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Estimating the Potential Effect of Climate Change on Rice Yield in India by Considering the Combined Effects of Temperature and Rainfall

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ABSTRACT

Background: Rising seasonal temperatures are associated with losses in most areas. Climate change is predicted to have an influence on cold-climate locations as well. In both the short and long term, agricultural production suffers marginal losses. This research analyses the long-term association as well as the short-term dynamics between rice yields and climatic variables, namely maximum and lowest temperature as well as rainfall.

Methods: This study used time-series data of India from 1991 to 2020 in India. By using the Autoregressive-Distributed Lag Regression or ARDL bounds testing technique for co-integration analysis.

Result: The study demonstrates that the variables do have a long-term connection with one another. According to the data, rainfall significantly impacts the amount of rice produced. Rice yields and rainfall have been shown to have a particular connection that is unidirectional, positive and substantial; however, this relationship only goes one way. Rice yields grow by 1.58 per cent for every millimeter when the amount of rainfall increases. Because of the impact of temperature on rice harvests and the increasing vulnerability of the rice crop to climate change, agricultural experts need to concentrate their efforts on studying and creating temperature-tolerant rice varieties to increase rice yields.

Key words: Climate change, Multiple regression analysis, Rice production.

INTRODUCTION

Temperatures on Earth have increased by 0.85 degrees Celsius over their pre-industrial levels in the last century and it is anticipated that they will rise by more than 2 degrees Celsius in the next century (RCP 8.5 scenario; IPCC, 2021). Climate change (CC) is the primary source of global warming, emission, carbon dioxide, nitrous, methane oxide and ecological assets, which affect temperature, rainfall, droughts, floods and water and land degradation. Depending on the area's physical characteristics, climate change might have either a negative, a positive, or no effect at all (Kumar *et al*., 2021). The effects of climate change pose a significant risk to the whole economy, but agriculture is particularly vulnerable to its knock-on effects. The IPCC's 6th Assessment Report emphasized that climate change may have a wide-ranging impact on agriculture (IPCC, 2021). It is vital, in order to minimize hunger among the constantly rising population, to do research on the connection between climate change and agriculture. The principal purpose of the United Nations Millennium Development Goals is to eradicate severe poverty and hunger. Asian nations provide around 90% of the world's total rice output. However, India is the world's greatest rice exporter, with 9.8 million tonnes, followed by Thailand (7.5 million tonnes), Vietnam (6.5 million tonnes), Pakistan (4.6 million tonnes) and the United States (3.1 million tonnes). After China, India is Asia's second-largest rice producer, followed by Indonesia, Bangladesh and Vietnam (FAO, 2019). Rice production eliminates hunger and supports 120 million families. Rice farming secures almost half the population's food. Rice production also depends on rice distribution (Lanka, 2004). However, the rate of production and output in agricultural businesses may drop due to climate change. The primary contributor to climate change is the decline in agricultural output in regions located at low latitudes (Vaghefi *et al*., 2016). Maize, wheat and rice yields will drop as temperatures and rainfall variability rise. By the end of this decade, agricultural production in India, the second-largest producer of rice and wheat in the world, will decrease by up to 30%. For every 1-degree rise in the average maximum temperature, Karnataka's agricultural income decreased by 17-21% (Kalli and Jena, 2022). In rainfed regions, rice is a staple crop. Rainfed rice farming is susceptible to climate change. It decreases plant transpiration. It may cause leaf

