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TIME SERIES MODELLING AND FORECASTING OF TEMPERATURE AND RAINFALL IN NIGERIA USING ARIMA MODELS

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Background: Temperature and rainfall are among the most important indicators of climate change because they directly influence water resources, agricultural productivity, ecosystem functioning, and human well-being. Although numerous studies have investigated historical climatic trends in Nigeria, comparative long-term forecasting across major ecological zones remains limited. Consequently, knowledge of how future climatic trajectories may differ among contrasting environmental regions remains incomplete, constraining evidence-based climate adaptation and environmental management planning. **Objectives:** This study evaluated long-term temperature and rainfall dynamics across three contrasting ecological zones of Nigeria and assessed the capability of ARIMA models to forecast future climatic conditions. The study further examined spatial differences in projected climate responses and tested hypotheses regarding regional climate variability and model suitability. **Methods:** Observed temperature and rainfall records from the Nigerian Meteorological Agency covering the period 1985–2023 were obtained for Sokoto (Sahel savanna zone), Abuja (Guinea savanna zone), and Port Harcourt (coastal rainforest zone). Following quality control and pre-processing, annual temperature and rainfall series were developed and analysed using the Box–Jenkins ARIMA framework. Model identification was performed using autocorrelation and partial autocorrelation diagnostics, and ARIMA (1,1,3) was selected as the optimal forecasting model. Model adequacy was evaluated using stationary R^2, Mean Absolute Percentage Error (MAPE), residual diagnostics, and significance testing. Forecasts were generated for 2024–2050, while long-term monotonic trends were assessed using Kendall's tau-b correlation analysis. **Results:** The forecasts revealed statistically significant warming trends across all three ecological zones through 2050. Temperature exhibited strong positive temporal associations at Sokoto station ($\tau\_b = 0.884$), Abuja station ($\tau\_b = 0.539$), and Port Harcourt station ($\tau\_b = 0.914$) ($p < 0.001$). Rainfall projections demonstrated substantial spatial variability. Increasing rainfall trends were observed at Sokoto station ($\tau\_b = 0.572$, $p < 0.001$) and Port Harcourt station ($\tau\_b = 0.673$, $p < 0.001$), whereas Abuja station showed a significant decreasing rainfall trend ($\tau\_b = -0.519$, $p < 0.001$). Model performance statistics indicated acceptable predictive capability, with low temperature forecasting errors and satisfactory diagnostic results. The findings reveal spatially heterogeneous climate-change responses among Nigeria's major ecological zones and confirm the operational usefulness of ARIMA forecasting under data-limited conditions. **Conclusion:** The study confirmed significant future warming across all investigated ecological zones, while rainfall trajectories varied considerably among regions. All proposed hypotheses were supported. The findings fill an important gap in comparative climate forecasting across Nigeria's major ecological systems and provide evidence that regional climate adaptation strategies should account for substantial spatial differences in future climatic change.

Keywords: climate change; climate forecasting; ARIMA model; temperature trends; rainfall variability; time series analysis; ecological zones; climate adaptation; Nigeria.

INTRODUCTION

Climate change is widely regarded as one of the greatest environmental challenges facing the world today. It is related with various undesirable effects on water resources, agriculture, increase in temperature levels, rise in the sea level, flood, drought cycles, forests and biodiversity (Chung et al., 2011). Climatic fluctuations are mostly ruled by the deviations that occur with natural phenomena such as rainfall and temperature. They are important climatic parameters that exert substantial influence on agriculture, water resources, ecosystem functioning, and human well-being. Nigeria, based on its location, it is endowed with an equatorial climate. Two air masses, namely the dry tropical-continental air mass, and the warm, tropical maritime air mass controlled the climate of Nigeria. The demarcation of these air masses is known as the Inter-Tropical Convergence Zone (ITCZ). The Inter-Tropical Convergence Zone (ITCZ) is the principal weather maker that is responsible for the summer monsoon precipitation in the country. The two seasons observed in the country are rainy and dry seasons. The dry season (November-March) is due to the influence of the dry tropical-continental air mass from the Sahara Desert, while the rainy season (April-October) is due to the warm, tropical maritime air mass from the Atlantic Ocean (Adejuwon & Dada, 2021).

Several studies have investigated temperature and rainfall trends in Nigeria among which include Abatan et al. (2016) and Okoro et al. (2016) which found a significant increase in mean annual temperature, at Port Harcourt (coastal rainforest zone) with a rate of approximately 0.06 °C per decade. Orisakwe et al. (2017) reported a consistent warming trend at Abuja (Guinea savanna zone), Nigeria, with increasing mean temperatures observed over the study period (1983–2014). Similar warming tendencies, particularly during dry-season months, have been reported across Nigeria (Abatan et al., 2018). Nwabachili et al. (2021) analysed temperature variability at Sokoto (Sahel savanna zone) using historical meteorological records from the Nigerian Meteorological Agency (NiMet) covering several decades. Their study identified significant seasonal variations and an increasing trend in maximum temperature, indicating a warming tendency in the region. The findings further revealed a significant increase in mean annual temperatures over the past century, with particularly pronounced warming trends observed in recent decades. Similarly, Odiana & Ibrahim (2015), Odiana & Idahosa-Ohio (2023), and Odiana & Ochulor (2024) conducted studies on climate change and variability in Nigeria. Comparable studies have also been reported in other parts of Africa, including Matata et al. (2019), who investigated climate variability in the Igunga and Kishapu Districts of Tanzania, and Samwel et al. (2021), who examined climate trends in Kenya.

Rainfall and temperature remain important climatic variables whose forecasting remains challenging because of their inherent temporal variability and complexity (Nirmala &

Sundaram, 2010). Variability in time and space contribute to difficulties encountered in forecasting rainfall and temperature, moreover, the inability to access all the parameters that influence the rainfall and changes in the temperature of a locality also make climate forecasting challenging. Climate forecast is of great significance to the economic development of a region in terms of agriculture, watershed management and human health and management. Numerous time series models have been developed to advance the efficacy and precision of time series modelling and forecasting. The Autoregressive Integrated Moving Average (ARIMA) model introduced by Box & Jenkins (1970) is among the most broadly used and statistically recognized procedures of time series model forecasting (Ayoade, 2023).

El-Mallah & Elsharkawy (2016) used ARIMA model for temperature forecasting in Libya. Balyani et al. (2014) used ARIMA model in a 50-year time period (1955–2005) for Shiraz, south of Iran. The ARIMA approach has also been applied for climate forecasting in Turkey. Yeşil & Serttaş (2025) employed ARIMA and SARIMA models to forecast temperature patterns in Afyonkarahisar Province, demonstrating the suitability of these models for capturing seasonal temperature variations and predicting future temperature trends. Aweda et al. (2022) also used ARIMA model to forecast temperature, rainfall and other metrological data in some cities in Nigeria.

Despite the growing body of literature on climate variability and forecasting, several important scientific gaps remain. First, most studies conducted in Nigeria and other developing countries have primarily focused on historical trend analyses of temperature and rainfall, with limited attention given to long-term forecasting capable of supporting climate adaptation and resource management planning (Aweda et al., 2022; Aborass et al., 2022; Jafarian-Namin et al., 2024). Consequently, current knowledge remains insufficient regarding the potential long-term evolution of key climatic variables across contrasting ecological zones.

