Projected Impact of Climate Change on Rice Production and Yield in India: A State-Wise Panel Data Empirical Analysis

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ABSTRACT

Background: This study evaluates the impact of climatic factors (CFs) on rice production and yield in 19 states of India. The elasticities of rice yield and production with CFs were determined. Future projections of rice production and yield were also estimated.

Methods: It uses state-wise balanced panel data of CFs, rice yield and production for the period of between 1966-2017. The coefficients of CFs with yield and production were estimated using Cobb-douglas production model. Marginal impact analysis (MIA) was used to observe the future prediction of rice yield and production in India.

Result: Production and yield of rice decrease due to marginal change in CFs. Rice yield is expected to decline by 1.54%, 1.86%, 2.18% and 2.37%, while its production to be declined by 2.39%, 3.01%, 3.63% and 4.30% in India due to change in CFs by 2040s, 2060s, 2080s and 2100s.

Key words: Agricultural sector, Climate change, Food security, Mitigation and adaptation, Production, Rice yield.

INTRODUCTION

Farming sector has a dependence on climatic factors (CFs). Rice is an important staple food and it is cultivated across India. Thus, it is significant to maintain the food security of Indians (Kumar and Upadhyay, 2019). It is also a requirement to estimate the future prediction of rice yield and production in India. Previous results highlight that climate change is producing a negative impact on world economies, as well as that the agricultural sector faces more risks (Terefe, 2023; Ashkra *et al.,* 2023). Highly dependent countries on agriculture and related sectors will worsen due to changes in CFs (Kaur *et al*., 2020; Terefe, 2023). Thereupon, climate change has also affected food security and water availability (Ali *et al.,* 2017). Livestock productivity, milk production and meat production are also negatively impacted due to climate change (Das, 2018).

Water scarcity may be more as temperature increases in Rajasthan (Ravindra *et al.,* 2024). The incidence of rise in temperature, rainfall, floods, landslides and cyclones have increased significantly in India. Madhya Pradesh has a largest experience of extreme weather events, while Bihar has the highest mortality due to extreme variability in CFs. Moreover, 1.84 million ha. of cropped area is destroyed due to these events in India. In future rainfall is expected to be more severe with less rainy days but with greater intensity. The geographical location and poor health care system of India will make it more vulnerable to spread of communicable diseases like malaria, dengue and chikungunya. The spread of insects and plant-based diseases are harmful for the agriculture sector (Gupta and Pathak, 2016). It is reported an increase in incidence of natural disasters due to changing climate in India.

Rice is a highly climate sensitive crop in many countries (Van and Zwart, 2017). The decline in the growing period due to increased temperature will negatively affect rice yield. Ali *et al.* (2017) estimated the effect of climatic variables on four major crops (rice, wheat, maize and sugarcane) grown in Pakistan. Chandio *et al.* (2019) assessed the long-term relationship between CFs and rice production in Pakistan. Liu *et al.* (2020) analyzed the effect of climatic variability on rice in the world. Li *et al.* (2025) noted that growth and yield of rice is sensitive due to change in CO_2 concentration and CFs.

Rice is an important and worthy staple food grain crop and ensures food and health security of people in India. In India, rice is grown in semi-arid to humid climatic conditions (Aggarwal and Mall, 2002). The production of rice requires high humidity and moderate temperature, extensive water supply and hours of sunshine. Aggarwal and Mall (2002) observed that the rice yield in northern and eastern regions is more vulnerable to climate change. The southern and western regions are less susceptible to changing climates. Mishra *et al.* (2013) applied the DSSAT

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model to analyze the impact of agro-climatic conditions on yield of both the crops and to make future predictions. It was observed that there was variation in crop yield due to the variation in solar availability. Birthal *et al.* (2014) assessed the impact of changing climate and its effect on yield of major food crops in India. Abeysingha *et al.* (2016) examined the impact of climate change on rice and wheat in the Gomti river basin of Uttar Pradesh. Vyanatrkao (2017) highlighted the mixed response of climate change to rice production. Kumar and Sidana (2019) observed that the increase in minimum temperature has a negative effect on the rice yield. Thereupon, rice production has high variability across years due to extreme events in India (Gupta and Mishra, 2019). Ashkra *et al.* (2023) reported that rice production is significantly associated with rainfall change in India. Therefore, rice crop is highly sensitive due to variability in climatic factors (CFs).

