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Trend Analysis of Rice Area, Production and Yield in Ghazipur District of Uttar Pradesh, India

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ABSTRACT

Rice (*Oryza sativa* L.) is one of the most important cereal crops widely grown for human consumption and serving as a staple food in many parts of India, including Uttar Pradesh. It grows well in regions with sufficient water availability, fertile soils, and favorable climatic conditions. Ghazipur district of Uttar Pradesh is known for its significant contribution to rice cultivation, where the crop is mainly grown during the *kharif* season. The present study analyzes long-term trends in rice area, production, and yield in Ghazipur district using time series data over an extended period. Growth performance was evaluated using the Compound Annual Growth Rate (CAGR) method, while variability and instability were assessed through the coefficient of variation and the Cuddy-Della Valle Index. The entire study period was divided into suitable sub-periods to understand temporal changes in growth patterns. Various statistical models, including linear, logarithmic, quadratic, cubic, exponential, and power models, were applied to estimate trends. Model performance was compared using statistical indicators such as coefficient of determination (R^2), adjusted R^2, root mean square error (RMSE) and relative mean absolute percentage error (RMAPE). Among the fitted models, the quartic model was found to provide the best fit for rice area, production, and yield in Ghazipur district. Decomposition analysis further indicated that changes in cultivated area played a dominant role in influencing rice production over the study period.

Keywords Rice, Ghazipur, Trend analysis, CAGR, Instability index, Decomposition analysis.

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INTRODUCTION

Rice (*Oryza sativa* L.) is a major cereal crop belonging to the Poaceae family, originating from the Indo-Burma region. It is mainly grown in warm, humid climates under waterlogged conditions and is a self-pollinated, short-day C_3 plant. Clay and clay loam soils with acidic pH (4-6) are most suitable, and it is typically cultivated during the *kharif* season (June-July). Rice is nutritionally rich, containing high carbohydrates along with moderate protein and small

amounts of fat and minerals, making it a staple food for more than half of the global population.

Globally, rice is the second most important cereal crop, with about 90% of its production concentrated in Asia. In recent years, global production has reached record levels, with major contributions from countries like China and India. India plays a significant role in global rice production, being one of the leading producers and exporters. In 2023 the country cultivated rice on about 47.8 million hectares, producing approximately 207 million tons. Uttar Pradesh is the top rice-producing state in India, supported by its favorable climate, fertile soils and abundant water resources.

Within Uttar Pradesh, Ghazipur district is an important rice-growing region located in the Eastern part of the state. The district has fertile alluvial soils, good monsoon rainfall, and suitable Argo-climatic conditions for rice cultivation. Rice is mainly grown during the *kharif* season and occupies a significant share of the cropped area. The district has a net sown area of about 2.54 lakh hectares with high cropping intensity. Rice productivity in Ghazipur is moderate, indicating scope for improvement through better agricultural practices, improved varieties, and efficient resource management. Overall, rice cultivation plays a crucial role in the agricultural economy of the district.