Second, previous studies have generally examined individual locations or relatively homogeneous climatic regions, thereby providing only a fragmented understanding of spatial differences in climate dynamics. Nigeria encompasses diverse ecological environments ranging from the semi-arid Sahel in the north to the humid coastal rainforest in the south, yet comparative forecasting studies across these major climatic zones remain scarce. As a result, the extent to which future temperature and rainfall trajectories differ among these ecological systems is still inadequately understood.

Third, although various forecasting approaches, including Artificial Neural Networks (ANNs), machine learning techniques, and hybrid models, have been increasingly applied in climate studies, their implementation often requires large datasets, complex parameterization, and extensive computational resources. In contrast, relatively few studies have systematically evaluated the capacity of the Autoregressive Integrated Moving Average (ARIMA) framework to provide reliable long-term forecasts of both temperature and rainfall across multiple ecological zones within a single national context (Ayoade, 2023; Aweda et al., 2022). This represents an important methodological gap, particularly in data-constrained regions where parsimonious forecasting approaches remain highly relevant.

Addressing these gaps is scientifically important because temperature and rainfall are among the most sensitive indicators of climate change and directly influence water resources, agricultural productivity, ecosystem stability, public health, and disaster risk management. Understanding their future trajectories is therefore essential for developing evidence-based adaptation strategies and strengthening climate resilience.

The present study seeks to fill these knowledge gaps by conducting a comparative long-term assessment of temperature and rainfall dynamics in three climatically distinct Nigerian cities: Sokoto (Sahel savanna zone), Abuja (Guinea savanna zone), and Port Harcourt (coastal rainforest zone). These locations were intentionally selected to represent major ecological zones characterized by different climatic controls and environmental conditions. By integrating historical observations with time-series forecasting, the study provides a broader understanding of the spatial heterogeneity of climate change signals across Nigeria.

Taking this into account, the present study aims to identify regional differences in future climatic trajectories and evaluate the suitability of ARIMA models for comparative climate forecasting under diverse environmental conditions. Unlike previous studies that focused primarily on trend detection or single-location forecasts, this work examines temperature and rainfall across three ecologically contrasting regions over an extended forecasting horizon (2024–2050).

Accordingly, the primary objective of this study is to develop and evaluate ARIMA-based forecasting models for predicting long-term changes in temperature and rainfall at Sokoto station, Abuja station, and Port Harcourt station, Nigeria. Specifically, the study aims to (i) examine historical temporal trends in temperature and rainfall between 1985 and 2023, (ii) generate forecasts for the period 2024–2050, (iii) assess spatial differences in projected climatic changes among contrasting ecological zones, and (iv) evaluate the reliability of ARIMA models for long-term climate forecasting.

The study is guided by the following scientific hypotheses:

H1: Temperature exhibits a statistically significant long-term increasing trend across all three ecological zones and will continue to increase during the forecast period.

H2: Rainfall dynamics differ among ecological zones, resulting in distinct future trajectories of precipitation across northern, central, and southern Nigeria.

H3: The magnitude and direction of projected climatic changes are influenced by ecological and geographical characteristics, producing spatially heterogeneous climate responses.

H4: ARIMA models provide statistically acceptable and operationally useful forecasts of temperature and rainfall in data-limited environments.

By addressing these hypotheses, the study contributes new evidence on the future evolution of climatic variables across major ecological zones in Nigeria and provides information that may support climate adaptation planning, environmental management, and sustainable development strategies.

MATERIALS AND METHODS

Study area

The study focuses on three Nigerian cities selected to represent distinct climatic zones: Sokoto in the Sahel savanna zone, Abuja in the Guinea savanna zone, and Port Harcourt in the coastal mangrove rainforest zone, as illustrated in Figure 1. These locations were selected to capture climatic variability across northern, central, and southern Nigeria.

Sokoto is located in north-western Nigeria and is characterized by a semi-arid climate with high temperatures and low annual rainfall. Abuja station, situated in central Nigeria, exhibits a tropical wet-and-dry climate influenced by its proximity to the Jos Plateau. Port Harcourt, located in the southern coastal region, experiences a humid tropical climate with high annual rainfall and relatively stable temperatures throughout the year.

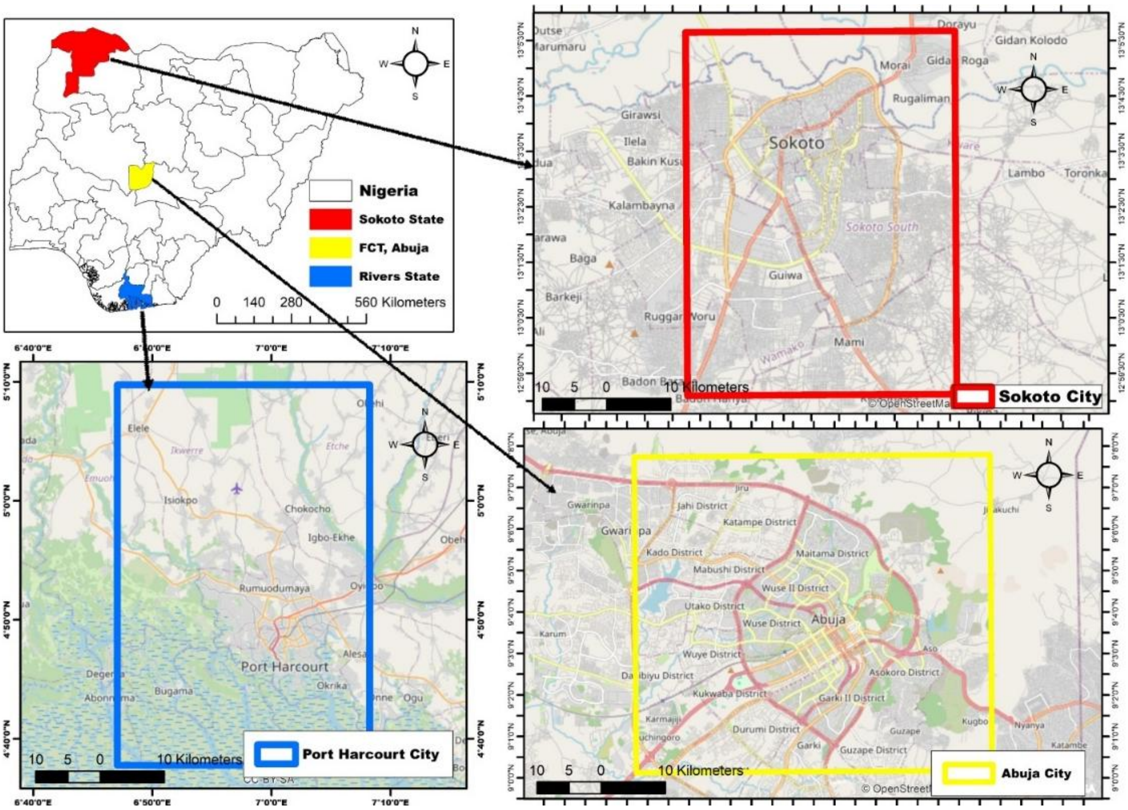


Figure 1. Map of study area showing the sampling sites

Data source and pre-processing

Temperature (°C) and rainfall (mm) data used in this study were obtained from the Nigerian Meteorological Agency (NiMet), which operates standardized meteorological observation stations across Nigeria. The data represent observational records collected from synoptic weather stations located at Sokoto station, Abuja station, and Port Harcourt station. The geographical coordinates and elevations of the stations are as follows:
– Sokoto station: latitude 13.01°N, longitude 5.25°E; elevation approximately 350 m above sea level;
– Abuja station: latitude 9.07°N, longitude 7.48°E; elevation approximately 840 m above sea level;
– Port Harcourt station: latitude 4.82°N, longitude 7.03°E; elevation approximately 18 m above sea level.