Rice crop required extensive water and high humidity during its planting and growing time. However, the extreme variability in maximum temperature and extensive rainfall pattern during harvesting time of rice may reduce its production and yield. Also, water scarcity is caused to diminish growth and development of rice. Earlier economic studies investigated the impact of most CFs excluding water deficit and evapotranspiration on rice yield and production in India. Accordingly, previous findings proved that rice and production decline as CFs increases. However, previous studies could not investigate the impact of CFs (including water deficit and Evapotranspiration) on variability of rice production and yield in India as using district-wise panel data. Thus, rice farming requires scientific cultivation mechanisms, adaptation and mitigation strategies and climate resilience to increase its production and yield in India (Singh *et al.*, 2023). Adaptation strategies can be applied in various aspects like less use of irrigation and minimum quantity of fertilizer to abate CO_2 and GHGs emissions from the agricultural sector. Moreover, improving in irrigation facilities, harvesting of rainwater, water conservation and management practices may be proactive to increase rice production and yield.

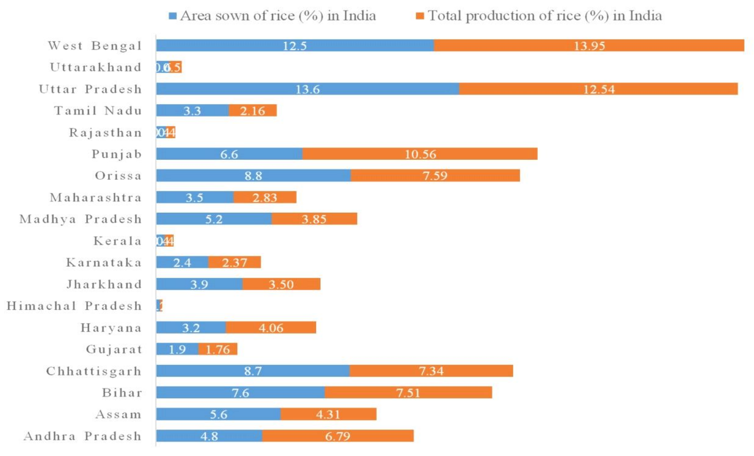
The above-mentioned review stated that rice production and yield decline due to variability in CFs in India (Mishra *et al.,* 2013). Past literature was majorly focused upon the international level for analysing the effect of changing climate on agriculture productivity in general (Liu *et al.,* 2020). Most studies have focused their investigations at macro, state and regional level in India (Aggarwal and Mall, 2002; Auffhammer *et al.,* 2011; Birthal *et al.,* 2014; Abeysingha *et al.,* 2016; Van and Zwart, 2017; Vyanatrkao, 2017; Pattanayak *et al.,* 2021; Kumar and Sidana, 2019; Kumar and Singh, 2023). However, earlier researchers could not make future predictions of rice yield and production in the era of global climate change in India. This research has following objectives:

- To observe the expected change in rice production and yield due to change in CFs in India.
- To examine the elasticity of production and yield of rice crop with respect to CFs in India.
- To observe the future prediction of rice production and yield in India.

MATERIALS AND METHODS

Study area

This study is conducted in the Department of Humanities and Social Sciences, Graphic Era (Deemed to be) University. The favorable soil, climatic conditions, geographical location, flora and fauna are beneficial for Indian agriculture. India has diverse regional patterns and climatic conditions. Northern India is covered by the Greater Himalayas. While southern India is surrounded by Sea from all the three sides; towards the East the country is surrounded by Bay of Bengal. The Tropic of Cancer divides the country into two parts. This study includes 19 rice farming intensive states of India (Fig 1). These states have 93% and 93% production and area sown of rice, respectively in India



Source: RBI (GoI).

Fig 1: % share of these states in rice production and area sown in India.

(Reserve Bank of India, GoI, 2017). Hence, these 19 states are major representatives of rice farming in India. West Bengal has a largest contribution in rice production in Indian states. Uttar Pradesh has a largest contribution in area sown of rice in India.

Sources of data and time period of this Research

In this study, yield and production of rice used as dependent variables (*DV*s), while area sown under rice crop, temperature, precipitation and water deficit are applied as independent variables (IVs) which are compiled in a panel data for 19 Indian states during 1966-2017. Production and yield of rice were taken from ICRISAT. ICRISAT provides average monthly data of the mentioned CFs at district level. Thus, the researchers prepare a state-wise crop calendar for rice. Accordingly, monthly average values of the aforesaid CFs during rice crop season are considered as *IV*s. Moreover, some useful data is also taken from various reports published by the Agriculture Ministry (GoI). The linear interpolation method is used for examining the missing values to make state-wise balanced panel data.

