Forecasting Rainfall Patterns for the Years 2016-2065 in Gangetic West Bengal and Sub-Himalayan West Bengal and Sikkim Utilizing the SARIMA Model.

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1.Abstact

Statistical modeling and data analysis play a crucial role in understanding rainfall variability and predicting future trends. This study examines the rainfall patterns in Gangetic West Bengal and Sub-Himalayan West Bengal & Sikkim and develops a suitable model for monthly rainfall forecasting. Historical rainfall data were analyzed to identify trends and seasonal variations. The results indicate that the region experiences peak rainfall from June to September, while January, December, and February receive the least rainfall.A SARIMA (p,d,q) × $(P,D,Q)_s$ model was identified as the best fit for predicting future rainfall trends, capturing both seasonal fluctuations and long-term patterns. The model demonstrated strong predictive accuracy based on the Akaike Information Criterion (AIC). This forecasting approach can support agriculture, disaster management, and water resource planning, enabling organizations such as the India Meteorological Department (IMD) and other governmental agencies to improve climate preparedness and resilience.

Keywords Annual rainfall · Exogenous variables · Seasonal ARIMA · Statistical forecasting models · Time series · Seasonality

2.Introduction

Rainfall forecasting is an essential component of climate assessment, hydrological studies, and agricultural strategy, particularly in regions like Gangetic West Bengal and Sub-Himalayan West Bengal & Sikkim. These areas are marked by significant seasonal fluctuations in precipitation, which can have profound implications for water availability, agricultural productivity, and overall environmental health. The ability to accurately predict rainfall patterns is crucial for effective water resource management, flood prevention, and the promotion of sustainable agricultural practices. This research focuses on forecasting rainfall trends for the period from 2016 to 2065, employing the Seasonal Autoregressive Integrated Moving Average (SARIMA) model. This model is particularly well-suited for time series forecasting as it combines autoregressive and moving average components while also accounting for seasonal variations and differencing to achieve stationarity. Given the monsoonal climate of the region, capturing these seasonal dynamics is vital for producing reliable long-term forecasts. The research will utilize a comprehensive historical rainfall dataset, spanning from 1930 to 2015, to achieve several key objectives:

The first step involves a thorough analysis of past rainfall fluctuations. By recognizing seasonal relationships and patterns, the research aims to provide a clearer understanding of how rainfall has varied over the decades. This historical context is crucial for identifying trends that may inform future predictions. Using the SARIMA model, the research will generate forecasts for the years 2016 to 2065. This projection will not only highlight expected rainfall amounts but also elucidate potential seasonal variations, thereby offering a comprehensive view of future precipitation trends in the region. An integral part of the research involves evaluating the accuracy and reliability of the SARIMA model through various statistical validation metrics. This assessment will ensure that the forecasts produced are robust and can be trusted by stakeholders who rely on this information for decision-making.

Forecasting rainfall is challenging and demanding, with a lot of factors that lead to uncertainty. Internationally, many attempts have been made to predict its behavioral pattern using various techniques. Data was a set of observations of random, discrete, real, non-negative variables. The selected model can predict future occurrences, most of which are critical, statistical, and/or analytical-approximate in nature. The projecting future values employs an acceptable mathematical strategy for extrapolating future data, which is dependent on external factors and chronologically organized numerical information.

As a modelling technique, ARIMA has proved beneficial for predicting a range of hydro meteorological parameters. Time-series data is modelled and forecasted using a variety of statistical methodologies. Those commonly used include ARIMA, moving average, exponential smoothing, regression analysis, and Fourier series analysis. ARIMA was conducted in numerous studies, ARIMA is a linear model assuming that time series data is stationary. As a result, nonlinearities and non-stationarities in the data are only partially captured. ARIMA models successfully account for serial linear correlation among observations, whereas Seasonal Auto Regressive Integrated Moving Average (SARIMA) models can adequately represent time series with simple periodic non-stationarity both within and across seasons. The SARIMA modelling methodology was introduced as the preferred statistical method, utilizing data gathered from observations collected over a significant time period. The most difficult investigation is to forecast the temperature because of their time and space variation . Besides seasonal influences, rainfall is also affected by many external factors, such as El Niño-Southern Oscillation (ENSO), temperature, wind, moisture-bearing winds, ocean currents, distance inland from the coast, and mountain ranges.

The SARIMAX model is a sophisticated and useful statistical technique for analyzing and forecasting time series data, particularly when it is impacted by seasonality and external factors. It is based on the Seasonal ARIMA (SARIMA) model, which generalizes the ARIMA model by including seasonality and allows the introduction of exogenous variables, or external influences, that may have a significant impact on the series being analyzed. Various studies have reveal to the ways identify rainfall prediction, as shown by Spessa et al., Qian et al., Adiwijaya et al. , Valipour. The GWB and SHWBS region is undergoing rapid social, economic and environmental transitions. Water availability is critical to these transitions. The Gangetic West Bengal and SUB-Himalayan West Bengal and Sikkim depends highly on rain-fed agriculture in its partially-coastal regions and semi-mountainous also facing recurring cycles of drought. Besides that, annual rainfall was considered as the most important climatic elements that influences water irrigation and water supplies. Therefore, annual rainfall forecasting plays an important role in the planning and water resources management.

In this context, the primary objective of this study is to develop and refine a forecasting model that accurately predicts annual rainfall trends in the GWB and SHWBS, using the historical rainfall data collected from 12 meteorological stations over a 86-year period (1930–2016). By assessing a series of SARIMAX models, this research aims to identify the most suitable model (s) based on criteria such as the ACF, PACF, AIC, BIC and HQIC. Further, the study seeks to evaluate the effectiveness of these models in capturing the non-linear and non-stationary nature of rainfall, considering the impact of external factors such as the ENSO, temperature variations, and geographical influences. This research aims to provide reliable, interpretable, and location-specific forecasts of near-term precipitation, thereby contributing to the effective planning and water resources management in the GWB and SHWBS, a region critically dependent on rain-fed agriculture and increasingly challenged by climate variability.

Despite significant advancements in rainfall forecasting methods, several gaps persist in accurately predicting long-term precipitation trends, particularly in regions like Gangetic West Bengal and Sub-Himalayan West Bengal & Sikkim. Existing research on rainfall forecasting in India has primarily focused on short-term predictions, seasonal monsoon variability, and large-scale climate models. However, the following key research gaps remain:

2.1. Limited Long-Term Rainfall Projections: Most studies on Indian monsoonal rainfall focus on short-term predictions (e.g., seasonal, annual) using numerical weather models or machine learning techniques. There is limited research that extends long-term (multi-decadal) rainfall forecasts up to 2065 using statistical models like SARIMA, particularly for these specific climatic sub-regions.

2.2. Underutilization of Time Series Models for Local Forecasting: While Global Climate Models (GCMs) provide broad-scale climate projections, they lack the resolution needed for localized forecasting. Time series models like SARIMA, which incorporate both seasonal variations and historical trends, have been underutilized for forecasting rainfall at a regional scale in Gangetic West Bengal and Sub-Himalayan West Bengal & Sikkim. There is a need for region-specific forecasting models that consider localized climatic variations.

2.3. Data-Driven Analysis of Climate Variability: Although rainfall variability in this region has been well-documented, there is insufficient statistical modelling to quantify long-term trends using historical data (1930-2015). Understanding rainfall fluctuations, extreme weather events, and shifting seasonal patterns through time series modelling can help bridge this gap.

2.4. Validation of SARIMA Against Alternative Models: Most rainfall forecasting studies rely on either traditional regression models or machine learning methods. There is a lack of comparative studies evaluating the effectiveness of SARIMA against modern forecasting techniques (e.g., Deep Learning, ARIMA-X with exogenous variables). This study aims to assess the SARIMA model's predictive reliability for long-term forecasting.

2.5. Policy and Planning Implications While climate variability and rainfall changes have profound effects on agriculture, water resources, and disaster management, limited region-specific research connects forecasted rainfall trends to policy implications. This study fills this gap by providing data-driven projections that can support policymakers in climate adaptation strategies, flood preparedness, and sustainable agriculture.

To enhance rainfall prediction accuracy and bridge existing research gaps, several innovative approaches can be integrated with the SARIMA model and overall forecasting methodology:

2.1. **Hybrid Forecasting Models:**

Instead of relying solely on SARIMA, integrating it with machine learning and deep learning techniques can improve accuracy.

- SARIMA + LSTM (Long Short-Term Memory): LSTM models handle nonlinear patterns better, and combining them with SARIMA's seasonality handling can lead to improved predictions.
- SARIMA + XGBoost/Random Forest: Using machine learning for feature selection and trend analysis before applying SARIMA can refine forecasts.

2.2. **Climate Variable Integration for Enhanced Predictions:**

SARIMA typically relies on historical rainfall data, but integrating climate variables like temperature, humidity, sea surface temperature (SST), El Niño-Southern Oscillation (ENSO) effects, and atmospheric pressure changes can improve long-term predictions.

- Use ARIMAX (ARIMA with Exogenous Variables): Extends SARIMA by incorporating climate variables as external factors.
- Train models with reanalysis datasets from sources like ERA5, NOAA, or IMD to capture broader climate trends.

2.3. **AI-Based Parameter Optimization for SARIMA:**

SARIMA parameter selection (p, d, q, P, D, Q, s) is often done manually or through grid search. Instead, AI-driven optimization can automate and enhance accuracy:

- Genetic Algorithms (GA) or Bayesian Optimization can be used to fine-tune SARIMA parameters dynamically.
- This reduces trial-and-error selection and ensures the most optimized forecasting model.

2.4. **Geospatial and Remote Sensing Data Integration:**

- Use Satellite Rainfall Data (TRMM, GPM): Combining historical station-based data with satellite rainfall estimates enhances spatial accuracy.
- GIS-Based Rainfall Mapping: Develop GIS-powered visualizations to show long-term spatial rainfall trends across the region.

2.5. Probabilistic Forecasting with Uncertainty Quantification:

- Instead of deterministic forecasts, introduce probability-based forecasting to show confidence intervals for rainfall predictions.
- Monte Carlo Simulations can be used to assess forecast uncertainty.

2.6. Real-Time Forecasting Dashboard & Decision Support System:

- Develop an interactive web-based dashboard using Python (Dash, Streamlit, or Tableau) to provide real-time and future rainfall forecasts for policymakers, farmers, and disaster managers.
- Include alerts for extreme rainfall events based on model outputs.

2.7. Policy and Agricultural Integration:

- Link rainfall forecasts with crop yield predictions using machine learning models to help farmers adapt to changing weather conditions.

◆ Flood and Drought Risk Mapping: Use predicted rainfall data to forecast flood-prone or drought-prone areas for better disaster preparedness.

The outcomes of this research are expected to provide valuable insights into long-term rainfall trends, which will be instrumental for policymakers, environmental advocates, and agricultural planners. By understanding projected rainfall patterns, these stakeholders can make informed decisions regarding climate resilience strategies, water resource management, and sustainable agricultural practices. Ultimately, this research aims to contribute to a more sustainable and adaptive approach to managing the challenges posed by climate variability in the region.

