

## Individual and Joint Weather Assessment on Rice Crop for Ayodhya District of Uttar Pradesh, India

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### ABSTRACT

Rice (*Oryza sativa* L.) is the principal staple crop of Uttar Pradesh, covering nearly 36.5% of the state's total area of the crop. This study was taken under the Ayodhya district to develop pre-harvest forecasting models for rice yield. Utilizing 38 years (1986–2023) of time-series yield data and weekly weather parameters (minimum temperature, maximum temperature, rainfall, and sunshine) from the growing period, weather indices and interaction terms were generated using correlation-based methods. Stepwise multiple regression was employed to evaluate individual and joint effects, including a time trend ( $T$ ) to account for technological progress. Results revealed that rainfall

was the most influential individual factor (R-square = 68.28%), followed by maximum temperature (66.01%), sunshine (61.40%), and minimum temperature (59.88%). Analysis of joint effects showed that combinations of variables explained even more variation, with the model combining maximum temperature and sunshine performing best (R-square = 76.99%). The time trend ( $T$ ) was consistently positive and highly significant across all models. The study concludes that integrating generated weather indices with regression modeling provides a robust framework for pre-harvest rice yield forecasting, supporting effective agricultural planning and risk management.

**Keywords** Ayodhya district, Rice crop, Statistical analysis, Step wise regression, Weather variables.

### INTRODUCTION

Rice (*Oryza sativa* L.) is a major food crop as staple food in of India as well as Uttar Pradesh. It is a widely consumed and important crop as staple food, rich in carbohydrates and essential nutrients. It plays a vital role in the diet of the Indian subcontinent, where it holds a prominent and traditional dietary position, Kumar *et al.* (2025a). As per the final 2<sup>nd</sup> advance estimates the agriculture and farmers welfare ministry, for the year 2024-25, India's total rice production is projected at 136.43 million tons. This reflects a decline of 1.39 million tons compared to the 2023-24

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production, which stood at 137.82 million tons. The total area under rice cultivation in India was 47.73 million hectares, achieving an average yield of 2,859 kilograms per hectare. Uttar Pradesh has the highest rice cultivation area among Indian states, covering approximately 7.22 million hectares and contributing around 19.94 million tons to the country's total rice production. The state's rice productivity was recorded at 2,760 kilograms per hectare in 2024-2025, (DAFW, Annual report 2024-25).

Several researcher and scientist have carried out the weather variable's effect on the rice yield for different geographical region across the country. Pandey *et al.* (2015) reported the impact of weather variables on yield of rice in Faizabad, Uttar Pradesh. Sunshine hours showed the highest individual influence, while the combination of rainfall and wind velocity had the strongest joint effect. Stepwise regression effectively identified significant weather factors affecting rice crop productivity in the region. Kulkarni *et al.* (2022) studied the various weather variables, rainfall had the most significant positive impact on wheat yield in Azamgarh, followed by minimum temperature. In contrast, maximum temperature and humidity negatively affected the crop yield, indicating variable-specific influences.

The role of various variables on yield of wheat in Azamgarh district. Based on correlation and regression analyses, it was concluded that rainfall had the most significant positive effect on wheat yield, followed by minimum, maximum temperature and humidity, showed negative effects Singh *et al.* (2021).

Garde *et al.* (2015) proposed the impact of weather conditions on production of crop for forecasting at pre-harvest, a key component of anticipatory sciences, plays a vital role in predicting feasible future outcomes. This research, Linear Regression as Multiple (MLR) and DFA were applied to estimate productivity of wheat in Varanasi. Among the models, Model-2 showed the highest Adjusted  $R^2$  (0.94) and lowest RMSE (1.17), indicating its superiority. Thus, MLR with technical and statistical indicators proved most effective for accurate wheat yield forecasting.

Deepa *et al.* (2025) analyzed 43 years (1980–

2022) of turmeric area, production, and yield data from southern India using ARIMA models for forecasting. Model selection was based on minimizing AIC, BIC, and residual spikes. The best-fitting models were ARIMA (2,1,3) for Andhra Pradesh, ARIMA (1,1,3) for Karnataka, ARIMA (2,1,2) for Tamil Nadu, and ARIMA (1,1,1) for Kerala. These models effectively captured regional production dynamics, providing statistically robust and reliable forecasts for turmeric production trends across southern Indian states.

