between time and rising temperatures. This increase in minimum temperatures, coupled with erratic rainfall, poses significant challenges to agriculture and water resource management.

Rising temperatures exacerbate the challenges posed by declining rainfall, as higher temperatures increase evaporation rates, reducing the availability of water for both agricultural and domestic use. Research by Conway [8] and the IPCC [2] supports these findings, indicating that rising temperatures in sub-Saharan Africa are likely to worsen water scarcity and increase the frequency of droughts. In Central Taraba, this could have severe implications for crop yields, particularly for staple crops like maize and rice, which are highly sensitive to temperature fluctuations. Additionally, higher temperatures may lead to increased soil degradation, further reducing agricultural productivity [5].

Based on the findings of the study in Table 3 on the Mean Absolute Deviation (MAD), Gembu has the highest MAD, indicating that, on average, the model's predictions for Gembu were furthest from the actual rainfall values. Bali has the lowest MAD, suggesting that the model's predictions for Bali were the most accurate.

For Mean Square Error (MSE), Gembu also has the highest MSE, confirming that its predictions had the largest squared errors. Mutum Biyu has the lowest MSE, indicating that its predictions were the most accurate in terms of minimizing squared errors. For Mean Absolute Percent Error (MAPE) on the other hand, Mutum Biyu has the highest MAPE, suggesting that its percentage errors were the largest. Gembu has the lowest MAPE, indicating that its percentage errors were the smallest. Overall, Gembu seems to be the location where the model's predictions were least accurate, while Bali and Mutum Biyu appear to be the locations where the model's predictions were most accurate.

7.3 Implications for ecosystem provisioning services

The observed trends in climate variability have direct implications for the ecosystem services that support rural livelihoods in Central Taraba. As rainfall becomes more unpredictable and temperatures rise, the region's ecosystems--particularly its forests, wetlands, and savannas--are under increasing stress. This study found that prolonged dry periods and erratic rainfall have contributed to the degradation of forest ecosystems, reducing the availability of non-timber forest products such as fruits, medicinal plants, and firewood. Similar impacts on forest ecosystems have been reported in other parts of Africa, where climate variability has altered species composition and reduced biodiversity [11].

The loss of ecosystem services, such as water regulation and soil fertility, further threatens the resilience of rural communities that depend on these resources for agriculture, livestock rearing, and subsistence. As noted by Shackleton and Shackleton [6], non-timber forest products play a crucial role in sustaining rural livelihoods, particularly during periods of agricultural shortfalls. In Central Taraba, the decline in these ecosystem services due to climate variability could exacerbate poverty and food insecurity, as households become increasingly vulnerable to environmental shocks.

7.4 Socio-economic impacts and livelihood vulnerability

The socio-economic impacts of climate variability in Central Taraba are significant, with rural households experiencing heightened vulnerability due to the combined effects of erratic rainfall, rising temperatures, and ecosystem degradation. The disruption of agricultural cycles has led to lower crop yields, increased food insecurity, and economic instability. Similar findings have been reported by [14], who found that climate variability reduces household income and exacerbates poverty in rural areas dependent on agriculture.

Furthermore, the increasing frequency of extreme weather events, such as droughts and floods, places additional pressure on local communities. These events not only reduce agricultural productivity but also damage infrastructure, such as roads and irrigation systems, further isolating rural populations from markets and essential services [15]. The vulnerability of rural households in Central Taraba is compounded by limited access to credit, markets, and infrastructure, which hinders their ability to adapt to changing climatic conditions.

The findings of this study underscore the critical challenges posed by climate variability in Central Taraba, Nigeria. The observed trends of declining rainfall and rising temperatures are consistent with regional patterns of climate variability in West Africa. These climatic shifts have significant implications for the region's ecosystems, agricultural productivity, and rural livelihoods. Addressing these challenges will require comprehensive adaptation strategies that enhance the resilience of both human and natural systems to ongoing climate variability. Further research is needed to explore the long-term impacts of these climatic changes on specific ecosystem services and to develop sustainable management practices that can mitigate the risks posed by future climate variability.

8. Conclusions

This study has shown that climate variability in Central Taraba, Nigeria, from 1980 to 2020 is marked by rising temperatures and erratic rainfall, significantly impacting local ecosystems and rural livelihoods. Results indicate consistent increases in minimum and maximum temperatures alongside irregular rainfall, which has caused periods of drought and excessive rainfall, affecting crop yields, water availability, and overall environmental stability.

In addressing the research questions, the findings confirm that key ecosystem services--such as agriculture, forestry, and water resources--are affected by climate variability, directly impacting local livelihoods and biodiversity. Recommendations for climate-resilient agricultural practices, improved water management, and policy integration offer actionable steps for sustainable ecosystem management, responding effectively to the study's objectives.

In conclusion, Central Taraba's climate variability presents increasing challenges to both ecosystems and community well-being, underscoring the need for ongoing research and targeted adaptation strategies to enhance resilience. This study's findings lay a foundation for future research and policy aimed at mitigating the impacts of climate variability.

9. Recommendations

Based on the findings of the study, the following recommendations are made;

i. Enhanced Climate Monitoring and Data Collection: To better understand the ongoing changes in climate variability, there is a need for the establishment of more localized and consistent climate monitoring systems. Long-term data on temperature, rainfall, and extreme weather events will provide a more accurate basis for developing strategies to mitigate the impacts of climate change in Central Taraba.

ii. Promotion of Climate-Resilient Agriculture: Given the vulnerability of rain-fed agriculture to erratic weather patterns, introducing drought-resistant crops, improved irrigation techniques, and soil conservation practices will help local farmers adapt to changing climatic conditions and stabilize food production.

iii. Improved Water Resource Management: Water scarcity caused by irregular rainfall and increased evaporation calls for better water management strategies, including rainwater harvesting, efficient irrigation systems, and the restoration of natural water bodies to ensure sustainable water supply for agriculture and domestic use.
iv. Ecosystem Restoration and Conservation: Degraded ecosystems need to be rehabilitated to enhance their resilience to climate variability. Reforestation, protection of watersheds, and sustainable land use practices will help preserve biodiversity and maintain the ecological balance necessary for rural livelihoods.
v. Policy Integration and Community Engagement: Climate variability should be integrated into regional development policies, ensuring that climate adaptation measures are prioritized. Local communities must be actively involved in planning and implementing these strategies to foster resilience and ownership.

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