Many researchers and scientists have carried out extensive studies using time series analysis on rice and various other crops. Singh (2019) examined rice-wheat production trends and causal growth factors in Eastern Uttar Pradesh districts. Chavhan *et al.* (2020) estimated growth and instability for wheat and rice from 1995-96 to 2014-15 using exponential functions and decomposition, noting inter-district variations. Dey and Rashmi (2020) analyzed wheat and rice growth-instability in India from 1950-51 to 2015-16 via time series and decomposition. Devegowda (2023) analyzed the growth, decomposition, and instability of rice in India using time-series data, and reported that the area effect was more prominent in influencing rice production. Singh *et al.* (2020) reported strong rice growth in Varanasi division from 2000-01 to 2014-15, led by productivity per CAGR and decomposition. Rout (2020) performed district-wise rice analysis in Gujarat from 1981-82 to 2017-18 with CAGR, Cuddy-Della Valle Index, and Minhas model. Kaur and Chauhan (2024) examined crop trends, instability, and decomposition analysis in Punjab using long-term time-series data. Joshi *et al.* (2021) calculated growth and instability for Nepal's major crops from 1990-91 to 2018-19 in three decades. Yadav *et al.* (2022) forecasted 1% annual declines in India's nutrient cereal area using ARIMA (0,1,1). Ansari and Ansari (2023) measured rice growth and instability in Uttar Pradesh from 1991 to 2020-21 via CAGR and Cuddy-Della Valle Index across sub-periods. Tripathi *et al.* (2023) quantified sesame instability with CV, Cuddy-Della Valle Index, and area-yield effects. Zahoor (2023) analyzed rice-maize growth, instability, and decomposition in Kashmir districts from 2001-02 to 2021-22. Pooja *et al.* (2023) defined forecasting of crop production as predicting the future values of cultivated crops before harvest and applied to the area and production of pulses in India over 71 years (1951-2021) using linear, logarithmic, quadratic, cubic, power, and exponential models. Yadav *et al.* (2023) analyzed both the area and production of cereals in India over 70 years (1951-2020) using several regression models. Jambhulkar *et al.* (2024) reviewed rice growth-instability in Chhattisgarh districts, where yields trailed national averages despite rainfall dependence. Abeysekara and Rathnayake (2024) surveyed global rice production, consumption, trade, tech advances, and climate hurdles. Singh (2024) linked rice growth-instability in Uttar Pradesh from 1990-91 to 2021-22 across periods using CAGR and indices, prioritizing productivity. Kumar *et al.* (2024) assessed long-term trends and growth rates of major millets in India (1966-2021) using regression and growth models on data from millet stat. Mahali *et al*. (2024) pinpointed precipitation, emissions, land, and electricity as crop drivers, advocating climate-resilient policies. Kumar (2025) forecasted millet trends from 1966-67 to 2022-23 with superior cubic and ARIMA models. Singh (2025a) modelled pulse trends in India (2000-2023) using cubic fits, CGRs, and instability indices for forecasts. Singh (2025b) applied similar cubic, CGR, and Cuddy-Della Valle methods to lentil trends in India (2000-2023). Deepa (2025) examined southern India turmeric from 1980-2022 with CAGR, CDVI, decomposition, and ARIMA. Dubey (2025)

identified cubic models as optimal for pulse trends in Mirzapur, Uttar Pradesh (1993-94 to 2021-22). Singh *et al.* (2024) analyzed the growth, instability, and decomposition of maize production in major Indian states, including Uttar Pradesh. Pal *et al.* (2025) evaluated trends in maize area, production, and yield in Uttar Pradesh using data from 1950-51 to 2022-23. Growth and instability were analyzed using CAGR, coefficient of variation, and Cuddy Della Valle Index. Different regression models were tested, and the cubic model was identified as the best fit based on statistical criteria. The results also showed that expansion in cultivated area was the major contributor to the increase in maize production. Deepa *et al.* (2025) analyzed 43 years (1980-2022) of turmeric area, production, and yield data for the Southern states of India using data collected from the India stat database. ARIMA models were applied to forecast turmeric production trends, and the best models were selected based on AIC, BIC, and residual analysis. The results showed that ARIMA (2,1,3) was most suitable for Andhra Pradesh, ARIMA (1,1,3) for Karnataka, ARIMA (2,1,2) for Tamil Nadu, and ARIMA (1,1,1) for Kerala. The selected models provided reliable forecasting performance and effectively captured the production trends across the states.

MATERIALS AND METHODS

Sources of data

This study analyzed secondary time-series data on crop production in Ghazipur district of Uttar Pradesh, India, covering the period from the 1993-94 to 2022-23 agricultural years. The data has been obtained from the Economics and Statistics Division of the Planning Department, Government of Uttar Pradesh, as reported in the official *Sankhikiya Patrika* publications.

Compound annual growth rate (CAGR)

The study utilized time-series data on rice area, production, and yield in Ghazipur district, Uttar Pradesh, along with estimates of compound annual growth rates. The data were categorized into three time periods. Period I (1993-94 to 2002-03), Period II (2003-04 to 2012-13), Period III (2013-14 to 2022-23), along with the overall period covering 1993-94 to 2022-23, to analyze growth trends effectively. To compute the annual compound growth rate (CAGR), the following model is used compound growth.

$$Y_t = ab^t$$

Where, Y_t = Dependent variable (Area, Production, Productivity of rice crop in the year 't'), t = Time variable in years taking the value of 1, 2, 3, …, a = Intercept, and b = Regression coefficient (1 + r), first linearized by taking the natural logarithm on both sides:

$$\ln (Y_t) = \ln (a) + t (\ln) (b)$$

Where,

$$Y = ab^t$$

The above-linearized function was fitted by the least square method and estimate of b was obtained. The annual compound growth rate is then computed as:

$$\text{CAGR } (b - 1) \times 100$$

This gives the percentage growth rate per year.