The dataset covers a 39-year period from 1985 to 2023 and consists of observed (in-situ) meteorological measurements, not reanalysis products. These observations are recorded using standard meteorological instruments maintained by NiMet in accordance with World Meteorological Organization (WMO) guidelines.

To ensure data reliability, the dataset underwent basic quality control procedures prior to analysis. These included:
– screening for missing values and inconsistencies in the time series;
– consistency checks to ensure continuity of observations across the study period.

Although the data obtained from NiMet are generally pre-validated, additional checks were performed to ensure suitability for time series modelling. The dataset was then aggregated into annual averages and totals for temperature and rainfall, respectively, before applying the Autoregressive Integrated Moving Average (ARIMA) model for forecasting.

Method of data collection and analysis

A schematic representation of the research workflow is presented in Figure 2 to enhance clarity, transparency, and reproducibility of the analytical process.

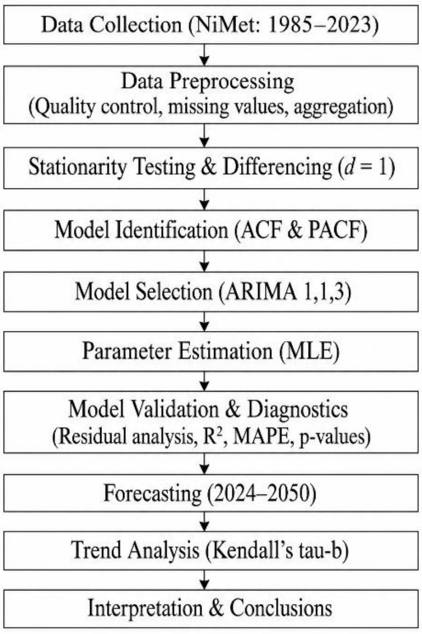


Figure 2. Flowchart of the ARIMA-based research methodology

Visualization of the analytical workflow

To enhance transparency and reproducibility of the study, the complete analytical workflow is visually documented in Figures 3–9. These figures provide step-by-step evidence of the dataset, pre-processing, model development, validation, and forecasting procedures used in this research.

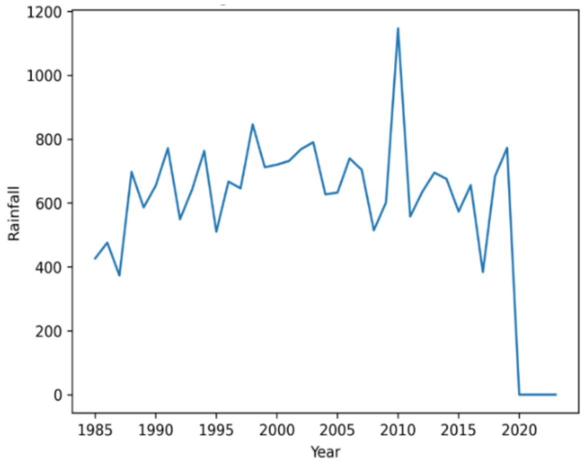


Figure 3. Overview of the raw rainfall dataset (1985–2023) extracted from NiMet prior to pre-processing and modelling

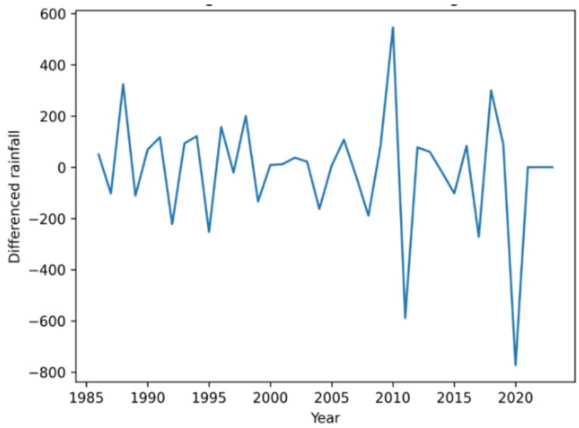


Figure 4. First-order differencing applied to the rainfall time series to achieve stationarity prior to ARIMA modelling

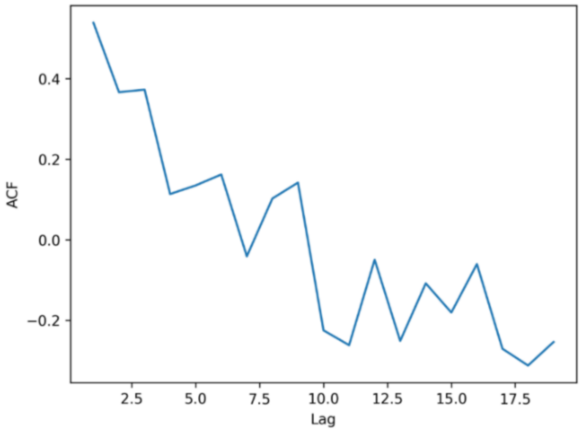


Figure 5. Autocorrelation Function (ACF) used to identify the moving-average component of the ARIMA model

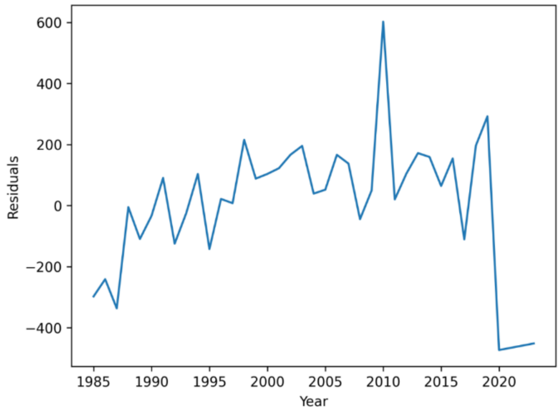


Figure 6. Residual diagnostics confirming absence of systematic autocorrelation and adequacy of the ARIMA model

