



# Application of Univariate Time Series Models for Forecasting Area, Production, and Productivity of Aman Rice in Jalpaiguri, West Bengal, India

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## Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

## Article Information

DOI: <https://doi.org/10.9734/jeai/2024/v46i82765>

## Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://www.sdiarticle5.com/review-history/121212>

Original Research Article

Received: 08/06/2024

Accepted: 10/08/2024

Published: 13/08/2024

## ABSTRACT

Agricultural production is reliant on modern technology and historical information to enhance the present outcomes and ensure future sustainability. In this study, the area, production, and productivity of Aman rice in Jalpaiguri district using data from 1977-2022 is modelled by two popular time series modelling techniques i.e., the Autoregressive Integrated Moving Average (ARIMA) method and the Generalized Autoregressive Conditional Heteroscedasticity (GARCH)

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**Cite as:** Rai, Nishtha Pradarshika, and Satyananda Basak. 2024. "Application of Univariate Time Series Models for Forecasting Area, Production, and Productivity of Aman Rice in Jalpaiguri, West Bengal, India". *Journal of Experimental Agriculture International* 46 (8):815-32. <https://doi.org/10.9734/jeai/2024/v46i82765>.

method. A comparison of the models based on the lowest values of Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), and Mean Absolute Error (MAE) revealed that ARIMA models performed better in the training period on all three series. However, in the test period, the GARCH models on area and production performed better while the ARIMA model performed better on productivity. The best-fitted models selected were AR (1) - GARCH (1,1) on Aman rice area, AR (1) - GARCH (1,1) on Aman rice production and ARIMA (0,1,1) on Aman rice productivity. Using the chosen models, forecasts are produced for the subsequent ten years.

**Keywords:** ARIMA; GARCH; ACF; PACF; forecasting; area; production; productivity.

## 1. INTRODUCTION

In agriculture, time series forecasting is a pathway to assist the decision-making process. For agricultural management, policy-making, and planning purposes, getting estimates of future values is beneficial. By harnessing the power of data analytics using historical data to get advanced estimates, sustainability can be ensured in the face of uncertainty. Time-series modelling is a productive and reliable tool for forecasting future outcomes. Time-series models take historical information to describe the underlying time-lagged relationships in the variables under study to produce accurate forecasts.

Two of the most popular time series forecasting techniques used are the ARIMA and GARCH modelling techniques. The Autoregressive Integrated Moving Average (ARIMA) model fitting is a linear modelling technique to ascertain the stochastic process involved in a univariate series. ARIMA models are popular due to their simplicity and availability in multiple softwares [1]. The ARIMA technique is an approach to model a time series variable with cyclical variation, irregular fluctuations, and trend components. This technique assumes that the residual variance is constant. However, in real datasets, changes in variance have been observed with trends modelled by non-linear processes. Often, the underlying pattern is inadequately explained by a linear model as the error variance is non-constant over time. In that case, the Generalized Autoregressive Conditional Heteroscedasticity (GARCH) model can capture the conditional variance or volatility present in the dataset. Other than traditional time series models, agricultural forecasting has proven to be successful by methods such as naïve forecasting [2], remote sensing-based methods [3], crop simulation models [4], machine learning techniques [5], and deep learning methods [6]. In India, the ARIMA and GARCH

models have been used in agriculture to study crop prices [7,8], area, production and yield [9,10].

Rice is a major cereal crop grown under a diverse range of soil and agroclimatic conditions in different states of India. It is a staple food for more than 60 % of the nation's population. Rice is grown extensively in West Bengal making it the largest producer of India. Around 5.29 % of the rice grown in West Bengal is exported (Source: IBEF,2022). In West Bengal, rice is grown primarily in three seasons, viz., Aus, Aman, and Boro. Of the three seasons, the area under Aman rice cultivation is the largest and so, the production is maximum. In the Terai Zone, heavy rainfall favours the growth of Aman rice. Jalpaiguri accounts for 2.7 % of the area under Aman rice cultivation and 2.5 % of Aman rice production in West Bengal (Source: Directorate of Agriculture, Govt. Of W.B., 2021). There is an emerging need to forecast the area, production, and productivity of Aman rice to help formulate policy to narrow the gap between supply and demand. An efficient and reliable method to produce forecasts is the time series approach. This study aims to model the area, production, and productivity of Aman rice using the univariate ARIMA and GARCH models for generating forecasts for the Jalpaiguri district of West Bengal.

## 2. MATERIALS AND METHODS

### 2.1 Study Area

Jalpaiguri is an Indian district in the state of West Bengal. As illustrated in Fig. 1, it is situated in the northern portion of West Bengal at latitudes 26° 16' to 27° 0' North and longitudes 88° 4' to 89° 53' East. The gross cropped area of Jalpaiguri is 329544 ha of which Aman rice is grown in 111502 ha (Source: Directorate of Agriculture, Govt. of W.B., 2021).

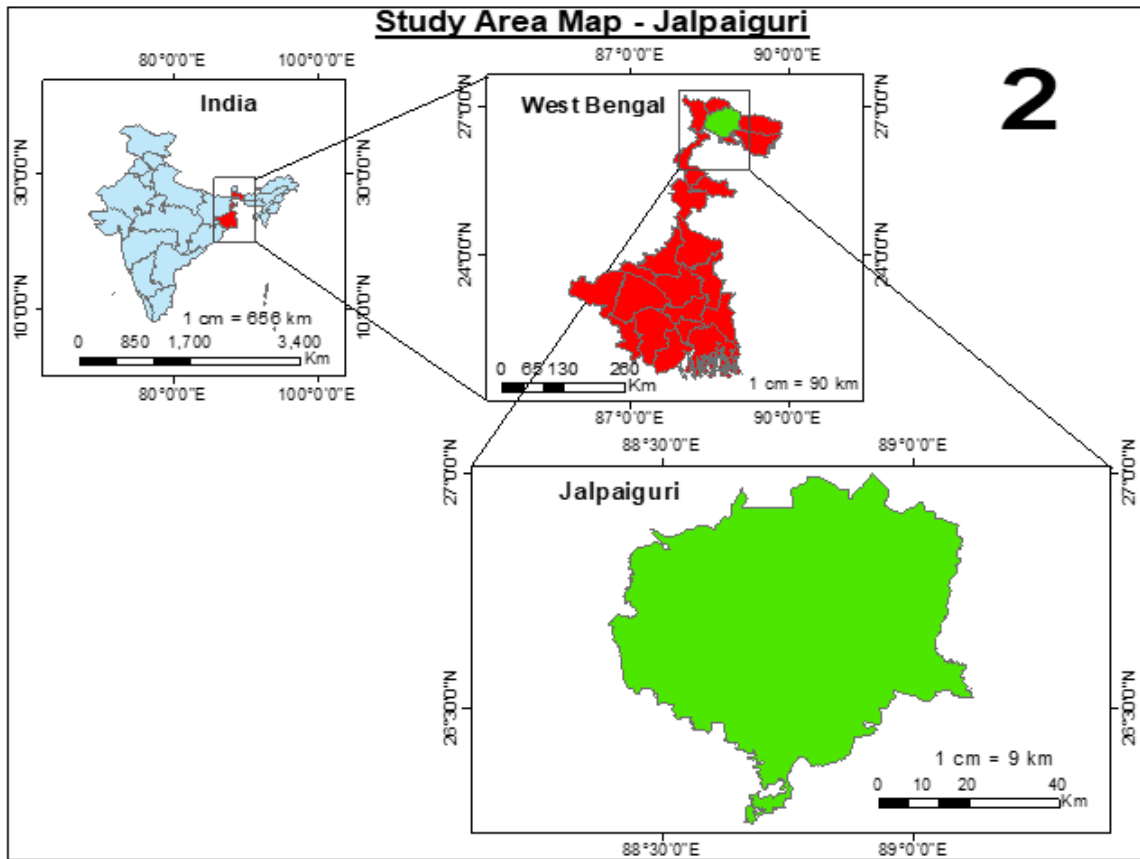


Fig. 1. Geographical map of Jalpaiguri district

## 2.2 Data Collection

Annual data from 1977 to 2022 on area ('000 ha), production ('000 tonnes), and productivity (kg/ha) of Aman rice of Jalpaiguri district were collected from Statistical Abstract, Govt. of W.B. from 1977-2014 and Directorate of Agriculture, Govt. of W.B. from 2015-2022. The dataset is divided into the training dataset consisting of the first 80% i.e. 1977 to 2013 for building the model while the rest 20% i.e., 2014 to 2022 is used for approving the selected model. The analysis was carried out in R Studio IDE.