Instability in rice area, production and yield in Ghazipur district, Uttar Pradesh, during the period 1993-94 to 2022-23 was evaluated using the Coefficient of Variation (CV) and the Cuddy-Della Valle Index (CDVI). These measures were applied to estimate the extent of variability in the data.

$$\text{Instability index} = \text{C.V.} \sqrt{1 - R^2}$$

$$\text{C.V.} = \frac{\sigma}{\mu} \times 100$$

$$R^2 = \frac{\text{Explained variation}}{\text{Total variation}} = 1 - \frac{\sum_{i=1}^{n} (Y_i - \hat{Y}_i)^2}{\sum_{i=1}^{n} (Y_i - \hat{Y})^2}$$

Where, n is the total sample size, C.V. is the coefficient of variation, R^2 is the coefficient of determination from the trend regression. σ = standard deviation, μ = Overall mean, Y_i is the actual value of dependent variable, $\hat{Y}_i$ is the predicted value of dependent vari-

able, $\bar{Y}$ is the mean of actual value of dependent variable. This index provides a more accurate estimate of instability by accounting for the trend component present in time series data.

Decomposition analysis

To estimate the contributions of area, productivity, and their interaction to the total production of rice crops, the following additive decomposition scheme can be applied:

$$\Delta P = A_0 (Y_n - Y_0) + Y_0 (A_n - A_0) + (A_n - A_0)\ (Y_n - Y_0)$$

$$100 = [(A_0 \Delta Y / \Delta P) \times 100] + [(Y_0 \Delta A / \Delta P) \times 100] + [((\Delta A)\ (\Delta Y) / \Delta P) \times 100]$$

Where,

ΔP = Change in production, A_0 = Area in the base year

An=Area in the current year, Y_0 = Yield in the base year

Yn = Yield in the current year, ΔA = Change in area ($A_n - A_0$),

ΔY = Change in yield ($Y_n - Y_0$).

By applying this decomposition, we can quantify how much of the change in total production is attributable to changes in area, changes in productivity, and the combined effect of both.

Linear and non-linear Trandmodels

To examine the trend patterns of rice area, production, and yield in Ghazipur district, various regression models were applied to estimate trend values. These models included linear, quadratic, cubic, quintic, logarithmic, exponential, and power functions fitted to the rice data.

Models	Form
Linear	$Y_t = m + nt + \varepsilon_t$
Quadratic	$Y_t = m + nt + ot^2 + \varepsilon_t$
Cubic	$Y_t = m + nt + ot^2 + pt^3 + \varepsilon_t$
Quartic	$Y_t = m + nt + ot^2 + pt^3 + qt^4 + \varepsilon_t$
Logarithmic	$Y_t = m + mln(t) + \varepsilon_t$
Exponential	$Y_t = ab^{nt} + \varepsilon_t$
Power	$Y_t = mt^n + \varepsilon_t$

Where, 'Y_t ' is dependent variable (i.e., area or production or yield of crop) 'm ' is the intercept, 'n', 'o', 'p' and 'q' area the regression coefficients, 't 'is an independent variable (i.e., time in years) and 'ε_t' is error term, $\varepsilon_t \sim N(0, \sigma^2)$.

Statistical measures for evaluation of the best fitted models

The accuracy of the fitted models was evaluated using different statistical indicators, including the coefficient of determination (R^2), adjusted R^2, root mean square error (RMSE), and relative mean absolute percentage error (RMAPE), as presented in the formulas below.

$$R^2 = 1 - \frac{SSR}{SST} = 1 - \frac{\sum_{t=1}^{n} (yt - \hat{y}t)^2}{\sum_{t=1}^{n} (yt - \bar{y})^2}$$

$$\text{Adjusted } R^2 = 1 - \frac{(1 - R^2)(n - 1)}{n - p - 1}$$

R^2 is the coefficient of determination, n is total sample size and p is a number of independent variables.

$$RMSE = \sqrt{\frac{1}{n} \sum_{t=1}^{n} (y_t - \hat{y}_t)^2}$$

$$RMAPE = \frac{1}{n} \sum_{t=1}^{n} \left| \frac{y_t - \hat{y}_t}{y_t} \right| \times 100$$

Here, n denotes the total number of years in the time-series data; y_t represents the observed value of the dependent variable (area, production and yield of rice), while $\hat{y}_t$ indicates the estimated or predicted trend value of the same variables.