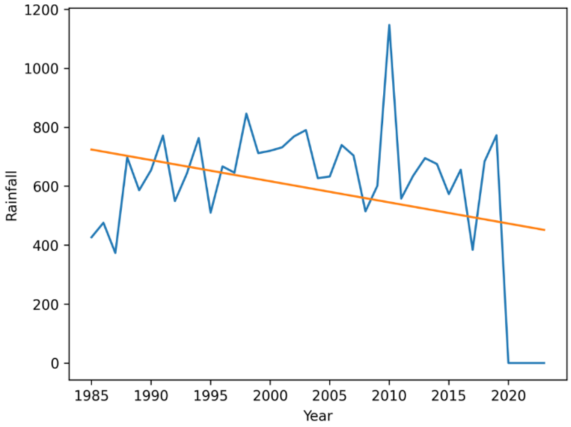


Figure 7. Comparison of observed and model-predicted rainfall values demonstrating strong model agreement

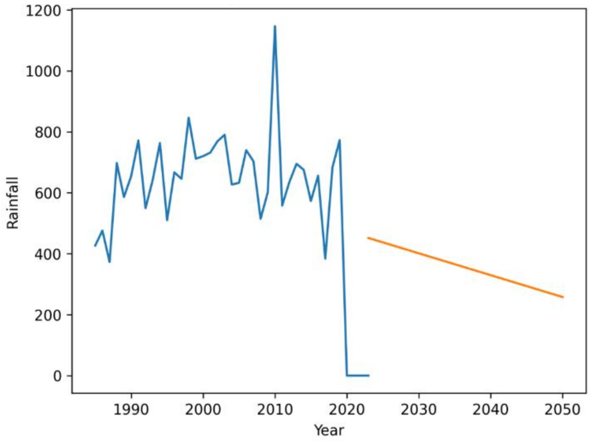


Figure 8. Forecast of rainfall up to 2050 using the fitted ARIMA model

Data preparation

The raw monthly temperature and rainfall data obtained from the Nigerian Meteorological Agency (NiMet) were first subjected to pre-processing. This included:
– handling missing values through interpolation where necessary;
– aggregation into annual series, where mean annual temperature and total annual rainfall were computed;
– visual inspection of time series plots to identify trends and irregularities;

– stationarity testing using differencing to remove trends and stabilize the mean.

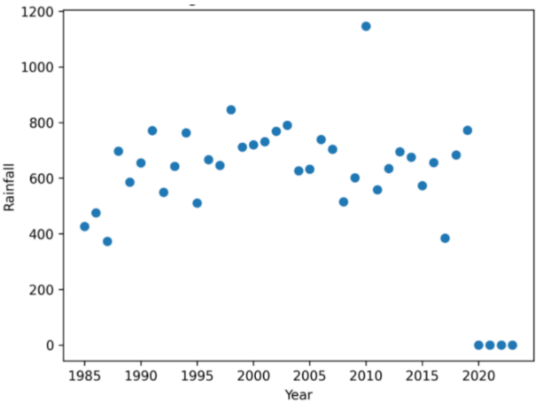


Figure 9. Scatterplot showing the monotonic temporal trend based on the Kendall's tau-b analysis

First-order differencing (d = 1) was applied to both temperature and rainfall series to achieve stationarity, as required for ARIMA modelling.

Model identification

Model identification was carried out using Autocorrelation Function (ACF) and Partial Autocorrelation Function (PACF) plots derived from the stationary series:
– the ACF plot suggested a gradual decay pattern, indicating the presence of a moving average component;
– the PACF plot indicated a limited number of significant lags, suggesting an autoregressive structure.

Based on these diagnostics, several candidate ARIMA models were tested, and ARIMA (1,1,3) was selected as the optimal model due to its superior statistical performance and stability across the datasets.

Parameter estimation and model selection

Model parameters (p, d, q) were estimated iteratively using maximum likelihood estimation. The selection of the ARIMA (1,1,3) model was based on the following criteria:
– statistical significance of model coefficients;
– goodness-of-fit indicators, including stationary R²;
– error minimization, assessed using Mean Absolute Percentage Error (MAPE);
– residual diagnostics, ensuring absence of autocorrelation.

The chosen ARIMA (1,1,3) model provided the best balance between model simplicity (parsimony) and predictive accuracy across all three study locations.

Model validation and diagnostic checking

To ensure model adequacy and reliability, several diagnostic checks were performed:
– residual analysis to confirm that residuals behave as white noise (i.e., no autocorrelation);
– statistical significance testing (p-values > 0.05) indicating good model fit;
– comparison of observed and predicted values to visually assess model performance.

The absence of systematic patterns in residuals confirmed that the model adequately captured the structure of the time series.

Accuracy metrics

Model performance and forecast accuracy were evaluated using the following metrics:
– stationary R²: measures the proportion of variance explained by the model;
– mean Absolute Percentage Error (MAPE): assesses forecasting accuracy as a percentage;
– significance values (p-values): used to evaluate model adequacy.

The relatively low MAPE values and acceptable R² across all stations indicate that the model provides reliable forecasts for both temperature and rainfall.

Forecasting procedure

After model validation, the fitted ARIMA (1,1,3) model was used to generate forecasts for temperature and rainfall from 2024 to 2050. Forecast outputs were analysed alongside historical data to evaluate long-term climatic trends.

Trend analysis

The Kendall rank correlation coefficient (Kendall's tau-b) was used to assess monotonic trends in temperature and rainfall over time. Statistical significance was evaluated at the 5% significance level ($p < 0.05$).

The moving average operator in the ARIMA model is expressed as:

$$\theta(U) = 1 - \theta_1 U - \theta_2 U^2 - \ldots - \theta_q U^q, \qquad (1)$$

where q is the order of the moving average process; θ_i are the moving average parameters (i = 1, 2, ..., q); U is the backward shift operator defined as:

$$UY_t = Y_{t-1}, \qquad (2)$$

The autoregressive operator is expressed as:

$$\mathrm{phi}(U) = 1 - \mathrm{phi}_1 U - \mathrm{phi}_2 U^2 - \cdots - \mathrm{phi}_p U^p, \qquad (3)$$

where p denotes the order of the autoregressive process; phi_i are the autoregressive parameters (i = 1, 2, ..., p).

The general ARIMA (p,d,q) model is written as:

$$\phi(U)(1 - U)^d Y_t = \theta(U)\varepsilon_t, \qquad (4)$$

where d represents the order of differencing; Y_t is the observed time series; ε_t is a white-noise error term.

The ARIMA model can also be expressed in expanded form as:

$$X_t = \phi_1 X_{t-1} + \phi_2 X_{t-2} + \cdots + \phi_p X_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \\ - \theta_2 \varepsilon_{t-2} - \cdots - \theta_q \varepsilon_{t-q}. \qquad (5)$$

The differenced series is defined as:

$$X_t = Y_t - Y_{t-1}, \qquad (6)$$

where X_t is the differenced series; ϕ_i are the autoregressive coefficients; θ_i are the moving average coefficients; ε_t denotes white noise.

All statistical analyses, including ARIMA model estimation, diagnostic testing, forecasting, and trend analysis, were conducted using IBM SPSS Statistics (Version 29.0). The analytical procedures described above enable full reproduction of the modelling framework and forecasting results.