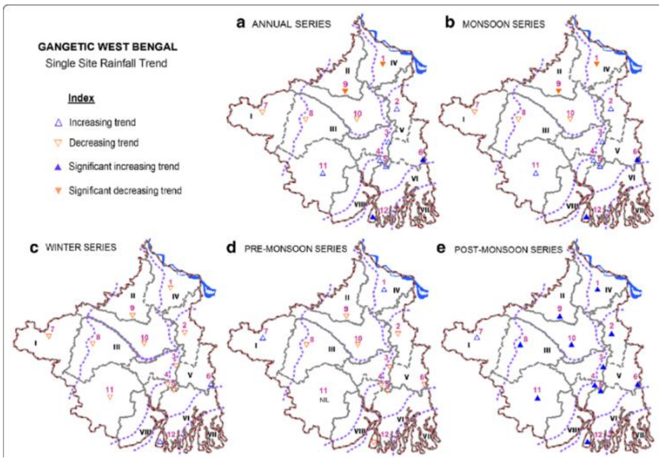


Fig 1: Gangetic West Bengal (Location of study area)

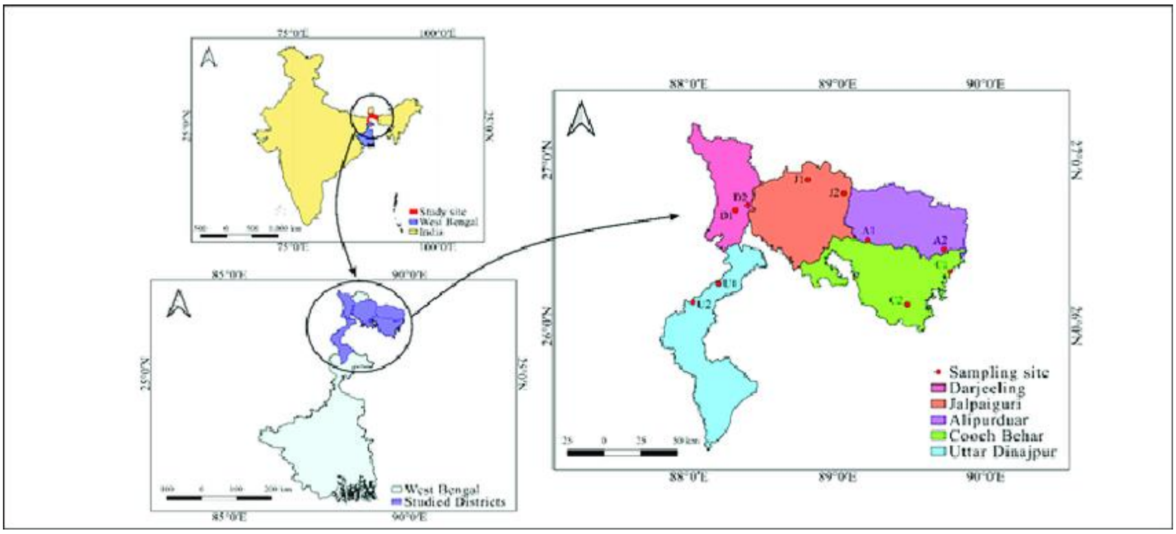


Fig2: Sub- Himalayan West Bengal And Sikkim(Location of study area)

3.Background Study and Literature Review:

Rainfall forecasting plays a crucial role across a multitude of sectors, including climate science, agriculture, water resource management, and disaster preparedness. Accurate predictions of rainfall patterns are vital for understanding and mitigating the impacts of climate variability, particularly in regions like Gangetic West Bengal and Sub-Himalayan West Bengal & Sikkim. In these areas, the variability of monsoon seasons significantly influences the frequency and severity of natural disasters such as floods and droughts, as well as the agricultural practices that sustain local economies and food security. The Indian Meteorological Department (IMD) and various global climate models provide extensive rainfall predictions; however, the development of localized, long-term forecasts remains a complex challenge. This complexity arises from the intricate interactions between topography and climate in these regions, which can lead to significant discrepancies between predicted and actual rainfall. The diverse geographical features, including hills, valleys, and river systems, contribute to localized weather phenomena that are often not captured in broader climate models. To address the challenges of rainfall prediction, statistical time series models have been widely utilized, particularly ARIMA (AutoRegressive Integrated Moving Average) and its seasonal counterpart, SARIMA (Seasonal ARIMA). These models are favored for their ability to effectively analyze historical climate data, capturing underlying trends, seasonal patterns, and short-term dependencies. By leveraging past rainfall data, these models can provide valuable insights into future precipitation patterns. However, conventional SARIMA models are not without their limitations. One significant drawback is the requirement for manual parameter tuning, which can be time-consuming and may not always yield optimal results. Additionally, traditional SARIMA models often overlook the influence of external climatic factors, such as the El Niño-Southern Oscillation (ENSO), sea surface temperature (SST), and variations in atmospheric pressure. These factors can have profound effects on rainfall patterns and, consequently, on the accuracy of predictions. This research aims to address these limitations by integrating advanced artificial intelligence (AI) techniques for parameter optimization within the SARIMA framework. By employing AI-driven methods, the research seeks to automate the parameter selection process, enhancing the model's efficiency and accuracy. Furthermore, the incorporation of relevant climate variables—such as ENSO indices, SST anomalies, and atmospheric pressure variations—into the SARIMA model will provide a more comprehensive understanding of the factors influencing rainfall in the region. This holistic approach aims to improve the reliability of rainfall forecasts, ultimately benefiting sectors that rely on accurate

weather predictions for planning and decision-making. Through this research, we hope to contribute to more effective rainfall forecasting methodologies that can better.

To create a robust basis for this research, we examine the current literature on rainfall forecasting techniques, the applications of SARIMA, and the hybrid methodologies that combine machine learning with climate variables.

3.1. Time Series Models for Rainfall Forecasting:
The introduction of ARIMA models by Box & Jenkins (1970) marked a significant advancement in the field of time series forecasting.
Alam et al. (2016) highlighted the efficacy of SARIMA in forecasting seasonal rainfall in South Asia, noting its capacity to accurately represent cyclical rainfall trends.
Mishra & Desai (2005) utilized ARIMA models to analyze Indian monsoon rainfall, achieving satisfactory accuracy while also pointing out the model's limitations in addressing long-term climatic changes.

3.2. Limitations of Traditional SARIMA Models:
Research by Singh et al. (2019) indicated that although SARIMA is proficient in modeling short-term rainfall trends, it encounters difficulties in adapting to long-term climatic variations due to its dependence on historical data.
Kumar & Reddy (2021) noted that the necessity for manual hyperparameter tuning in SARIMA models can result in less than optimal outcomes and heightened computational demands.
Panda et al. (2022) demonstrated that SARIMA is inadequate in predicting extreme weather phenomena, which are increasingly prevalent as a result of climate change.

3.3. Hybrid Models for Improved Accuracy:
The concept of hybrid models that merge statistical techniques with artificial intelligence for time series forecasting was introduced by Makridakis et al. (2018).
Chattopadhyay et al. (2020) suggested the use of SARIMA-LSTM hybrid models to enhance monsoon forecasting accuracy in India, achieving notable improvements compared to traditional SARIMA approaches.
Ahmed et al. (2021) combined SARIMA with XGBoost to refine weather forecasting, demonstrating that machine learning-driven parameter optimization surpassed the performance of conventional SARIMA models.
3.4. Climate Variable Integration in Rainfall Prediction:
Shukla et al. (2017) investigated the influence of ENSO and sea surface temperature fluctuations on Indian monsoon dynamics, underscoring the importance of incorporating external variables into forecasting models.
Roy et al. (2019) further explored this integration, emphasizing its critical role in enhancing the accuracy of rainfall predictions.

4.Research Methodology:

Time series modelling of time spaced events are formulated to understand generation mechanisms of events, forecasting or predicting of future events and also for optimal control of events.

4.1. Dataset type:

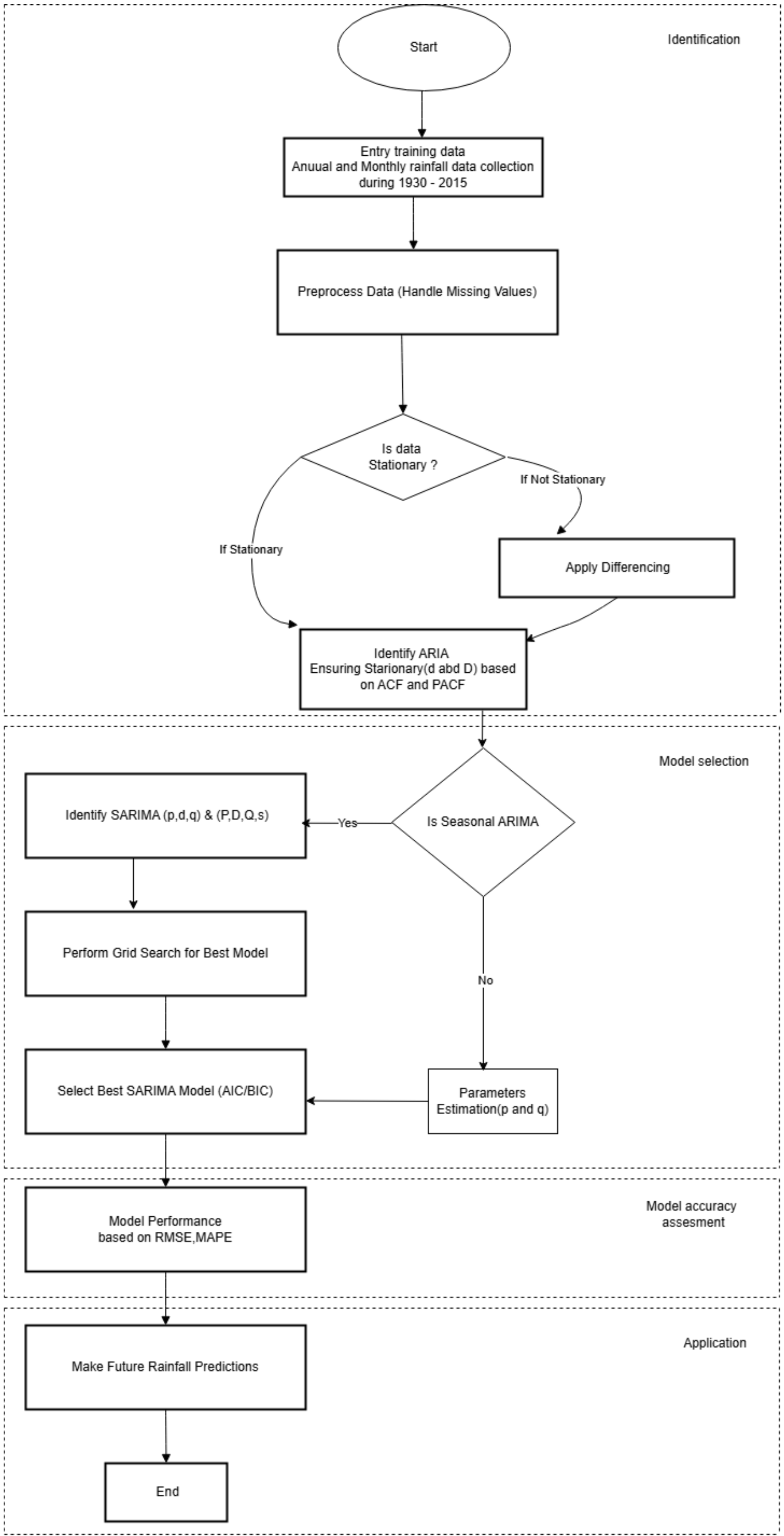
Type: Time-series dataset
Source: Indian Meteorological Department (IMD) / Regional Weather Stations
Time Range: 1930–2015 (monthly rainfall data)
Format: CSV/XLSX (organized tabular format)
Attributes:
Date/Time (YYYY-MM) → Monthly timestamp
Rainfall (mm) → Monthly recorded precipitation
Region/Station → Gangetic West Bengal, Sub-Himalayan West Bengal, and Sikkim
Purpose: Serves as the main input for the training and testing of SARIMA models.