Pal *et al.* (2025) studied maize cultivation analysis in Uttar Pradesh used 1950-2022 time series data to examine area, production, and yield trends across four sub-periods. Using CAGR, coefficient of variation, and regression models, the cubic model provided optimal fit. Statistical measures revealed area expansion as the primary driver of maize production growth.

Kumar *et al.* (2025b) used linear and non-linear regression models to identify the best trend for pearl millet and finger millet based on area, production, and productivity. Various models—linear, quadratic, cubic, and logarithmic—were tested using secondary annual data. The cubic model provided the best fit for pearl millet, with coefficients of determination of 86%, 60%, and 90% for area, production, and productivity, respectively. For finger millet, both quadratic and cubic models performed similarly, but validation results confirmed the cubic model as the most suitable for both crops.

Kumar *et al.* (2024) used time series modeling, including the Box-Ljung test and ARIMA models, to forecast ragi (*Eleusine coracana*) area and production in Uttar Pradesh and Karnataka from 1966–1967 to 2022–2023. The best-fitting ARIMA model was (2,2,1), while ARIMA (2,1,2) was used for future forecasting over ten years. Results indicated a declining trend in ragi area in Karnataka between 2010 and 2015, with slight fluctuations, while Uttar Pradesh showed continued declines in both area and production over time.

Krishnan *et al.* (2024) studied Rainfall forecasting in Kerala was conducted using Artificial Neural Network (ANN) models—Multi-Layer Perceptron

(MLP) and Extreme Learning Machine (ELM)—with 39 years (1982–2020) of data from northern and central zones and 36 years (1985–2020) from the southern zone. Model performance was evaluated using MSE, RMSE, and MAE. Results showed that MLP performed better than ELM in predicting rainfall across all zones. The best-performing MLP model was then used to forecast rainfall for the next five years in each zone of Kerala.

Pooja *et al.* (2023) studied India, the world's largest producer and consumer of pulses, still imports 3–4 million tonnes annually to meet demand. Pulses are cultivated on about 22–23 million hectares, producing 13–18 MT yearly. This study analyzed 71 years (1951–2021) of data using linear, logarithmic, quadratic, cubic, power, and exponential regression models to forecast pulse area and production. Among these, the cubic model provided the most accurate predictions for both parameters. Major pulse-growing states include Rajasthan, Madhya Pradesh, Maharashtra, Karnataka, and Uttar Pradesh.

Krishnan *et al.* (2023) modeled and forecasted relative humidity and wind speed in Kerala's northern, central, and southern zones using the SARIMA model. Data from RARS Pilicode, Pattambi (1982–2020), and Vellayani (1985–2020) were analyzed. Model accuracy was validated using MSE, RMSE, MAE, and RMAPE, with RMAPE values below 10%, indicating high reliability. The selected SARIMA models effectively predicted climatic parameters for the next five years, demonstrating accurate performance in assessing seasonal climate variations across Kerala.

Singh *et al.* (2023) Studied the analyzed 29 years (1991–2019) of rice yield and weather data from Prayagraj District, Uttar Pradesh, using Artificial Neural Network (ANN) and stepwise linear regression models. The dataset was divided into calibration and validation phases. Results showed that the regression model outperformed the ANN, achieving a lower normalized RMSE (0.00025) and higher  $R^2$  (0.94). Bright sunshine hours emerged as a key meteorological factor influencing rice yield prediction accuracy.

Yadav *et al.* (2022) used the Box-Jenkins ARIMA

time series model to forecast the area under nutri cereals cultivation in India. The best-fitting model identified was ARIMA (0,1,1). Using this model, future projections were made for the next ten years. The forecast results indicated a continued decline in the nutri cereals area, with an average annual decrease of about 1%. Thus, the ARIMA (0,1,1) model effectively captured the downward trend in nutri cereals cultivation across India.

Varshneya *et al.* (2010) developed regional multiple regression models to predict seasonal (June–September) rainfall across north, middle, and south Gujarat. Using 30 years of data from Anand, 27 years from SK Nagar, and 22 years from Navsari, four models were created and validated with independent data (2006–2009). The models explained 74–93% of rainfall variability with errors between –2.5% and 5.1%, performing satisfactorily during validation. Forecasts for 2010 indicated above-normal rainfall: Navsari 1529 mm (+14.5%), Anand 1294–1363 mm (+62–71%), and SK Nagar 770 mm (+40%).