Limitations of the study

This study is subject to several limitations that should be considered when interpreting the results. First, the use of a univariate ARIMA model assumes linear and stationary temporal dependence and does not incorporate exogenous climatic drivers that may influence temperature and rainfall variability. Consequently, important teleconnection patterns and large-scale climate forcings (e.g., atmospheric circulation processes) are not explicitly represented, which may limit the model's explanatory and predictive capacity.

Second, the use of annually aggregated data reduces temporal resolution and may obscure important intra-annual and seasonal variability, particularly for rainfall, where extreme events and seasonal dynamics play a critical role. This aggregation may therefore smooth variability and potentially underrepresent short-term extremes, thereby limiting the representation of important temporal fluctuations.

Third, although standard quality control procedures were applied, reliance on observational data from a limited number of meteorological stations may introduce spatial sampling bias and measurement uncertainty, potentially affecting the representativeness of the results for broader regional climate conditions.

In addition, forecast uncertainty was not explicitly quantified using probabilistic or ensemble-based approaches, limiting the assessment of forecast uncertainty and confidence intervals. The focus on mean trends rather than distributional characteristics further restricts the ability of the model to capture extreme climate events, which are often most relevant for impact assessments and informed climate-related decision-making processes.

Finally, the analysis is based on data from only three cities in Nigeria, which constrains the generalizability of the findings and limits the extent to which the results can be extrapolated to other climatic zones within the country or to regions with different environmental conditions.

RESULTS

This study presents results in a manner consistent with the methodological procedures outlined in the Box–Jenkins framework of the Autoregressive Integrated Moving Average (ARIMA). The outputs are organized to reflect model estimation, validation, and forecasting stages. Model performance is evaluated using statistical indicators such as stationary R^2, Mean Absolute Percentage Error (MAPE), and significance values (p-values), which provide evidence of the validity and reliability of the results across the different stages of the modelling process. Visual outputs of the ARIMA modelling workflow are presented in Figures 3–9 to facilitate interpretation of the analytical procedures and findings.

Temperature and rainfall forecasting at Sokoto station

The ARIMA model used is a good fit for both temperature and rainfall forecasting from 2024 to 2050, with p-values of 0.213 and 0.246 for temperature and rainfall, respectively, both of which are greater than the 0.05 significance threshold. The stationary R^2 values are 0.440 and 0.461 for temperature and rainfall, respectively, as shown in Tables 1 and 2, indicating an acceptable level of model performance and explanatory capability. The observed and forecast values reveal a consistent increasing trend in both temperature and rainfall, as shown in Figures 10 and 11. Therefore, it can be deduced that the future trend of temperature and rainfall in Sokoto is expected to continue increasing beyond 2024.

Table 1. ARIMA model summary for temperature

Statistic	Value
Stationary R^2	0.440
Mean Absolute Percentage Error (MAPE), %	1.013
Degrees of Freedom (DF)	14
p-value	0.213

Table 2. ARIMA model summary for rainfall

Statistic	Value
Stationary R^2	0.461
Mean Absolute Percentage Error (MAPE), %	15.655
Degrees of Freedom (DF)	15
p-value	0.246

The results of the Kendall rank correlation analysis (Kendall's tau-b), presented in Table 3, indicate a statistically significant positive association between the meteorological parameters and time over the period 1991–2050. For temperature, a very strong positive correlation was observed ($\tau\_b = 0.884$, $p < 0.001$), while rainfall exhibited a moderate positive correlation ($\tau\_b = 0.572$, $p < 0.001$). Since the p-values were less than 0.001, the null hypothesis (H_0), which states that there is no statistically significant relationship between the meteorological parameters and time, was rejected. These findings indicate statistically significant increasing trends in both temperature and rainfall at Sokoto station over the study period (1991–2050). The stronger correlation observed for temperature suggests a more consistent temporal pattern compared with rainfall, which typically exhibits greater natural variability. Overall, these results provide additional statistical support for the projected long-term changes identified through the ARIMA forecasting analysis.

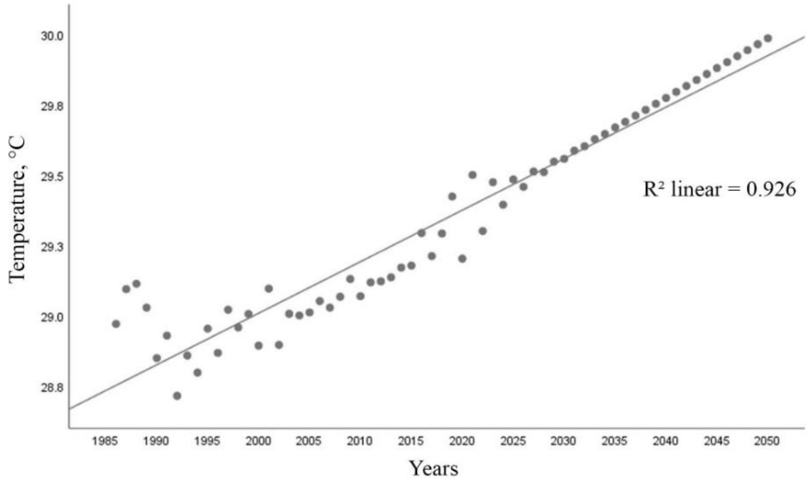


Figure 10. Scatterplot of forecasted temperature trend at Sokoto station

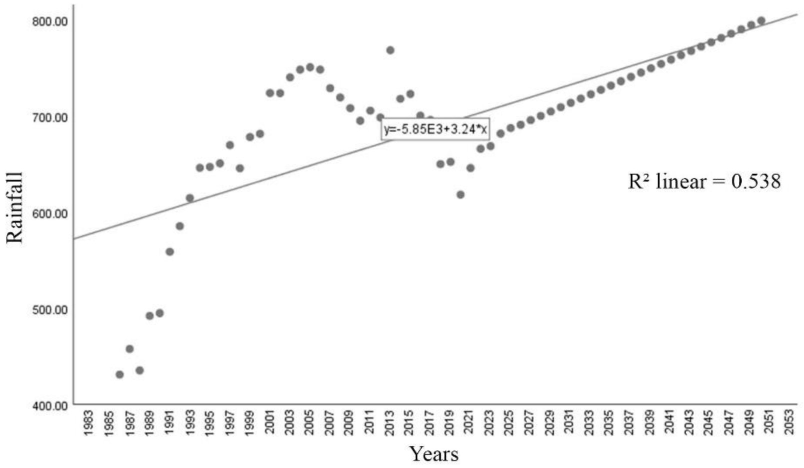


Figure 11. Scatterplot of forecasted rainfall trend at Sokoto station

Table 3. Kendall's tau-b correlation between year, temperature and rainfall (1991–2050)

Variables	Kendall's tau-b (τ_b)	p-value (2-tailed)	N
Year vs. temperature	0.884	<0.001	65
Year vs. rainfall	0.572	<0.001	66

The reliability of the model results is supported by acceptable goodness-of-fit statistics (R^2 values) and low forecast errors (MAPE). In addition, the non-significant results of the diagnostic tests ($p > 0.05$) suggest that the residuals are not statistically different from white noise, indicating that the model assumptions are satisfied. The close agreement between observed and predicted values (as shown in the Figures 10 and 11) further supports the adequacy of the model for forecasting.