Selection of dependent and independent variables

Yield of a crop signifies the quality and fertility of soil. Irrigated area, farm management practices, seed quality and use of fertilizer also determine the crop yield. Production and yield of rice are used as dependent variables (*DV*s) to examine their sensitivity due to variation in climatic factors in this research (Ali *et al.*, 2017; Kumar and Singh, 2023). Finally, monthly average maximum temperature, minimum temperature, precipitation and water deficit during rice crop season are used as climatic factors (CFs). Ali *et al.* (2017) also included similar kinds of CFs to observe climate change impact on yield of rice, wheat, maize and sugarcane in Pakistan. Auffhammer *et al*. (2011); Abeysingha *et al.* (2016); Vyanatrkao (2017); Guntukula (2019); Ashkra *et al*. (2023); Terefe (2023) also used similar types of CFs in their empirical investigation in India and other nations.

Specification of empirical models

This research applies a Cobb-douglas production function (CDPF) model to examine the impact of selected climatic factors (CFs) on rice yield and production. This study assumes that rice yield (*RY*) and rice total production (*RTP*) are a function of rice cropped area (RA) and monthly average evapotranspiration (*RMAE*), monthly average water deficit (*RMAWD*), monthly average maximum temperature (*RMAMAT*), monthly average minimum temperature (*RMAMIT*) and monthly average precipitation (*RMAPR*) during rice crop season of respective states. The mathematical association of *RY* and *RTP* with the CFs are defined as:

$$(RY) = f\{(RA), (RMAE), (RMAWD), (RMAMAT), (RMAMIT), (RMAPR)\} \quad \text{... (1)}$$

$$(RTP) = f\{(RA), (RMAE), (RMAWD), (RMAMAT), (RMAMIT), (RMAPR)\} \quad \text{... (2)}$$

Following equations are used under CDPF model:

$$ln(RY)_{st} = \alpha_0 + \alpha_1\, ln(RA)_{st} + \alpha_2\, ln(RMAE)_{st} + \alpha_3\, ln(RMAWD)_{st} + \alpha_4\, ln(RMAMAT)_{st} + \alpha_5\, ln(RMAMIT)_{st} + \alpha_6\, ln(RMAPR)_{st} + \tilde{O}_{st} \quad \text{... (3)}$$

$$(RTP) = \beta_0 + \beta_1\, ln(RA)_{st} + \beta_2\, ln(RMAE)_{st} + \beta_3\, ln(RMAWD)_{st} + \beta_4\, ln(RMAMAT)_{st} + \beta_5\, ln(RMAMIT)_{st} + \beta_6\, ln(RMAPR)_{st} + \hat{\imath}_{st} \quad \text{... (4)}$$

Where,

ln = Natural logarithm of corresponding variables;

α_0 and β_0 are intercept terms; α_1, ..., α_6 and are β_1, ..., β_6 are coefficients of associated *IV*s; ϕ and $\hat{\imath}$ are residual terms; and s and *t* are the cross-sectional states and years, respectively in the above-mentioned equations. Table 1 explores the description of the variables. While the elasticities of rice yield and production with respect to CFs are also estimated. The coefficients are estimated using PCSEs model for rice yield and production function.

Examination of projected rice yield and production

This research estimates the projected value of rice production and yields as per the climate change perspectives and methods used by Singh and Jyoti (2021); Kumar and Singh (2023). Marginal impact analysis (MIA) is adopted to examine the predicted values of rice production and yield in different climatic conditions by 2040s, 2060s, 2080s and 2100s. Following equations are adopted for the mentioned investigations:

$$\Delta(RTP)_{2040s} = \alpha_1 \times \Delta(RMAE) + \alpha_2 \times \Delta(RWAWD) + \alpha_3 \times \Delta(RMAMAT) + \alpha_4 \times \Delta(RMAMIT) + \alpha_5 \times \Delta(RMAPR) \quad \text{... (5)}$$

$$\Delta(RY)_{2040s} = \beta_1 \times \Delta(RMAE) + \beta_2 \times \Delta(RWAWD) + \beta_3 \times \Delta(RMAMAT) + \beta_4 \times \Delta(RMAMIT) + \beta_5 \times \Delta(RMAPR) \quad \text{... (6)}$$

Where,

$\Delta(RTP)_{2040s}$ and $\Delta(RY)_{2040s}$ are the expected values of rice production and yield, respectively for 2040s and $\Delta(RMAE)$, $\Delta(RMAWD)$, $\Delta(RMAMAT)$, $\Delta(RMAMIT)$ and $\Delta(RMAPR)$ are the projected change in these CFs by 20240s (Table 2) in equation (5) and equation (6). The projected change in CFs is adopted of the studies of Singh and Jyoti (2021); Kumar and Singh (2023). Thereupon, projected values for rice production and yield are projected for the remaining years. SPSS and STATA software are used for statistical and empirical analysis.