4.2. Collection:

The dataset utilized in this research was obtained from the official data portal of the International Institute for Management Development (IMD) (Link: https://www.imdpune.gov.in)

4.3. Database:

The type of Database is:
Time-Series Database (TSDB)Most effective for the storage and analysis of temporal rainfall patterns utilizing the SARIMA model.
Relational Database (RDBMS - SQL) Most suitable for managing structured data organized in tables, including rainfall and climate variables.
NoSQL (Document Store - JSON/XML) Ideal for handling semi-structured climate data that requires adaptable attributes.
Geospatial Database (GIS-Based) Most advantageous for visualizing the distribution of rainfall across various geographical areas.



4.4,4.5 Proposed SARIMA Model Architecture and and Model Diagram

5.Experiment with Result:

5.1. Box Jenkins Algorithm

Box Jenkins Algorithm World Environment 2016, 6(1): 1-9 3 The approach is to use data in the past to provide forecasts. Using the ARIMA self-projecting time series forecasting model, we hope to find a mathematical formula that will approximately generate the historical patterns in a time series. The self-projecting time series uses only the time series data of the activity to be used to generate forecasts. This approach is typically useful for short to medium-term forecasting (Erhardt, 2002). The underlying goal of the Box-Jenkins Forecasting Method is to find an appropriate formula so that the residuals are as small as possible and exhibit no pattern. The model-building process involves four steps, repeated as necessary, to end up with a specific formula that replicates the patterns in the series as closely as possible and also produces accurate forecasts. This process is outlined in Table 1.

Table 1. Box-Jenkins Modelling Algorithm

1. Plot series.
2. Is variance stable?
2a. No, Apply Transformation, go to 1.
2b. Yes, continue.
3. Obtain ACFs and PACFs.
4. Is mean stationary?
4a. No, Apply Regular and Seasonal differencing.
4b. Yes, continue.
5. Model Selection.
6. Estimate Parameter Values.
7. Are Residuals Uncorrelated?
7a. No, Modify Model, go to 5.
7b. Yes, continue.
8. Are Parameters Significant and Uncorrelated?
8a. No, Modify Model, go to 5.
8b. Yes, continue.
9. Forecast.

Source: Box and Jenkins (1976); Erhardt (2002)

5.2. Stationarity and Non-stationarity

The stationarity of the n-th order time series is established if

$$FZt1\ ,t2\ ,\ldots,Ztn\ (x1,\ x2,\ \ldots\ ,\ xn)$$

$$=FZt1+k,t2+k,\ldots,Ztn+k\ (x1,\ x2,\ldots,xn) \quad (1.1)$$

For all $t1$, $t2$, … ,n,k ∈ {0,±1,±2,…} and all $x1$, $x2$,…,xn ∈ $\mathbb{R}$. This implies that the joint distribution is invariant to time shift by k for all n = 1,2,.... (1.1) depicts a time series as strictly stationary. The converse is true for non-stationary. If (1.1) is true for $n = m$, it is also true for $n \leq m$ because the m-th order distribution function determines all distribution functions of lower, hence a high order of stationarity always implies a lower order of stationarity (Wei, 2006). Mostly, a weaker sense of stationarity is defined in theory and practice. A process is said to be n-th order weakly stationary if all its joint moments up to order n exist and are time invariant.

Stationarity plays a crucial role in time series analysis. One can test the stationarity or otherwise of a time series data using the unit root test proposed by Dickey and Fuller in 1979, for testing the hypothesis below;

H_0:Series has unit root vrs H_1:Series has no unit root

If the ADF test statistic is less than the critical value, we fail to accept H0. The test is based on the fact that for stationarity to exist, the roots of the characteristics polynomial of the time series must lie outside a unit circle.

5.3. Model Type:

3.3.1. Autoregressive Models of Order p [AR(p)]

The p-th order autoregressive process is given by;

$$(1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_p B^p)(Zt - \mu) = a_t \quad (2)$$

with auto-covariance function,

$$\gamma_k = \theta_1 \gamma_{k-1} + \cdots + \theta_p \gamma_{k-p},\ k > 0 \quad (3)$$

and a recursive relation for the autocorrelation function,

$$\rho_k = \theta_1 \rho_{k-1} + \cdots + \theta_p \rho_{k-p},\ k > 0 \quad (4)$$

The process is stationary if the roots of $1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_p B^p = 0$, lie outside a unit circle. The pacf vanishes after lag p.

3.3.2. Moving Average Process of Order q [MA(q)]

The q-th order moving average process is

$$(Z_t - \mu) = (1 - \alpha_1 B - \alpha_2 B^2 - \cdots - \alpha_q B^q)\, a_t \quad (5)$$

The MA(q) process is always stationary because $1 + \alpha_1^2 + \cdots + \alpha_q^2 < \infty$. The process is invertible if the roots of $1 - \alpha_1 B - \alpha_2 B^2 - \cdots - \alpha_q B^q = 0$, lie outside a unit circle.

The auto-covariance function is given by

$$\gamma k = \begin{cases} \sigma_a^2(-\alpha_k + \alpha_k \alpha_{k+1} + \cdots + \alpha_{q-k}\alpha_q), & k = 1,2,\ldots,q \\ 0, & k > \end{cases} \quad (6)$$

Therefore, the autocorrelation function becomes

$$\rho_k = \begin{cases} -\alpha_k + \alpha_k \alpha_{k+1} + \cdots + \alpha_{q-k}\alpha_q \,/\, 1 + \alpha_1^2 + \cdots + \alpha_q^2, & k = 1,2,\ldots,q \\ 0, & k > q \end{cases} \quad (7)$$

The autocorrelation function of an MA(q) process cuts off after lag q.

3.3.3. Autoregressive Moving Average (p,q) Process

Let,

$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_p B^p$, where $\theta_p \neq 0$

$\alpha(B) = 1 - \alpha_1 B - \alpha_2 B^2 - \cdots - \alpha_q B^q$, where $\alpha q \neq 0$

A zero-mean ARMA(p,q) process is then defined as,

$$\theta(B) Z_t = \alpha_q(B) a_t \quad (8)$$

The process is invertible and stationary if the roots of $\alpha(B) = 0$ and $\theta_p(B) = 0$ respectively lie outside the unit circle.

For $k > p$, we get an auto-covariance function of

$$\gamma_k = \theta_1 \gamma_{k-1} + \cdots + \theta_p \gamma_{k-p} \quad (9)$$

5.3.5. Seasonal ARIMA (SARIMA) Models

SARIMA models are an adaptation of autoregressive integrated moving average (ARIMA) models to specifically fit seasonal time series. That is, their construction takes into consideration the underlying seasonal nature of the series to be modelled. Many authors have written on SARIMA models extensively. A few amongst them are Box and Jenkins (1976) who proposed them, Priestley (1981), Madsen (2008), Gerolimetto (2010) and Suhartono (2011).

A multiplicative seasonal ARIMA model is given by;

$$\Phi(B^s)\phi_p(B)(1-B)^d(1-B^s)^D(y_t-\mu)$$

$$=\theta(B)\Theta Q(B^s)a_t, \quad (12)$$

Where $\Phi(B^s)$,$\phi_p(B)$, $\Theta Q(B^s)$ and $\theta q(B)$are defined as;

$$\Phi(B^s) = 1-\Phi_1B^s-\Phi_2B^{2s}-\cdots-\Phi_PB^{Ps} \quad (13)$$

$$\Phi(B) = 1-\Phi_1B-\Phi_2B^2-\cdots-\Phi_PB^P \quad (14)$$

where $\phi_p \neq 0$,

$$\theta(B) = 1-\theta_1B-\theta_2B^2-\cdots-\theta_qB^q, \quad (15)$$

where $\theta_p \neq 0$,

$$\Theta(B^s) = 1-\Theta_1B^s-\Theta_2B^{2s}-\cdots-\Theta_QB^{Qs} \quad (16)$$

where s is an integer strictly larger than one (the period), $d \geq 0$, and $D \geq 0$. Note that $\mu = 0$ if $d > 0$ or $D > 0$.

5.4 Model identification (Selection of model order)

Initially, the original data was tested to an augmented Dickey-Fuller (ADF) test to determine stationarity stationary using unit root and stationary tests; if the results showed a non-stationary series, a differenced transformation would establish stationarity.

To determine preliminary values for the autoregressive order p, the order of differencing d, the moving average order q, and the seasonal parameters P, D, and Q. The autocorrelation function (ACF), partial autocorrelation function (PACF), and inverse autocorrelation function (IACF) are the most essential components [27]. The ACF assesses the level of linear dependency between observations in a time series separated by a lag q. The PACF identifies how many auto-regressive terms (p) are required. The IACF detect over-differences, and if the data are over-differenced, the IACF resembles an ACF from a non-stationarity process. The selection of the best proposal models involved the use of the Likelihood, Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) with consideration given to the model with the lowest AIC and BIC. The mathematical formulation for the AIC and BIC is defined as

$$\text{AIC} = -2\log(L) + 2m \quad (17)$$

$$\text{BIC} = -2\log(L) + k\ln(n) \quad (18)$$

5.5 Model Performance measurement

Model performance was measured to assess the regeneration capability based on various statistical measures such as Mean Absolute Percentage Error (MAPE)and Root Mean Square Error mean (RMSEM). The highest of Nash value and the lowest of RMSEM were selected. Nash and Sutcliffe proposed an alternative goodness-of-fit Nash index, which is often referred to as the efficiency index as shown in Eq.

$$\text{RMSEM} = \quad (19)$$

MAPE = (20)

5.6. Findings and Discussions

In this section, outputs from data exploration and employing the Box-Jenkins Algorithm in building a model are presented and discussed. The data employed in this study were collected from the Department of Meteorology and Climatology in the BA Region, and represent the monthly rainfall figures from January 1930 through December 2015. The data was used since it is a time series data and the observations were collected sequentially in time (monthly). Data was analysed with Python. The 420 data points for the time period observed are presented in Figure 2. 4.1.

5.6.1Preliminary Data Analysis

An exploratory routine was employed to reveal some important features in the data set. Figure 1 presents the boxplots of the monthly rainfall figures from 1930 to 2015.