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rolling and drying, reduced leaf expansion and biomass, solute immobilization and leaf heat stress (Singh *et al*., 2017). Rice is classified as a C3 plant. Higher CO_2 emissions inhibit transpiration and stimulate photosynthesis in C3 plants. These two factors contribute to an increase in rice crop yield. CO_2 benefits decrease as temperature increases. From 1950-1951, rice output was 20.58 million tonnes on 668 million hectares. After 70 years, 2,424 million hectares yield rice and 106.54 million tonnes are produced. The late 1960s green revolution increased rice output. Agricultural policy, irrigation expansion, fertilizers, new seed breeds and technology have increased agricultural productivity. Additionally, the amount of land devoted to agriculture has expanded, which has led to a rise in rice output (Kumar *et al*., 2021). Efforts were undertaken in the 1970s and 1980s to boost rice production via science, research and development. These efforts allowed global rice production to meet the demand of a growing population, created employment opportunities, increased rice farmers' income and improved rice access for poor folks living in urban centers across the world. In recent years, Green Revolution benefits have started to wane. Since 2000, buffer stockpiles have covered the global rice production imbalance. According to the status of food insecurity report, India contributes to almost a quarter of the global hunger burden, as the nation has 224.3 million undernourished people, which is 16.3 percent of the total population. This percentage is the highest in any country (FAO, 2022).

Rice cultivation is sustained by carbon and environmental footprints. Rainfall increases rice crop output temporarily but decreases it permanently (Kumar *et al*., 2021). Yield and expenses enhance income. This cash helps expand their agricultural company and maintain rice production. We must sustainably increase grains, improve lives and boost rural development via local and regional government engagement (Connor *et al*., 2022). India produces the most rice, 50% of which is grown in rainfed regions. The estimated result suggests that 15%–40% of rainfed rice farming areas in India's most eastern and northern regions are in danger. This research helps marginal farmers in climate-threatened regions (Singh *et al*., 2017). DSSAT model predicts that rising temperatures and rainfall trends will reduce rice output by 12 and 31.3% by 2030, lowering farmers' income and self-sufficiency. Rice output was projected to decrease farmers' gross revenue and the nation's rice self-sufficiency (Vaghefi *et al*., 2016).

However, increased temperature decreases net income by RM 3.02 per hectare, whereas increasing rainfall increases it by RM 1.32 per hectare (Masud *et al*., 2014). Pooled mean group analysis of climate change's impacts on rice output in 30 Chinese provinces from 1998 to 2017. Dumitrescu-Hurlin test to examine rice output and climate. The average temperature will adversely affect rice output in the long term, whereas average rainfall, fertilizer consumption and the planted area will benefit it. Moderate temperatures and developed regions affect rice output in the near term, although rainfall and fertilizers do not. (Pickson *et al*., 2022). The Indian agriculture sector is the most sensitive and exposed to climate change due to its poor capacity to adapt to its negative impacts (Guntukula 2020). India has a population of over 50% whose primary source of income is agriculture. Therefore, it is essential to comprehend how climate change affects agricultural productivity (Pattanayak and Kumar 2013).

The preceding empirical review shows that climate change reduces Indian rice production. Most empirical research on climate change and rice production focused on temperature and rainfall in one state or area. There was limited literature on this crop in India and a recent climatic study is unavailable. Existing studies used different variables such as CO_2 emission, cultivation area, irrigated area, temperature, precipitation, etc. However, this study uses core climate change variables such as minimum, mean and maximum temperature and rainfall. Rice cultivation is crucial to food security. Hence, climate change's impact must be assessed. Using time series data from 1991 to 2020, we investigate the asymmetrical causal link between climate change and rice production in the instance of India in this research. The Reserve Bank of India (RBI), the World Development Indicators (WDI) and the Climate Change Knowledge Portal (CCKP) are a few of the sources from which the information is gathered.

MATERIALS AND METHODS

Research methodology refers to the theoretical process used to establish a research subject, choose variables to study and gather data on those variables. Rice production was the dependent variable and minimum, mean, maximum and rainfall were the independent variables.

Model of econometric

Rice = β0 + β1 (Annual rainfall) + β2 (Minimum temprature) + β3 (Maximum temprature) + β4 (Mean temprature) + μ ...(1)

Where,

β0 = Intercept ,

β1, β2, β2, β3, β4, β5 = Slope coefficient.

μ = Error term.