RESULTS AND DISCUSSION

The statistical values

The statistical values of all variables in given in Table 3. Thereupon, it is noticed a high difference in minimum and maximum values of all variables in the overall sample. Furthermore, most CFs are in abnormal form.

Correlation matrix

Table 4 show the Spearman's rank correlation coefficient among the *DV*s and *IV*s. *RTP* is negatively correlated with water deficit. Rice yield (*RY*) is positively associated with *RTP*, area sown and all CFs (except, evapotranspiration and precipitation). Thereupon, it is found a significant correlation among the CFs. Maximum temperature is also negatively associated with evapotranspiration and precipitation. While precipitation and evapotranspiration have a positive correlation. The results also signify temperature is positively associated with water deficit.

Rice yield and production

Table 5 explore the impact of CFs on rice yield and production. Rice is a dominant foodgrain crop in India. Thus, rice yield and production would be improved as cropped under increases. Despite that, this research suggested that sustainability of cropped areas under rice crop would enhance rice production and yield in India.

Table 1: Explanation of the variables.

Variables	Units	Symbol
Rice total production	000' tons	*RTP*
Rice yield	Kg./Ha.	*RY*
Area sown under rice crop	000'	*RA*
Monthly average evapotranspiration during rice crop season	mm	*RMAE*
Monthly average water deficit during rice crop season	mm	*RMAWD*
Monthly average maximum temperature during rice crop season	0C	*RMAMAT*
Monthly average minimum temperature during rice crop season	0C	*RMAMIT*
Monthly average precipitation during rice crop season	mm	*RMAPR*

Table 2: Projected trend in CFs in India by the coming years.

CFs	2040s	2060s	2080s	2100s
Rainfall (in mm)	4	5	6	7
Precipitation (in mm)	4	5	6	7
Maximum temperature (in °C)	5	0.75	1	1.5
Minimum temperature (in °C)	5	0.75	1	1.5
Evapotranspiration (in mm)	4	5	6	7

Table 3: Statistical values of variables.

Variable		Mean	Std. Dev.	Min	Max	Skewness
ln (*RTP*)	Overall	7.551496	1.3409	3.1091	10.2428	-0.6743
	Between		1.2808	4.6850	9.4503	
	Within		0.4923	4.9500	9.0133	
ln (*RY*)	Overall	9.802752	0.6943	7.4601	11.6713	-0.2105
	Between		0.6158	8.7136	11.1102	
	Within		0.3499	8.2472	10.7847	
ln (*RA*)	Overall	7.10993	1.2120	4.1620	8.7243	-0.8369
	Between		1.2072	4.4538	8.5872	
	Within		0.2948	5.4392	7.8872	
ln (*RMAE*)	Overall	4.494384	0.1787	3.6123	4.8043	-1.2579
	Between		0.1541	4.1694	4.7239	
	Within		0.0972	3.8625	4.7735	
ln (*RMAWD*)	Overall	3.130008	1.5046	-8.5172	6.1628	-1.6348
	Between		1.0776	0.3464	4.4588	
	Within		1.0782	-5.7336	8.6532	
ln (*RMAMAT*)	Overall	3.42623	0.1169	3.0635	3.5976	-1.7123
	Between		0.1191	3.0983	3.5496	
	Within		0.0146	3.3705	3.4828	
ln (*RMAMIT*)	Overall	3.068001	0.1637	2.4947	3.2356	-2.2308
	Between		0.1661	2.5687	3.2010	
	Within		0.0252	2.9892	3.1614	
ln (*RMAPR*)	Overall	5.064846	0.4615	3.3381	6.2369	-0.4594
	Between		0.4149	4.3047	5.9021	
	Within		0.2229	4.0983	5.6435	

Source: Estimated by authors.