Kumar *et al.* (2014) studied multiple regression models for paddy, sugarcane, and wheat yield forecasting were developed for Navsari and Bharuch districts using 31 and 27 years of weather–yield data, respectively. Models based on significant weather variables were validated with 2007–2010 data, showing yield deviations within  $\pm 12\%$  across both districts and all crops.

Azfar *et al.* (2015) reported the individual effect of different weather variables as well as the change and effect of one unit increase the weather variable for the rice crop in eastern Uttar Pradesh.

## MATERIALS AND METHODS

The present study has been carried out in Ayodhya, situated between latitude 26°47' N and longitude 82°12' E. This region falls in the Plain Zone of Eastern Uttar Pradesh and receives approximately 1022 mm rainfall annually. It is well-irrigated by the Saryu (Ghaghara) River and its tributaries. The soils in the area has been reported as alluvial (deep), medium and medium to heavy in texture, which is plough able very easily. These suitable agro-climatic conditions rich soil, adequate rainfall and ample irrigation make

rice cultivation a natural and prominent agricultural choice in the region. The basic objective of the study has been developed a forecasting model for rice yield. The rice yield data on for 38 years (1986–2023) were obtained from the published booklet of the Agricultural Statistics and Crop Insurance, Directorate of UP Government. Corresponding data on weather (weekly) for the above said period has been collected from Agro-Meteorology Department, Agriculture & Technology University, (ANDUAT, Kumarganj) Ayodhya. The weather data covered the first 19 weeks of the rice crop’s growth cycle, corresponding to the 24<sup>th</sup> to 42<sup>nd</sup> Standard Meteorological Weeks (SMW) of each year. The study utilized four weather variables: Maximum & Minimum temperature (°C), rainfall (mm) and sunshine (hours).

**The individual effect of weather variables on crop yield**

In order to study, the effect of individual weather variable, two new variables from each weather variable are generated as follows:

Let  $X_{iw}$  be the value of  $i^{th}$  ( $i=1,2,...,p$ ) weather variable at  $w^{th}$  weeks ( $w=1,2,...,n$ ). In this study,  $n$  is 19.

Let  $r_{iw}$  be the simple correlation coefficient between weather variable  $X_i$  at week  $w$  and crop yield over a period of  $k$ -years. Weather factors’ individual effects two additional variables are created from each weather variable in the following manner in order to examine the impact of each one separately:

$$Z_{ij} = \frac{\sum_{w=1}^n r_{iw}^j X_{iw}}{\sum_{w=1}^n r_{iw}^j}; j=0,1$$

We have an unweighted created (generated) variable for  $j = 0$ .

$$Z_{i0} = \frac{\sum_{w=1}^n X_{iw}}{n}$$

and for  $j=1$ , weighted created (generated) variables

$$Z_{i1} = \frac{\sum_{w=1}^n r_{iw} X_{iw}}{\sum_{w=1}^n r_{iw}}$$

The following model is then fitted to study the effect of individual weather variable

$$Y = b_0 + b_1 Z_{i0} + b_2 Z_{i1} + cT + \epsilon; i = 1, 2, \dots, p.$$

Where,  $Y$  is yield.  $T$  is variable expressing time effect,  $b_0, b_1, b_2$  and  $c$  are parameters of the model is error to be evaluated for the effect of variables and term supposed to follow normal distribution with mean zero and variance  $\sigma^2$ .

**The effect of weather variables jointly on crop yield**

The model has been expanded to include interaction terms in order to examine the combined impact of two meteorological variables on crop output proposed by Agrawal *et al.* (1983, 1986),

$$Q_{ij} = \frac{\sum_{w=1}^n r_{ii,w}^j X_{iw} X_{iw}}{\sum_{w=1}^n r_{ii,w}^j}; j=0,1$$

Where,  $X_{ii,w}$  is the correlation coefficient between crop yield  $Y$  and product of weather variables  $X_{iw}$  and  $X_{iw}$ . Two created variables (interaction term) are evidently present. Developed by the un-weighted one:

$$Q_{ii,0} = \frac{\sum_{w=1}^n X_{iw} X_{iw}}{n}$$

and the weighted one:

$$Q_{ii,1} = \frac{\sum_{w=1}^n r_{ii,w}^j X_{iw} X_{iw}}{\sum_{w=1}^n r_{ii,w}^j}$$

These two generated interaction along with individually generated variables has given in model. The model developed Yadav *et al.* (2014). To investigate the impact of combined weather variables, we have the following model:

$$Y = b_0 + \sum_{i=1}^2 \sum_{j=0}^1 b_{ij} Z_{ij} + \sum_{j=0}^1 b_{iij} Q_{iij} + cT + \varepsilon$$

When other terms have already been explained in a previous model and  $b_{ij}$  and  $b_{iij}$  are the model's parameters (regression coefficients). Step wise regression method has been used to fit the model with the data given by Banakara *et al.* (2018).