RESULTS AND DISCUSSION

Compound annual growth rate (CAGR)

The yearly growth rates for rice area, production and yield in Ghazipur district, Uttar Pradesh, were calcu-

Table 1. Compound growth rate of area, production and yield of rice Ghazipur in Uttar Pradesh.

Particulars	Area CGR	Production CGR	Yield CGR
Overall period (1993-94 to 2022-23)	0.66*	1.88*	1.23*
I Period (1993-94 to 2002-03)	2.72*	3.54	0.79
II Period (2003-04 to 2012-13)	–0.47*	0.87	1.35
III Period (2013-14 to 2022-23)	0.10	4.83*	4.79*

*Significant at 0.05 level

lated using methods: Compound Growth Rate (CGR).

The Compound Growth Rate (CGR) analysis presented in Table 1 reveals that during the overall period (1993-94 to 2022-23), all three variables area, production, and yield registered positive and statistically significant growth at the 5% level in Ghazipur district. Area expanded at 0.66% per year*, production grew at 1.88% per year*, and yield improved at 1.23% per year*, collectively indicating that agricultural progress over the three decades was driven by both extensification and intensification of cultivation.

During Period I (1993-94 to 2002-03), area recorded the strongest and statistically significant growth at 2.72% per year*, reflecting a considerable expansion of cultivated land. Production grew at 3.54% per year and yield at 0.79% per year, both of which were positive but statistically non-significant at the 5% level, suggesting that the rise in production during this phase was largely attributable to area expansion rather than productivity gains.

In Period II (2003-04 to 2012-13), area witnessed a negative and statistically significant decline of -0.47% per year*, implying a contraction in the cultivated area. Despite this, production and yield registered positive growth rates of 0.87% per year and 1.35% per year respectively, though both remained statistically non-significant, indicating that modest productivity improvements helped sustain output even as the area under cultivation shrank.

Period III (2013-14 to 2022-23) presents the most encouraging trend, with production and yield recording the highest growth rates of 4.83% per year* and 4.79% per year* respectively, both statistically significant at the 5% level. Area growth, however, remained marginal at 0.10% per year and was non-significant.

Instability index of area, production and yield of rice:

Growth rate alone cannot fully explain the real situation because it only shows the increase ordecreasesin area, production, or yield over time. It does not indicate whether the changes are stable or highly fluctuating. Therefore, instability analysis is also important. Instability measures the variation in data over time. The Coefficient of Variation (CV) is commonly used, but it includes trend effects and may overestimate instability. To overcome this problem, the Cuddy-Della Valle (1978) instability index is used, as it removes the trend effect and provides a more accurate measure of fluctuations.

The instability analysis presented in Table 2 reveals interesting patterns across different periods. During the overall period (1993-94 to 2022-23), production exhibited the highest variability with a CV of 19.17% and a CDVI of 9.42%, followed by yield (CV: 15.06%; CDVI: 9.92%), while area remained comparatively more stable (CV: 7.35%; CDVI: 4.81%). The relatively higher instability in production and yield

Table 2. Instability index of area, production and yield of rice Ghazipur in Uttar Pradesh.

Particulars	Area		Production		Yield	
	CV	CVDI	CV	CVDI	CV	CVDI
Overall period (1993-94 to 2022-23)	7.35	4.81	19.17	9.42	15.06	9.92
I Period (1993-94 to 2002-03)	8.72	3.06	12.08	6.37	5.73	5.23
II Period (2003-04 to 2012-13)	1.81	1.10	6.78	6.26	6.94	5.58
III Period (2013-14 to 2022-23)	2.02	2.01	15.79	6.34	16.01	7.10

Table 3. Decomposition analysis of area, production and yield of rice Ghazipur in Uttar Pradesh.

Particular	(In %)
Area Effect	61.6
Interaction Effect	16.8
Yield Effect	21.6

may be attributed to climatic uncertainties, variations in input use, and fluctuations in technology adoption, whereas area fluctuations could be linked to shifting cropping patterns and prevailing agricultural policies.