## 2.3 Methods of Data Analysis

### 2.3.1 Trend analysis

A time series displaying a clear pattern, either an upward or a downward, is called a trend. The nonparametric Mann–Kendall (MK) test [11,12] and Sen's slope Test [13] were employed for trend analysis. The MK test is a statistical test employed for quantifying the significance of trends and Sen's slope for measuring the magnitude of the trend [14]. The  $\tau$  of the MK test

is the coefficient of correlation ranging between  $\pm 1$  [15] with positive values indicating a positive trend and negative values indicating a decreasing trend. The Sen's slope assumes a linear trend in a time series represented by  $\beta$ . Positive  $\beta$  values indicate an upward trend while negative values indicate a downward trend [16].

### 2.3.2 ARIMA

The ARIMA [17] model predicts future values based on a linear function of past values of the time series and its error values. The Moving Average (MA) and Autoregressive (AR) terms make up the ARIMA model. The Autoregressive terms are time-lagged values of that variable with its immediate past value. The Moving average terms, on the other hand, are time-lagged errors resulting from previously made estimates. An important criterion for ARIMA models is that the series should be stationary i.e. the autocorrelation, mean and variance should be unchanging across time. If a series is nonstationary, it implies the presence of a seasonal, cyclical, or trend component. To make it stationary, the series should be differenced  $d$

times. This combination of the AR, MA, and differenced terms is called the ARIMA model. The ARIMA ( $p, d, q$ ) model is expressed as follows:

$$\kappa(\beta)(1 - \beta)^d z_t = \lambda(\beta) \omega_t$$

Where,  $\kappa(\beta) = (1 - \kappa_1\beta - \kappa_2\beta^2 - \dots - \kappa_p\beta^p)$ ,  $\lambda(\beta) = (1 - \lambda_1\beta - \lambda_2\beta^2 - \dots - \lambda_q\beta^q)$ ;  $\beta$  is known as the backshift operator;  $\beta z_t = z_{t-1}$ ;  $z_t$  is the  $t^{th}$  time series value;  $\omega_t$  is the  $t^{th}$  white noise assumed to be independently distributed;  $d$  is the order of differencing;  $p$  is the AR order;  $q$  is the MA order;  $\kappa$ 's are the AR coefficients and  $\lambda$ 's are the MA coefficients.

The Box Jenkins procedure of ARIMA modelling consists of the following stages: Model Identification, Parameter Estimation, and Diagnostic Checking.

### 2.3.2.1 Model Identification

The identification stage is a stage of determining the orders of the AR, differencing, and MA process i.e.  $p, d,$  and  $q$  respectively. For an ARIMA model, a time series should be stationary. Non-stationary data is made stationary by differencing the series or sometimes, by transforming the data using logarithmic transformations [18]. A differenced series is obtained by subtracting values from the current period from its last. The Augmented Dickey-Fuller (ADF) Test is employed to test the stationarity of a series. The results of the ADF test determine the order of  $d$ . To determine the  $p$  and  $q$  orders, one must visualize the ACF and PACF plots. The lag at which the PACF plot has a significant spike and the lag at which the ACF plot has a significant spike, determines the order of the AR and MA process, respectively. The tentative models are examined and the model with the smallest Information Criteria values is selected.

### 2.3.2.2 Parameter estimation

When the series is stationary, i.e.  $d = 0$ , then, a constant term is included in the model, and when  $d = 1$ , a constant is included if it improves the AICc value. For  $d > 1$ , the constant term is omitted as higher-order trends are harmful to forecasts [19]. After the model is identified, the parameter coefficients of the AR and MA order are estimated using the maximum likelihood function [17]. The forecast performance of the

models is assessed by accuracy metrics like-RMSE, MAE, and MAPE.

### 2.3.2.3 Diagnostic checking

In this stage, residuals are screened for their departure from white noise. White noise is characterized by residuals that are independently and normally distributed. The Normality assumption is visualized by the histogram and checked using the Shapiro Wilk's statistic. The residual ACF plot and Ljung Box test are employed to check the independence of residuals.

**Ljung-Box Test-** The Ljung Box test [20] is a lack-of-fit test. It is employed to test the absence of serial autocorrelation up to lag  $k$ . The null hypothesis states that data is distributed independently. The alternate hypothesis is the data are not independently distributed.

$$Q = t(t+2) \sum_{k=1}^h (t-k)^{-1} \hat{\rho}_k^2,$$

Where,  $h$  is the total number of lags being tested,  $t$  is the sample size,  $\hat{\rho}_k$  is the sample autocorrelation at lag  $k$ , and  $Q$  is distributed asymptotically as  $\chi_{(h)}^2$  with  $h$  degrees of freedom.

The null hypothesis of independence is rejected when the value of  $Q$  is greater than the selected critical value of the  $\chi^2$  distribution with  $h$  degrees of freedom.

### 2.3.3 GARCH

The GARCH [21] model is a generalization of the ARCH [22] model. It is used for modelling a series possessing conditional heteroscedasticity or non-constant variance. To test the presence of ARCH effects, the ARCH L-M Test is used. The ARCH ( $q$ ) process for the residual series  $\varepsilon_t$  is defined by the conditional distribution of  $\varepsilon_t | \psi_{t-1}$ , where  $\psi_{t-1}$  is the information about volatility up to  $t - 1$ . Here,  $\varepsilon_t | \psi_{t-1} \sim N(0, v_t)$ .

$$\varepsilon_t = \omega_t \sqrt{v_t} \text{ and } v_t = \alpha_0 + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2$$

Where,  $\omega_t$  is white noise and  $\omega_t \sim \text{i.i.d.}(0,1)$ ,  $\alpha_0 > 0, \alpha_i \geq 0, \sum_{i=1}^q \alpha_i < 1 \forall i$  to ensure positive and unconditional variance of the stationary  $\varepsilon_t$  series. It means that  $\varepsilon_t$  is serially uncorrelated with zero mean and changing conditional variance of  $v_t$  over time.

**Table 1. Model evaluation metrics**

Statistics	Formula
Akaike Information Criteria	$2f - 2 \ln(\hat{L})$
Bayesian Information Criteria	$\ln(T)f - 2 \ln(\hat{L})$
Akaike Information Criteria with correction	$AIC + \frac{2f^2 + 2f}{T - f - 1}$
Mean Absolute Percent Error	$100 \times T^{-1} \times \sum_{t=1}^T  \hat{\omega}_t  / z_t$
Mean Absolute Error	$T^{-1} \times \sum_{t=1}^T  \hat{\omega}_t $
Root Mean Square Error	$(T^{-1} \sum_{t=1}^T \hat{\omega}_t^2)^{1/2}$

Where,  $T$  = no. of observations ;  $f$  = no. of parameters ;  $\hat{L}$  = maximized value of the maximum likelihood function of the estimated model,  $\hat{\omega}_t = z_t - p_t$ ,  $\hat{\omega}_t$  = estimated white noise at time 't',  $\hat{\omega}_t^2$  = squared value of estimated white noise at time 't',  $z_t$  = original value at time 't',  $p_t$  = predicted value at time 't'.