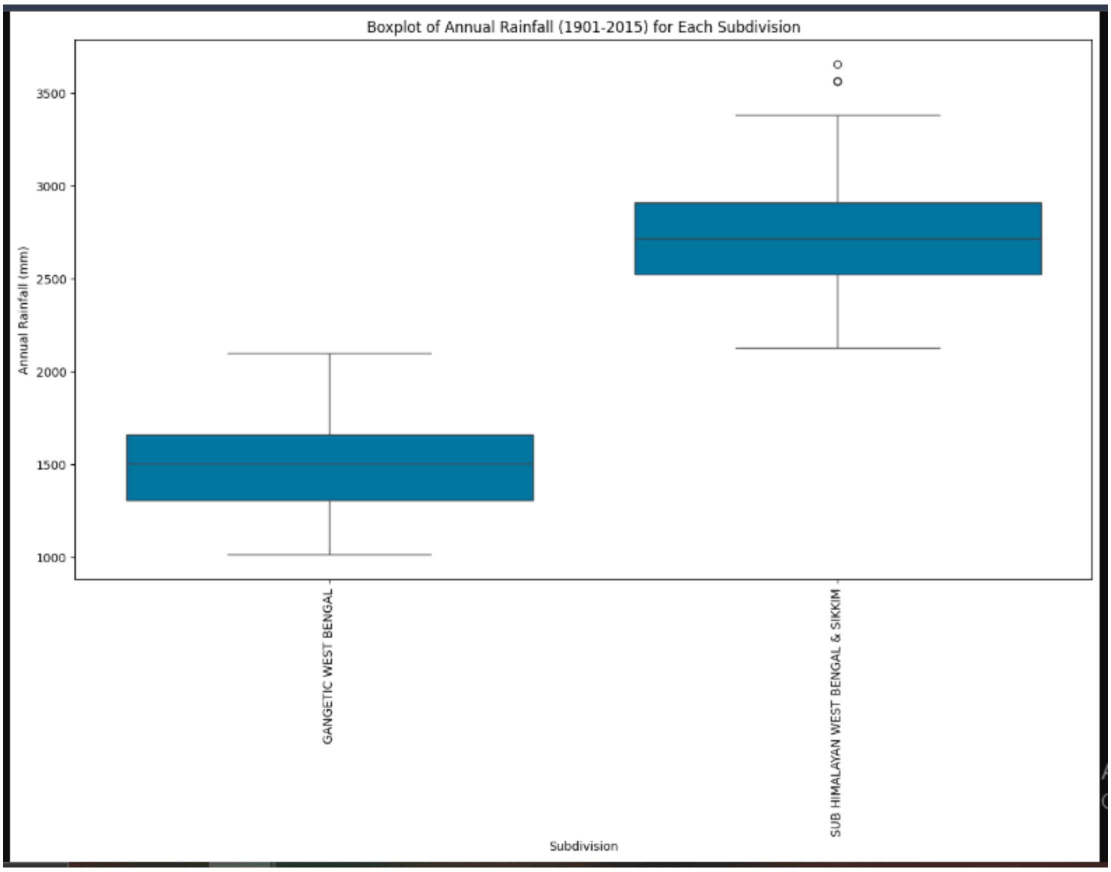


Figure 1. Boxplot of the monthly rainfall figures from Jan. 1930 to Dec. 2015

The data considered on monthly basis has some outliers. However, the data look stationary by observation from Figure 2. The month of September recorded the highest amount of rainfall, followed closely by October, which had the highest upper quartile value. The months of January, December and February recorded the least amount of rainfall. The time series plot for the amount of rainfall recorded for the Brong Ahafo from January 1930 to December, 2015 is presented in Figure 2. The regular pattern of up and down is an indication of seasonality. Figure 3 was further investigated by decomposing it into the various components. The decomposed plots of the various components of the time series plot in Figure 2 is as presented in Figure 3. From Figure 3, the data have seasonal effect, with a usual rise and fall pattern being experienced yearly over the period. This implies that regular monthly rainfall figures recorded each year was influenced by the rise and fall pattern of the seasonality component. However, the trend seems to be very constant over time, although there are a few ups and downs over some periods.

5.6.2. Stationarity Test

A formal statistical test is performed at this stage to ascertain the stationarity or otherwise of the data. The hypotheses under consideration are; H0: The data is stationary vrs H1: The data is explosive The Augmented Dickey-Fuller test reported a test value of -2.759 and a p-value of 0.0643 for GWB. The data is explosive The Augmented Dickey-Fuller test reported a test value of -3.654 and a p-value of 0.0048 for SHWB. This result presents evidence in favour of the null hypothesis, postulating that the data is stationary.

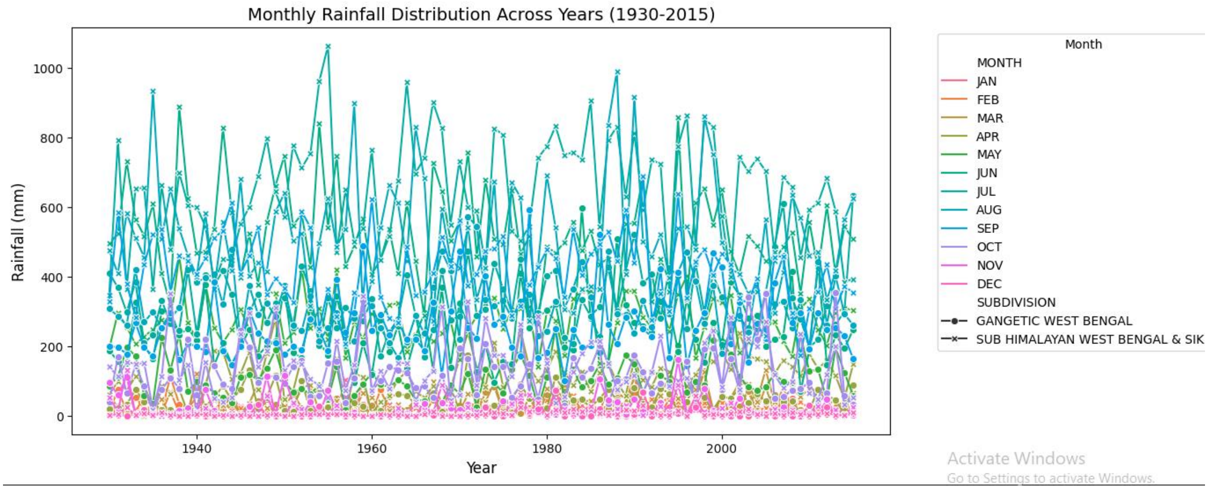


Figure 2. Time Series plot for Monthly rainfall figures from Jan. 1901 to Dec. 2009

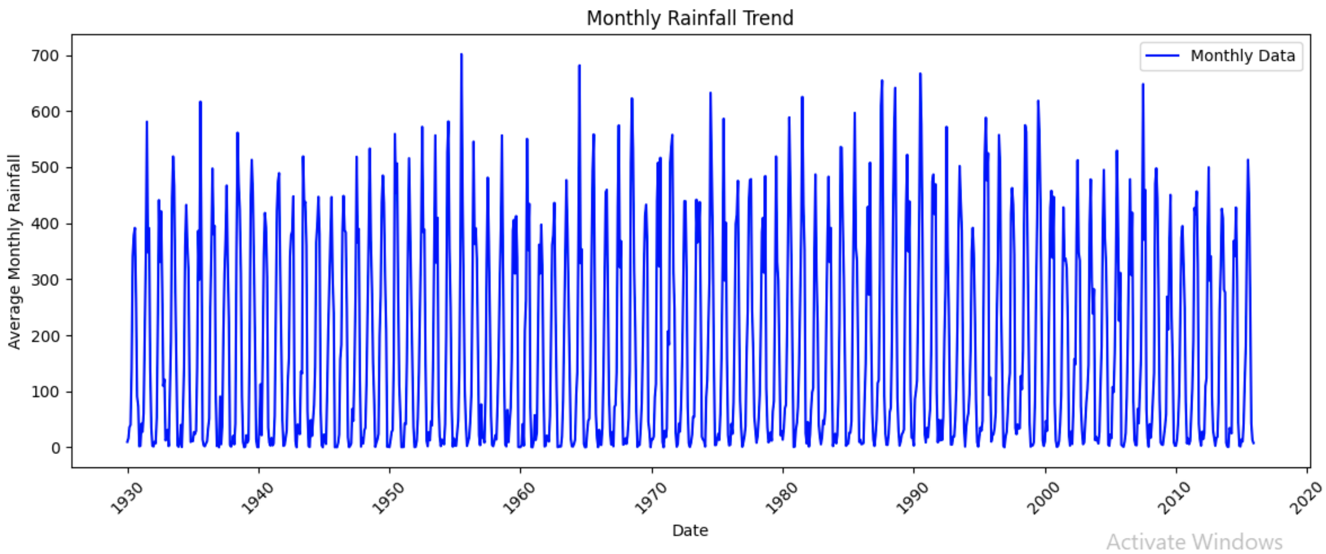


Figure 3. Monthly Rainfall Trend plot for Monthly rainfall figures from Jan. 1930 to Dec. 2015

5.6.3. Model Identification and Fit

The data was divided into two sets, training and test data. Data from January 1930 to December, 2015 were used as training data whiles rest of the data were used as test data for consistency and reliability of our model. The sample autocorrelation function (acf) and partial autocorrelation function (pacf) were examined in Figure 4. There is a slow decay of the acf and pacf at multiple lags of 12, which are significant. This supports the earlier assertion of seasonality in the data, hence, the need for seasonal differencing with period of 12. The seasonally differenced data is stationary by observing Figure 5.

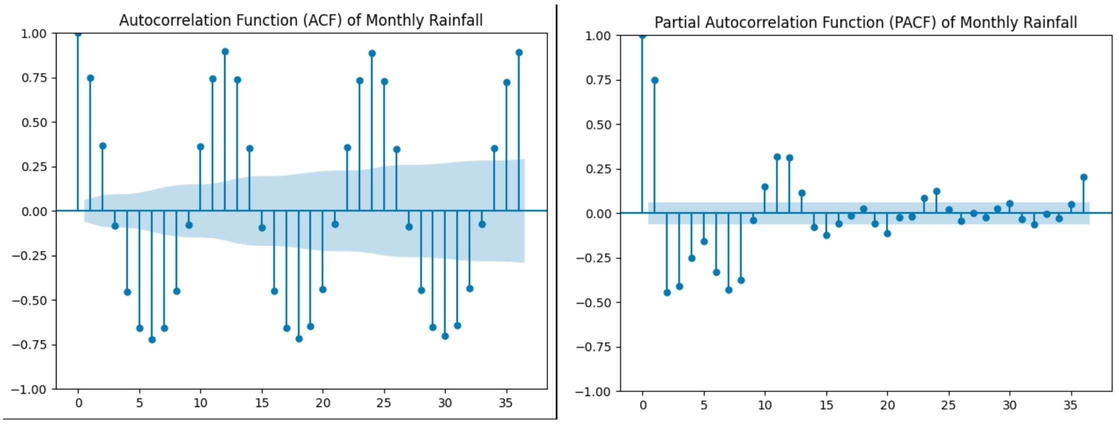


Figure 4. ACF and PACF plots for the monthly Rainfall figures from January 1930 to December 2015