Model of ARDL

The ARDL method is used in the study investigating how climate change would affect rice output in India. Elasticity was included in the ARDL-bound testing procedures designed by Pesaran *et al*. (1996) and Pesaran *et al*. (2001). The variables in the model specification must be able to be integrated at either order 0 or 1, denoted by the symbols I (0) or I (1). Even tiny samples benefit from this estimation methodology. Model variables have varied lag durations. The ARDL equation is as follows:

$$Yt = \beta 0 + \beta 1Yt\text{-}1 + .. + \beta qYt\text{-}p + \alpha Oxt + \beta 1xt\text{-}1 + \alpha 2xt\text{-}2 + + \alpha kxt\text{-}k + \mu t \quad ...(2)$$

The unconstrained vector error model follows.

$$\Delta \text{ (Rice) } t = \alpha 0 + \Sigma pi{=}1\ \alpha 1 \text{ (Rice) } t\text{-}i + \Sigma pi{=}0\ \alpha 2 \text{ (Annual rainfall) } t\text{-}i + \Sigma pi{=}0\ \alpha 3 \text{ (Minimum tem) } + \Sigma pi{=}0\ \alpha 4 \text{ (Maximum tem) } + \Sigma pi{=}o\ \alpha 5 \text{ (Mean tem) } t\text{-}1 + \alpha 6 \text{ (Rice) } t\text{-}1 + \alpha 7 \text{ (Annual rainfall) } t\text{-}1 + \alpha 8 \text{ (Minimum temp) } t\text{-}1 + \alpha 9 \text{ (Maximum tem) } t\text{-}1 + \alpha 10 \text{ (Mean tem) } t\text{-}1 + \mu t \quad ...(3)$$

Intercept α0. The long-run coefficients of explanatory variables are α6, α7, α8, α9 and α10. The stochastic error, ìt, contains all the equation's missing variables.

RESULTS AND DISCUSSION

Descriptive statistics include median, mean, minimum, maximum, skewness, standard deviation, kurtosis, jarque-bera and likelihood. The time series data cover a period of thirty years and include yearly observations beginning in 1991 and ending in 2020. According to the information shown in Table 1, the typical output is 2125.8 units, with a standard deviation of 289.54 units. The standard deviation of the rainfall rate is 96.16, with the average rainfall rate at 1190.47. The standard deviation is 0.40°C, while the mean or average lowest temperature is 19.18°C. The standard deviation for the highest temperature is 0.35 and the standard deviation for the mean temperature is 0.30. The mean value for maximum temperature is 29.67 and the mean temperature is 24.13. All variables have a positive bias, including rice, rainfall, minimum, maximum and mean temperature. Since their value is less than three, the kurtosis statistics for the variables show that rice, rainfall, minimum and mean are all platykurtic, which means they have a smaller peak and shorter tails. Because their value is more than 3, variables such as the highest temperature have a Laptokurtic distribution, often known as a long-tailed or high peak. According to the findings, the value of the Jarque-Bera probability for rice is 0.37, which is higher than 10%. As a result, we have decided to adopt the null hypothesis, which states that data is typically distributed. The Jarque-Bera P value of rainfall is 0.85, which indicates that the percentage is higher than 10%. We will accept the null hypothesis since it indicates that the data follows a normal distribution.

Correlation analysis

Table 2 demonstrates that rice output is substantially associated with all of the factors under consideration. A positive correlation exists between rainfall and rice productivity and minimum, maximum and mean temperatures. Rainfall, the lowest, highest and middle temperatures, as well as the average temperature, are all totally reliant on one another. Because r is more than 0.30, the correlation between rice output and rainfall is positive at 0.35. A moderate connection exists between minimum temperature and precipitation since r is more than 0.30 and less than 0.70. The degree of relationship between minimum temperature and precipitation is 0.36 and the correlation is moderate. The coefficient of association between rice and mean temperature is 0.55, which indicates that there is a strong link between the two variables.

ADF test

Table 3 lists stationary and non-stationary variables. Because acquiring excellent findings and making accurate

Table 1: Results of descriptive statistics.