Temperature and rainfall forecasting at Abuja station

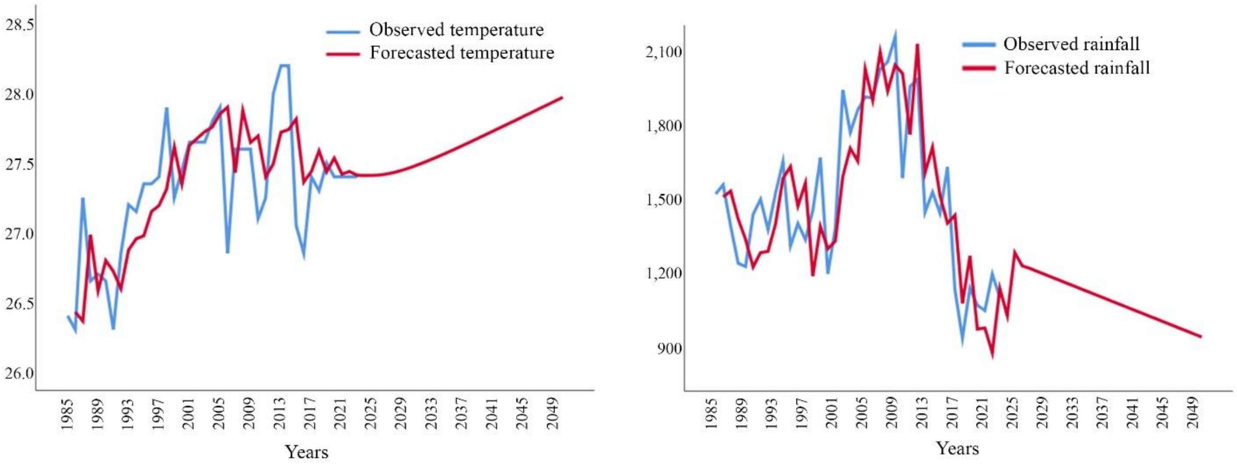
The ARIMA model demonstrates an adequate fit for both temperature and rainfall forecasting over the period 2024–2050 at Abuja station. The diagnostic p-values for temperature ($p = 0.945$) and rainfall ($p = 0.805$) are greater than 0.05, indicating that the model residuals are not statistically significant and satisfy the assumptions of model adequacy. The stationary R^2 values are relatively low for temperature (0.230) and moderate for rainfall (0.383), as shown in Table 4. In addition, visual comparison between observed and fitted values (Figure 12) indicates a reasonable agreement, supporting the reliability of the model.

Table 4. ARIMA model performance for temperature and rainfall forecast (2024–2050)

Variable	Stationary R²	MAPE	DF	p-value
Temperature	0.230	1.011	14	0.945
Rainfall	0.383	10.955	14	0.805

The forecast results suggest a decreasing trend in rainfall (Figure 13) and an increasing trend in temperature (Figure 14) over the study period. These projections imply that rainfall at Abuja station is likely to continue decreasing, while temperature is expected to increase beyond 2024.

The results of the Kendall's tau-b analysis (Table 5) indicate a statistically significant positive correlation between temperature and time over the period 1991–2050 (τ_b = 0.539, $p < 0.001$), while rainfall shows a statistically significant negative correlation with time (τ_b = –0.519, $p < 0.001$). These results suggest a statistically significant upward trend in temperature and a downward trend in rainfall at Abuja station over the study period, indicating continued changes in the local climatic conditions.



a b

Figure 12. Comparison between observed and forecasted values at Abuja station: a – temperature; b – rainfall

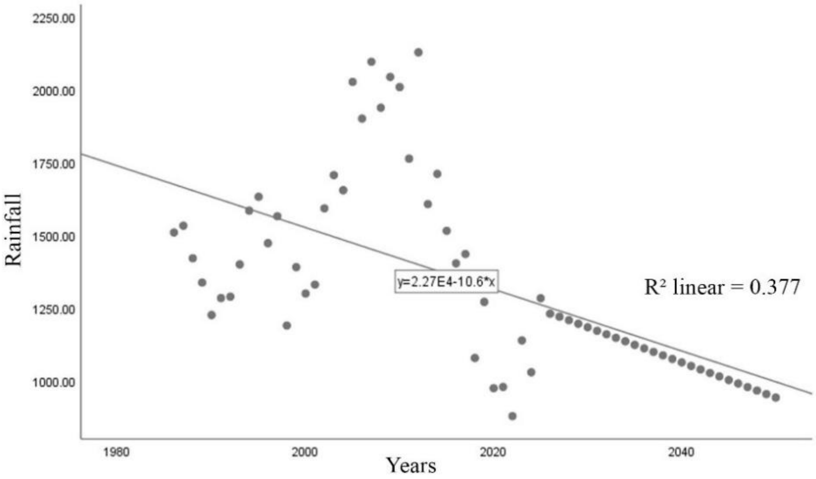


Figure 13. Scatterplot of forecasted rainfall trend at Abuja station

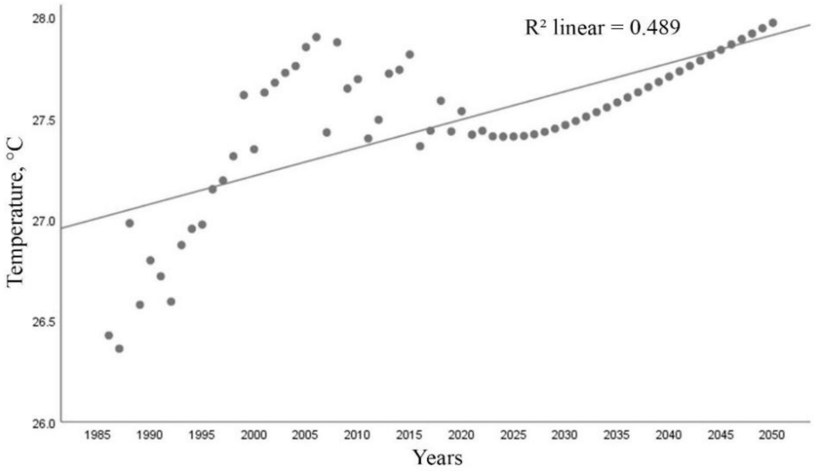


Figure 14. Scatterplot of forecasted temperature trend at Abuja station

Table 5. Kendall's tau-b correlation between year, temperature and rainfall (1991–2050), Abuja station

Variables	Kendall's tau-b (τ_b)	p-value (2-tailed)	N
Year vs. temperature	0.539	<0.001	65
Year vs. rainfall	–0.519	<0.001	66

Since the p-values are less than 0.05, the null hypothesis (H_0), which states that there is no statistically significant relationship between the meteorological variables and time, is rejected.