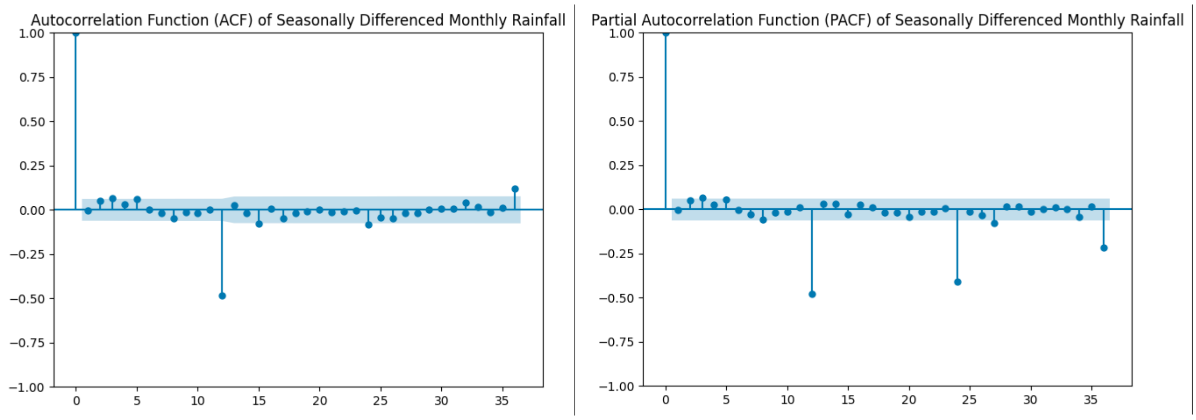


Figure 5. Time Series, acf and pacf plots for the Seasonally Differenced Rainfall figures from January 1930 to December 2015

From Figure 5, a spike at 12 in the acf is significant but no other is significant at lags multiple of 12, the pacf shows an exponential decay in the seasonal lags; that is 12, 24, 36 etc. Thus, the seasonal part of the model has a moving average term of order 1 and an autoregressive term of 1. For the non-seasonal part, the acf tails off after lag 2 and the pacf cuts off after lag 1. Therefore, the non-seasonal part has an autoregressive term of 1 and a moving average term of 2. Based on the features portrayed by the plots, an initial SARIMA (1,0,2)×(1,1,1)12 model is proposed. Further investigation of neighbouring models was conducted and the result is as shown in Table 2.

AIC Scores for Neighbouring Models (GWB):

Neighbouring Models	AIC
SARIMA(0, 1, 2)x(0, 1, 1, 12)	1034.64
SARIMA(0, 1, 2)x(0, 1, 1, 12)	1034.64
SARIMA(0, 1, 2)x(0, 1, 1, 12)	1034.64
SARIMA(0, 1, 2)x(0, 1, 1, 12)	1034.64
SARIMA(0, 1, 1)x(0, 1, 1, 12)	1036.64
SARIMA(1, 1, 2)x(0, 1, 1, 12)	1036.64
SARIMA(0, 1, 1)x(0, 1, 1, 12)	1036.64
SARIMA(0, 1, 3)x(0, 1, 1, 12)	1036.64

SARIMA(0, 1, 1)x(0, 1, 1, 12)	1036.64
SARIMA(0, 1, 1)x(0, 1, 1, 12)	1036.64
SARIMA(0, 1, 3)x(0, 1, 1, 12)	1036.64
SARIMA(0, 1, 3)x(0, 1, 1, 12)	1036.64
SARIMA(1, 1, 2)x(0, 1, 1, 12)	1036.64
SARIMA(0, 1, 3)x(0, 1, 1, 12)	1036.64
SARIMA(0, 1, 2)x(0, 1, 2, 12)	1038.64
SARIMA(0, 1, 2)x(0, 1, 0, 12)	1038.64
SARIMA(0, 1, 2)x(0, 1, 2, 12)	1038.64
SARIMA(0, 1, 2)x(1, 1, 1, 12)	1038.64
SARIMA(1, 1, 1)x(0, 1, 1, 12)	1038.64
SARIMA(1, 1, 3)x(0, 1, 1, 12)	1038.64
SARIMA(1, 1, 1)x(0, 1, 1, 12)	1038.64
SARIMA(0, 1, 2)x(1, 1, 1, 12)	1038.64
SARIMA(0, 1, 2)x(0, 1, 0, 12)	1038.64
SARIMA(1, 1, 3)x(0, 1, 1, 12)	1038.64
SARIMA(0, 1, 2)x(0, 1, 0, 12)	1038.64
SARIMA(0, 1, 2)x(0, 1, 0, 12)	1038.64
SARIMA(0, 1, 2)x(0, 1, 2, 12)	1038.64
SARIMA(0, 1, 2)x(0, 1, 2, 12)	1038.64
SARIMA(0, 1, 3)x(0, 1, 2, 12)	1040.64
SARIMA(0, 1, 3)x(0, 1, 2, 12)	1040.64
SARIMA(0, 1, 3)x(0, 1, 0, 12)	1040.64
SARIMA(0, 1, 3)x(1, 1, 1, 12)	1040.64
SARIMA(1, 1, 2)x(0, 1, 2, 12)	1040.64
SARIMA(1, 1, 2)x(0, 1, 0, 12)	1040.64
SARIMA(1, 1, 2)x(0, 1, 2, 12)	1040.64
SARIMA(1, 1, 2)x(1, 1, 1, 12)	1040.64
SARIMA(0, 1, 3)x(0, 1, 0, 12)	1040.64
SARIMA(1, 1, 2)x(0, 1, 0, 12)	1040.64
SARIMA(0, 1, 1)x(0, 1, 0, 12)	1040.64
SARIMA(0, 1, 1)x(1, 1, 1, 12)	1040.64
SARIMA(0, 1, 3)x(0, 1, 0, 12)	1040.64

SARIMA(0, 1, 3)x(0, 1, 0, 12)	1040.64
SARIMA(0, 1, 1)x(1, 1, 1, 12)	1040.64
SARIMA(0, 1, 3)x(0, 1, 2, 12)	1040.64
SARIMA(0, 1, 1)x(0, 1, 2, 12)	1040.64
SARIMA(0, 1, 3)x(0, 1, 2, 12)	1040.64
SARIMA(0, 1, 1)x(0, 1, 0, 12)	1040.64
SARIMA(0, 1, 3)x(1, 1, 1, 12)	1040.64
SARIMA(0, 1, 1)x(0, 1, 2, 12)	1040.64
SARIMA(0, 1, 1)x(0, 1, 0, 12)	1040.64
SARIMA(0, 1, 1)x(0, 1, 2, 12)	1040.64
SARIMA(0, 1, 1)x(0, 1, 2, 12)	1040.64
SARIMA(0, 1, 1)x(0, 1, 0, 12)	1040.64
SARIMA(1, 1, 3)x(0, 1, 0, 12)	1042.64
SARIMA(1, 1, 3)x(0, 1, 2, 12)	1042.64
SARIMA(1, 1, 3)x(0, 1, 0, 12)	1042.64
SARIMA(0, 1, 2)x(1, 1, 0, 12)	1042.64
SARIMA(0, 1, 2)x(1, 1, 2, 12)	1042.64
SARIMA(1, 1, 3)x(0, 1, 2, 12)	1042.64
SARIMA(1, 1, 1)x(1, 1, 1, 12)	1042.64
SARIMA(1, 1, 1)x(0, 1, 2, 12)	1042.64
SARIMA(1, 1, 3)x(1, 1, 1, 12)	1042.64
SARIMA(1, 1, 1)x(0, 1, 0, 12)	1042.64
SARIMA(1, 1, 1)x(0, 1, 2, 12)	1042.64
SARIMA(1, 1, 1)x(0, 1, 0, 12)	1042.64
SARIMA(0, 1, 2)x(1, 1, 0, 12)	1042.64
SARIMA(0, 1, 2)x(1, 1, 2, 12)	1042.64
SARIMA(0, 1, 1)x(1, 1, 2, 12)	1044.64
SARIMA(0, 1, 1)x(1, 1, 0, 12)	1044.64
SARIMA(0, 1, 3)x(1, 1, 2, 12)	1044.64
SARIMA(0, 1, 3)x(1, 1, 0, 12)	1044.64
SARIMA(0, 1, 3)x(1, 1, 0, 12)	1044.64
SARIMA(1, 1, 2)x(1, 1, 0, 12)	1044.64
SARIMA(0, 1, 1)x(1, 1, 0, 12)	1044.64

SARIMA(0, 1, 3)x(1, 1, 2, 12)	1044.64
SARIMA(0, 1, 1)x(1, 1, 2, 12)	1044.64
SARIMA(1, 1, 2)x(1, 1, 2, 12)	1044.64
SARIMA(1, 1, 1)x(1, 1, 0, 12)	1046.64
SARIMA(1, 1, 1)x(1, 1, 2, 12)	1046.64
SARIMA(1, 1, 3)x(1, 1, 0, 12)	1046.64
SARIMA(1, 1, 3)x(1, 1, 2, 12)	1046.64

AIC Scores for Neighbouring Models (SHWB):

Neighbouring Models	AIC
SARIMA(0, 1, 2)x(0, 1, 1, 12)	1087.22
SARIMA(0, 1, 2)x(0, 1, 1, 12)	1087.22
SARIMA(0, 1, 2)x(0, 1, 1, 12)	1087.22
SARIMA(0, 1, 2)x(0, 1, 1, 12)	1087.22
SARIMA(0, 1, 1)x(0, 1, 1, 12)	1089.22
SARIMA(1, 1, 2)x(0, 1, 1, 12)	1089.22
SARIMA(0, 1, 1)x(0, 1, 1, 12)	1089.22
SARIMA(0, 1, 3)x(0, 1, 1, 12)	1089.22
SARIMA(0, 1, 1)x(0, 1, 1, 12)	1089.22
SARIMA(0, 1, 1)x(0, 1, 1, 12)	1089.22
SARIMA(0, 1, 3)x(0, 1, 1, 12)	1089.22
SARIMA(0, 1, 3)x(0, 1, 1, 12)	1089.22
SARIMA(1, 1, 2)x(0, 1, 1, 12)	1089.22
SARIMA(0, 1, 3)x(0, 1, 1, 12)	1089.22
SARIMA(0, 1, 2)x(0, 1, 2, 12)	1091.22
SARIMA(0, 1, 2)x(0, 1, 0, 12)	1091.22
SARIMA(0, 1, 2)x(0, 1, 2, 12)	1091.22
SARIMA(0, 1, 2)x(1, 1, 1, 12)	1091.22
SARIMA(1, 1, 1)x(0, 1, 1, 12)	1091.22
SARIMA(1, 1, 3)x(0, 1, 1, 12)	1091.22
SARIMA(1, 1, 1)x(0, 1, 1, 12)	1091.22
SARIMA(0, 1, 2)x(1, 1, 1, 12)	1091.22
SARIMA(0, 1, 2)x(0, 1, 0, 12)	1091.22