	Rice production	Annual rainfall	Minimum temperature	Maximum temperature	Mean temperature
Mean	2125.80	1190.47	19.18	29.67	24.13
Median	2090.50	1187.98	19.08	29.61	24.09
Maximum	2722.00	1379.63	20.04	30.41	24.80
Minimum	1740.00	1002.58	18.57	28.75	23.47
Std. Dev.	289.54	96.16	0.40	0.35	0.30
Skewness	0.40	0.13	0.58	0.10	0.37
Kurtosis	2.04	2.57	2.27	3.52	2.81
Jarque-Bera	1.94	0.31	2.38	0.39	0.75
Probability	0.37	0.85	0.30	0.82	0.68

Calculated by author.

Table 2: Results of the correlation matrix.

Variables	Rice yield	Rainfall	Minimum temperature	Maximum temperature	Mean temperature
Rice yield	1	0.35	0.73	0.48	0.55
Rainfall	0.35	1	0.36	-0.11	0.10
Minimum temperature	0.73	0.36	1	0.76	0.90
Maximum temperature	0.48	-0.11	0.76	1	0.94
Mean temperature	0.55	0.10	0.90	0.94	1

Calculated by author.

predictions with a non-stationary series is impractical, avoiding spurious regression analysis requires that time series data be stationary. This is because it is mandatory. The results of the Augmented Dickey-Fuller test indicated that certain variables are stationary at the level, while other variables are stationary at the 1st Difference. Rice is integrated at 1st Difference with a 10.30 t-statistic and 0.00 probability. The highest temperature is stationary at 1st Difference with a -7.26 t-statistic and 0.00 probability. The yearly rainfall is integrated at -4.66 t-statistic and 0.00 probability. At -4.47 and 0.00, the minimum temperature is stationary. The mean temperature is stagnant at -4.19 t-statistics and 0.00 probability. Time series analysis displays all variables combined in various orders. The ARDL model may be used since variables are not co-integrated.

The ARDL model shows the long-term and short-term relationship between the dependent and independent variables.

Test of bound

The bound test for co-integration is used to determine whether or not the variables are associated with one another over the long term. Table 4 presents the findings in their entirety.

The critical values of the upper and lower-bound I (1) and I (0), respectively, are shown in the table that can be found above. Since the observed value of the F-statistic is 3.23, which is higher than the upper-bound of F-statistics, we can conclude that the null hypothesis is false and instead adopt the alternative hypothesis, which states that there is a long-run link between the variables.

Long-term ARDL model relationship

An equation may be used to describe the relationship that exists in the long term between a dependent variable and an independent variable.

$$\Delta \text{(Rice) t} = \Upsilon 0 + \Sigma \text{pi=1}\ \Upsilon 1 \text{ (Rice) t-i} + \Sigma \text{pi=0}\ \Upsilon 2 \text{ (Annual rainfall) t-i} + \Sigma \text{pi=0}\ \Upsilon 3 \text{ (Minimum tempature) t-i} + \Sigma \text{pi=0}\ \Upsilon 4 \text{ (Maximum temprature) t-i} + \Sigma \text{pi=0}\ \Upsilon 5 \text{ (Mean temperature) t-i} + \mu t \quad ...(4)$$

Where,

s = Coefficient of the lagging.

X = Component in the equation.

The correlation over the long term is shown in Table 5 as follows.

The findings of the ARDL model are shown in Table 5 and they suggest that the long-term significance of the co-efficient value of rainfall is negligible. It indicates a positive correlation with the rice production rate, which means that if there is an increase of one unit in the rainfall rate, there would likely be an increase of 1.58 per cent in the rice production rate. In the long term, there is a positive correlation between the co-efficient minimum temperature value and rice yield. This relationship is statistically

Table 3: ADF test results.