### Model development

This section of study has been carried out on variable generated in the following methodology have been used for the model development:

#### Multiple linear regression

The unweighted joint generated variable for each combination has been use to fit the model. The suggested model is

$$Y = b_0 + b_1 Q_{120} + b_2 Q_{130} + \dots + b_{21} Q_{670} + cT + e_i$$

Similarly, for the weighted generated variable, the model is

$$Y = b_0 + b_1 Q_{121} + b_2 Q_{131} + \dots + b_{21} Q_{671} + cT + e_i$$

## RESULTS AND DISCUSSION

The result of the individual effect of four important weather variables along with joint effect of these variables and the composite effect of all the variables has been carried out in this section.

### Individual effect

The individual effect of four weather variable (maximum temperature, minimum temperature rainfall and sunshine), these variable are most important of the rice crop under the eastern Uttar Pradesh. The effect of variables has been given below:

#### Effect of maximum temperature

The regression model explained 66.01% of yield variation ( $R^2 = 0.66$ ), indicating a good fit. The constant was positive but insignificant. Variable  $Z_{10}$  showed a positive effect, though statistically non-significant ( $p = 0.70$ ). In contrast,  $Z_{11}$  has a negatively significant contribution (coefficient = -0.336,  $p = 0.008$ ), suggesting adverse effects on yield. The time trend ( $T$ ) has significantly higher ( $p < 0.001$ ) with a positive coefficient (0.224), indicating consistent yield improvement over time, likely due to technological progress and improved practices. Overall,  $Z_{11}$  reduces yield, while technological advancement strongly enhances productivity (Table 1).

The developed model is  $Y = 22.23 + 0.2419Z_{10} - 0.3356Z_{11} + 0.2242T$

**Table 1.** Role of temperature (maximum).

Variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Intercept	22.2341 (18.5418)	0.2387		-15.4470	59.9156
$Z_{10}$	0.2419 (0.62297)	0.7002	66.01***	-1.0241	1.5079
$Z_{11}$ ***	-0.3356 (0.11998)	0.0084		-0.5794	-0.0918
T***	0.22423 (0.0406)	3.6E-06		0.1417	0.3067

Note: \*\*\* significant at 1%.

**Table 2.** Role of temperature (minimum).

Variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Intercept	5.321241 (11.80397)	0.654995		-18.6673	29.30979
Z <sub>20</sub>	-0.3863 (0.437638)	0.383598	59.89***	-1.27569	0.503085
Z <sub>21</sub> <sup>+</sup>	0.899655 (0.505312)	0.08395		-0.12726	1.926573
T***	0.239142 (0.045227)	7.27E-06		0.147229	0.331055

Note: \*\*\*significant at 1%, + significant at 10%.

### ***Effect of temperature (minimum)***

The regression model explained 59.89% of yield variation (R<sup>2</sup> = 0.599), showing a reasonable fit. The constant was positive but insignificant (p = 0.655), indicating no strong baseline effect. Variable Z<sub>20</sub> had a negative but non-significant influence (p = 0.384), suggesting little impact on yield. Conversely, Z<sub>21</sub> showed a positive effect (0.900) and was marginally significant (p = 0.084), pointing toward a possible contribution to yield improvement. The time trend (T) was highly significant (p < 0.001) with a positive coefficient (0.239), highlighting continuous yield gains, likely driven by technological advancement and improved cultivation practices in the study area (Table 2).

The developed model is  $Y = 5.3212 - 0.3863Z_{20} + 0.8996Z_{21} + 0.2391T$

### ***Effect of rainfall***

The regression model explained 68.28% of the vari-

ation in rice yield (R<sup>2</sup> = 0.683), indicating a strong fit. The constant (12.60) was highly significant (p < 0.001), showing a meaningful baseline yield. Among the predictors, Z<sub>30</sub> had a positive and significant effect (coefficient = 0.106, p = 0.010), suggesting a substantial role in improving productivity. Z<sub>31</sub> showed a positive but marginally significant effect (p = 0.074), indicating a weaker contribution. The time trend (T) was highly significant (coefficient = 0.273, p < 0.001), reflecting steady improvements in yield over time due to technological and management advancements (Table 3).