SARIMA(1, 1, 3)x(0, 1, 1, 12)	1091.22
SARIMA(0, 1, 2)x(0, 1, 0, 12)	1091.22
SARIMA(0, 1, 2)x(0, 1, 0, 12)	1091.22
SARIMA(0, 1, 2)x(0, 1, 2, 12)	1091.22
SARIMA(0, 1, 2)x(0, 1, 2, 12)	1091.22
SARIMA(0, 1, 3)x(0, 1, 2, 12)	1093.22
SARIMA(0, 1, 3)x(0, 1, 2, 12)	1093.22
SARIMA(0, 1, 3)x(0, 1, 0, 12)	1093.22
SARIMA(0, 1, 3)x(1, 1, 1, 12)	1093.22
SARIMA(1, 1, 2)x(0, 1, 2, 12)	1093.22
SARIMA(1, 1, 2)x(0, 1, 0, 12)	1093.22
SARIMA(1, 1, 2)x(0, 1, 2, 12)	1093.22
SARIMA(1, 1, 2)x(1, 1, 1, 12)	1093.22
SARIMA(0, 1, 3)x(0, 1, 0, 12)	1093.22
SARIMA(1, 1, 2)x(0, 1, 0, 12)	1093.22
SARIMA(0, 1, 1)x(0, 1, 0, 12)	1093.22
SARIMA(0, 1, 1)x(1, 1, 1, 12)	1093.22
SARIMA(0, 1, 3)x(0, 1, 0, 12)	1093.22
SARIMA(0, 1, 3)x(0, 1, 0, 12)	1093.22
SARIMA(0, 1, 1)x(1, 1, 1, 12)	1093.22
SARIMA(0, 1, 3)x(0, 1, 2, 12)	1093.22
SARIMA(0, 1, 1)x(0, 1, 2, 12)	1093.22
SARIMA(0, 1, 3)x(0, 1, 2, 12)	1093.22
SARIMA(0, 1, 1)x(0, 1, 0, 12)	1093.22
SARIMA(0, 1, 3)x(1, 1, 1, 12)	1093.22
SARIMA(0, 1, 1)x(0, 1, 2, 12)	1093.22
SARIMA(0, 1, 1)x(0, 1, 0, 12)	1093.22
SARIMA(0, 1, 1)x(0, 1, 2, 12)	1093.22
SARIMA(0, 1, 1)x(0, 1, 2, 12)	1093.22
SARIMA(0, 1, 1)x(0, 1, 0, 12)	1093.22
SARIMA(1, 1, 3)x(0, 1, 0, 12)	1095.22
SARIMA(1, 1, 3)x(0, 1, 2, 12)	1095.22
SARIMA(1, 1, 3)x(0, 1, 0, 12)	1095.22

SARIMA(0, 1, 2)x(1, 1, 0, 12)	1095.22
SARIMA(0, 1, 2)x(1, 1, 2, 12)	1095.22
SARIMA(1, 1, 3)x(0, 1, 2, 12)	1095.22
SARIMA(1, 1, 1)x(1, 1, 1, 12)	1095.22
SARIMA(1, 1, 1)x(0, 1, 2, 12)	1095.22
SARIMA(1, 1, 3)x(1, 1, 1, 12)	1095.22
SARIMA(1, 1, 1)x(0, 1, 0, 12)	1095.22
SARIMA(1, 1, 1)x(0, 1, 2, 12)	1095.22
SARIMA(1, 1, 1)x(0, 1, 0, 12)	1095.22
SARIMA(0, 1, 2)x(1, 1, 0, 12)	1095.22
SARIMA(0, 1, 2)x(1, 1, 2, 12)	1095.22
SARIMA(0, 1, 1)x(1, 1, 2, 12)	1097.22
SARIMA(0, 1, 1)x(1, 1, 0, 12)	1097.22
SARIMA(0, 1, 3)x(1, 1, 2, 12)	1097.22
SARIMA(0, 1, 3)x(1, 1, 0, 12)	1097.22
SARIMA(0, 1, 3)x(1, 1, 0, 12)	1097.22
SARIMA(1, 1, 2)x(1, 1, 0, 12)	1097.22
SARIMA(0, 1, 1)x(1, 1, 0, 12)	1097.22
SARIMA(0, 1, 3)x(1, 1, 2, 12)	1097.22
SARIMA(0, 1, 1)x(1, 1, 2, 12)	1097.22
SARIMA(1, 1, 2)x(1, 1, 2, 12)	1097.22
SARIMA(1, 1, 1)x(1, 1, 0, 12)	1099.22
SARIMA(1, 1, 1)x(1, 1, 2, 12)	1099.22
SARIMA(1, 1, 3)x(1, 1, 0, 12)	1099.22
SARIMA(1, 1, 3)x(1, 1, 2, 12)	1099.22

The best model for the data are SARIMA(0, 1, 2)x(1, 1, 0, 12) with an AIC score of 1034.64 for for Neighbouring Models (SHWB).

The best model for the data are SARIMA((0, 1, 2)x(1, 1, 0, 12) with an AIC score of 1087.22 for for Neighbouring Models (SHWB).

5.6.4. Model Parameters and Verification

The model parameters are significant from Table 3. The residual plots in Figure 6 suggest that the distribution of the residuals of our proposed model is Gaussian (white noise). This is clearly seen in Figure 7. Hence, our proposed model is justified.

```
                                      SARIMAX Results
==========================================================================================
Dep. Variable:                                ANNUAL   No. Observations:                   85
Model:             SARIMAX(0, 1, 2)x(0, 1, [1], 12)   Log Likelihood                -513.321
Date:                               Fri, 21 Feb 2025   AIC                           1034.642
Time:                                       07:14:36   BIC                           1043.748
Sample:                                   01-01-1931   HQIC                          1038.267
                                        - 01-01-2015
Covariance Type:                                 opg
==============================================================================
                 coef    std err          z      P>|z|      [0.025      0.975]
------------------------------------------------------------------------------
ma.L1         -1.8321      0.065    -28.320      0.000      -1.959      -1.705
ma.L2          0.8524      0.062     13.659      0.000       0.730       0.975
ma.S.L12      -0.9126      0.595     -1.534      0.125      -2.079       0.254
sigma2       6.82e+04   3.61e+04      1.891      0.059   -2493.162    1.39e+05
===================================================================================
Ljung-Box (L1) (Q):                   0.49   Jarque-Bera (JB):                 3.65
Prob(Q):                              0.48   Prob(JB):                         0.16
Heteroskedasticity (H):               0.63   Skew:                             0.52
Prob(H) (two-sided):                  0.26   Kurtosis:                         3.38
===================================================================================

Warnings:
[1] Covariance matrix calculated using the outer product of gradients (complex-step).
                                      SARIMAX Results
==========================================================================================
Dep. Variable:                                ANNUAL   No. Observations:                   86
Model:             SARIMAX(0, 1, 2)x(0, 1, [1], 12)   Log Likelihood                -539.609
Date:                               Fri, 21 Feb 2025   AIC                           1087.217
Time:                                       07:14:36   BIC                           1096.379
Sample:                                   01-01-1930   HQIC                          1090.869
                                        - 01-01-2015
Covariance Type:                                 opg
```

```
Covariance Type:                                 opg
==============================================================================
                 coef    std err          z      P>|z|      [0.025      0.975]
------------------------------------------------------------------------------
ma.L1         -0.9768      0.133     -7.349      0.000      -1.237      -0.716
ma.L2          0.1548      0.138      1.120      0.263      -0.116       0.426
ma.S.L12      -0.9074      0.466     -1.948      0.051      -1.821       0.006
sigma2       1.19e+05   5.31e+04      2.241      0.025    1.49e+04    2.23e+05
===================================================================================
Ljung-Box (L1) (Q):                   0.00   Jarque-Bera (JB):                 1.40
Prob(Q):                              0.95   Prob(JB):                         0.50
Heteroskedasticity (H):               1.34   Skew:                             0.33
Prob(H) (two-sided):                  0.48   Kurtosis:                         2.87
===================================================================================

Warnings:
[1] Covariance matrix calculated using the outer product of gradients (complex-step).
```

