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Forecasting onion price volatility in Madhya Pradesh markets using Arma-Garch models

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Abstract

The present study examined and forecasted onion price volatility in major markets of Madhya Pradesh using the ARMA-GARCH modeling framework. Weekly price data covering nearly twelve years were obtained from AGMARKNET for four important onion markets, namely Indore, Mandsaur, Ratlam, and Sagar. Stationarity of the series was evaluated using Augmented Dickey-Fuller (ADF) and KPSS tests, and first-order differencing was applied to achieve stationarity. The presence of conditional heteroskedasticity was verified through the ARCH-LM test, justifying the application of GARCH models. The dataset was divided into training and testing subsets in an 8:2 ratio, and model estimation was performed using the rugarch package in R software. Based on the minimum Akaike Information Criterion (AIC) values, ARMA(1,1)-GARCH(1,1), ARMA(2,1)-GARCH(1,1), ARMA(1,1)-GARCH(1,2), and ARMA(1,1)-GARCH(2,1) were identified as the most suitable models for Indore, Mandsaur, Ratlam, and Sagar markets, respectively. The fitted models exhibited satisfactory forecasting performance, with R^2 values ranging from 0.86 to 0.90. Forecasted results indicated an increasing trend in onion price volatility across all selected markets in the coming weeks. The findings highlight the effectiveness of ARMA-GARCH models in capturing and forecasting agricultural price volatility, thereby providing useful insights for farmers, traders, and policymakers in market planning and price risk management.

Keywords: Onion prices, price volatility, ARMA-GARCH model, volatility modelling

Introduction

Onion is among the most extensively grown and consumed vegetable crops worldwide. In 2023, global onion production was estimated at about 111 million tonnes (FAO, Agriculture Production Statistics, 2010-2023). India ranked first with 31.68 million tonnes, followed by China with 23.5 million tonnes, and Egypt with 3.2 million tonnes (FAOSTAT, 2024). Together, these three countries account for a major portion of the world's onion output. The area under onion cultivation also differs across nations, with India alone cultivating onions on roughly 1.8 million hectares in 2022, achieving an average productivity of around 17.5 tonnes per hectare (FAO, 2024). Within the domestic context, India has consistently retained its position as the leading onion producer, with recorded outputs of 31.68 million tonnes in 2021-22, 30.21 million tonnes in 2022-23, and an estimated 25.47 million tonnes in 2023-24, according to the First Advance Estimates (Department of Agriculture and Farmers Welfare, 2024). Among Indian states, Maharashtra continues to dominate production, followed by Madhya Pradesh, Gujarat, and Karnataka (FNB News, 2024). To maintain domestic price stability and adequate supply, the Government of India procured 4.68 lakh tonnes of onions for its price stabilization buffer during 2024-25. Furthermore, initiatives such as Operation Greens have been launched to strengthen supply chain management and extend support to farmers cultivating the TOP crops tomato, onion, and potato (Ministry of Food Processing Industries, 2024).

In 2024, Madhya Pradesh recorded a notable 20% decrease in onion production, yielding 41.66 lakh tonnes, compared to the previous year. Despite this decline, the state continued to rank as India's second-largest onion producer. At the national level, overall onion output also fell by approximately 19.84%, dropping from 302.08 lakh tonnes in 2022-23 to 242.12 lakh

tonnes in 2023-24, according to estimates from the Ministry of Agriculture and Farmers Welfare (MoA&FW). This nationwide reduction in production has been primarily attributed to drought conditions in major producing regions of Maharashtra and Karnataka, coupled with pest and disease infestations reported in certain areas of Madhya Pradesh.

The major onion-producing regions of Madhya Pradesh include Mandsaur, Ratlam, Neemuch, Bhopal, Sagar, and Khandwa (Chouhan *et al.*, 2022; Kamble *et al.*, 2018) [2, 10]. Among the state's districts, Dewas, Indore, Ujjain, Sagar, and Rewa rank as the top five producers, recording onion outputs of 5.16, 4.83, 4.23, 3.54, and 3.06 million tonnes (MT), respectively (Department of Horticulture and Food Processing, Madhya Pradesh, 2nd Estimate, 2022; Table 1.1). The Malwa Plateau region is particularly prominent for its onion cultivation and marketing activities. Districts such as Indore, Ujjain, Dewas, Ratlam, Mandsaur, and Neemuch are recognized as the principal contributors, owing to their favorable agro-climatic conditions and efficient supply chain networks, which collectively support both large-scale production and effective market distribution. Onion (*Allium cepa*) prices in India tend to fluctuate due to a combination of factors, including climatic conditions, supply chain challenges, and seasonal shifts in production and demand.

Methodology

Data

The data was sourced from AGMARKNET, a portal under Ministry of Agriculture, Government of India. The data was collected for four selected major Onion markets of MP, i.e., Indore, Ratlam, Mandsaur and Sagar. The weekly observations up to 12 years were collected.