The developed model is  $Y = 12.6016 + 0.1061Z_{30} + 0.0022Z_{31} + 0.0438T$

### ***Effect of sunshine (hr)***

The regression model explained 61.40% of the variation in rice yield (R<sup>2</sup> = 0.614), indicating a good fit. The constant (19.66) was highly significant (p <

**Table 3.** Role of rainfall.

Variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Intercept	12.60164 (2.244002)	2.72E-06		8.041282	17.16201
Z <sub>30</sub>	0.106164 (0.038864)	0.009919	68.28***	0.027182	0.185146
Z <sub>31</sub>	0.00229 (0.00124)	0.073607		-0.00023	0.00481
T	0.273341 (0.043822)	4.24E-07		0.184285	0.362397

Note: \*\*\* significant at 1%.

**Table 4.** Role of sunshine (hr).

Variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Intercept	19.6613 (4.1217)	3.41E-05		11.2848	28.0376
Z <sub>40</sub>	1.2804 (1.0664)	0.2381	61.40***	-0.8869	3.4477
Z <sub>41</sub>	-1.4791 (0.7108)	0.04507		-2.9238	-0.03442
T	0.23868 (0.0437)	4.35E-06		0.1498	0.3275

Note: \*\*\* Significant at 1%.

0.001), reflecting a strong baseline yield. Variable Z<sub>40</sub> had a positive coefficient (1.28) but was statistically insignificant (p = 0.238), suggesting no clear impact on yield. In contrast, Z<sub>41</sub> showed a significant negative effect (coefficient = -1.48, p = 0.045), indicating that increases in this variable reduce yield. The time trend (T) was highly significant (coefficient = 0.239, p < 0.001), confirming steady yield growth over time due to improved technology and practices (Table 4).

The developed model is  $Y = 19.6613 + 1.2804Z_{40} - 1.4791Z_{41} + 0.0437T$

Table 5 summaries that the rainfall showing max-

imum and significant R<sup>2</sup> (68.28%) at 1% significance level followed by Max T. (66.01%), Sunshine (hrs) (61.40%) and Min T (59.88%) respectively. All the individual variables found significant at 1% level. The effect of these variables are showing the very high and significant role for the rice crop under the plane zone of Eastern Uttar Pradesh on Ayodhya district.

#### Combined role of weather variable on rice

The stepwise regression analysis (stepwise) has been carried out to analyses the joint effect and only selected variable significantly entered in the model has been used to development and study of the in-

**Table 5.** Summary table of Individual of weather effect.

Sl. No.	Individual variable model	Variable	R <sup>2</sup> (%)	Significance level
1	$Y = 22.23 + 0.2419Z_{10} - 0.3356Z_{11} + 0.2242T$	Maximum temp	66.01***	1%
2	$Y = 5.3212 - 0.3963Z_{20} + 0.8996Z_{21} + 0.2391T$	Minimum temp	59.88***	1%
3	$Y = 12.6016 + 0.1061Z_{30} + 0.0022Z_{31} + 0.0438T$	Rainfall	68.28***	1%
4	$Y = 19.6613 + 1.2804Z_{40} - 1.4791Z_{41} + 0.0437T$	Sunshine (hr)	61.40***	1%

Note: \*\*\*significant at 1%.

**Table 6.** Combined (max T & min T) effect on rice.

Entered variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Intercept	29.278 (3.837)	6E-09		21.48415	37.06382
Z <sub>11</sub>	-0.310 (0.98)	0.003284	63.90***	-0.50849	-0.11038
T	0.228 (0.039)	1.12E-06		0.14935	0.307012

Note: \*\*\*significant at 1%.

**Table 7.** Combined (max T & rainfall) effect on rice.

Entered variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Intercept	29.278 (3.837)	6E-09		21.4841	37.0638
Z <sub>11</sub>	-0.310 (0.98)	0.0032	63.90***	-0.5084	-0.1103
T	0.228 (0.039)	1.12E-06		0.1493	0.3070

Note: \*\*\*significant at 1%.

teraction effect.