During Period I (1993-94 to 2002-03), production again showed the greatest instability (CV: 12.08%; CDVI: 6.37%), followed by yield (CV: 5.73%; CDVI: 5.23%), while area remained the most stable among the three variables (CV: 8.72%; CDVI: 3.06%), suggesting that output fluctuations during this phase were primarily governed by productivity and production-related factors rather than changes in cultivated area.

In Period II (2003-04 to 2012-13), area emerged as remarkably stable, recording very low CV (1.81%) and CDVI (1.10%) values. In contrast, yield (CV: 6.94%; CDVI: 5.58%) and production (CV: 6.78%; CDVI: 6.26%) displayed comparatively higher instability, indicating that output variability during this period was largely driven by yield fluctuations rather than by changes in the extent of cultivation.

Period III (2013-14 to 2022-23) witnessed a continued stability in area (CV: 2.02%; CDVI: 2.01%), while both production (CV: 15.79%; CDVI: 6.34%) and yield (CV: 16.01%; CDVI: 7.10%) recorded a notable rise in instability compared to Period II. This increase suggests that despite advancements in irrigation infrastructure and farming technology, persistent climatic variability continued to exert a significant influence on yield performance and overall production outcomes during this phase.

Decomposition analysis

The relative contribution of area, yield and their interaction to the change in production of rice is presented in the Table 3. The results indicated that all three components contributed to the overall growth in rice production during the study period.

The decomposition analysis reveals that the area effect emerged as the most dominant contributor, accounting for 61.6% of the total change in rice production. The yield effect made a substantial contribution of 21.6%, while the interaction effect accounted for the remaining 16.8%. This indicates that although the expansion of cultivated area remained the primary driver of increased rice production, the contribution of yield improvement was also considerably significant and cannot be overlooked.

The relative contributions of area, yield, and their interaction to the overall change in rice production are presented in the Table. It is evident that all three components played a positive role in enhancing rice production during the study period. Among these, the area effect was the leading factor with a share of 61.6%, suggesting that a significant portion of production growth was achieved through the bringing of additional land under cultivation. However, unlike what is observed in many traditional agricultural settings, the yield effect here contributed a noteworthy 21.6%, reflecting meaningful improvements in productivity. The interaction effect, representing the combined influence of simultaneous changes in both area and yield, contributed 16.8%, indicating that the joint effect of these two factors also played a non-trivial role in shaping production outcomes.

Linear and non-linear trend models

To understand the trend pattern of rice area, production and yield in Ghazipur district from 1993-94 to 2022-23, various linear and non-linear regression models were applied.

Statistical models for area of rice in Ghazipur district of Uttar Pradesh.

The average area of the rice crop in Ghazipur district of Uttar Pradesh during the period 1993 to 2022 was 146372.12 hectares. The maximum area was recorded in 2001 with 156,348 hectares, while the minimum area was observed in 1993 with 117,786 hectares. The results of applying suitable linear, non-linear growth,

Table 4. Statistical models for area of rice in Ghazipur district of Uttar Pradesh.

Parameters	Models						
	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quartic
α	1.29×10^{5}*	1.16×10^{5}*	11.76*	11.67*	1.17×10^{5}*	1.07×10^{5}	**1.15×10^{5}**
β	1.19×10^{3}*	1.21×10^{4}*	0.008*	0.08*	3.97×10^{3} *	7.85×10^{3}	**2.87×10^{3}**
γ					-1.06×10^{2}*	-4.72×10^{2}	**-3.50×10^{3}**
θ						9.38	**–39.21**
δ							**0.93**

*Significant at 0.05 level.

and time series models to the dataset of rice cultivated area present in Table 4 which help in understanding the trend and variation in rice cultivation over the study period.

The forecasted quartic area model is:

$$\hat{Y}\ \text{area} = 1.15 \times 10^{5} + 2.87 \times 10^{3}t - 3.50 \times 10^{2}t^{2} - 39.21t^{3} + 0.93t^{4}$$

The Table 5 shows that a– 3.50 mong all growth models the quartic model was selected as the most appropriate for forecasting rice cultivation in the region up to the year 2027, and the projected results are presented accordingly. Based on the model selection criteria, the quartic model showed the highest R^2 (0.90) and adjusted R^2 (0.88), along with the lowest RMSE (3460.48) and MAPE (1.74). Therefore, the model was used to estimate the future area under rice cultivation in Ghazipur district of Uttar Pradesh. The estimated rice area for 2027-28 was about 366470.6

Table 5. Measures for evaluation of fitted models of rice area of Ghazipur in Uttar Pradesh.