ARIMA model

The ARIMA model is commonly represented as ARIMA (p, d, q), where p denotes the order of the autoregressive component, d indicates the number of times the data must be differenced to achieve stationarity, and q represents the order of the moving average component. For a given time series y_t or X_t the model can be expressed as:

$$\phi(B)(1 - B)^d y_t = \theta(B)\varepsilon_t$$

In this formulation, $\phi(B)$ is the Auto Regressive (AR) operator, $\theta(B)$ is the Moving Average (MA) operator, d is the degree of differencing and B denotes the backward shift operator.

GARCH Model

Since Onion crop was famously known for its volatile prices, GARCH model helps estimating volatility in crop prices. Economic and commodity variables, such as onion prices, often exhibit time-varying volatility rather than remaining constant over periods. To effectively model this dynamic nature, the Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model, proposed by Bollerslev (1986) [1] as an extension of Engle's (1982) [5] ARCH model, is extensively applied. The GARCH framework is particularly useful for analyzing and forecasting time series data characterized by heteroskedasticity, where the variance fluctuates over time. In a general GARCH (p, q) specification, the conditional variance (V_t) is expressed as a deterministic function of past squared residuals (innovations) and its own previous values.

$$V_t = a_0 + \sum_{i=1}^q a_i \varepsilon_{t-i}^2 + \sum_{j=1}^p b_j V_{t-j}$$

Here, a_0 is a constant, a_i are the ARCH coefficients, and b_j are the GARCH coefficients. The appropriate order of the GARCH (p, q) model is often selected using the Portmanteau Q test applied to the squared residuals, which helps in identifying the adequacy of the model in capturing conditional heteroskedasticity (Li & Mak, 1994) [11].

Results: Onion crop prices of all the four selected markets of Madhya Pradesh, were interpolated and then tested for stationarity using ADF test and KPSS test. The data were found to be non-stationary. Hence first order differenced data were used to fit ARIMA model. Before proceeding towards GARCH model, the residuals from ARIMA model were tested for the presence of Arch effect using ARCH-LM test, and the residuals of ARIMA models of Sagar, Ratlam, Mandsaur and Ratlam markets indicated presence of Arch effect (presence of conditional heteroskedasticity in residuals). This confirmation gave green signal to model data using GARCH.

Suitable GARCH models were selected for the four onion markets, based on their goodness of fit (R^2) and Akaike's information criterion values.

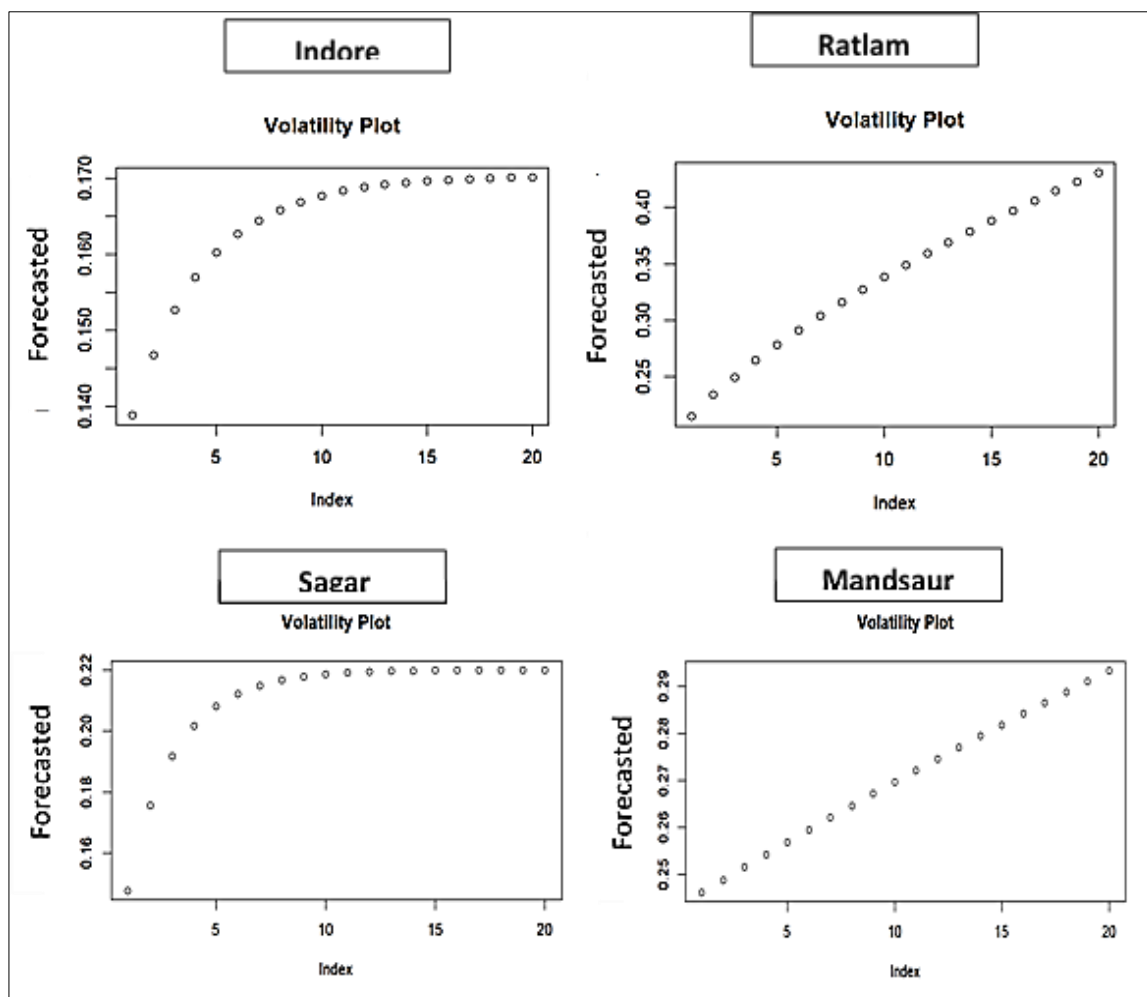
After confirming the stationarity of the dataset, it was divided into training and testing subsets in an 8:2 ratio. Prior to this partitioning, the dataset was converted into a time series object to ensure proper temporal alignment. The analysis employed the "rugarch" package in R software, which provides the necessary functions for estimating GARCH models. Model parameters were determined by selecting combinations of p and q values that minimized the Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC), with both parameters restricted to a maximum value of 2. The GARCH and ARMA components were jointly utilized for volatility forecasting, where the GARCH component represents the variance equation and the ARMA component captures the mean equation. Parameter values were intentionally kept below 3 to maintain model simplicity and avoid overfitting, as lower p values are generally sufficient to capture past volatility dynamics effectively.