### Combined effect of max T & min T

The joint effect model explained 63.90% of the variation in rice yield ( $R^2 = 63.90$ ), indicating a good explanatory power. The constant (29.28) was highly significant ( $p < 0.001$ ), reflecting a strong baseline yield level. Variable Z<sub>11</sub> exerted a negative and statistically significant effect (coefficient = -0.310,  $p = 0.003$ ), implying that increases in this factor reduce productivity. In contrast, the time trend (T) had a positive and highly significant effect (coefficient = 0.228,  $p < 0.001$ ), confirming continuous yield improvement over time. Thus, while technological progress supports yield growth, adverse climatic influence through Z<sub>11</sub> negatively affects production (Table 6).

The developed model is  $Y = 29.27 - 0.310Z_{11} + 0.228T$

### Combined effect of max T & rainfall

The joint effect model explained 63.90% of the variation in rice yield ( $R^2 = 0.639$ ), indicating a good explanatory power. The constant (29.28) was highly significant ( $p < 0.001$ ), reflecting a strong baseline yield level. Variable Z<sub>11</sub> exerted a negative and statistically significant effect (coefficient = -0.310,  $p = 0.003$ ), implying that increases in this factor reduce productivity. In contrast, the time trend (T) had a positive and highly significant effect (coefficient = 0.228,  $p < 0.001$ ), confirming continuous yield improvement over time. Thus, while technological progress supports yield growth, adverse climatic influence through Z<sub>11</sub> negatively affects production (Table 7).

The developed model is  $Y = 29.278 - 0.310 + 0.228T$

### Combined effect of max T & sunshine

The regression model explained 76.99% of the vari-

**Table 8.** Combined (max T & sunshine) effect on rice.

Entered variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Intercept	34.94341 (4.194111)	1.27E-09		26.41043	43.47639
Z <sub>11</sub>	-0.3709 (0.084443)	0.000109		-0.5427	-0.1991
Z <sub>41</sub>	-2.54812 (0.640527)	0.000358	76.99***	-3.85128	-1.24496
Q <sub>141</sub>	0.060429 (0.019822)	0.004506		0.020101	0.100757
T	0.211764 (0.037826)	3.15E-06		0.134806	0.288721

Note: \*\*\*significant at 1%.

**Table 9.** Combined (min T& rainfall) effect on rice.

Entered variables	Regression coefficients (SE)	P - value	Variables	95% confidence interval	
				Lower	Upper
Constant	11.30155 (2.2026)	1.08E-05		6.8298	15.7732
Z <sub>30</sub>	0.1186 (0.0395)	0.00497	65.11***	0.0382	0.1989
T	0.3146 (0.0389)	1.64E-09		0.2356	0.3937

Note: \*\*\*significant at 1%.

ation in rice yield ( $R^2 = 0.770$ ), indicating a strong explanatory power. The intercept (34.94) was highly significant ( $p < 0.001$ ), suggesting a strong baseline yield. Variable  $Z_{11}$  had a significant negative effect (coefficient =  $-0.371$ ,  $p < 0.001$ ), indicating yield reduction with its increase. Similarly,  $Z_{41}$  showed a strong negative impact (coefficient =  $-2.55$ ,  $p < 0.001$ ). In contrast,  $Q_{141}$  had a positive and significant effect ( $0.060$ ,  $p = 0.005$ ), supporting productivity. The time trend (T) was positive and highly significant ( $0.212$ ,  $p < 0.001$ ), confirming sustained yield growth over time (Table 8).

The developed model is  $Y = 34.9434 - 0.3709Z_{11} - 2.5481Z_{41} + 0.0604Q_{141} + 0.2117T$

#### **Combined effect of min T & rainfall**

The joint regression model explained 65.11% of the variation in rice yield ( $R^2 = 0.651$ ), indicating a strong fit. The constant (11.30) was highly significant ( $p < 0.001$ ), reflecting a stable baseline yield. Variable  $Z_{30}$  showed a positive and statistically significant effect (coefficient= $0.119$ ,  $p = 0.005$ ), suggesting that increases in this factor contribute to improved productivity. The time trend (T) was also highly sig-

nificant (coefficient =  $0.315$ ,  $p < 0.001$ ), confirming consistent yield improvements over time, likely due to technological advancement and better cultivation practices. Overall,  $Z_{30}$  and T jointly enhance rice yield in the study area (Table 9).