The unconditional ACF of squared residuals of the ARCH model, if it exists declines rapidly, excepting the case when the maximum lag is large. While the unconditional ACF of squared residuals of the GARCH model decays slowly which gives a more parsimonious model of the conditional variance [1]. The conditional variance of the GARCH model represents an ARMA process [23] which is a linear function of its lagged terms as well and is given as

$$v_t = \alpha_0 + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^p \beta_j v_{t-j}$$

Where,  $\alpha_0 > 0, \alpha_i \geq 0, \beta_j \geq 0, \sum_{i=1}^q \alpha_i + \sum_{j=1}^p \beta_j < 1 \forall i, j$  to ensure positive conditional variance.  $\varepsilon_{t-i}^2$  is the squared residual of  $t-i$  period from the mean equation and  $v_{t-j}$  is the forecast variance of  $t-j$  period.

Such models are called GARCH ( $p, q$ ) where  $p$  denotes the GARCH order and  $q$  denotes the ARCH order. The model parameters are estimated by the method of maximum likelihood estimation. Here,  $(\alpha_i + \beta_j)$  is the measure of volatility persistence. This sum values closer to 1 indicate a longer duration of persistence [7].

**2.4 Test for Stationarity and Normality**

**1) Augmented Dickey Fuller Test** - The ADF test [24] checks the stationarity of a series. The test is applied to the following model:

$$\Delta z_t = \alpha + \beta t + \Psi z_{t-1} + \varphi_1 \Delta z_{t-1} + \dots + \varphi_p \Delta z_{t-p} + \varepsilon_t$$

Where,  $\alpha$  is a constant,  $\beta$  is the coefficient of time trend,  $\Delta z_t = z_t - z_{t-1}$ ,  $\sum_{i=1}^p \varphi_i \Delta z_{t-i}$  are lag terms up to order  $p$ ;  $\Psi$  is the coefficient of interest and  $\varepsilon_t$  is the error term

The null hypothesis is  $\Psi = 0$ , i.e., the presence of unit root indicating that the series is non-stationary. The alternate hypothesis is that the time series is stationary.

$$DF_T = \frac{\hat{\Psi}}{SE(\hat{\Psi})}$$

If  $DF_T$  calculated < the critical value, the null hypothesis is rejected. If it is not stationary, we travel further and test the series at first and second differences sequentially.

**2) Wilk's Shapiro Test-** The Wilk's Shapiro test [25] is a goodness-of-fit test to check the departure from normality. The null hypothesis is the time series  $y_1, y_2, \dots, y_t$  is normally distributed. The alternative hypothesis is the series is not normally distributed.

$$W = \frac{(\sum_{i=1}^t k_i y_{(i)})^2}{\sum_{i=1}^t (y_i - \bar{y})^2}$$

Where,  $k_i$  are coefficients generated from variance, covariance and mean of the sample

order statistics;  $y_{(i)}$  is the  $i^{\text{th}}$  order statistic and  $\sum_{i=1}^t (y_i - \bar{y})^2$  is the error sum of squares.

The null hypothesis is rejected when W statistic > the selected critical value.

## 2.5 Test for ARCH Effect

**ARCH L-M Test-** Engle's [22] ARCH test is a Lagrange Multiplier test to evaluate the presence of conditional heteroscedasticity in the squared residuals. The null hypothesis is  $\alpha_j = 0$ ,  $j = 1, 2, \dots, m$  and the alternative hypothesis is at least one of the  $\alpha_j$  coefficients is significant which is tested by the F-test indicating the presence of autocorrelation in the squared residuals of the regression:

$$\varepsilon_t^2 = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \dots + \alpha_m \varepsilon_{t-m}^2 + \omega_t$$

Where,  $\varepsilon_t^2$  is the squared residuals,  $t = m + 1, \dots, n$ ,  $\omega_t$  is the white noise term,  $m$  is the number of lags being tested, and  $n$  is the total sample size.

The null hypothesis is rejected when the value of the F statistic is larger than the selected critical value of the  $\chi^2$  distribution with  $m$  degrees of freedom.

## 3. RESULTS AND DISCUSSION

### 3.1 Data Description

Descriptive statistics for Aman rice data between 1977-2022 are presented in Table 2. The area has decreased from 212.00 '000 ha to 111.34 '000 ha, production has increased from 224.30 '000 tonnes to 299.23 '000 tonnes, and productivity has increased from 1058 kg/ha to 2687 kg/ha during the study period. The average yearly area of Aman rice is 175.44 '000 ha, production is 269.59 '000 tonnes, and productivity is 1624.28 kg/ha. Kurtosis value (0.84) of area indicates a leptokurtic nature, 0.50 of production suggests a mesokurtic nature and -1.00 of productivity indicates platykurtic distribution. Negative skewness value (-1.33) of area implies that area decreased continuously and positive skewness values 0.762 and 0.626 indicate an increase in the Aman rice production and productivity respectively. The CV and SD explain variability. The CVs of area, production and productivity are 18.60%, 25.28%, and 37.08%, respectively and SDs are 32.63, 68.15, and 602.35, respectively.

### 3.2 Trend Analysis

The Mann-Kendall test and Sen's slope test (Table 3) are used for trend analysis. The results of the MK-Test indicate that the area shows a significant negative trend while both production and productivity show a significant positive trend and the same was established by the Sen's slope method at 0.1 % significance level. Sen's slope for area, production, and productivity are -1.24 '000 ha, 3.37 '000 tonnes, and 42.02 kg/ha. The existence of trends observed in the study encourages us to adopt time series models for forecasting.

### 3.3 ARIMA

The primary step in ARIMA modelling is to determine the stationarity of the dataset. For this purpose, the ADF test was employed.  $P > 0.05$  of ADF statistic (Table 4) of the original series for Aman rice area, production and productivity depict that the series are non-stationary. To achieve stationarity, the above series are differenced. As shown in Table 4, differencing operations of the order  $d = 1$  result in a stationary dataset for Aman rice area, production, and productivity. Once the stationarity condition is met, the AR and MA orders ( $p$  and  $q$ ) were determined from the ACF and PACF plots of the differenced series shown in Fig. 2. Since the ACF and PACF plots of the Aman rice area, production, and productivity are significant at lag 1 each, the ARIMA model combinations of Aman rice is of the order  $p = 0, 1$ , and  $q = 0, 1$ . To determine the best-performing model, the models- ARIMA (0,1,1), ARIMA (1,1,0), and ARIMA (1,1,1) are fitted to the training set and evaluated using the lowest values of AICc, AIC, and BIC. From the order analysis, ARIMA (0,1,1) for Aman area, ARIMA (0,1,1) with a constant for production, and ARIMA (0,1,1) with a constant for productivity are selected for Jalpaiguri district which is presented in Table 5.