Measures	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quartic
R^2	0.61	0.80	0.59	0.80	0.82	0.87	**0.90**
Adj. R^2	-	-	-	-	0.79	0.86	**0.88**
RMSE	6850.0	4824.89	7041.14	4921.86	4728.51	3854.02	**3460.48**
MAPE	3.770	2.53	3.87	2.56	2.59	2.14	**1.74**

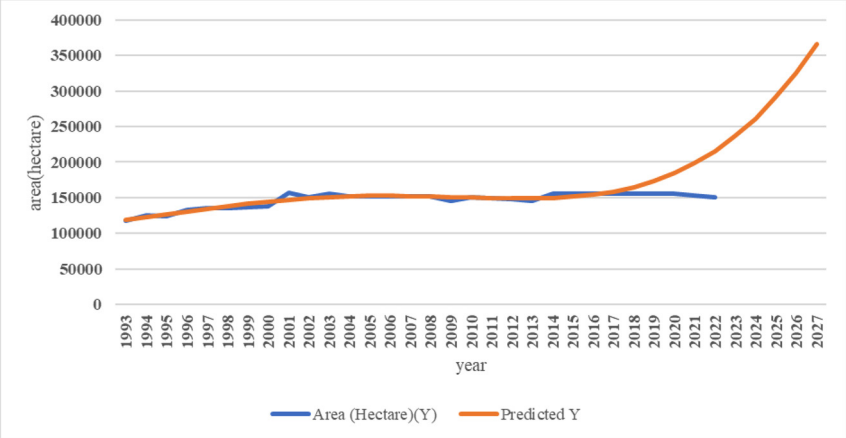

Fig. 1. Actual vs predicted values of area of rice data using the best-fitted model.

Table 6. Actual value and Forecasted value of rice Area in India (2018 to 2022).

Year	Actual Area	Forecasted value
2018	154945	164845.59
2019	154945	173269.95
2020	154945	184220.23
2021	152900	198077.93
2022	149976	215247

hectares The data shows in the Fig.1 that rice cultivation started showing a noticeable trend from around 1993, after which it experienced continuous ups and downs over the years.

Validate of rice area

The present study in the Table 6 is based on the validation of data for the period 2018 to 2022, focusing on the rice crop using secondary time series data from 1993 to 2022. Different regression techniques were applied, and the quartic model was found to provide the best fit for the data. The validation results indicate that the data used for the study period is reliable and show a consistent increases trend from 2018 to 2022. Based on this validated model, future projections suggest that the area under rice cultivation is likely to continue decreasing up to the year 2032.

Statistical models for production of rice in Ghazipur district of Uttar Pradesh

The average production under rice cultivation in Ghazipur district of Uttar Pradesh during the study period was 326,520 metric tonnes, The maximum area was recorded in 2022 with 503,647, while the minimum area was observed in 1993 with 222,212 metric tonnes. In the Table 7 show that the use of appropriate linear, non-linear growth, and time series models helps in understanding the trend and variations in the area under cultivation over the study period.

The Table 8 shows that among all the growth models analyzed the quartic model performs the best. It has the highest values of R^2 (0.81) and adjusted R^2 (0.77), along with the lowest values of RMSE (16510.2) and MAPE (4.75). Therefore, the quartic model is considered the mostappropriate for predicting future changes in the production under rice cultivation in Ghazipur district of Uttar Pradesh.

Table 7. Statistical models for Production of rice in Ghazipur district of Uttar Pradesh.

Parameter	Linear	Logarithmic	Exponential	Models Power	Quadratic	Cubic	Quartic
α	-8.57×10^{6}*	2.12×10^{5}*	$-2.12^{*}\times 10^{4}$	12.29	2.34×10^{5} *	1.97×10^{5}*	**2.05×10^{5}**
β	4.43×10^{3}*	4.02×10^{4}*	29.60*	0.14	7.37×10^{3} *	2.30×10^{4}*	**1.17×10^{4}**
γ					-1.13×10^{2}	-1.59×10^{3}*	**-7.13×10^{2}**
θ						3.79×10^{1}*	**-1.39×10^{1}**
δ							**0.99**

*Significant at 0.05 level

Table 8. Measures for evaluation of fitted models of rice production of Ghazipur in Uttar Pradesh.