Variable	Level		1st Difference		2nd Difference		
	Intercept	Trend and intercept	Intercept	Trend and Intercept	Intercept	Trend and intercept	Decision
Rice	0.55 (0.98)	-4.12 (0.01)	-10.30 (0.00)	-10.37 (0.00)	-5.35 (0.00)	-5.13 (0.00)	I (0)
Annual rainfall	-4.66 (0.00)	-4.30 (0.013)	-7.38 (0.00)	-7.21 (0.00)	-7.47 (0.00)	-7.74 (0.00)	I (0)
Minimum temprature	-2.13 (0.23)	-4.47 (0.00)	-6.05 (0.00)	-5.92 (0.00)	-7.63 (0.00)	-7.49 (0.00)	I (0)
Maximum temprature	-3.10 (0.37)	-3.95 (0.02)	-7.26 (0.00)	-4.40 (0.01)	-5.02 (0.00)	-4.85 (0.00)	I (1)
Mean temprature	-2.97 (0.04)	-4.19 (0.01)	-6.54 (0.00)	-6.44 (0.00)	-7.70 (0.00)	-7.60 (0.00)	I (0)

Calculated by author.

Table 4: Bound test results.

Test statistics	Value	Significance	I (0)	I (1)
F-statistics	3.23	10%	2.2	3.09
K	4	5%	2.56	3.49
		2.5%	2.88	3.87
		1%	3.29	4.37

Calculated by author.

Table 5: Long-term variable relationships.

Variables	Coefficient	Standard error	t-statistics	p-value
Rainfall	1.58	0.65	2.40	0.02
Minimum temperature	1600.52	346.07	4.62	0.00
Maximum temperature	2017.74	544.22	3.70	0.00
Mean temperature	-3651.4	937.44	-3.89	0.00

Calculated by author.

significant. In the long term, using HYV, irrigation and other applications of contemporary technology is the reason for the critical and good linkages. Therefore, there is a detrimental impact that rice experiences as a result of the mean temperature. Maximum temperature has a co-efficient value that is significantly positive over the long term and demonstrates statistical significance.

Short-run relationships according to the error-correction model

Utilizing this method, one may ascertain the short-run correlation between rice production and several other free variables. The equation for the short-run error correction may be written as follows.

$$\Delta \text{ (Rice) t} = \eta 0 + \Sigma pi=1\ \eta 1i \text{ (Rice) t-i} + \Sigma pi=0\ \eta 2i \text{ (Minimum temprature) t-i} + \Sigma pi=0\ \eta 3i \text{ (Maximum temprature) t-i} + \Sigma pi=o\ \eta 4i \text{ (Mean temprature) t-i} + \mu t \quad ...(5)$$

(ECMt-i) The ECM indicates the short-run influence on the variables x and y, as well as the rate of adjustment.

$$\Delta Yt = \eta + \delta t\text{-}i + \lambda \text{ (ECMT-I)} + \mu t \quad ...(6)$$

The short-run impact and adjustment speed are in an equation. Table 6 shows ECM findings.

According to the data in the table above, rice production is the most crucial factor in the long and short run. The value of the ECM coefficient is -0.60, which is a substantial and adverse number. The finding that the coefficient of error correction model is substantial and negative provides evidence that a causal relationship operates throughout a lengthy period. The value of ECM indicates the transition rate from a state of disequilibrium to one of equilibrium. Rice, which is the dependent variable, shows a fluctuation of 52% as a result of changes in the independent factors, according to the modified R2 value of 0.52. The fact that the likelihood of the F-statistic is statistically significant at a 5% significance level further confirms the model's claim that it has a high goodness of fit.