The parameters of the selected models are tested for their statistical significance which is given in Table 6. The MA components of all the series are negative and statistically significant at a 0.1% level of significance implying that previous period shocks have a crucial role in describing Jalpaiguri's area, production, and productivity. Then, the residuals from the models are analyzed for independence and normality to ascertain that they are white noise. There is no serial autocorrelation in the residuals as

observed in ACF plots (Fig. 3) and the Q-statistic's p-value is  $P > 0.05$ , meaning that every series is independent (Table 7). To detect the presence of normality, the Shapiro Wilk's Test presented in Table 7 and the histogram (Fig. 3) explain that the residuals for area are non-normal

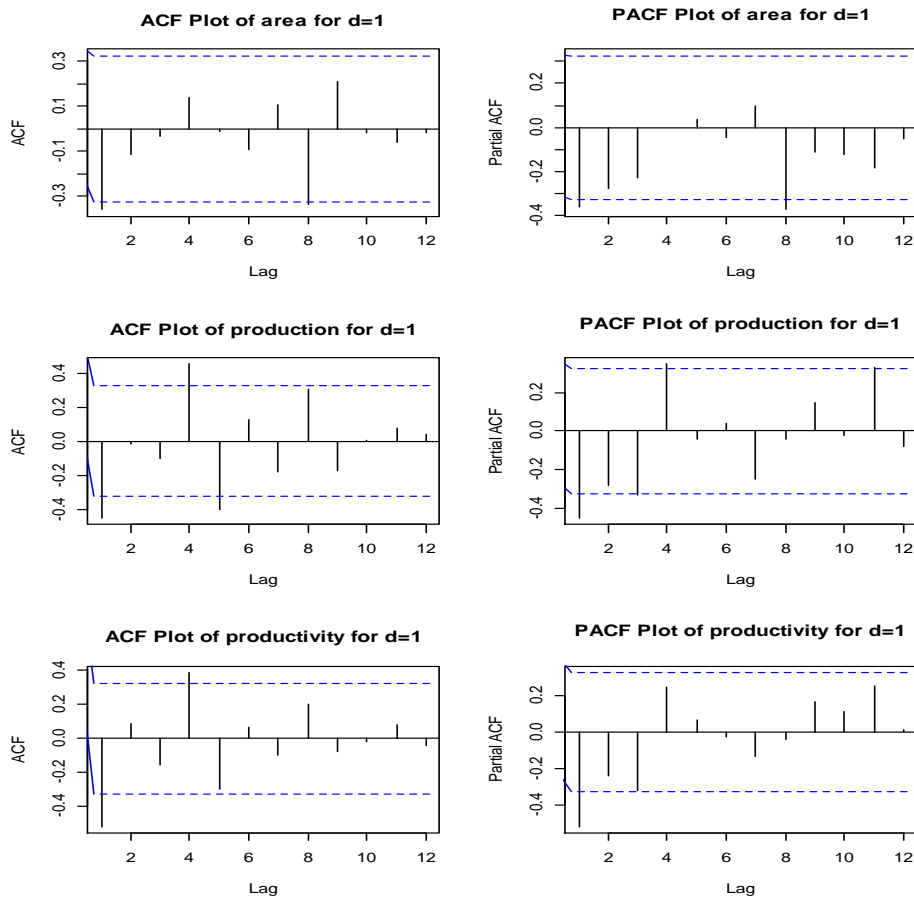
( $P < 0.05$ ) while production and productivity are normal ( $P > 0.05$ ). Ultimately, ARIMA (0,1,1) for area, ARIMA (0,1,1) for production with a constant, and ARIMA (0,1,1) with a constant for productivity are selected as best-fitted models.

**Table 2. Descriptive statistics of Aman rice area, production, and productivity in Jalpaiguri**

	Maximum	Minimum	Mean	S.D.	C.V. (%)	Kurtosis	Skewness
Area	220.70	99.74	175.44	32.63	18.60	0.84	-1.33
Production	433.90	138.40	269.59	68.15	25.28	0.50	0.76
Productivity	2794.00	751.00	1624.28	602.35	37.08	-1.00	0.63

**Table 3. Mann Kendall test and Sen's Slope Test of area, production, and productivity of Aman rice in Jalpaiguri**

Parameters	Mann Kendall Test				Sen's Slope Test		
	Kendall's $\tau$	p-value	MK test statistic (S)	Z	p-value	Sen's Slope estimator ( $\beta$ )	p-value
Area	-0.59***	0.00	-614.00***	-5.80	0.00	-1.24***	0.00
Production	0.60***	0.00	617.00***	5.83	0.00	3.37***	0.00
Productivity	0.82***	0.00	842.00***	7.96	0.00	42.02***	0.00



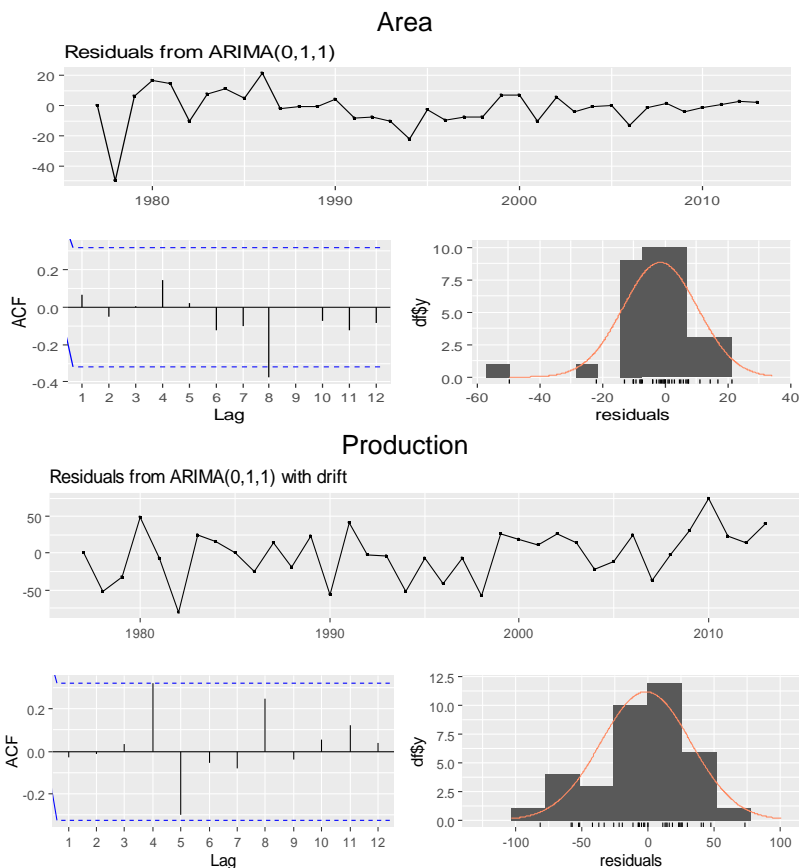
**Fig. 2. ACF plot and PACF plots of the differenced series of Aman rice area, production and productivity in Jalpaiguri**

**Table 4. ADF Stationary test of the time series variables for different differencing orders**

Time series	$d = 0$		$d = 1$	
	ADF statistic	P value	ADF statistic	P value
Area	-2.70	0.30	-5.22	0.01
Production	-2.58	0.34	-6.08	0.01
Productivity	-2.52	0.37	-7.37	0.01

**Table 5. Selection criteria for the plausible model identification in Jalpaiguri**

Aman Rice Area			
<b>ARIMA (p,d,q) Model</b>	<b>AICc</b>	<b>AIC</b>	<b>BIC</b>
ARIMA (0,1,1)	286.069	285.7053	88.8724
<b>AR (m) - GARCH (p,q) model</b>	<b>AIC</b>	<b>BIC</b>	<b>.LLH</b>
AR (1) - GARCH (1,1)	285.40	293.46	137.70
Aman Rice Production			
<b>ARIMA (p,d,q) Model</b>	<b>With constant</b>		
	<b>AICc</b>	<b>AIC</b>	<b>BIC</b>
ARIMA (0,1,1)	363.5239	362.7739	367.5244
<b>AR (m) - GARCH (p,q) model</b>	<b>AIC</b>	<b>BIC</b>	<b>LLH</b>
AR (1) - GARCH (1,1)	388.98	397.04	-189.49
Aman Rice Productivity			
<b>ARIMA (p,d,q) Model</b>	<b>With constant</b>		
	<b>AICc</b>	<b>AIC</b>	<b>BIC</b>
ARIMA (0,1,1)	479.95	479.20	483.95
<b>AR (m) - GARCH (p,q) model</b>	<b>AIC</b>	<b>BIC</b>	<b>LLH</b>
AR (1) - GARCH (1,1)	510.77	518.83	-250.39