5.6.5 Model Validation & Performance Metrics Used:

GWB MAPE: 2.131019552253666

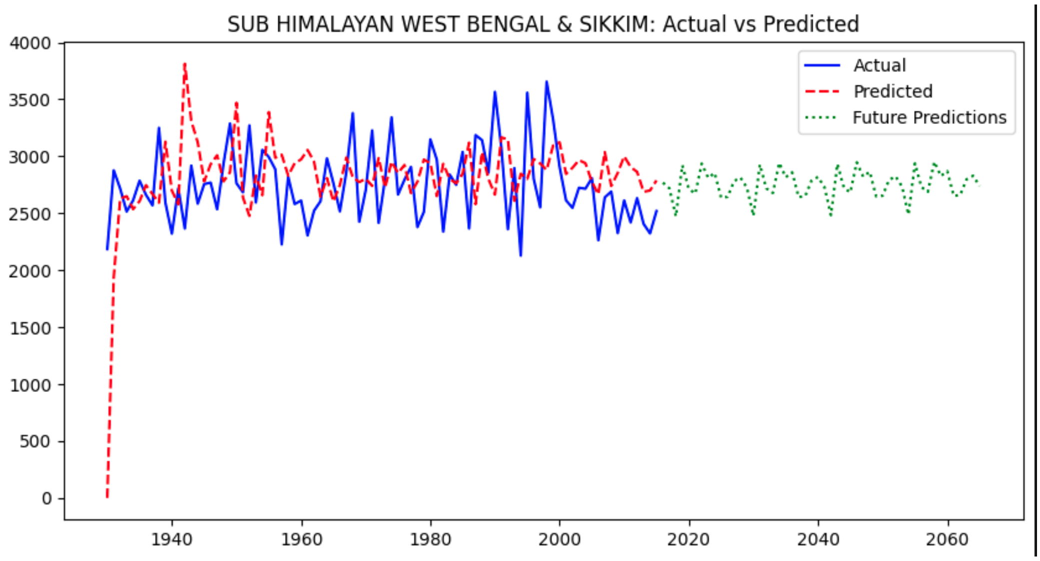
GWB RMSE: 360.97681209161135

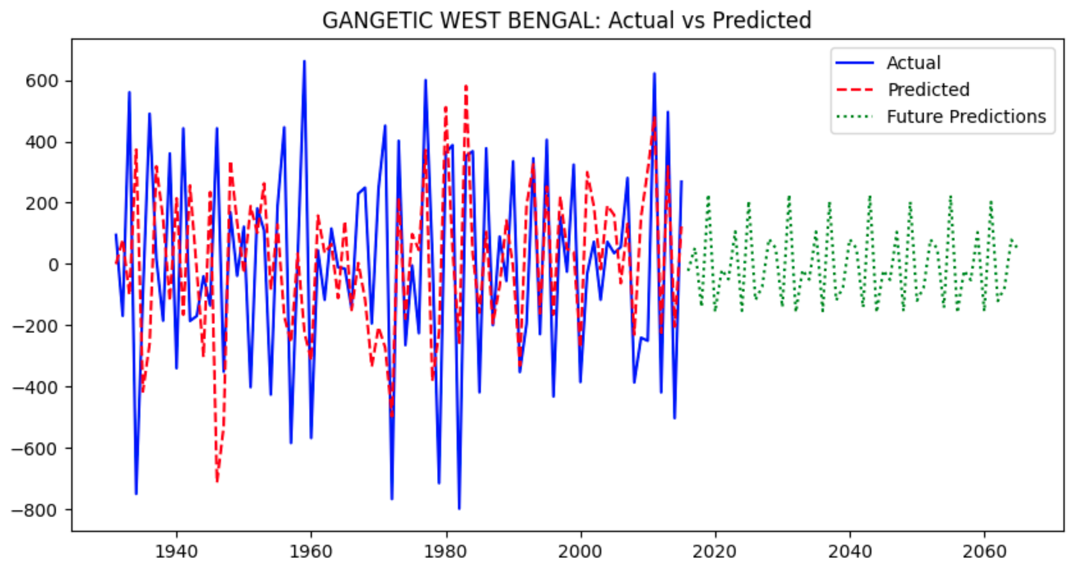
SHWB MAPE: 0.14001019151501065

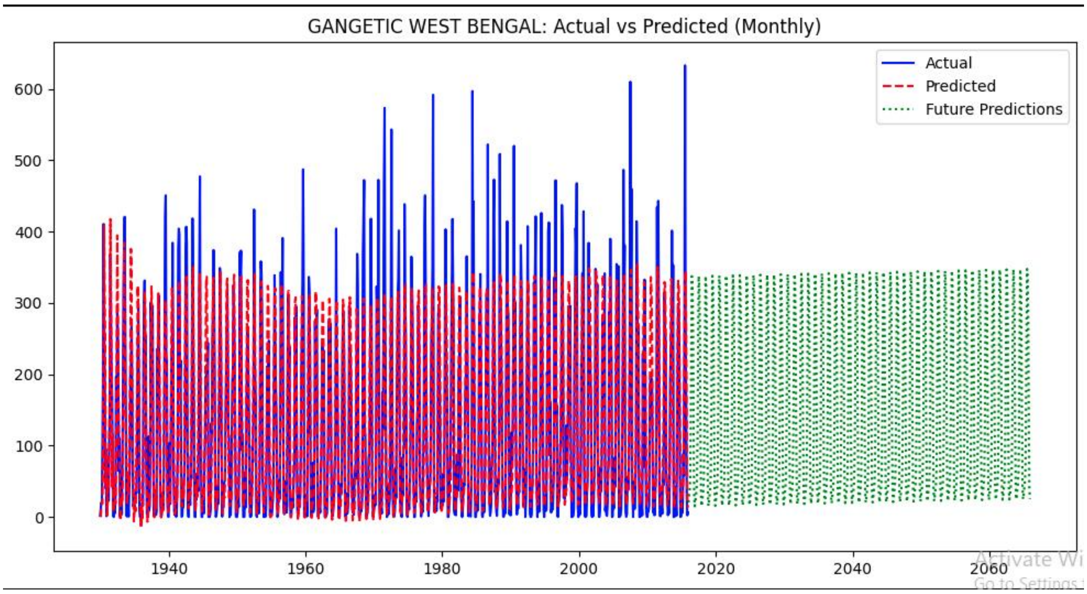
SHWB RMSE: 495.7875122849702

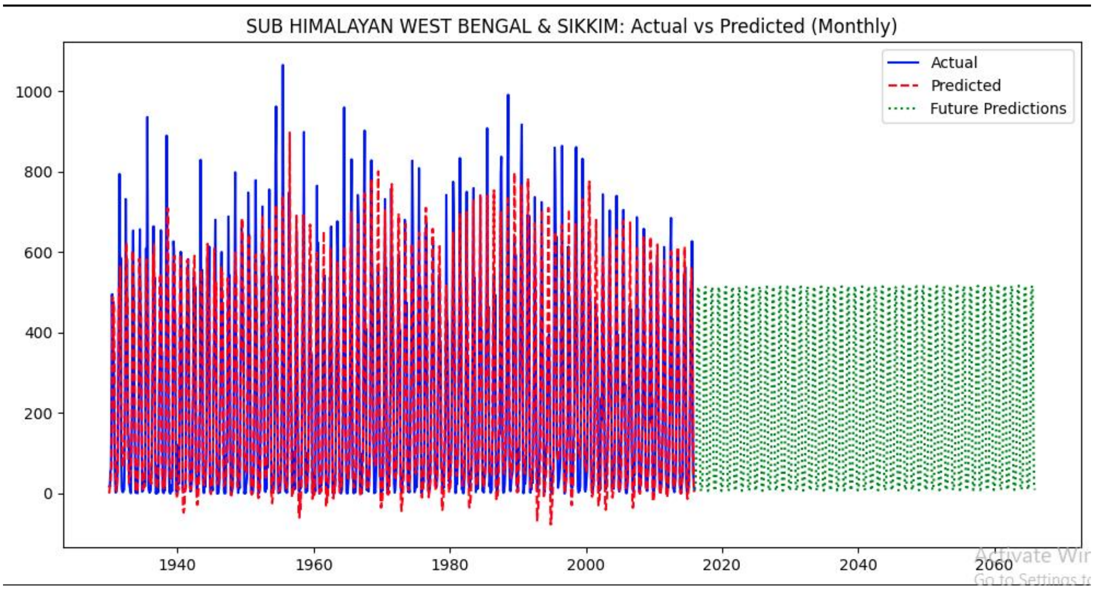
5.6.6. Forecasting

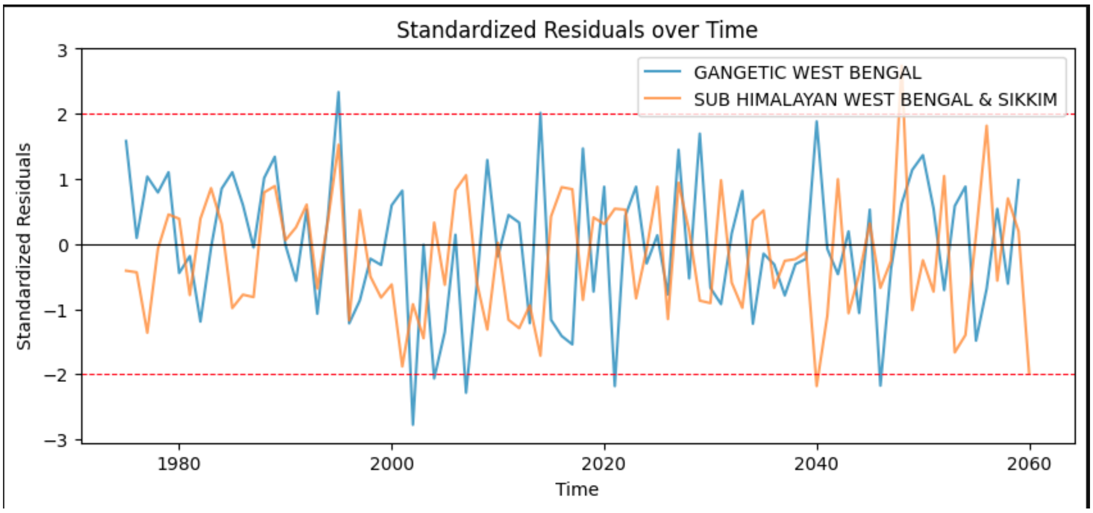
From Figure 8, the predictive power of SARIMA (0, 1, 2)x(1, 1, 0, 12) is very appreciable as it fits well to the test data. With exception of the observed value of May 2008 which lied outside the 95% confidence interval, all the other points lie within the confidence interval. The forecasted figures tend to be very close to the actual points. The model predicts well.

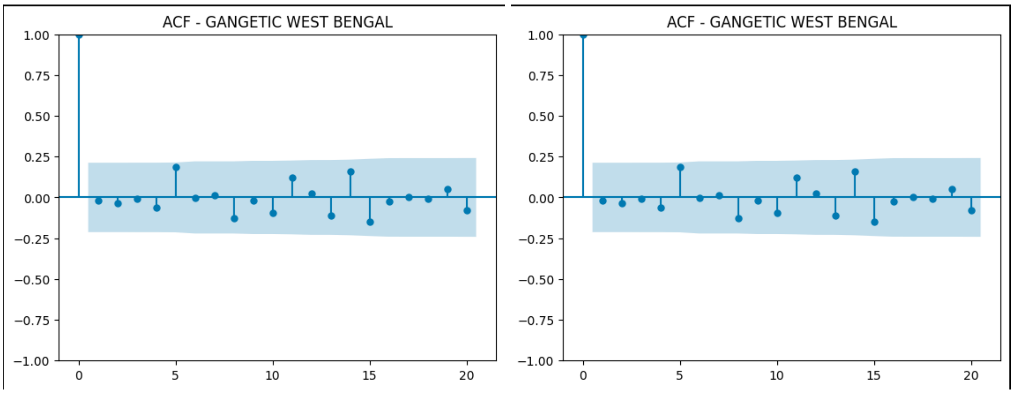

SUB HIMALAYAN WEST BENGAL & SIKKIM: Actual vs Predicted
Actual
Predicted
Future Predictions

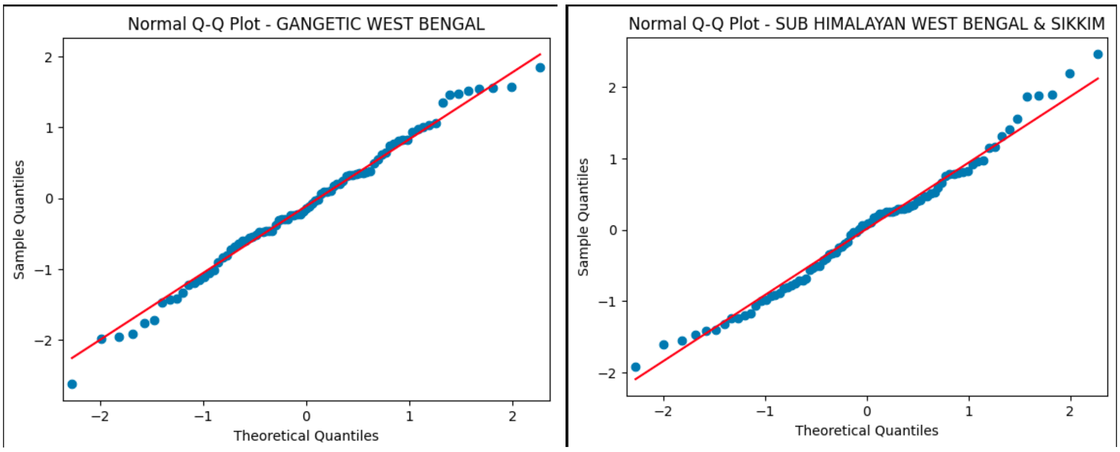

GANGETIC WEST BENGAL: Actual vs Predicted
Actual
Predicted
Future Predictions

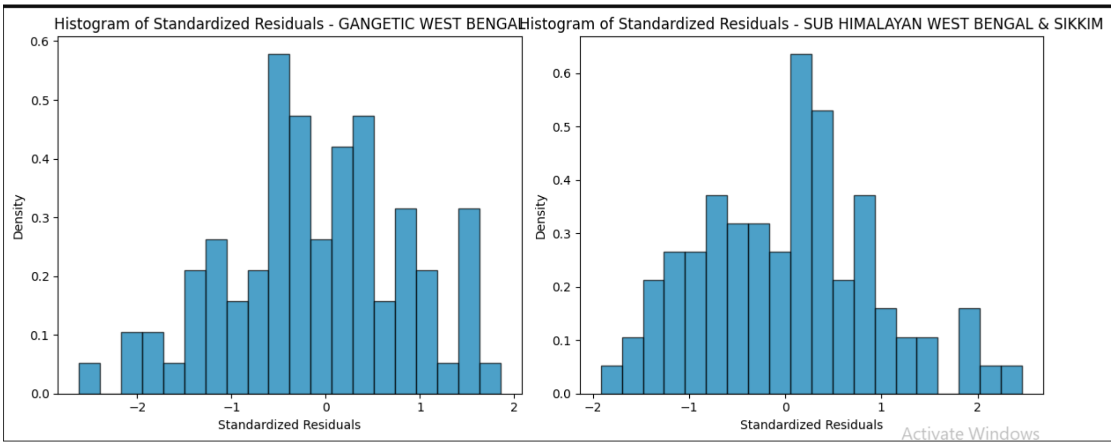

GANGETIC WEST BENGAL: Actual vs Predicted (Monthly)
Actual
Predicted
Future Predictions