Measures	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quartic
R^2	0.71	0.74	0.69	0.78	0.72	0.80	**0.81**
Adj. R^2	–	–	–	–	0.69	0.78	**0.77**
RMSE	20644.60	19113.5	21114.58	18865.04	19964.78	16609.44	**16510.2**
MAPE	5.78	5.37	5.81	5.20	5.53	4.83	**4.75**

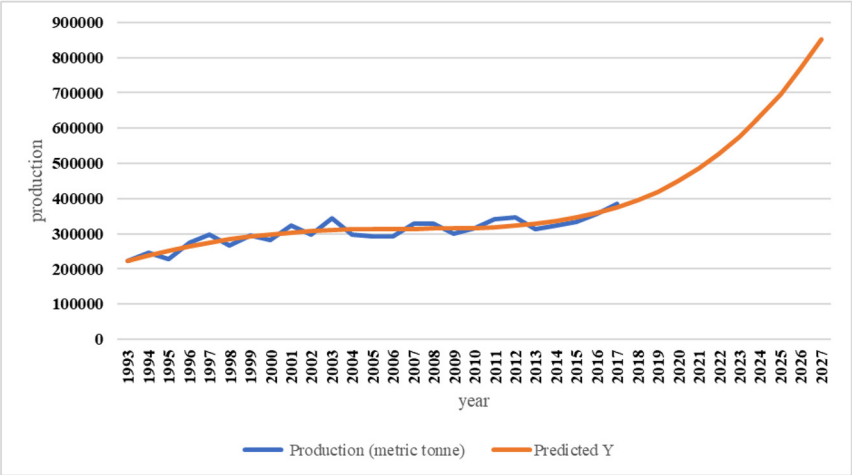

Fig. 2. Actual vs predicted values of production of rice data using the best-fitted model.

The forecasted quartic production model is:

$\hat{Y}$ Production = $2.05 \times 10^5 + 1.17 \times 10^4 t - 7.13 \times 10^2 t^2 - 1.39 \times 10^1 t^3 + 0.99 t^4$

The quartic model, identified as the best-fitting model, was used to generate future forecasts for rice production in the region up to the year 2027-28. Model selection was based on statistical criteria such as maximum R^2 and adjusted R^2, along with minimum values of RMSE and MAPE. Based on these measures, the quartic model was considered the most appropriate for forecasting rice production in Uttar Pradesh. The results indicate in the Fig. 2 an increases trend in rice production starting from 2022, with production projected to reach approximately 851647.58 by 2027-28.

Table 9. Validate Value and Actual Value of rice Production in India (2018 to 2022).

Year	Actual value	Validate value
2018	400087	395138.16
2019	382273	419976.03
2020	467290	449859.38
2021	408054	485363.37
2022	503647	527087.07

Validate of rice production

The Table 9 validation results showed that the predicted rice production values were reasonably close to the actual values during 2018-2022, indicating good forecasting accuracy of the quartic model. Despite minor variations, the model successfully captured the overall increasing trend in rice production. Therefore, the quartic model was found to be suitable and reliable for forecasting future rice production up to 2032.

Table 10. Statistical models for yield of rice in Ghazipur district of Uttar Pradesh.

Parameter	Models						
	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quartic
α	-2.51×10^2*	18.47*	2.95*	2.92*	19.90*	18.59*	**17.89***
β	0.13*	1.09*	0.006*	0.05*	–0.01	0.54	**0.99**
γ					0.005	–0.04	**–0.121**
θ						0.001	**0.005**
δ							**–0.0001**

*Significant at 0.05 level

Table 11. Measures for evaluation of fitted models of rice yield of Ghazipur in Uttar Pradesh.

Measures	Linear	Logarithmic	Exponential	Power	Quadratic	Cubic	Quartic
R^2	0.42	0.35	0.42	0.36	0.45	0.51	**0.52**
Adj.R^2	–	–	–	–	0.40	0.44	**0.43**
RMSE	1.15	1.21	1.14	1.21	1.11	1.05	**1.03**
MAPE	4.64	4.7	4.63	4.72	4.64	4.22	**4.21**