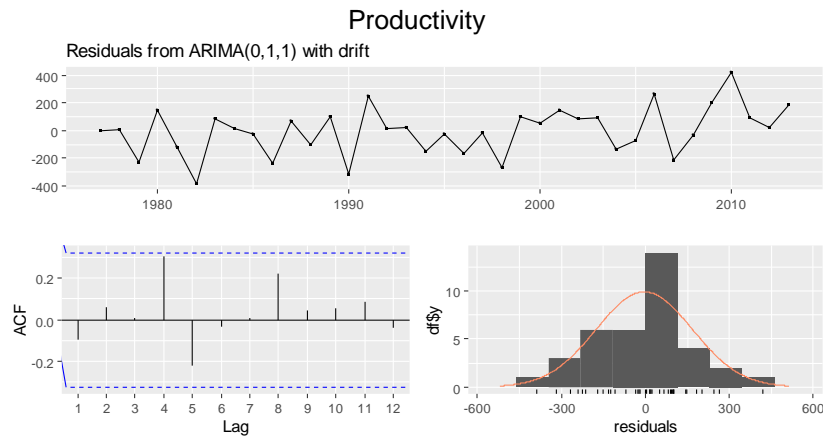


Fig. 3. Residual plots, ACF plots, and distribution of ARIMA (0,1,1), ARIMA (0,1,1), and ARIMA (0,1,1) for Aman rice area, production, and productivity in Jalpaiguri

Table 6. Estimated parameters of Aman rice Area, Production, and Productivity for the chosen models

Area					
ARIMA (0,1,1)	Parameters	Coefficient	Std. error	z- statistic	P value
	MA1	-0.65***	0.12	-5.44	0.00
AR (1) - GARCH (1,1)	Mean Equation				
	Parameters	Coefficient	Std. error	t statistic	P value
	Constant	180.17***	2.28	78.98	0.00
	AR1	0.54***	0.15	3.67	0.00
	Variance Equation				
	Parameters	Coefficient	Std. error	t statistic	P value
	Constant	0.00	0.01	0.00	1.00
$\alpha_1$	0.16	0.16	0.99	0.32	
$\beta_1$	0.76***	0.14	5.32	0.00	
	$(\alpha_1 + \beta_1)$	0.92			
Production					
ARIMA (0,1,1)	Parameters	Coefficient	Std. error	z- statistic	P value
	MA 1	-0.66***	0.13	-5.06	0.00
	Constant	5.70**	2.07	2.75	0.01
AR (1) - GARCH (1,1)	Mean Equation				
	Parameters	Coefficient	Std. error	t statistic	P value
	Constant	255.81***	37.87	6.76	0.00
	AR1	0.87***	0.14	6.31	0.00
	Variance Equation				
	Parameters	Coefficient	Std. error	t statistic	P value
	Constant	6.05	206.02	0.03	0.98
$\alpha_1$	0.00	0.04	0.00	1.00	
$\beta_1$	0.991***	0.12	8.03	0.00	
	$(\alpha_1 + \beta_1)$	0.991			
Productivity					
ARIMA (0,1,1)	Parameters	Coefficient	Std. error	z- statistic	P value
	MA1	-0.62***	0.12	-5.09	0.00
	drift	34.23***	11.37	3.01	0.00
AR (1) - GARCH (1,1)	Mean Equation				
	Parameters	Coefficient	Std. error	t statistic	P value
	Constant	1057.91***	238.59	4.43	0.00
AR1	1.00***	0.08	11.87	0.00	

Variance Equation				
Parameters	Coefficient	Std. error	t statistic	P value
Constant	168.09	9199.60	0.02	0.99
$\alpha_1$	0.00	0.04	0.00	1.00
$\beta_1$	0.995***	0.01	73.23	0.00
$(\alpha_1 + \beta_1)$	0.995			

# $P < 0.1$ ; \*  $P < 0.05$ ; \*\*  $P < 0.01$ ; \*\*\*  $P < 0.001$

**Table 7. Tests of Normality, and Independence for the residuals of the selected models for Aman rice in Jalpaiguri**

Model	Shapiro Wilk's Test		Ljung- Box (Q) Test		
	W statistic	p value	Q statistic	df	p value
Area: ARIMA (0,1,1)	0.87	0.00	2.41	6	0.88
Production: ARIMA (0,1,1)	0.98	0.58	8.96	6	0.18
Productivity: ARIMA (0,1,1)	0.99	0.94	6.82	6	0.34

### 3.4 GARCH

Like ARIMA models, GARCH models also undergo the identification, estimation and diagnostic checking procedure. The first step of GARCH modelling is to fit a suitable autoregressive ( $m$ ) process by examining the PACF plot. From the PACF plots given in Fig.4, it is seen that 1<sup>st</sup> lag for area, production, and productivity has a significant spike. It can be concluded that the model for the conditional mean is AR (1). To test the heteroscedasticity of the residuals obtained from the AR (1) process, we looked at the ACF plots of the squared series of area, production, and productivity and their standardized squared residuals. The ACF plots depict dependency in both the squared series as well as squared residuals (Fig. 5). The ARCH-LM Test is tested on the squared residuals. The result of the test shows that  $P < 0.05$  (Table 8) indicating the presence of conditional heteroscedasticity. Hence, we can proceed to build a GARCH model.

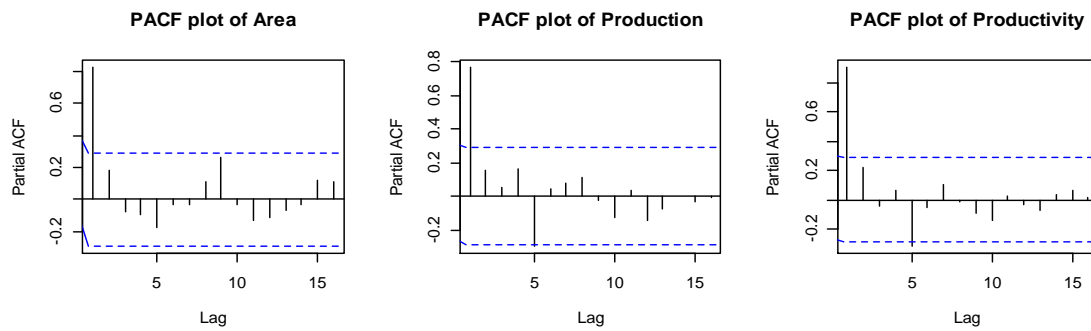
To establish a GARCH (p,q) model, the orders of p and q must be determined. Generally, GARCH models of the order  $p=1,2$  and  $q=1,2$  are formulated on the training set. The different specification models are compared and AR (1) - GARCH (1,1) is found to be the best model for area, production, and productivity based on the least value of AIC and BIC criteria which are given in Table 5. The estimated model parameters and their statistical significance are given in Table 6. The constant, AR (1) of the mean equation and  $\beta_1$  of the variance equation are statistically significant at 1 % level of significance for area, production, and

productivity. Significant AR (1) coefficients indicate significant conditional mean effect and  $\beta_1$  coefficients indicate strong GARCH effects. However, there are no significant ARCH effects in all three series. This implies that there is no significant error variance, however, there is conditional variance in the lagged innovations. The sum of  $\alpha$  and  $\beta$  coefficients give a measure of the volatility persistence. The results given in Table 6 indicate that there is persistent volatility in the Aman rice area (0.92), production (0.991) and productivity (0.995) in Jalpaiguri. It is seen that  $\beta_1$  values are high indicating persistent volatility that takes a longer duration to change [26].