Temperature and rainfall forecasting at Port Harcourt station

The ARIMA model demonstrates an adequate fit for both temperature and rainfall forecasting over the period 2024–2050 at Port Harcourt station. The diagnostic p-values for temperature ($p = 0.949$) and rainfall ($p = 0.570$) are greater than 0.05, indicating that the residuals are not statistically significant and that the model assumptions are satisfied. The stationary R^2 values indicate moderate explanatory power for temperature (0.404) and rainfall (0.377), as shown in Table 6.

Table 6. ARIMA model performance for temperature and rainfall forecast (2024–2050), Port Harcourt

Variable	Stationary R²	MAPE	DF	p-value
Temperature	0.404	0.800	14	0.949
Rainfall	0.377	10.057	14	0.570

In addition, a visual comparison between the observed and predicted values (Figure 15) shows good agreement, further supporting the reliability of the model.

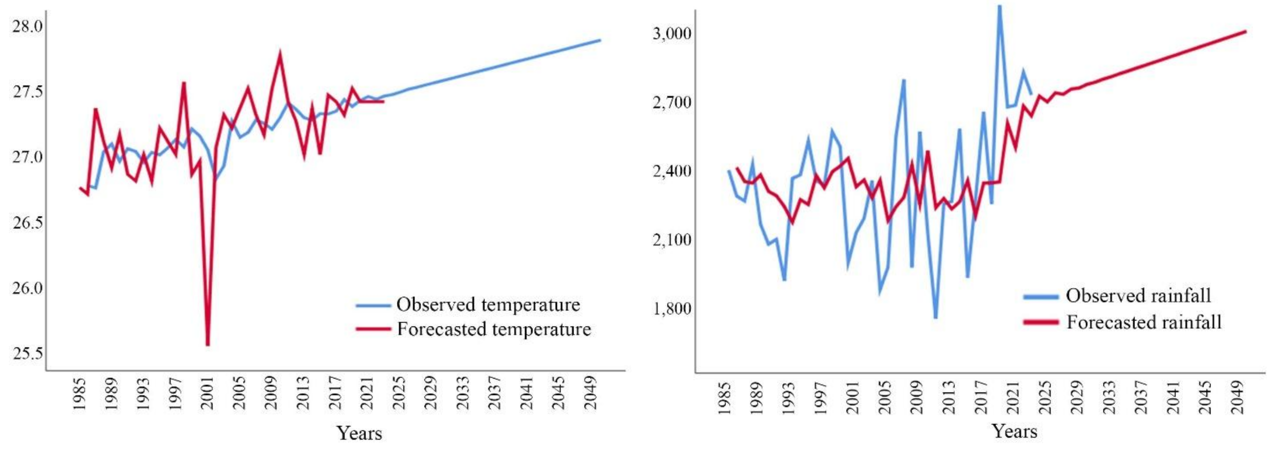
The forecast results indicate increasing trends in both temperature and rainfall (Figures 16 and 17). These projections suggest that temperature and rainfall at Port Harcourt station are likely to continue increasing beyond 2024.

The results of the Kendall's tau-b analysis (Table 7) indicate a statistically significant positive correlation between temperature and time over the period 1991–2050 ($\tau\_b = 0.914$, $p < 0.001$), and a statistically significant positive correlation between rainfall and time ($\tau\_b = 0.673$, $p < 0.001$). These findings suggest a strong upward trend in both temperature and rainfall at Port Harcourt station over the study period.

Table 7. Kendall's tau-b correlation between year, temperature and rainfall (1991–2050), Port Harcourt station

Variables	Kendall's tau-b (τ_b)	p-value (2-tailed)	N
Year vs. temperature	0.914	<0.001	65
Year vs. rainfall	0.673	<0.001	66

Since the p-values are less than 0.05, the null hypothesis (H_0), which states that there is no statistically significant relationship between the meteorological variables and time, is rejected.



a

b

Figure 15. Comparison between observed and forecasted values at Abuja station: a – temperature; b – rainfall

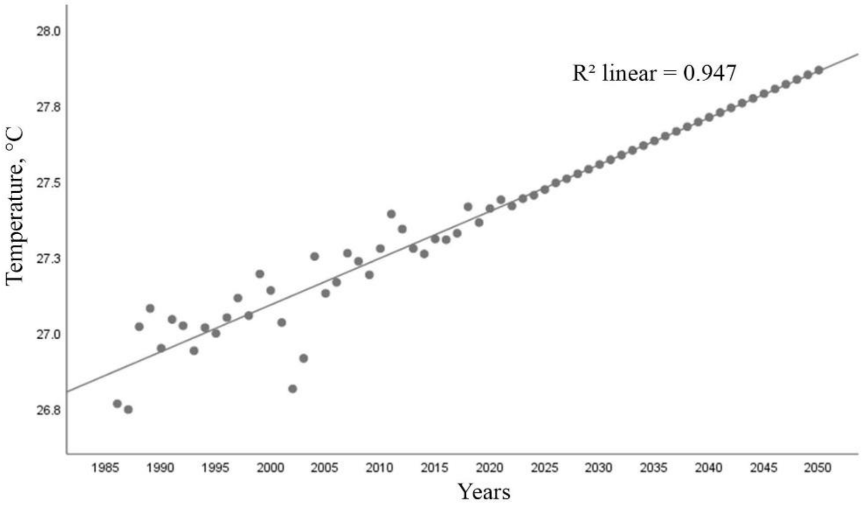


Figure 16. Scatterplot of forecasted temperature trend at Port Harcourt station

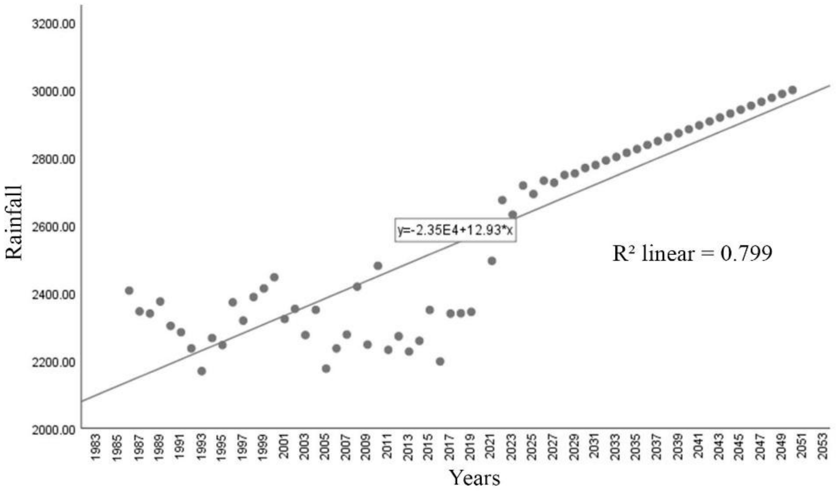


Figure 17. Scatterplot of forecasted rainfall trend at Port Harcourt station

The reliability of the model results is supported by acceptable goodness-of-fit statistics (R^2 values) and low forecast errors (MAPE). In addition, the agreement between observed and predicted values, as shown in the figures, provides further evidence of the model's adequacy for forecasting. The diagnostic tests indicate that the model assumptions are satisfied, suggesting that the estimated relationships are statistically valid and the model is appropriate for predictive applications.