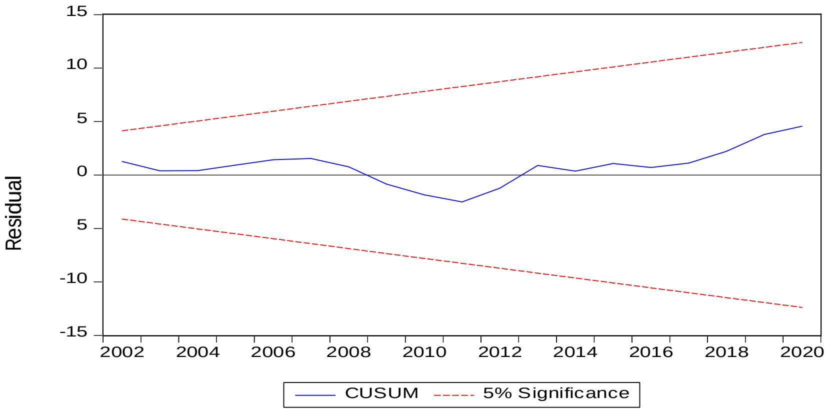
Model stability

CUSUM is an abbreviation for the cumulative sum of recursive residuals and it is used to identify whether or not a model is stable with regard to both short-run and long-run

Table 6: ECM results.

Variables	Coefficient	Standard error	t-statistics	Probability
D (Rainfall)	0.08	0.24	0.37	0.71
D (Min_temperature)	-0.76	250.09	2.06	0.05
D (Max_temp)	24.83	225.45	2.04	0.05
D (Mean_temp)	21.77	436.46	2.13	0.04
CointEq (-1)*	-0.58	0.12	4.95	0.00
R-squared	0.52	Mean dependent variable		33.86
Adjusted R-squared	0.44	S.D. dependent variable		116.40
S.E. of regression	86.49	Akaike info criterion		11.91
Sum squared resid	179569.8	Schwarz criterion		12.14
Log-likelihood	-167.74	Hannan-Quinn criteria		11.98
		Durbin-Watson stat		2.37

Calculated by author.



Source: Calculated by author.

Fig 1: The recursive residuals cumulative sum.

correlations between variables. The recursive residuals comulative sum graph is shown in Fig 1.

CUSUM Test checks model stability using time series on the horizontal axis and residual on the vertical. Fig 1 demonstrates CUSUM is within 5% crucial lines. The graph avoids this essential barrier. Thus, the model is steady with no major gap. Correct specification models accept the null hypothesis at 5% significance. This section examines how the factors that explain rice production affect the crop. The findings of the ARDL model indicate that all of the independent variables, such as the lowest temperature, the maximum temperature and rainfall in the long and short term, are substantially and favorably associated with rice output in India. The only exception to this is the mean, which has a negative influence on rice production. The R-square value obtained from the research demonstrates that the independent variable substantially influences the dependent variable and the model obtained from the study presents a good match between the data.

CONCLUSION

The autoregressive distributed lag (ARDL) model is utilized in this research to determine how climate change factors impact rice output in India. Data from the last 30 years were used in the study. The results showed that mean, minimum, maximum temperature and low rainfall conditions reduce Indian rice yield, hurting India's economy. The coefficient values for the maximum, minimum, mean temperature and rainfall are significant with rice production. The mean temperature negatively affects rice production in the long run. On the other hand, the rainfall, maximum and mean temperatures were positively associated, while the minimum temperature was negatively associated and correlated with rice output in the short term. The research demonstrates that increasing rice output depends critically on short- and long-term temperature. A change in rainfall, on the other hand, has no immediate influence on rice output because of irrigation but may have a long-term impact on Indian rice. Creating climate change awareness among farmers is necessary. Most farmers in our nation cannot afford excellent seeds, equipment, or fertilizer to utilize their land efficiently due to insufficient irrigation and feudalism. The government should invest in the construction of dams to create water reservoirs to alleviate the water shortage for irrigation. India should discourage feudalism and subsidize poor farmers for fertilizers, equipment and quality seeds. This study is necessary for enhancing food production, revenues from foreign currency and employment opportunities in India. It benefits farmers, the general public, the government, students, teachers, investors, common readers, economists and policymakers. Further research on this topic can be done by considering other factors such as soil type, soil quality, farm management and scale/area of operation. With such factors included, it is possible to separate the impacts of each variable on rice production and calculate the individual elasticities with maximum and lowest temperatures and rainfall.

Conflict of interest: None.

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