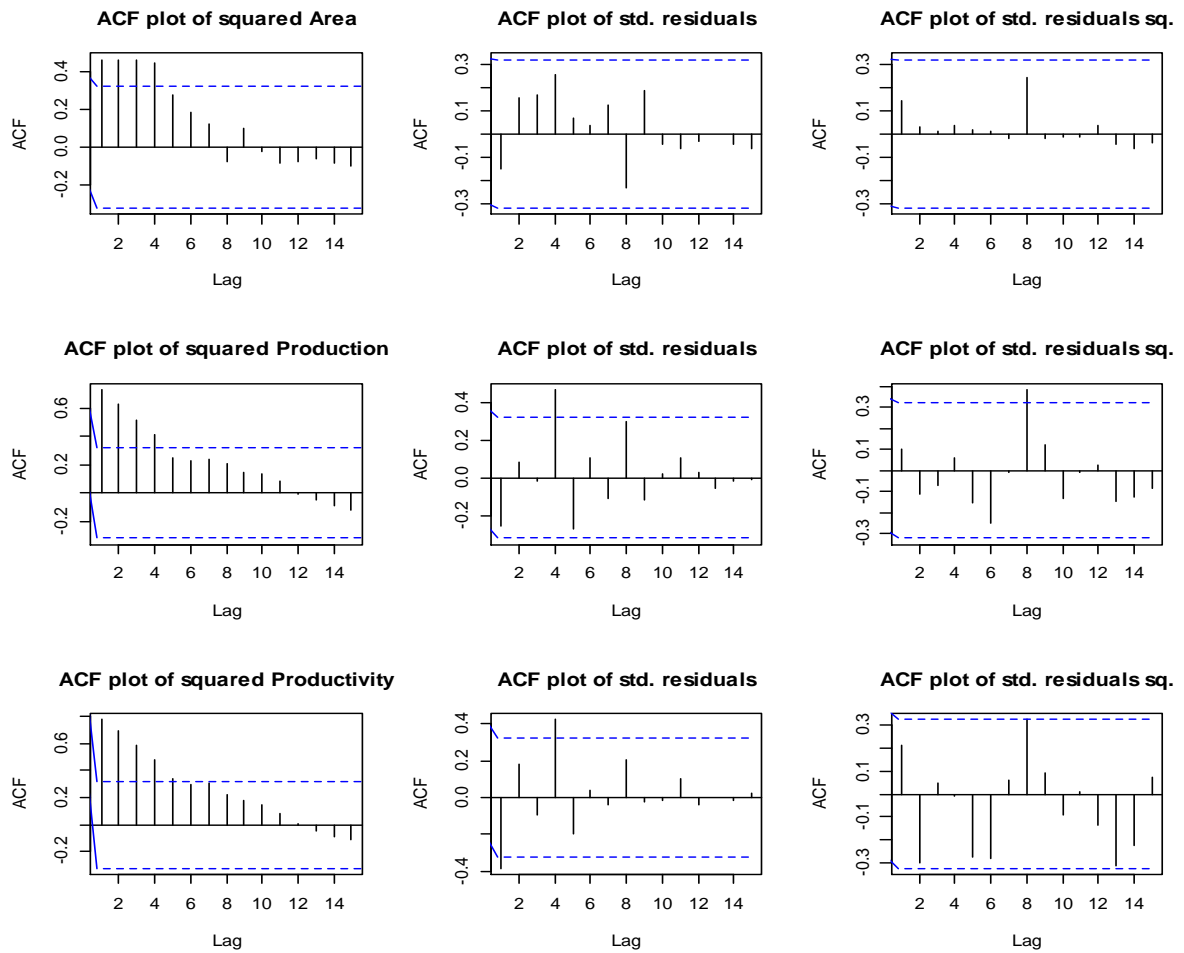
Once the presence of volatility is confirmed, residual diagnostics are employed to detect the presence of any systematic pattern in the data. The standardized residual time plot in Fig. 7 shows no noticeable patterns. The Ljung-Box statistic for the standardized residuals and standardized squared residuals is given in Table 9. The values indicate the absence of serial autocorrelation in the standardized squared residuals for area, production and productivity at different lags (Table 9) demonstrating that it is suitable for describing the dynamic volatility. The ACF plot of the standardized residuals (Fig. 7) and squared standardized residuals (Fig. 5) depict no departure from the model assumptions. The residuals of area are non-normal while production and productivity are normal as observed from the histogram (Fig. 6) and the p-values ( $P > 0.05$ ) of the W-S statistic (Table 9). The  $P > 0.05$  of the ARCH L-M Test show no ARCH effect exists in the standardized squared residuals.

**Table 8. Test of heteroscedasticity for the residuals of the AR (1) models**

Model	ARCH - LM Test	
	Statistic	p-value
Area: AR1	404.89	0.00
Production: AR1	30.32	0.00
Productivity: AR1	22.57	0.00



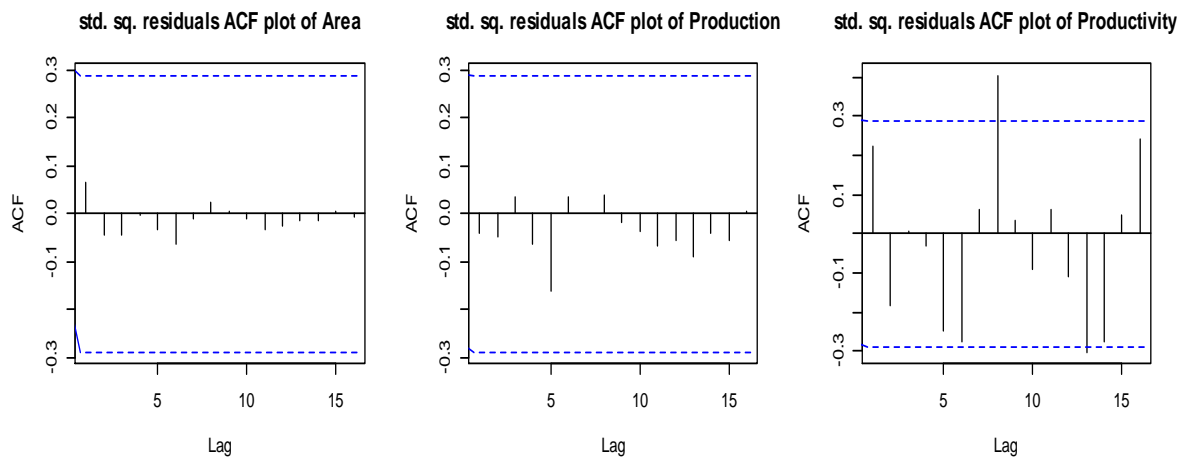
**Fig. 4. PACF plot of Aman rice area, production, and productivity in Jalpaiguri**