The R^2 and *Wald Chi*^{2} values are significantly different for rice yield and production due to their different magnitude. For instance, rice yield is productivity (it is the ratio of total rice production with area sown under this crop), while rice production is gross production. Thus, it is obvious that statistical values of R^2 and *Wald Chi*^{2} are reported differently. The statistical values of R^2 and *Wald Chi*^{2} are estimated through regression analysis. Moreover, area sown under rice crop is found conducive to increase its production and yield in India. Thus, protection of the area sown under this crop would be significant to increase production and yield. The results are controversial with the findings of Kumar and Singh (2023) and observe a positive impact of area sown on rice yield and production in Himachal Pradesh.

Rice yield and production are significantly associated with evapotranspiration. The estimates reveal that rice yield and production may be declined by 0.9172% and 1.3042, respectively as monthly average evapotranspiration increases by 1% during rice crop season. Rice yield and production are adversely impacted due to increase in maximum temperature and evapotranspiration in India. Birthal *et al.* (2014); Abeysingha *et al.* (2016); Kumar and Sidana (2019); Kumar and Singh (2023) also noted a declining trend in rice yield due to change in CFs in India in future.

Controversial impact of water deficit on rice yield and production is found. It may be due to the existence of interaction effects between the CFs. Despite that, the estimates provide a clarity that rice production is likely to decrease by 0.0294% as water deficit increases by 1%. Further, it seems that rice yield and production may have declined by 0.4073% and 1.1563%, respectively as monthly average maximum temperature during rice crop season increases by 1%. While increasing minimum temperature is found favorable to increase rice yield and production. Thereupon, the impact of precipitation on rice yield is observed negatively. Kumar and Sidana (2019) also notified that an increase in temperature by 1°C may reduce rice yield by 1.20% in India. Ashkra *et al.* (2023) detect similar predictions about rice yield in India. Therefore,

Table 4: Non-parametric correlation coefficients among the *DV*s and *IV*s.

Variables	*RTP*	*RY*	*RA*	*RMAE*	*RMAWD*	*RMAMAT*	*RMAMIT*	*RMAPR*
RTP								
RY	0.531**	1						
RA	0.892**	0.247**	1					
RMAE	0.228**	-0.114**	0.411**	1				
RMAWD	-0.056*	0.249**	-0.178**	-0.587**	1			
RMAMAT	0.287**	0.320**	0.182**	-0.329**	0.511**	1		
RMAMIT	0.469**	0.226**	0.439**	0.151**	0.161**	0.686**	1	
RMAPR	0.125**	-0.137**	0.241**	0.660**	-00.587**	-0.619**	-0.158**	1

Note: ** implies that correlation is significant at the 0.01 level (1-tailed) and * implies that correlation is significant at the 0.05 level.

Table 5: Impact of CFs on rice yield and production.

DVs	Rice yield	Rice production		
Number of obs.	988	988		
Number of groups	19	19		
Obs. per group: Min	52	52		
Obs. per group: Max	52	52		
R^2	0.1799	0.8864		
Wald Chi^2	1937.22*	17769.1		
IVs	*Reg. Coef.*	*Std. Err.*	Reg. Coef.	Std. Err.
ln (*RA*)	0.1757*	0.0123	1.0670*	0.0127
ln (*RMAE*)	-0.9172*	0.1704	-1.3042*	0.1718
ln RMAWD)	0.0367***	0.0227	-0.0294***	0.0164
ln (*RMAMAT*)	-0.4073	0.6074	-1.1563**	0.5128
ln (*RMAMIT*)	0.9226**	0.4203	0.9830*	0.3350
ln (*RMAPR*)	-0.0091	0.0755	0.0900	0.0663
Con. Coef.	11.1726*	1.3912	6.4087*	1.2694

Note: *, ** and *** imply that coefficients are statistically significant at the 1%, 5% and 10% significance level, respectively.

Table 6: Elasticities of rice yield and production with CFs.

	RA	RMAE	RMAWD	RMAMAT	RMAMIT	RMAPR
Elasticity of rice yield with *IV*s	0.0157	-0.0037	0.0001	-0.0006	0.0009	-0.0001
Elasticity of rice production with *IV*s	0.5859	-0.0319	-0.0004	-0.0096	0.0058	0.0042

Table 7: Prediction of rice crop in India.