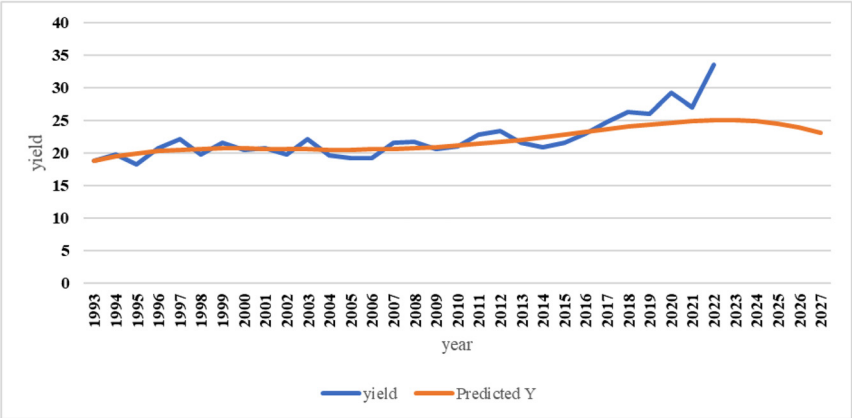

Fig. 3. Actual vs Predicted values of yield of rice data using the best-fitted model.

Statistical models for yield of rice in Ghazipur district of Uttar Pradesh

The average yield of the rice crop in Ghazipur district of Uttar Pradesh during the period 1993 to 2022 was 20.20 quintals per hectare. The maximum yield was recorded in 2022 with 33.58 quintals per hectare, while the minimum yield was observed in 1995 with 18.31quintals per hectare. In the Table 10 show that the application of suitable linear, non-linear growth, and time series models to the yield data helps to understand the trend and fluctuations in productivity over the study period.

The Table 11 shows that among all the growth models analyzed the quartic model performs the best. It has the highest values of R^2 (0.52) and adjusted R^2 (0.43), along with the lowest values of RMSE (1.03) and MAPE (4.21). Therefore, the quartic model is considered the most appropriate for predicting future changes in the yield under rice cultivation in Ghazipur district of Uttar Pradesh.

Table 12. Actual Value and Forecasted Value of rice Yield in India (2018 to 2022).

Year	Actual value	Validated value
2018	26.36	24.05
2019	26.05	24.40
2020	29.21	24.70
2021	26.99	24.92
2022	33.58	25.04

The forecasted quartic yield model is:

$$\hat{Y}\ \text{yield} = 17.89 + 0.99t - 0.12t^2 + 0.005t^3 + 0.0001t^4$$

The quartic model, identified as the best-fitting model, was applied to generate forecasts of rice yield in the region up to the year 2027. Model selection was based on statistical criteria, including higher values of R^2 and adjusted R^2, along with lower values of RMSE and MAPE. Based on these indicators, the quartic model was considered the most appropriate for predicting rice yield in Uttar Pradesh. The forecast results reveal in the Fig. 3 a declining trend in rice yield beginning from 2022, with the yield expected to reach approximately 23.15 quintals per hectare by 2027.

Validation of rice yield

The Table 12 validated for the period 2018-2022 by comparing the observed and predicted values. The estimated values were found to be close to the actual observations, indicating satisfactory accuracy and a good fit of the model. Despite slight deviations, the model successfully captured the overall trend and maintained a stable pattern throughout the validation period. These results confirm the reliability and suitability of the selected model for future forecasting purposes.

CONCLUSION

Over the three decades from 1993-94 to 2022-23, rice production showed an overall positive trend. In Period-I, growth was mainly due to an increase in cultivated area. In Period-II, area slightly declined but yield and production still improved. Period-III recorded the highest growth in production and yield, while area remained almost stagnant. Overall, all three variables showed significant growth, with production growing the fastest.

Regarding instability, yield was the most unstable variable, followed by production, while area remained the most stable. Period-II was the most stable phase, whereas Period-III showed higher fluctuations despite recording the best growth rates.

The decomposition analysis showed that around 62 percent of production growth came from area expansion, while yield contributed only about 22 percent. This suggests that growth so far has largely depended on expanding area rather than improving productivity. Since the scope for further area expansion is limited, future growth must focus on improving yield through better technology, farming practices, and supportive policies to ensure sustainable wheat production in the coming years.

The quartic model is the best-fitted model for area, production, and yield, based on measures for the evaluation of fitted models, including higher R^2 values and lower RMSE and MAPE. To stabilize Rice production in Ghazipur district, Uttar Pradesh, focus on securing the cultivated area and enhancing yield through improved varieties, timely inputs, and climate-adaptive practices. Use the quartic model for accurate forecasting and data-driven agricultural policy planning.

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