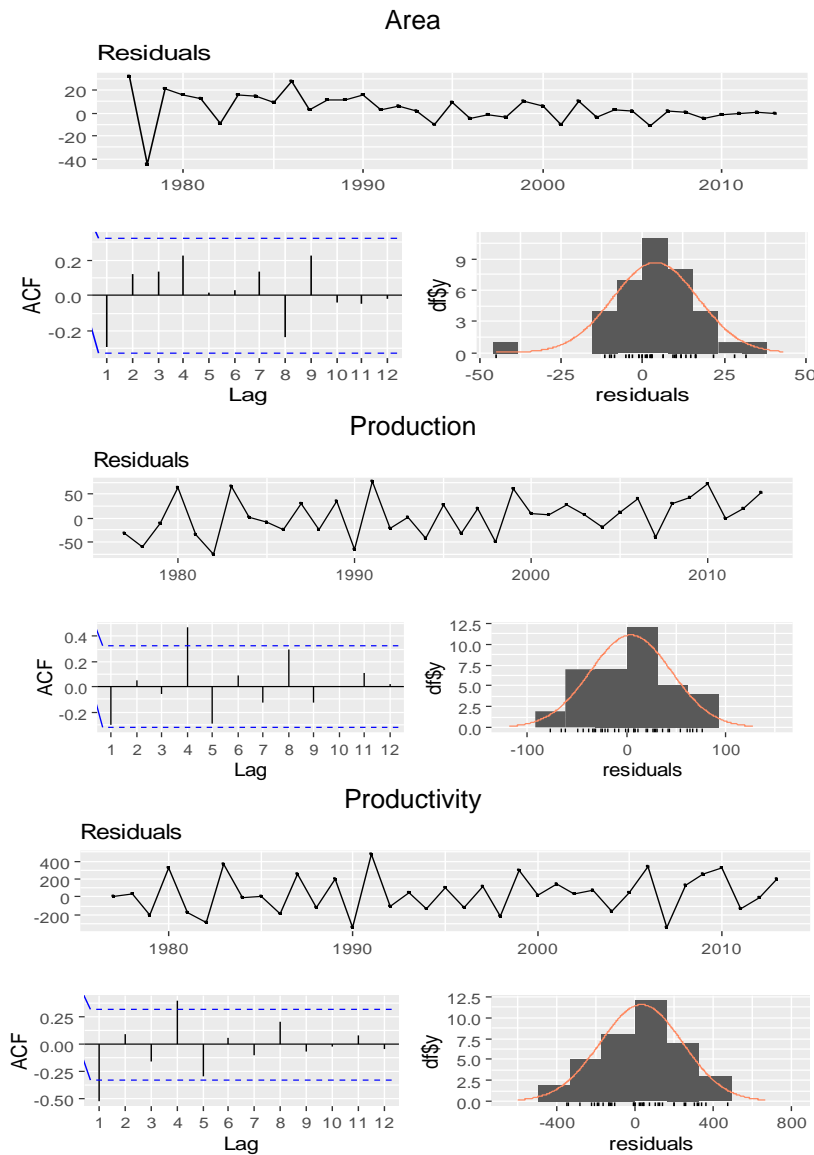
**Fig. 5. ACF plot of squared series, standardized residuals, and standardized squared residuals of Aman rice area, production, and productivity in Jalpaiguri**

**Table 9. Standardized residual tests for AR (1) – GARCH (1,1) models of Aman rice area, production, and productivity in Jalpaiguri**

Area				
Residual Test	Test statistic	Variable	Test value	p-value
Shapiro Wilk	W	Residual	0.91	0.01
Ljung Box	Q (1)	Residual	3.05	0.08
Ljung Box	Q (2)	Residual	3.14	0.03
Ljung Box	Q (5)	Residual	4.61	0.14
Ljung Box	Q (1)	Residual <sup>2</sup>	1.09	0.30
Ljung Box	Q (5)	Residual <sup>2</sup>	1.45	0.75
Ljung Box	Q (9)	Residual <sup>2</sup>	1.90	0.92
ARCH L-M	$\chi^2(3)$	Residual <sup>2</sup>	0.17	0.68
Production				
Residual Test	Test statistic	Variable	Test value	p-value
Shapiro Wilk	W	Residual	0.98	0.69
Ljung Box	Q (1)	Residual	3.49	0.06
Ljung Box	Q (2)	Residual	3.58	0.01
Ljung Box	Q (5)	Residual	8.31	0.01
Ljung Box	Q (1)	Residual <sup>2</sup>	0.39	0.53
Ljung Box	Q (5)	Residual <sup>2</sup>	1.51	0.74
Ljung Box	Q (9)	Residual <sup>2</sup>	5.75	0.33
ARCH L-M	$\chi^2(3)$	Residual <sup>2</sup>	0.11	0.74
Productivity				
Residual Test	Test statistic	Variable	Test value	p-value
Shapiro Wilk	W	Residual	0.98	0.64
Ljung Box	Q (1)	Residual	10.68	0.00
Ljung Box	Q (2)	Residual	10.87	0.00
Ljung Box	Q (5)	Residual	15.11	0.00
Ljung Box	Q (1)	Residual <sup>2</sup>	1.46	0.23
Ljung Box	Q (5)	Residual <sup>2</sup>	4.41	0.21
Ljung Box	Q (9)	Residual <sup>2</sup>	10.59	0.04
ARCH L-M	$\chi^2(3)$	Residual <sup>2</sup>	0.03	0.85



**Fig. 6. ACF plots of standardized squared residuals of AR (1) - GARCH (1,1) models for Aman rice area, production, and productivity in Jalpaiguri**



**Fig. 7. Residual plots, ACF plots, and distribution of standardized residuals of AR (1) - GARCH (1,1) models for Aman rice area, production, and productivity in Jalpaiguri**

### 3.5 Validation and Forecasting

Table 10 presents the actual versus predicted Area, production and productivity values from 2014-2022. The predicted values are close to the actual values indicating that the fitted model is appropriate. A two-way validation of the training and testing set is done to select the best forecasting model. The selected models are compared and the model with the lowest accuracy statistics is selected (Table 11). It can be seen that ARIMA models perform best in the training series of all three series. In the case of Aman rice area, the AR (1) - GARCH (1,1) outperformed ARIMA (0,1,1) in the test period. The performance of Aman rice production

reveals that AR (1) - GARCH (1,1) is better due to lower values of evaluation metrics in the test period. From the results of the accuracy statistics of the test set, the linear ARIMA (0,1,1) model performed better for Aman rice productivity due to its lowest values of all forecasting accuracy statistics. Eventually, the models AR (1) - GARCH (1,1), AR (1) - GARCH (1,1), and ARIMA (0,1,1) performed better during the testing period. Hence, these models are chosen for forecasting Aman rice area, production, and productivity since they have better performance in the new dataset. The forecast values along with their 95 % confidence interval for the next ten years from 2023 to 2032 are presented in Table 12 and Fig. 8.