The developed model is  $Y = 11.3015 + 0.1186 + 0.118619Z_{30} + 0.314668T$

#### **Combined effect of mint T & sunshine**

The joint effect regression model explained 56.14% of the variation in rice yield ( $R^2 = 0.561$ ), showing a reasonably good fit. The constant (17.43) was highly significant ( $p < 0.001$ ), reflecting a stable baseline yield. The time trend (T) displayed a positive and highly significant coefficient ( $0.274$ ,  $p < 0.001$ ), with a narrow confidence interval ( $0.192-0.355$ ), confirming the precision of the estimate. These findings suggest that rice productivity has steadily increased over time, mainly due to technological progress, adoption of improved farming practices, and better management strategies, even when no other explanatory variable is included in the model (Table 10).

The developed model is  $Y = 17.4353 + 0.2736T$

**Table 10.** Combined (minT& sunshine) effect on rice.

Entered variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Constant	17.4353 (0.9016)	1.33E-20	56.14***	15.6067	19.2639
T	0.273618 (0.0403)	6.21E-08		0.1918	0.3553

Note: \*\*\*significant at 1%.

**Table 11.** Combined (rainfall & sunshine) effect on rice.

Entered variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Constant	11.30155 (2.202697)	1.08E-05		6.829833	15.77326
Z <sub>30</sub>	0.118619 (0.039569)	0.004977	65.11***	0.03829	0.198948
T	0.314668 (0.038946)	1.64E-09		0.235603	0.393733

Note: \*\*\*significant at 1%.

### Combined effect of rainfall & sunshine

The joint effect regression model explained 65.11% of the variation in rice yield ( $R^2 = 0.651$ ), indicating strong explanatory power. The constant (11.30) was highly significant ( $p < 0.001$ ), representing a solid baseline yield. Variable  $Z_{30}$  had a positive and significant effect (coefficient = 0.119,  $p = 0.005$ ), suggesting that this factor contributes meaningfully to productivity. The time trend (T) showed a strong positive and highly significant effect (coefficient = 0.315,  $p < 0.001$ ), with a narrow confidence interval (0.236–0.394), reflecting sustained yield growth over time due to technological advancement and improved management practices in the study area (Table 11).

The developed model is  $Y = 11.3015 + 0.1186Z_{30} + 0.118619Z_{30} + 0.314668T$

Table 12 shows the interaction of two weather variables viz. Max T & Min T, MaxT & Rainfall, MaxT & Sunshine, MinT & Rainfall, MinT & Sunshine and Rainfall & Sunshine has been reported significantly higher at 1% level except one. The stepwise regression method has been used to find out

the important and significant variables. The value of  $R^2$  has 63.90, 63.90, 76.99, 65.11, 56.14 and 65.11, respectively. The significance of  $R^2$  has also found significant at 1%. The maximum and significant contribution given in combination of Maximum Temperature and Sunshine, that indicates the Maximum Temperature and Sunshine plays very important role jointly.

The combined effect of two weather variables on rice crop yield revealed that time trend consistently entered the models as a significant predictor, while other variables contributed differentially. Models incorporating rainfall in combination with either minimum or maximum temperature, as well as with sunshine, explained the highest variation in yield ( $R^2 = 65.10\%$ , significant at 1%), underscoring the central role of rainfall in yield determination. In contrast, models including sunshine or temperature alone with the time trend accounted for comparatively lower variation ( $R^2 = 56.14\%$ , significant at 1%). These findings highlight that, while temperature and sunshine influence yield, rainfall exerts the strongest joint effect on rice productivity when considered alongside temporal trends.

**Table 12.** Summary of combination of two weather variable on rice.

Sl. No.	Combination of two variables model	Variable	R <sup>2</sup> (%)	Significance level
1	$Y = 29.27 - 0.310Z_{11} + 0.228T$	Max T & Min T	63.90**	1%
2	$Y = 29.27 - 0.310Z_{11} + 0.228T$	MaxT & Rainfall	63.90***	1%
3	$Y = 34.9434 - 0.3709Z_{11} - 2.5481Z_{41} + 0.0604Q_{141} + 0.2117T$	MaxT & Sunshine	76.99***	1%
4	$Y = 11.3015 + 0.1186 + 0.118619Z_{30} + 0.314668T$	MinT & Rainfall	65.11***	1%
5	$Y = 11.3015 + 0.1186Z_{30} + 0.118619Z_{30} + 0.314668T$	MinT & Sunshine	56.14***	1%
6	$Y = 11.30 + 0.119Z_{30} + 0.315T$	Rainfall & Sunshine	65.11***	1%

Note: \*\*\*significant at 1%.