Among the models evaluated, ARMA(1,1)-GARCH(1,1), ARMA(2,1)-GARCH(1,1), ARMA(1,1)-GARCH(1,2), and ARMA(1,1)-GARCH(2,1) were identified as the best-fitting models for Indore, Mandsaur, Ratlam, and Sagar, respectively (Table 1), based on their lowest AIC values (12.87, 12.40, 13.17, and 12.40). The models demonstrated stronger performance on the training set compared to the testing set, with RMSE values of 215.72, 219.02, 236.85, and 203.19, indicating the Sagar market achieved the highest accuracy. The R^2 values further confirmed good model fitness, capturing 89%, 86%, 89%, and 90% of the variation in the respective markets. Similarly, the mean absolute percentage error (MAPE) indicated variation in predictive accuracy across markets, where Mandsaur showed the lowest error (37.70%), followed by Indore (42.12%), Sagar (45.21%), and Ratlam (48.03%), reflecting how effectively each model responded to unseen price movements.

The GARCH models, widely recognized for their effectiveness in volatility forecasting, were used to predict future price fluctuations. The forecasts for all markets indicate an upward trend in volatility, suggesting that price variability is expected to increase in the coming weeks across all the markets included in the study (Fig. 1).

Table 1: AIC, R^2 , and error metrics of GARCH models

Market	Model	AIC	RMSE		R^2	MAPE	
			Train	Test		Train	Test
Indore	ARMA (1,1)	12.87	215.72	1143.85	0.89	11.38	42.12
	GARCH (1,1)	(-0.90)	(0.15)	(0.18)			
Mandsaur	ARMA (2,1)	12.40	219.02	987.86	0.86	12.85	37.70
	GARCH (1,1)	(-0.80)	(0.19)	(0.20)			
Ratlam	ARMA (1,1)	13.17	236.85	1255.15	0.89	15.46	48.03
	GARCH (1,2)	(-0.35)	(0.23)	(0.21)			
Sagar	ARMA (1,1)	12.40	203.19	1177.91	0.90	11.24	45.21
	GARCH (2,1)	(-1.04)	(0.16)	(0.14)			

**Fig 1:** Volatility forecast for future 20 weeks by GARCH models

Conclusion

The results of the study revealed that the ARMA-GARCH models effectively captured onion price dynamics across the selected markets, with high explanatory power (R^2 ranging from 86% to 90%) and moderate forecasting accuracy indicated by MAPE values between 37.70% and 48.03%. The Sagar market exhibited the lowest RMSE, reflecting relatively stable price behavior. However, forecasts indicated an upward trend in volatility, suggesting heightened price fluctuations in the coming weeks. From a farmers' and economic perspective, such volatility implies increased income uncertainty and marketing risk, particularly for smallholders lacking storage or price information access. Strengthening price stabilization mechanisms, expanding storage infrastructure, and adopting forecast-based market advisories can help farmers make informed decisions and enhance economic resilience in onion production and marketing.

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