Table 10. Actual vs. predicted values for validation set

Year	Area ('000 ha)			Production ('000 tons)			Productivity (kg/ha)		
	Actual	ARIMA	AR-GARCH	Actual	ARIMA	AR-GARCH	Actual	ARIMA	AR-GARCH
2014	176.40	176.22	123.97	433.9	433.68	403.29	2460.00	2458.84	2460.00
2015	167.78	175.01	152.36	425.33	437.26	429.90	2535.00	2500.38	2460.00
2016	103.43	167.79	147.69	249.33	426.45	422.45	2411.00	2543.98	2535.00
2017	104.95	142.02	112.85	263.93	361.98	269.46	2515.00	2523.61	2411.00
2018	99.74	128.24	113.67	278.70	331.89	282.15	2794.00	2556.15	2515.00
2019	104.68	118.05	110.85	276.90	318.77	294.99	2645.00	2681.31	2794.00
2020	105.29	113.33	113.53	277.91	309.90	293.43	2640.00	2701.68	2645.00
2021	111.50	110.51	113.86	296.18	304.55	294.30	2656.00	2712.51	2640.00
2022	111.34	110.86	117.22	299.23	307.37	310.18	2687.00	2725.34	2656.00

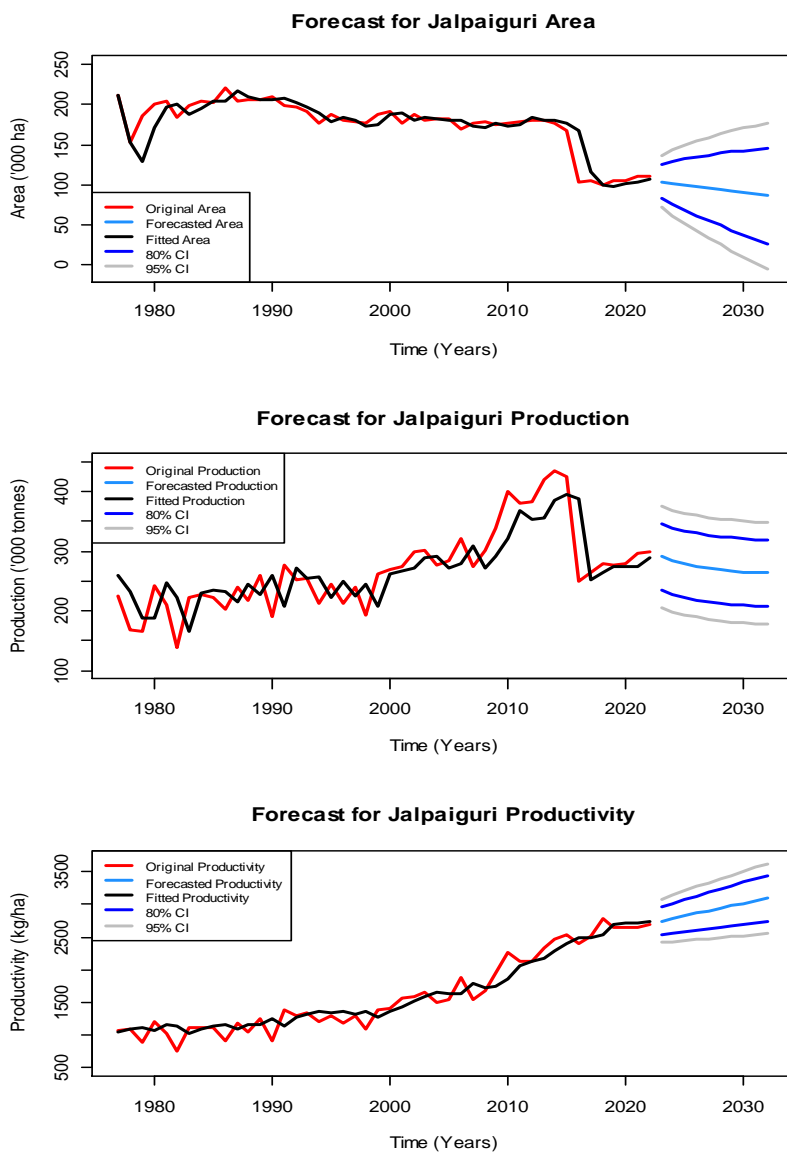


Fig. 8. Forecast plot of AR (1) - GARCH (1,1) of Aman rice Area, AR (1) - GARCH (1,1) of Production, ARIMA (0,1,1) of Productivity for Jalpaiguri

**Table 11. Model accuracy statistics for validation of Aman Rice in Jalpaiguri**

Model	Training set			Testing set		
	RMSE	MAE	MAPE	RMSE	MAE	MAPE
Area: ARIMA (0,1,1)	7.77	11.85	0.04	17.80	27.13	0.17
Area: AR (1) - GARCH (1,1)	9.57	13.49	0.05	17.40	24.38	0.14
Production: ARIMA (0,1,1)	26.82	33.61	0.12	47.88	72.17	0.18
Production: AR (1) - GARCH (1,1)	33.91	40.65	0.14	29.30	59.31	0.11
Productivity: ARIMA (0,1,1)	131.74	169.49	0.11	67.56	97.37	0.03
Productivity: AR (1) - GARCH (1,1)	171.19	210.25	0.13	87.00	121.61	0.03

**Table 12. Forecasted values of best-fitted models of Aman rice Area, Production, and Productivity for Jalpaiguri**

Year	Area ('000 ha)			Production ('000 tons)			Productivity (kg/ha)		
	low 95	Point forecast	high 95	low 95	Point forecast	high 95	low 95	Point forecast	high 95
2023	85.26	111.44	137.62	205.21	290.47	375.74	2421.41	2749.61	3077.82
2024	85.37	111.54	137.72	198.40	283.67	368.95	2431.54	2787.74	3143.94
2025	85.47	111.64	137.81	193.11	278.40	363.68	2443.72	2825.87	3208.01
2026	85.57	111.74	137.91	189.00	274.30	359.60	2457.55	2863.99	3270.43
2027	85.67	111.84	138.01	185.81	271.12	356.43	2472.76	2902.12	3331.48
2028	85.77	111.94	138.11	183.33	268.65	353.98	2489.12	2940.25	3391.37
2029	85.87	112.04	138.21	181.41	266.74	352.07	2506.49	2978.37	3450.25
2030	85.97	112.14	138.31	179.91	265.25	350.60	2524.74	3016.50	3508.26
2031	86.07	112.24	138.41	178.74	264.10	349.45	2543.75	3054.62	3565.49
2032	86.16	112.34	138.51	177.84	263.20	348.57	2563.46	3092.75	3622.04

#### 4. CONCLUSION

The production of Aman rice is the highest among all the three seasons- Aus, Aman, and Boro in Jalpaiguri district. Aman rice is an indispensable crop as it is the major rice contributor providing extensive employment and income. It is imperative to study the scenario of the crop area, production, and productivity and make predictions of the future outcomes to ascertain that the demands are met for feeding the Jalpaiguri populace. The model AR (1) - GARCH (1,1) for Aman rice area, AR (1) - GARCH (1,1) for production, and ARIMA (0,1,1) for productivity is found to be a parsimonious model for Aman rice in Jalpaiguri. It is unsuitable to comment on the supremacy of either of the models since both ARIMA and GARCH models can be used for forecasting. The forecast estimates suggest that the Aman rice area is increasing at a slow rate while production is likely to decrease and productivity is projected to increase. Rice production decreases due to several reasons such as lack of infrastructure, investment, poor seed quality, deficiency of technological advancement, diseases [27], poor condition of farmers, poor irrigation facilities, transportation challenges, absence of a proper market [28], pest attack, and climate change. Over time, the decline in production could be severe, threatening the livelihoods of poor farmers. In the long run, to maintain the sustainability of rice production, it is vital to save natural resources such as soil flora, fauna, land, and water that support the production of rice [29]. As natural resources and labour are getting scarce, rice will be severely affected since its water and manpower requirements are highest. It is recommended that the social and practical obstacles to such advancements be overcome with the use of existing resources, research, and expertise [30]. This research thus suggests making policies to increase Aman rice area and production in Jalpaiguri to ensure nutritional security.

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Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

#### ACKNOWLEDGEMENTS

We would like to express our gratitude to Shri Bidhayak Mukherjee, Additional Director of

Agriculture, Evaluation Wing, Govt. of West Bengal and Prof. (Dr.) K. K. Das, Department of Agricultural Economics, Uttar Banga Krishi Viswavidyalaya, Pundibari for providing the research data.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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