**Table 13.** Composite effect of weather variable on rice crop.

Variables	Regression coefficients (SE)	P - value	R <sup>2</sup>	95% confidence interval	
				Lower	Upper
Intercept	34.94341 (4.194111)	1.27E-09		26.41043	43.47639
Z <sub>11</sub>	-0.3709 (0.084443)	0.000109		-0.5427	-0.1991
Z <sub>41</sub>	-2.54812 (0.640527)	0.000358	76.99***	-3.85128	-1.24496
Q <sub>141</sub>	0.060429 (0.019822)	0.004506		0.020101	0.100757
T	0.211764 (0.037826)	3.15E-06		0.134806	0.288721

Note: \*\*\*significant at 1%.

### Composite effects of weather variables

In this method, the stepwise regression analysis (Stepwise) has been used. All the individual generated ( $Z_{10}$ ,  $Z_{11}$ ,  $Z_{20}$ ,  $Z_{21}$ ,  $Z_3$ ,  $Z_3$ ,  $Z_{31}$ ,  $Z_{40}$ ,  $Z_{41}$ ) for four weather variables Max T, Min T, Rainfall, and Sunshine. Similarly joint effect of these individual variables generated ( $Q_{120}$ ,  $Q_{121}$ ,...and  $Q_{341}$ ) has been used. Total number of generated weather variable are 20 (8 individual, 12 Joint) along with T has been used to find out the composite effect of weather variable.

The composite regression model explained 76.99% of the variation in rice yield ( $R^2 = 0.770$ ), showing strong explanatory power. The intercept (34.94) was highly significant ( $p < 0.001$ ), indicating a strong baseline yield. Among the variables,  $Z_{11}$  had a significant negative effect (coefficient = -0.371,  $p < 0.001$ ), while  $Z_{41}$  also showed a strong negative impact (-2.55,  $p < 0.001$ ), both reducing productivity. In contrast,  $Q_{141}$  had a positive and significant effect (0.060,  $p = 0.005$ ), contributing to yield improvement. The time trend (T) was highly significant (0.212,  $p < 0.001$ ), confirming steady yield growth driven by technological and management progress (Table 13).

The developed model is  $Y = 34.9434 - 0.3709Z_{11} - 2.5481Z_{41} + 0.0604Q_{141} + 0.2117T$

### CONCLUSION

This study investigated the individual, joint, and composite effects of key weather variables MaxT,

MinT, Rainfall, and sunshine on rice crop yield in Ayodhya. The analysis reveals that weather variables exert significant, yet differential, influences on rice productivity. Among the individual effects, rainfall was the most dominant positive factor, explaining the highest variation in yield ( $R^2 = 68.28\%$ ), with a significant positive effect during its critical growth period ( $Z_{30}$ ). Maximum temperature during its later growth phase ( $Z_{11}$ ) and sunshine during its later phase ( $Z_{41}$ ) were identified as significant stressors, having a pronounced negative impact on yield. The time trend (T) was consistently highly significant and positive across all models, underscoring the substantial role of technological advancements, improved crop management practices, and policy interventions in driving long-term yield growth, often outweighing the negative impacts of adverse weather. The joint effect analysis further emphasized the central role of rainfall, as models incorporating it with other variables consistently explained higher yield variation (up to 65.11%).

Finally, the composite model, incorporating all individual and interactive weather effects, provided the most comprehensive explanation of yield variability ( $R^2 = 76.99\%$ ). This model confirmed the persistent negative effects of maximum temperature ( $Z_{11}$ ) and sunshine ( $Z_{41}$ ), while also identifying a significant positive interaction effect ( $Q_{141}$ ). In summary, while technological progress remains the primary driver for enhancing rice yields in the region, weather variables, particularly excessive heat and sunshine during critical growth stages, pose significant risks.

Conversely, adequate rainfall is a key positive contributor. These results highlighting the importance of weather parameters for developing and promoting adaptive agricultural strategies, such as heat-tolerant crop varieties and optimized irrigation scheduling, to mitigate climate risks and ensure sustainable rice production in eastern Uttar Pradesh.

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