Future prediction of rice crop	Region	Year	Author (s)
Decline in rice yield by 15%	India	2100	Birthal *et al.* (2014)
Increase in rice yield in different emission scenarios by 5-6, 16-20 and 26-33%, respectively	Gomti Basin	2020, 2050 and 2080	Abeysingha *et al.* (2016)
Decrease in rice yield by 8.10%	Punjab	2080	Kumar and Sidana (2019)
Decrease in rice yield by 6%	Himachal Pradesh	2100	Kumar and Singh (2023)
Decline by 20% Decline by 47%	India	20502080	MOA and FW (2023a)

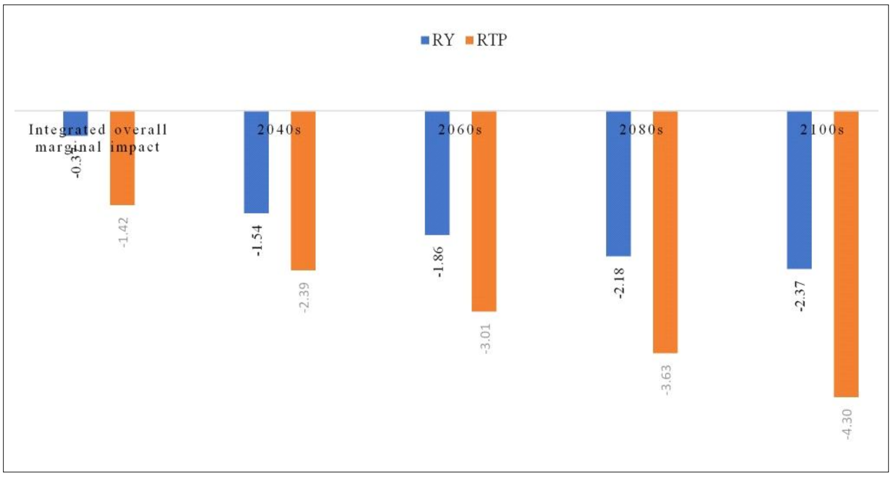


Fig 2: Projected rice yield and production in India.

farmers should focus upon rural development, flood control and improving irrigation facilities rice cultivation in India. Appropriate mitigation and adaptation measures are necessary to overcome this challenge of climate change.

The government should focus on helping weaker sections, small and marginal farmers of society. Crop insurance schemes, weather forecasting, SMS based information, digital technology, information and communication technologies (ICTs) and climate-smart technologies should be provided to the marginal farmers for improving their trust in the agricultural. Crop management technology and development in technologies enhance sustainable agriculture growth of rice cultivation in India. The use of climate-resilient technology must be adopted in cultivation to increase crop productivity in India (Kumar and Upadhyay, 2019). Public-private partnership is also required to increase sustainable development and resolve the food security related issues in India (Kumar and Upadhyay, 2019).

Elasticities

Table 6 provide the elasticities of rice yield and production with CFs. Rice yield and production may increase by 0.0157% and 0.5859% due to 1% change in cropped area under this crop. 1% change in monthly average evapotranspiration is caused to reduce rice yield and production by 0.0037 and 0.0319, respectively. The results imply that changes in CFs are accountable to make significant changes in rice yield and production in India.

Expected trend in rice yield and production

Fig 2 infer the integrated marginal impact of CFs on rice yield and production. Rice yield and production declined by 0.37% and 1.42% as marginal increases in all CFs. Thereupon, projected results highlighted that rice yield to be decreased by 1.54%, 1.86%, 2.18% and 2.37% by 2040s, 2060s, 2080s and 2100s due to substantial change in CFs in India. Accordingly, rice production would decline by 2.39%, 3.01%, 3.63% and 4.30% for the same years in India. Gupta and Pathak (2016) argued that cereal crop productivity may decline by 10 to 40% by 2100s due to variation in temperature and water availability. Hence, India should apply appropriate water management and conservation policies. Table 7 provided the prediction of rice yield and production in India as per the existing studies.

CONCLUSION

Rice yield and production were positively correlated with area sown. Water deficit is negatively and positively correlated with rice production and yield, respectively. Rice yield and production are declining due to increase in monthly average evapotranspiration, maximum temperature and precipitation increase in India. While rice production and yield increase as monthly average minimum temperature increases. Marginal increase in CFs is accountable for decreasing rice yield and production in India. Rice yield is expected to decline by 1.54%, 1.86%, 2.18% and 2.37% in India by 2040s, 2060s, 2080s and 2100s due to change in

CFs. Rice production is likely to decline by 2.39%, 3.01%, 3.63% and 4.30% in India by the mentioned years.

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Disclaimers

The authors take all responsibilities of data accuracy and statistical analysis.

Informed consent

This article does not include any experimental design based on animal and human.

Conflict of interest

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