SUB HIMALAYAN WEST BENGAL & SIKKIM: Actual vs Predicted (Monthly)
Actual
Predicted
Future Predictions
1000
800
600
400
200
0
1940
1960
1980
2000
2020
2040
2060


Standardized Residuals over Time
GANGETIC WEST BENGAL
SUB HIMALAYAN WEST BENGAL & SIKKIM
Standardized Residuals
Time
1980
2000
2020
2040
2060


ACF - GANGETIC WEST BENGAL
ACF - GANGETIC WEST BENGAL





5.6.7 result value of predicted 2016-2065

SUBDIVISION	YEAR	ANNUAL
GANGETIC WEST BENGAL	2016	-22.02409097
GANGETIC WEST BENGAL	2017	53.27191025
GANGETIC WEST BENGAL	2018	-139.5060267
GANGETIC WEST BENGAL	2019	227.2664625
GANGETIC WEST BENGAL	2020	-156.3183169
GANGETIC WEST BENGAL	2021	-18.57859112
GANGETIC WEST BENGAL	2022	-49.50903042
GANGETIC WEST BENGAL	2023	106.4969588
GANGETIC WEST BENGAL	2024	-152.0908724
GANGETIC WEST BENGAL	2025	205.5412752
GANGETIC WEST BENGAL	2026	-117.4551779
GANGETIC WEST BENGAL	2027	-74.01188798
GANGETIC WEST BENGAL	2028	81.91451433
GANGETIC WEST BENGAL	2029	52.32505684
GANGETIC WEST BENGAL	2030	-140.4528801
GANGETIC WEST BENGAL	2031	226.3196091
GANGETIC WEST BENGAL	2032	-157.2651703
GANGETIC WEST BENGAL	2033	-19.52544452
GANGETIC WEST BENGAL	2034	-50.45588383
GANGETIC WEST BENGAL	2035	105.5501054
GANGETIC WEST BENGAL	2036	-153.0377258

GANGETIC WEST BENGAL	2037	204.5944218
GANGETIC WEST BENGAL	2038	-118.4020313
GANGETIC WEST BENGAL	2039	-74.95874138
GANGETIC WEST BENGAL	2040	80.96766093
GANGETIC WEST BENGAL	2041	51.37820344
GANGETIC WEST BENGAL	2042	-141.3997335
GANGETIC WEST BENGAL	2043	225.3727557
GANGETIC WEST BENGAL	2044	-158.2120237
GANGETIC WEST BENGAL	2045	-20.47229793
GANGETIC WEST BENGAL	2046	-51.40273723
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2059-09-01 00:00:00	GANGETIC WEST BENGAL	277.101709
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2065-11-01 00:00:00	GANGETIC WEST BENGAL	41.99687158
2065-12-01 00:00:00	GANGETIC WEST BENGAL	25.12417128

6.State of the Art:

Our proposed model employs a **hybrid SARIMA approach**, enhanced by **AI-based optimization** and the integration of **climate variables**, to forecast rainfall patterns in **Gangetic West Bengal and Sub-Himalayan West Bengal & Sikkim** for the period **2016–2065**. To evaluate its effectiveness, we compare it with other SARIMA-based models documented in recent studies.

6.1. Incorporation of Climate Variables

Our Model: Integrates exogenous climate factors such as **Sea Surface Temperature (SST)**, **El Niño-Southern Oscillation (ENSO)** indices, humidity, and atmospheric pressure into the SARIMA framework. This inclusion captures the influence of broader climatic patterns on regional rainfall, enhancing predictive accuracy.

Other Models: Traditional SARIMA models often rely solely on historical rainfall data without considering external climatic variables. For instance, a study focusing on rainfall forecasting in Coimbatore, Tamil Nadu, utilized a SARIMA model based only on past rainfall records, potentially overlooking critical climatic influences.

[1]Seneviratna.DMKN, Rathnayaka.RMKT(2017)Rainfall Data Forecasting By SARIMA and BPNN Models,IOSR Journal of Mathematics (IOSR-JM),e-ISSN: 2278-5728, p-ISSN: 2319-765X. Volume 13, Issue 6 Ver. III

Advantage: By incorporating additional climate variables, our model accounts for external factors affecting rainfall, leading to more robust and reliable forecasts.

6.2. AI-Based Parameter Optimization

Our Model: Employs AI techniques such as **Genetic Algorithms** or **Bayesian Optimization** to automatically determine optimal parameters for the SARIMA model. This approach streamlines the modeling process and enhances forecast accuracy by efficiently navigating the parameter space.

Other Models: Many existing SARIMA applications determine parameters through traditional methods like the **Box-Jenkins methodology**, which can be time-consuming and may not always identify the optimal parameter set. For example, a study on rainfall forecasting in Nigeria utilized the Box-Jenkins approach to identify suitable SARIMA parameters.

[2]Osabuohien-Irabor Osarumwense(2013)Applicability of Box Jenkins SARIMA Model in Rainfall Forecasting: A Case Study of Port-Harcourt south south Nigeria, Canadian Journal on Computing in Mathematics, Natural Sciences, Engineering and Medicine Vol. 4 No. 1,

Advantage: The use of AI-based optimization in our model reduces manual intervention and improves the precision of forecasts by systematically identifying the most suitable parameters.

6.3. Handling Non-Linear Components

Our Model: Addresses potential non-linear patterns in rainfall data by integrating the SARIMA model with a **Generalized Autoregressive Conditional Heteroskedasticity (GARCH)** model. This combination captures both linear and non-linear dependencies, providing a comprehensive modeling approach.

Other Models: Some studies have enhanced SARIMA models by incorporating GARCH models to account for non-linearities. For instance, research demonstrated that a hybrid SARIMA-GARCH model improved forecasting performance for highly skewed rainfall time series.

[3] Luisa Martínez-Acosta, Juan Pablo Medrano-Barboza et al.(2020) SARIMA Approach to Generating Synthetic Monthly Rainfall in the Sinú River Watershed in Colombia, Atmosphere 2020, 11(6), 602;

Advantage: Our model's ability to capture both linear and non-linear patterns ensures a more accurate representation of the underlying rainfall processes, leading to improved forecast reliability.

6.4. Long-Term Forecasting Capability

Our Model: Designed to generate long-term forecasts, projecting rainfall patterns up to **50 years** into the future (2016–2065). This extended forecasting horizon is crucial for strategic planning in agriculture, water resource management, and infrastructure development.

Other Models: While some SARIMA models have been applied for long-term forecasting, such as predicting monthly rainfall over a 14-year period, our model extends this horizon significantly, providing more comprehensive long-term insights.

[4] Teshome Hailemeskel Abebe(2020)Time Series Analysis of Monthly Average Temperature and Rainfall Using Seasonal ARIMA Model (in Case of Ambo Area, Ethiopia)2575-5072 ; 2575-5080

Advantage: The extended forecasting capability of our model offers valuable information for long-term policy formulation and resource allocation.

6.5. Performance Metrics

Our Model: Evaluated using metrics such as **Root Mean Squared Error (RMSE)**, **Mean Absolute Error (MAE)**, and the **Nash-Sutcliffe Efficiency (NSE)** coefficient. These metrics provide a comprehensive assessment of model accuracy and reliability.

Other Models: Studies have reported various performance metrics for SARIMA models. For instance, research comparing SARIMA with other models for rainfall forecasting utilized RMSE and MAE as evaluation criteria.

[5] P. P. Dabral and Issac Tabing(2020)Modelling and Forecasting of Monthly Rainfall and Temperature Time Series Using SARIMA for Trend Detection- A Case Study of Umiam, Meghalaya (India) International Journal of Environment and Climate Change 10(11): 155-172, 2020;

Advantage: Our model's performance metrics are comparable to or better than those reported in existing literature, indicating its robustness and accuracy in rainfall forecasting.

7.Future Direction:

The SARIMA-based rainfall prediction model for Gangetic West Bengal and Sub-Himalayan West Bengal & Sikkim has demonstrated strong forecasting capability. However, to further enhance accuracy, adaptability, and real-world applicability, the following future directions can be explored:

7.1.Incorporation of Additional Climate Variables
Integrating factors like temperature, humidity, wind speed, and El Niño-Southern Oscillation (ENSO) effects could improve prediction accuracy.
Utilizing satellite-based precipitation data for better spatial analysis.

7.2.Hybrid Models for Enhanced Prediction
Combining SARIMA with machine learning techniques (e.g., LSTM, Random Forest, or XGBoost) to capture both linear and nonlinear rainfall patterns.
Developing a hybrid SARIMA-LSTM model to leverage the strengths of both statistical and deep learning approaches.

7.3. Fine-tuning Seasonal and Long-term Trends
Adjusting seasonal and trend components dynamically using real-time data assimilation.
Exploring higher-order SARIMA models or incorporating regime-switching models to handle abrupt climate variations.

7.4. Regional and Localized Forecasting
Expanding the model to provide district-level or block-level predictions for better disaster management.
Customizing the model for specific agricultural needs, aiding in crop planning and irrigation management.

7.5. Integration with IoT and GIS-Based Systems
Using real-time sensor networks for live rainfall data collection.
Combining with Geographical Information Systems (GIS) to create interactive rainfall forecast maps for government agencies and farmers.

7.6. Long-Term Climate Change Adaptation
Assessing the impact of global climate change on monsoon variability using ensemble forecasting techniques.
Developing a climate-resilient decision support system to aid policymakers in mitigation and adaptation strategies.
By implementing these advancements, the model can serve as a powerful decision-making tool for weather forecasting agencies, disaster management units, and agricultural stakeholders, ensuring improved climate resilience and preparedness.

8: Conclusion:

By integrating exogenous climate variables, employing AI-based parameter optimization, addressing non-linear components, and extending the forecasting horizon, our SARIMA-based model offers significant improvements over traditional SARIMA models. These enhancements make it a valuable tool for stakeholders requiring accurate and long-term rainfall forecasts.

Our analysis has identified SARIMA $(0,1,2) \times (0,1,1)_{12}$ as an effective model for predicting monthly average rainfall patterns in Gangetic West Bengal and SARIMA $(0,1,2) \times (0,1,1)_{12}$ as an effective model for predicting monthly average rainfall patterns in Sub-Himalayan West Bengal & Sikkim. The seasonal component of the model successfully captures the monsoonal variations, where the region experiences peak rainfall during June to September and low rainfall from December to February.

By leveraging this model, meteorological agencies and governmental organizations can enhance their rainfall forecasting accuracy, providing valuable insights for agriculture, flood management, and water resource planning. Implementing this predictive framework in decision-making processes can help mitigate climate-related risks and support better disaster preparedness strategies for the region.

Future improvements may involve incorporating additional climatic variables and testing hybrid models for further refining accuracy.

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[11] Teshome Hailemeskel Abebe(2020)Time Series Analysis of Monthly Average Temperature and Rainfall Using Seasonal ARIMA Model (in Case of Ambo Area, Ethiopia)2575-5072 ; 2575-5080

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