DISCUSSION

The current study provides evidence of spatially heterogeneous climate trajectories across three major ecological zones of Nigeria. The ARIMA forecasts indicate a consistent increase in temperature at Sokoto, Abuja, and Port Harcourt stations through 2050, whereas rainfall exhibits contrasting patterns, increasing at Sokoto station and Port Harcourt station but decreasing at Abuja station. These findings support the hypothesis that climatic responses are not spatially uniform and are strongly influenced by regional ecological and geographical characteristics.

The projected increase in temperature across all three locations is consistent with the broader pattern of global and regional warming reported throughout sub-Saharan Africa. The strongest positive temporal associations were observed for temperature at Sokoto station and Port Harcourt station ($\tau\_b = 0.884$ and 0.914, respectively), indicating persistent long-term warming. Similar increasing temperature trends have been reported in Nigeria by Ayoade (2023) and Aweda et al. (2022), as well as in other developing regions including Bangladesh (Mainuddin et al., 2022) and East Africa (Samwel et al., 2021). The observed warming may be associated with increasing greenhouse gas concentrations, land-use changes, urban expansion, and altered surface energy balances that collectively contribute to regional climate warming.

The contrasting rainfall projections among the study locations highlight the complexity of precipitation responses to climate variability. At Sokoto station and Port Harcourt station, rainfall is projected to increase significantly, whereas Abuja station exhibits a statistically significant decline. The increasing rainfall trend at Port Harcourt station may be linked to its coastal location and continued influence of moisture-laden maritime air masses originating from the Atlantic Ocean. Similarly, the projected increase in rainfall at Sokoto station may reflect ongoing shifts in monsoonal circulation and northward migration of rainfall-bearing systems. In contrast, the declining rainfall trend at Abuja station suggests increasing climatic variability within the Guinea savanna zone and may indicate a future tendency toward drier conditions in central Nigeria. Such spatial differences emphasize that rainfall responses to climate change are often more complex and region-specific than temperature responses.

From an environmental management perspective, the projected climatic changes have important implications. Rising temperatures across all ecological zones may increase evapotranspiration rates, water demand, heat stress, and pressure on agricultural productivity. Increasing rainfall at Sokoto station and Port Harcourt station could elevate the risk of flooding, soil erosion, and infrastructure damage, particularly in vulnerable urban and low-lying areas. Conversely, decreasing rainfall at Abuja station may contribute to water-resource constraints, agricultural stress, and increased drought susceptibility. These findings highlight the need for region-specific climate adaptation strategies rather than uniform national approaches.

The results also provide evidence supporting the operational usefulness of ARIMA models for climate forecasting in data-constrained environments. Although the stationary R^2 values indicate moderate explanatory performance, the low MAPE values for temperature and acceptable forecast accuracy for rainfall demonstrate that the models adequately captured the temporal structure of the observed series. Furthermore, non-significant diagnostic statistics ($p > 0.05$) and the close agreement between observed and predicted values indicate that the model assumptions were reasonably satisfied. These findings are consistent with previous studies that successfully applied ARIMA models for climatic forecasting in Nigeria and elsewhere (Uba & Bakari, 2015; Murat et al., 2018; Ayoade, 2023).

The findings also allow an evaluation of the study hypotheses. Hypothesis H1, which proposed a statistically significant long-term increase in temperature across all ecological zones, is supported by both the ARIMA forecasts and Kendall's tau-b analysis. Positive and significant temperature trends were observed at Sokoto station, Abuja station, and Port Harcourt station, indicating a consistent warming signal despite substantial ecological differences among the study regions.

Hypothesis H2 is also supported, as rainfall dynamics were found to differ considerably among ecological zones. While Sokoto station and Port Harcourt station exhibited increasing rainfall trends, Abuja station showed a statistically significant decline in projected precipitation. These contrasting trajectories demonstrate that rainfall responses to climatic change are spatially heterogeneous and cannot be generalized across Nigeria.

The observed differences among the three cities further support Hypothesis H3, which proposed that climatic changes are influenced by ecological and geographical characteristics. The contrasting behaviour of rainfall and the varying strengths of the temperature trends suggest that local climatic controls, including ecological setting, atmospheric circulation patterns, and proximity to moisture sources, may contribute to the regional variability observed in the forecasts.

Finally, the results provide support for Hypothesis H4 regarding the suitability of ARIMA models for long-term climate forecasting in data-limited environments. The acceptable goodness-of-fit statistics, low forecast errors, satisfactory residual diagnostics, and consistency between observed and predicted values indicate that the ARIMA framework can provide operationally useful projections of temperature and rainfall. Nevertheless, future research should compare ARIMA performance with alternative forecasting approaches and incorporate additional climatic drivers to further improve predictive robustness.

CONCLUSION

The study successfully achieved its objectives and provided a comparative assessment of long-term temperature and rainfall dynamics across three climatically distinct ecological zones of Nigeria. The findings confirmed that future climate trajectories are not spatially uniform and vary substantially among ecological regions.

Hypothesis H1 was supported, as all three study locations exhibited statistically significant increasing temperature trends extending to 2050. Hypothesis H2 was also supported because rainfall projections differed among ecological zones, with increasing trends observed at Sokoto station and Port Harcourt station and a decreasing trend identified at Abuja station. The observed regional variability further supports Hypothesis H3, indicating that ecological and geographical characteristics play an important role in shaping future climatic responses. Finally, Hypothesis H4 was supported, as the ARIMA framework demonstrated acceptable predictive performance and generated statistically reliable forecasts under data-limited conditions.

The principal scientific contribution of this study lies in the comparative evaluation of future temperature and rainfall dynamics across major Nigerian ecological zones within a single forecasting framework. Unlike previous studies that primarily focused on historical trend analysis or individual locations, this research provides evidence of spatially heterogeneous climate-change signals and demonstrates that future rainfall responses may differ substantially even within the same country. The study therefore contributes new knowledge regarding the regional character of climate change in Nigeria and highlights the importance of location-specific climate adaptation strategies.

Furthermore, the research addresses an important knowledge gap concerning long-term climate forecasting across contrasting ecological environments in developing countries where observational data and computational resources are often limited. The results demonstrate that parsimonious statistical approaches such as ARIMA can provide useful insights into future climatic trajectories and support environmental planning, water-resource management, and climate adaptation decision-making.

Author's statements

Contributions

Conceptualization: S.O.; Data curation: S.O., D.D.Y.; Formal Analysis: S.O.; Investigation: S.O., D.D.Y.; Methodology: S.O.; Validation: S.O.; Visualization: S.O., D.D.Y.; Writing – original draft: S.O.; Writing – review & editing: D.D.Y.

Declaration of conflicting interest

The authors declare no competing interests.

Financial interests

The authors declare they have no financial interests.

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Data availability statement

Data used for the study would be made available on request.

AI Disclosure

Generative AI tools were used solely for language editing and proofreading. The authors take full responsibility for the content of the manuscript, including its arguments, analysis, interpretations, and conclusions.

Ethical approval declarations

Not applicable.

Additional information

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